IIHF INTERNATIONAL ICE HOCKEY FEDERATION

IIHF GUIDE TO SUSTAINABLE ICE ARENAS

INTERNATIONAL ICE HOCKEY FEDERATION

SUMMARY

The aim of this document is to give a general technical overview of the specifics of ice arenas and their technical systems. Special attention is directed to the functions that use energy, since the overall aim is to give the readers ideas on how to successfully save energy in their own arena.

Initially the key aspects and meaning of “sustainable ice arena technology” must be defined and the word “sustainable” literally means “able to be upheld at a certain level”. This indicates something that is robust and may be maintained long-term without a problem, thus for ice rinks sustainability generally leads to two areas of focus: Functions and Resources. From a reader perspective it should be understood that sustainable ice rink technologies consist of long-term solutions that lead to optimum function in a way that manages resources efficiently.

Further, this guide discusses passive and active functionality in the ice arena where the “passive” part refers to the “building structure” and its particular properties. Secondly, the “active” functionality covers the energy systems that work together to maintain the ice, temper the arena room, dehumidify the indoor air, etc.

The process to achieve sustainability should always be based on hard technical facts. The ambition in this guide is to base the presented technical arguments and solutions on a scientific background and context; therefore, the guide has an extensive list of references where many are different scientific papers and reports. An unbiased and scientific base is key for best practice and thus it should be viewed as a cornerstone in this guide.

This guide also covers softer factors such as the process to procure the technical upgrades and retrofits necessary to achieve the desired results. Again, the importance of an impartial perspective to achieve the best results is stressed. Therefore, it is recommended for the arena owner to consult competent neutral players, at least in the prestudy and specification processes, to receive an unbiased and vendor neutral view on the planned measures.

Lastly, improving the energy efficiency of an ice arena, not the least by optimizing heat recovery from the refrigeration system, is one of the most important ways to make the facility more sustainable. In most cases this also implies that the ice rink owner benefits from an increased economic performance of the facility.

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1.1. OBJECTIVE

The scope and objective of this document is to give a general and not too deep technical overview of the specifics of ice arenas and their technical systems. Special attention is directed to the technical functions that use energy in one way or another, since the overall aim is to give the readers ideas as to how to successfully save energy in their own arena.

1.2. AUTHORS

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EKA (Energi & Kylanalys) consists of specialists in the field of refrigeration, energy analysis, energy efficiency and building physics in ice arenas in particular.

EKA's core competence lies in refrigeration engineering with a focus on natural refrigerants. Past projects include Europe's first full CO2 ice arena which became self-sufficient on its own heat recovery system. As an impartial expert in the field of sustainable energy and especially ice rinks, EKA is of service to both private and public sectors worldwide.

EKA has developed and possesses a bank of technical information and experience developed during its activity in the refrigeration and ice arena industry since 2004. EKA's designs are based on a combination of accumulated experience and field data, which are implemented in energy calculations that are done with publicly available softwares. These tools, methods and results have to a large extent been peer reviewed by the research community in the industry in scientific articles and academic conferences.

EKA provides a wide range of services in refrigeration and other ice arena technologies. The general idea is that as an industry expert, EKA can support and, if necessary, also represent the client with the necessary knowledge in the process of developing and realise the best system solution.

The following people have contributed to the creation of this report:

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TECHNOLOGY

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2 INTRODUCTION TO SUSTAINABLE ICE ARENA TECHNOLOGY

2.1. WHAT IS SUSTAINABLE ICE ARENA TECHNOLOGY?

Before introducing the key aspects of sustainable ice arena technology, an understandable question that may arise to the reader is: what is really meant by the word Sustainable?

The word sustainable literally means “able to be upheld at a certain level”, indicating something that is robust and can be maintained the way it is on the long-term without problem. From a building management point of view, reaching sustainability generally leads to two areas of focus: Functions and Resources, where the latter are used to achieve the previous.

These two elements of sustainability are listed below along with some examples from the ice arena technology perspective. While the examples listed below could be expanded further considerably, the most important thing to remember from the reader perspective is that **sustainable ice rink technology consists of long-term solutions that lead to optimum function in a way that manages resources efficiently.**

Figure 1. A sustainable ice arena consists of long-term solutions that lead to optimum function in a way that manages resources efficiently.

FIELD OF ACTION
TECHNOLOGY

A Sustainable Ice Arena involves Sustainable:

1. Functions, e.g.:

a. Ice arena specific functions
- i. Ice quality
- ii. Lighting conditions
- iii. Heat load management
  - 1. Minimize unnecessary loads on ice sheet
- iv. Moisture load management
  - 1. Minimize unnecessary loads in arena room

b. Visitor comfort
- i. Temperature levels
- ii. Indoor air quality
- iii. Air and heat distribution

c. Structural integrity & health
- i. Load bearing capabilities
- ii. Moisture handling
  - 1. Dehumidification control
  - 2. Zonal Air management
- iii. Moisture safe building envelope design

d. Visitor safety
- i. During hockey / ice skating activities in general
- ii. In case of:
  - 1. Fire
  - 2. Refrigerant leaks

These are of course just a selection of many functional requirements a good ice arena needs to comply with.

2. Resources, e.g.:

a. Technical properties
- i. Building materials
- ii. Refrigeration system
  - 1. Refrigerant and other fluid types
- iii. Heating sources
- iv. Dehumidifier type

b. **Energy type & its use for:**
   i. Cooling
   ii. Heating
   iii. Dehumidification
   iv. Ventilation
   v. Lighting
   vi. Misc.

c. **Water usage**

Now that the sustainable ice arena has been defined within the context of this guide, the next step is to look at the key aspects of sustainable ice rink technology that should be understood by an ice rink owner, and which will be the main focal points when discussing sustainable solutions in this guide.

2.2. PASSIVE AND ACTIVE MANAGEMENT OF ICE ARENA CONDITIONS

An ice arena is a building with particular conditions: Within the same arena room there is an ice sheet that needs to stay frozen, while there generally also are heating and air quality demands for visitor comfort. Furthermore, these conditions often result in a special challenge, where the air humidity in the arena room may become too high and needs to be controlled to avoid problems, such as damage to structures. Last but not least, the space should also be well illuminated for comfort and safety reasons.

A well-functioning ice arena must be able to handle the complex heat loads and moisture loads that come along with the abovementioned type of environment. This leads to two areas of focus:

1. The Building Structures
   a. To **passively** manage the heat and moisture loads in the ice arena
2. The Energy Systems
   a. To **actively** manage the heat and moisture loads in the ice arena

Sustainable building structures, such as the building envelope, will be treated in this guide. However, **Improving the energy efficiency of the ice arena is one of the most important ways to make the facility more sustainable,** and for the benefit of the ice rink owner it will often also increase the economic performance of the facility.

FIELD OF ACTION
ENERGY SYSTEMS

Figure 2. A well-functioning ice arena must be able to handle the complex heat loads and moisture loads that come along with this specific environment. In this picture they are not well managed, causing foggy conditions.

2.3. THE BIG FIVE ENERGY SYSTEMS

To operate an ice arena there are generally five basic energy systems required:

- Refrigeration
  To manage the heat loads on the ice sheet
- Heating
  Space heating
  Hot water
- Dehumidification
  To manage the humidity level in the arena room
- Ventilation
  When necessary, to maintain air quality
- Lighting
  To maintain lighting conditions

FIELD OF ACTION
ENERGY SYSTEMS

These systems are here referred to as the "big five" because they typically 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.

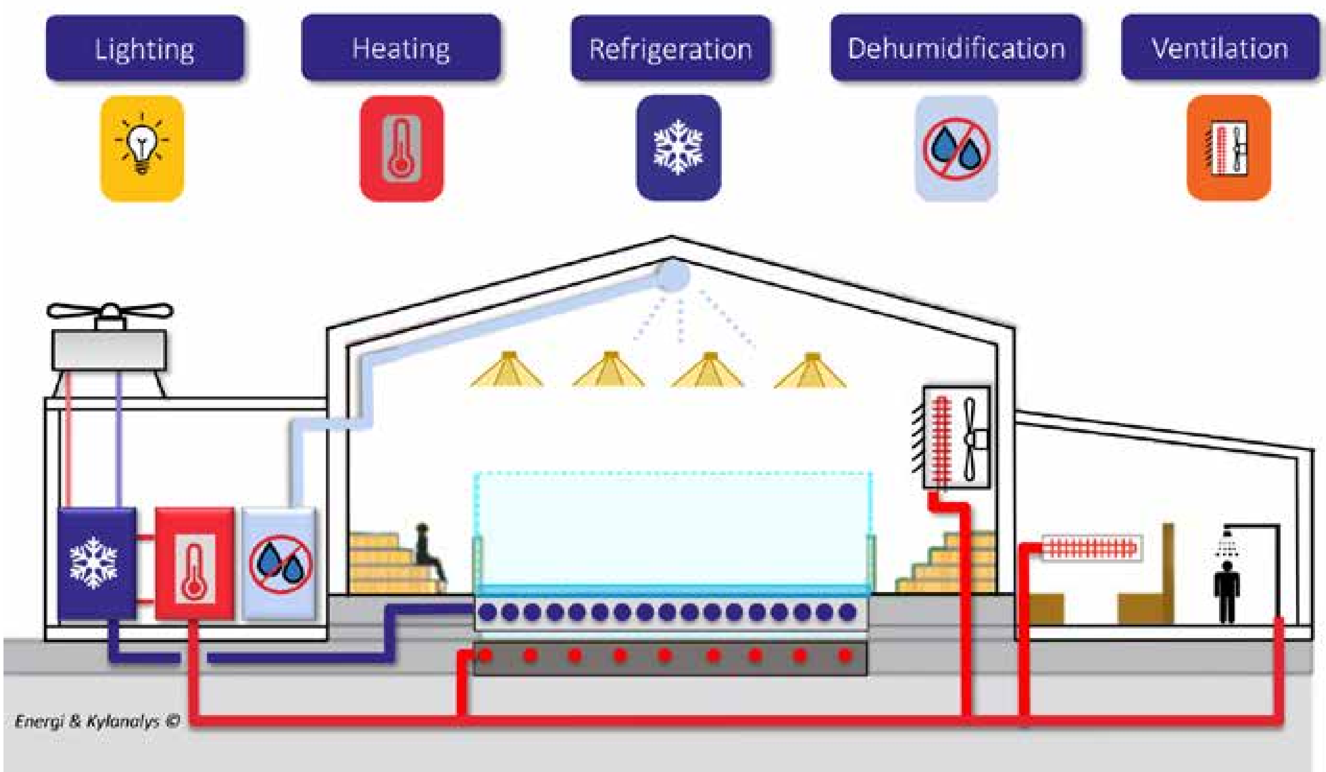


Figure 3. Indoor ice rink energy systems – The big five.

The big five energy systems are present in essentially every ice rink – big or small – as will be covered many times in this guide. Further, these systems interact – regardless of, if you want it or not. By connecting these 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 affect 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.

FIELD OF ACTION
SAVINGS POTENTIAL

To further illustrate the significance of the five main energy systems, Figure 4 is shown. Results from investigations suggest that in conventional ice arenas refrigeration contributes to the largest portion with around 43% and heating demands come next with around 26%. The other functions are estimated with up to a 10% share each.

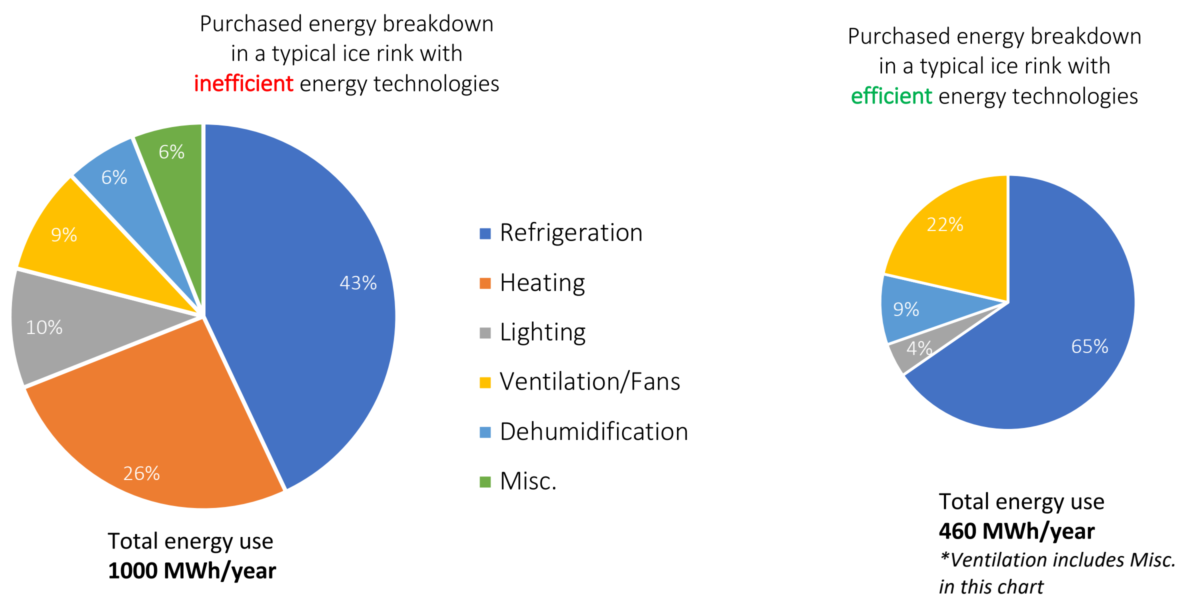


Figure 4. Main energy uses in a typical/conventional ice rink in Sweden with inefficient and efficient energy technologies (Stoppsladd, 2014; ASHRAE, 2017).

In modern ice arenas with efficient system solutions the relations between energy demands are a bit different, as shown to the right in the Figure above, but the conclusion remains nevertheless the same: **the big five energy systems that are emphasized here are of crucial importance and should be the focus when it comes to improving energy efficiency in ice rinks.**

The biggest energy savings potential is often to cover the heating demands with recovered heat from the refrigeration system, with the possibility of eliminating the purchased heating energy demand as indicated in Figure 4, and this will be further discussed later on in the guide.

2.4. SAVINGS POTENTIAL IN ICE ARENAS

Savings potential is understandably of high interest to an ice rink owner since it also can lead to increased economic performance of the facility. Below, aspects of energy and cost savings potential are discussed to give an ice arena owner the proper decision-making tools to make the facility more sustainable.

FIELD OF ACTION SAVINGS POTENTIAL

2.4.1 Energy savings potential

When looking into the energy savings potential of an existing ice rink, the options can often be divided into two groups of measures: Quick fixes and Long-term solutions. In the table below these two groups are compared, but generally it can be said that quick fixes are easy to implement with low/no investment costs, while long-term solutions require more effort yet yield the biggest savings (most often also with increased comfort).

Table 1. Energy savings in an ice rink – Comparison of measure groups.

	Quick fixes	**Long-term solutions**
Definition	Measures that are aimed at single system adjustments. Require low effort and low/no investment.	Measures that require a comprehensive and often cross-system approach. Require higher effort and investment.
Pros	Low/no investment. Short implementation time. Immediate savings effect.	Minimal operational costs in the long-term. Optimum functions: e.g. comfortable and healthy indoor environment. All-encompassing energy system solution. Best possible economic performance long-term.
Cons	Potentially sacrificed comfort, with unsatisfied visitors as result. Potential risk of function: e.g. mold growth in structures, condensation and other moisture problems. Major function and resource inefficiencies may still remain, e.g. non-sustainable refrigerants.	Requires larger investments. Longer design and implementation time.

Given the comparison of the two measure groups above, it is understandable that many ice arena owners may prefer to go for the lower-hanging fruit and only apply quick savings. It is always highly recommendable for any ice rink owner first to look for potential quick savings, since they may have minimum/no impact on function and yet improve performance very quickly. Furthermore, quick fixes are a good way to engage facility owners in the process of making the facility more sustainable, where long-term solutions are recommended to be applied.

Figure 5 compares the energy performance of a large number of Nordic ice rinks, from which data have been gathered. **The shown values in Figure 5 reflect the average amount of purchased energy during a day of ice arena activity.** On the left side of the figure, larger arenas are represented, and this is understandable since they are bigger and more complex facilities with many other additional functions that require purchased energy. They are therefore somewhat more difficult to compare. However, the rest of the ice arenas are by incredible majority of similar size and capacity, making them more comparable in terms of energy performance.

FIELD OF ACTION
SAVINGS POTENTIAL

Typical sized ice arenas with conventional technologies purchase more than 3000 kWh of energy (electricity and any other potential heat sources) per day during the ice season on average. With quick fixes an ice rink owner can reach below this limit and improve energy performance with minor savings. **The big savings are however only attainable by applying long-term sustainable solutions,** where proven results have shown that existing ice rinks can reach below 1500 kWh/day, indicating that energy costs get cut by more than 50%, which in turn make the investments more profitable than continuing with existing solutions.

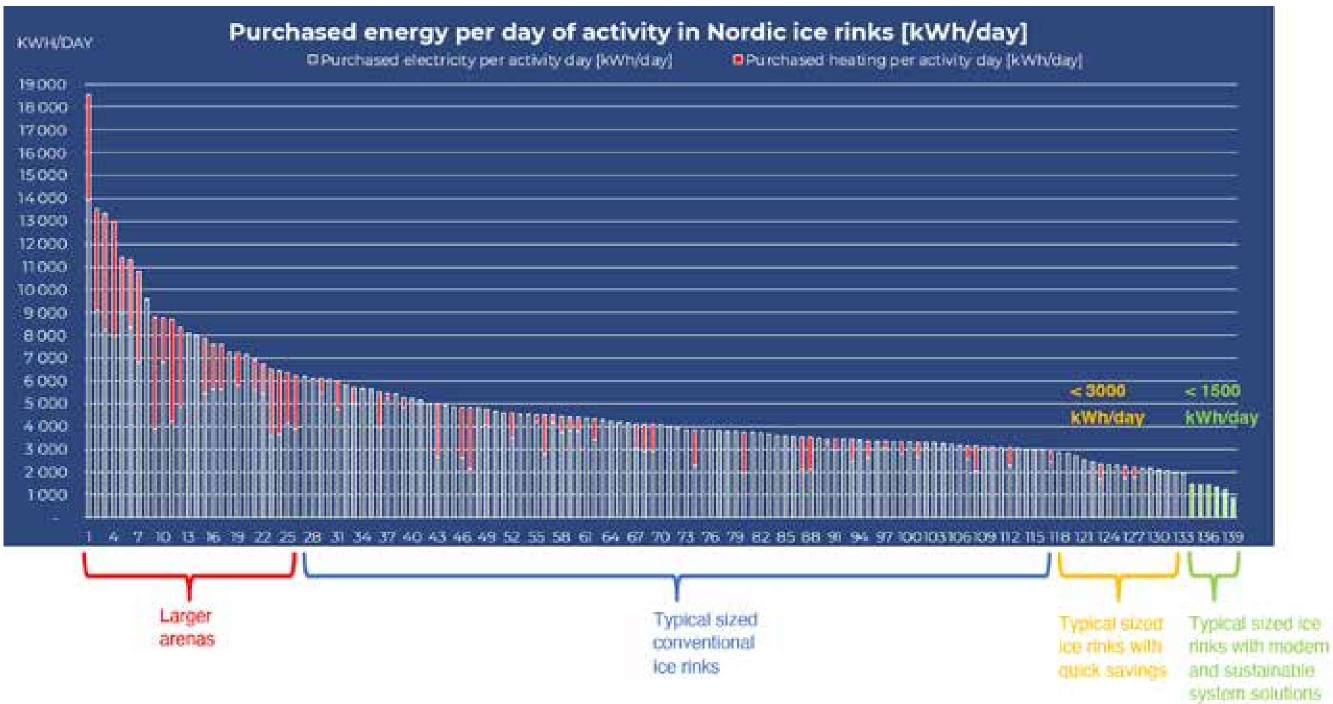


Figure 5. Comparison of energy performance in Nordic ice rinks. The shown values reflect the average amount of purchased energy (electricity and any other potential heat source) during a day of ice arena activity.

2.4.2 Cost savings potential

As discussed above, energy savings measures can be divided into so called "quick fixes" and "long-term solutions", where the latter generally yield the best results both in terms of energy and economic performance. However, a typical challenge for an ice rink owner relates to the investments required for the long-term solutions, since they may become of a significant size. This is the most common reason why only quick fixes are applied first, since they require low/no investment.

FIELD OF ACTION
SAVINGS POTENTIAL

Figure 6 shows an example where the economic performance of an existing ice rink, that has already applied quick fixes, is compared with two other "future scenarios", where the same ice rink is equipped with modern sustainable solution alternatives 1 or 2. The comparison includes investment (CAPEX) for the alternative solutions as well as all operating costs (OPEX), including energy and service, for each scenario over a reasonable length of time (often 20 years). This approach to compare economic performance is called life-cycle cost analysis, where all relevant costs over the long-term are recalculated to a single lump sum by which the economic performance of each scenario can be compared.

As can be seen in Figure 6, the sustainable long-term solutions show a considerably better economic performance than continuing with the existing system solution where only quick fixes have been applied. This also means that for each day that goes by, the ice rink owner is losing money by continuing with the existing system instead of investing in a sustainable long-term solution.

The actual savings potential will vary depending on several factors such as system, size of ice arena, energy prices, etc., but the main thing to remember is that economic performance of system solutions should always be compared on the long-term since it will show which solution saves most money for the ice rink owner. It should also be noted that the operating costs of the "future scenarios" in the Figure below are based on actual data from existing ice rinks that have switched to sustainable solutions, the values are therefore based on reality.

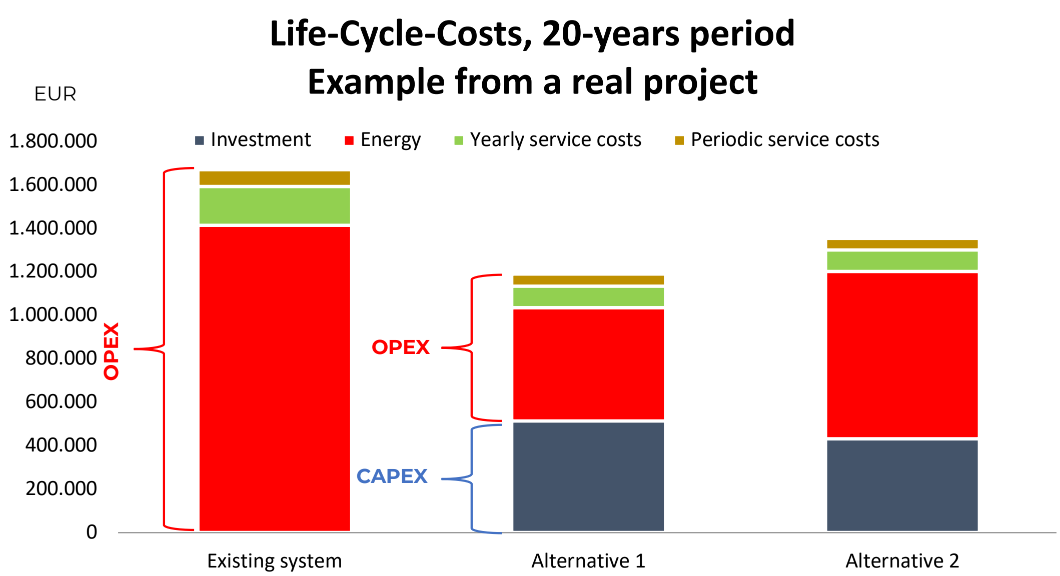


Figure 6. Life-cycle cost results for sustainable energy solutions (alternative 1 & 2) in an ice rink compared to existing system. The results show that investing in long-term solutions will yield the biggest savings for the ice rink owner.

FIELD OF ACTION
ENVIRONMENTAL IMPACT

2.5. ENVIRONMENTAL IMPACT OF TECHNICAL SOLUTIONS

These days, the economy often plays the decisive role in the selection of technical solutions. Nevertheless, other factors such as safety and, not the least, environmental impact are gaining more ground.

The importance of minimizing energy and water usage as well as the importance of applying sustainable building materials are themes that are becoming increasingly known to the wide audience, since they are applicable to more or less any kind building, be it residential, commercial, industrial, etc.

In the world of refrigeration systems and heat pumps, to which ice rinks also belong, the environmental impact of the refrigerant used in the refrigeration system will also play a significant role whether the facility is sustainable or not. This is further discussed below.

2.5.1 Refrigerant environmental impact

As more and more facts about climate change have been brought to light, environmental factors have become increasingly included in the legislation processes around the world, affecting the technology development, including refrigeration technology. Typical refrigerants that have been used over the years have certainly had an impact on climate change, causing both ozone depletion and global warming.

Signed in 1987, the Montreal Protocol reduced and then banned chlorine- and bromine- based chemicals as refrigerants. It was motivated by scientific observations from laboratories, the ground, aircraft, and satellites, which all indicated that ozone depletion was taking place. Figure 7 compares the ozone layer between the years 1979 and 2011 with the south pole in the center. The deterioration of the ozone layer results in a more intense ultraviolet radiation from the sun penetrating until the surface of the planet, increasing the risk of sunburns, skin cancer and eye damage.

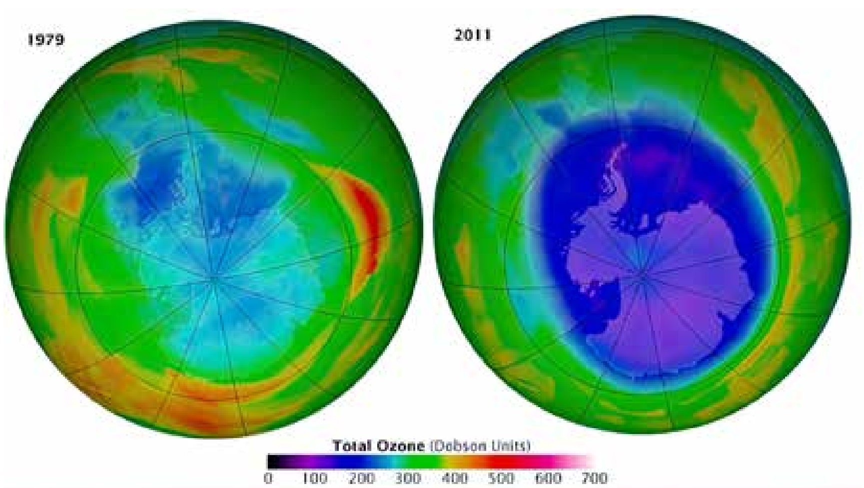


Figure 7. The Antarctic ozone hole on September 16 in the years 1979 and 2011 (NASA Earth Observatory, 2012).

FIELD OF ACTION
ENVIRONMENTAL IMPACT

Another aspect of climate change, which today is a more pressing topic, is the so-called global warming, which is defined as an unusually rapid increase in Earth's average surface temperature over the past century – 0.6 to 0.9 degrees Celsius between 1906 and 2005. Moreover, the temperatures are without a doubt going up further. The main factor contributing to it are the greenhouse gas emissions released due to human activities.

The main legislation related to global warming in the refrigeration industry is the "F-gas regulation" made in the EU that aims to control the emissions from fluorinated greenhouse gases (F-gases). One of the measures is phasing out the F-gases by limiting the sales. Every region of the world has its own pace, with EU in the forefront, where the goal in 2030 is to have one fifth of the sales of 2014.

To understand how refrigerant properties, including environmental impact, have affected the industry over the last decades, Figure 8 is illustrated. Here refrigerants have been divided into four generations. Up until 1990's the focus was on safety and durability, after which the 3rd generation refrigerants were substances with no ozone depletion potential. The latest generation represents even further environmental advancements that have been implemented, tackling the global warming effect of the refrigerants.

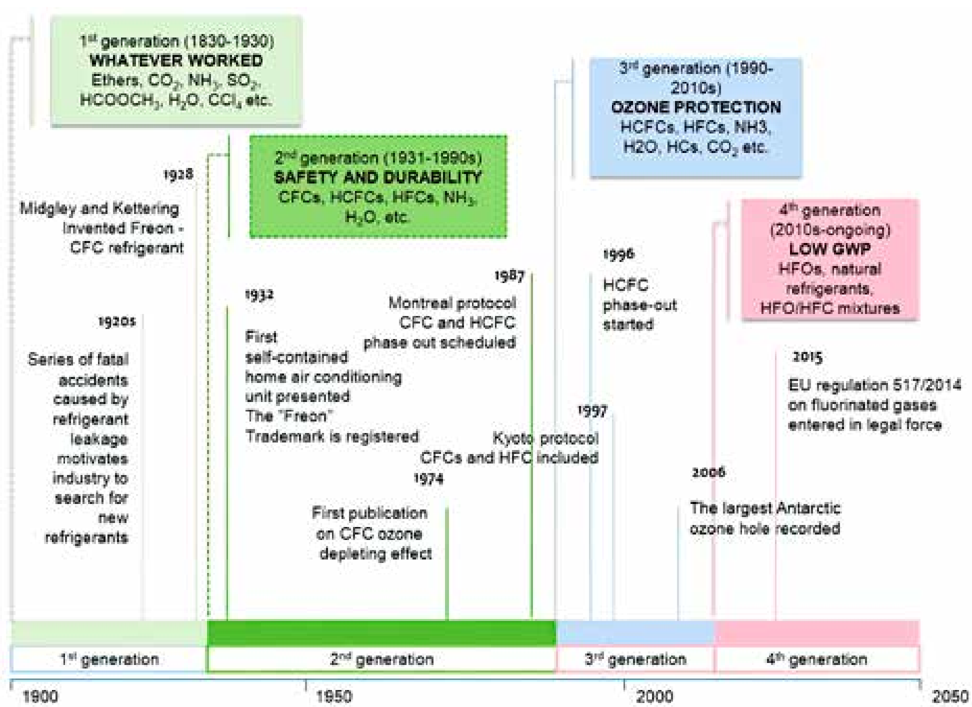


Figure 8. History and future of refrigerants divided in 4 generations (Makhnatch, 2018).

Refrigerant properties will be discussed further in this guide when presenting sustainable refrigeration systems.

3 BUILDING AND RETROFITTING ICE RINKS – SUSTAINABLE WORKING PROCESSES

This chapter will go through how an ice rink owner can ensure, or at least maximize the probability, that an ice rink project becomes successful by consulting an impartial industry expert. A successful project indicates achieving optimum quality for the lowest possible price as well as on time.

While there are new ice rinks being built still today, most ice rink related projects are retrofits. The retrofitting process of an ice rink, and how it can be done sustainably, is therefore also discussed further.

3.1. CONSULTING AN IMPARTIAL INDUSTRY EXPERT

When an ice rink owner is presented with a situation, where something needs to be investigated, designed, built, fixed, etc., a natural step (and in many ways also a decisive step for the final outcome of the project) is how the procurement process is handled.

In the procurement process, regardless if it is public or private, a typical challenge for facility owners is how to compare different tenders. The most common path is to select the tender with the lowest price, but in many unsuccessful procurement processes, the presented offers vary enormously in terms of quality. As a result, the client often ends up choosing the supplier with the lowest price but not the solution with the desired or optimum quality. This in turn, has a negative impact also on the long-term economy of the client.

Especially in private procurements where offers vary in quality, clients may also select the solution based on best perceived quality. But the perceived quality may not reflect reality, resulting in that the client ends up paying even more for something that still does not fulfill the demands optimally.

The best way to avoid these typical problems in procurement is to clearly specify what kind of system solution is to be implemented, since it will make the tenders comparable in terms of quality and therefore making the price the decisive factor. The challenge here, however, is that most facility owners, contractors, and even consultants do not know which system solution best covers the demands in terms of both quality and (long-term) economy. And even if they would know, they even more likely lack the knowledge on how the contract documents should be specified so that the desired system solution also will become reality in the most time- and cost-efficient manner, if at all.

PROCESSES
CONSULTING AN EXPERT

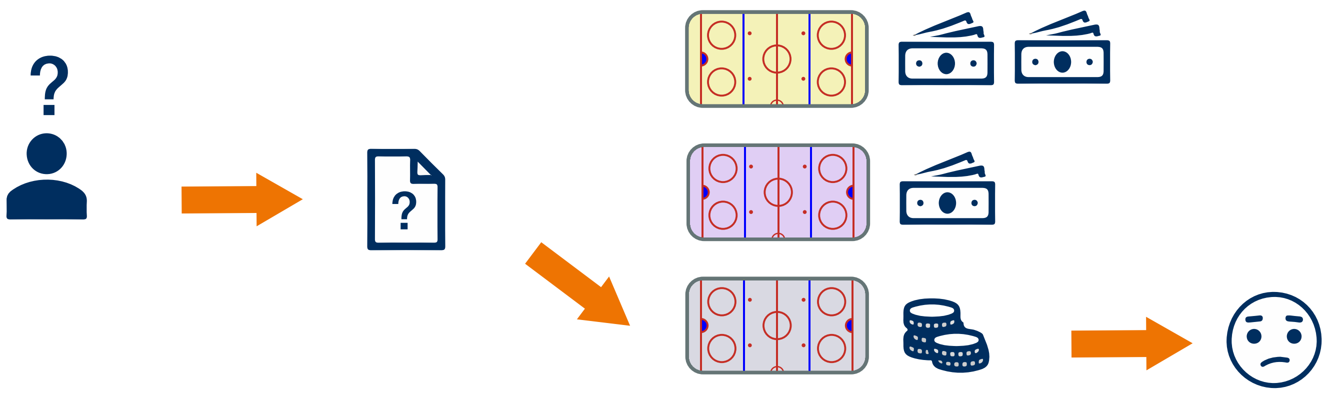


Figure 9. The procurement process contains many pitfalls, which mainly occur due to the lack of knowledge, and may lead to low quality results and/or significant waste of money.

A good way to ensure that the procurement process becomes successful, regardless if it is public or private, is to include an unbiased industry expert that can support the client with necessary information so that the quality related requirements for the project become clearly specified in contract documents. This will result in comparable tenders in terms of quality in their technical solutions and ensure that the client will be procuring the best solution to cover demands for the best price. In the ice rink industry this means that the client then will get the most energy and cost-efficient ice rink for the lowest investment cost.

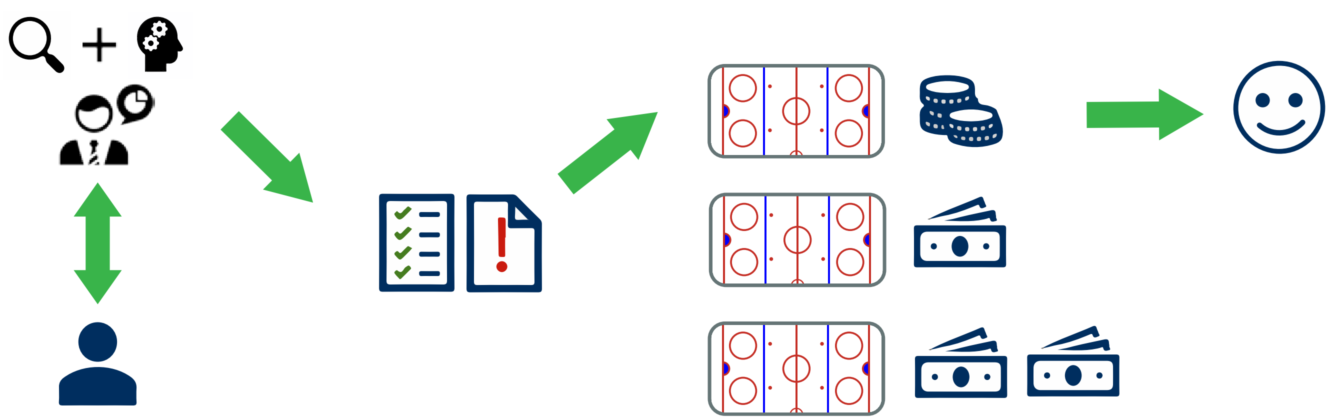


Figure 10. An impartial industry expert can support the ice rink owner in investigating, designing, and specifying the optimum system solution in procurement documents. Tenders will as result be comparable in terms of quality, and the client will get the best possible solution to cover demands for the lowest price.

Consulting an impartial expert in ice rink technology is therefore of high importance to achieve a sustainable ice arena. While there are many consultants out there, an impartial expert is focused on making sure that solutions created for the client combine excellent performance with good economy and minimal environmental effect, all backed by latest peer-reviewed scientific research. The work of an impartial expert often consists of developing energy concepts for newly built or renovated ice rinks to optimize the facility and/or lower its operating costs. This means that the solutions in each project where an impartial industry expert is involved in will maximize the benefits of the client, and make sure that suppliers continuously update their service in order to fulfill the requirements of state-of-the-art technology backed by scientific based data.

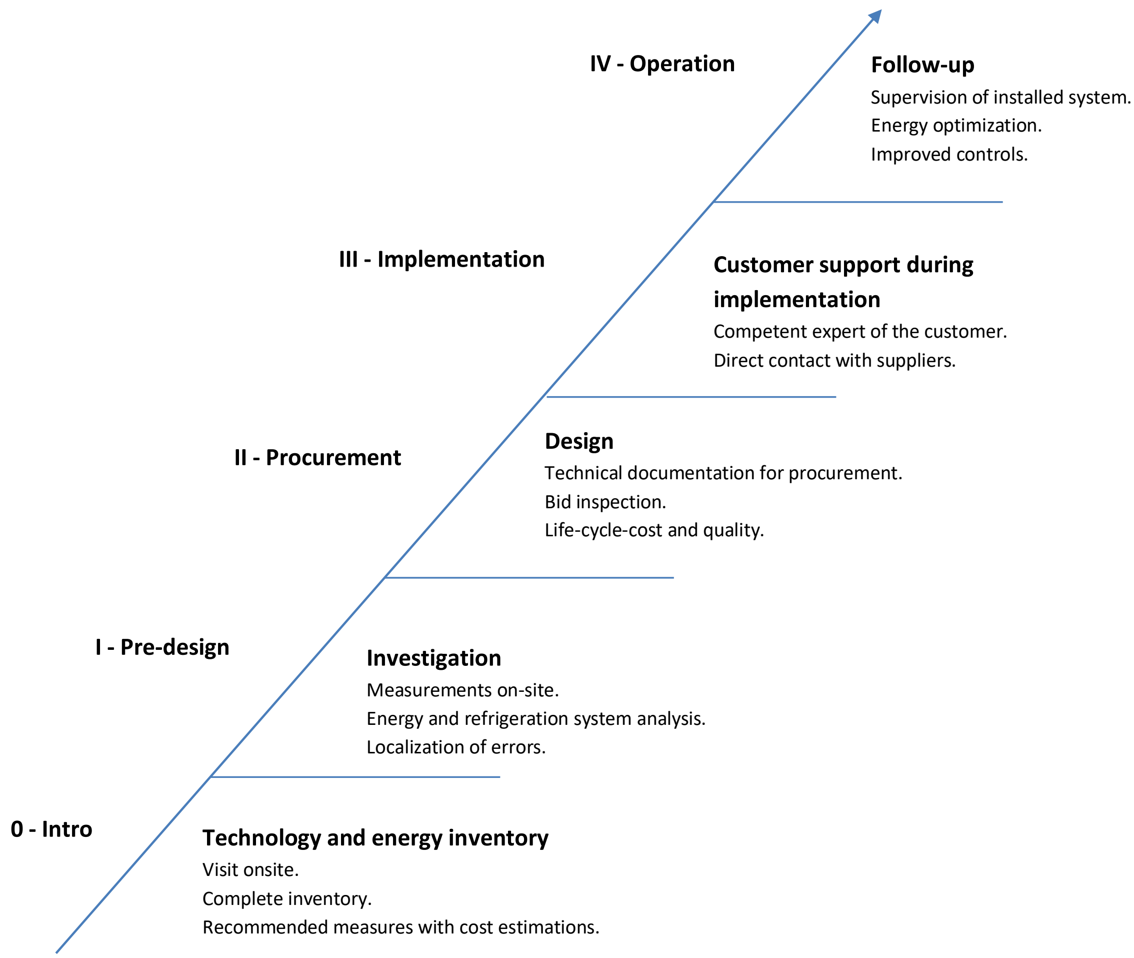
3.2. RETROFITS

As indicated in this chapter, a key component in successful procurement is knowledge. The client is typically not so well-informed regarding what exactly should be procured, how its requirements should be specified, and why the chosen quality is the best solution. The best way to tackle this problem is to have an impartial industry expert guide the client in the right direction. In the ice rink industry this typically this means that the expert will collect information regarding the circumstances of the particular project and the client's needs, in existing facilities often by establishing technical status and performing energy audits. Suggestions for system solutions that fit the scope of the project and fulfill the demands of the client will then be presented.

When the client and the impartial industry expert have decided on the final solution that is to be implemented, the expert will create the specifications and drawings that are to be used in the procurement process. The specifications will be precise enough to make sure that received tenders will be comparable in terms of solution quality, while at the same time respect the principles that are used in public procurement (in case the procurement is done publicly). This way the client will get the desired system solution for the best price, which in the ice rink industry means the most energy and cost-efficient ice rink for the lowest investment cost.

Furthermore, the industry expert can support the client in auditing and follow up on the project, where it can be ensured that the delivered system solution fulfils the requirements and that it also works as intended when put into operation.

PROCESSES
RETROFITS



In the illustration above, the work process of developing energy concepts is shown for newly built or to be renovated ice rinks, in order to optimize the facility or lower its operating costs. Different arenas have different requirements; therefore, every ice arena needs a tailored solution.

4 SUSTAINABLE BUILDING ENVELOPE

The main function of the building envelope is to separate the indoor climate from the alternating outdoor weather in a controlled manner. Support systems such as heating, ventilation and dehumidification should not have to work more than necessary in order to maintain the desired indoor climate.

Figure 11. Ice arena with wooden material elements in the building envelope.

The building envelope should therefore be designed and built to handle the local outdoor climate conditions in the best way possible.

4.1. ENVELOPE – ROOF AND WALL CONSTRUCTIONS

It goes without a discussion that the main property of the building envelope is its structural durability. However, the purpose is to separate the indoor environment from the ambient conditions, with the least energy required for the mechanical equipment. This implies that heat and moisture transport should be controlled in a proper manner for the intended application in the prevailing climate conditions.

ENVELOPE
ROOF AND WALL

4.1.1 Insulation

To reduce the capacity required of the heating as well cooling equipment, insulation is used. It is a thermal barrier in the building envelope structure with the aim to halt the undesirable heat transfer consequences, ensuring that reasonable thermal comfort conditions are achieved at any time of the year.

Materials that can be used for the insulation must have sufficient resistance for the given conditions, which is the governing parameter. Since the availability and price of the material depends on the location, there is a wide range of wall structure combinations. In Nordic ice rinks, for example, two commonly used materials are mineral wool and polyurethane.

4.1.2 Air barrier

Minimization of air leakages is required in order to avoid excessive infiltration or exfiltration rates. In ice rinks, infiltration rate is especially critical for the dehumidification load during the warm part of the season due to the fact that air carries water vapor with it. The heating or cooling demand is also important, since the volume of air that is transferred in our out by air leakage, impacts the heating or cooling demand. In this section attention is paid to moisture rather than heat transfer.

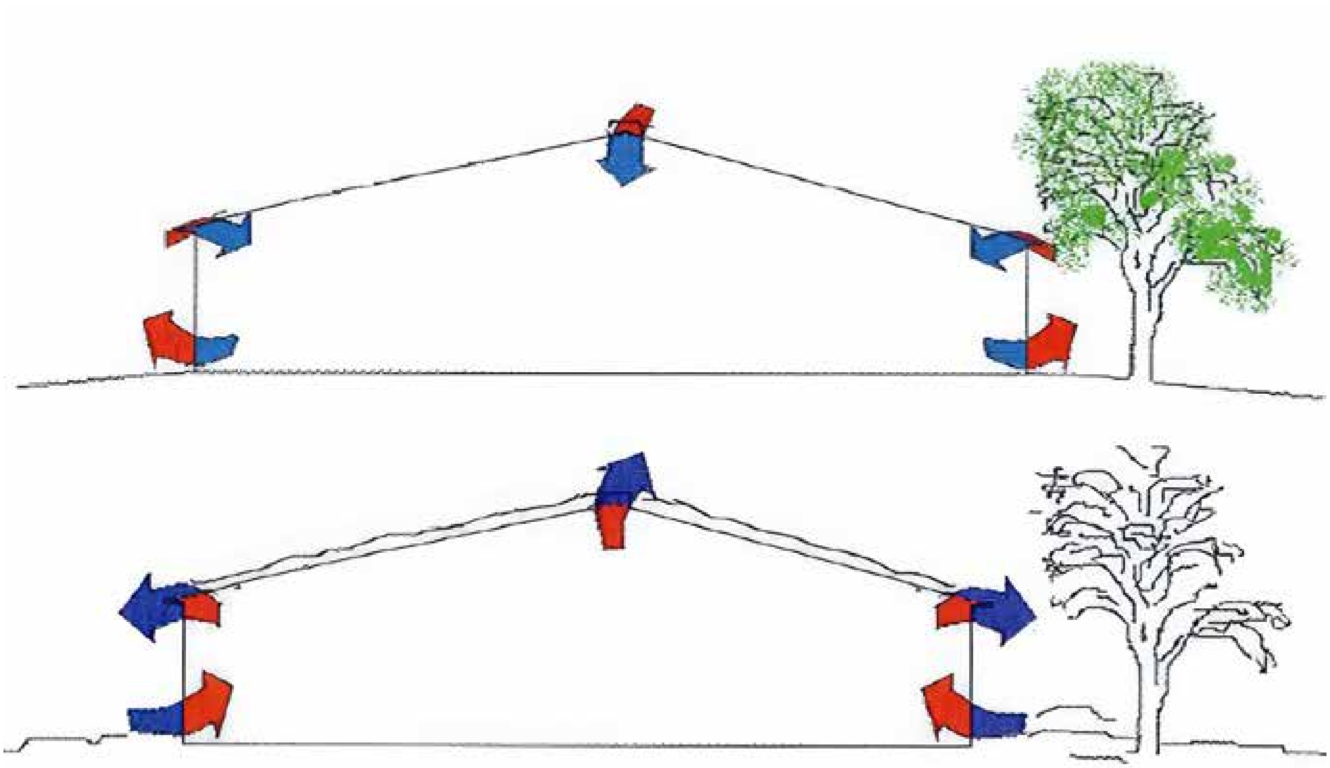


Figure 12. Stack effect in an ice rink depending on a time of a year (Rakennustieto, 2007)

ENVELOPE
ROOF AND WALL

Air leaks through openings or space between joints, or cracks in the building structure, thus a continuous air barrier which seals the whole building envelope is very important. The air barrier material of the wall must seal to the air barrier material of the roof. Usually, in case of unproperly sealed envelopes, moisture tends to deposit at a discrete location near the leakage point on the inside of the ice rink arena room.

In Figure 13 an example is shown from an ice rink where evidence of air leakage can be seen. In summertime the total air pressure difference between indoor and outdoor air is negative at the top of the building - above the neutral pressure line, as shown in Figure 12. And provided there are unintentionally created channels for air to flow, infiltration occurs. Condensation eventually happens since the humid outdoor air meets with a material having a temperature that is lower than the dew point of the incoming air.

Figure 13. Air leakage traces near the joint between roof and wall.

There are materials available with practically zero air leakage, but it is important to account for the complete air barrier system - including joints and all the imperfections, since there are forces applied to the air barrier due to the stack effect, mechanical-system-induced and wind pressures. Therefore, when integrating an air barrier into the wall structure a proper consolidation method must be applied, since if an air pressure difference cannot move air, it will act to displace the materials that prevent the air from flowing.

ENVELOPE
ROOF AND WALL

Figure 14. Polyethylene self adhering air barrier (Delta Vent, 2019)

In summary, regardless of which materials chosen, the air barrier must be impermeable to air, able to support the peak pressure load, continuously applied from foundation to roof, and durable.

4.1.3 Vapor barrier

The nature of diffusion is different than that of air leakage, since it is a much slower process, as a result it is not a noteworthy indoor air moisture source in ice rinks. The impact on the structure itself, on the other hand, can be very destructive. The main reason being condensation of the vapor, which appears if the vapor pressure at any point is lower than its saturation pressure. But the moisture diffusion process itself may not affect the structure, as long as the moisture is naturally ventilated.

Vapor resistance should be as low as possible in an air barrier in ice rinks, and commonly used materials are compared in Table 2. The Sd value represents vapor diffusion resistance for a given material and its thickness. It can be understood that a metal sheet and/or a polyethylene foil are practically completely blocking the vapor diffusion. Plywood and softwood are also considerable water vapor barriers, and therefore care must be taken when using these in a building envelope structure. Important to notice that commercially available polyurethane air barriers may have a very low vapor resistance, implying that there is no risk of condensation due to its location in a wall.

Table 2. Vapor resistance for common wall structure material

Material	Thickness (mm)	Sd value (m)
Metal sheet	0.4	1500
Ployethylene foil	0.2	70
Plywood	18	12.6
Softwood	28	5.6
Mineral wool	200	0.26
Plasterboard	13	0.11
Polyurethane air barrier	0.2	0.025

The use of vapor barrier is therefore generally seen as a potential risk factor with low benefits, and it is instead suggested that an air barrier with low vapor resistance should be placed in the ice rink wall or roof structure.

4.2. CLIMATE ZONES

Due to the special indoor climate in the arena room of the ice rink, it is preferable to separate it from the outdoor climate with airlocks to minimize unwanted leakage of air, with associated loads such as moist air into the ice rink. Furthermore, it is recommended that the arena room is well insulated from the other (heated) climate zones in the facility to minimize air leakage, waste of energy and to increase the comfort.

The same problem, i.e. air leakage, is often found at the ice resurfacer garage in connection to the ambient. Here it would be good if an automatic/remote-controlled closing function was applied to minimize air leakage into the arena room when driving in/out to dump snow.

ENVELOPE
CLIMATE ZONES

Figure 15. Open doors either directly towards outdoors, or between comfort and arena zone cause significant energy and moisture influx into the arena room. In addition, basic uninsulated wooden doors are found between climate zones in some ice rinks which is not an optimal solution.

In general, it can be recommended to place signs at the doors to the arena room reminding users to ensure that the arena room is kept "closed". Door type should be selected such that is hermetically sealed and with materials that have a high thermal resistance.

Figure 16. Doors between the cold space and heated spaces must be with high thermal resistance, hermetically sealed and normally kept close.

As bringing this essential information regarding closing doors etc. to all ice users have proven to be challenging, an automatic self-closing function is a recommended feature. Sometimes an alternate function that monitors the opening time and produces an alarm (sound and/or visual) may be an interesting solution as well.

5 SUSTAINABLE RINK FLOORS

The rink floor is a very important component in the ice rink since it is the base for the ice and the largest heat exchanger in the facility. 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 60×30 m whereas in North America the typical measure is 61×26 m.

5.1. STRUCTURE

An ice rink floor typically consists of a number of layers illustrated in Figure 17, where the top one is the ice sheet with a recommended thickness of 25-30 mm. The floor itself is often made out of concrete (designed for freezing temperatures) for best durability, although sand/gravel and asphalt may used as well due to lower investment costs. In the top part of the concrete the cooling pipes are typically embedded which provides the heat transfer function as the load on the ice needs to be transferred to the refrigeration system. The pipes should be placed as close as possible to the ice sheet (max appr. 35-40 mm between top of pipe and concrete surface) to minimize the resistance in heat transfer, since it otherwise implies that the refrigeration system will be forced to work at a lower temperature (and thus become less efficient).

RINK FLOORS
STRUCTURE

Under the concrete layer, which is normally about 150 mm thick in total, there is an insulation layer. The insulation is there to reduce the heat load from the ground and the material is normally extruded polystyrene (XPS). There is a similar product referred to as EPS which is slightly more permeable to air and moisture, and **this must not be used** since it is less resistant to water vapour than the XPS quality.

Below the insulation layer there is very important function – the so-called freeze protection or sub floor heating – which consists of heating pipes. Although there is an insulation layer above, with time, the ground will 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 associated problems.

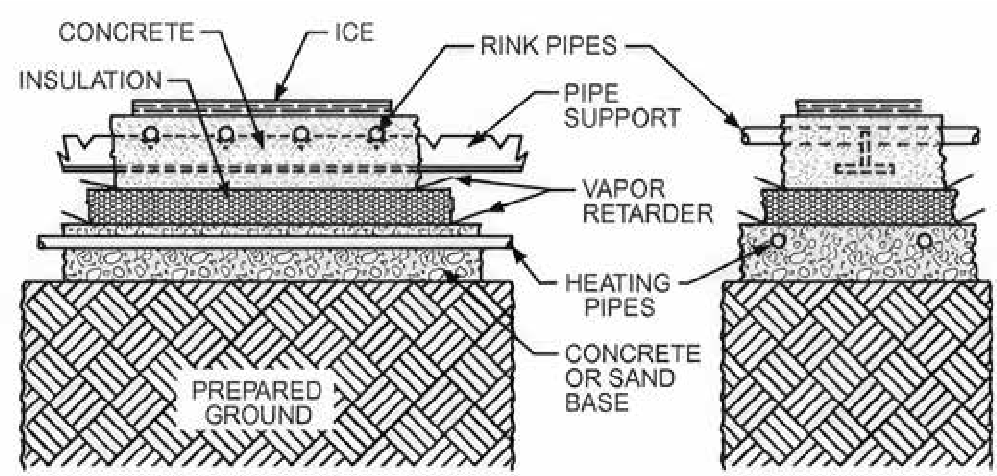


Figure 17 Typical layout of and ice rink floor (ASHRAE Refrigeration, 2014)

Vapor retarders are often also recommended to be installed, at least below the concrete layer, to halt moisture transfer from the ground into the concrete. The material used below the rink floor should not have properties to support capillary transfer of moisture from the ground towards the rink floor. In case it does, there is a risk that moisture over time may reach the rink floor structure from the ground and cause damage to the structure.

RINK FLOORS
RINK PIPES

Table 3 lists the typical dimensions for rink floor layers and rink piping.

Table 3. Typical ice rink floor and pipe/tube dimensioning

Parameter	Size
Ice Thickness	25-30 mm
Concrete thickness	150 mm
Insulation thickness	100 mm
Rink pipe headers diameter	150-200 mm
Rink pipe distribution pipes diameter	25-32 mm (plastic), 12.7 mm (copper)
Rink pipe distribution spacing	75-125 mm (100 mm typically)
Rink floor pipe top – bottom ice distance	35-40 mm (the less, the better)

5.2. RINK PIPES

There are mainly three types of materials used for the rink piping 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 refrigeration systems where CO2 is used as secondary refrigerant, 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, resulting in a more efficient heat transfer and better energy performance.

Material costs vary when comparing copper tubes to steel pipes, but the installation cost of copper tubes is often lower since they can be bought at long lengths and rolled out on site. Steel pipes on the other hand are often delivered at fixed lengths and will have to be welded together.

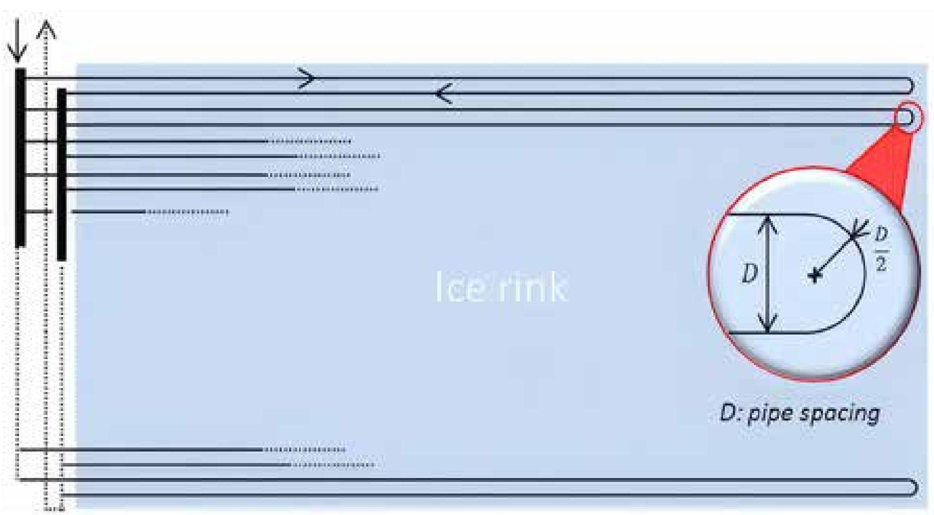


Figure 18. Typical piping layout in Europe with headers on the one short end side.

RINK FLOORS
SUBFLOOR HEATING

The piping layout is normally arranged like indicated above where the feed (supply) and return headers are placed on the short end side of the ice rink. 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 reversed return arrangement on the header side. This is also often referred to as a Tichelmann connection.

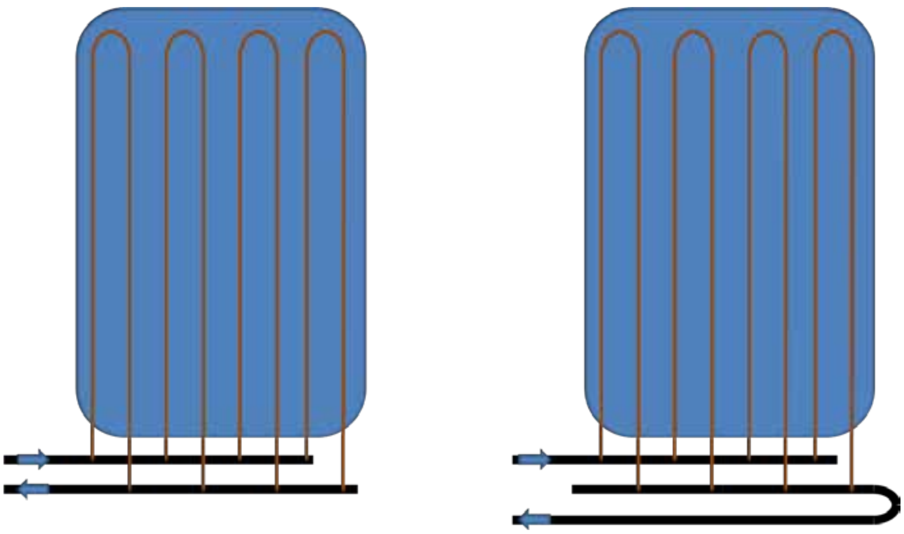


Figure 19. Two different header arrangements: conventional (left) and reversed return (right), where the latter is generally recommended.

The advantage of the reversed return is that since it is "hydraulically balanced" it will provide an even flow distribution regardless of the fluid flow. Some header designs use restrictions to control the distribution, which increases the pressure drop and it cannot be capacity controlled within a large flow range.

Distribution of secondary refrigerant is further discussed in the refrigeration system chapter of this guide.

5.3. SUBFLOOR HEATING / FREEZE PROTECTION

"Subfloor heating pipes are normally made of plastic, and often of the same quality as the plastic pipes used for the secondary refrigerant distribution (see above) with a pipe spacing of approximately 500 mm. It is important that the subfloor heating fulfils its function with lowest possible temperature level, so that it does not unnecessarily cause heat loads on the ice sheet itself.

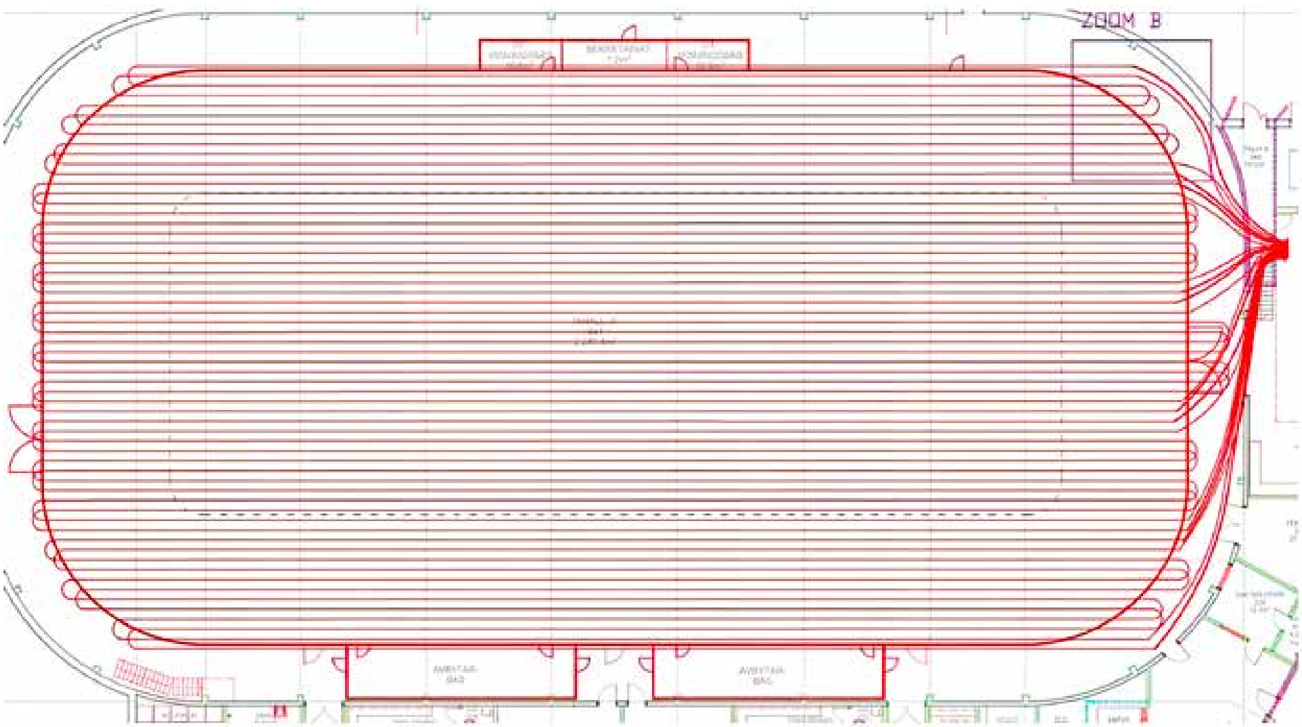


Figure 20. Principle solution on freeze protection distribution below the rink floor.

When a rink floor has a freeze-protection function, the ground temperature should be maintained at around 3°C. This further indicates that the fluid itself needs to be freeze-protected and a recommended solution here is often an adequate mixture of water with propylene glycol or equivalent with low enough freezing temperature.

5.4. DASHER BOARDS

Dasher boards are found in most ice arenas and are generally less of a concern from an energy point of view. Nevertheless, they are important in terms and function and safety, and an impartial industry expert should be consulted in the design and procurement of services related to dasher boards.

Figure 21. Dasher boards fulfil important functions, not the least in terms of safety.

Regular maintenance and status checks are also important to ensure that player/visitor safety is upkept.

6 SUSTAINABLE ENERGY SYSTEMS

Whether the specific ice rink facility is going to be profitable to a major extent depend on the awareness of ice rink management that energy usage is a major expenditure. Sustainable energy systems in an ice rink present an opportunity for a significantly more cost-competitive ice rental rates, making ice hockey more affordable.

This chapter provides a general overview about the key energy systems an ice rink depends on. For each system the best practices according to evidence from real installations and research are suggested.

6.1. REFRIGERATION SYSTEM

Refrigeration system is the largest energy user in an ice rink and often presents the most significant saving potential. Principally the refrigeration system can be divided into two main subsystems – the primary and the secondary.

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Figure 22. The primary system (on the left) involves a primary refrigerant, it cools a fluid in a secondary system (on the right) that circulates in the rink pipes.

- **Primary system** is the central refrigeration plant with refrigerant, typically placed in a technical room or an outdoor container. A distinct part of a primary system are compressors, heat exchangers among other components.
- **Secondary system** is the cooled fluid circulation system that absorbs heat from the ice slab and transports it to the primary refrigeration system where it is cooled. It is comprised of a long distribution piping that is embedded in the rink floor and with common pipes connected to the primary system.
- **Refrigerant** is the fluid that is used in the primary system.
- **Secondary fluid** is the fluid that is used in the secondary system.

6.1.1 System configurations

Ice rink refrigeration system can principally be divided in two types – direct and indirect.

An indirect system has a separation between the primary refrigerant that is used in the refrigeration cycle, while the secondary fluid is circulated through the rink piping system and brought to the evaporator.

A direct system has one fluid in the complete system used without separation, i.e., the same refrigerant that evaporates in the rink pipes is also passed through the compressors.

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A more widespread configuration is the indirect configuration, which is partly because of the popularity NH3 has had as a primary refrigerant. The reason why NH3 systems need indirect design is that a separate rink pipe loop allows to avoid the use of toxic NH3 to be circulated in the rink pipes, which also reduces the total charge.

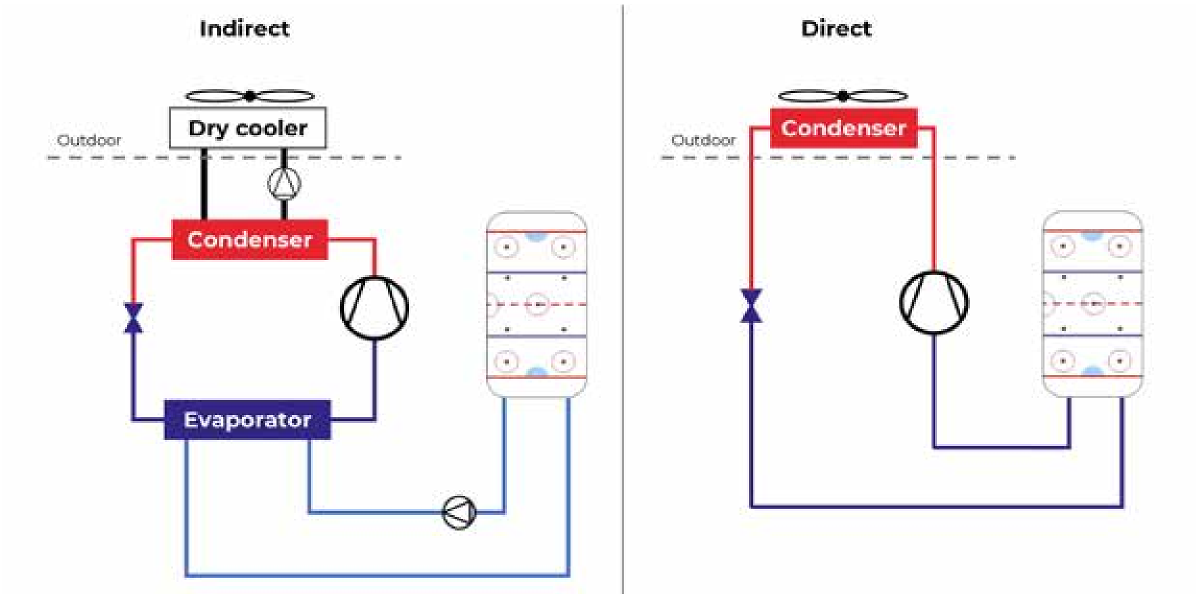

Figure 23. Two main refrigeration system configurations in ice rinks, simplified schematic.

The advantage of a direct configuration is the ability to achieve a more even ice temperature, less pump work, and thus a higher energy efficiency compared to the indirect design. The key disadvantage is the capital cost and limited refrigerant choice.

6.1.2 Primary system

When designing the primary system, several ground principles shall be followed to achieve the best long-term performance.

6.1.2.1 Selection of refrigerants

Many different fluids (media) can be used as refrigerants; however, for practical reasons the actual usage is limited to a few candidates. Of great 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 4, a couple of candidates are listed. As can be seen, natural substances have a significantly lower Global Warming Potential (GWP), thus natural refrigerants do not have long-lasting detrimental effects on the nature when leaked into the atmosphere, which is the case for synthetic refrigerants.

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Table 4. GWP and safety classes of several refrigerants.

Refrigerant	Type	Toxicity	Flammability	GWP
R744 (carbon dioxide)	Natural	Non-toxic	Non-flammable	1
R717 (ammonia)	Natural	Toxic	Low	0
R290 (propane)	Natural	Non-toxic	High	3
R404A	Synthetic	Non-toxic	Non-flammable	3922
R134a	Synthetic	Non-toxic	Non-flammable	1430
R513A	Synthetic	Non-toxic	Non-flammable	631
R1234yf	Synthetic	Non-toxic	Low	4

6.1.2.1.1 Synthetic refrigerants

R22 (HCFC-group)

This refrigerant is normally only referred to as R22 and is a synthetic compound belonging to the HCFC-group. Due to its “ozone eating” properties it is subject to phase out in most parts of the world.

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

Together with the natural refrigerant ammonia, these are the refrigerants found mostly in typical/conventional ice rinks today. This group consists of different alternatives and is normally just referred to as “HFCs” which are syn-thetic compounds. HFCs have no effect on the ozone layer, and they are still widely accepted. Due to their green-house properties, they are not a “final solution” and are therefore also subject to phase out.

R1234yf, R1234ze, R513A, etc. (HFO-group)

In order to mitigate the greenhouse effect of the HFCs, another replacement chemicals are proposed – HFOs (hydrofluoroolefins). These synthetic refrigerants have medium to very low GWP values and do not deplete the ozone layer. However, several studies have reported about other environmental and health concerns that HFOs introduce. When leaked into the atmosphere, in only 10-14 days HFOs form into another chemical trifluoroacetic acid (TFA). The main problem TFAs cause, suggested by various studies, are the negative effects on the immune system and human development, cancer and other detrimental health complications. (Atmosphere, 2022)

6.1.2.1.2 Natural refrigerants

R290 (Propane)

Propane is a natural compound in the HC-group often referred to as the hydrocarbons. One major drawback is the flammability and due to the safety aspects, propane can be used only in an indirect system, confined in a well-ventilated technical room or placed outdoors. Nevertheless, in recent years a significant commercialization of R290 refrigeration plants in various applications has been observed.

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R717 (Ammonia)

Ammonia is a commonly used refrigerant in ice rinks. It 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 drives 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 people present such as supermarkets, ice rinks, etc. It can still be used as primary refrigerant (in the machine room) but will require a secondary refrigerant 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 and has recently become a standard solution in ice rinks due to its combination of favourable properties. As primary refrigerant CO2 is generally less efficient than ammonia in warm climate, but the non-flammable and non-toxic properties offers technical advantages which makes it very interesting.

The unique characteristics give R744 an advantage in terms of heat recovery, meaning that especially in ice rinks where both cooling and heating demands need to be covered, the refrigerant can often be the most energy and cost efficient solution. CO2 is also a safe refrigerant compared to other sustainable alternatives such as propane or ammonia, where e.g. with ammonia a small leakage of 0,5 kg can already cause a lethal environment in a typical refrigeration machinery room.

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SUMMARY:

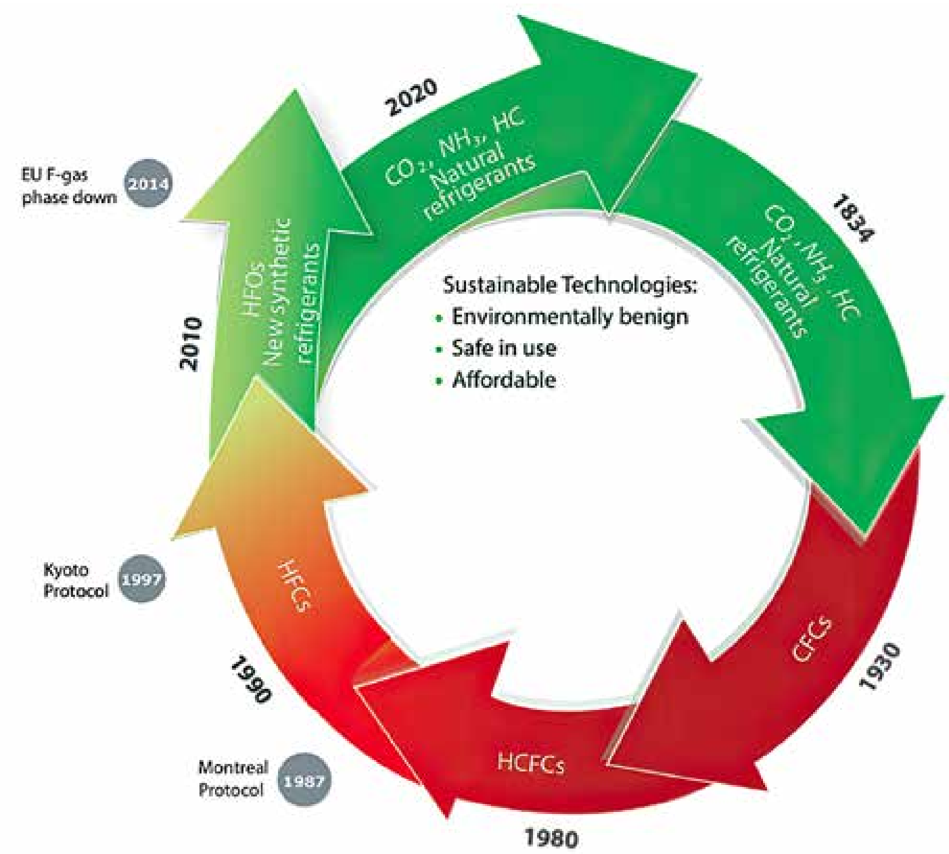

Figure 24. The global tendency is to “return to the roots” and select natural refrigerants (Danfoss).

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.

6.1.2.2 Heat recovery function

In ice rinks, the largest energy savings potential can often be found in optimizing the heat recovery from the refrigeration system, and therefore minimizing the demand for a supplemental heat source. An energy balance in an ice rink that covers 100% of its heating demand by heat recovery from refrigeration is shown in Figure 25.

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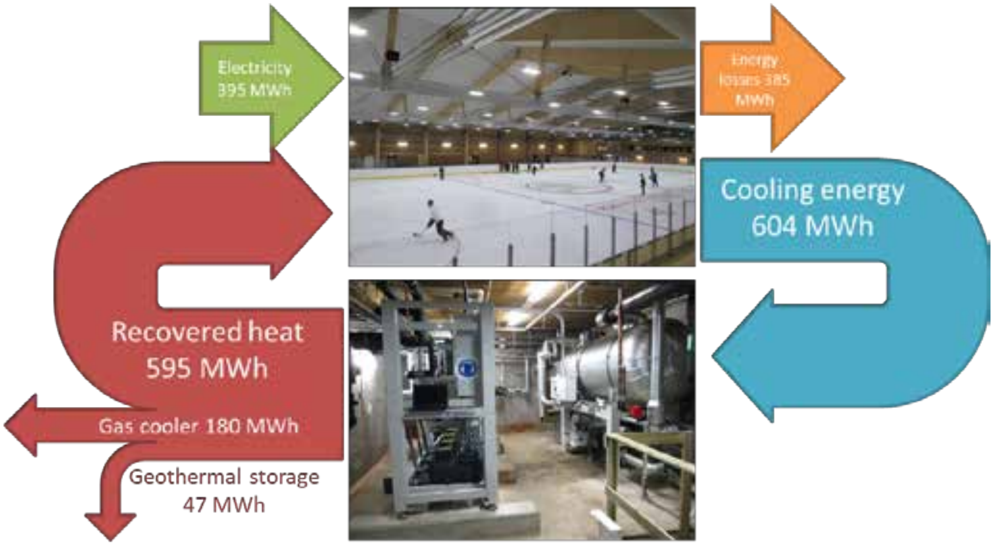

Figure 25. Energy balance in a Nordic training ice rink with 8-month season.

Figure 26 shows an example from a Nordic ice rink with the cooling demand in blue, heating demand in red, and available heat coming off the refrigeration system in green. Here it can clearly be seen that considerably savings in heating are achievable with optimized heat recovery. Furthermore, the graph indicates that it is often interesting to not only look at the heating demands of the ice rink itself, but also other heating demands in close proximity to the facility that may also be potentially provided with this “free heat”.

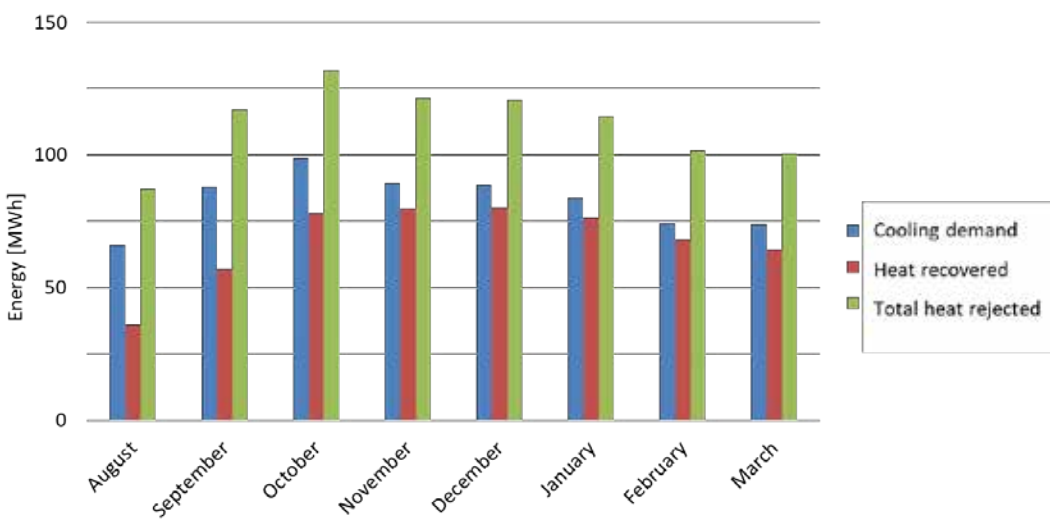

Figure 26. The refrigeration system usually releases more heat than what a typical ice rink needs. It is therefore interesting to look for heating demands beyond an ice rink.

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The heat recovery system can also be optimized by connecting the refrigeration system to a geothermal storage, which provides further possibilities both during warm and cold weather conditions. When warm, the storage may be used to improve the (sub-)cooling of the refrigeration process, resulting in a higher energy efficiency of the system, as well as storing excess heat in the boreholes. The very same heat can later be used during colder periods when there is an increased demand for heat in the facility.

An optimized heat recovery system can therefore cover the entire heating demand of an ice rink, even during colder periods, eliminating the need for any external heat source. In fact, reference systems have proven so efficient, that they may be used to export heat to nearby facilities such as swimming pools.

6.1.2.3 Modern primary refrigeration system solutions

The primary refrigeration technology choice has a considerable effect on the function of the facility and resource efficiency for the whole economic lifespan of the system, typically 15-20 years. Out of a vast majority of options to select from, the most optimum alternatives are CO2 or NH3 as the primary refrigerants. If local expertise in those refrigerant technologies is limited, synthetic refrigerant alternatives may be considered, however taking into account the aspects that are described in chapter 6.1.2.1.

6.1.2.3.1 CO2 as a primary refrigeration system

After the first ice rink system using carbon dioxide, CO2, as secondary refrigerant was built in 1999, it took until 2010 before the first ice rink using CO2 as a primary refrigerant was realized. Today the number of ice rinks in Europe and North America using CO2 technology is significant.

Figure 27 The first CO2 primary refrigerant system in ice rink in Europe was installed in 2014 in Gimo, Sweden. Picture source: Google maps.

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CO2 direct & CO2 indirect

Today CO2 systems are becoming a standard solution in ice rinks, however being divided into direct expansion (DX) systems and indirect systems. The main difference is that in the DX system, the CO2 fluid also goes in the distribution pipes (rink floor), while in the CO2 indirect system a different secondary refrigerant is used in the rink floor. Furthermore, in the CO2 indirect system a heat exchanger (evaporator) is used between the primary and secondary refrigerant circuits. For the rink floor distribution in indirect systems, aqua ammonia is today recommended to be used as secondary refrigerant due to that it requires much lower pumping power than other commonly used alternatives, such as ethylene glycol and calcium chloride.

Both DX and indirect solutions shall be designed with heat recovery before the condenser/gas cooler, and it is the feature that allows such solutions to outperform the alternatives, especially in ice rinks with high heating demands.

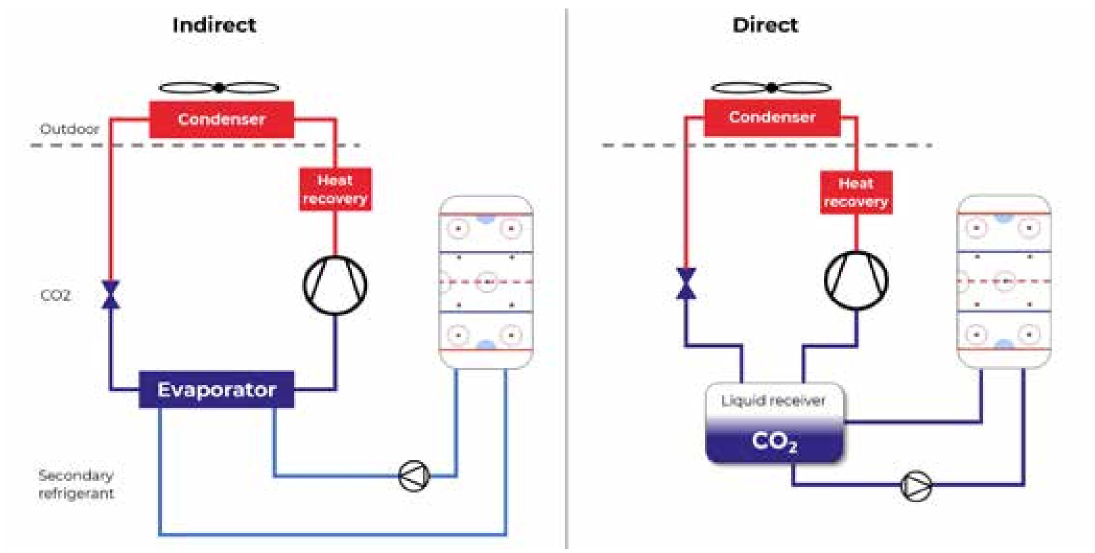

Figure 28. Principle of a CO2 indirect to the left and CO2 DX to the right, with heat recovery.

Both systems have their pros and cons when compared to each other, as listed in Table 5.

Table 5. General differences between the possible CO2 configurations.

	CO2 DX	CO2 indirect
Pros	• More efficient than CO2 indirect, less compressor work needed • More accurate ice temperature control	• Safer due to less charge • Lower investment
Cons	• More CO2 charge thus theoretically less safe • Higher investment than indirect	• Less efficient due to; heat exchange in the evaporator, more compressor work needed and more pump power • Requires a secondary fluid in the rink floor

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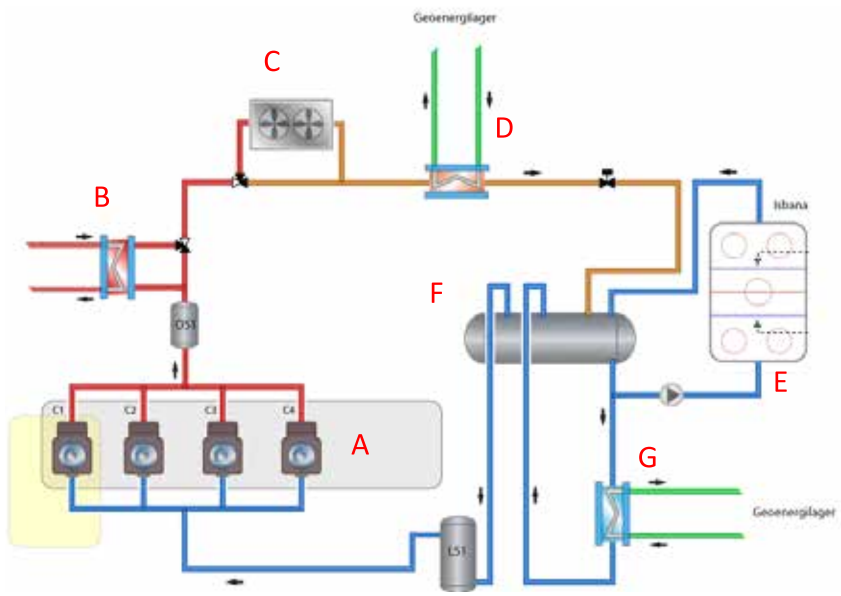
In general, it can be said that direct (DX) solutions normally suits better in new construction or when a rink floor is replaced, since it requires metal pipes for the distribution. Due to the higher investment and lower energy consumption a longer ice season is also positive from a profitability point of view.

Indirect systems offer a slightly lower investment since "normal" plastic pipes may be used in the rink floor. On the other hand, this solution is slightly less efficient which increases the operating cost somewhat.



A: Compressors

B: Heat recovery heat exchanger

C: Gas cooler

D: Subcooler

E: Ice rink tube system

F: CO_2 accumulator

G: Additional evaporator

Figure 29. Overview of a CO2 DX refrigeration system in an ice rink.

At the end of the day, the choice of technical solution will be based on a combination of facility related constraints, energy profile and financial considerations which will impact the environmental profile as well as the profitability.

6.1.2.3.2 NH3 as a primary refrigeration system

As described in chapter 6.1.2.1, ammonia (NH3) is a widely used refrigerant in ice rinks since the first artificial ice rinks were introduced. A traditional fully indirect NH3 system is a proven solution. In a more modern form, these systems today offer small charge quantities (<50kg), high efficiency, good capacity regulation and a long service life.

A factor that has increasingly become a decisive reason for changing systems is that ammonia is a more dangerous refrigerant for humans. Even though modern solutions have succeeded in reducing the refrigerant charge considerably, there is still a risk of personal injury.

NH3 is a colorless gas with a strong and irritating smell. Its main danger to humans is its toxicity. Two minutes of exposure to 1000 ppm of ammonia may lead to the need for medical attention, while two minutes at a concentration

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of 10,000 ppm means that the probability of death is over 5%. However, the advantage of ammonia is that most people can already smell it at 5-10 ppm. Furthermore, there are few who can withstand 100 ppm, which means a warning in good time of any leakage or release. By far the greatest risk zone is the refrigerating machine room, where a very small leak, less than 1kg, can create a life-threatening concentration.

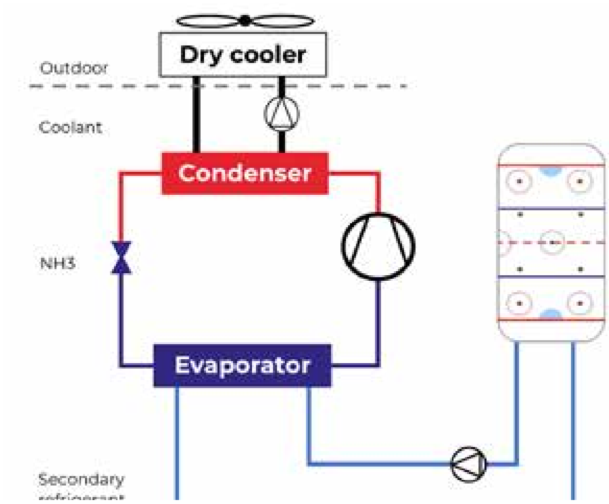

Figure 30. A modern fully indirect NH3 refrigeration system.

The disadvantages compared to direct system solutions that can be mentioned, are the slightly higher energy consumption for the auxiliary equipment (fans and pumps). Furthermore, the heat exchanges on both the cold and warm side cause losses in the overall system. As emphasized previously, heat recovery has a key role in an ice rink's operating economy, and for ammonia the inherent properties are less favourable than for CO2, which makes it difficult to produce the heat at the temperature level that is needed in an ice rink. In general, these systems may be supplemented with, for example, a heat pump or district heating to cover the needs completely.

In summary, ammonia is a very efficient refrigerant that, from a theoretical perspective, surpasses CO2 in terms of cooling performance. In practice, due to the factors mentioned earlier, the CO2 technology properly designed becomes safer, cheaper, more efficient and normally lead to a lower life cycle cost.

6.1.3 Secondary refrigeration system

The secondary refrigerant is the heat transfer fluid which brings the heat from the cooling object (rink floor) to the primary refrigerant via the evaporator in an indirect refrigeration solution. This fluid is sometimes referred to as; secondary coolant, heat transfer fluid, brine, etc.

The thermophysical properties of these fluids can have a large impact on the overall performance of the refrigeration system. Secondary refrigerants most typically are aqueous solution, with a concentration adapted to an appropriate freezing point for the operating conditions of the specific system.

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6.1.3.1 Commonly used secondary refrigerants

The most common secondary refrigerants used in ice rinks are:

- Ethylene glycol (EG)
- Calcium chloride (CaCl2)
- Aqua ammonia (NH4OH)
- Carbon dioxide (CO2)
- Potassium formate (KF)

and less commonly:

- Propylene glycol (PG)
- Ethyl alcohol (EA)
- Potassium acetate (KAc)

These fluids may have advantages and disadvantages for use in ice rink refrigeration. Safety considerations will include toxicity, which refers to risks from inhalation, ingestion, skin and/or eye exposure, and flammability, which refers to the flash point (also known as auto-ignition temperature). Environmental considerations include toxicity and damage to local ecosystems.

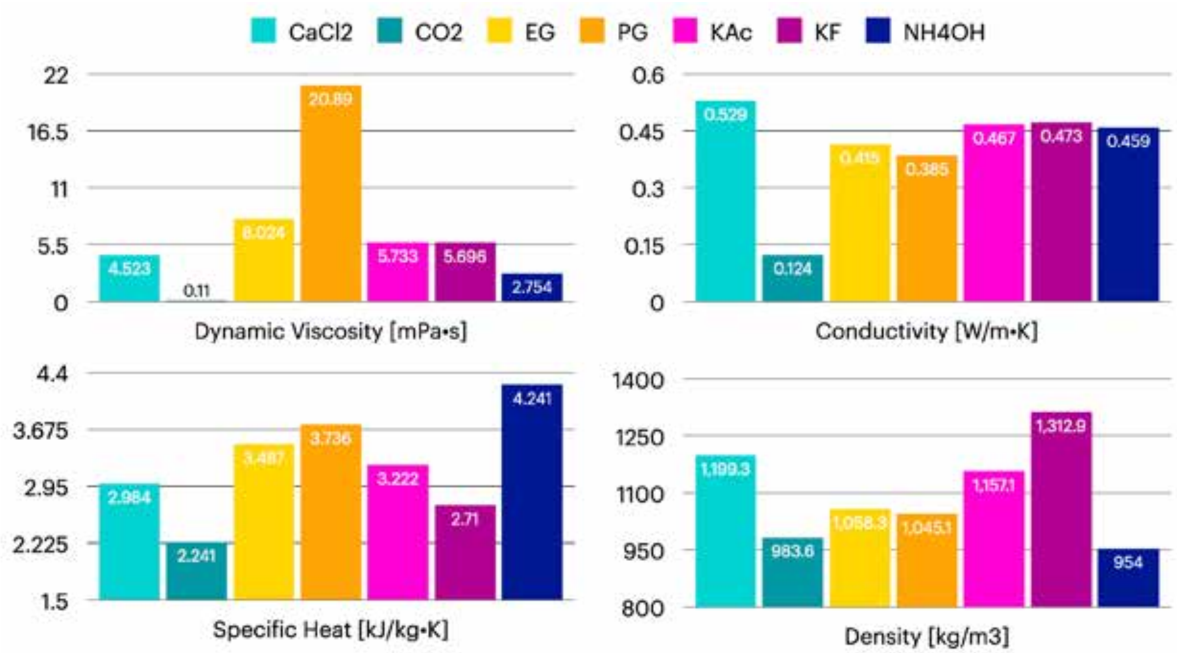

Figure 31. Thermophysical properties of discussed secondary refrigerants at -10°C having freezing points of -20°C (Kilberg, 2020).

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Low dynamic viscosity, high conductivity, high specific heat, and low density are all advantageous for reducing pumping power and efficiently transferring heat. It is clear from the figure above that aqua ammonia has favourable thermophysical properties. On the other hand CO2 is difficult to compare since it is used as a volatile (phase changing) fluid.

Figure 32. Summary about main advantages and disadvantages with the most common secondary fluids in ice rinks.

Secondary fluid	Pros	Cons
Brine (Calcium Chloride)	Non-toxic, non-flammable, low viscosity, plastic material for rink piping allowed, lower investment.	High corrosivity, low specific heat, relatively high pumping power.
Carbon dioxide	Non-toxic, non-flammable, very low viscosity, high heat transfer properties, low pumping power, allows more even ice temperatures.	High pressures, metal material for rink piping required, higher investment.
Propylene glycol	Quasi non-corrosive, low fire hazard, non-toxic, low environmental hazard risk, plastic material for rink piping allowed, lower investment.	High viscosity, high pumping power.
Ethylene glycol	Plastic material for rink piping allowed, lower investment.	Toxic, high environmental hazard risk, high viscosity, high pumping power.
Potassium Acetate and Potassium Formate	Low environmental hazard risk, relatively low corrosiveness, low viscosity, low pumping power, plastic material for rink piping allowed, lower investment.	Toxic.
Aqua ammonia	Low viscosity, high heat transfer properties, low pumping power, plastic material for rink piping allowed, lower investment.	Toxic, however possesses very low danger due to low ammonia concentration.

6.1.3.1 Modern secondary system solutions

Out of the available fluid options presented above, the optimum alternatives in an ice rink, from a technical perspective, are CO2 or aqua ammonia, which are here elaborated further.

6.1.3.1.1 CO2 as secondary refrigerant

Using carbon dioxide as the secondary refrigerant in the distribution system brings several advantages over traditional solutions, e.g. calcium chloride and glycol. The most prominent ones are that CO2 utilizes the phase change (evaporation) and has a low viscosity which leads to a considerably lower pumping power. Measurements done in ice rinks indicate that about 20-25 % of the refrigeration system energy consumption stems from the auxiliary equipment, such as fans and pumps.

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REFRIGERATION

By applying CO2 as the secondary refrigerant pumping power can be reduced to about 1kW compared with traditional fluids which require 5-15 kW. Thus, the energy consumption of the auxiliary equipment in such a refrigeration system becomes less than 3% of the grand total.

CO2 may be used as the secondary fluid only, where it is cooled by another primary refrigeration plant. Another, even more efficient solution is a direct system where it serves as both - secondary and primary refrigerant, see Figure 28 in Chapter 6.1.2.3.1.

Figure 33. CO2 receiver in a large ice arena where CO2 is circulated in the rink piping.

The pipes in the ice rink floor must be adapted to the properties of CO2, as the substance has a much higher working pressure than other secondary refrigerants typically used. Welded steel pipes used to be the norm but are nowadays often substituted with more convenient copper tubes designed for ice pads. Therefore, in existing ice rinks where the rink floor has plastic pipes and is in good conditions, CO2 is typically not economically profitable, but rather aqua ammonia shall be used in the existing piping if the materials are compatible.

6.1.3.1.1 Aqua ammonia as secondary refrigerant

Aqua ammonia is becoming increasingly popular especially when retrofitting existing and building new ice rinks. The first ice rink installation with ammonia water in Sweden took place in 2007 and in 2018 there were at least 34 installations in indoor ice hockey ice rinks and today this number is considerably higher. Most Nordic ice rinks use CaCl2 but the trend is clearly going direction CO2 and ammonia-water.

ENERGY SYSTEMS
REFRIGERATION

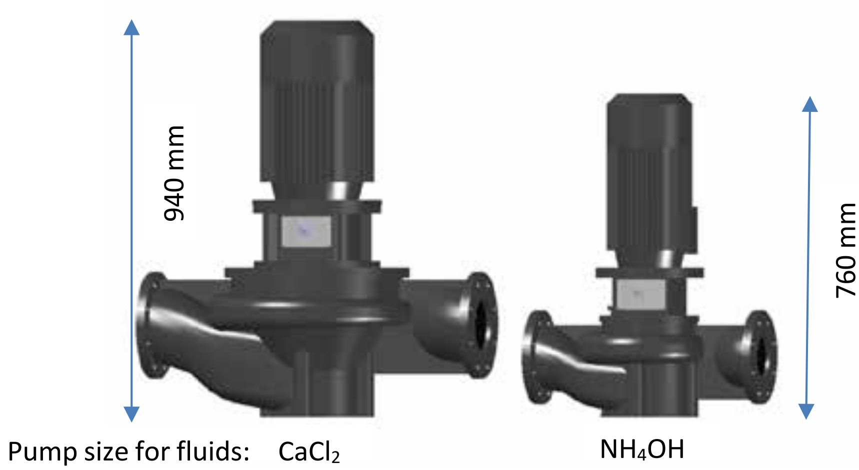


Figure 34. Required pump size difference between CaCl2 pump (on the left) and NH4OH pump (on the right), for the same cooling capacity of 250 kW at -10/-8°C.

The reason why the number of installations is growing so rapidly, is primarily the good experience from the installations. As mentioned, issues with CaCl2 has motivated the market to look at alternatives, and ammonia-water does offer practical advantages as well as some disadvantages. A further reason for the interest in aqua ammonia is the rapid growth CO2-systems. To use CO2 as primary refrigerant with its high operating pressures in combination with a titanium alloy evaporator, drives the cost of the evaporator and consequently of the whole refrigeration unit. If ammonia water is being used, normal stainless steel can be used in the evaporator, thus saving considerably on the investment. This cost offsets the secondary refrigerant retrofit cost which is typically of the same order of magnitude. Consequently, the retrofit is "paid" by the cheaper evaporator, and then the system has half the pump power for the rest of its technical life compared to conventional solutions.

ENERGY SYSTEMS
HEATING

6.2. HEATING SYSTEMS

6.2.1 Heat demand in ice rinks

Ice rinks have a number of different heating requirements. Space heating is required to provide comfort in public areas and the arena room at a comfortable level. Public areas such as locker rooms and offices require a temperature of around 20°C while the arena room may be kept at essentially any temperature depending on type of arena, activity and preferences, but in most conventional arenas it ranges from 5 to 15°C. Hot water for showers in the locker rooms and resurfacer, needs to be heated to a temperature about 55-60°C in order to prevent the reproduction of legionella bacteria.

Figure 35. Ice rinks are heating intensive facilities with many demands.

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

- Space heating
  - Arena room
  - Surrounding spaces
    - Locker rooms
    - Cafeteria
- Ventilation

ENERGY SYSTEMS
HEATING

- Hot tap water
  - Showers
  - Resurfacing water
- Subfloor heating / Ground freeze protection
- Melting pit

It can be mentioned that an ice rink with a tempered arena room, 5-10°C, uses about the same amount of heat as cooling!

6.2.2 Heat sources in ice rinks

There is a large variety of heating methods and sources being used in ice rinks. As very often mentioned in this document, heat recovery makes a lot of sense since so much heat is used – and produced!

Typical auxiliary heat sources may be:

- Gas or oil
- District heating
- Electricity
  - Boiler
  - Resistance heaters
- Heat pump
  - External heat source (air, geothermal, etc.)
  - Internal (refrigeration system coolant, etc.)
- Wooden pellets

Whereas internally:

- Heat recovery from refrigeration

The choice of heat source depends on several factors like availability, level of acceptable investment, operational costs, security of supply, environmental considerations, among other.

ENERGY SYSTEMS
HEATING

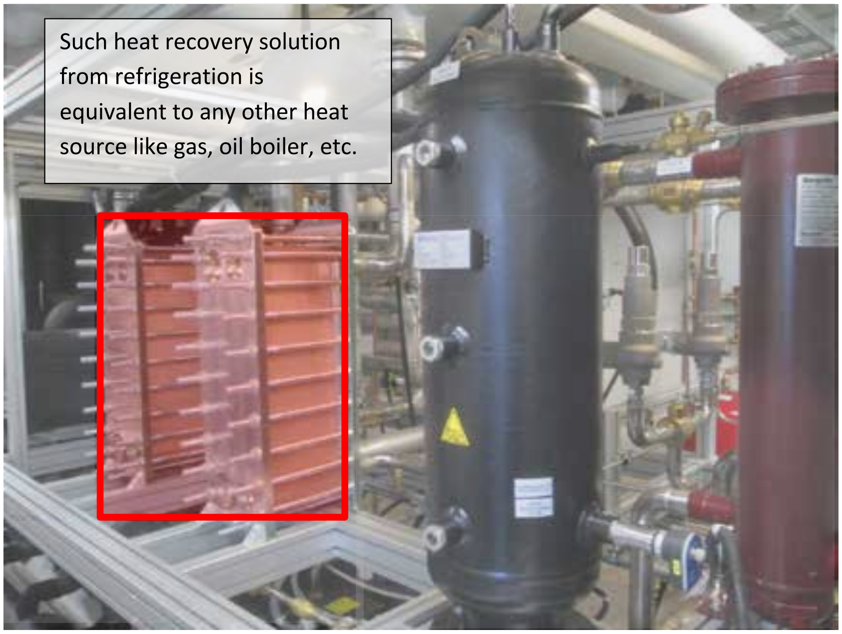


Figure 36. Heat recovery from modern refrigeration makes such systems a 2-in-1 solutions as they provide both cooling and heating.

The refrigeration system of an ice rink produces excess heat during its operation. It is therefore vital to address the waste heat utilization properly by implementing energy recovering measures. Compared to any other heat source it offers the most economical and environmentally friendly performance.

6.2.3 System solutions

Heat recovery from a refrigeration system can be implemented in both new and existing ice rink facilities. There are a few key principles to follow in order to utilise the heat recovery efficiently.

The design of a modern heat recovery system, which separates an ice rink from traditional facilities, is done by following what is referred to as the “waterfall concept”. The idea behind the concept is to extract heat to various heating systems in temperature steps, where the heating system with the highest temperature demand comes first and others with lower temperature demands follow. This concept should provide lowest possible return temperature which is beneficial from a heat recovery point of view – especially if CO_2 is used in the refrigeration system.

Figure 38 shows an example of an ice rink heat recovery system, where the temperature profile is tailored to the demands of the facility as well as the properties of CO_2 refrigeration system. The waterfall concept has the inherent advantage that it cools the primary loop to the lowest possible return temperature, resulting in an optimized heat recovery system for the ice rink.

ENERGY SYSTEMS
HEATING

Figure 37. Groups of accumulator tanks with coils for tap water pre- and post- heating.

Those demands can then be gathered in bigger group of temperature level and connected to groups of water accumulators (Figure 37) to store the heat recovery production over time and adapt to the fluctuations in heat available.

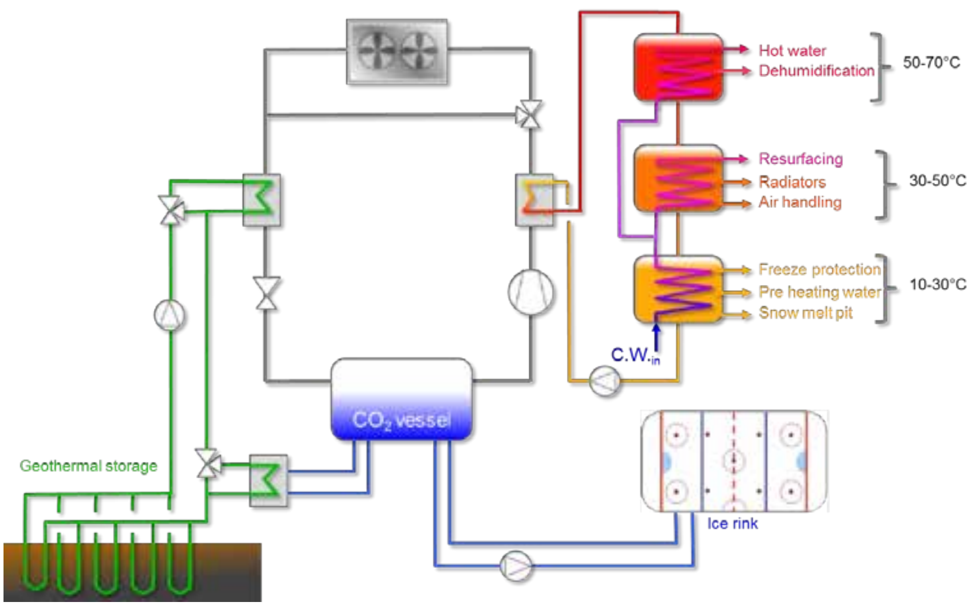


Figure 38. Principle overview of a refrigeration and heat recovery system (Illustration by EKA).

ENERGY SYSTEMS
DEHUMIDIFICATION

Backup heating systems are needed when the heat recovery cannot cover the demand or during off-season. In the figure above a so called “false load” is applied where a geothermal storage is used to supply heat to the refrigeration /heat pump system during peak loads or off-season operation. More commonly any of the traditional sources may be used as mentioned above.

6.3. ARENA ROOM DEHUMIDIFICATION

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

Ice rinks have a large cold surface and condensation will occur when warm and humid air enters the building through doors and other openings. Condensation may form on any cold surface if it is colder than the so-called dew point. Such surfaces are obviously the ice but potentially also the ceiling or parts of the building structure facing the ice, due to the radiation heat transfer with the ice. If the climate in the ice rink space is too humid, corrosion and mould growth may occur which leads to an unpleasant and potentially unhealthy indoor climate for the occupants.

Figure 39. Moisture problems are known in many ice rinks. Solution to keep the indoor humidity at acceptable level must be used.

ENERGY SYSTEMS
DEHUMIDIFICATION

6.3.1 Selection of dehumidification technology

Two types of dehumidification technologies are the most commonly used in ice rinks – sorption and refrigeration-based.

Sorption type of dehumidifier system are the most common types in Nordic ice rinks, and they are designed and controlled to maintain a constant dew point within the building. In some markets these systems are often reactivated by means of heat generated from electrical heaters. To produce heat from electricity is practical but not necessarily the best way to use the energy – provided you have an alternative. In an ice rink there is plenty of waste heat that may be used for such purposes which is shown in Figure 26 from Chapter 6.1.2.2.

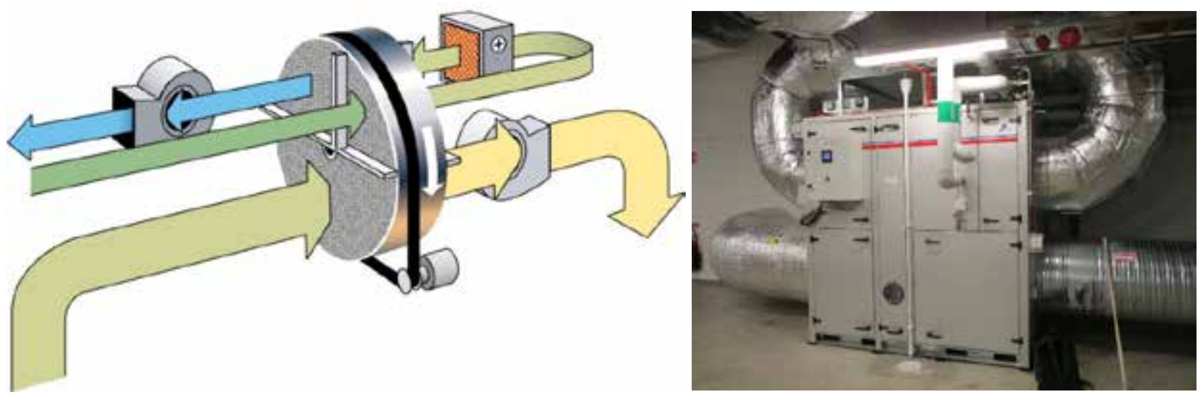


Figure 40 The working principle of a sorption type of dehumidifier (left) and unit (right).

The other dehumidification method is 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.

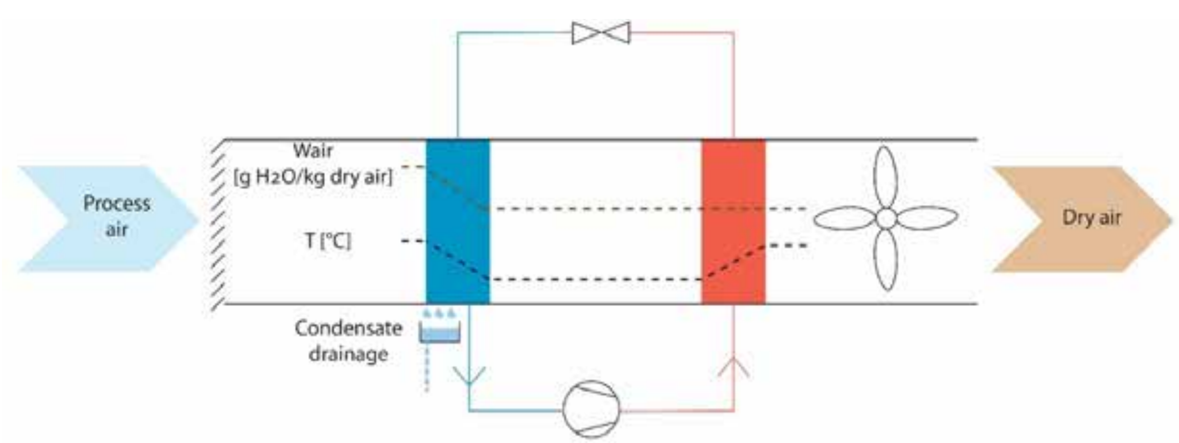


Figure 41 The working principle of a refrigeration type of dehumidifier.

ENERGY SYSTEMS
DEHUMIDIFICATION

The disadvantage with refrigeration-based dehumidification is that the air can only be dried to a certain limit – typically to a dew point close to 0°C. This is the level that is actually required in the arena room so having this being produced in the dehumidifier is not sufficient. To provide an acceptable climate in the arena room therefore requires very large air flows through the dehumidifier, which will be very costly from a fan power energy point of view.

Another drawback is the inefficient energy usage with this type of technology for dehumidification purpose. In the summer, when there is plenty of heat available from heat recovery, it is cheaper to operate sorption type dehumidifier than a refrigeration-based equivalent (NERIS 2018).

6.3.2 System solutions

The sorption dehumidification method has proven to be the most suitable technology for ice rinks. It can remove moisture from air in the subzero dew point humidity range without performance issues, like frost formation, and it does not require as high air volumes as the refrigeration-based method. The majority of consumed energy in a sorption dehumidifier is used to heat the reactivation air, and that is where the highest saving potential also lies since it can be coupled with “free” heat released from the refrigeration system. The challenge, however, is achieving a sufficient amount of the high temperature level that is required for the reactivation process.

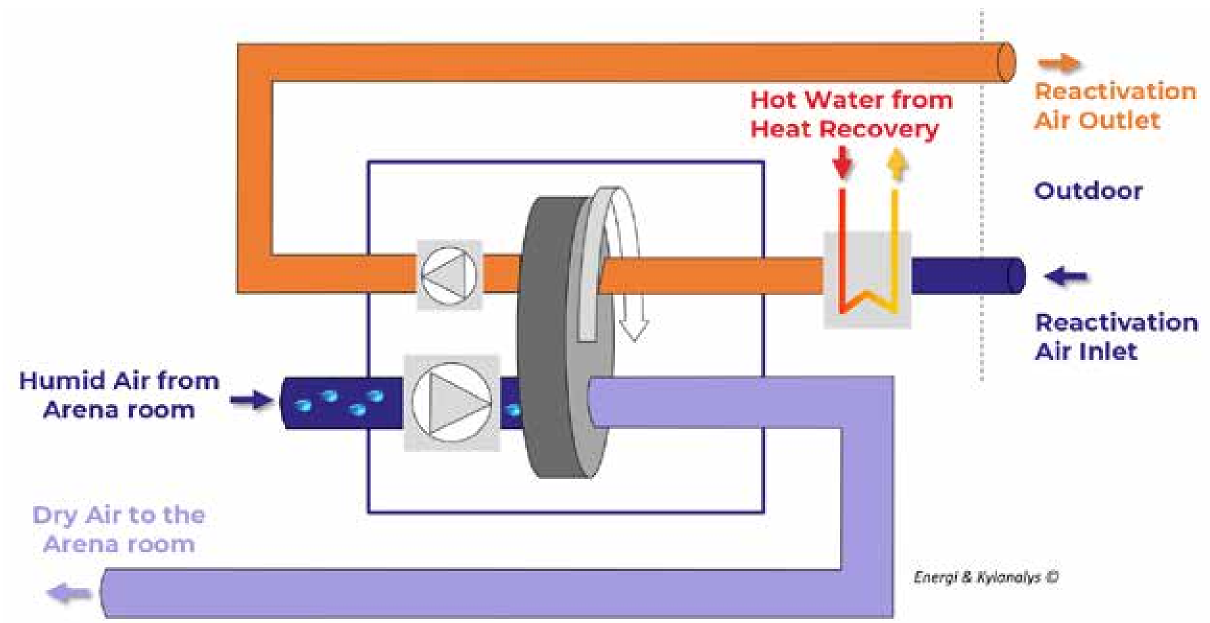


Figure 42. Sorption based dehumidification that utilizes the heat recovery from refrigeration, referred to as Generation 2.

Successful application of refrigeration system heat recovery in the dehumidification process has been documented in both Generation 1 and Generation 2 sorption dehumidifiers. Generation 1 dehumidifiers are more traditional,

ENERGY SYSTEMS
DEHUMIDIFICATION

where the temperature requirement for the reactivation process is ca 110°C. In this application recovered heat covers the preheating-range that begins with the ambient air temperature and ends at around 55°C, subsequently followed by the electric heater which further raises the temperature from 55°C to 110°C. Generation 2 dehumidifiers have larger sorption wheels, which lowers the temperature level requirement of the reactivation process down to 55-60°C. This in turn leads to a higher requirement in fan power, but the sacrifice is made in order to be able to cover the reactivation process heat demand with recovered heat only.

6.3.3 Dehumidification control

Correct control of humidity level is important to achieve good ice quality and healthy indoor climate in the most energy efficient manner. One project (NERIS 2018) documented a 30+ percent energy reduction when changing the control strategy from the typical relative humidity to dew point based. The dehumidifier should be controlled to maintain a dew point between 0°C and ca 2°C in typical ice rinks, where indoor temperatures range between 5-10°C. If the dew point is lower than 0°C it operates unnecessarily and if it is higher than 2°C there is an increased risk of problems related to condensation. Figure 43 illustrates the condensation risk zones and also shows over time how energy is saved by applying a control strategy based dew point instead of the traditional relative humidity, where the latter especially tends to “over dry” the arena room when there actually is no dehumidification demand.

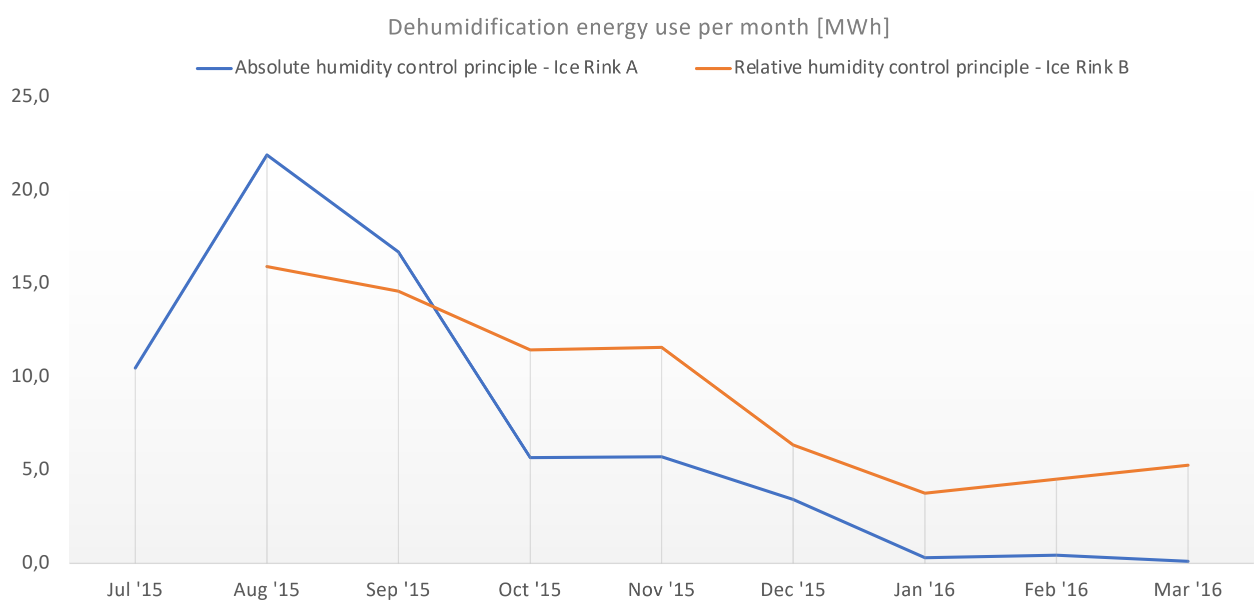


Figure 43. Comparison of energy use between control strategies based on relative humidity and dewpoint/absolute humidity in two ice rinks.

ENERGY SYSTEMS
AIR HANDLING

6.3.4 Energy usage

The performance of both a Generation 1 and a Generation 2 sorption dehumidifier is illustrated in Figure 44. The results show that in a Generation 1 dehumidifier almost 40 percent of the total energy use is saved in the operation thanks to the application of recovered heat that otherwise would have been rejected to the ambient air. For the Generation 2 dehumidifier it can be seen that even with a higher fan power requirement the reactivation process still requires by far most of the energy, with the additional observation that recovered heat now can cover up to 100% of the reactivation demand and after that electrical energy is only needed for the fans. A Generation 2 solution can therefore save ca 85% of the total dehumidifier energy consumption.

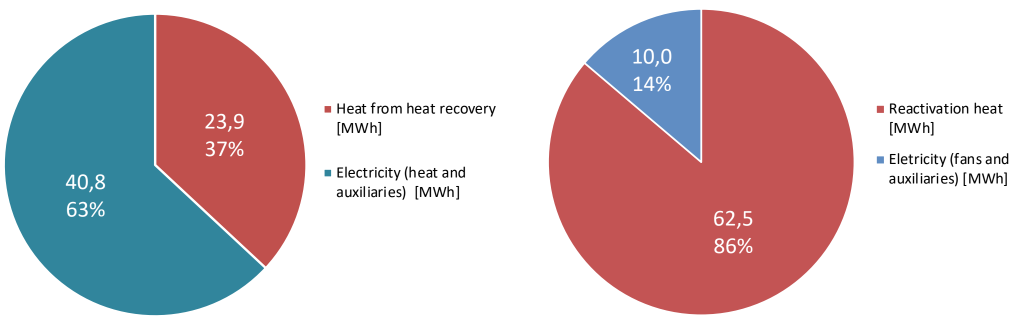


Figure 44. Application of recovered heat from a modern refrigeration system in the reactivation process leads to energy savings of ca 40% in Gen 1 and 85% in Gen 2 sorption dehumidifiers.

6.4. AIR HANDLING

The main purpose of the ventilation system in the arena room is often to provide space heating and, when needed, also fresh air. The ice arena ventilation is normally divided into different parts: the arena room and surrounding spaces including locker rooms etc. This is due to the special indoor climate of the arena room, which requires its own system solution for successful management. In many ice rinks, the arena room ventilation has been integrated together with the dehumidifier, but the recommendation nowadays is to keep these separate.

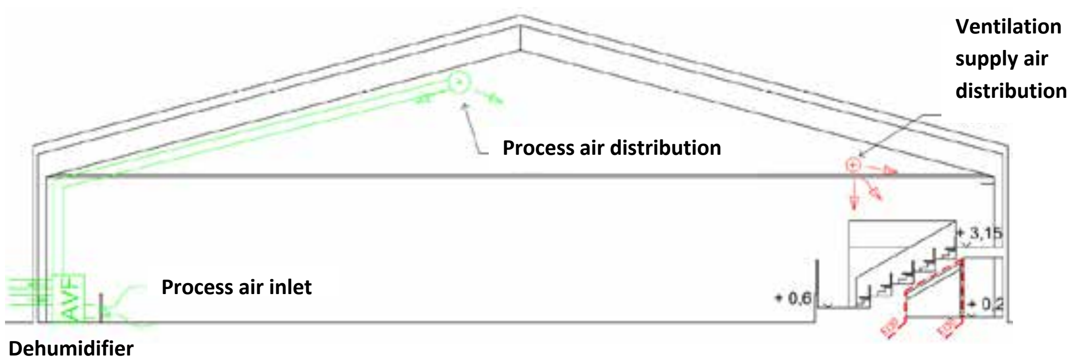


Figure 45. Air supplied to different zones in ice arena: Dehumidified air above the ice, and heated air towards the stands. Fresh air intake only when necessary.

ENERGY SYSTEMS
AIR HANDLING

6.4.1 Air distribution in arena room

In order to further maximize the energy efficient climate control of an ice rink, the ventilation and dehumidification distribution systems should be separated in the arena room. Warm ventilation air should be blown towards the spectators where the real heat demand is located, while the dehumidification supply air should be distributed in a duct centered above the ice. This minimizes unnecessary heat loads towards the ice while also maintaining optimal comfort levels where they should be.

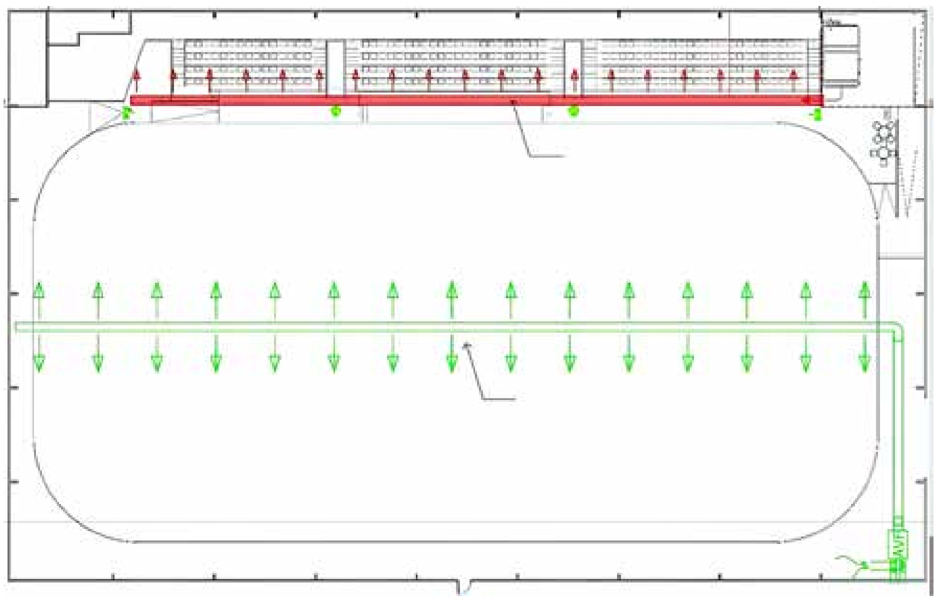


Figure 46. The ventilation and dehumidification distribution systems should be separated.

In smaller typical sized arena rooms, ventilation/heated air is generally distributed from a single duct above the stands, with its blowing direction away from the ice. In larger arena rooms the duct can be divided into two or more groups so that heat is more optimally spread across the stands to maintain adequate comfort levels regardless of where spectators are seated.

Figure 47. Textile ducts in an ice rink where dry air is distributed over the ice and "comfort air" to the stands.

6.4.2 Energy efficient principles

Ventilation of the facility shall be based on centralized air handling units (AHU) for the different zones in the building. An AHU can provide ventilation to several rooms with similar air quality and thermal comfort requirements. The main benefits are related to energy efficiency of central AHU, in addition the optimisation of maintenance costs is possible because fewer units will require less frequent "hands-on" service staff maintenance, and simpler control adjustments compared to several small ventilation units.

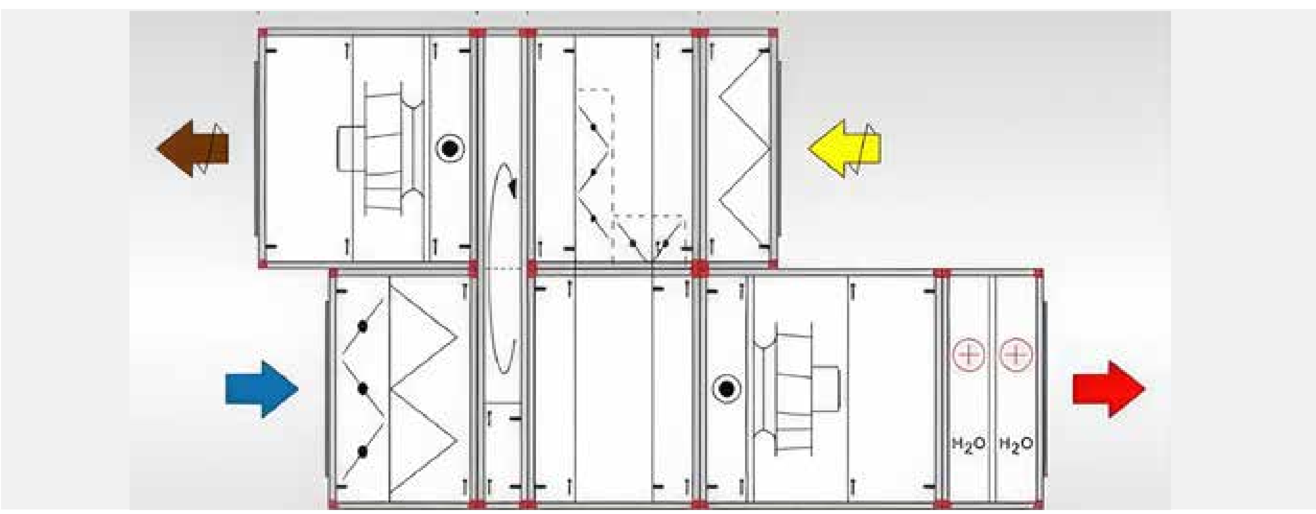


Figure 48. Example of a principle AHU solution for arena room (IV Produkt, 2022).

ENERGY SYSTEMS
AIR HANDLING

Energy efficiency for a ventilation system shall be maximized by designing systems with air-to-air heat recovery and efficient fans. In the EU, for example, it is required that AHU is complying with the minimum performance criteria. The latest Ecodesign update was in 2018.

- Heat recovery efficiency, which is expressed as the percentage of energy recovered from the extract air flow:
  For rotary heat exchangers, counter-flow heat exchangers or plate heat exchangers > 73%
  For run-around coil heat exchangers > 68%
- SFP - Specific Fan Power, is expressed as the electrical input required for the fan to supply the airflow. The lower the SFP, the greater the fan's energy efficiency:
  Internal SFP < 0.8 (considering pressure drop within the AHU)
  Corresponding SFP < 1.9 (considering pressure drop within the AHU + distribution duct pressure 200 Pa)

Figure 49. Example of a central air handling unit in an ice arena, the unit is located in a technical room.

Normally the ice rink arena room has little or no need for fresh air ventilation since it consists of a large air volume, where it takes a long time before the air actually needs to be exchanged due to air quality requirements. Furthermore, such large cold spaces typically have considerable air leaks which reduces the need for active ventilation. One of the most important reasons for avoiding fresh air is that it brings moisture with it, which will increase the dehumidification demand. This is discussed in Chapter 2 of the guide.

ENERGY SYSTEMS
AIR HANDLING

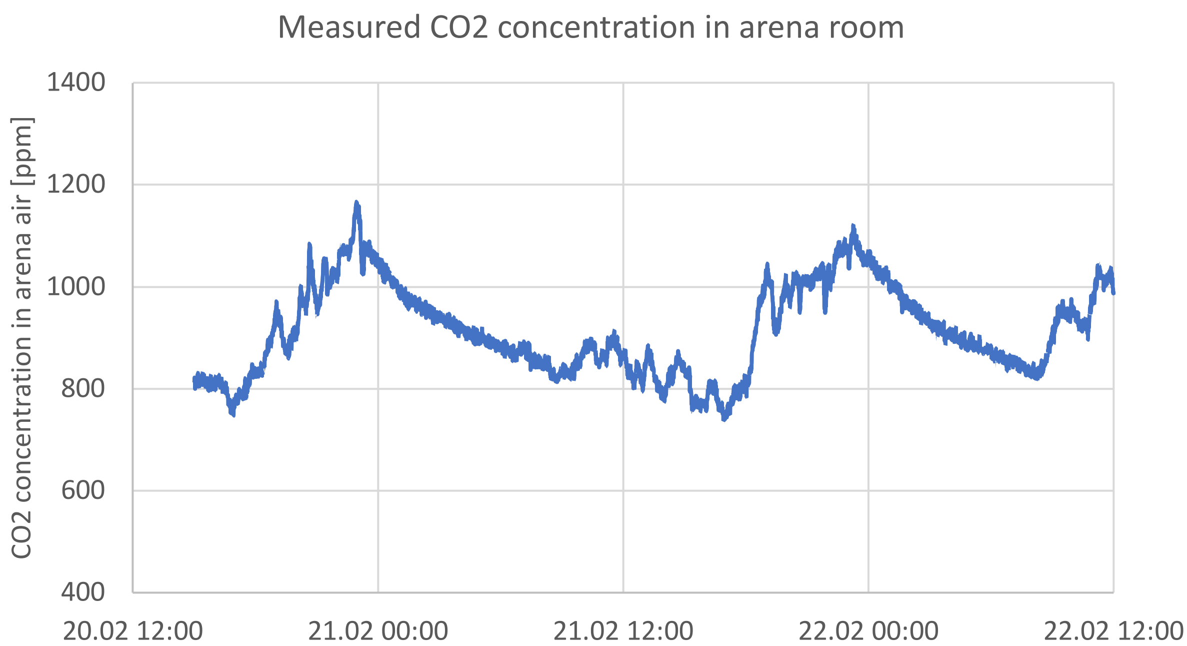


Figure 50.. Measured CO2-levels in a typical Nordic ice rink operating on full air recirculation.

It is therefore recommended that the ventilation/heating function in the arena room is normally operated only by recirculation, i.e. fresh air is not brought in. As a result, the moisture load is reduced while fresh air still enters the ice rink through the building envelope as air leakage which in most ice rinks has actually been found to be enough to maintain appropriate CO2-levels, see example in Figure 50.

Best practice is to have the fresh air supply system controlled by a CO2-sensor, so that necessary fresh air would only be supplied on demand. A CO2 concentration of > 1500 ppm can be used as the starting signal for fresh air intake.

6.5. ARENA ROOM LIGHTING

Arena room lighting accounts for around 10 percent of the total energy usage in a typical ice rink. The radiation from the lighting may contribute to the heat load of the ice as well. There are specific requirements for illuminance on the ice surface, it varies between different categories of ice rinks according to local country standards. In order to respect illuminance, there are different alternatives available for the type of technology. The lighting efficiency of the particular technology is important, i.e., what power is needed to provide the necessary illuminance.

Many ice rinks still use different types of light tubes such as T5/T8 HF, although the trend is clearly going in the direction towards LED, which will eventually take over in the ice rinks as the old equipment is being phased out. Other types like halogen and metal halogen still exist but much less frequently.

ENERGY SYSTEMS
LIGHTING

Figure 51. Example of an ice rink with a light tube installation.

In Figure 52 the lighting efficiency of previously typical lighting solutions is presented over time. Halogen lighting have 4000 lighting hours compared to 9000 hours for metal halogen lighting, which is an increase by 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. As said, however, LED is becoming the main alternative in modern solutions.

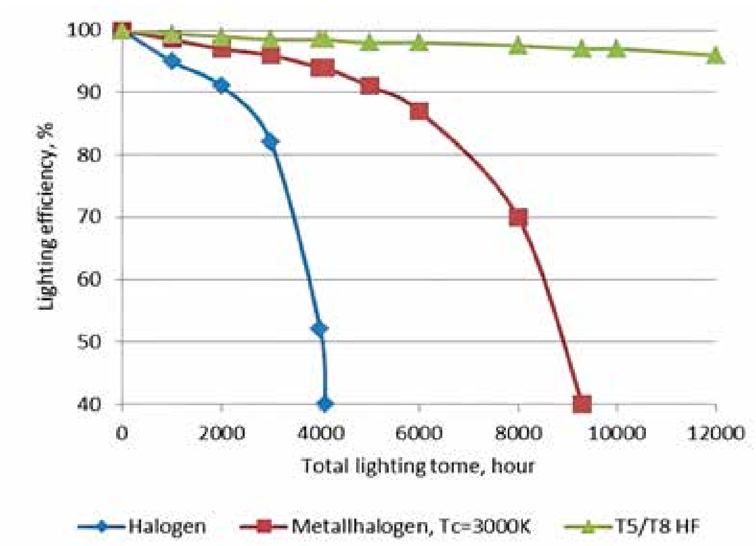


Figure 52. Efficiency of different lighting types during their lifespan.

ENERGY SYSTEMS
LIGHTING

Nowadays, LED technology is the best solution on the market, both in terms of quality and efficiency. An approximation of energy savings with LED technology compared to previous generation technologies is given in Table 6. As seen between 40 to 75 percent is the possible improvement, and additional benefits of considerably longer LED lifetime has to be taken into account also.

Table 6. Comparison of energy performance in lighting technologies.

Type of Lighting	Efficiency	Expected energy savings substituting with LED
Halogen	12-40 lm/W	50-75%
Fluorescent (T5, T8 bulbs)	40-80 lm/W	20-40%
LED	120+ lm/W	10-15%*

*replacing old LED with new LED

Figure 53. An ice rink with a modern LED-lighting system.

In the case of a new LED-lighting system in a typical sized ice rink, a nominal average light intensity of 600 lux and a total installed power of ca 10 kW is reasonable. Furthermore, the lighting should be controlled either by a dimmer alternatively with fixed steps adjusted for game time, training/general and preferably another for ice maintenance. In practice normally three steps are often used: 0, 50 and 100 % corresponding to about 0, 5 and 10 kW, but more steps according to demand are certainly recommended and a stepless dimming function is by far the most favourable solution.

ENERGY SYSTEMS MANAGEMENT

6.6. BUILDING AND ENERGY SYSTEM MANAGEMENT

Ice rink energy and climate controls often appears difficult to manage, as very complex interactions between the various physical processes happen continuously. It may happen that changing a setpoint in, e.g., air handling system, there is a need to adjust a certain setpoint in the refrigeration system.

This leads to a necessity for not only the physical integration but also the control strategy and its implementation. In addition to that a possibility of monitoring the main functions on-site and remotely plays a key role in the failure prevention and long-term energy use reduction.

6.6.1 Monitoring and control

A modern ice arena should apply a monitoring and control system, often a Programmable Logic Controller (PLC) system, which functions as the brain of the facility. In addition to refrigeration, the PLC-system should also control the functions such as heating, domestic hot water, dehumidification, freeze protection, ventilation, and lighting systems, as well as potential geothermal storage or heat export functions. By having an externally accessible control system, it becomes possible to synchronize and/or prioritize the energy systems, when necessary, which also is a prerequisite for the energy optimization process in modern ice rinks.

6.6.2 Visualization

The information that is being measured and calculated by the PLC system shall be visible locally, i.e., in the technical room. The information shall be well structured and user-friendly, so that the technical staff or external experts are able to verify functions, localize problems, etc., as conveniently as possible. That in turn provides the facility management with convenient feedback and allows smoother implementation of control changes.

ENERGY SYSTEMS MANAGEMENT

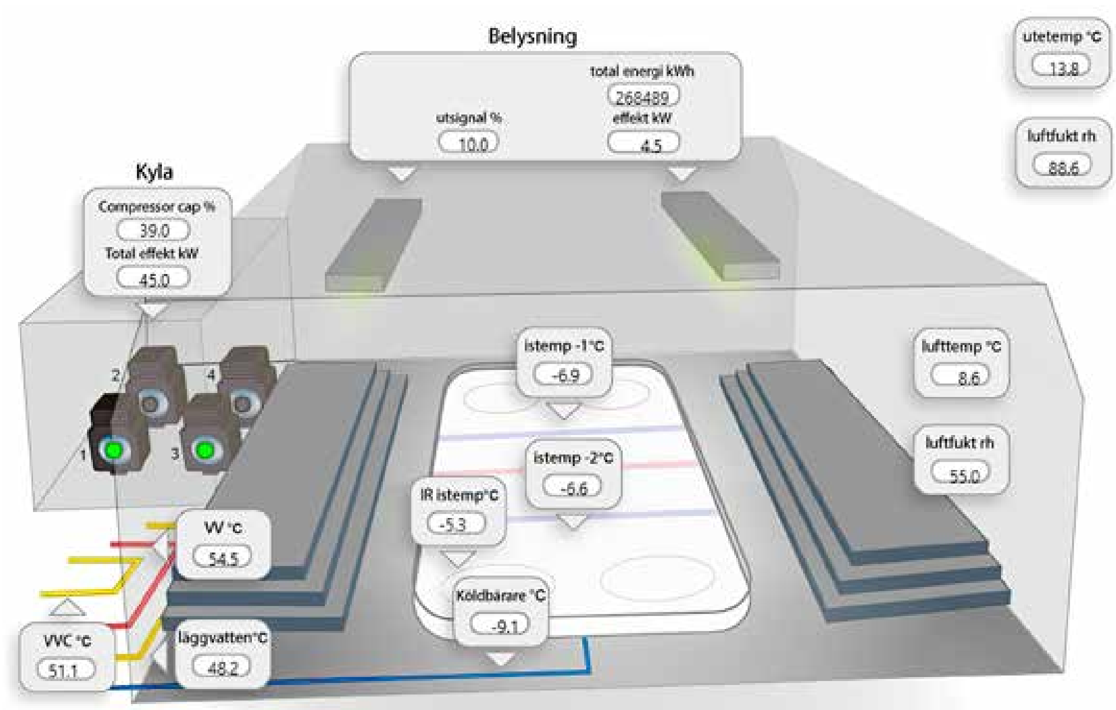


Figure 54 The control system overview in an ice rink showing the lighting control signal, power and energy.

6.6.3 Energy monitoring

Ice rink further benefit from modern control system that measure the energy usage of the big five energy systems individually (refrigeration, heating, ventilation, dehumidification, lighting). This allows to optimize the performance of each individual system further through analysis and also allows for the follow-up of the results after implemented changes.

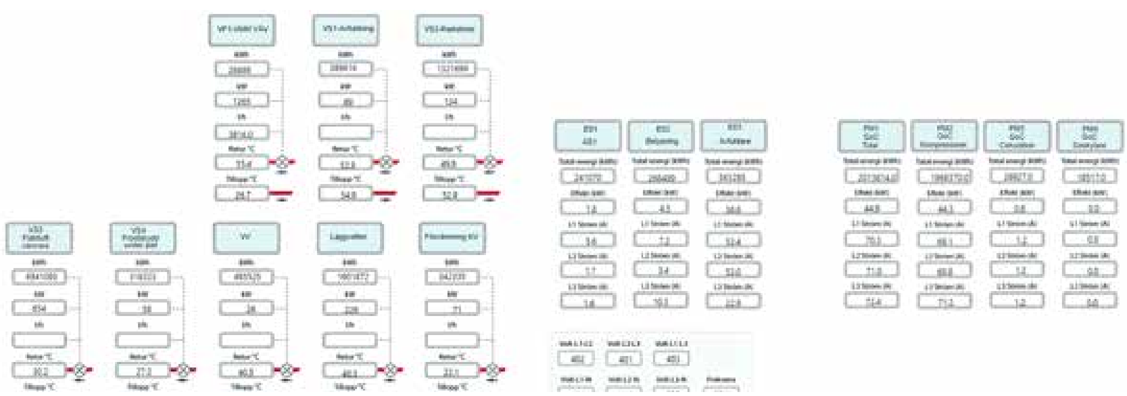


Figure 55. Screenshot from an ice rink online monitoring system that includes 1 main and 6 submeters of both heat and electricity. It allows to analyse and optimize the systems with high accuracy.

A modern control system should also be able to optimize the performance of the energy systems in the ice rinks based on parameters such as energy use, temperature, humidity etc. Furthermore, the control system must log all the data so that it can be analyzed for further optimization or error investigations. Ease of access to the control system is also recommended, e.g. by having it connected to the internet, which allows remote access for operational staff as well as service companies.

7 SUSTAINABLE WATER MANAGEMENT

An ice rink uses vast amounts of water and 2–3 million litres per year is often the case in a single sheet ice arena of a typical size. About 1 million litres of the total amount is used as resurfacing water on the ice sheet to maintain the ice quality.

Potential energy savings can be achieved by lowering the water consumption in an ice arena. This can be done by optimising the water flow in showers and also by reviewing the ice maintenance routines, if there e.g. is a possibility to reduce the frequency in ice resurfacing or the amount of water used.

Figure 56. Resurfacing water account for approximately 1 mil litres per year and ice sheet.

Lately, however, water recycling has gained interest. This does not necessarily lead to savings in energy costs itself but minimizes the amount of fresh water that is needed in the ice rink. As mentioned earlier, resurfacing water represents a significant portion of the total water consumption, and by applying water recycling in this function, the water management of the ice arena can be improved significantly to make it more sustainable.

WATER RECYCLING

Figure 57. By recycling the resurfacing water from the melting pit, the water management of an ice arena can be significantly improved.

The first step to recycle the water is to have a melting pit function which collects the snow and melts it back to liquid water. After that the treatment and recycling process can start.

7.1. RESURFACING WATER RECYCLING

In recent years, several European countries have suffered from water shortages, where the cause typically has either been unusually low groundwater levels or that waterworks were close to their maximum technical capacities and could not cover the increasing water needs. Authorities have therefore occasionally had to introduce restrictions on water use and sometimes this has hit ice rink operations.

As stated above, a typical ice rink use about 1 million litres of water per year and ice sheet, for resurfacing to maintain the ice quality. The ice quality is regularly updated by having the ice resurfacer scrape off the topmost part of the ice layer, which is then dumped either outside the ice rink or into a melting pit connected to the facility's sewer, and then replace the scraped off part with resurfacing water which freezes and becomes the “new” topmost layer of the ice sheet. Figure 58 shows how the process is done in most ice arenas, indicating that new fresh water is needed for each resurfacing.

WATER RECYCLING

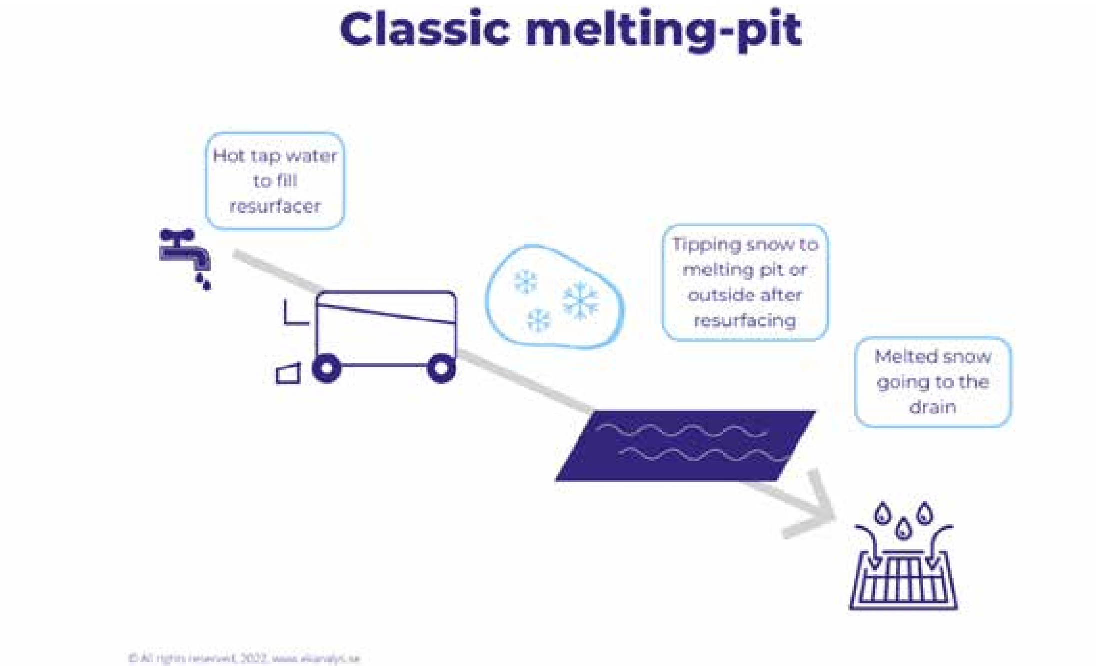


Figure 58. Classic melting pit function without water recycling.

Nowadays, there are opportunities to recycle this amount of water from the ice that is scraped off and reuse it in the resurfacing process without deteriorating the quality of the ice. This will potentially save up to the full 1 million litres of water, which creates benefits for the ice rink's operating economy, for society and for the environment. Heat recovery from the cooling system can be used both to melt the snow and heat the resurfacing water, implying that additional heating costs can be avoided.

Figure 59 shows each stage of the water recycling process in the resurfacing (or melting pit) function. The main addition is a filtering function to maintain the water quality so it can be reused for resurfacing. There are different kinds of filters which can be used. Some technologies are listed below as examples, but will not be further discussed within the context of this guide:

- Reverse osmosis
- Sand filters
- Gravel filters
- Carbon filters
- Membrane filtration

CASE STUDIES
FACILITY

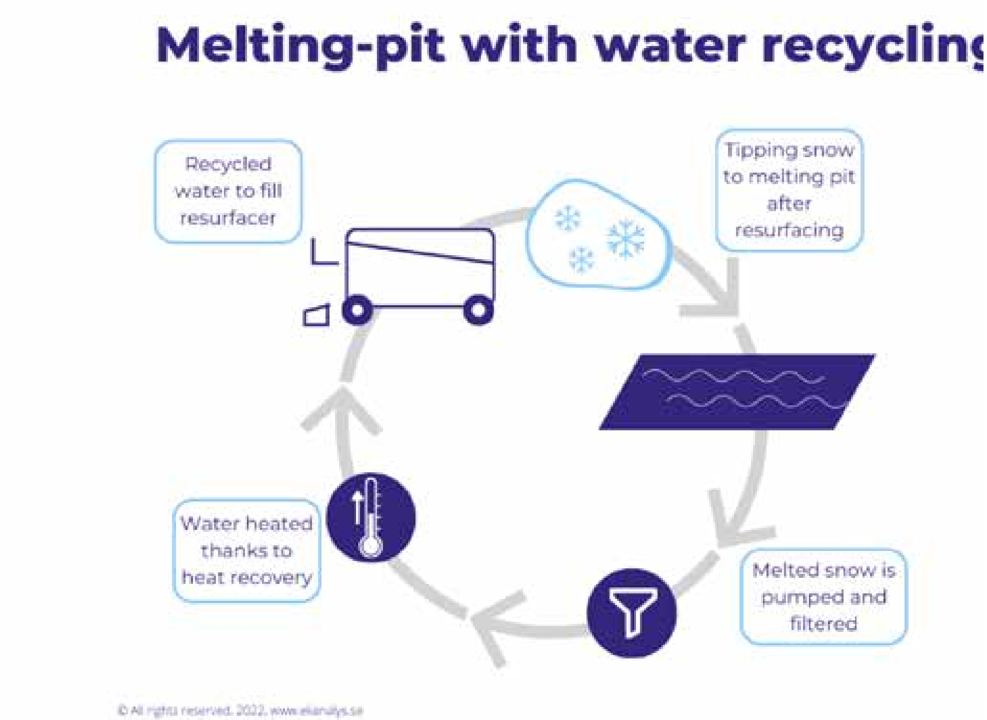


Figure 59. Water recycling applied in melting pit function.

The filtering process also helps making the water safer for visitors. By removing micro-organisms from the water and making it clean, complications due to infections in case of injury on the ice is further minimized. Nevertheless, the water should not be mixed with potable and/or shower water. Even if the water is clean after the filtration process, it still should be seen as greywater. The recycled resurfacing water should therefore have its own specific tank-filling system to keep the water in a closed loop.

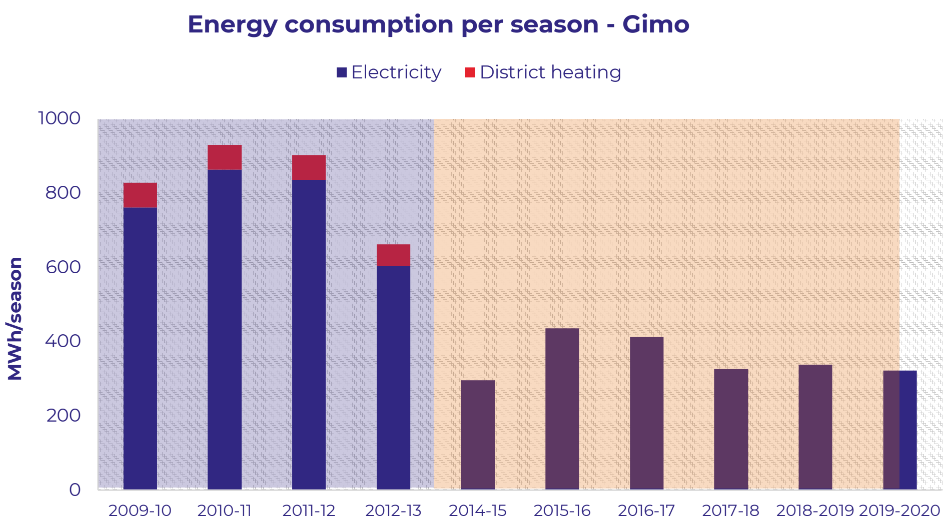
8 CASE STUDIES

8.1. FACILITY CASE STUDIES

This chapter looks into case studies on a facility-basis, i.e. individual ice arenas where each have been subject to a number of measures and the changes in total performance is are discussed.

8.1.1 Ice rink 1 - Gimo (Sweden)

The municipality of Östhammar in Sweden wanted to lead by example and apply the most environmentally friendly technology in the renovation of Gimo ice rink. In this system the ice rink refrigeration is combined with a heat pump function and geothermal storage. The facility used to depend on district and electric heating for its heating purposes, but it is now self-sufficient on the heat recovered from the refrigeration system.

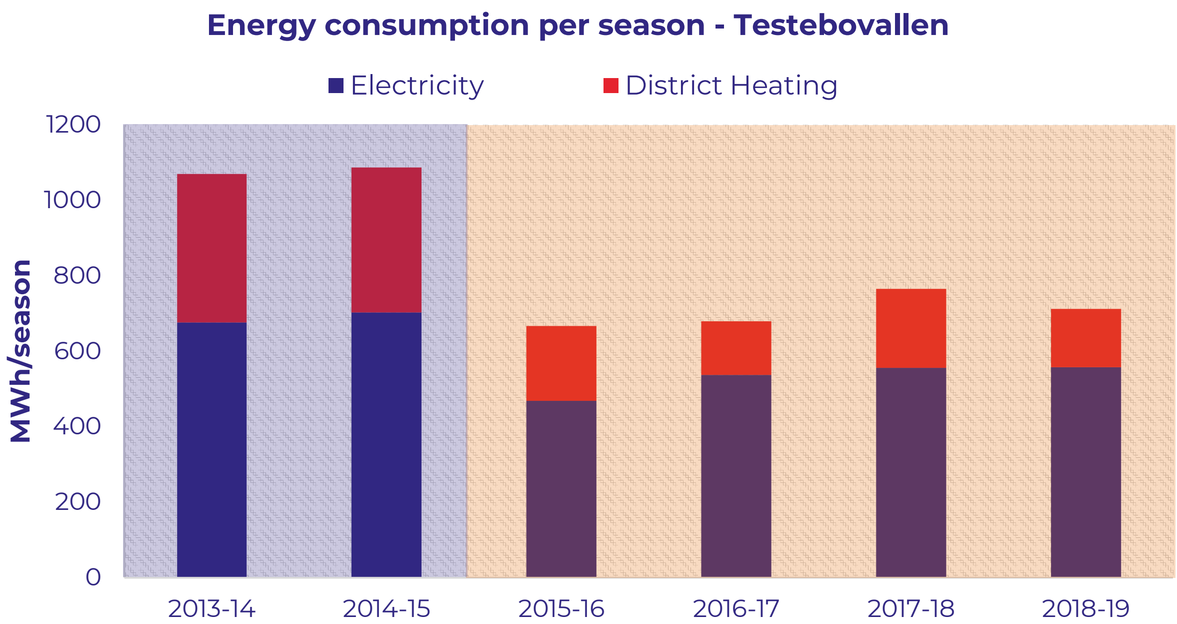


	Before	***After***
Primary Refrigerant	Ammonia	**CO_2**
Secondary Refrigerant	Calcium Chloride	**CO_2**

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

8.1.2 Ice rink 2 - Testebovallen (Sweden)

This facility consists of two ice sheets (ice hockey and curling in separate buildings) and a sports hall. Before interventions, a **R404A** refrigeration system was used. The heating demand was mainly covered by district heating. In 2015, an **indirect CO2 refrigeration system** replaced the old one. The existing secondary circuits were reused and retrofitted with aqua ammonia, reducing the pumping power demand.



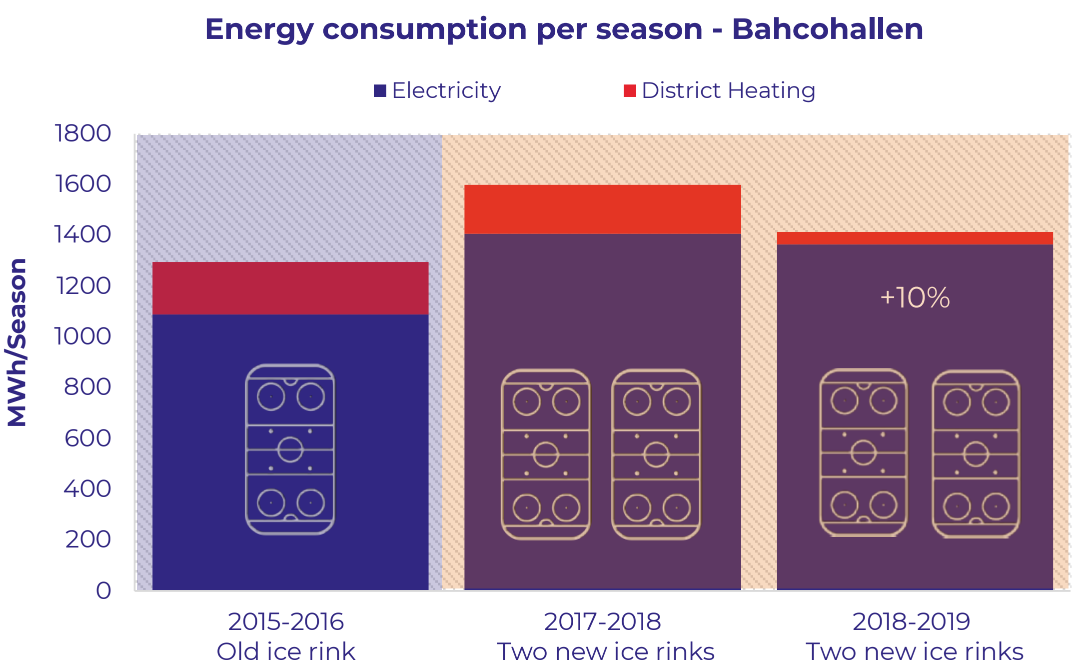
	Before	*After*
Primary Refrigerant	R404A	**CO2**
Secondary Refrigerant	Calcium chloride	**Ammonia-Water**

The new system provides a new complete **one-stage heat recovery** function with a **constant 60°C forward temperature**. A new sorption dehumidifier utilizes part of the recovered heat for reactivation, lowering its energy consumption.

CASE STUDIES
FACILITY

8.1.3 Ice rink 3&4 - Bahcohallen (Sweden)

Bahcohallen was a typical single sheet ice rink, with a heated arena room. An ammonia refrigeration unit was connected to a brine circuit in the rink floor. In 2016 a new CO2 system was installed to replace ammonia, with direct expansion. An additional indoor ice sheet located in a brand-new building adjacent to the existing ice rink completed the renovation in 2017.

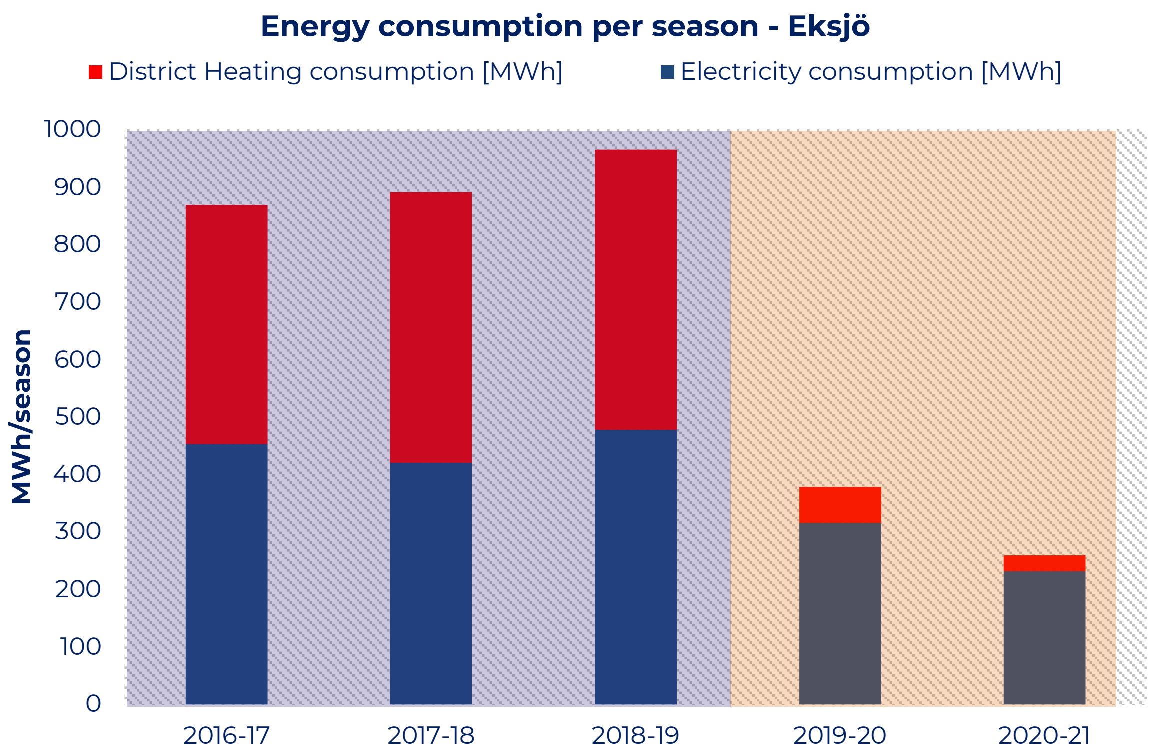


	Before	*After*
Primary Refrigerant	Ammonia	**CO2**
Secondary Refrigerant	Brine	**CO2**

The new ice sheet was connected to the unit at the beginning of the season 2017-2018. The CO2 system is **now** able to run **two ice sheets** with an **energy consumption** that is **only 10% higher** than what the previous ammonia system needed when running one ice sheet. Almost no district heating is utilized.

8.1.4 Ice rink 5 - Eksjö (Sweden)

This facility consists of one ice sheet. Before interventions, an **ammonia** refrigeration system was used. The heating demand was mainly covered by district heating. In 2019, a **direct CO2 refrigeration system** replaced the old one. The old ice sheet has been replaced by a new concrete floor with copper piping.



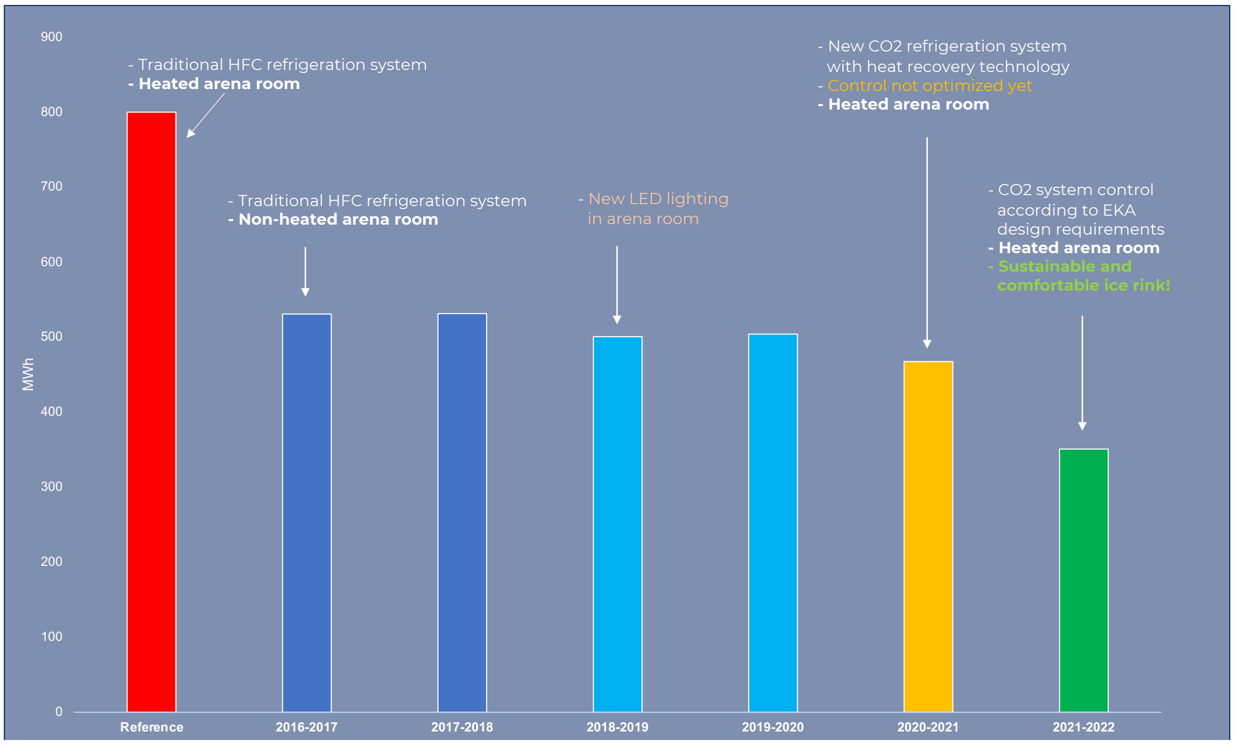
	Before	*After*
Primary Refrigerant	Ammonia	**CO2**
Secondary Refrigerant	Calcium chloride	**CO2**

The new system provides a new complete two-**stage heat recovery** function with a **constant 70°C forward temperature.** A new sorption dehumidifier utilizes part of the recovered heat for reactivation, lowering its energy consumption.

8.1.5 Ice rink 6 - Pirkkala (Finland)

This facility consists of one ice sheet. Before interventions, an **R404A** refrigeration system was used. The heating demand was mainly covered by electric heating. In order to minimize costs, the arena room was not heated, which lead to regular complaints from visitors regarding comfort.

In 2020, an **indirect CO2 refrigeration system** replaced the old solution and was connected to the existing rink floor which uses Freezium as secondary refrigerant.



	Before	*After*
Primary Refrigerant	R404A	**CO2**
Secondary Refrigerant	Freezium	Freezium

CASE STUDIES
FUNCTION

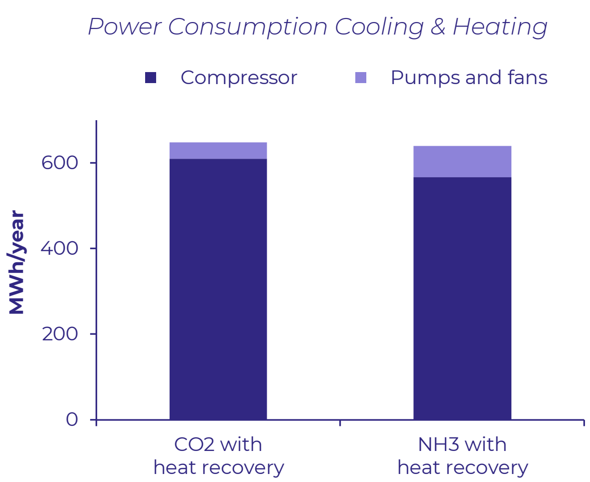
The new system provides a new complete two-**stage heat recovery** function with a **constant 70°C forward temperature**. A new sorption dehumidifier utilizes part of the recovered heat for reactivation, lowering its energy consumption.

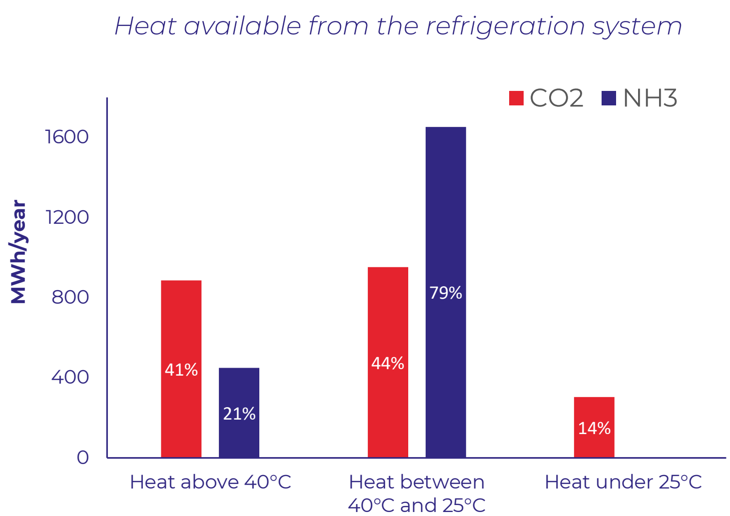
Today the ice rink arena room is heated and spectators can be found sitting **comfortably** in the stands in the sustainable ice rink.

8.2. FUNCTION CASE STUDIES

This chapter looks into case studies on a function-basis, i.e. how a change in an individual function has changed its performance.

In this project, two different solutions for suppling **cold and heat to a Bandy and to an Ice Hockey arena**, located in the center of Stockholm, Sweden, were assessed.



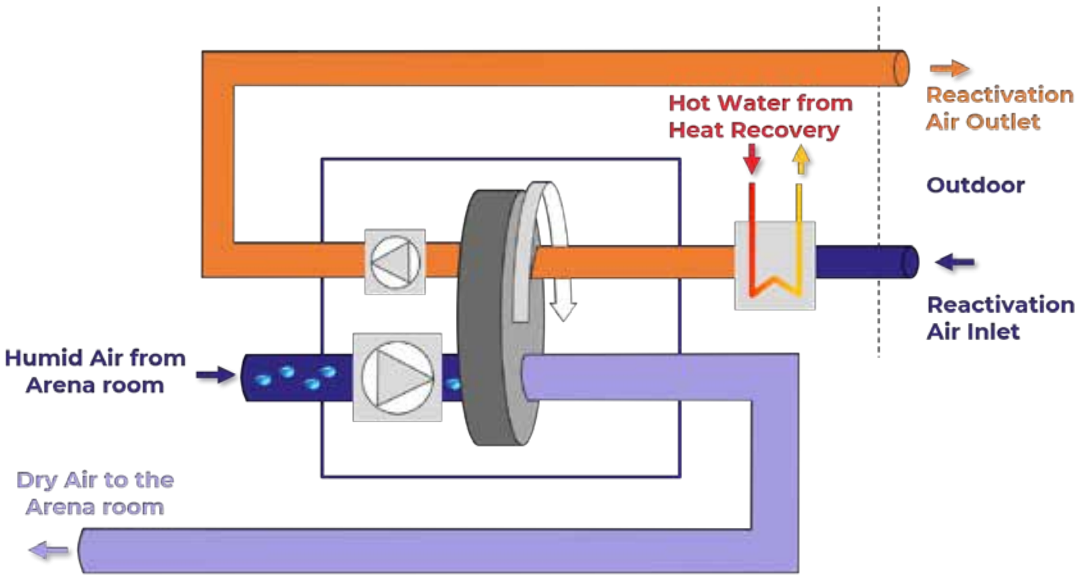


The aim of the study was to identify the best solution in terms of system layout and refrigerant. The calculation shows that difference in terms of power consumption between CO2 and ammonia is negligible.

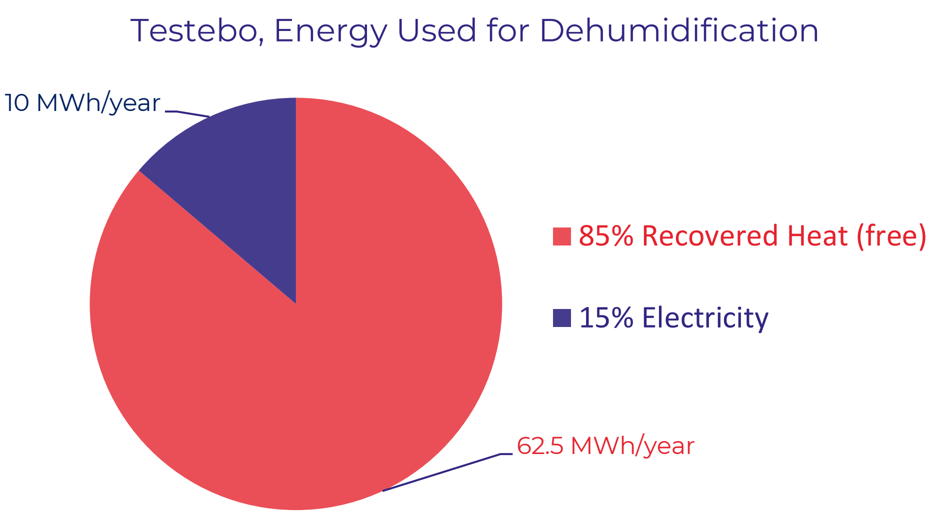
Since, CO2 has more heat available at high temperature. Considering that 2/3 of the heat in ice rinks is consumed at temperatures higher than 40°C, **CO2 was chosen as the best solution**.

8.2.2 Dehumidification with Full Heat Recovery – Testebovallen (Sweden)

A common best practice in ice rinks is to use **adsorption based dehumidification systems**, to take advantage of the heat recovery from the refrigeration system. The full heat recovery solution is characterized by a relatively low **reactivation temperature (55-60°C)**. Therefore, the **heat recovered from the refrigeration cycle is enough to heat the reactivation air**.



Heat recovered from the refrigeration cycle can be utilized for dehumidifying the air. In the sport facility called Testebo, Sweden, the solution was implemented where ca **85% of the energy cost** for dehumidification can be covered by the heat recovery. The estimated energy saving is equivalent to 5000 - 6500 Euros/year.



8.2.3 Climate Control of large arenas – Scaniarinken (Sweden)

In **medium and large arenas**, ensuring comfort for the spectators while providing dry and cold air on the ice sheet can be very challenging. The presence of **areas with different comfort levels**, such as restaurants, can complicate the picture further.

One of these examples is Scaniarinken, an ice hockey stadium in Sweden with capacity of **6200 spectators**. Before interventions there was a temperature difference of 8°C **between the top and the bottom of the stands**. Nowadays, this **temperature difference** is reduced to less than **2°C only**.

The system solution, as indicated in the pictures, is **mainly based in dividing the air distribution in "rings"**, where the innermost is purely used by the dehumidification system and the rest for ventilation / air heating.

9 QUICK SAVINGS IN EXISTING ICE ARENAS – NO/LOW INVESTMENT

While the long-term sustainable solutions will require some investments, as discussed in this guide, many ice arenas can already achieve some quick savings by making adjustments to their existing systems with little to no capital cost. This is often a good first step in the process of making the ice arena more sustainable, since it engages staff and decision-makers into making changes happen.

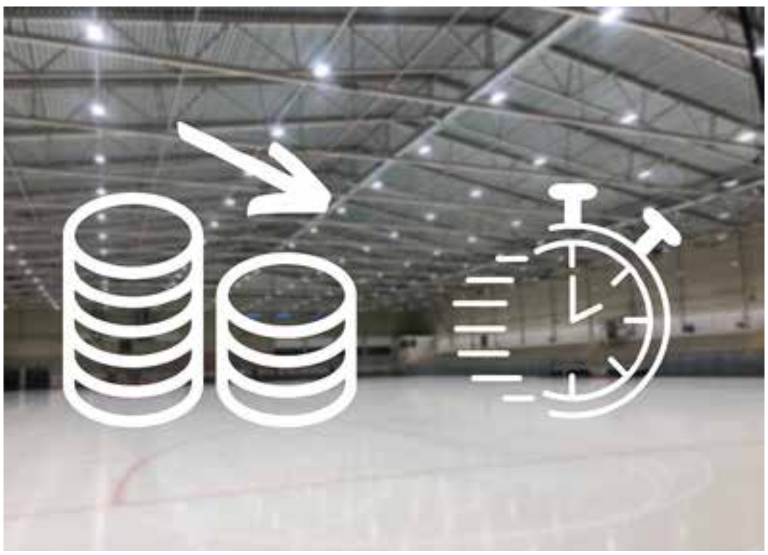


Figure 60. Quick savings can often be achieved in existing ice arenas by adjusting and/or optimizing the operation of existing solutions.

Below a number of typical quick savings tips are listed, these are further treated in the document **Quick Ice Arena Energy Savings, which is available separately via IIHF**. It should, however, be stressed again that the biggest savings by far are achieved by retrofitting ice arenas according to this guide.

- Quick tip #1 – Reduce arena room air temperature
- Quick tip #2 – Increase ice temperature during no activity
- Quick tip #3 – Optimize refrigeration system operation
- Quick tip #4 – Optimize condenser performance
- Quick tip #5 – Optimize pump control
- Quick tip #6 – Optimize dehumidifier control
- Quick tip #7 – Optimize ice thickness
- Quick tip #8 – Optimize ice resurfacer use
- Quick tip #9 – Optimize/reduce fresh air intake
- Quick tip #10 – Separate the climate zones

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Title page photo by Andreas Bobert.

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More studies available via EKA website www.ekanalys.se

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