



**KTH Industrial Engineering  
and Management**

# Energy Usage in Ice Rink Resurfacing

Roni Kaya

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Energy Technology EGI\_2017-005 MSC  
Division of Applied Thermodynamics and Refrigeration  
SE-100 44 STOCKHOLM



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## Energy Usage in Ice Rink Resurfacing

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Approved	Examiner Samer Sawalha	Supervisor Jörgen Rogstam
	Commissioner	Contact person

## Sammanfattning

Ishallar kräver stora mängder energi för sin verksamhet. Undersökningar har visat att en typisk ishall i Sverige använder ca 1 000 MWh per år. Data från de mest effektiva ishallarna har visat att en väl utformad ishall kan nå en energiförbrukning på mindre än 500 MWh per år, vilket ger en stor potential för energisparande åtgärder. En statistisk studie av ett stort antal ishallar i Sverige har visat att kylsystemet har den största andelen av den totala energianvändningen i en ishall, motsvarande 43% i genomsnitt. Kylsystemets energianvändning är kraftigt beroende av olika värmebelastningar på isytan. Tidigare studier har fastställt andelarna i den totala värmebelastningen i ishallar som visat att de värmelaster som uppstår vid avspolning av isytan motsvarar mellan 14-17% av den totala värmelasten. I denna undersökning har spolvattnets volym och temperatur utvärderats med insamlad data genom experimentella mätningar och analyserats vidare med målet att bestämma andelen i totala värmelastningen och föreslå energisparande åtgärder. Resultaten av studien bygger på data som samlats in i fem olika ishallar i Stockholm, och visar att de flesta fyllningar har en volym mellan 300-500 liter vid en temperatur mellan 30-50°C. Större volymer och högre temperaturer ökar värmebelastningen på isen genom latent och sensibel värme, vilket innebär att mindre volymer och lägre temperaturer minskar värmebelastningen och i sin tur energianvändningen. Undersökningen visar också att energiförbrukningen vid laddning av ismaskinerna varierar och pekar åt att förbrukningen ökar med äldre maskiner. Studien visar att genomsnittliga energiförbrukningen för de fem ishallarna vid en avspolning är 18 kWh i en hall med 100% värmeåtervinning (18% till laddning av ismaskin och 82% till kylsystemets kompressor) och 36 kWh utan värmeåtervinning (9% till laddning av ismaskin, 49% uppvärmning av spolvatten och 42% till kylsystemets kompressor), vilket indikerar en besparing i energiförbrukning genom integrerat värmeåtervinningssystem. Andelen av den totala värmelasten från mätningar visar att i genomsnitt 11% av totala värmebelastningen uppstår på grund av avspolningar. Resultaten har visat att vattentemperaturen vid utloppet av tanken skiljer sig avsevärt från fyllningstemperaturen. Detta innebär att den önskade spolvattentemperaturen skiljer sig från vad som faktiskt läggs på isen. I sin tur innebär det en stor energiförlust mellan 7 000-14 000 kWh / säsong för de undersökta ishallarna.

## Abstract

Ice rink operations require significant amounts of energy. It has been concluded that a typical single sheet ice rink in Sweden uses around 1 000 MWh per year. Data from the most efficient ice rinks has shown that a well-designed ice rink could reach an energy usage of less than 500 MWh per year, which leaves a great potential for energy saving actions. A statistical study of a large number of ice rinks in Sweden has shown that the refrigeration system has the largest share of the total energy usage in an ice rink, corresponding to 43% in average. The energy consumption of the refrigeration system is depending on various heat loads on the ice surface. Previous studies has determined the shares of the total heat load in ice rinks, concluding that one of the four largest heat loads in an ice rink comes from the ice resurfacing, corresponding to 14-17%. Floodwater volume and temperature has been evaluated by collecting data through experimental measurements and further analysed with the goal to find energy saving actions. The results of the study are based on data collected in five different ice rinks in Stockholm, Sweden and shows that most fillings of resurfacing machines has a volume between 300-500 litres at a temperature between 30-50°C. Larger volumes and higher temperatures increase the heat load on the ice surface through latent and sensible heat, which means that smaller volumes and lower temperatures decrease the energy consumption. It has also been concluded that older resurfacing machines are larger energy consumers compared with newer models. The study shows that the energy consumption for an average resurfacing process 18 kWh with 100% heat recovery (18% from charging and 82% compressor electricity) and 36 kWh without heat recovery (9% from charging, 49% heating electricity and 42% compressor electricity), which indicates a decrease in energy consumption in ice rinks with heat recovery. The resurfacing share of the total heat loads from the measurements show that in average 11% of the heat load occurs by ice resurfacings. The results have shown that the water temperature at the outlet of the tank differs substantially from the filling temperature. This means that the desired floodwater temperature is different from what you actually get and there is a large waste in energy consumption for heating as the desired resurfacing temperature is rarely achieved. Studies show an approximate waste in energy consumption between 7 000 - 14 000 kWh/season



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## NOMENCLATURE

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<b>Symbol</b>	<b>Description</b>
$\dot{m}$	Mass flow (kg/s)
$t$	Temperature/Absolute temperature (°C/T)
$\dot{Q}$	Heating/Cooling capacity (W)
$\alpha_c$	Convective heat transfer coefficient
$A$	Area (m <sup>2</sup> )
$v$	Velocity (m/s)
$K$	Mass heat transfer coefficient
$X$	Mole fraction
$f_{ci}$	Gray body configuration factor for radiation from ceiling to ice surface
$\sigma$	Stefan-Boltzmann constant
$\varepsilon_{ceiling}$	Emissivity factor for normal ceiling constructions
$F_{ci}$	Angle factor
$\dot{E}_k$	Compressor work (W)
$\dot{E}_{el}$	Compressor electrical input (W)
$h$	Enthalpy (J)
$\eta_{elm}$	Electrical motor efficiency compressor
$V$	Volume (m <sup>3</sup> )
$C_p$	Specific heat capacity (kJ/KgK)
$\Delta H_{water \rightarrow ice}$	Heat fusion water to ice (kJ/Kg)
$RH$	Relative humidity (%)
$AH$	Absolute humidity (gH <sub>2</sub> O/kgAir)
$\rho$	Density (kg/m <sup>3</sup> )
$M$	Molecular weight (g/mol)
$P$	Pressure (Pa)
$n$	Moles
$R$	Universal gas constant
$P_{sat}$	Saturation pressure for water vapours
$DHW$	Domestic Hot Water
$HW$	Hot Water
$MW$	Mixed Water
$CW$	Cold Water
$COP$	Coefficient of Performance

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*This chapter describes the background of how the general ice rink for various types of activities has developed a need of energy efficient solutions for a sustainable future. It also contains the objectives, methods and limitations in this thesis.*

As the request of artificial ice surfaces has grown in pace with climate change and commercial availability requirements, the use of ice surfaces has changed through history from being a way to travel to become a worldwide industry in sports as ice hockey, curling, figure skating, speed skating, recreational skating etc. (ASHRAE, 2014). Meanwhile, an increased awareness regarding the environment, energy consumption and expenses has led to technical developments and efficiency improvements in ice rinks and refrigeration systems. The development of sports on ice has also led to increased demands regarding the ice quality depending on the activity that is taking place.

Ice rink operations require significant amounts of energy. It has been concluded that a typical single sheet ice rink in Sweden uses around 1 000 MWh per year. Data from the most efficient ice rinks has shown that a well-designed ice rink could reach an energy usage of less than 500 MWh per year (Stopppladd, 2010), which leaves a great potential for energy saving actions. A statistical study of more than one hundred ice rinks in Sweden has shown that the refrigeration system has the largest share of the total energy consumption in an ice rink, corresponding to 43% in average (Rogstam, 2010).

There are currently over 360 indoor and 140 outdoor ice rinks in Sweden, with a continuously increasing rate. Ignoring investigations regarding energy efficient solutions will thus result in a steady increase of energy consumption (Rogstam, 2010). The energy consumption of the refrigeration system is totally dependent on various heat loads on the ice surface (ASHRAE, 2014). A closer look on where these loads originates from gives an idea of where efficiency measures can help to reduce the energy consumption of the ice rink's refrigeration system. Previous studies has determined the shares of the total heat load in ice rinks, concluding that one of the four largest heat loads in an ice rink (14-17%) occurs by ice resurfacings (Rogstam, 2010). Despite the large amount of heat charged by the ice resurfacing process, it is currently uncommon with measurement equipment on board on ice resurfacing machines for monitoring temperature and used water volume (Olympia, 2014) (Zamboni, 2014). This indicates an obvious need for evaluating the volume and temperature of the water, as well as finding a practical way to measure and display these parameters by e.g. retrofitting current machines, which will be one of the objectives to evaluate in this work.

## **1.1 Objectives**

The objective of this study is to evaluate the resurfacing floodwater amount and temperature used in ice rinks with the goal to determine if reduction of water and thus cooling energy is possible while maintaining similar ice quality. The aim to reduce used energy by feeding the evaluated information back to operators will be followed by these steps:

- Maintain a fundamental understanding regarding heat loads, refrigeration systems and resurfacing machines in ice rinks
- Evaluate measurements regarding heat loads from resurfacing machines, amount of water used, water temperature, electrical energy and temperature drop rate of floodwater in resurfacing machines
- Define "good quality ice" and examine the freezing time depending on actual amount and temperature of the floodwater
- Evaluation of how temperature and floodwater volume affects the refrigeration system and ice quality
- Estimate the saving potential with optimized use of floodwater
- Evaluate the potential impact of water treatment
- Find a suitable solution for the measurement of water volume and temperature with the ambition to install a monitor on ice resurfacing machines in the future

## **1.2 Methodology**

The basic understanding of how ice rink systems work is a vital first step towards the goal of introducing energy efficient measures. A large-scale literature review of how the system is affected by heat loads, how the refrigeration systems are designed and how resurfacing machines work today is made. The literature review also includes how to define “good quality ice” to be able to determine the results of ice resurfacing experiments.

The experiments will be made on five different ice rinks in the south part of Stockholm, Sweden, where temperature measurements, water volume and energy consumption of the resurfacing machines will be considered. The number of resurfacing processes will be confirmed by thermocouples, ultrasonic flow meter and an online tool connected to the ice rinks named ClimaCheck, where a real time analysis of the ice rink parameters is received.

## **1.3 Scope and limitations**

The experiments in this thesis have been made in five different typical indoor ice rinks of about 1800 m<sup>2</sup>, located south of Stockholm, where hockey and other activities are practiced. The ice rinks are categorized as training facilities without requirements regarding audience seats, lighting, and seats for media or TV-cameras etc. The facilities are most often used as training area for school activities, for the public and lower division teams. Making good ice is based on craftsmanship, which puts some limitations as to the icemakers want to do.

## 2. ICE RINK SYSTEMS

This chapter will briefly explain the different parts of the energy systems in an ice rink and some energy efficient measures that can be made to decrease the energy consumption for these systems.

### 2.1 Energy demands

As there are various demands in an ice rink, identified in *figure 2*, different energy systems require different amounts of energy. *Figure 1* shows an overview of the different energy users in ice rinks, concluding that refrigeration (43%), heating (26%), lighting (10%), ventilation fans (9%) and dehumidification (6%) are among the largest energy consumers.

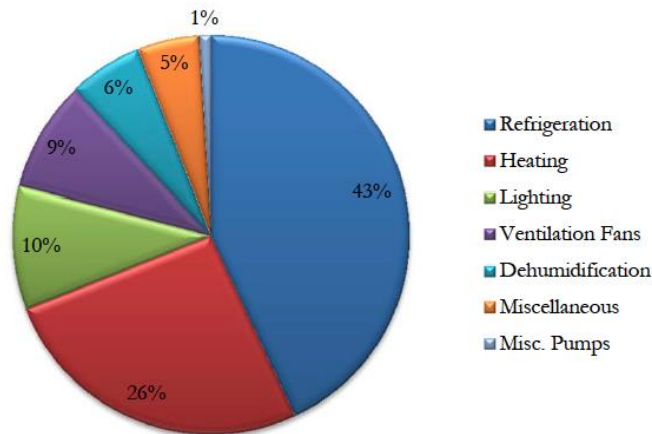


Figure 1. Typical shares of energy consumers in ice rinks (Rogstam, 2010)

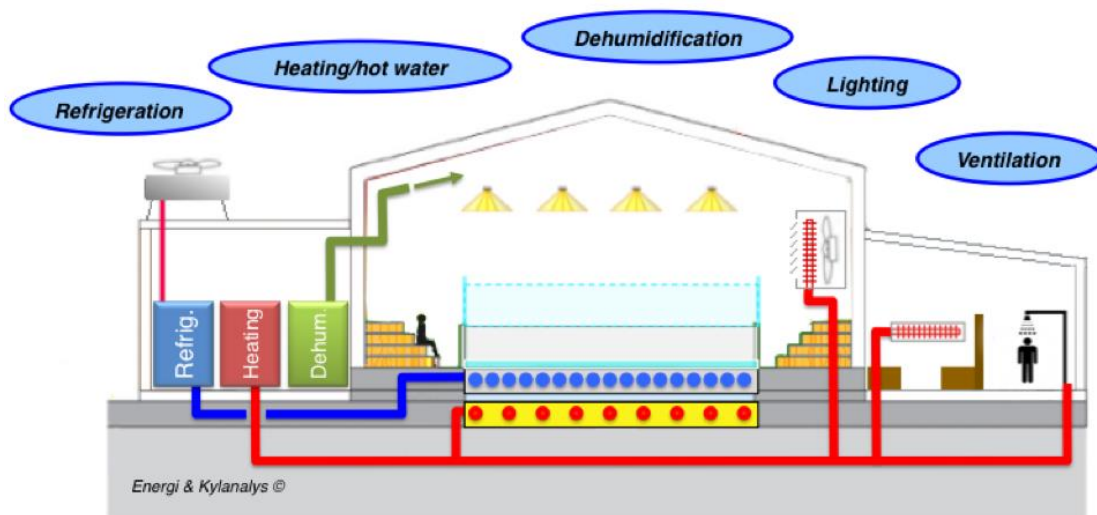


Figure 2. Energy systems in ice rinks (Energi- & Kylanalys, 2014)

#### 2.1.1 Heating and ventilation

The proportion of energy for heating is slightly more than 25% in an average ice rink, which puts it as the second-largest energy user. It provides the required heat for needs such as:

*Space Heating* – The warm, heated zones as spectator stands, locker rooms, office spaces

*Ventilation* – The heat needed for the ventilation system. Delivers fresh air to occupants and provides the standard air change rate to avoid pollutant, smell, fog and biological disease sources concentration. For public



areas, air change required in the closed spaces including restaurant, offices, drying rooms, medical rooms, locker rooms (for players, coaches, referees and linesmen) and toilets/showers should be considered (IIHF, 2010)

*DHW* – Domestic hot water used in the building for purposes as sanitation, personal hygiene

*Resurfacing Water* – Heated water (usually 30-40°C in Sweden) used for filling of resurfacing machines

*Floor/Subsoil Heating* – Pipes placed in the ground under the ice surface to prevent it from freezing

A great share of the heating demand, up to 100% (ASHRAE, 2014), can be covered by sensible heat recovery by using the rejected heat from the refrigeration system through the condenser or de-superheater, as the refrigeration system can be used both on the evaporator side for cooling and condenser side as a heat pump. Some examples of the integrated method are shown in *figure 3*. The left layout is called floating condensing, a refrigeration system without heat recovery, where the refrigerant heat is rejected to atmosphere as the condensation pressure follows the ambient temperature. This case requires the heating demand to be covered by a separate heat source as district heating, heat pump, electrical heating etc. The middle layout is a heat recovery system with a de-superheater. This system is suitable when the discharge temperature is relatively high, which is common for refrigeration systems using NH<sub>3</sub> or CO<sub>2</sub>. The regulating valve placed after the condenser/gas cooler can adjust the discharge pressure hence the heating capacity. The layout to the right is a fixed-head pressure heat recovery system. The discharge pressure is adjusted according to the HVAC system demand. A coolant transfers the heat from the condenser to the HVAC system. The temperature is comparatively low (~30°C) to the discharge temperature (~100°C), which limits the usage. (Sawalha, 2010)

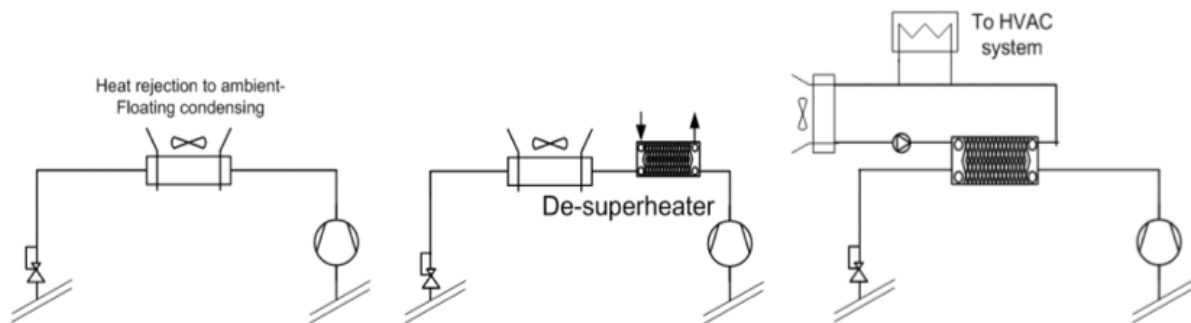


Figure 3. Configurations of heat rejection and heat recovery from a refrigeration system (Sawalha, 2010)

*Figure 4* shows how the shares of the heat sources are divided in Swedish ice rinks and leaves a great potential for energy savings with an integrated system instead of electrical and district heating, commonly used for additional heating. There are probably a few plants that are heated by oil, gas or pellets but they are unusual and therefore overlooked.

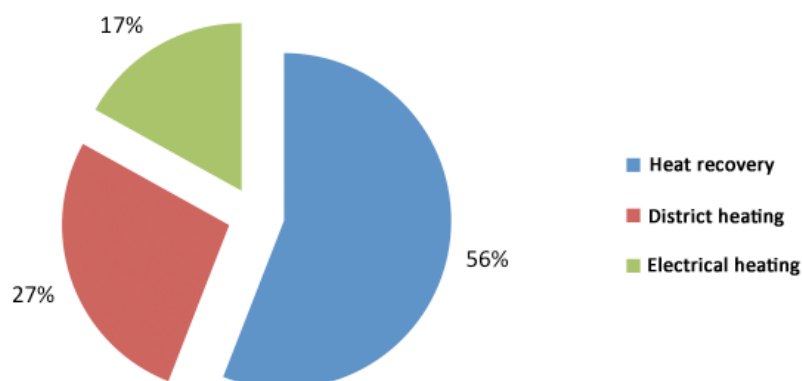


Figure 4. Heat sources in ice rinks (Stopppladd, 2010)

### 2.1.2 Dehumidification

The climate in an ice rink is important for the building and its visitor's well being. A humid environment thrive mould that can affect the working environment for employees and visitors, but also cause corrosion of metal and wooden structures of the building. The climate has a major impact on ice quality and load on the ice surface. The moisture in the surrounding air is also defrosting the ice surface and makes it porous, which in turn degrades the ice quality. A controlled dehumidified air above the ice provides a solid foundation for good ice quality and a lower heat load on the ice, resulting in a reduction of energy consumption for the refrigeration system. There are currently two common ways of dehumidifying the air. One is by water vapour condensation where the principle is to cool the humid air below its dew point. The humid air is cooled through the evaporator or cold brine to create a cooled surface where the humidity of the air condenses and is separated, which process can be seen in *figure 5*. This method needs a large volume of air to flow through and is also heated through the condenser before it is sent back to the ice rink.

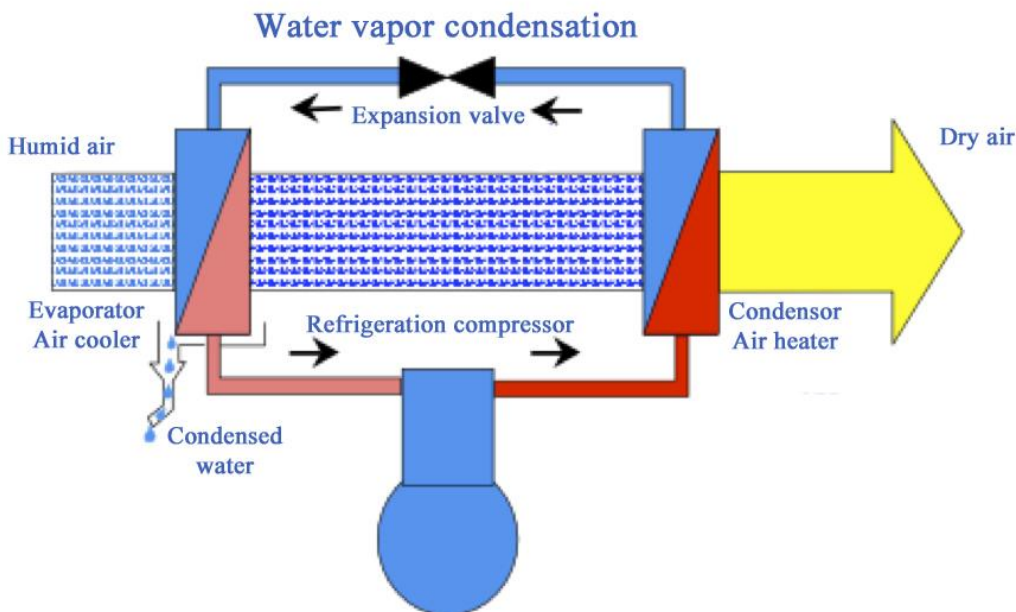


Figure 5. Principles of water vapour condensation

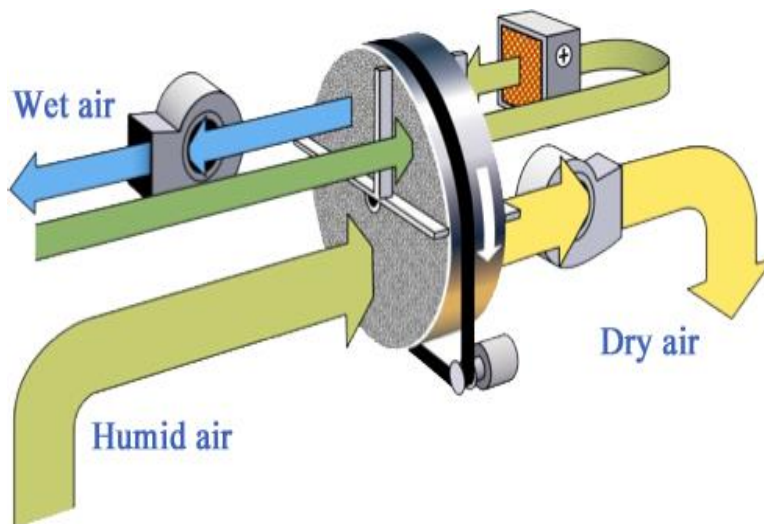


Figure 6. Desiccant dehumidification system

The most common method for dehumidifying the air is through the desiccant dehumidification system shown in *figure 6*. The figure shows the “desiccant wheel” that rotates, which consists of a water-absorbing material, usually silica gel, which absorbs the moisture of the humid air passing through. The dry air is then supplied back to ventilation system and distributed back to the ice rink. The absorbed moisture is simultaneously released as the wheel is regenerated in another part by heated air and driven out as wet air. Electrical heaters are often used for regenerating the desiccant wheel, but can partly be heated by suction gas from the refrigeration system to

decrease the energy consumption of the humidifier. *Figure 7* illustrates a typical desiccant humidification system installed in a Swedish ice rink. (Rogstam, 2010)



Figure 7. Desiccant humidification system connected to the ventilation system in a Swedish ice rink

### 2.1.3 Lighting

There are different requirements for brightness, 200-1 000 lux. Light installation requirements are determined based on what type of ice rink it is, both in terms of the level at which the sport will be exercised in and the performance of energy efficiency.

Table 1. Lighting options for ice rinks (IIHF, 2010)

Type	Applicability	Power range [W]	Lifetime [h]	Comment
<b>Compact fluorescent lamps</b>	General lighting	5-55	8 000 - 12 000	Good energy efficiency
<b>Standard fluorescent lamps</b>	General lighting Rink lighting	30-80	20 000	Good energy efficiency
<b>Metal halide lamps</b>	Rink lighting	35-2000	6 000 - 20 000	Good for rink lighting
<b>High pressure sodium lamps</b>	Rink lighting	50 - 400	14 000 - 24 000	Poor color rendering
<b>Induction lamps</b>	Rink lighting	55 - 165	60 000	Long life, expensive
<b>Halogen lamps</b>	Special lighting	20 - 20 000	2 000 - 4 000	Excellent color rendering, good dimming possibilities

To meet these requirements there are different types of installations like metal halide and various types of fluorescent tubes. For the lighting, which is the third largest energy consumer, it is clear that the newer systems with modern lights and good control system uses significantly less energy than older models. Since lighting sources must be replaced at regular intervals, such situation is a good occasion to upgrade the whole lighting system instead of just buying new fluorescent lamps. Over half of the installed capacity in ice rinks is of the older model. If all these older fixtures were replaced, it would provide savings of an average of 23.6 MWh per year and rink. Different types of fluorescent lighting is the most common form of Swedish ice rinks. 75% of installed power is divided between fluorescent T5 and T8 with or without electronic ballast. Of these, the majority is, 53%, fluorescent tubes with conventional ballast. (Rogstam, 2010)

## 2.2 Heat loads

An important aspect of the refrigeration system is to understand where the heat load is coming from, which in turn determines the required cooling demand. The amount of energy being used decrease as these heat loads are reduced. *Figure 8* shows a comparison of shares of heat loads in a Swedish ice rink made in a previous study. (Abdi et al., 2012)

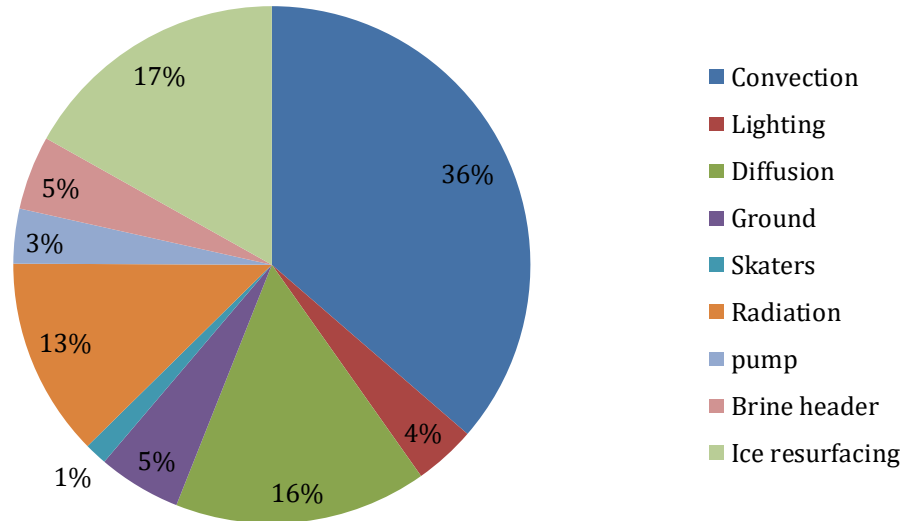


Figure 8. Shares of the total heat load in a Swedish ice rink (Abdi et al., 2012)

### 2.2.1 Conductive loads

Brine pump, activities on ice, ground heat, header pipe and resurfacing water together form the *conductive* loads affecting the refrigeration system. (ASHRAE, 2014) A frequency controlled brine pump, regulated by the heat load on the ice is one way to decrease its conductive load on the system. In other words, the pump is not working under a constant speed but slower the smaller load and faster as the load increase. A proper insulation of the substrate reduces the heat flux from the ground heat significantly. If ground frost protection is installed, insulation between it and the brine circuit is very important to avoid a thermal short circuit between the systems, where the heat goes from frost protection directly to the brine which in turn results in a larger load on the refrigeration system. (Rogstam, 2010) Ice resurfacing is a requirement to maintain the ice surface in a good condition. Ice resurfacing machines shaves the ice surface and pours down a layer of water on the ice. The volume and temperature of the water is directly affecting the heat load on the ice as sensible and latent heat and it varies between ice rinks. (ORFA,1991) The ice-resurfacing load is examined separately as one of the cornerstones in this thesis and can be followed in *chapter 4*.

### 2.2.2 Convection and condensation loads

*Convective* loads are affected by air temperature, water content and air velocity over the ice. Water vapour in the humid air rejects its heat to the ice and condenses on the surface. Dehumidifying the air is necessary to avoid *condensation* and keep the relative humidity low. A proper installation of vents with a lower air velocity over the ice is also a solution to decrease the load as the convective heat transfer decreases. The temperature difference between the ice temperature and moving air above the ice is the driving force for convection and can be calculated by following equation:

$$\dot{Q}_{convection} = \alpha_c A_{ice} (t_{air} - t_{ice}) \quad (2.1)$$

Where  $\alpha_c$  is the convective heat transfer coefficient, which is dependent of the air velocity over the ice as following:

$$\alpha_c = 3.41 + 3.55v_{air} \quad (2.2)$$

The driving force for condensation is the difference between the partial pressure of water vapour in the air close to the ice surface and the saturation pressure of water on the ice surface. Following equation is used for ice rink floors (ASHRAE, 2014):

$$\dot{Q}_{diffusion} = [K(X_{air} - X_{ice})(2852 \text{ kJ/kg})(18 \text{ kg/mole})] \quad (2.3)$$

Where:

$K$  = mass heat transfer coefficient  $\approx 0.23 \text{ g/(s}\cdot\text{m}^2)$

$X_{air}$  = mole fraction of water in air, kg mole/kg mole  $\approx 6.6 \cdot 10^{-3}$

$X_{ice}$  = mole fraction of water in saturated ice, kg mole/kg mole  $\approx 3.6 \cdot 10^{-3}$

### 2.2.3 Radiation

The ceiling and lighting are the two major sources of *radiation* in an ice rink as it is designed with a large flat ice surface during a relatively warmer roof. The roof and ice emissivity is very important for the radiation exchange and can be reduced considerably e.g. with canvas or low emissivity sheets as aluminium foils or aluminium based clothes and paints covering the roof. The lighting has a major impact where as much as 60% of rated output can be radiation that is absorbed by the ice directly. (Rogstam, 2010) A simple way to reduce this heat load is to control the light intensity according to the demand since it is not necessary to have lighting with full intensity all the working hours of the ice rink. It could instead keep a lower intensity during public openings and training sessions as it increase in intensity during competitive games with spectators. As seen in *figure 9*, a low emissivity ceiling that reduces the radiation load on the ice surface, allows the refrigeration system to work with a higher brine temperature and thus work with lower energy consumption. (ASHRAE, 2014)

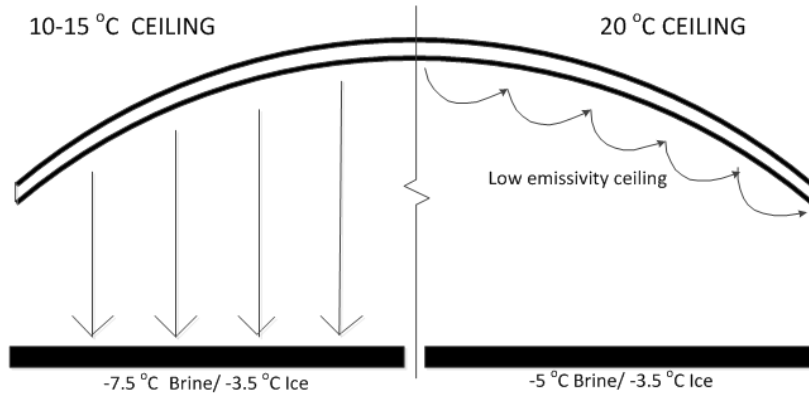


Figure 9. Comparison between high and low emissivity ceilings

Stefan-Boltzmann equation can be applied to calculate the radiation from the ceiling as following:

$$\dot{Q}_{Radaition} = A_{ceiling} f_{ci} \sigma (t_{ceiling}^4 - t_{Ice}^4) \quad (2.4)$$

Where:

$A$  = area ( $\text{m}^2$ )

$t$  = absolute temperature (K)

$\sigma = 5.67 \times 10^{-8} \text{ W/(m}^2\text{K}^4)$  (Stefan-Boltzmann constant)

$f_{ci}$  = gray body configuration factor for radiation from ceiling to ice surface:

$$f_{ci} = \left[ \frac{1}{F_{ci}} + \left( \frac{1}{\epsilon_{ceiling}} - 1 \right) + \frac{A_{ceiling}}{A_{ice}} \left( \frac{1}{\epsilon_{ice}} - 1 \right) \right]^{-1} \quad (2.5)$$

Where  $\epsilon$  is the emissivity factor and for normal ceiling constructions and ice structure ranges between 0.8 and 0.95. Special aluminium paint can lower the emissivity to between 0.5 and 0.2 and polished metals as aluminium

foil has an emissivity factor around 0.05. Low-emissivity ceilings also decrease condensation problems as it is just slightly cooled by radiant loss and its temperature remains above the dew point of the rink air (ASHRAE, 2014).  $F_{ci}$  is the angle factor and depends on the geometric properties of the ceiling surface, ice surface and the ice rink height. Angle factor for radiation between parallel rectangles is show in *figure 10*.

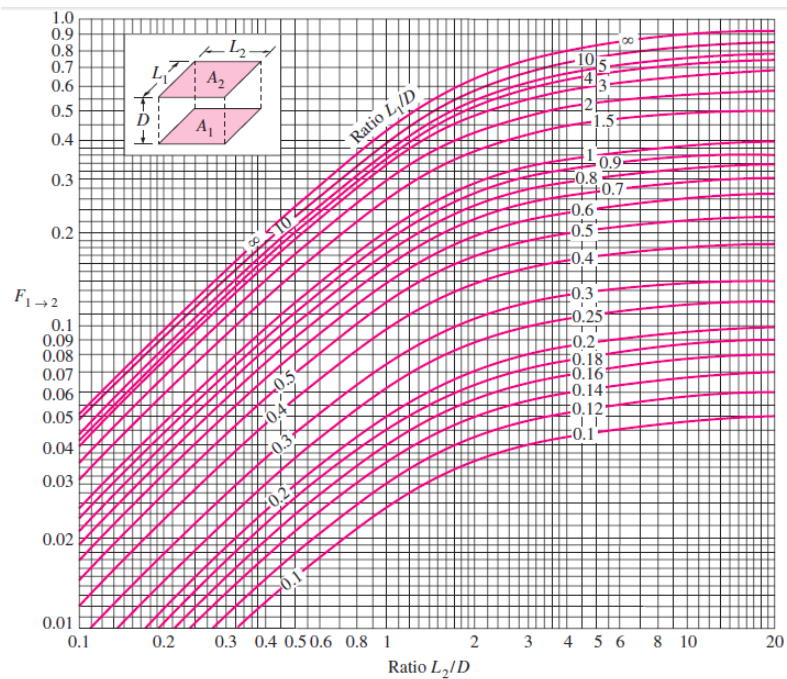


Figure 10. Angle factor for radiation between parallel rectangles

### 2.3 Refrigeration system

The refrigeration system can be referred as the cornerstone of the ice rink since it provides the rink with the main purpose of an ice rink – the ice surface. It includes electricity for compressors, coolant pumps, brine pumps and dry cooler fans. *Figure 11* illustrates the shares of energy usage in refrigeration systems, indicating the compressors as the by far largest consumer.

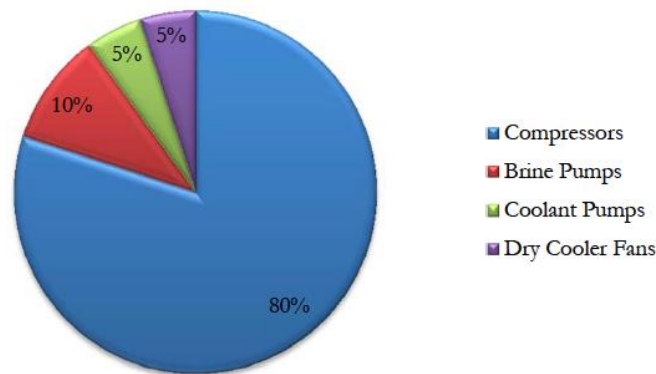


Figure 11. Shares of energy usage in refrigeration systems (Rogstam, 2010)

The cooling capacity in a vapour compression cycle unit depends on the mass flow and enthalpy difference of the refrigerant as it passes through the evaporator by following equation:

$$\dot{Q}_2 = \dot{m} * (h_{2k} - h_s) \quad (2.6)$$

All of the supplied electrical power to the compressors is not converted to use work as some is rejected as heat to the ambient and is defined as  $\dot{Q}_{losses}$  and each compressor has its own specific electrical motor efficiency,  $\eta_{elm}$ . A correlation for power consumption is expressed in equation 2.7. The mass flow rate is obtained in eq. 2.9 by combining eq. 2.7 and 2.8.

$$\dot{E}_k = \dot{E}_{el} * \eta_{elm} - \dot{Q}_{losses} \quad (2.7)$$

$$\dot{E}_k = \dot{m} * (h_{1k} - h_{2k}) \quad (2.8)$$

$$\dot{m} = \frac{\dot{E}_{el} * \eta_{elm} - \dot{Q}_{losses}}{(h_{1k} - h_{2k})} \quad (2.9)$$

The COP (Coefficient Of Performance) of the unit can be calculated with the known cooling and heating capacity and the electrical power input:

$$COP_1 = \frac{\dot{Q}_1}{\dot{E}_{El}} \quad (2.10)$$

$$COP_2 = \frac{\dot{Q}_2}{\dot{E}_{El}} \quad (2.11)$$

where COP<sub>1</sub> is for heating and COP<sub>2</sub> for cooling. The ratio between COP<sub>1</sub> and COP<sub>2</sub> is:

$$COP_1 = COP_2 + 1 \quad (2.12)$$

Figure 12 shows an example of how the different enthalpies for cooling and heating capacity and compressor work can be spotted in a log p-h diagram:

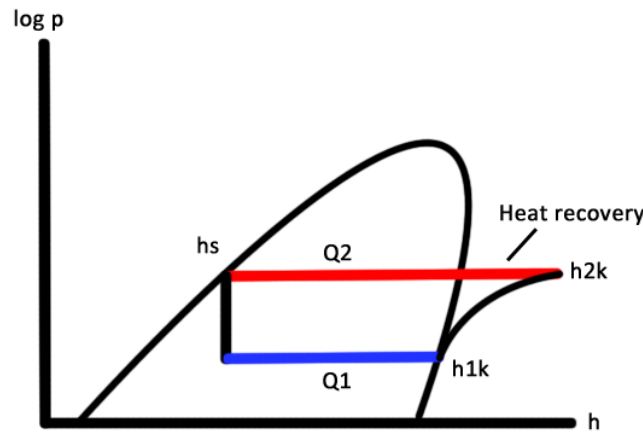


Figure 12. Log p-h diagram with marked area of possible heat recovery

### 2.3.1 Indirect and direct systems

The refrigeration systems in ice rinks are usually compact units with compressor, condenser and evaporator in the machine room connected to a heat exchanger (indirect system) or a spread system with the ice pad as evaporator and a condenser cooled by ambient air (direct system). The direct system uses a flooded evaporator, which is a type of tank, where refrigerant is available in both gas and liquid form. The liquid is pumped from the lower part of the tank into the pipes under the rink and absorbs heat. The partially vaporized liquid is then returned to the same tank as a mix of both gas and liquid. The gaseous refrigerant is sucked out of the compressor in the upper part of the tank and then compressed. Direct systems contain a larger volume of refrigerant compared with indirect systems. The risk of leakage among people in ice rinks and the willingness to reduce refrigerant volumes has decreased the production of the direct system dramatically in recent years.

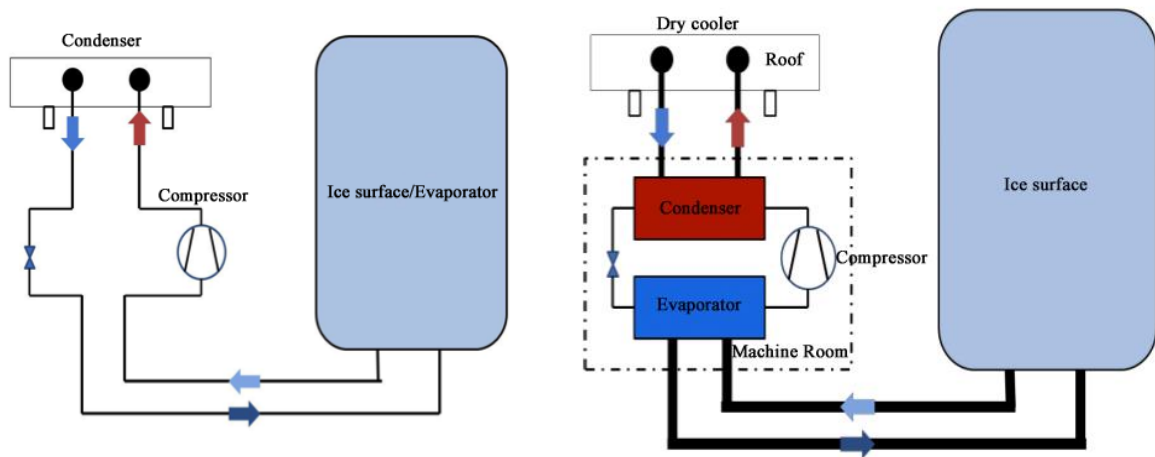


Figure 13. Direct (left) and indirect (right) refrigeration systems in ice rinks

Indirect cooling systems are built in most cases as a more compact system with less leakage as the amount of refrigerant is reduced considerably. It consists of three components; a coolant circuit for cooling the condenser heat through the dry cooler, a brine circuit to remove heat from the ice and a refrigerant circuit in the cooling unit. The different parts in direct and indirect systems are described in *figure 13* with the cooling unit/machine room inside the dashed line. There are also some cases where one side of the system is of direct type. These are called partially indirect systems. The current distribution of different types of systems is shown in *figure 14*.

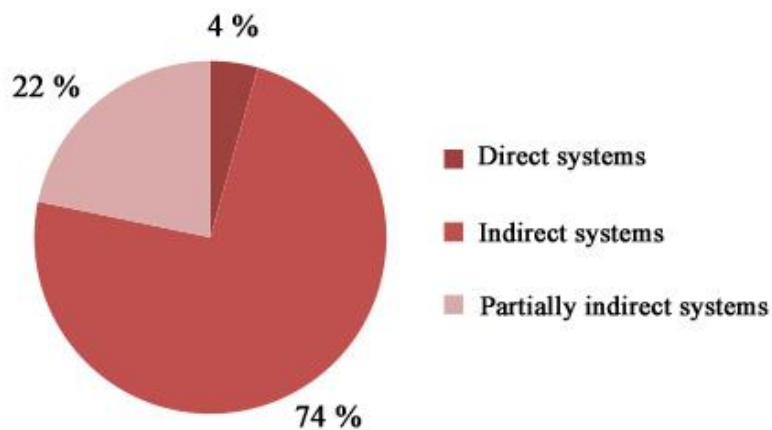


Figure 14. Distribution of different types of systems in Swedish ice rinks 2010 (Rogstam, 2010)

The refrigeration unit cools the brine in the evaporator and the brine is sent to the embedded cooling pipes below the ice pad. The refrigeration system typically consists of a vapour compression cycle driven by electricity as the primary cycle. About 85% of the Swedish ice rinks use ammonia as refrigerant while the remaining rinks use R404A, R134a or other HFC refrigerants (Makhnatch, 2010). *Figure 15* shows the layout of a typical ice rink with indirect system and heat recovery.



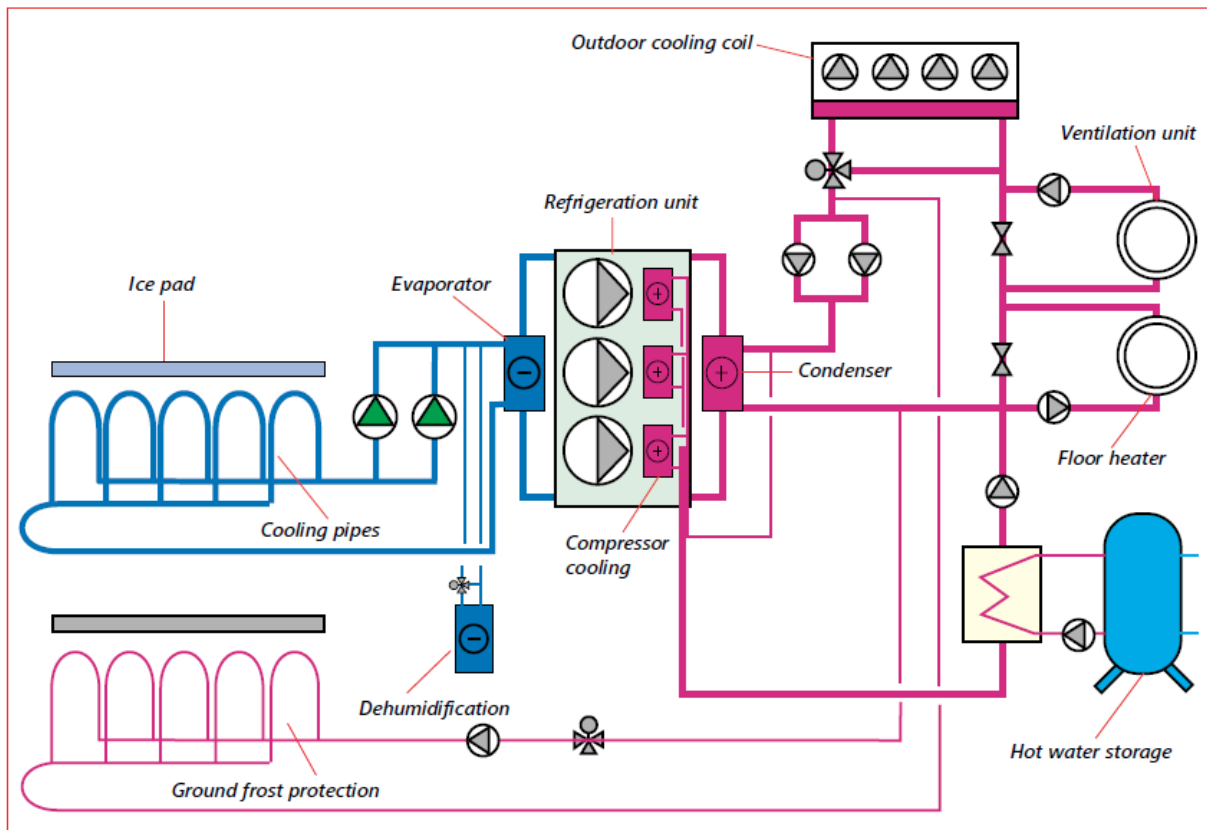


Figure 15. System layout for an indirect refrigeration system integrated with heat recovery (IIHF, 2010)

### 2.3.2 Refrigerants

A working fluid in a vapour compression refrigeration system has to satisfy a number of requirements that can be divided into two groups (Graneryd et al. 2011):

- Safety: Not cause any risk of injuries, panic, fire or property damage in case of leakage
- Fluid properties: Chemical, physical and thermo dynamical properties of the refrigerant have to be suitable for the system and the working condition at lowest cost

Table 2. Criteria for refrigerants (Graneryd et al. 2011)

<b>Chemical</b>	<ul style="list-style-type: none"> <li>• Stable and inert</li> </ul>
<b>Health, safety and environmental</b>	<ul style="list-style-type: none"> <li>• Non-toxic</li> <li>• Non-flammable</li> <li>• Friendly for the atmosphere</li> </ul>
<b>Thermal</b>	<ul style="list-style-type: none"> <li>• Critical point and boiling point temperatures appropriate for the application</li> <li>• Low vapour heat capacity</li> <li>• Low viscosity</li> <li>• High thermal conductivity</li> </ul>
<b>Miscellaneous</b>	<ul style="list-style-type: none"> <li>• Satisfactory oil solubility/miscibility</li> <li>• High dielectric strength of vapour</li> <li>• Low freezing point</li> <li>• Reasonable containment materials</li> <li>• Easy leak detection</li> <li>• Low cost</li> </ul>

The most important criterion is a chemical stability within the refrigeration system, as other criteria are meaningless if the refrigerant decompose or react with other materials in the system. However, it should not

be too stable and prevent from decomposing and not form any harmful substances when it does. The thermodynamic and transport properties will determine the performance of the refrigeration system. The pressures should not be too high as it require an excessively heavy construction and not too low as a pressure below atmosphere can suck air into the system, which can cause inert gases in the condenser or ice plugs in the expansion device. A refrigerant with a high pressure gives higher volumetric cooling capacity but a larger pressure ratio in the system, which results in a lower COP.

Ammonia is often used as refrigerant in ice rink installations. A few facilities also use refrigeration systems with R134a, R404A or hydro fluorocarbons. The shares of different used refrigerants in ice rinks can be seen in *figure 16*. Ammonia is a natural gas and environmentally friendly. It is however flammable, has a specific toxicity and a very strong smell and it is therefore important to keep such a low volume of the fluid in the system as possible. In case of leakage, it must not be a risk that areas where people reside get affected. (Rogstam, 2010)

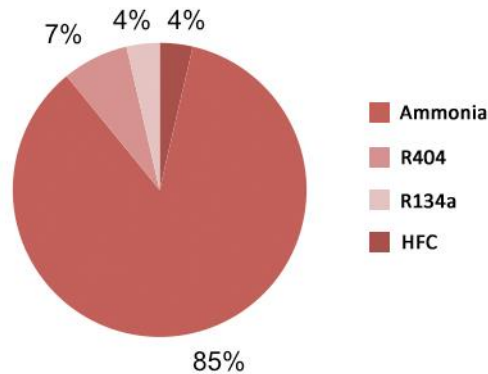


Figure 16. The use of various refrigerants in Swedish rinks (Rogstam, 2010)

### 2.3.3 Secondary refrigerants

An ideal secondary refrigerant should have a freezing point that is at least 3 degrees below the lowest temperature in the brine circuit and at this temperature possess advantageous properties such as good heat transfer and low viscosity (Graneryd, 2011). Since no liquid possesses all these qualities at the same time, the most important priority is the selection of a coolant that will not freeze. The secondary refrigerant is in most cases an anti-freeze, which changes the temperature but do not undergo any phase change when it is pumped through the system. Calcium chloride ( $\text{CaCl}_2$ ) solutions are most common but glycol ( $\text{C}_2\text{H}_4(\text{OH})_2$ ) and ammonia water ( $\text{NH}_4\text{OH}$ ) has also been used recently, where the latter offers about 50% reduction in pump power. Carbon dioxide ( $\text{CO}_2$ ) has recently been used as refrigerant in some ice rinks around the world. The latent heat when the carbon dioxide passes from liquid to gas is utilized, which results in a lower required flow rate. The low flow rate requires a low pump power, about 90% lower than the  $\text{CaCl}_2$ , and there are significant savings in pump energy with the use of  $\text{CO}_2$ .

Table 3. Advantages and drawbacks of secondary refrigerants used for ice rink application (Mazzotti, 2014)

Secondary Fluids		Advantages	Drawbacks
<b>Calcium Chloride</b>	CaCl <sub>2</sub>	<ul style="list-style-type: none"> <li>• Non-toxic</li> <li>• Non-flammable</li> <li>• Rather low viscosity at low temperatures</li> </ul>	<ul style="list-style-type: none"> <li>• Highly corrosive</li> <li>• Corrosion inhibitors used with CaCl<sub>2</sub> may cause health problems</li> <li>• Source of scaling</li> <li>• Low specific heat capacity</li> </ul>
<b>Ammonia</b>	NH <sub>3</sub>	<ul style="list-style-type: none"> <li>• Low viscosity at low temperatures</li> <li>• High specific heat capacity</li> <li>•</li> </ul>	<ul style="list-style-type: none"> <li>• Flammability risk</li> <li>• Highly toxic</li> <li>• Low boiling point</li> </ul>
<b>Ethylene Glycol</b>	C <sub>2</sub> H <sub>4</sub> (OH) <sub>2</sub>	<ul style="list-style-type: none"> <li>• □</li> <li>• Low fire hazard</li> </ul>	<ul style="list-style-type: none"> <li>• Highly toxic</li> <li>• Environmental pollution risk</li> <li>• Rather high viscosity at low temperatures</li> </ul>
<b>Propylene Glycol</b>	C <sub>3</sub> H <sub>6</sub> (OH) <sub>2</sub>	<ul style="list-style-type: none"> <li>• Non-toxic</li> <li>• Quasi non-corrosive</li> <li>• Low fire hazard</li> </ul>	<ul style="list-style-type: none"> <li>• High viscosity at low temperatures</li> <li>• Slightly water polluting</li> </ul>
<b>Ethyl Alcohol</b>	C <sub>2</sub> H <sub>5</sub> OH	<ul style="list-style-type: none"> <li>• Non-toxic unless ingested</li> <li>• High specific heat capacity</li> </ul>	<ul style="list-style-type: none"> <li>• Flammability risk (concentration limit of 30% by weight)</li> <li>• Low boiling point</li> <li>• Toxic if ingested</li> <li>• High viscosity at low temperatures</li> </ul>
<b>Potassium Acetate</b>	CH <sub>3</sub> CO <sub>2</sub> K	<ul style="list-style-type: none"> <li>• Low hazard potential</li> <li>• Environmentally friendly</li> </ul>	<ul style="list-style-type: none"> <li>• Long term effect not yet known</li> <li>• Rather high pH-value</li> </ul>
<b>Potassium Formate</b>	CHO <sub>2</sub> K	<ul style="list-style-type: none"> <li>• Environmentally friendly</li> <li>• Low viscosity at low temperatures</li> </ul>	<ul style="list-style-type: none"> <li>• Long term effect not yet known</li> <li>• High pH-value that can cause eye damage</li> </ul>
<b>Carbon Dioxide</b>	CO <sub>2</sub>	<ul style="list-style-type: none"> <li>• Environmentally friendly</li> <li>• Non-flammable</li> <li>• Low toxicity</li> <li>• Inexpensive</li> <li>• Low pumping power</li> </ul>	<ul style="list-style-type: none"> <li>• Low heat transfer rate and specific heat capacity (compared to aqueous solutions)</li> <li>• High pressure in system</li> </ul>

### 2.3.4 Coolants and dry cooler

The dry cooler is a liquid-to-air heat exchanger where the coolant gives off heat to the ambient. Capacity control in these types of fans is very profitable and appears on almost every dry cooler. If the cooling system is of direct type, the heat dissipating heat exchanger will be the condenser. This means that the refrigerant releases heat directly to the ambient air. A condenser is normally very similar to a dry cooler to the appearance. For trouble-free and energy-efficient operation, it is important that the dry cooler is kept clean and free of leaves, plastic bags and other things that can be sucked up against the fins. It is also common to use a water spray system during hot weather and high load, in case of early beginnings of the season in July or August. (Rogstam, 2010)



Figure 17. Dry cooler in a Swedish ice rink

### 2.3.5 Compressors

The most common compressors in ice rink installations today are mainly of piston or screw type. The cooling system usually has two or more compressors to provide redundancy in the system and get better efficiency at part load. Redundancy provides a high reliability on the system in cases where if one compressor breaks down, the second one is ready to take over. One compressor can provide sufficient capacity for normal conditions and the other engage at peak load cases as when resurfacing the ice or warm weather conditions during the early fall and late spring.

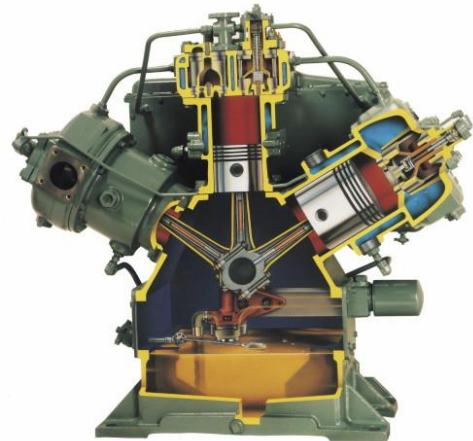
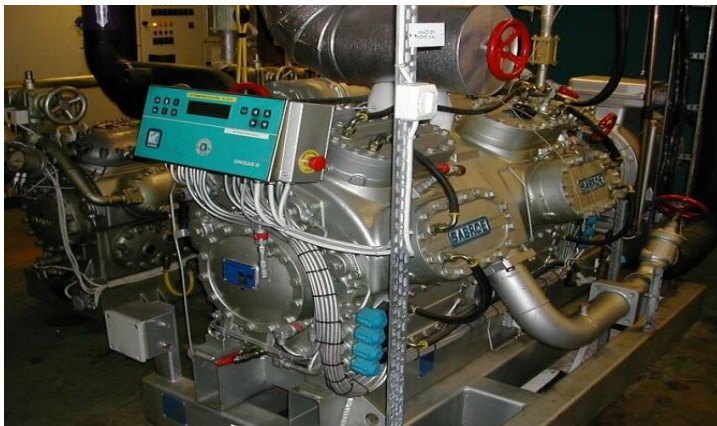


Figure 18. Piston compressor

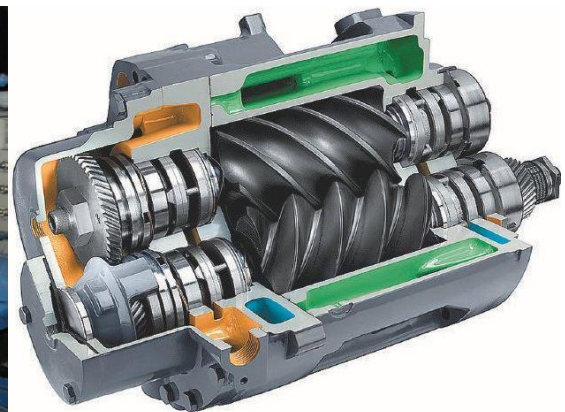


Figure 19. Screw compressor

If the possibility of capacity control is available, it is an advantage for the whole system. The swept volumes of the compressors are adjusted to match the needed cooling capacity or recovered heat load continuously and thereby decrease its energy consumption. Compressor capacity can be managed by speed control from a

frequency converter. By having at least one speed-controlled compressor, cooling capacity can be adapted to the ice rink's demand and also ensure that there is always heat available for heat recovery. (Rogstam, 2010)

### 3. ICE MAINTENANCE

No matter how well maintained the ice is, it will eventually be cut, pitted and dusted, which will spoil the ice. A humid environment will eventually also cause condensation on the ice, which will impair the ice quality. The ability to resurface the ice quick and effectively is as important to skating as the development of indoor ice itself. When ice is resurfaced mechanically, a thin layer of ice is removed (as snow) and replaced by a thin layer of clean water. The snow may then be placed outdoors or in a snow-melting pit. (ORFA, 1991)

#### 3.2 Ice resurfacing

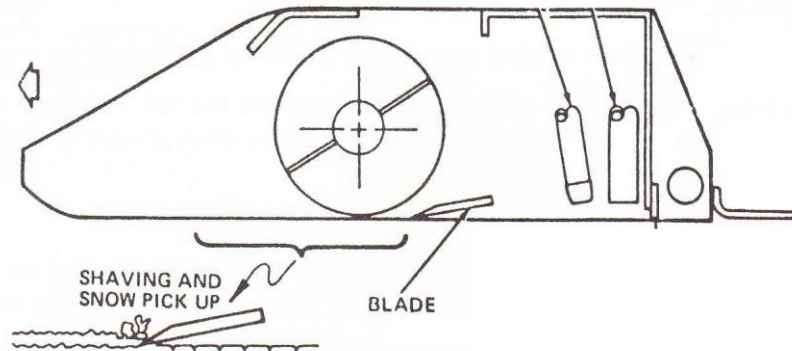


Figure 20. Sketch of resurfacing machine shaving the ice surface (ORFA, 1991)

The ice is usually resurfaced 5-10 times in the daily operation depending on the activity with amounts of 400-700 liters of floodwater each time. (ASHRAE, 2014) A problem today is that operators are working with different temperatures and additives around the world to achieve the desired ice quality of the rink, but strangely enough, most modern resurfacing machines do not have measurement equipment on board to monitor the amount of water used or the temperature of the floodwater. These measurements are very important from an energy perspective as the ice thickness, water temperature and volume affects the refrigeration system and its energy consumption. Balance in ice thickness could easily be achieved with properly installed measuring equipment, as the energy consumption could increase by 12-15% for every  $\frac{1}{2}$  " (~1.25 cm) of ice over the ideal  $1\frac{1}{2}$  " (~3.8 cm). At the same time as the energy consumption reduces, the less ice is to be removed as it results in a smaller amount of water placed back on the ice. The ice depth is checked continuously to maintain an even thickness across the ice. A drill is used to check 25 separate points, seen in *figure 21*, according to industry standards. (ORFA, 2009)

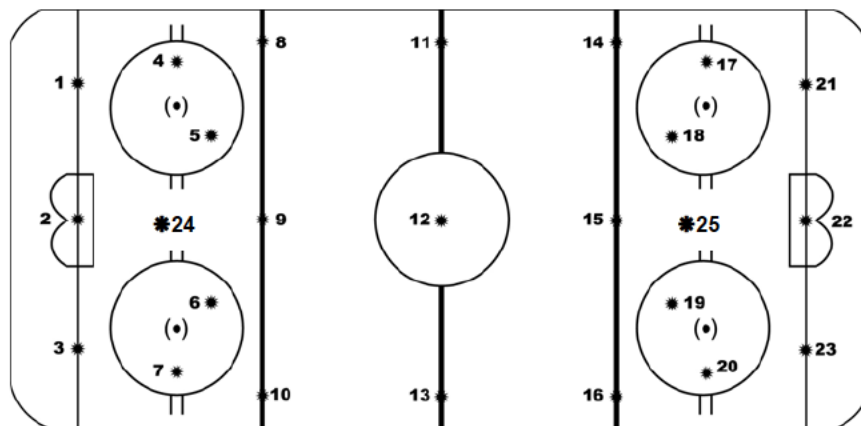
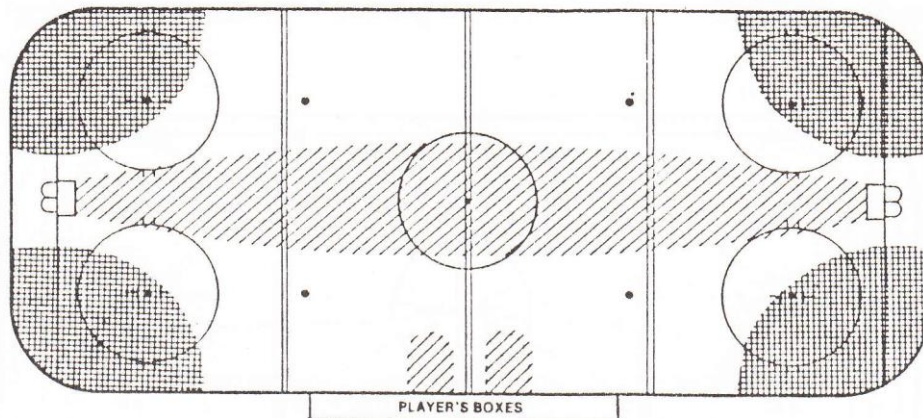


Figure 21. Ice depth checkpoints

Daily maintenance of ice rinks will not eliminate the ice depth roughness completely, but it will reduce the number of times a year major shavings will need to be done. A major shaving can consist of reducing the ice level over the entire rink or just specific areas. A major shaving will reduce the ice thickness, level the ice and

brighten up the lines and markings. The most common areas of thick and thin ice conditions are illustrated in *figure 22*.





-  Area subject to ice build-up (may also extend further into face-off circle).
-  Area subject to thin ice conditions.

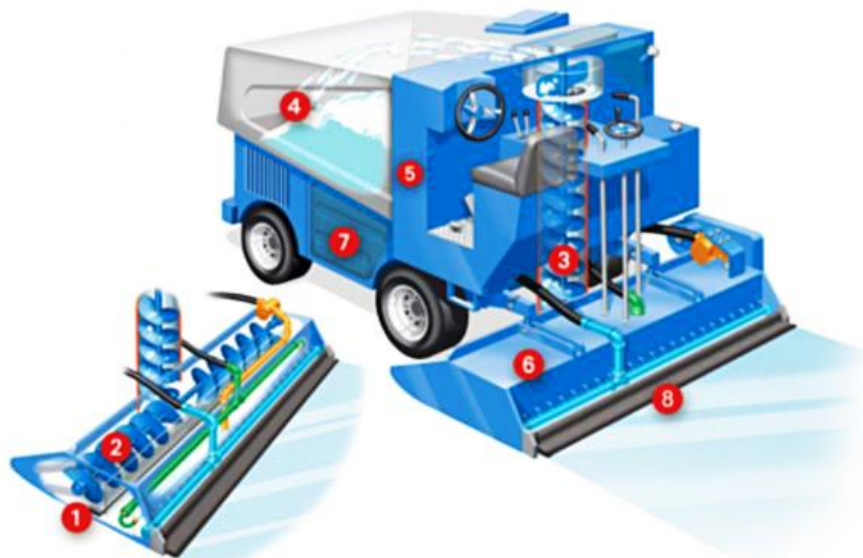
Figure 22. Common areas of thin ice and ice build-up in ice rinks (ORFA, 1991)

### Shaving

A blade **1** shaves a thin layer from the surface of the ice.

### Collecting

After a horizontal screw **2** (auger) gathers the shavings, a vertical screw **3** propels them into the snow tank **4**.



### Washing

Water is fed from a wash-water tank **5** to the "conditioner" **6**, which rinses the ice. Dirty water collected in front of a squeegee is vacuumed, filtered, and returned to the tank.

### Resurfacing

Clean water from the ice making tank **7** is delivered to the ice through a pipe and spread evenly by a towel pulled across the ice behind the conditioner **8**.

Figure 23. A typical resurfacing machine in detail (DailyMail, 2013)

## 3.2 Water and Ice Quality

There are many theories about how water quality and temperature has for impact on the ice quality. Water contaminants such as minerals, organic matter and dissolved air can affect both the freezing temperature and the ice thickness necessary to provide satisfactory ice conditions. (ASHRAE, 2014) In general there are four properties used to evaluate the overall quality of the ice sheet for skating; smoothness, friction, hardness and brittleness. These properties are directly affected by five factors; water quality, water temperature, ice temperature, building air temperature and humidity level. (Theiler, 2011) In some cases, the chemical content of the water may be such that the making of satisfactory ice is not possible without first treating the water supply. There are different methods of purification to treat the water and provide it as chemically “pure”. (ORFA,1991)

### 3.2.1 Water heating

The most common way to treat the floodwater is by heating it. One reason is that it is claimed the hot water loosens the crystal structure of the old ice underneath, so the new ice will form a solid bond with the old ice instead of a separate layer that chips off easily (Russell-Ausley, 2015). Shavings or chips left on the ice might not be melted with cold water and could form imperfections on the ice surface.



Figure 24. Resurfacing machine water tank inlet marked with "Only hot water"

Another reason for using hot water is that it is distributed smoother and allowed to blend in to scratches caused by activities on the ice. The solubility of air in water for different temperatures can be seen in *figure 25*, concluding that the air content is decreasing with an increased temperature. The heating of the water is however a cost if the facility is designed without heat recovery.



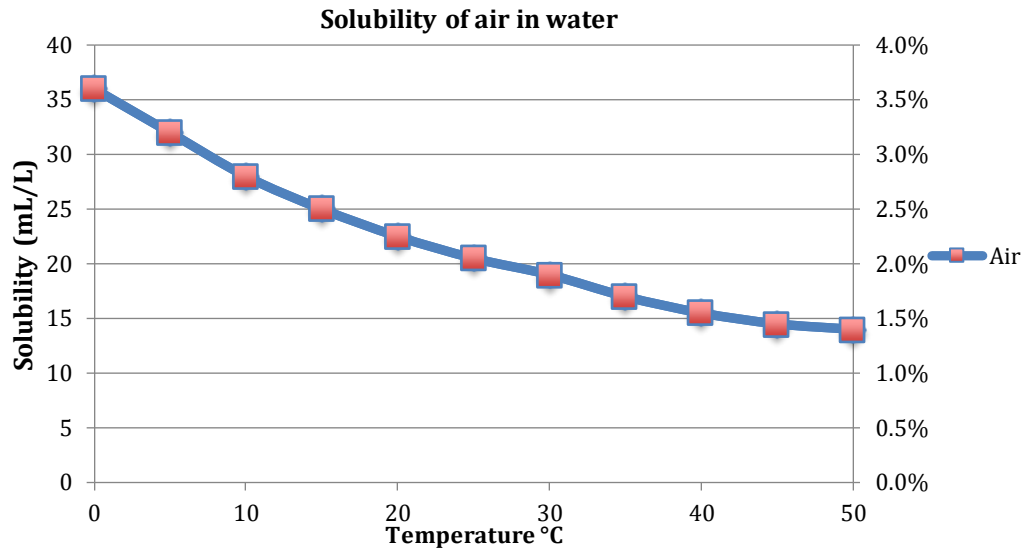


Figure 25. Solubility of air in water for different temperatures

### 3.2.2 Deionization

One way of determining the water quality is by its “degree of purity” from resistance or conductance measurements. The resistance to passage an electrical current through the water increases as ionisable solids decrease. For instance, water at 25 °C can theoretically approach  $5.5 \times 10^{-3} \mu\text{S}/\text{m}$  (ORFA,1991), which would be the purest condition, while drinking water has a resistance between 500 to 50,000  $\mu\text{S}/\text{m}$  (Pashley et.al, 2004).

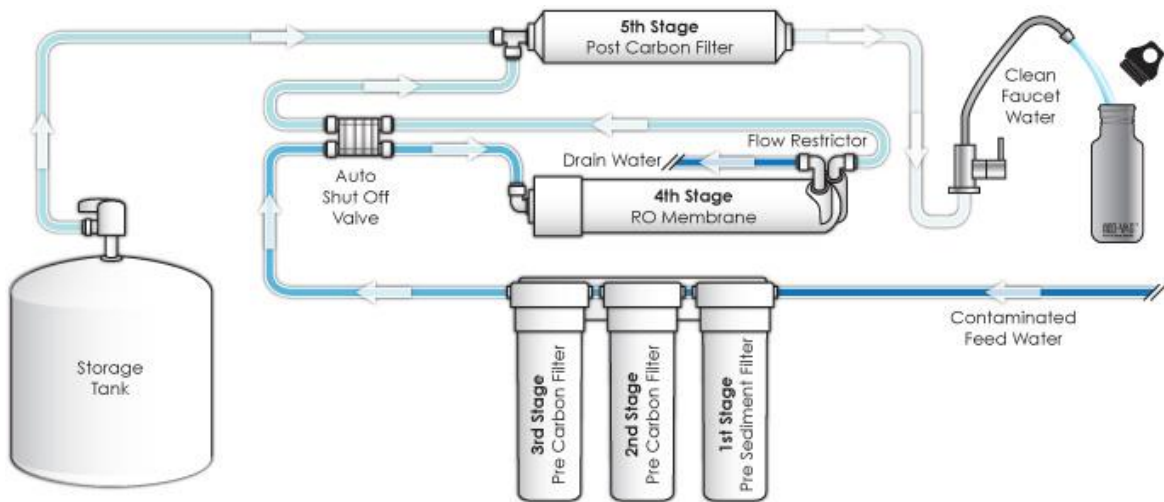


Figure 26. Reversed osmosis flow chart (deionization system)

([http://fc00.deviantart.net/fs71/i/2010/167/9/d/Reverse\\_Osmosis\\_Flow\\_Chart\\_by\\_BrentPoynter.jpg](http://fc00.deviantart.net/fs71/i/2010/167/9/d/Reverse_Osmosis_Flow_Chart_by_BrentPoynter.jpg))

Deionization/demineralization are two terms used to describe the process of removing ionisable dissolved solids from water. It is a chemical process where the ionisable mineral salts are exchanged for hydrogen or hydroxyl ions to form water. This process is accomplished with synthetic cat ion and anion resins, which have special properties. When all of the ionisable mineral salts have been exchanged, the water has been deionized. Deionization is less expensive and produces higher quality water than other methods. In addition, it can produce this high quality water in a pressure system, at normal temperatures and make the water available to many points simultaneously. The following table lists solids dissolved in raw water supplies.

Table 4. List of solids dissolved in raw water supplies (ORFA,1991)

CATIONS	ANIONS
Calcium, Ca (2+)	Bicarbonate, HCO <sub>3</sub> (2-)
Magnesium, Mg (2+)	Carbonate, CO <sub>3</sub> (2-)
Sodium, Na (1+)	Surfate, SO <sub>4</sub> (2-)
Potassium, K (1+)	Chloride, CL (1-)
Iron, Fe (2+)	Nitrate, NO <sub>3</sub> (1-)
Manganese, Mn (2+)	Silica, SiO <sub>2</sub> (1-)
Aluminum, Al (3+)	Silicate, SiO <sub>3</sub> (2-)

As raw water freezes, the water portion freezes first, pushing the dissolved solids into the remaining liquid portion, concentrating these salts until it becomes salt water. This final portion eventually freezes but at these concentrated locations the ice is opaque and soft. (ORFA, 1991) Deionized water results allegedly in a low salt content, low lime content, low gas content, a neutral pH value and free from particles. Deionized water is also heat resistant and therefore claimed to be less disposed to attract moisture. (RiteIce, 2011) This type of purification system, however, requires a certain consumption of energy such as pumping power. The electrical power demand increases in most cases with the capacity of purified water per hour. All of the following systems in *table 5* has a degree of purification >95%. The purity can be measured with an EC meter (Electrical conductivity meter).

Table 5. List of different types of deionization systems and energy consumption (Kinetico, 2015) (Seleko, 2015)

Purification system	Capacity at 15°C (l/h)	Peak load (kW)	kWh/m <sup>3</sup> purified water
S-70	70	0.6	8.6
S-140	90	0.6	6.7
TC 401 Mini	100	0.6	6.0
TC 401	180	0.6	3.3
TC 401 C	180	0.6	3.3
N1	230	1.1	4.8
N2	460	1.5	3.3
N3	690	1.5	2.2
N4	920	2.2	2.4

### 3.2.3 Vortex treatment

Another theory of how to maintain good water quality is by using a vortex generator. The water is put into a powerful three-dimensional vortex motion that changes the waters nature and structure with claimed energy savings and improved ice quality. According to the manufacturer, you can lower the temperature of the floodwater to under 20 °C with treated water. By using vortex water, you can raise the temperature of the ice by 1-2 °C and reduce the hot water consumption at the same time. The water freezes faster since water molecules are affected and prepared to freeze. Vortex-treated water results in a lower viscosity of the water so that it flows out easily despite a lower temperature. These improvements should result in a better, faster, smoother and more durable ice. However, there are no scientific evaluations that can confirm that this is the case.

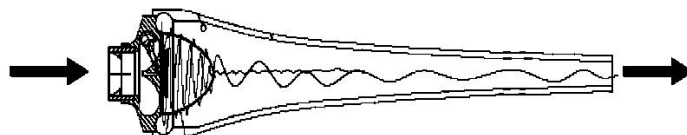


Figure 27. Sketch figure over vortex treatment generation

## 4. EXPERIMENTS

The experiments chapter contains the different types of experiments used in this study and how results are obtained with the methods and described equipment.

### 4.1 Temperature and Water Volume Measurements

The purpose of the temperature and water volume measurements is to experimentally determine the amounts and temperatures of the water being used for the resurfacing process. These types of measurements have not been made scientifically before. The hypothesis is that the results will further refine the ice-resurfacing share of the heat loads on the refrigeration system in ice rinks and that different water temperatures will result in different ice quality. The measurements are made in five different ice rinks in the southern part of Stockholm, Sweden.

#### 4.1.1 Measuring methods

The method to achieve the requested measurements is to install a solution suitable for each ice rink, which water systems in most cases look different. In the performed measurements, there are two common types of water systems being used for the added water, seen in figure 28.

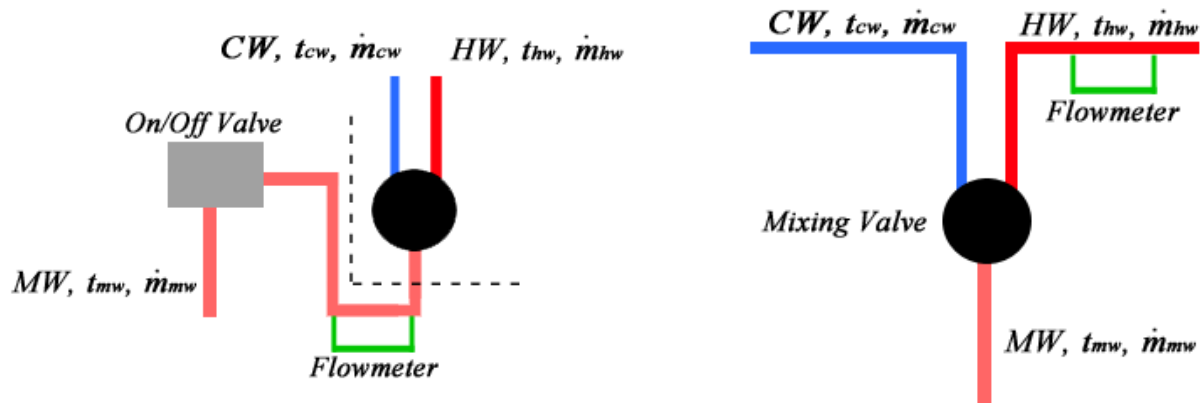


Figure 28. Water mixed before valve, System 1 (right) and water mixed in valve, System 2 (left)

These different water systems require different setups for the installation of the measuring equipment, as the availability of measuring points is limited. The mixed water flow from the filler hose into the resurfacing machine,  $\dot{m}_{mw}$ , can be measured directly without further calculations in system 1. System 2 requires a different setup, as the mixing valve usually is connected directly to a water hose, where the flow meter cannot be placed. The flow meter is therefore placed on the hot water pipe,  $HW$ , and thereby requires further calculations to maintain the mixed water flow.  $\dot{m}_{mw}$  is being calculated with help of three different temperature-measuring points,  $t_{hw}$  (hot water temperature),  $t_{cw}$  (cold water temperature) and  $t_{mw}$  (mixed water temperature) together with  $\dot{m}_{hw}$ . These measurements are sufficient to establish an energy balance over the system and thereby maintain the mixed water flow. The method used can be seen in following equations:

$$\dot{m}_{mw} = \dot{m}_{hw} + \dot{m}_{cw} \quad (4.1)$$

$$\dot{m}_{cw} = \frac{\dot{m}_{hw} * (t_{hw} - t_{mw})}{(t_{mw} - t_{cw})} \quad (4.2)$$

$$\dot{m}_{mw} * t_{mw} = \dot{m}_{hw} * t_{hw} + \dot{m}_{cw} * t_{cw} \quad (4.3)$$

## 4.1.2 Equipment

Following equipment has been used for a complete installation:

- Ultrasonic Flow Meter (Flexim FLUXUS ADM 5107) (1)
  - Measuring water flow through pipes
- Pipe thickness measurer (2)
  - Measuring water pipe thickness for input in flow meter
- Data logger for temperature and flow measurements (HOBO) (3)
  - Temperature changes indicates that machine is being filled
- Computer (4)
  - Used for importing collected data and evaluation
- Conductive paste (5) (5)
  - Increase the connection between thermocouples and material
- Calliper (6) (6)
  - Measuring outer diameter of water pipes for input in flow meter
- Aluminium tape (7) (7)
  - For keeping the thermocouple stuck to the measuring point
- Insulation tape (8) (8)
  - For insulating thermocouples and misc.



### 4.1.3 Methods description

These steps follow the experiment:

1. Each ice rink is being visited before any setup is made. This is done to avoid any types of complications regarding measuring points but to also determine what type of water system the ice rink uses for filling the resurfacing machine.



Figure 29. Water system with water mixed before valve in one of the examined ice rinks

2. The HOBO data loggers are set with the same logging interval (15 seconds used in this experiment).

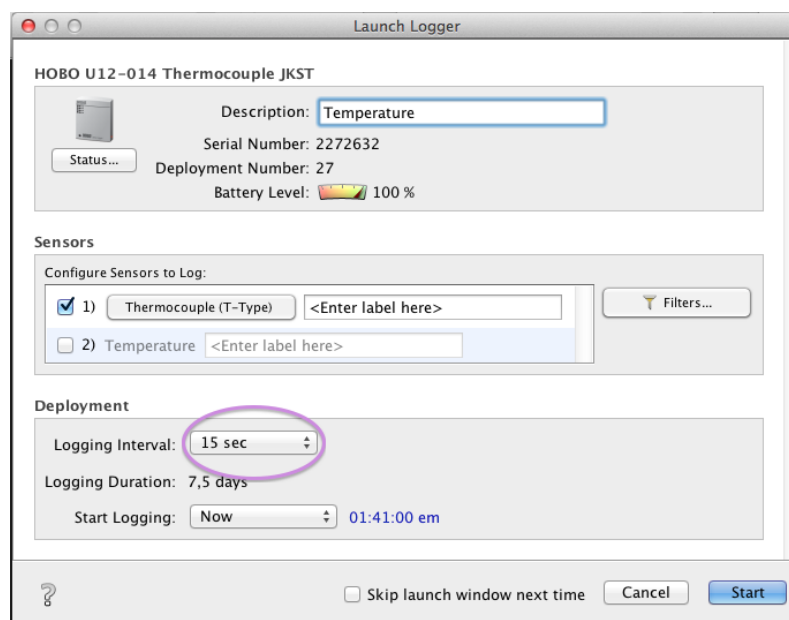


Figure 30. Logging interval set in HOBOWare software

3. The temperature points are being setup by connecting the thermocouples with conductive paste attached with aluminium tape on each water pipe. For system 1, only one temperature point is needed ( $t_{mw}$ ). System 2 requires three different temperature points ( $t_{mw}$ ,  $t_{hw}$ ,  $t_{cw}$ ). The mixed water thermocouple shall be attached to the resurfacing machine, as it will confirm that the water through the flow meter goes to the machine as the temperature rises simultaneously with the flow.

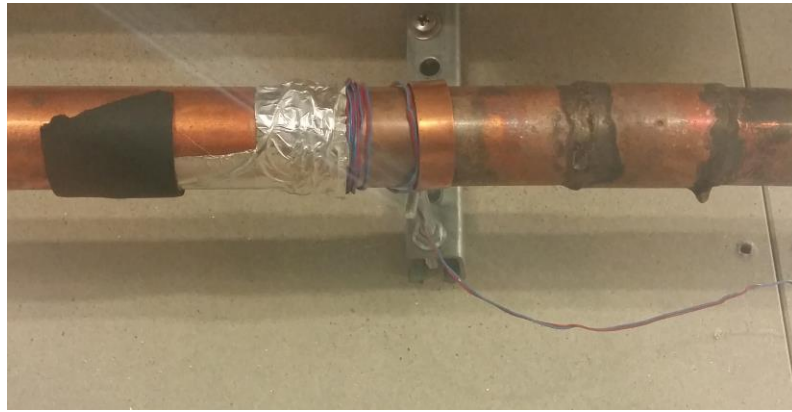


Figure 31. Thermocouple attached to water pipe

4. Set up the flow meter at a suitable location. It is preferred to use a location where the pipe is straight without any turns that could affect the signal strength. The flow meter requires input data regarding the piping material, thickness and fluid properties. The pipe thickness measurer can calculate the pipe thickness for some materials, but copper pipes thicknesses is usually found in tables for standard dimensions. Outer diameter can be measured with calliper. Contact paste shall be applied on the sensors and then strapped on the pipe at a distance suggested by the flow meter. A signal meter will show to regulate distance of the sensors for an accurate setup.

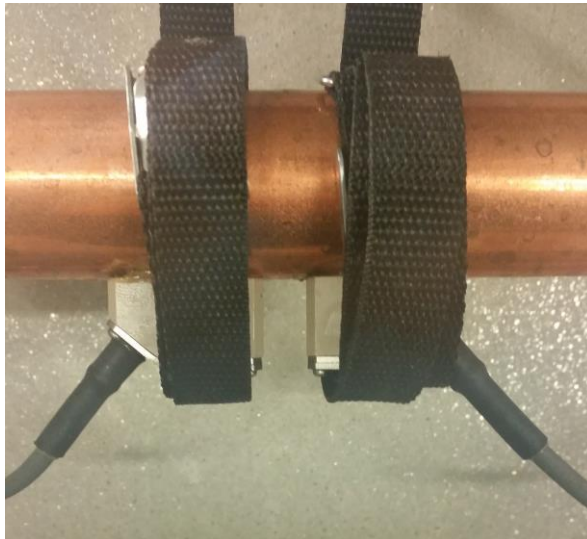


Figure 32. Flow meter sensors attached to water pipe

5. Start the loggers and confirm that they are logging. HOBO loggers have a red light, which blinks each time it logs. If not, it can be checked with a computer.
6. Collect the data after a couple of days (2-3 days) to check that the setup is working correctly. If not, correct the errors.
7. Collect data and remove the equipment. Insulate areas where insulation has been removed with insulation tape or removed insulation.
8. Evaluate collected data in HOBOWare software and Microsoft Excel.

#### 4.1.4 Results

Each measured ice rink corresponds to data between 35 and 50 fillings collected during one to two weeks for each rink. The results are presented as the average, maximum and minimum values. *Table 6* also contains results of resurfacing occasions and total water consumption for each ice rink during one season based on resurfacing occasions and average water volumes. One season normally extends over 35 weeks.

Table 6. Results from temperature and volume measurements

Ice rink	1	2	3	4	5	Average
Water flow (m <sup>3</sup> /h)	5.3	4.1	5.5	3.6	3.4	4.4
Max water flow (m <sup>3</sup> /h)	5.7	5.4	6.4	4.1	4.0	5.1
Min water flow (m <sup>3</sup> /h)	5.1	3.2	4.3	2.6	2.8	3.6
Average filling time (min)	5.1	6.5	5.3	6.3	6.6	6.0
Max filling time (min)	8.0	11.7	9.5	14.5	12.0	11.1
Min filling time (min)	3.5	3.5	3.3	3.5	2.7	3.3
Average water temperature (C°)	67.4	31.5	38.1	44.4	44.5	45.2
Max water temperature (C°)	71.2	37.5	45.1	52.7	51.6	51.6
Min water temperature (C°)	61.8	27.5	29.2	25.8	22.4	33.3
Average water volume (l)	452.1	438.3	492.1	371.8	389.0	428.7
Max water volume (l)	714.8	648.7	868.9	855.7	697.6	757.2
Min water volume (l)	310.9	212.4	289.1	208.8	146.2	233.5
Resurfacing occasions per week	37	39	43	50	34	41
Resurfacing occasions per season	1307	1348	1501	1737	1201	1419
Water consumption per season (l)	590 791	590 558	738 388	645 987	466 975	606 540

Previous studies have used the resurfacing process calculations as a part of the heat loads on ice rinks, with assumed volumes between 400-700 litres of floodwater. The results from this study have shown that most volumes are between 300-500 litres, which is a slightly smaller volume than expected resulting in smaller impacts on the heat load from resurfacing. The results have also shown that rink operators commonly resurface the ice with a larger volume than usual before closing at night. One reason is to smooth the ice as good as possible at the end of the day as a larger volume has all night to freeze. The water does not have the same time to freeze during activities each and another hour in daytime. The main reason however, is that the machines are designed in such way that a manual control system of the blades usually planes away more than what you put back. This extra removed ice is compensated at the end of the day by a larger volume of water. One available solution is to integrate the resurfacing machines with laser control systems to maintain the ice level control. This way you can avoid different thicknesses at local places across the ice.

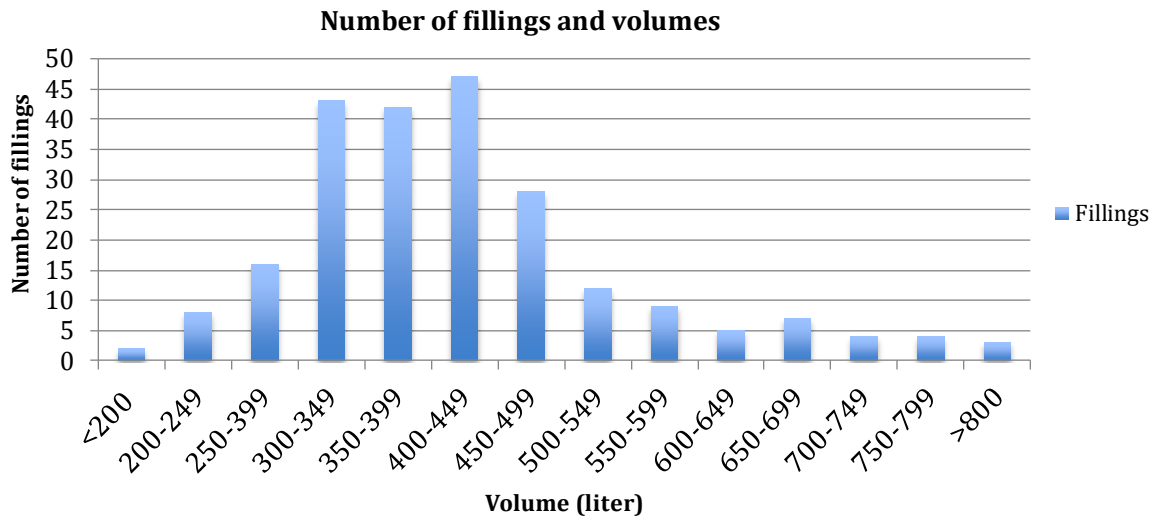


Figure 33. Total numbers of fillings and volumes for all ice rinks

As seen in *figure 33*, the bulk of fillings are between 300-500 litres with an average filling time of 6 minutes (*table 6*).

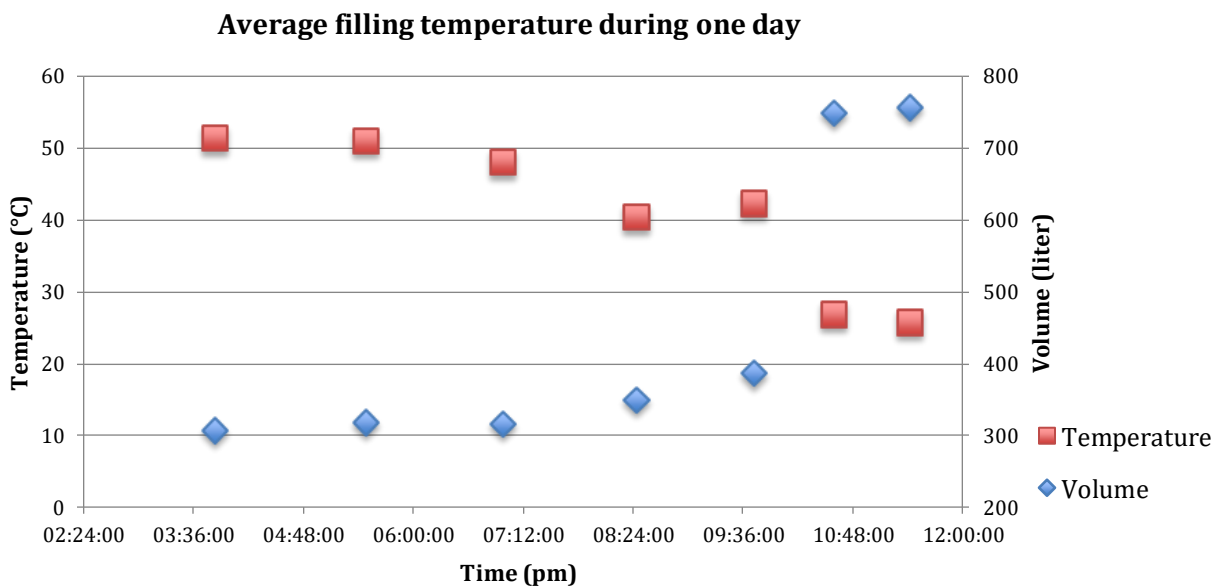


Figure 34. Average filling temperature and volume in ice rink 4 during one day

The results also show a variation of water temperature for the studied ice rinks as the temperature drops with larger volumes and increased activities in the ice rink (showers, etc.). In other words, the heating system has not enough time to heat the water at the same rate as the demand. This problem may be solved due to better heat recovery systems or larger accumulator tanks fitted with electrical heaters used at peak load. This observation can be seen in *figure 34*.



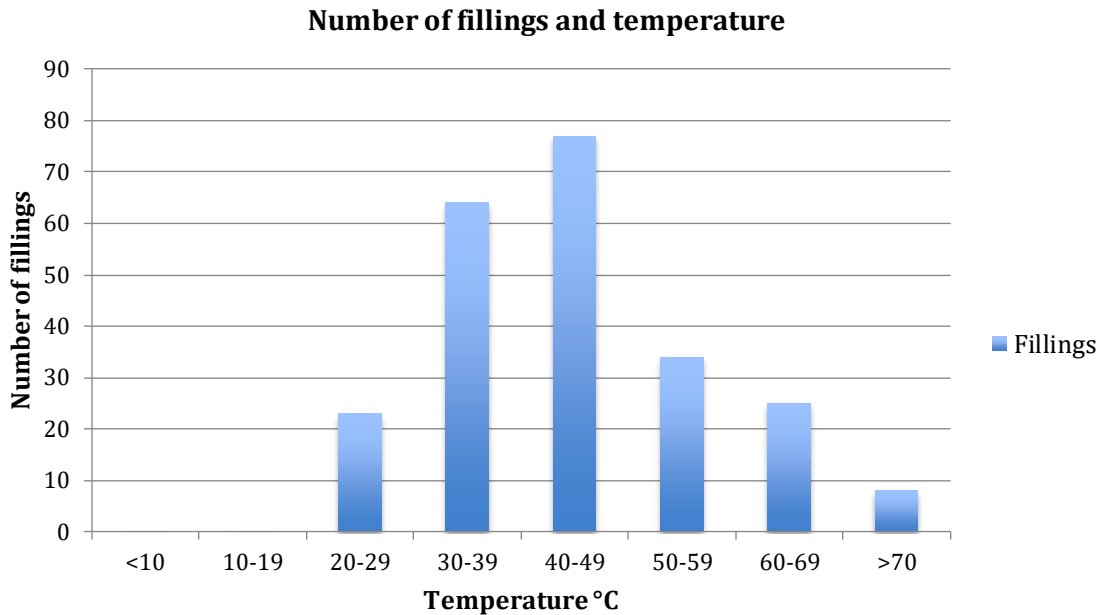


Figure 35. Total number of fillings and temperature for all ice rinks

The average water temperature is around 50°C for these five ice rinks, but worth noting is the range between 71.2 – 22.4 °C between the maximum and minimum temperature. Assumptions of water volumes and temperatures made to calculate heat loads may therefore not be generalized and measurements should be made in each individual ice rink to calculate the specific heat load that occur during resurfacing processes.

## 4.2 Energy Consumption of Resurfacing Machine

All energy-consuming areas are opportunities for efficiency improvements from an engineering perspective. Battery driven resurfacing machines charged with electricity is the most common ones in ice rinks in Sweden. This electricity is included as a part of the energy consumption share of the resurfacing process. The purpose of these measurements is to get a hint of the size of impact the charging of the machine has on the total energy consumption and how it is varying between new and older models.

### 4.2.1 Equipment

The equipment used for this experiment is an electricity meter. The connectors are assembled to fit the electricity output at 32 A. *Figure 36* illustrates the display of the electricity meter, which indicates the amount of used electricity in kWh.



Figure 36. Electricity meter with 32 A connectors

#### 4.2.2 Measuring methods

The method to achieve the requested measurements is to install a solution suitable for each ice rink, which in most cases, as in the examined ice rinks, looks the same. The measurements have been made on five different resurfacing machines with the aim to determine the kWh consumption per resurfacing occasion. All ice rinks have the same type of power connector corresponding to 32 A, and therefore only one type of electricity meter was needed. The layout of the measuring method is illustrated in *figure 37*.

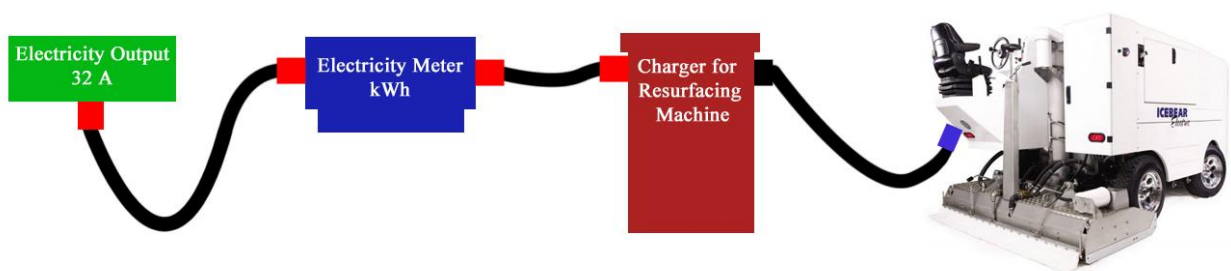


Figure 37. Method for measuring electricity consumption of resurfacing machine

The electricity meter is placed as long as the water temperature and volume measurements are taking place. The total amount of used electricity is then displayed on the electricity meter and divided with the amounts of fillings to determine the consumption per resurfacing occasion in kWh.

#### 4.2.3 Results

The results show that different machines usually consume different amounts of electricity. The energy consumption based on charged electricity divided by amounts of resurfacing processes equal the energy

consumption for one resurfacing occasion. The five different ice rinks use three different types of resurfacing machines of different model year:

Table 7. Resurfacing machines energy consumptions for the five different ice rinks

Ice rink number	Resurfacing machine	Model year	Energy consumption one resurfacing (kWh)	Resurfacing occasions one week	Energy consumption one week (kWh)	Energy consumption one season (kWh)
1	Olympia Icebear Electric	2008	2.6	37	96	3 360
2	Eisbär Electric	2004	3.3	39	129	4 515
3	Olympia Icebear Electric	2011	2.4	43	103	3 605
4	Olympia Icebear Electric	2008	2.4	50	120	4 200
5	Zamboni 552	1998	5.5	34	187	6 545

The energy consumption for one week is based on the energy consumption for one-occasion times the average occasions during one week for each specific ice rink. How frequently electricity is charged can depend on how old the machine and/or the batteries are. For instance, older batteries could require extra charging occasions, according to one of the studied ice rink's icemaker. The results show that the oldest machine consumes the largest amount of electricity compared to the newest one that consumes least. It may be regarded as small amounts of energy but it should be taken into account that resurfacing processes occur several times a day during a whole season.

### 4.3 Heat loads and Energy Consumption from Resurfacing

Every resurfacing occasion results in heat loads on the refrigeration system and consumed energy by the resurfacing machine. The heat loads are based on the amount and temperature of the floodwater and the desired ice temperature in form of latent and sensible loads, but also due to humidity changes from openings to the ambient related to resurfacing occasions. This study examines the heat loads and energy consumption from resurfacing based on the temperature and water volume measurements for the five ice rinks and a method to calculate heat loads from humidity changes.

Another concern is how the humidity level affects the loads on the ice surface when the gates are opened. A theory of how to prevent this is to have a sluice between the outside and the ice rink. ClimaCheck provides information about humidity level changes during resurfacing processes. The resurfaced ice results in a filled snow tank, which has to be emptied either in a snow pit or on the ground outside of the rink. This creates a small time period where the ice rink is directly connected with the outside climate if no gates are closed in between. The used data is from two different periods; late summer in September and late falls in October for the ice rink listed as number 2. The bumps in ice surface temperature represent the ice resurfacing occasions and each occasion results in a minor bump in absolute humidity over the ice. The difference in absolute humidity over ice before and after resurfacing of the ice is considered as heat loads on the refrigeration system. The absolute humidity in the ice rink is not particularly dependent on the resurfacing process, as it does not show any related pattern during the occasions.

#### 4.3.1 ClimaCheck method

$COP_1$  is the coefficient of performance of cooling for the refrigeration system and is based on ClimaCheck data. For a simple basic refrigeration cycle, seven temperature sensors, two pressure sensors and one electrical power meter are used to determine the performance of the system from a thermodynamic point of view. The data, which are measured, are refrigerant temperatures and pressures before and after the compressor(s),

air/water temperatures in and out from evaporator/condenser and refrigerant temperature before the expansion valve. Furthermore, compressor electrical voltage and amperage are measured to know the electrical power input to the refrigeration system. To analyze the performance of the ice rink's refrigeration system an "internal method" is used. This method is referred to as the "ClimaCheck method". In the internal method the compressor is used as a mass flow meter without any need of setting up an external mass flow meter. An energy balance calculates the refrigerant mass flow rate over the compressor. (Karampour, 2011) By measuring the pressure and temperature before and after the compressor and the electricity input to the compressor it is possible to calculate the mass flow rate according to *figure 38*:

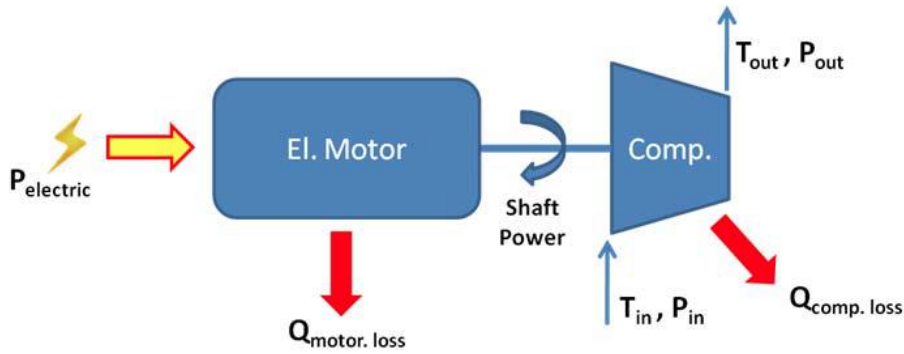


Figure 38. Energy balance over compressor

ClimaCheck data is then used to maintain the electrical input of the compressor. The compressor electricity is calculated with following equation:

$$E_{compressor} = \frac{\dot{Q}_{resurfacing}}{COP_1} \quad (4.6)$$

Equation 4.5 and 4.6 is used separately for each ice rink and then presented as average values.

### 4.3.2 Calculating methods

The heat load from one resurfacing process can be calculated with following equation:

$$\dot{Q}_{resurfacing} = 1\,000 * V_{water} (Cp_{water} * t_{water} + \Delta H_{water \rightarrow ice} - Cp_{ice} * t_{ice}) \quad (4.4)$$

Where:

$\dot{Q}_{resurfacing}$  is the total heat load from one resurfacing occasion

$V_{water}$  is the water volume (m<sup>3</sup>)

$Cp_{water}$  is the specific heat capacity of water (4,2 kJ/kgK)

$t_{water}$  is the water temperature used for resurfacing

$\Delta H_{water \rightarrow ice}$  is the heat fusion water to ice (334 kJ/Kg)

$Cp_{ice}$  is the specific heat capacity of ice (2,04 kJ/kgK)

$t_{ice}$  is the desired ice temperature (-4°C)

The energy shares for resurfacing processes has been divided into two different scenarios; one with 100% heat recovery used for heating the floodwater and one without any heat recovery. The energy is based on electrical heating for the last mentioned scenario, where 1 kWh of electricity corresponds to 1 kWh heating. Following equations were used to calculate the energy for heating the floodwater:

$$E_{heating} = V_{water} * \rho_{water} * Cp_{water} * (t_{water} - t_0) \quad (4.5)$$

Where:

$\rho_{water}$  is the density of water set to 1000 (kg/m<sup>3</sup>)

$t_0$  is the initial water temperature for cold water (10°C)

Figure 39 and figure 40 illustrates the absolute humidity in an ice rink during two different days. These data are used to transform changes in humidity level to heat loads.

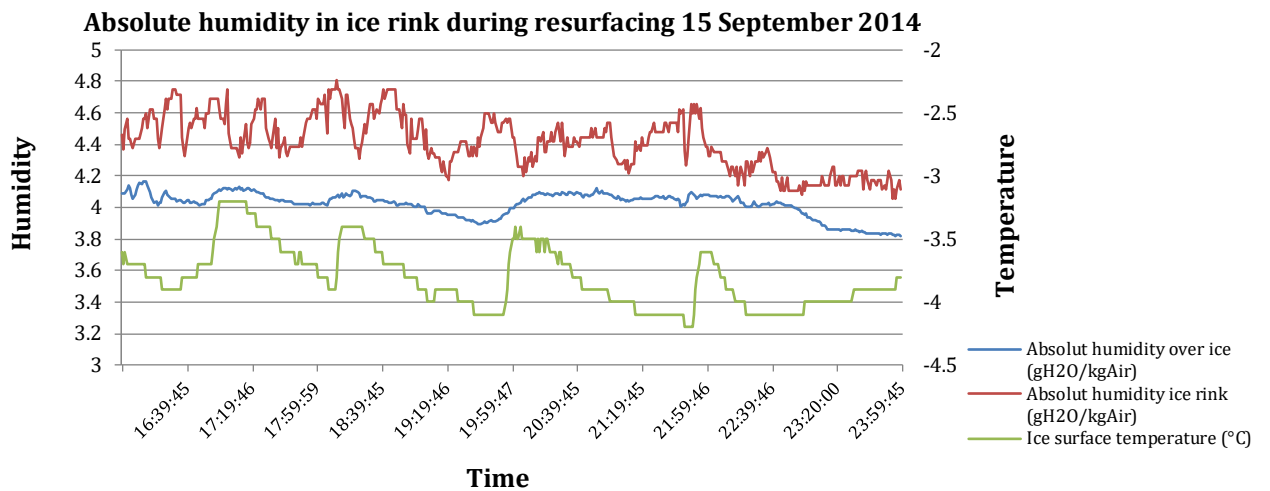


Figure 39. Humidity in ice rink 2 during one day in September 2014

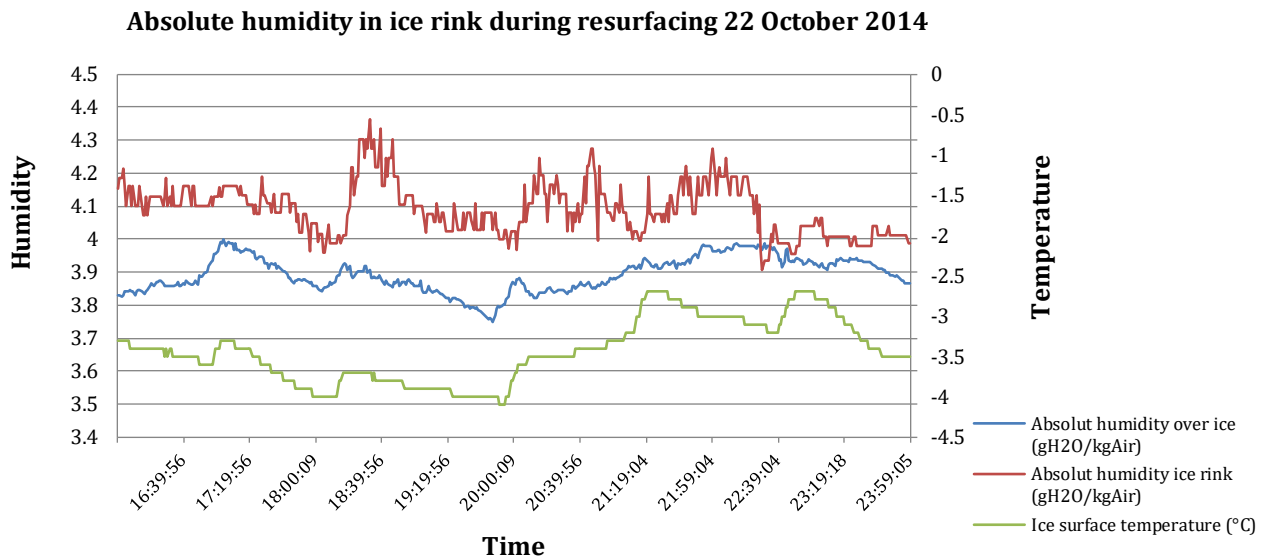


Figure 40. Humidity in ice rink 2 during one day in October 2014

Following equation has been used for calculating the heat load depending on humidity difference during resurfacing occasions:

$$\dot{Q}_{humidity} = \Delta AH_{ice} * V_{ice\ rink} * \Delta t_{ice} * Cp_{water} \quad (4.7)$$

Where:

$\Delta AH_{ice}$  is the difference in absolute humidity during resurfacing (kgH<sub>2</sub>O)

$V_{ice\ rink}$  is the total volume of the ice rink (60x30x1.3 m)

$\Delta t_{ice}$  is the temperature difference above the ice before and after resurfacing

$Cp_{water}$  is the specific heat capacity of water (4.2 kJ/KgK)

The data is given in relative humidity and must therefore be converted before equation 4.7 can be used. The absolute humidity (AH) is calculated in (gH<sub>2</sub>O/kgAir) as following:

$$AH = \left[ \frac{6.112 * \exp\left(\frac{17.67 * t_{air}}{t_{air} + 243.5}\right) * RH_{air} * M_{water}}{(273.15 + t_{air}) * 100 * 0.08314} \right] * \frac{1}{\rho_{water}} \quad (4.8)$$

The equation is based on the ideal gas *equation 4.9* and the saturated vapour pressure when 100% relative humidity, *equation 4.10*:

$$PV = nRT \quad (4.9)$$

$$P_{sat} = 6.112 * \exp[(17.67 * t_{air}) / (t_{air} + 243.5)] \quad (4.10)$$

Where:

$P_{sat}$  is the saturation pressure for water vapours

$n$  is the amount of water vapor in moles

$M_{water}$  is the molecular weight of water (18.02 g/moles)

$t_{air}$  is the air temperature (°C)

$RH_{air}$  is the relative humidity (%)

$R$  is the gas constant

To compute the pressure for any value of relative humidity expressed in %,  $P_{sat}$  is multiplied by the factor (RH/100).

### 4.3.3 Results

Figure 41 illustrates the heat loads on the refrigeration system based on different temperatures and volumes of the resurfacing water.

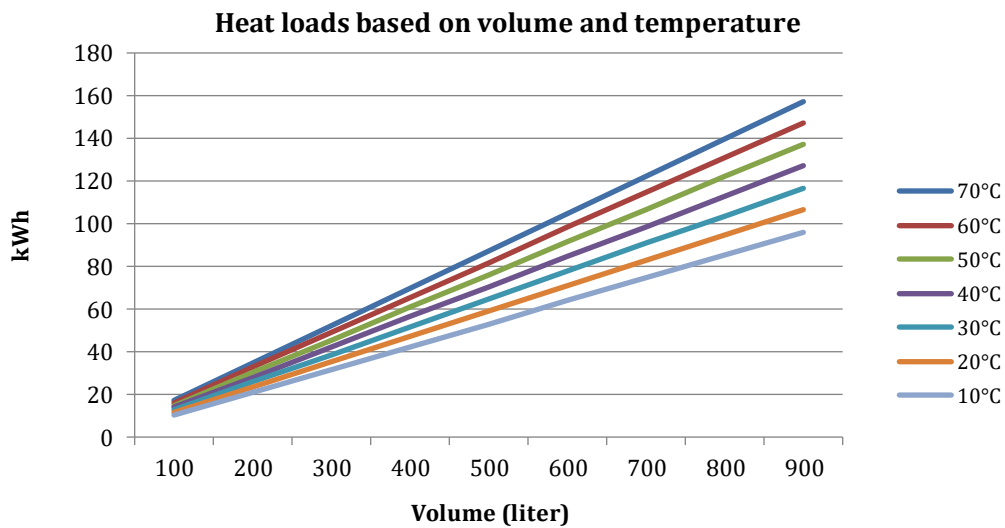


Figure 41. Heat loads depending on volume and temperature

The graph shows that the heat load increases linearly with volume and temperature.

Table 8. Average energy consumption for one resurfacing occasion

Ice rink	1	2	3	4	5	Average
COP <sub>1</sub>	5.1	3.6	3.7	4.3	4.3	4.1
Water heating (kWh)	29.6	11.0	16.0	14.6	15.3	17.3
Heat load (kWh)	77.6	57.6	68.3	54.2	56.7	62.9
Compressor electricity (kWh)	15.2	16.0	18.5	12.6	13.2	15.1
Resurfacing machine electricity (kWh)	2.6	3.3	2.4	2.4	5.5	3.2
Total electricity without heat recovery (kWh)	47.4	30.3	37.4	30.4	33.5	35.8
Total energy with heat recovery (kWh)	17.8	19.3	21.4	15.8	18.2	18.5

The average energy consumption for one resurfacing process is based on the specific Coefficient of Performance (COP<sub>1</sub>) for each ice rink. A higher COP<sub>1</sub> results in lower compressor electricity. The heat load

is however based on each ice rink's volume and temperature of the floodwater. The heat load calculations on the ice due to resurfacing are based on the measured temperatures of the water before it enters the tank. For this reason, some uncertainties in the calculations are possible but performed as good as possible to be practical. The calculations are made with the assumption that the ice temperature is  $-4^{\circ}\text{C}$  for all ice rinks, which is a common ice temperature for ice hockey. Both the specific heat capacity of ice and water varies slightly with the temperature, but the calculations overlook the small change and are instead assumed to be constant values (4.2 kJ/kg for water and 2.04 kJ/kg for ice).

Table 9. Average energy consumption for resurfacing during one season

Ice rink	1	2	3	4	5	Average
Water heating (kWh)	38 687	14 828	24 016	25 360	18 375	24 253
Heat load (kWh)	101 423	77 645	102 518	94 145	68 096	88 765
Compressor electricity (kWh)	19 866	21 568	27 769	21 886	15 853	21 388
Resurfacing machine electricity (kWh)	3 398	4 447	3 602	4 169	6 606	4 444
Total energy without heat recovery (kWh)	61 952	40 844	56 137	52 805	40 234	50 394
Total energy with heat recovery (kWh)	23 265	26 016	32 121	27 444	21 858	26 141

Table 9 shows the average energy consumption during one season to understand how large amounts of energy it involves.

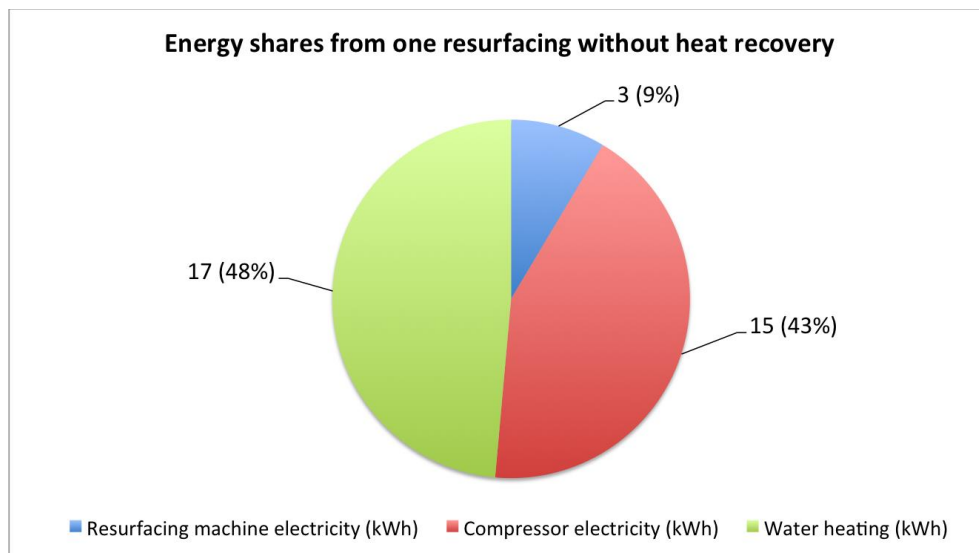


Figure 42. Energy shares from one resurfacing without heat recovery

Figure 42 shows the average energy shares from one resurfacing occasion without heat recovery. The figure, based on the results from previous table 8, shows that the greater part of the energy consumption during one resurfacing occasion in an ice rink without heat recovery is consumed by water heating.

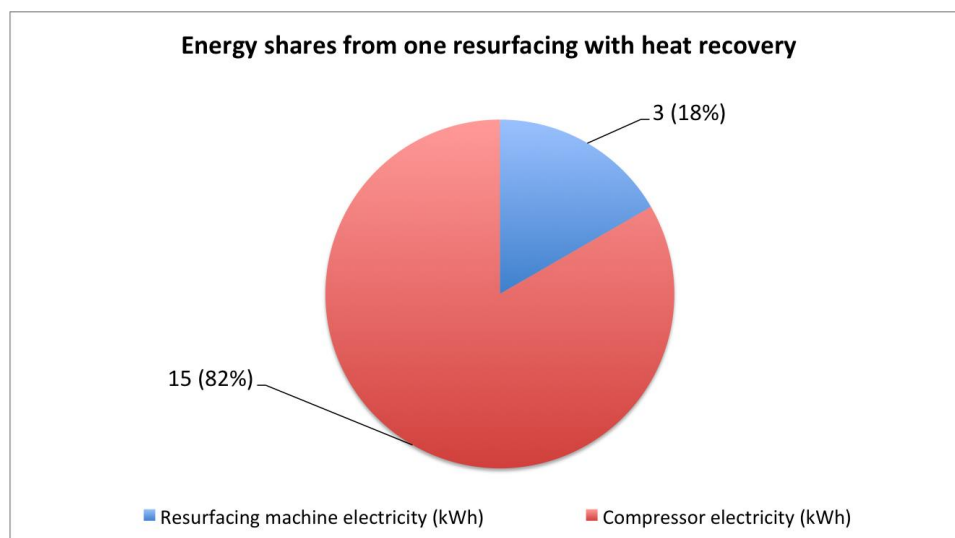


Figure 43. Energy shares from one resurfacing with heat recovery

Figure 43 shows the average energy shares from one resurfacing occasion with heat recovery. In this scenario, with heat recovery, the greater part of the energy consumption during one resurfacing occasion is consumed by compressor electricity. The results also show a large amount of energy saved by heat recovery. Increasing the share of electricity for compressors requires that the resurfacing machine consume as little energy as possible.



Table 10. Resurfacing share of total heat loads from measurements

Ice rink	1	2	3	4 & 5	Average
Total cooling energy (kWh)	25 200	14 923	28 084	48 150	29 089
Resurfacing heat load (kWh)	2 167	1 734	3 076	5 698	3 169
Resurfacing heat load share	9 %	12 %	11 %	12 %	11 %

The percentage of heat loads occurred by resurfacing the ice to the total heat load is calculated by dividing the resurfacing heat load based on the total amount water with specific temperatures from the measurements divided by the total cooling capacity during the same period. The results can be seen in *table 10*. A previous study based on simulation with assumed volume of 600 litres at 35°C, seen in *figure 8*, resulted in a heat load share of 17% from resurfacing while this study results in a slightly lower percentage of 9-12% of the total heat load. The difference in results may be due to how many resurfacings occurring during the period, in both cases confirmed with ClimaCheck, and also the assumed volume and temperature in the earlier study.

Table 11. Heat loads caused by humidity difference caused by open gates to the outdoor air during one resurfacing occasion

Date	$\Delta AH_{ice}$ (kgH <sub>2</sub> O)	$\Delta t_{ice}$ (°C)	$Q_{humidity}$ (kWh)
15 September	0.30	0.20	0.06
22 October	0.45	0.41	0.20

Unfortunately, only one ice rink has the correctly installed device to receive humidity data. The relative humidity is also dependent on the temperature. The ice rink has a relatively low indoor temperature already, which leads to a small temperature difference between the ice surface and ice rink resulting in an insignificant amount of heat load. This ice rink, listed as number 2, has a garage/machine room functioning as a sluice between the outside and ice rink. Data from an ice rink directly connected to the outside may show different results in form of a larger heat load but the same method can be used.

#### 4.4 Ice thickness measurements

One theory of determining the ice quality was by measuring the ice thickness with an ultrasonic thickness meter assuming a cleaner (higher ice quality) ice would give a more accurate result. The idea was to examine if any regular deviations would occur when comparing the measured thickness from the ultrasonic thickness meter with the actual thickness by drilling. The experiment was to investigate whether the deviations could possibly result in a scale for the ice's purity and if a more practical solution for measuring ice thickness without drilling was possible. *Figure 44* illustrates the theory of how the thickness meter could operate to possibly determine the air content/pureness of the ice.

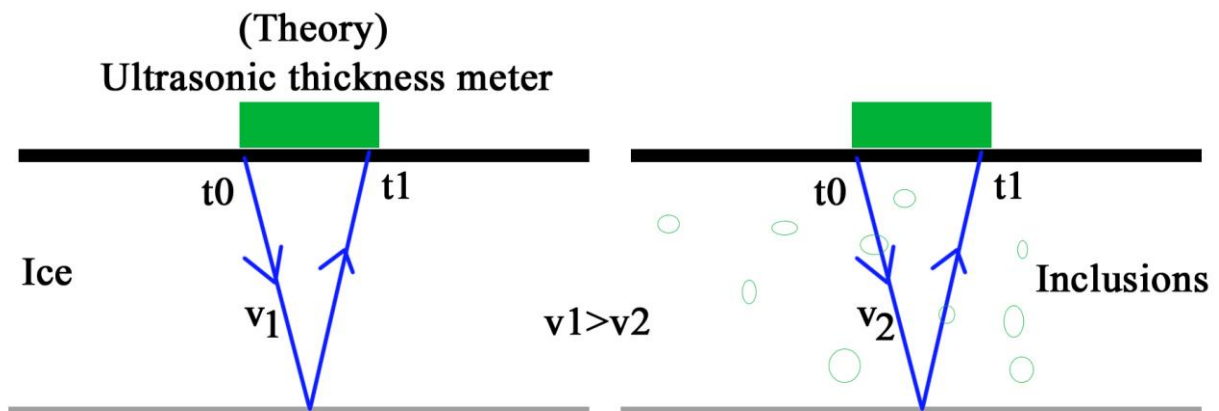


Figure 44. Theory of how ultrasonic signals could be used to determine air content in ice

The theory is based on that the speed of the signal was assumed to reduce as the content of air bubbles increase. A reduced signal speed would then be recognized as higher air content since the speed of the signal is slower

in air than ice. A relation between real ice depth and the displayed depth on the ultrasonic meter could then indicate the amount of air content and ice quality. If the ultrasonic meter worked as in theory, it would indicate a thicker ice than the real ice depth captured by drilling caused by a slower velocity of the signal (larger  $\Delta t$ ) and thus a longer distance for the signal to travel.

#### **4.4.1 Equipment**

- Deionised water
- Isolated jar
- Ultrasonic thickness meter
- Drill
- Calliper
- Notebook and pencil

#### **4.4.2 Methods description**

The first step was to determine that the ultrasonic thickness meter, manufactured to measure the thickness of metal pipes, could work on ice by setting the speed of sound in the measured material as the speed of sound in pure ice. This can be illustrated in *figure 45*. According to a properly executed previous study, the speed of sound in ice at a certain temperature was maintained with data from *figure 46*.



Figure 45. Menu for adjusting velocity in measured material

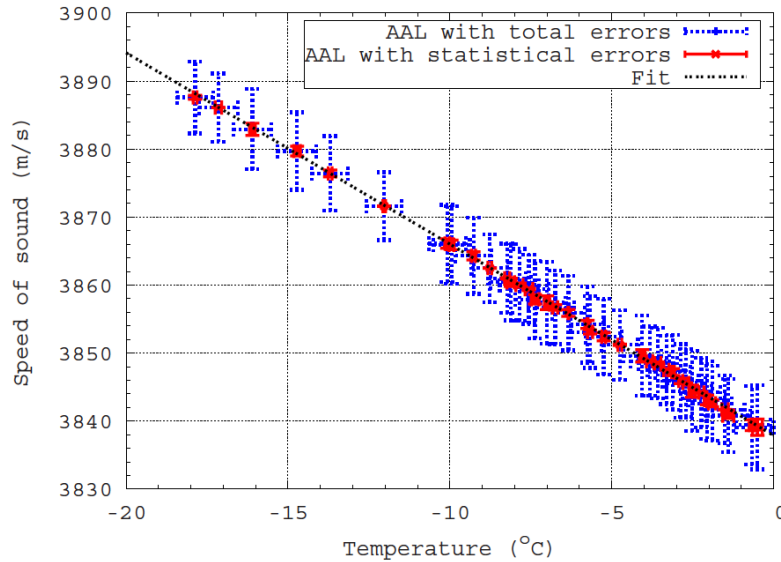


Figure 46. Speed of sound in pure ice at temperatures between 0 and -20°C (Vogt et. al, 2008)

The second step was to freeze ice in an isolated jar. Two types of ice were made; one with deionised water and one with tap water. Both fluids were heated until it started boiling to get rid of any air bubbles, to obtain as pure ice as possible. The thickness meter was then used to measure the thickness of the ice in the isolated jar and compared to the real thickness measured by calliper.



Figure 47. Ice in isolated jar

The results showed that the possibility of measuring ice thickness with the ultrasonic thickness meter could work. The measurements can be seen in following table:

Table 12. Validation of measuring equipment

	Speed of sound	Ice temperature	Ice thickness from ultrasonic thickness meter	Ice thickness from calliper
<b>Boiled deionised water</b>	3 860	-8	31.2	31.0
<b>Boiled tap water</b>	3 860	-8	28.0	27.5

The results from the ice tests were accurate enough to try at one of the examined ice rinks. Measurements were made at 20 different locations on the ice similar to industry standards for ice thickness measurements. The measuring points can be seen in *figure 48*.

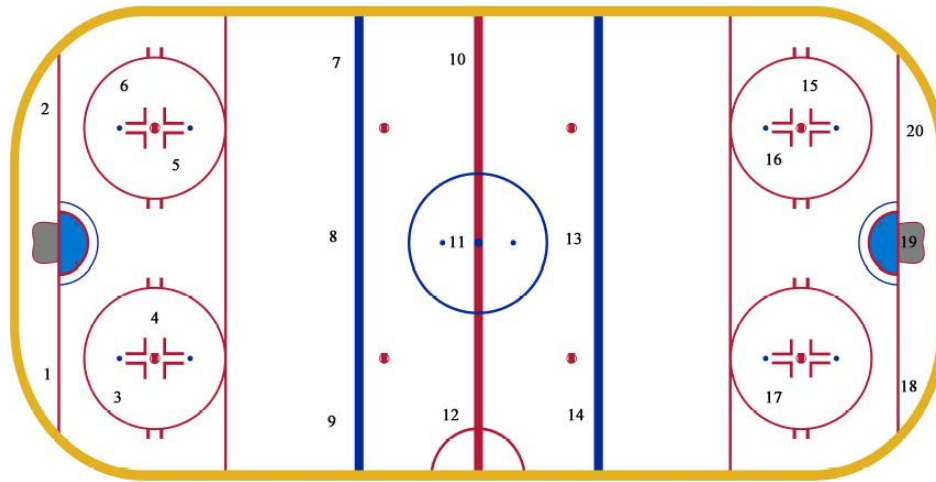


Figure 48. Measuring points at examined ice rink

### 4.4.3 Results

The results showed that it was possible to measure the ice thickness at an ice rink as well, but with some complications. It was not possible to measure the thickness at every place on the ice since it had to be very clear and free from inclusions and air that possibly blocked the ultrasonic sound. In those cases, the measurements show a very small thickness. The ultrasonic thickness meter reads the minimum and maximum thickness when measuring at a certain location. The results can be seen in *table 13*.

Table 13. Ice depth measurements in ice rink

Measuring point	Drilling depth (mm)	Ultrasonic maximum (mm)	Ultrasonic minimum (mm)	Difference Max/Min	Difference Drilling/Ultrasonic (mm)	Factor Drilling/Ultrasonic maximum
1	40.0	40.5	1.6	38.8	0.5	0.989
2	41.0	44.2	2.1	42.1	3.2	0.928
3	49.5	51.1	1.4	49.7	1.6	0.969
4	37.0	38.0	2.0	36.0	1.0	0.973
5	46.5	49.0	5.2	43.8	2.5	0.950
6	39.0	43.4	3.0	40.5	4.4	0.898
7	50.0	51.0	1.9	49.1	1.0	0.980
8	56.6	56.6	3.7	53.0	0.0	0.999
9	38.0	39.3	2.5	36.7	1.3	0.967
10	55.5	55.8	1.7	54.1	0.3	0.995
11	52.2	55.0	1.4	53.6	2.8	0.949
12	38.5	39.0	2.9	36.0	0.5	0.988
13	61.4	63.0	2.5	60.5	1.6	0.974
14	50.0	50.8	2.3	48.5	0.8	0.984
15	55.6	56.9	1.6	55.3	1.3	0.977
16	59.5	60.9	2.5	58.4	1.4	0.977
17	56.0	65.8	3.1	62.7	9.8	0.851
18	71.0	70.6	3.2	67.4	0.4	1.006
19	28.0	27.6	2.5	25.2	0.4	1.014
20	63.4	65.0	2.5	62.5	1.6	0.975
Average					1.8	0.967

It can be concluded that ultrasonic signals could be a possibility for measuring ice thickness. It should however be taken into account that it may not work on every location on the ice surface due to bad contact, inclusions or air content. The ultrasonic meter did not operate in reality as it was assumed to do in theory. *Figure 49* illustrates how it operated, resulting in very low values for areas with air content. This did not match with the previous hypothesis of how the ultrasonic thickness meter could be used to determine the ice quality/air content of the ice.

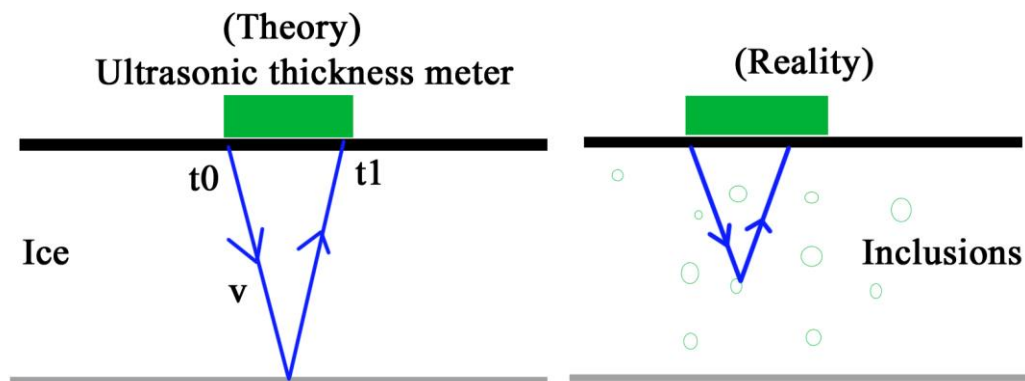


Figure 49. Comparison between theory and reality of how ultrasonic thickness meter operated

## **4.5 Freezing time and temperature drop of floodwater**

As mentioned in previous experiments, the sensible heat totally depends on the floodwater temperature. This known fact means that a certain temperature drop of floodwater results in a lower sensible heat and therefore a lower heat load on the refrigeration system. The temperature drop inside the resurfacing machine tank is also a waste of heat for the facility. The aim is to investigate if there is a change in temperature, why it occurs, how it affects the freezing time and energy consumption.

### **4.5.1 Equipment**

- Thermal imaging camera
- HOBO Data temperature logger

### **4.5.2 Method**

Temperature loggers were mounted at the inlet and outlet of resurfacing machine in two ice rinks. Thermal pictures were taken from the rear as the water is distributed from behind. Meanwhile, one temperature logger was mounted on the ice surface to capture the temperature change of the floodwater to determine the freezing time.



Figure 50. Temperature logger attached to resurfacing machine water outlet



Figure 51. Temperature logger attached to resurfacing machine water inlet



Figure 52. Temperature logger attached to ice surface

### 4.5.3 Results

The results have shown that the water temperature at the outlet of the tank differs substantially from the filling temperature. Both two different ice rinks show the results of a temperature drop. This basically means that the desired floodwater temperature is different from what you actually get. The results from two different ice rinks can be seen in *figure 53* and *figure 54*.

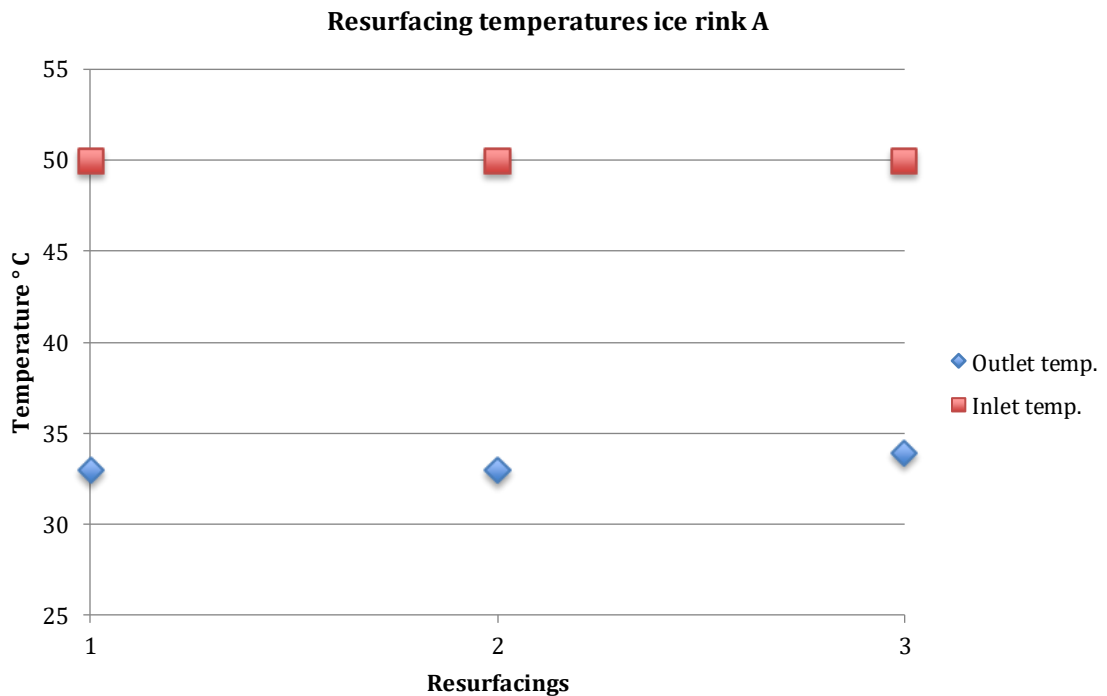


Figure 53. Inlet and outlet temperatures measured during resurfacing occasions in ice rink A

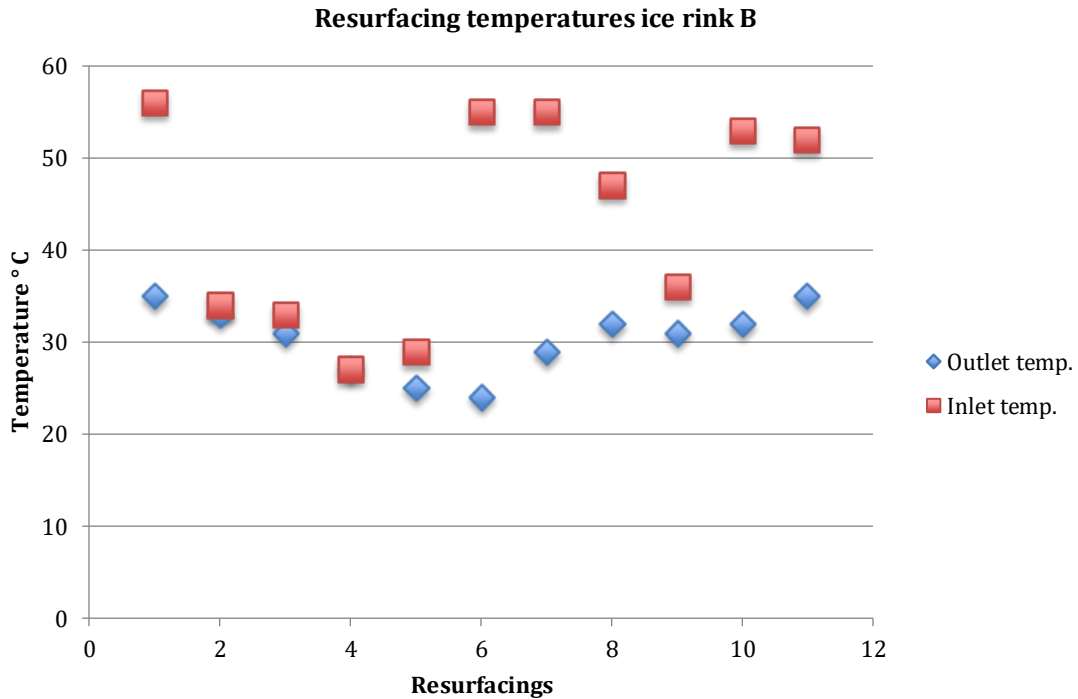


Figure 54. Inlet and outlet temperatures measured during resurfacing occasions in ice rink B

Previous measurements have shown that a season involves, on average, approximately 1420 resurfacings with a volume of 430 litres each. This means there is a large waste in heat and energy consumption for heating as the desired resurfacing temperature is rarely achieved. *Table 14* shows an approximate waste in energy consumption, between 7 000 - 14 000 kWh/season, based on average water volumes and resurfacing occasions from experimental measurements with temperature drops between 10-20°C.

Table 14. Waste in energy consumption for heating of resurfacing water caused by temperature drop

Temp. drop °C	kWh/season
10	7 124
11	7 836
12	8 548
13	9 261
14	9 973
15	10 686
16	11 398
17	12 110
18	12 823
19	13 535
20	14 247

The cause of this temperature drop is most likely due to the mixture between fresh water and leftovers from previous resurfacings, since resurfacing machines have a water capacity of 900-1200 litres but in most resurfacings only using 300 – 500 litres. Other factors such as the ambient temperature can also cause temperature drops depending on the environment; heated garage or not. The temperature drop may decrease if the tank is filled just before resurfacing.



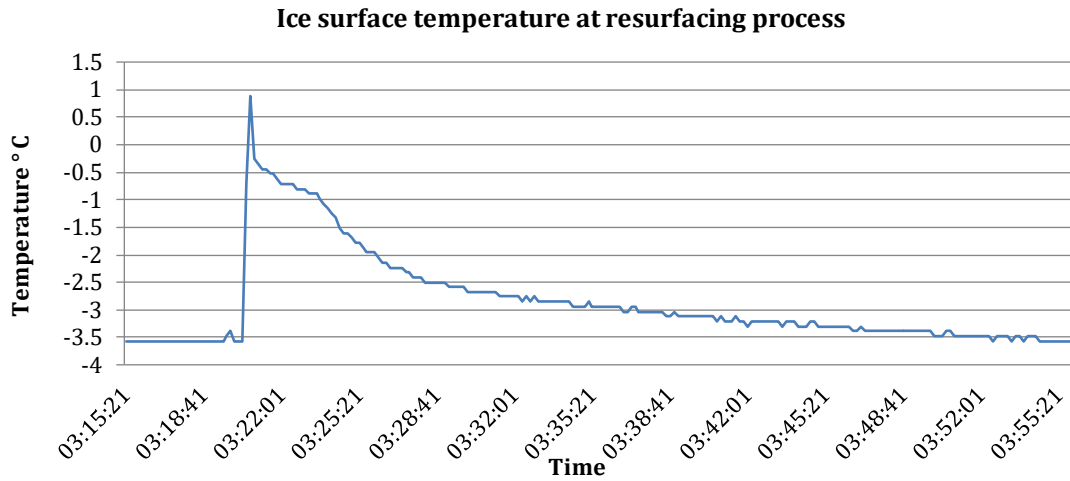


Figure 55. Recovering time for ice surface temperature after resurfacing process

The temperature tests on the ice surface were made to determine the time for the floodwater to freeze. The sensible heat of the floodwater has to be absorbed before the water starts to freeze ( $0^{\circ}\text{C}$ ). Results, seen in *figure 55*, has shown that the floodwater achieves a temperature of  $0^{\circ}\text{C}$  almost immediately with a floodwater temperature of approximately  $30^{\circ}\text{C}$ . Because of this rapid freezing time virtually no water evaporates thus the entire amount of energy (heat load) in the water can be assumed absorbed by the ice surface and the cooling system. *Figure 56* and *figure 57* shows the resurfacing machine in action where the highest temperature is around  $29^{\circ}\text{C}$ . It also shows that the water temperature is above  $0^{\circ}\text{C}$  as it hits the ice surface, but quickly freezes with a distance around 1 m from outlet.

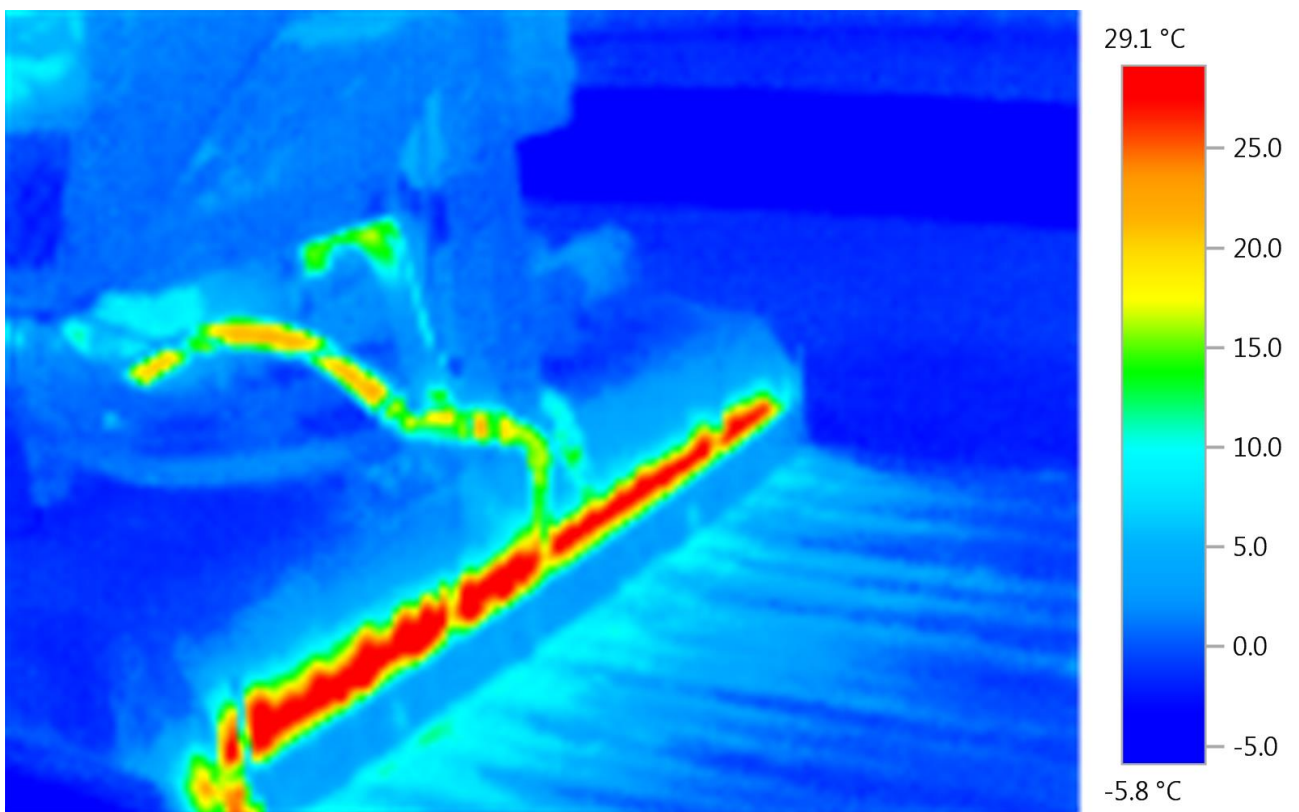


Figure 56. Resurfacing machine outlet

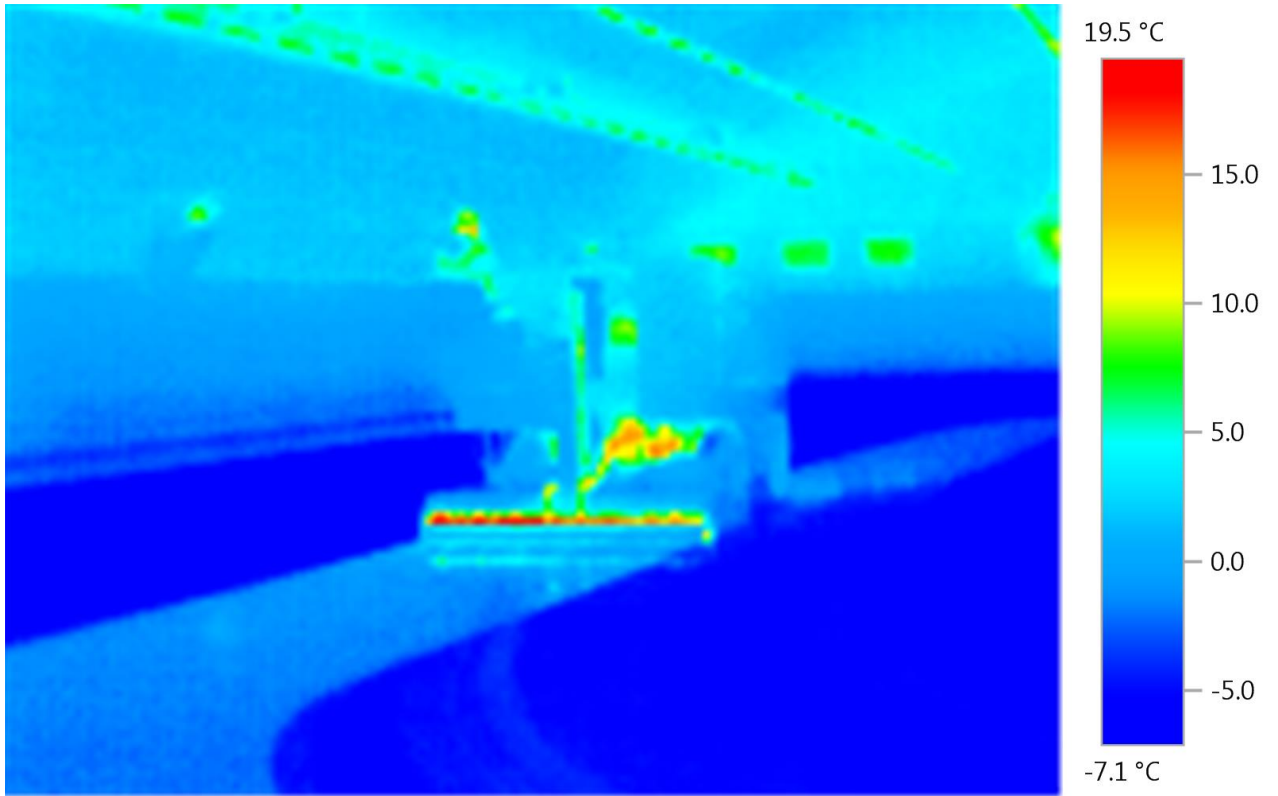


Figure 57. Temperature layers during resurfacing process

## 5. DISCUSSION AND CONCLUSIONS

### 5.1 Temperature and Water Volume Measurements

There are probably as many theories about floodwater as there are icemakers in the world. Temperature, volume and additives are experimented to get the water to form the best possible ice quality, which is a matter of definition. Previous studies have not been done at the same depth, but an earlier study in project “Stoppsladd”, conducted through a questionnaire survey to approximately 100 Swedish ice rinks, showed that most ice rinks use water between 30 and 40°C.

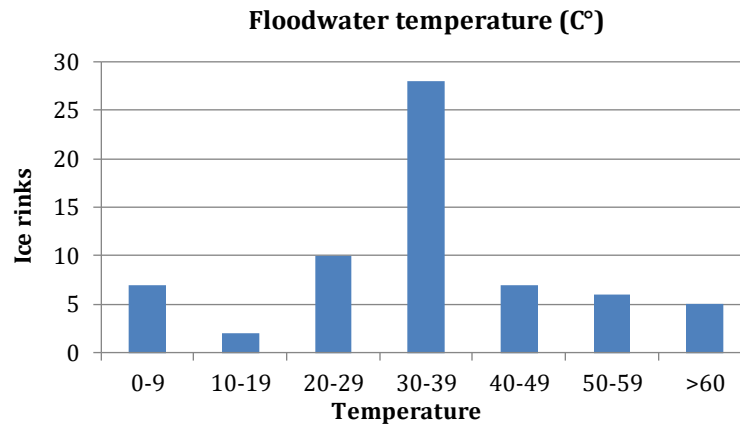


Figure 58. Floodwater temperatures conducted through questionnaire survey (Stoppsladd, 2010)

Since no previous measurements have been made, one can discuss how specific the reported temperatures in the survey are. Both temperatures and volumes have now been measured experimentally with results proven to differ from the previous survey as more specific but within the same range. Most fillings were made with a temperature between 40-50°C, seen in *figure 59*. But one should not draw a rapid conclusion since the measurements were made in five rinks from the same municipality with the same policy versus hundred surveyed rinks in the questionnaire survey.

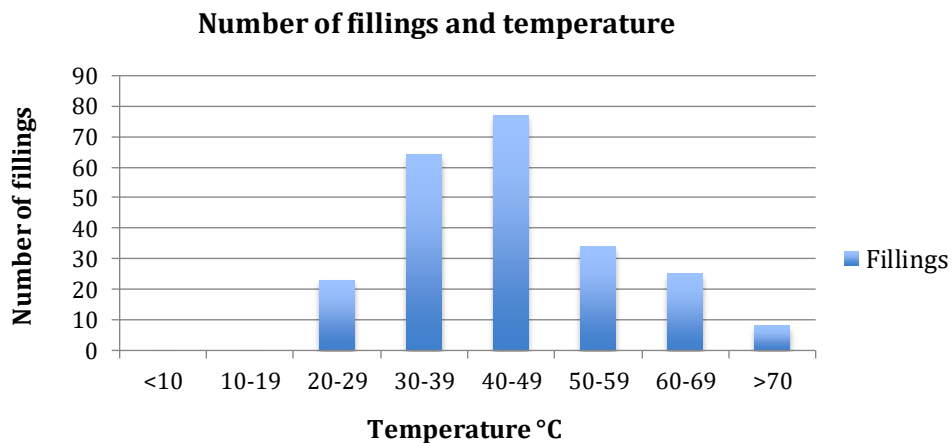


Figure 59. Total number of fillings and temperature for all ice rinks

#### 5.1.2 Energy Consumption of Resurfacing Machine

The energy shares of one resurfacing process between the resurfacing machines of ice rink 3 and 5 is compared in *figure 60*:

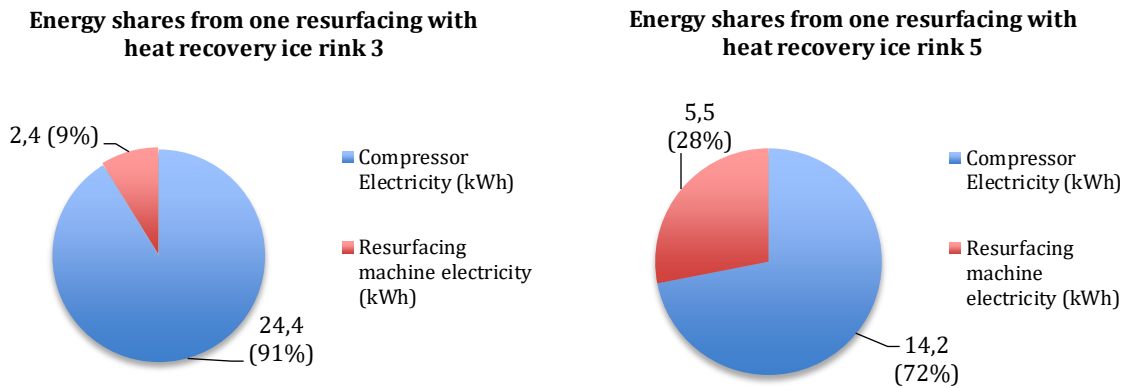


Figure 60. Comparison of energy shares with heat recovery between largest and least energy consuming machine

Assumed the ice rink is working with full heat recovery, the share of energy consumption becomes more than a quarter of the total consumption for a less efficient machine. The total amount of energy consumed during one season has been presented as:

$$E_{kWh-Season} = E_{kWh-Week} * 35 \text{ weeks}$$

It may be taken into account that the results are based on an assumption that the resurfacing pattern is the same for the whole season i.e. if one ice rink resurfaced the ice 20 times the measured two weeks; it is assumed that it is resurfaced 10 times a week during the season. The only way to improve the efficiency is in this case by purchasing a new machine (if it is worth it). If the most efficient resurfacing machine in this study (ice rink 3 & 4) would be used for resurfacing the least efficient machine (ice rink 5) it would result in energy savings of 3 690 kWh per season (130%).

### 5.1.3 Heat loads and Energy Consumption from Resurfacing

As it has been difficult to ascertain how many percent of the heat recovery the various plants use only for the heating of floodwater, the results have been divided into two scenarios; one with 100% heat recovery and one without any heat recovery. Electricity is used as heating source in the second scenario with an assumed efficiency of 100%, where 1 kWh of electricity is equivalent to 1 kWh of heat. The real efficiency is between 90-98% depending on the boiler but is assumed to be 100% in order to facilitate the calculations.

The average value of COP<sub>1</sub> during stable operation for one day with the average outdoor temperature for the certain month is used, since the outdoor temperature in many cases can affect the performance of the refrigeration system. If the COP<sub>1</sub> would be constant for every month, the required cooling capacity for resurfacing can be determined as constant, with the assumption that floodwater volumes and temperatures are the same during one season. For instance, if the average outdoor temperature of January is 4°C, ClimaCheck data from one day that corresponds to an average outdoor temperature of 4°C is used.

### 5.1.4 Ice thickness measurements

The measurements on ice thickness were made for two reasons; to check if it was possible to use an ultrasonic thickness meter as a convenient tool to measure ice thickness and to check if it was able to predict the ice quality. The hypothesis was that the ice with more air bubbles and thus lower quality would get the signal to take a longer time to bounce back and thus show a greater thickness since the signal has a lower speed in the air than ice. The first part of this experiment, on the ice in isolated jar, showed that it was able to use ultrasonic sound for thickness measurements, but the expected results from the measurements in the ice rink did in most cases either give a relatively accurate result or nothing at all. The signal is probably bouncing back as it hits the first air bubbles in the ice. One reason could be that the ultrasonic signal for the used equipment is not strong enough, since there are commercial measurement tools using similar technique. "IceTec8" from PrecICE is one, seen in *figure 61*.



Figure 61. IceTec8 measurement tool for ice thickness

How accurate this tool is cannot be determined in this experiment as it has not been available for the experiment, but according to the user manual, the transducer must be flush to the ice surface for accurate readings. Excessive moisture on the transducer can also cause inaccurate or “phantom” readings, which recalls the earlier measurements made with the available thickness meter. The tool does require a certain level of ice quality and under certain conditions such as poor water quality, excessive ice thickness, air entrained in the ice, surface frost or poor ice maintenance practices, the tool may not function adequately. If this measurement method enables to record the thickness all over the ice, a solution could be to integrate the meter with resurfacing machines to give the operator a clear view of where the ice is too thick or too thin and thus add more or less water at a resurfacing process.

### **5.1.5 Freezing time and temperature drop of floodwater**

The measuring points are of highest significance. It is known that temperature drops occur between the tap and outlet of the resurfacing machine. By filling the tank with e.g. 50°C does not mean that it has the same temperature as when it hits the ice, as different icemakers got different routines. Some fill the tank immediately after resurfacing, whilst some fill the tank just before. It is also very common that the tank is filled before closing to have the machine ready to resurface in the morning. This results in a severe temperature drop, which can be seen in *figure 62*. Data has been received from ClimaCheck in an ice rink where temperature sensors have been installed inside the water tank of two resurfacing machines. The temperature drop reduction can vary depending on the environment the resurfacing machine is in. It is obviously reduced more if it is stored in a cold garage compared to a heated one.

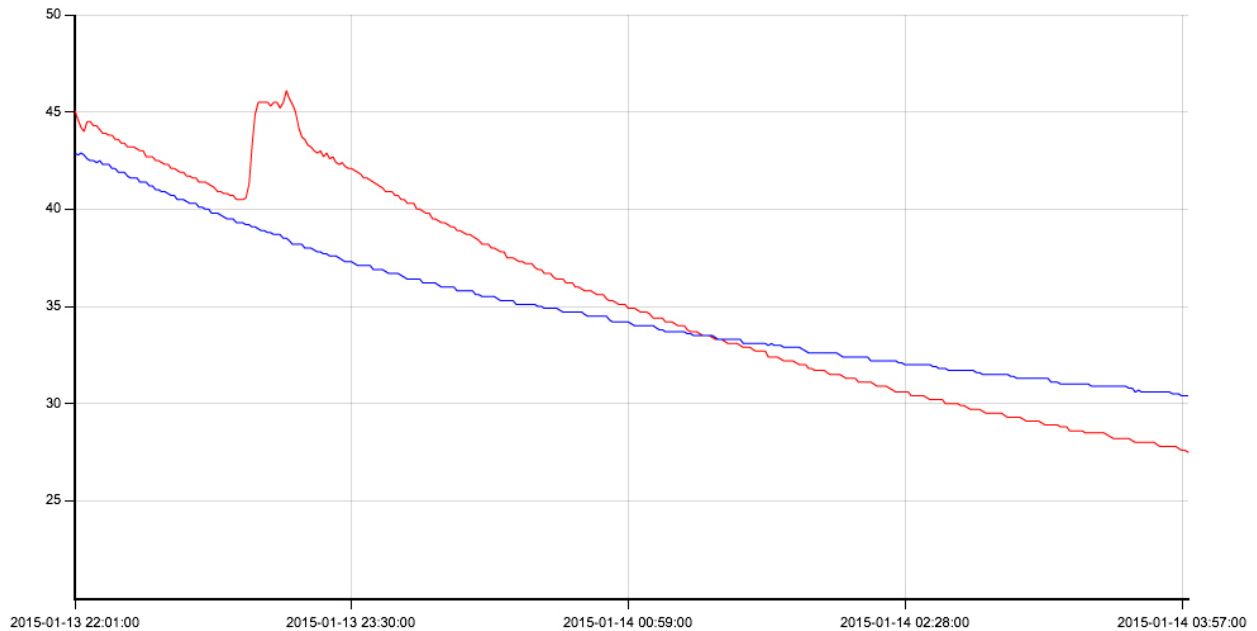


Figure 62. Temperature drop in tank during night

This temperature drop should be taken into account in calculations of heat loads occurring with resurfacing processes as the sensible heat is reduced significantly with a reduced temperature. In this case the temperature inside the water tank decreased with 17°C during 6 hours for one machine and 13 °C for the second machine during the same time.

## 5.2 Conclusions

Extensive measurements have resulted in a clearer overview of volumes and temperatures used in the examined ice rinks. These results have then been used to accurately determine the contribution of heat loads from the resurfacing process. It has also been concluded that different machines consume different amounts of energy depending on condition and how old they are, which is understandable as batteries gets worse with age while new technologies are developed. With these results it has been possible to determine the shares of energy consumption from resurfacing divided into charging the machines and compressor electricity. It has also been concluded that a great energy saving measurement is to integrate heat recovery with the refrigeration system, where an average of 49% of the consumed energy from the resurfacing process for the examined ice rinks is used for water heating. A well-functioning heat recovery system is preferred in order to reduce the energy consumption for heating of the floodwater with alternative sources as electricity and district heating. This allows ice rinks to avoid costs for heating while keeping a descent water temperature. The results of the measurements have shown that many facilities do not have the capacity to handle large volumes and the water cannot be kept at a constant temperature during the day.

A smaller volume and lower temperature of the floodwater will result in a lower heat load on the ice surface as both latent and sensible heat reduces with these factors. How this affects the ice quality is difficult to determine as additional factors than volume and temperature is affecting. Water treatment methods as deionization and vortex generation are used to obtain a higher ice quality and reduction of energy consumption.

Results show that resurfacing processes in ice rinks can be more efficient in both energy consumption and operation. Integrated volume and temperature control provides a better understanding in what you actually put on the ice and allows one to use the same routines with a desired volume and temperature at each occasion. This could prevent problems as a too thick ice caused by unnecessary large water volumes and also too thin ice with a smaller amount of water. A thin ice may burst during activities while a thick ice causes the cooling system to consume more energy than needed. An integrated volume and temperature control that display the volume and temperature inside the water tank may also facilitate new icemakers to learn how to manage this craftsmanship easier.

The volume measurement results have shown that the majority of the resurfacings barely exceeds half the tank volume. Some newer models have the function to set half a tank to fill but this function is rarely used according to the visited ice rink's icemakers. A usual way is to fill the tank until it is full to avoid an empty water tank during resurfacing. Most fillings take place right after the resurfacing occasion, which allows the water temperature to drop during the time until next occasion. The later you fill the tank, the less time the water has time to cool down and it is therefore preferred that routines are changed to filling the tank just before resurfacing instead of after. An integrated solution where you can choose the desired volume will prevent wastage of water and result in a small volume of residual water left inside the tank. This residual water drops in temperature and prevents the desired floodwater temperature to maintain the same. For this reason, the results show that the outlet temperature in most cases is much lower than the inlet temperature. The easiest way to avoid this problem is to empty the tank after each resurfacing occasion. This solution, however, is both time consuming, impractical and a waste of heating energy that were used to heat the water in the first place. Another way to maintain a desired floodwater temperature inside resurfacing machine tanks could be to connect the machine to the water system and recirculate the water. This type of solution would compensate the loss of heating energy and provide desired temperatures. A well-insulated tank is also preferable to reduce the temperature drop.





### **6.1 Future work**

Digitalization and collection of so-called “big data” (IBM, 2016) would be a natural step for the ice rink community and energy engineers to consider. A lot of data was collected in order to compile this report with many (nowadays) primitive methods. Machines and equipment being used are old-fashioned without any profound technical measurements available. Control systems of cooling and heat systems are moving in the right direction where data is logged and monitored, even live. This has been a great advantage in order to streamline efficiency and study patterns. Ice rink operators could learn a lot from these types of control systems and it would be a great advantage in scientific aspects as well. This study might be used as an inspiration for future data-collectors to consider what kind of data to collect and how to use it in order to contribute for further energy efficient ice rinks. Hopefully, in the future, it will not be needed to attach thermocouples on a resurfacing machine’s parts nor the ice surface, to come back two weeks later, in order to collect and use important data for energy saving purposes.



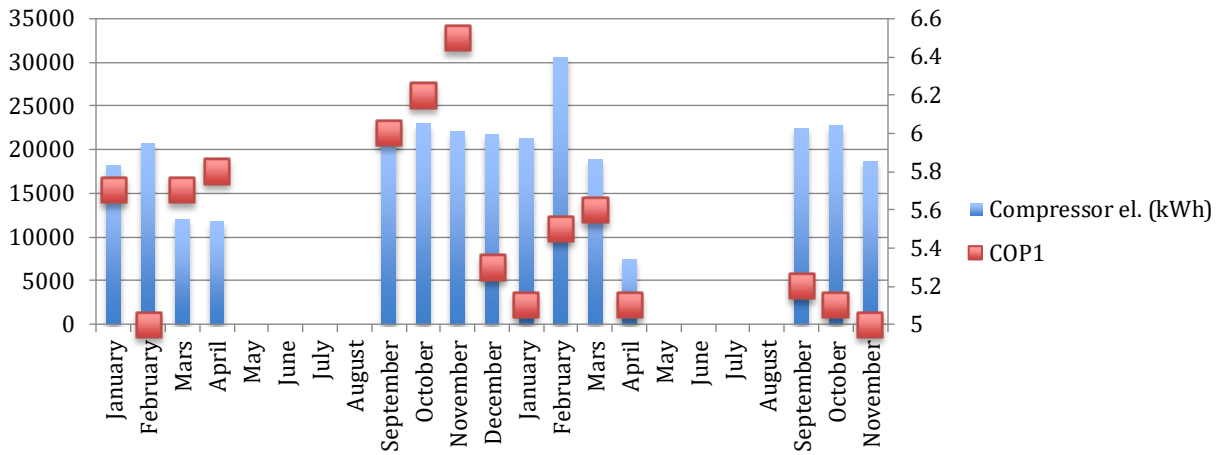
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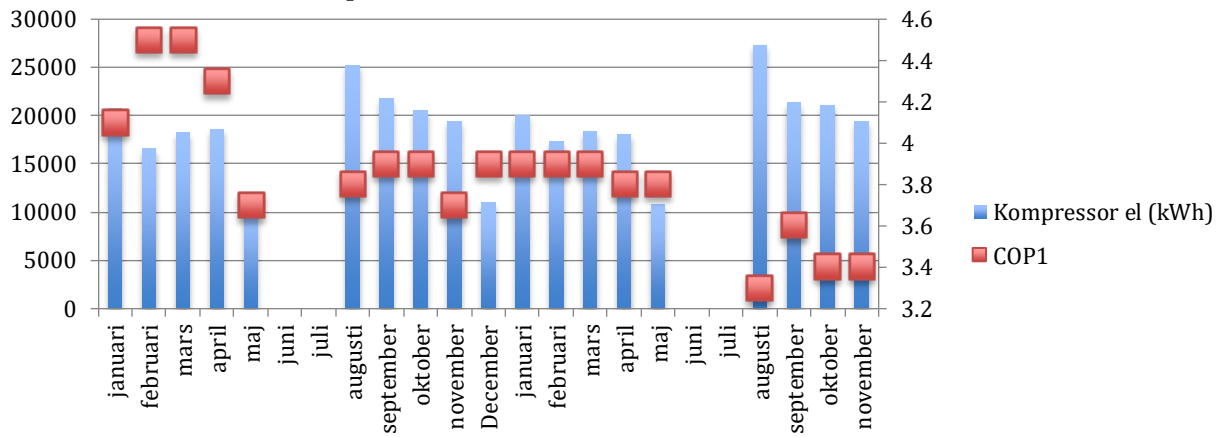
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**APPENDIX: Compressor utilization and COP1 of each month in a year**

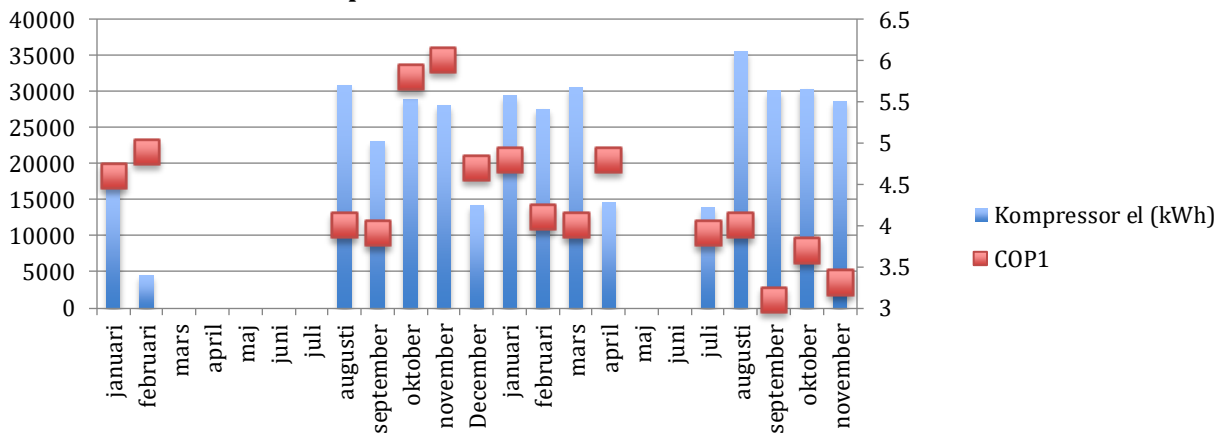
**Comp kWh vs. COP1 ice rink 1**



**Comp kWh vs. COP1 ice rink 2**



**Comp kWh vs. COP1 ice rink 3**



Comp kWh vs. COP1 ice rink 4&5

