NERIS - Part 1

An introduction to moisture handling in ice rinks
Fuktproblematiken i ishallar - en introduktion

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Authors:
Jörgen Rogstam, Juris Pomerancevs, Simon Bolteau och Cajus Grönqvist

EKA - Energi & Kylanalys AB

EKA I Varuvägen 9 I 125 30 Älvsjö I Tel. 08-550 102 10 I www.ekanalys.se

ABSTRACT

The project name NERIS is an acronym for Nordicbuilt: Evaluation and Renovation of Ice halls and Swimming halls. NERIS is led by the department of Civil Engineering at the Royal Institute of Technology (KTH) in Stockholm, Sweden.

This report is part one in a series of four, which will address moisture in ice rinks. Moisture is not an uncomplicated phenomenon and therefore a short recap of the most important terms and definitions is necessary to understand the physics behind it all. The project has had access to numerous measurements carried out in ice rinks, which will be discussed in this report in order to illustrate the “actual operating conditions” in facilities of this type.

The general goal is to make the reader understand the importance of the recommended moisture level, including its control, when striving to guarantee the successful and sustainable operation of an ice rink.

The moisture sources in an ice rink can be divided into two groups: External and Internal. External sources bring moisture from the surrounding climate into the ice rink, either by convection (air leakage) through openings in the building envelope or by diffusion through the structure of the building envelope. Internal sources (e.g. skaters, audience and in some cases also vaporized water from resurfacing or the melting pit) cause moisture loads on the indoor climate from within the ice rink.

Air leakage turns out to be the biggest moisture source by far, where openings in the building envelope allow large amounts of outdoor air to leak into the ice rink due to the differences in air pressure between the indoor and outdoor climates. The geographical location of the ice rink will therefore largely affect the moisture load it has to manage. The involuntary air leakage through the building envelope is usually of such magnitude that it practically becomes unnecessary for the ventilation system to bring fresh outside air into the arena room. The damper of the outside air should therefore be kept closed to minimize the moisture load and only be opened if the CO2-levels of the arena room become too high, i.e. the ventilation system should control the intake of outdoor air according to measured CO2-levels in the arena room.

Focus is often put on relative humidity when moisture levels are discussed in an ice rink. The problem with relative humidity is that it changes with temperature and therefore does not indicate the actual moisture content in air, which can change significantly over an ice season. The humidity levels in an ice rink should instead be discussed by using absolute terms such as “dew point” or “humidity ratio”. As an example, the indoor climate in an ice rink can be 5°C and 70% RH, however, in absolute terms the moisture level is 3.8 g H2O per kg dry air and the dew point is ca 0°C. Drying the air further is not recommended since it will lower the dew point below 0°C resulting in unnecessary moisture loads from e.g. vaporization of resurfacing water. On the other hand, the dew point should not be too high either since it increases the risk of condensation on surfaces that have significant visual contact with the ice surface, such as the boards or the roof. The risk increases further the lower the air temperature gets in the arena room, since it will lower the surface temperatures even more so. This report shows that the dew point in an ice rink should be maintained between 0°C and ca 2°C in order to secure a sustainable indoor climate.

The energy use of the dehumidification systems in different ice rinks are compared, where clear differences can be observed depending on the control strategy. Controlling the dehumidifier according to relative humidity instead of dew point or humidity ratio often results in unnecessary operation. The reason behind this is that the lower temperature levels in an ice rink can still result in high RH-values even when the

absolute moisture content, and dew point, get low during the colder part of the year. The end result is that the arena room gets “over dried”, which primarily causes the dehumidification system to use wasteful amounts of energy. Controlling the dehumidification system according to dew point or humidity ratio leads to a more optimum operation where the air is dried when necessary. Modern dehumidifiers are nowadays supplied with control units that are capable of working according to the control strategies discussed in this report, which makes it easier to make the changes needed in order to achieve energy efficient and sustainable operation.

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1 Introduction

1.1 Background and scope of NERIS

The overall project name is NERIS which is an abbreviation based on Nordicbuilt: Evaluation and Renovation of Ice halls and Swimming halls – NERIS, which is managed by Department of Civil and Architectural engineering at the Royal Institute of Technology (KTH) in Stockholm, Sweden.
The financing stems from the organisations; Formas (The Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning) and Energimyndigheten (the Swedish Energy Agency).
Overall targets for the project is: “This project aims at the proposal of methods for inspection and evaluation of the functionality of buildings of this kind and by demonstration of different methods for renovation for improving their performance”. This implies building of a knowledge bank related to moisture handling in ice rinks and swimming halls. The NERIS project was initiated in 2014 and will be finished in 2018.

This report is part 1 in a series of four addressing the humidity issue in ice rinks. In these four reports the mechanisms of humidity in ice rinks will be explained and anlaysed. It all starts with the specifics of ice rinks as applications and how the humidity issue comes into the picture. Further, the idea is to build a logical order of reports that describe the moisture challenges in ice rink applications ranging from the moisture sources through the building physics challenges to dehumidification methods and the associated energy usage. In conclusion, the different parts should be linked together containing practical advice and instructions for design and sizing of ice rink dehumidification systems.

1.2 Scope of NERIS – Part 1

This report addresses the humidity issue in the context ice rink applications. Firstly, the general ice rink application and function is described including the building as well as the so-called energy systems. The latter refers to the dominating installations in ice rinks of which the dehumidification is one of them and the others will be defined in the subsequent chapter on ice rinks. Humidity and moisture in air is not uncomplicated so to facilitate the understanding of the physics behind a short introduction to the most important terms and definitions is included. Different geographical locations may affect the climate – outdoor and indoor – therefore examples of typical climate in conditions in different parts of Sweden is included for illustrative purposes. The project has access to a large number of field measurements in ice rinks which also serve as evidence for the “real life conditions” in a typical ice rink.
The sources of humidity in an ice rink as well as the mechanisms related to that will be discussed together with the potential negative influence and the associated risk for the building and ice. As a direct consequence of the risk it is natural to continue with recommended levels and control of humidity to guarantee the function and life time of the facility.

2 Ice rinks and dehumidification

This chapter introduces the dominating technical systems normally found in ice rinks. This will serve as background when the specific of humidity and dehumidification is further discussed.

2.1 Ice rinks

The number of ice rinks in Sweden is about 360 and grows in a rate of 5 to 10 new constructions per year [2]. At the moment, the average annual purchased energy of an ice rink in Sweden is 1000 MWh/year, where typically about 80% is electricity and 20% is heat [3]. Currently, the total energy usage of indoor ice rinks, in Sweden, reaches a total of 300 GWh/year. Since indoor ice rinks are still increasing numbers in the country, it is very important to practice a policy of sustainability and search for better energy efficient techniques, given that the amount of energy used to these facilities will continuously increase.

Ice skating installations are one of the largest energy consumers in terms of public buildings and areas with simultaneous needs of cooling, heating, ventilation and lighting for different parts of the structure. Ice skating rinks may be often associated to countries with an extensive cold climate average per year, but it is a fact that an ice rink can be built everywhere, even in countries that never had snow or ice.
Canada and United States of America are the countries in the world with the highest number of ice skating rinks built (more than 5000 ice rinks built in both countries), followed by the Scandinavian countries of Sweden and Finland (more than 500) in Europe.

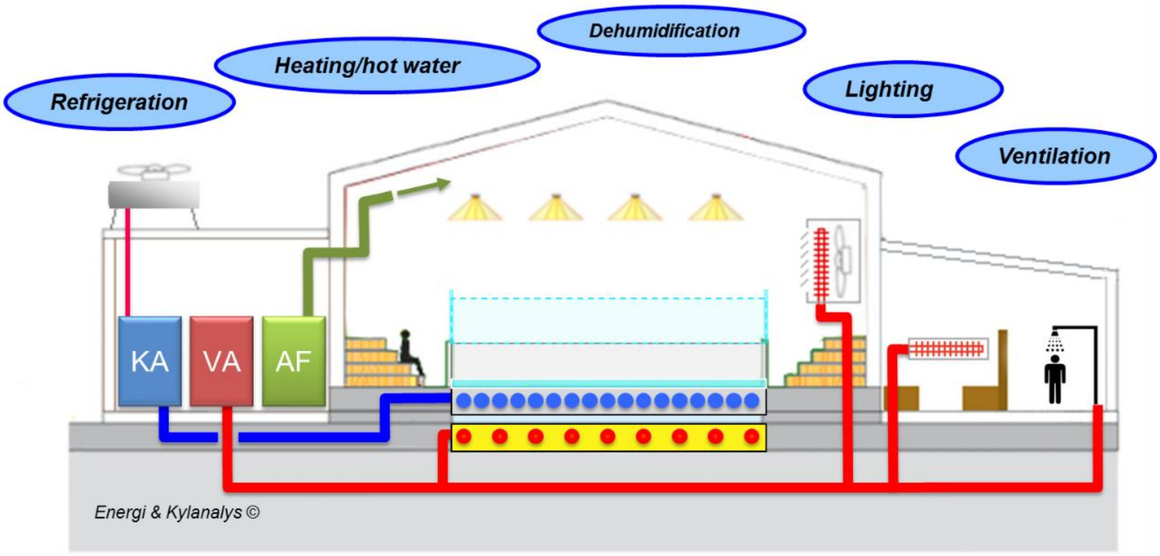

Figure 1 Indoor ice rink energy systems

To operate an ice rink these five basic energy systems are normally required:

- Refrigeration
- Heating
- Dehumidification
- Lighting
- Ventilation

The systems are often referred to as the "big five" because they typically account for more than 90% of the energy used in the ice rink. In the figure above these energy systems are schematically indicated in the ice rink. Results from an investigation in 135 ice rink energy usage in Sweden are shown in Figure 2. The highest energy share is used in the refrigeration system, constituting to around 43%, while the heating system fill almost a third of the whole energy usage.

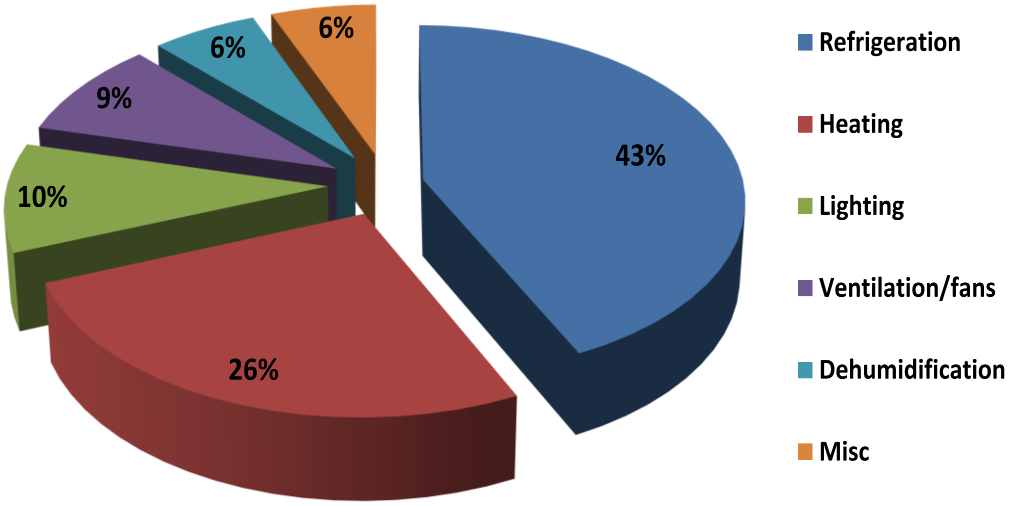

Figure 2 Relative annual energy usage in dominating energy systems in ice rinks

These systems are present in essentially every ice rink – big or small – and as will be covered many times in this report. Further, these systems interact – regardless if you want it or not! By connecting those systems in a sensible way there are great energy savings to profit from. When looking at the picture above it is evident that the heat supplied in the ice rinks space will affect the ice. In fact an indoor ice rink space is nothing but a thermal short cut with 1800 m^2 ice surface which cools the space. At the same time we want to provide thermal comfort for users and spectators by supplying heat by means of warm air, radiators or floor heating. The warmer the air the larger are the "short cut" losses which results in higher demand for cooling on the refrigeration system side. Lighting and dehumidification also affects indoor climate and the heat transfer to the ice which again takes to the conclusion that all systems interact. Interconnecting and controlling these systems together is key to optimise the energy usage.

2.2 Dehumidification in ice rinks

The dehumidification system of an ice rink is key to control the quality of the indoor air, keeping it in a ab acceptable level and avoiding problems due to the presence of moisture, such as degradation of structure materials, corrosion of metal, rotting of the wooden structures and development of fungi and bacteria but, dehumidification in ice rinks is still a very delicate subject in terms of energy efficiency concerning these buildings.

Figure 3 A common symptom of too high humidity in an ice rink.

Like humans, a building's health is directly related to air quality. Failing to control moisture trapped in the air will dramatically reduce the life-cycle of the materials used during construction. Further, moisture will impact ice quality and patron satisfaction. An ice technician must understand how the air and moisture found in an ice rink can influence the sport played and the amount of maintenance and upkeep that will be required to maintain a healthy facility.

The first generation of arenas were built to provide a comfortable indoor environment from the harsh cold outdoor conditions for skaters and spectators alike. Ice was put in for a much shorter season. Most of the operating hours were the cold winter months where humidity was not a concern. In fact, in the coldest days, a build-up of indoor humidity inside the building would find its way out through many of the openings in the building (remembering the indoor vapor pressure would now be higher than the outdoor vapor pressure in winter). Most of the older arenas have today been modernized with the proper dehumidification capacity to handle a longer season of ice operation.

As demand for ice time increased at the recreational level as well as the demand for offseason practice camps, tournaments and summer leagues, humidity issues became more apparent. An early attempt at removing the formation of fog was moving air over the ice with fans. Unfortunately, this caused more problems with the ice quality. Exhausting air continuously was tried but unfortunately the air that replaced the exhausted air (or what we might call make up air), was not treated or dehumidified properly and just made a bad situation worse. As the impact of high a humidity coming in contact with cold surfaces was studied further, the concerns moved beyond the problems with beams and boards and the unwanted drips on the ice. When left unchecked, the build-up of heavy condensation on the walls and floors could allow the formation of unwanted biological growth on those same surfaces.

Arenas are challenged to keep a safe and good sheet of ice when the indoor humidity level or dew point increases to a point that is well above freezing, because the rate at which frost builds up on the ice also increases. To keep the ice from being too soft, operators are forced to run the ice plant at very low temperatures, resulting in the easy build up ruts and heavy snow accumulation from skaters. Typically these periods that require colder ice are the same periods when the outdoor temperatures are elevated; which negatively impacts the ice plant’s efficiency and the total hours of operation. (ORFA, 2014)

In conclusion, it can be stated that the moisture control, regardless how it is performed, is key to achieve a good ice quality as well as good indoor climate. The latter should provide a healthy air quality for the people, staff, players as well as visitors, and the building. This takes us back to the target of the NERIS project – to improve the knowledge and understanding of the moisture implication in ice rinks.

3 Climate – air quality in ice arenas

Before starting the discussion as to the actual climate and existing air quality inside ice rinks a few terms and definitions may need to be introduced. The science surrounding air quality and specifically humidity is rather complex. Therefore, this report aims to limit the terms and definitions to what is practically used in this field.

3.1 Terms and definitions

This section introduces the most common terms and definitions used in the indoor climate business.

Relative humidity

The amount of water vapor in the air, at any given time, is usually less than that required to saturate the air. The relative humidity is the ratio of the water vapor pressure to the vapor pressure of saturated air at the same temperature (or actual water vapor content to the saturated air vapor content). Relative humidity is usually expressed in per cent and abbreviated by ϕ or RH.

$$RH = \frac{actual\ vapor\ content}{saturated\ vapor\ content} \cdot 100\% \tag{1}$$

Dew-point temperature

The temperature at which water vapor starts to condense out of the air, the temperature at which air becomes completely saturated. Above this temperature the moisture will stay in the air. If the dew-point temperature is close to the air temperature, the relative humidity is high, and if the dew point is well below the air temperature, the relative humidity is low.

Humidity ratio

The ratio of the mass of water vapor to the mass of dry air of a given sample, expressed usually as gram of water per kilogram of dry air (gH_2O/kg, dry air).

$$\omega = \frac{M_w}{M_{air}} \cdot \frac{P_{sat} \cdot RH}{P_{atm} - P_{sat} \cdot RH} \tag{2}$$

Absolute humidity

Mass of moisture (water vapor) per unit volume of air, expressed usually as kilogram per cubic meter (kg/m^3).

Specific humidity

The specific humidity is the ratio of water vapor in the air to the total mass of the air and water vapor.

$$W = \frac{\omega}{1 + \omega} \tag{3}$$

Dry-bulb temperature

This temperature is usually referred to as the “air temperature”, is the air property that is most common used. When people refer to the temperature of the air, they are normally referring to its dry-bulb temperature. Dry-bulb temperature - T_{db}, can be measured by using a normal thermometer.

Wet-bulb temperature

The wet bulb temperature is associated with the moisture content of the air. Wet bulb temperature can be measured with a thermometer that has the bulb covered with a water-moistened bandage with air flowing over the thermometer. Wet bulb temperatures are always lower than dry bulb temperatures but they will be identical with 100% relative humidity in the air.

3.2 Examples of air properties

Naturally water vapor together with many gaseous components and pollutants is always present in atmospheric air. Composition of atmospheric air is dynamic, however composition of dry air is regarded as relatively constant, with variations in time, location and altitude.

Moist air is a mixture of dry air and water vapor. The amount of the water vapour may vary from zero to a maximum that is determined by the temperature and pressure of the mixture. When the air contains the maximum value of water vapour, which is denominated as saturated air, there is a neutral equilibrium state between the moist air and the liquid or solid phases of water. (Bermejo, 2013) Maximum water vapor content that can be achieved in air increases exponentially with dry-bulb temperature, which is shown in Figure 4.

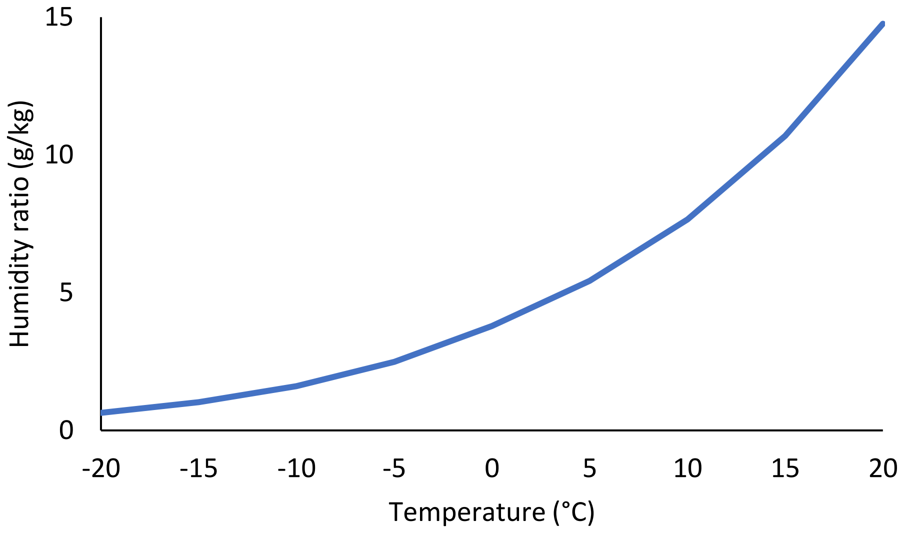

Figure 4 Humidity ratio in saturated air for selected temperature range

As an example, the typical air condition in an ice rink may be 5°C and 70% relative humidity. This implies that the actual humidity ratio is 3.8 g H_2O per kg of dry air, whereas saturated air of 5°C would be able to hold 5.4 g/kg. This is illustrated in Figure 5 where these assumed conditions are shown relatively to the saturation line.

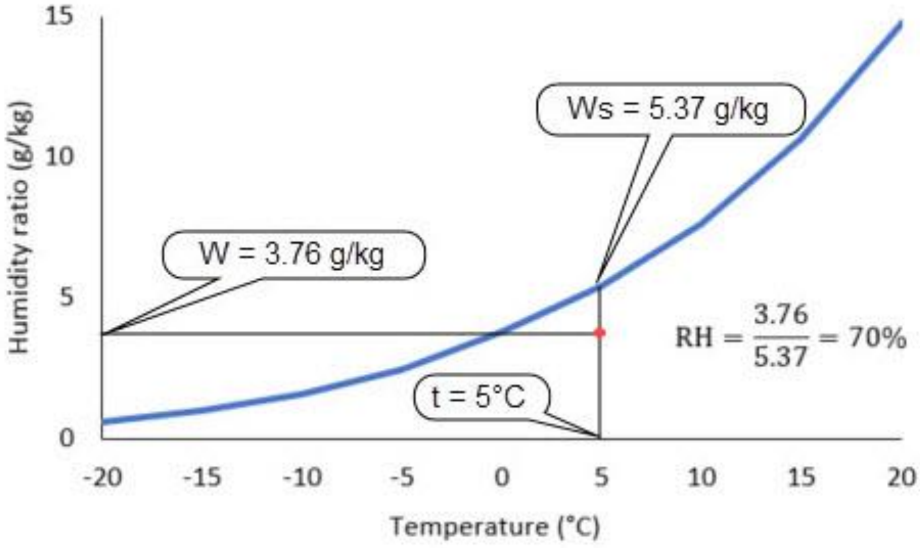

Figure 5 Typical indoor air conditions in an ice rink, with an explanation of the RH calculation

The relative humidity, RH, is a parameter that strongly depends not only on water vapor content, but also on the temperature. If the air temperature is increased without changing the water vapor content, the relative humidity will decrease, as shown in Figure 6.

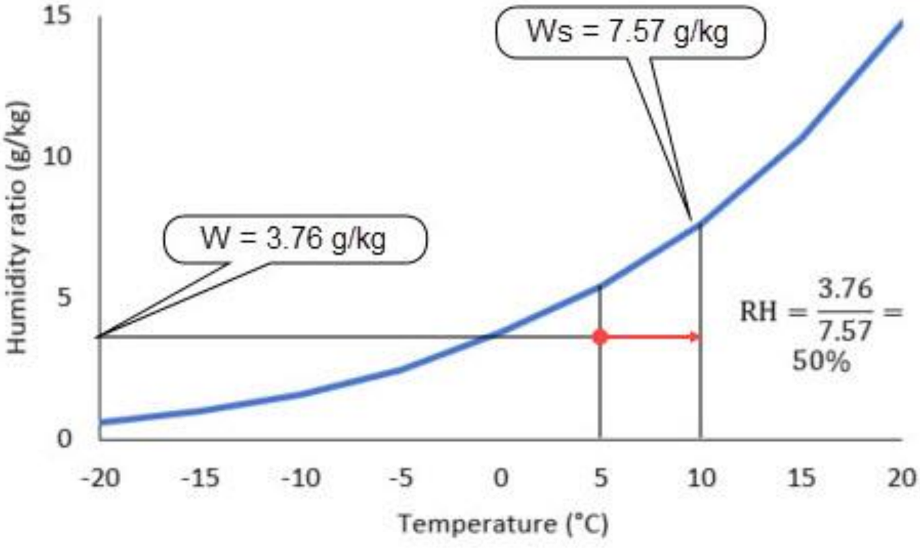

Figure 6 Illustration of Relative Humidity when increasing the air temperature.

On contrary, when the air is being cooled, also without affecting the humidity ratio, the relative humidity will increase, since the saturation line will be closer to the actual state point. In Figure 7 it can be seen that the relative humidity will change from 70% at 5°C to 86% at 2°C (at constant humidity ratio).

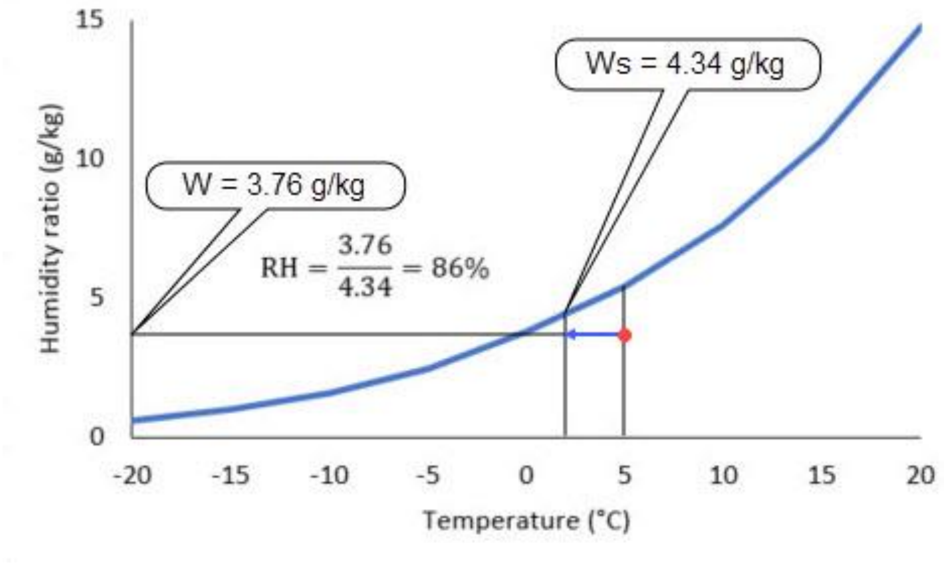

Figure 7 Illustration of an air cooling process

At some point, if the air temperature is further decreased (cooled), the saturation point/line will be reached. At this state the air has reached saturation which implies a relative humidity of 100%, as illustrated in Figure 8. The temperature at this state is called the dew point, since below this temperature condensing of water vapor will occur.

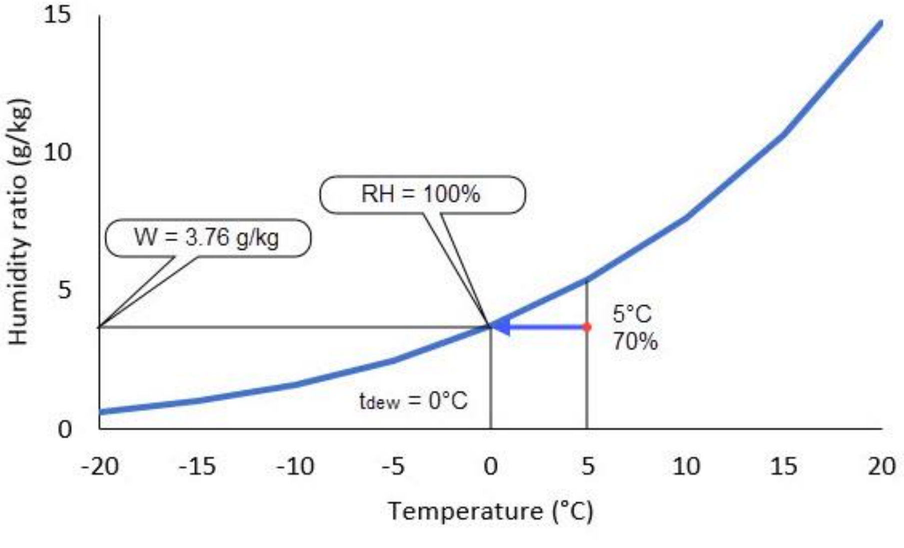

Figure 8 Air cooling down to the saturation line, where the dew point is reached

3.3 Outdoor air conditions

In real life the outdoor air conditions will affect the indoor climate in ice rinks significantly. To illustrate the differences in outdoor climate depending on the geographical location three different cities in Sweden have been selected. These three are Kiruna, Stockholm and Malmö which are respectively located in the very north, the mid-south and the very south of the country. These represent respectively; Kiruna - a typical northern inland climate, Stockholm – average to mild coast climate and Malmö – mild and humid for being in a Swedish context.

When comparing the climatic conditions of the different locations below (ASHRAE, 2013) it is evident that the temperature level is rather different. But when looking at the relative humidity a less significant difference may be noticed. We have, however, learnt above what the combination implies in terms of humidity ratio, which will be further illustrated below.

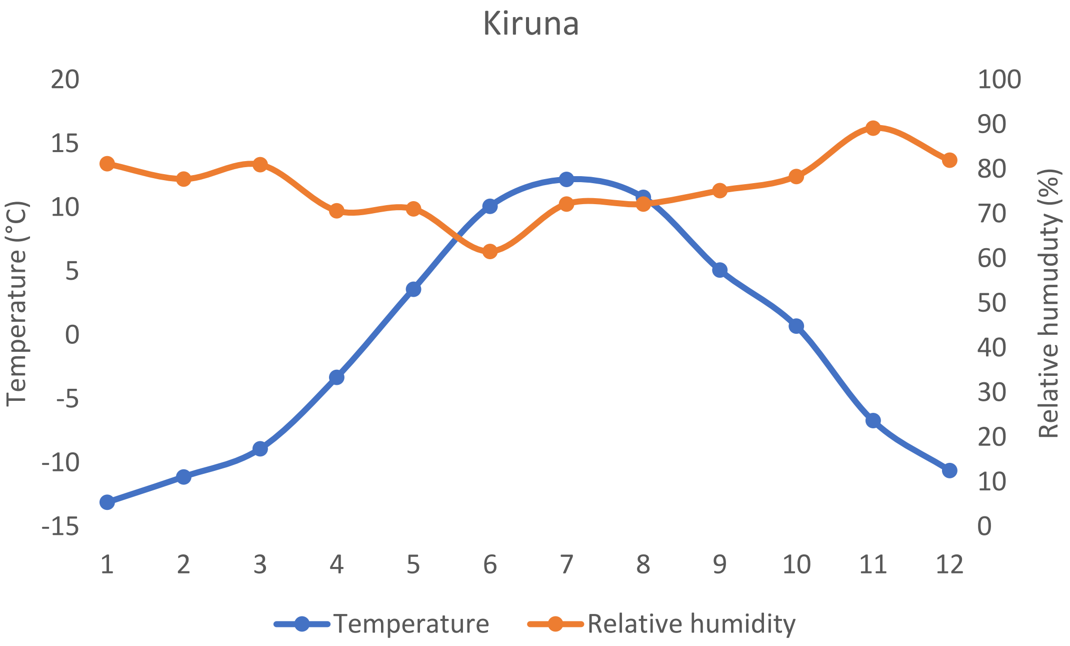

Figure 9 Temperature and relative humidity in Kiruna

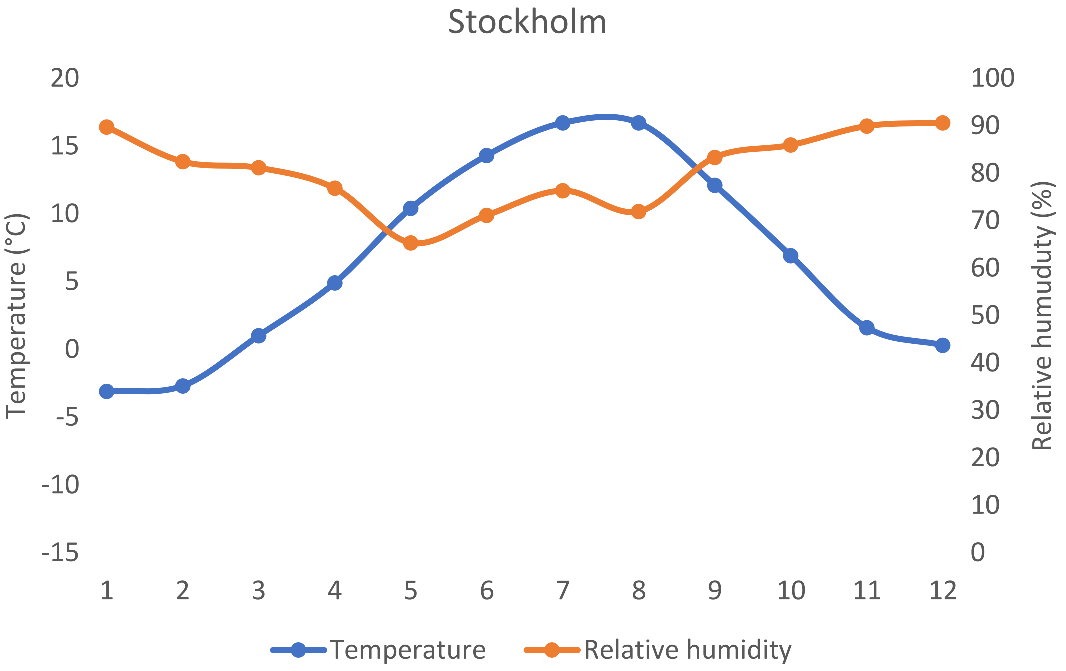

Figure 10 Temperature and relative humidity in Stockholm

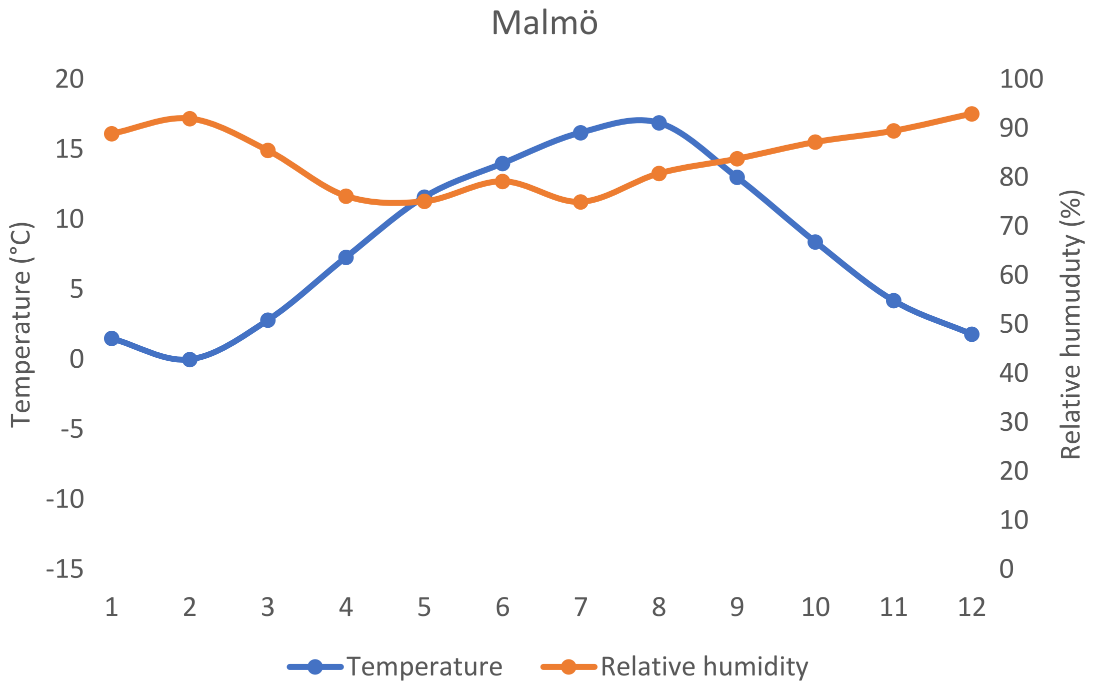

Figure 11 Temperature and relative humidity in Malmö

To calculate the moisture content of air, two parameters – dry-bulb temperature and relative humidity are usually measured. Figure 9 to Figure 11 illustrate as mentioned the dry-bulb temperature and relative humidity in the three cities.

A common misunderstanding when discussing moisture in air is that relative humidity is the main influential factor. If so, previous illustrations would suggest that in winter there is higher humidity than in summer, which is not the case. Therefore, to evaluate humidity in absolute terms, the humidity ratio is used in this report. As defined in section 3.1, the humidity ratio is expressed as the mass of water vapor per kilogram of dry air.

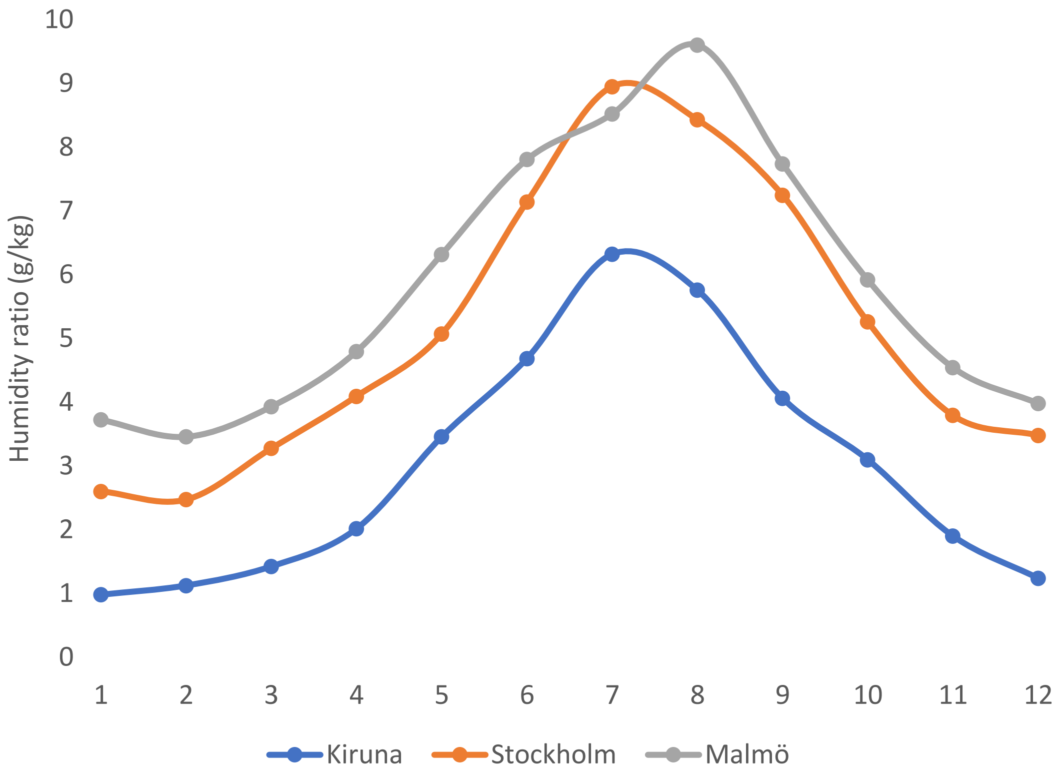

Figure 12 Humidity ratio of air in different cities

The Figure above shows the humidity ratio in three cities mentioned previously. The graph shows that the most humid months are July and August, on the contrary the driest are January and February. As concluded above, the season length in the early indoor ice hockey rinks was shorter than as it is nowadays, with many ice rinks operating for the whole year. In Stockholm a full year operation gives ambient air humidity ratios in range of 2.5-9.0 g of H_2O to kg of dry air, which implies a dew point temperature of -5°C and 12°C respectively.

The pattern along the year line is similar, but there is an evident offset between the cities, which indicates that the geographic location has an important influence on ambient air properties. In the north, as the temperatures are lower, the moisture content is significantly lower when compared to cities further to the south. As a reference, it can be mentioned that the vertical distance between Malmö and Kiruna is approximately 1350 km and the average moisture content difference is 2.9 grams.

3.4 Ice rink indoor air conditions

The rink space is where people either watch or skate on ice. Spectators are those, who require heating the most, to have comfortable conditions, while being in “passive state”. Normally, ice rinks are heated, however it is not always the case. In this report most ice rinks studied are heated.

To provide comfortable conditions for the spectators is normally the main target of the arena space heating system. This is most commonly performed via the ventilation system by means of air diffusers directed towards the stands. The overall indoor temperature is, however, highly dependent on the ambient temperature. In the following graphs the indoor temperature, relative humidity and water vapor content is showed in air in 8 Swedish ice rinks located near Stockholm. Typically the length of the season is between the end of July and mid-March, however, longer and shorter seasons are possible.

Figure 13 shows the indoor temperature profile. In the beginning of the season it is normal, that the temperature level is up to 12°C, which obviously leads to high thermal load at start up. Once the refrigeration system has started to cool the rink floor, the temperature drops in the arena room. There is, however, a considerable thermal mass to work with when rink floor, building, etc. are at "summer temperatures". Most smaller ice halls, where the climate is controlled, keep controlled air temperatures in the range of 5 to 10°C during normal operation. In some cases where the ice halls are uninsulated, the temperature in winter can drop significantly.

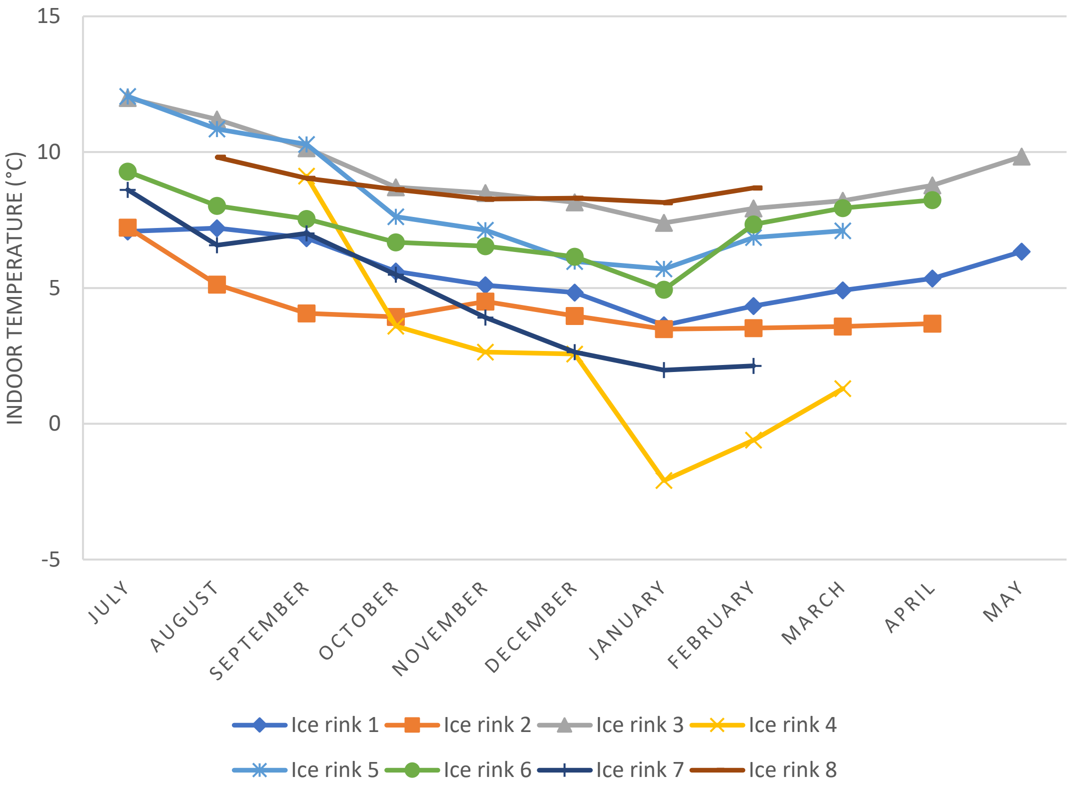

Figure 13 Indoor temperature in 8 ice rinks during one season

The indoor temperature trend is similar for all ice rinks studied. It is only in ice rink 4, where the temperature drops much more during the cold period, which is due to an uninsulated building. Interestingly enough this is the warmest ice rink in the beginning of the season and among the coldest in the end, which illustrates challenges with uninsulated ice rinks without climate control, i.e. influence of the ambient climate is much more significant.

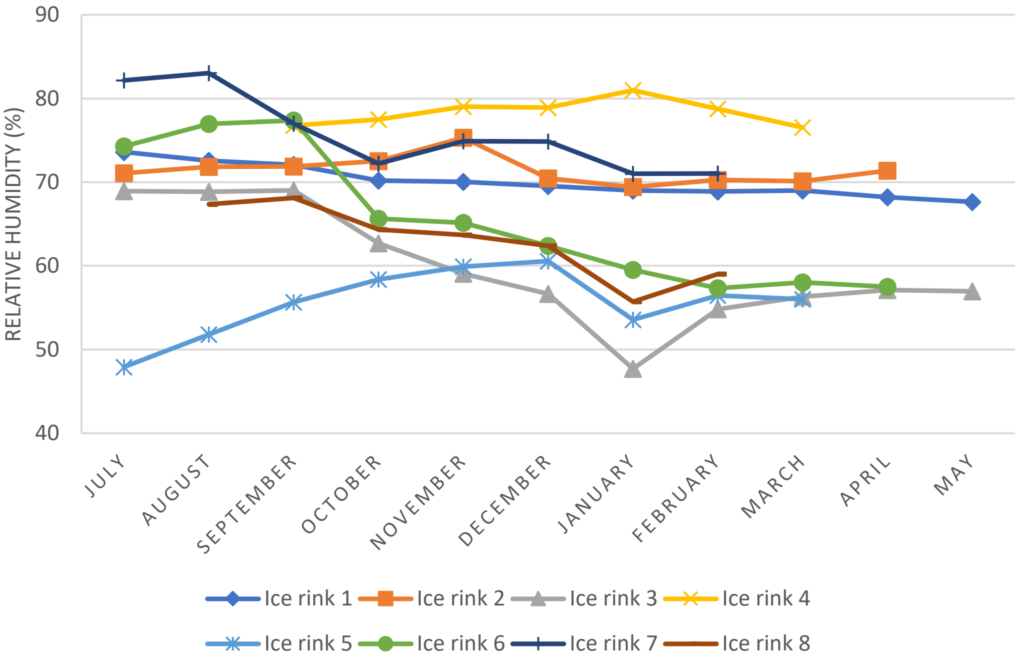

Figure 14 Indoor relative humidity in 8 ice rinks for one season

In Figure 14 the monthly average relative humidity (RH) inside each ice rink is illustrated. It can be noted that in ice rinks 1 and 2, the dehumidifiers are controlled to an RH-value, which is around 70% all season long. In the beginning of the season it can be seen that, in some ice rinks, the dehumidifiers do not have capacity enough. For most ice rinks the RH value is decreasing until October and after that they level out, like in ice rink 3, 6, 7 and 8. This shows that the dehumidifier is probably running full capacity and as the load is decreasing with the ambient temperature and the associated humidity load the indoor RH decreases. Rink 5 stands out, having a completely different pattern than the others, which is due to the control strategy being based on humidity ratio, rather than RH-value. Control strategies will be further discussed later in the report.

As the temperature changes, the constant relative humidity control will change the absolute moisture content. By using the temperature and relative humidity data from above, the water content per kilogram of air has been calculated and is shown in the figure below.

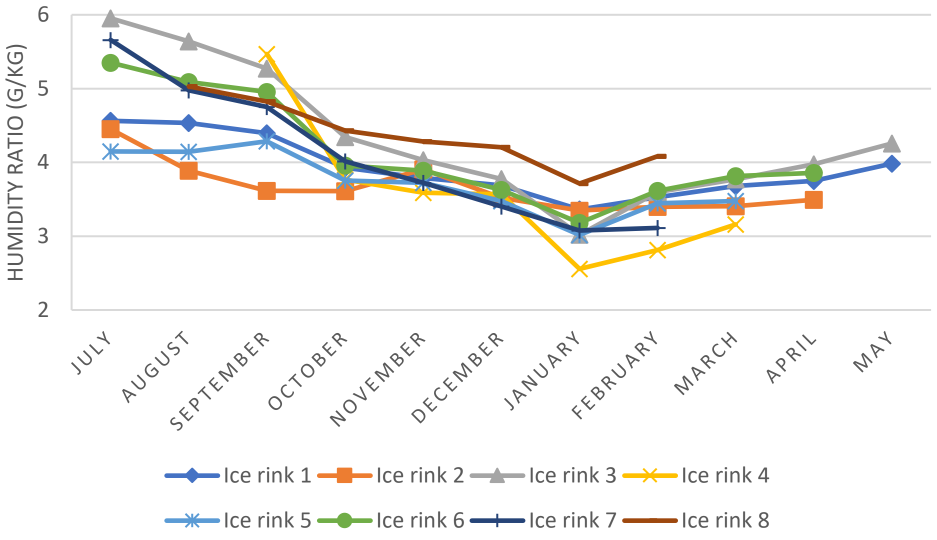

Figure 15 Indoor humidity ratio in 8 ice rinks for one season

From practical experience, the dew point should be maintained between 0°C and 2°C, due to several aspects, like avoiding high condensation rate on ice, while at the same time preventing the evaporation of water that is laid on ice during the resurfacing. Converting the dewpoint of 0°C to humidity ratio results in around 3.7 g H_2O. As shown in Figure 15, most arenas have moisture levels well above 3.7 g H_2O/kg of air at the beginning of the season. Later in the season, some arenas have too low moisture levels, i.e. <3.7 g H_2O/kg of air. This means that the arena is "over-dried", which implies that either the dehumidifier is operated unnecessarily, or the infiltration of outside cold and dry air lowers the humidity level unintentionally. In January, all ice rinks have very low humidity ratio, due to dry outdoor air, which should imply that the dehumidifiers are not operated in these conditions.

The water content expressed as mixing ratio (or absolute humidity) is an important parameter that has a major impact on the moisture load on the ice surface, but also on the building, and not least on energy use.

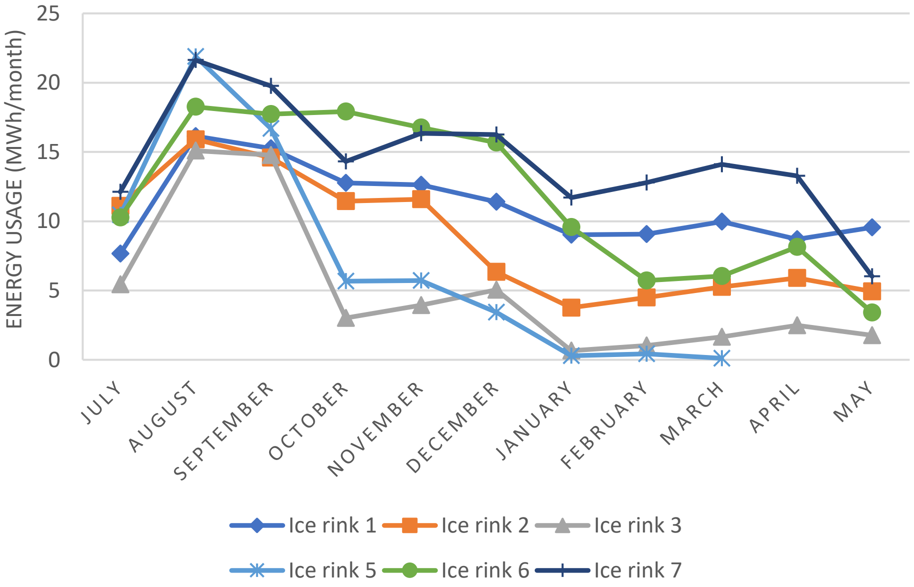

Figure 16 Monthly energy usage in a couple of ice rinks during the season of 2015/2016.

In the graph above the corresponding dehumidifier energy usage can be seen for the ice rinks studied. Although the humidity ratio is lower than 3.7 g H_2O/kg of air for most ice rinks as from November the energy usage is still significant. This is a good piece of evidence that the control principle and/or the setpoint is not appropriate since the dehumidifiers continue to operate although the humidity ratio is lower than necessary.

4 Moisture sources

Moisture in air is by the laws of nature transferred from higher to lower concentration, due to the difference in vapor pressure. When air is saturated with vapor or cooled down to the dew point, it cannot hold more moisture, there is a neutral equilibrium state between the moist air and the liquid or solid phases of water. If the temperature decreases further, the moisture will condense, in the form of fog. In ice rinks condensation may take place on cold surfaces, like the ice surface, as shown in figure below, but also on metal beams or the protective glass along the sides, causing sweating or dripping. (Zhang, 2013)

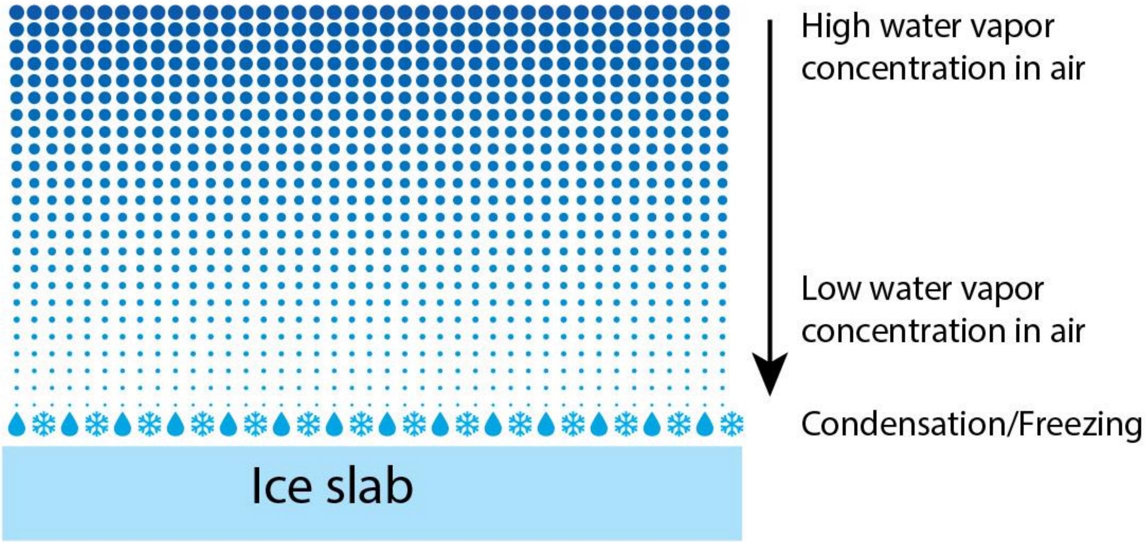

Figure 17 Diffusion of water vapor in air and condensation and freezing on ice

So, what generates these high humidity levels or too high dew point level in an ice rink? There are two main groups of moisture sources in an ice rink building:

- external, due air leakage where ambient air infiltrates into the ice rink, and moisture transfer through the building shell (walls, roof and floor)
- internal sources, due to skaters in activity, spectators, potentially resurfacing and melt pit water that evaporates

It will later be concluded that the largest contributor is the infiltration of outdoor air into the arena room.

Any opening will allow an airflow through the building enclosure, which is driven by the pressure differential, due to wind, mechanical equipment operation, or stack effect. (Lstiburek, 2014; Straube, 2006)

Figure 18 gives an overview of major moisture sources. Ventilation supply air also carries water vapor, which may be treated in the air handling unit before getting into the rink, but this is seldom the case. Therefore, unless there are specific reasons, it should be avoided to bring in fresh (ambient) air. (Rogstam & Mazotti, 2014)

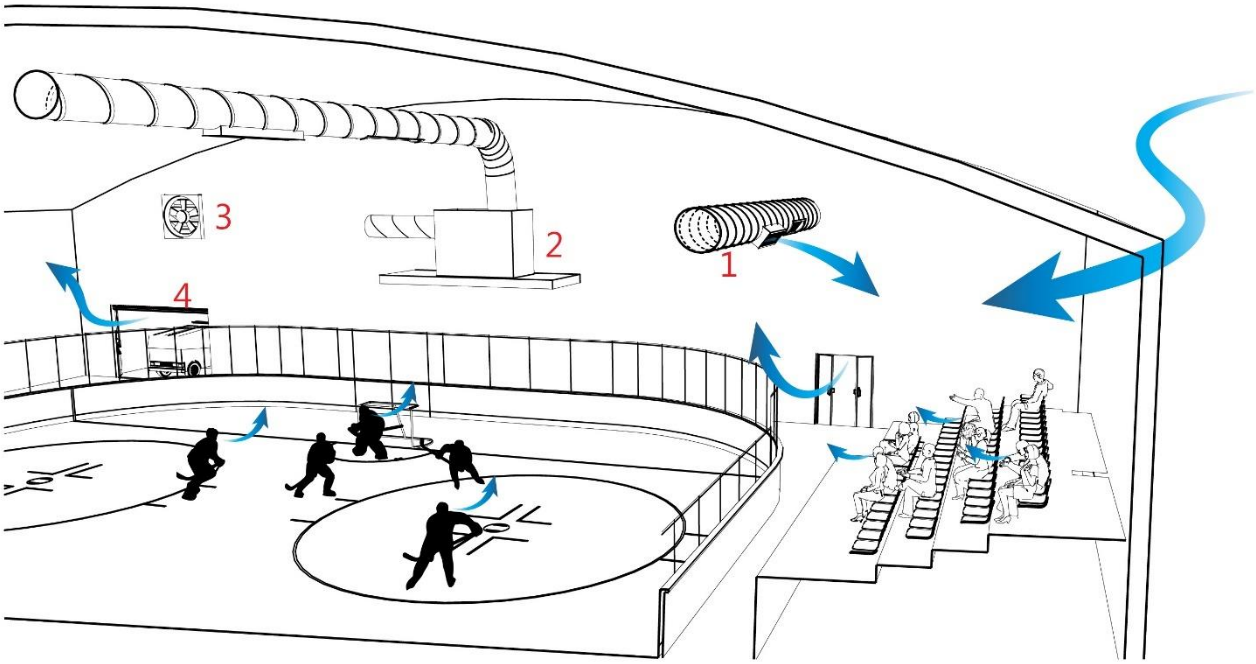

Figure 18 Moisture sources in ice rink (1 – Make-up air; 2 – Dehumidifier; 3 – Exhaust fan; 4 – Ice resurfacer garage)

A part of the moisture in the air will deposit on the ice slab and part will be removed by the dehumidifier. During low outdoor humidity conditions, exfiltration may be possible, eliminating the need of a dehumidifier. The ventilation system could extract moisture, but it should be noted, that the very same air is typically supplied since the units are controlled to full return air. Thus, leading to a theoretical neutral effect on the moisture content.

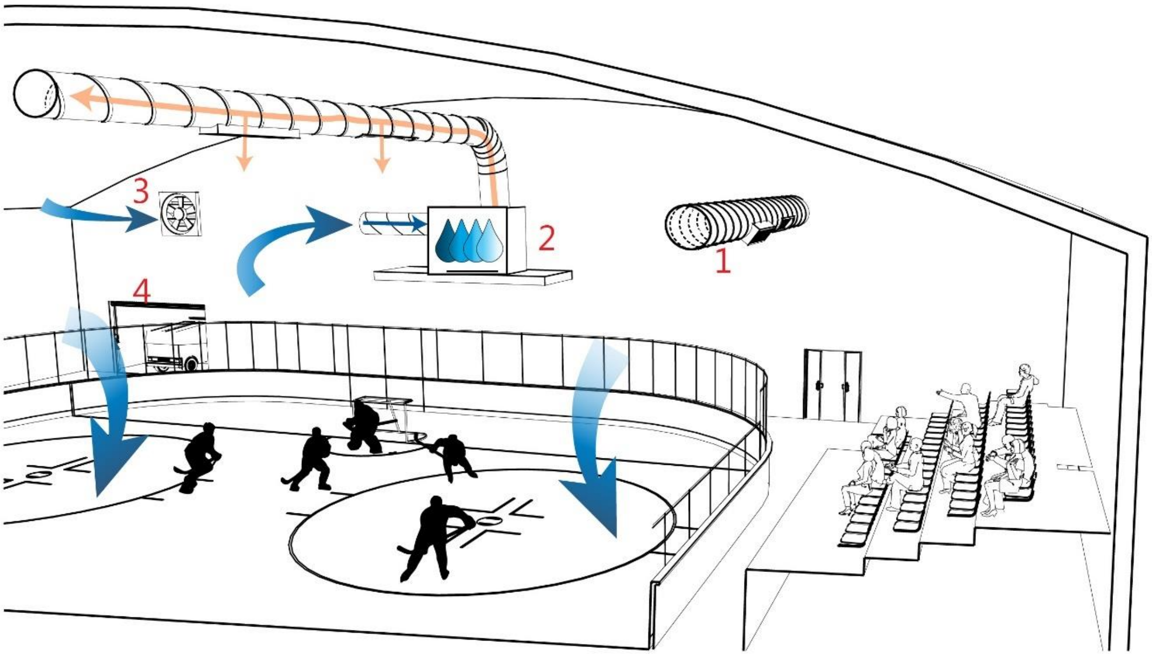

Figure 19 Moisture sinks in ice rink (1 – Make-up air; 2 – Dehumidifier; 3 – Exhaust fan; 4 – Ice resurfacer garage)

In general, as the air leakage is the main moisture contributor, the building envelope airtightness will mainly determine the dehumidification and to some extent the refrigeration energy usage. The dependency on the ambient air condition will be treated and discussed further in subsequent parts but in the meantime, we can conclude that to avoid even higher moisture rates, openings like doors, fire exhaust vents, etc. should be closed and sealed.

5 Climate and moisture impact

5.1 Ice quality

Ice surface quality is a crucial factor, whether it is for ice hockey players, curlers, who prefer hard ice, or it is for figure skaters in favour to softer ice. Hardness level is achieved with ice temperature control – lower temperature typically leads to harder ice. (ASHRAE, 2014)

As the harder ice is achieved with lowering the ice temperature, rate of moisture condensation on ice may increase. The condensed moisture forms a frost layer on ice, which can reach a level when skating leads to deep ruts and heavy snow accumulation. Some of the best ice conditions and the easiest to maintain sheets of ice are achieved when the dew point is just above the freezing level. (ORFA, 2014) This allows the ice rink operator to run a warmer surface temperature on the sheet of ice. Beyond ice quality, a warmer surface temperature reduces the load on the ice as well. Condensation on ice also adds latent heat load to the refrigeration system and further, the thickness of the ice will increase. An ice surface with frost formation is typically greyish and rough which will call for resurfacing although no activity has taken place.

Figure 20 Frost formation on ice due to moisture deposit.

Conditions may occur when the dew point is lower than ice surface temperature. This is either due to over drying or when dry ambient air infiltrates to a rate where the indoor humidity (dew point) drops below the surface temperature. When this happens a reversed mass transfer will occur as the ice sublimates. In this process, the ice evaporates from solid (ice) to vapor phase (moisture), thus leading to a reversed energy flow as well, implying that the ice is cooled by the evaporation to the air. This not only affects the ice surface negatively which results in increased number of resurfacings but it may also imply that the ice is cooled by the dehumidifier! This is obviously only the case if the dehumidifier is operated due poor control which again puts the finger on the importance on controlling the dehumidifier to a dew point or absolute humidity. If the low humidity happens due to infiltration of dry air it does not have a cost implication as far as the dehumidifier is concerned, but may affect other systems such as heating and temperature control due to an increased heating demand when cold air enters the building.

Water dripping on ice is a common problem. Drips build up bumps or stalagmites, which interfere skater performance and requires more frequent ice resurfacings, leading to higher operating costs. The cause of dripping is the accumulation of condensation on the interior surfaces, that have temperatures below the air dew point. (Straube, 2006) As metal beams are very good heat conductors and located directly above the ice slab, heat exchange by radiation transfers heat from beams to the ice, thus increasing refrigeration load and decreasing the beam temperature. One strategy to avoid temperatures lower than the dew point, is to increase ice temperature, however this is not always desirable, due to ice softening. Other solution is to decrease emissivity of the ceiling, by painting structures or suspending aluminium foil to the ceiling. In addition, lower emissivity reduces the radiation load to the ice, allowing the refrigeration system to work with a higher brine temperature and thus work with lower energy consumption. (Kaya, 2017)

5.2 Building envelope

Visible and invisible degradation caused by moisture is an important factor limiting the useful life of a building. Invisible degradation includes the decrease of thermal resistance of building and insulating materials and the decrease in strength and stiffness of load-bearing materials. Visible degradation includes: mould on surfaces, decay of wood-based materials, spalling of masonry and concrete caused by freeze/thaw cycles, hydration of plastic materials, corrosion of metals, damage from expansion of materials, and decline in appearance. In addition, high moisture levels can lead to odours and mould spores in indoor air. (ASHRAE, 2009)

The most common type of ice arena uses several large full-span frames of steel or glulam wood with purlins that span from frame to frame supporting the exterior metal cladding and low-slope metal roofing. In many cases the buildings are simple in plan and pre-manufactured metal buildings. The building enclosure usually comprises, from the inside, a wooden or sheet metal surface, a layer of low-density fiberglass insulation, and metal roofing/cladding.

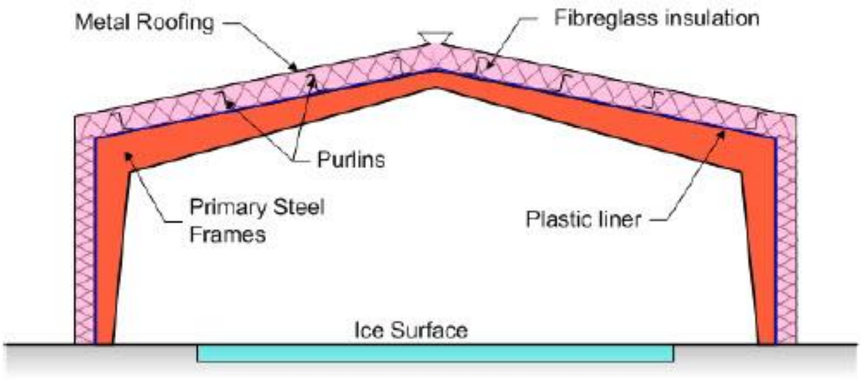

Figure 21 Typical simplified cross-section of ice hall

Structural failures caused by wood decay are rare, but have occurred. Decay generally requires wood moisture content at fibre saturation (usually about 30%) or higher and temperatures between 10 and 40°C. (ASHRAE, 2009)

Often the ice arenas are heated with a heating system which is based on air distribution. In the arena room the surface temperature of the structures may be rather low because of the low air temperature but also because of the heat transfer with the ice. This increases the risk of condensation on and in the building structure. The problem can essentially only be prevented by controlling the humidity accordingly. As previously mentioned the dew point need to be below the surface temperature of the structure otherwise condensation will occur.

Figure 22 Mould on and in in wall structures.

In the figure above an obvious example of a seriously affected structure is shown. The insulation as well as the beams show clear signs of moisture deposits and mould growth. On the right parts of the structure even shows signs of rotting.

Sick building syndrome (SBS) a medical condition where people in a building suffer from symptoms of illness or feel unwell for no apparent reason. The symptoms tend to increase in severity with the time people spent in the building, and improve over time or even disappear when people are away from the building. (World Health Organisation, n.d.) Spectators and skaters might be under risk of SBS, if mould is extensively present in the structures. Mould will grow on most surfaces if the relative humidity at the surface is above a critical value, the surface temperature is conductive to growth, and the substrate provides nutritional value to the organism. The growth rate depends on the magnitude and duration of surface relative humidity. (ASHRAE, 2009)

6 Moisture content control

It is clear that moisture content can cause problems, if rink space is exposed to high humidity levels for a long period, and in any case it contributes to energy consumption increase. The only method to overcome this issue is to control the moisture content by aid of a dehumidifier. There are different types of dehumidifiers, which are described further in a subsequent report. This section covers a discussion on the required measurements (or sensors) on which dehumidification unit can rely on , as well as what is the appropriate operation range.

The most obvious property of air, that represents its moisture quality is the relative humidity, hence it is commonly used as the reference measurement. In offices or residential buildings, moisture can be controlled by the relative humidity, since the temperature is rather constant. This is not always the case in ice rinks as was shown previously in this report. From Figure 14 it is difficult to analyse moisture content, as relative humidity is affected by the temperature. However, it is obvious that ice rinks 1 and 2 have dehumidification system working according to RH-values, as the air RH is maintained around 70% all season.

To illustrate how RH control approach differs from humidity ratio control, Table 1 is shown. Ice rink 1 is controlled by RH which can be seen due to Ice rink 5 is controlled by humidity ratio, and both in July and December temperatures are considerably higher, however moisture content is lower. From this example it can be concluded, that relative humidity control might be more problematic at higher temperatures, whereas humidity ratio control allows to maintain appropriate moisture levels in a wide temperature range, provided that the dehumidifier capacity is high enough.

Table 1 Comparison between ice rink indoor air parameters, with dehumidifier control based on RH-value (ice rink 1) and on humidity ratio (ice rink 5)

		t (°C)	RH (%)	W (g/kg)
Ice rink 1	July	7.1	74	4.6
	December	4.8	70	3.7
Ice rink 5	July	12	48	4.2
	December	6	61	3.5

Indoor climate data from several ice rinks is compiled, which is described in section about indoor climate. To analyse different humidity control measures, a selection of ice rinks are analysed in further figures.

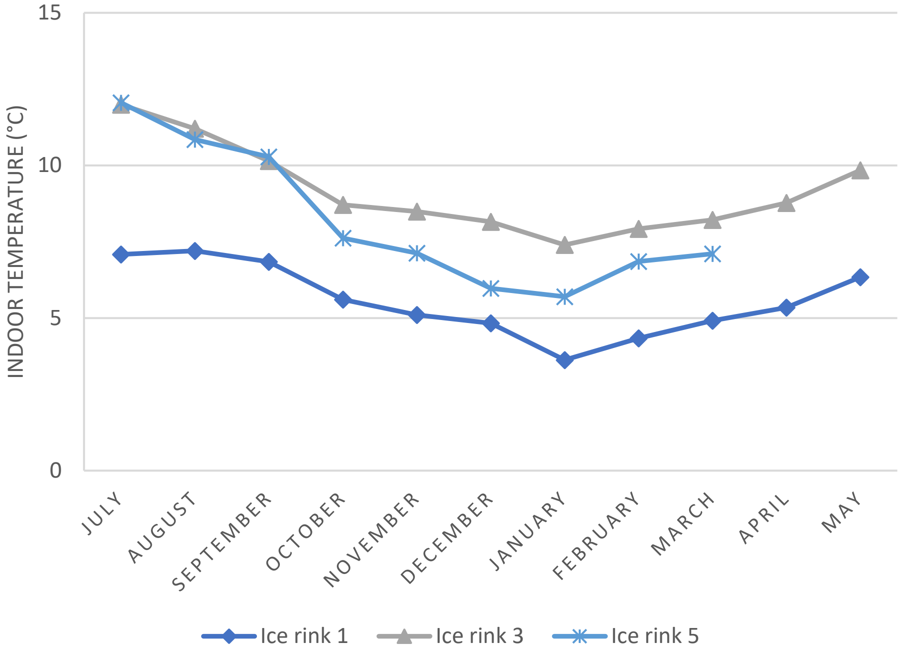

Figure 23 Indoor temperature in selected ice rinks for one season

As can be seen in Figure 23, ice rinks 3 and 5 have similar temperature profiles in the beginning of the season. Until October they are almost equal and have the highest temperatures amongst all analysed rinks. This makes them relevant to compare when it comes to the moisture handling during the most humid part of the season.

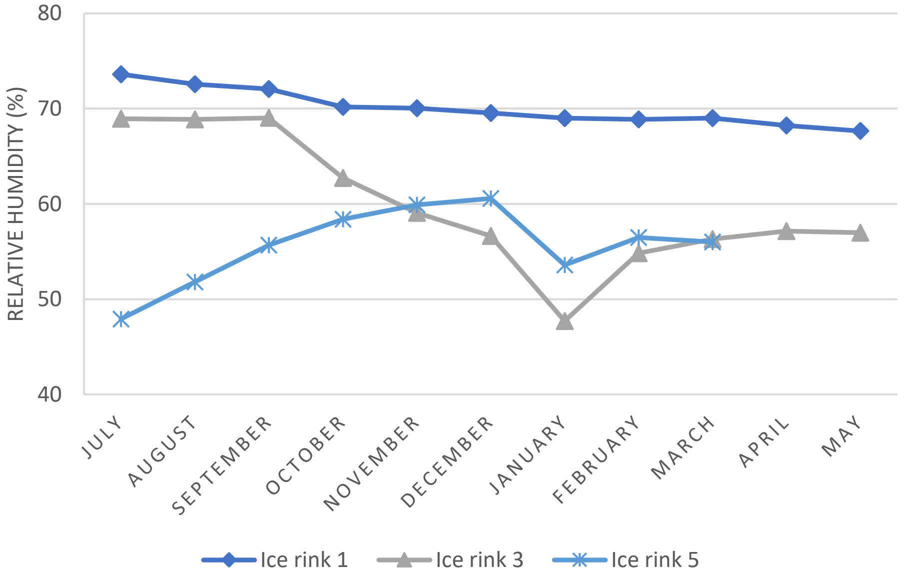

Figure 24 Indoor relative humidity in selected ice rinks for one season

The figure above represents the indoor relative humidity profile for the same three ice rinks. When comparing ice rinks 3 and 5 in period from July to September, it can be seen that in ice rink 3, the RH-value is constant at 69%, whereas ice rink 5 has a trend ranging from 48 to 56 percent. This is due to the fact that in ice rink 3, from October relative humidity becomes dynamic. It might be that dehumidifier is not powerful enough during the period when the ambient air is more humid. On contrary, ice rink 5 maintains a lower relative humidity, when indoor the temperature is higher, which is due to the difference in control strategy.

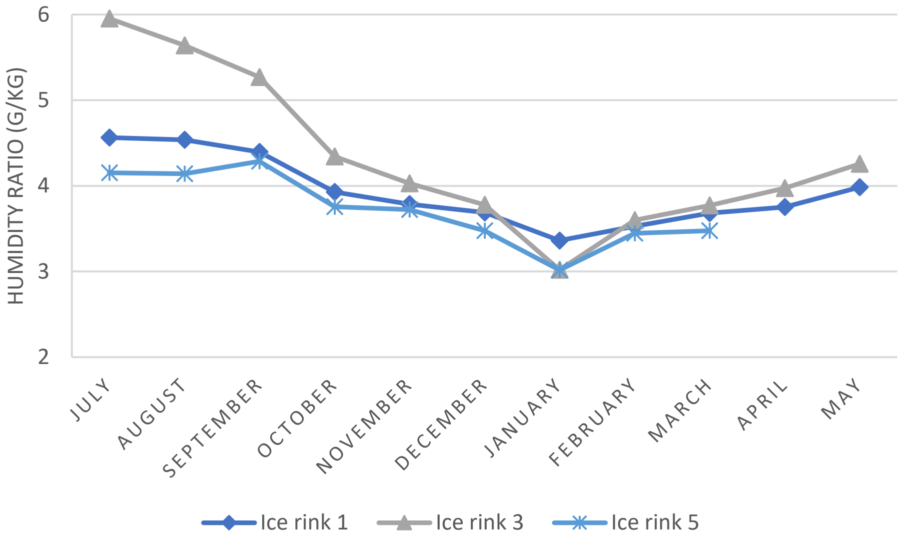

Figure 25 Indoor humidity ratio in selected ice rinks for one season

To illustrate the effect of the temperature and relative humidity combination on the actual moisture content in the rink space, Figure 25 is produced. Undoubtedly, ice rink 3 stands out with the highest humidity ratio values in range from 5.3 to 6 g H_2O per kg of dry air. While ice rink 5, with almost the same temperatures from July to September, but with variable relative humidity, has humidity ratio around 4.2 g H_2O per kg of dry air. Again, the reason for the high humidity content in ice rink 3 is probably the insufficient dehumidifier capacity. Ice rink 5 is as previously stated controlled to humidity ratio and is therefore much more stable.

It is interesting to observe is that in ice rink 1, although the temperature is lower than in ice rink 5, where the temperature ranges from 1 to 5°C, the humidity ratio is always higher. The answer is to be found in Figure 24 where it can be seen that the dehumidifier (ice rink 1) is RH-controlled, as oppose to ice rink 5 which is humidity ratio control.

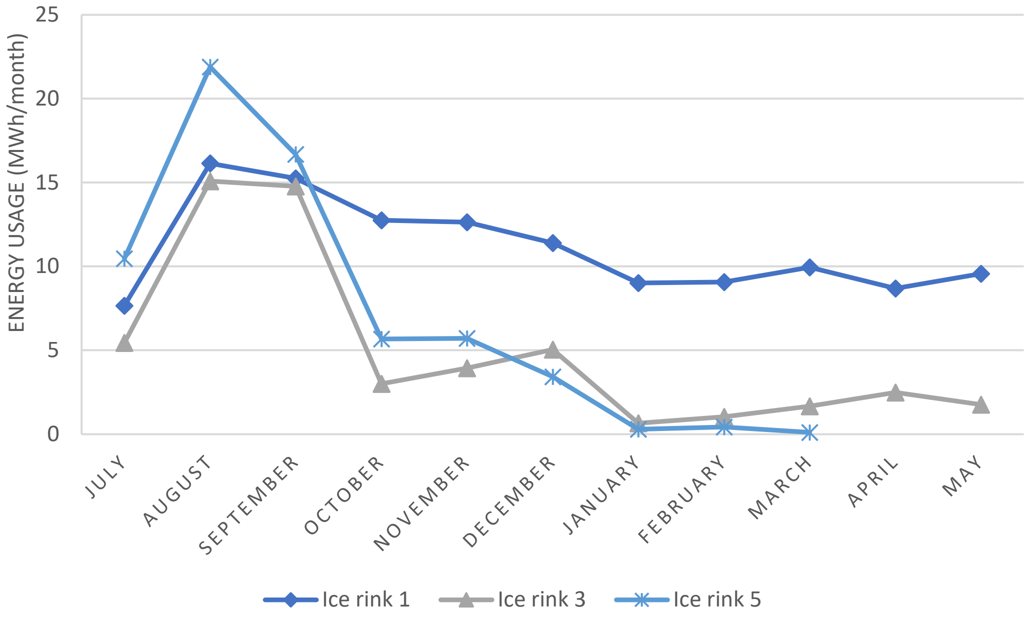

Figure 26 Difference in dehumidification energy usage profile depending on the control strategy.

Another example of the control implication is seen in the figure above where only two ice rinks are studied. Ice rink 5 is at mentioned above controlled to the humidity ratio and number 2 to RH. Once again the pattern is verified that the dehumidifier that is controlled to absolute or dew point will stop operating when the demand decreases whereas the RH controlled often continue to operate. The reason being the lower air temperature in the ice rinks at the colder period which still generates a “high” RH although the dew point (and absolute humidity content) is low.

To understand the impact on energy of previously discussed dehumidifier control strategies Figure 26 is illustrated. Dehumidifier in ice rink 1 operates with the RH setpoint, while two other rinks relate on the actual vapor content (humidity ratio) in air. Once again, the pattern is verified that the dehumidifier that is controlled to absolute or dew point will stop operating when the demand decreases whereas the RH controlled often continue to operate. The reason being the lower air temperature in the ice rinks at the colder period which still generates a “high” RH although the dew point (and absolute humidity content) is low. Without the direct impact on the dehumidifier energy consumption, indirectly “over-drying” may increase the heating system energy usage, because if the vapor pressure in the rink space is decreased unnecessarily even at low ambient humidity levels, it may result in negative pressure in the rink space, which intensifies the driving force of cold ambient air leakages.

Based on the results and discussion above it seems that the best option is to control the humidity to the humidity ratio or the dew point. It is much a more precise control, especially when the indoor temperature changes along the season. Even if the relative humidity control is done according to recommended values at the temperature range, it requires continuous manual change in settings, which is not a modern approach and is not as precise.

Figure 27 Electronic humidistat for dehumidifier control

Many modern dehumidifiers have control units that can handle the different control strategies discussed above, i.e. Relative humidity, Absolute humidity (or Humidity ratio) and Dew point. Figure 27 shows an example of a humidistat controller, where all three options for humidity control are indicated, which implies that the control strategy can easily be changed.

7 Conclusions

You can find the five major energy systems – cooling, heating, ventilation, dehumidification, and lighting – in almost all ice rinks, whether they are large or small. These energy systems interact with each other, whether intended or not. Therefore, it is crucial to develop these systems to work harmoniously; otherwise, achieving significant energy savings might not be feasible.

An ice rink consists of a large ice surface that cools the arena space, driving the heating requirement – assuming a specific temperature is to be maintained. The higher the desired temperature in the arena, the greater the heat load on the ice surface. Ventilation, lighting, and dehumidification systems also contribute to creating a favorable indoor climate, but they also impact both cooling and heating functions.

Moisture sources in an ice rink can be categorized into two main groups: "external sources," such as air leakage where humid outdoor air infiltrates the ice rink through openings, or diffusion where moisture from the outside is transported through the building envelope, and the second group; "internal sources," such as ice rink users (athletes and spectators), resurfacing water, and potentially melted ice pit water that evaporates.

Air leakage proves to be the most significant moisture source, where leaks in the building envelope allow outdoor air to enter the ice rink due to pressure differences caused by wind, ventilation, or a combination of both. The geographical conditions significantly influence the moisture load. Moreover, these conditions vary significantly across Sweden, from north to south. Due to the colder climate in the northern part of the country, the absolute humidity is lower compared to the southern part. For example, the average absolute humidity in Malmö is 2.9 g $H2O$ per kg of dry air lower than in Kiruna.

Unintentional air leaks through the building envelope often negate the need for the ventilation system to introduce outdoor air. Hence, it is generally recommended to close outdoor air dampers to prevent unnecessary intake of outdoor air (and potentially its moisture). If outdoor air is to be introduced, it should only be done when the $CO2$ levels necessitate it. Therefore, fresh air intake should be controlled based on measured $CO2$ levels in the ice rink arena.

Proper humidity control is essential to achieve good ice quality and a healthy indoor climate in the building. When discussing air humidity in ice rinks, people often refer to relative humidity. However, this value varies with air temperature, which in turn often fluctuates during the ice rink season. Therefore, air humidity should be discussed in "absolute terms" to gain an accurate perspective. This can be achieved by using concepts like "dew point" and/or "moisture/steam ratio." A "normal" temperature and relative humidity in an ice rink might be, for instance, 5°C and 70% RH, which corresponds to approximately 3.8 g $H2O$ per kg of dry air and a dew point of about 0°C. Experience has shown that the dew point in an ice rink should be between 0°C and 2°C. If the dew point is below 0°C, the moisture load increases due to greater evaporation of resurfacing water, for instance. On the other hand, if the dew point is higher than around 2°C, there is an increased risk of undesired condensation on boards and other building components cooled by the ice. This becomes more pronounced as the air temperature in the ice rink arena decreases since the inner surfaces of the building become correspondingly cooler, leading to the risk of condensation and frost formation.

The study presents the energy usage of different dehumidification systems in ice rinks, and clear differences emerge based on control strategies. In one ice rink, humidity is controlled towards constant relative humidity (RH), while another is regulated based on steam ratio/dew point. Control based on steam ratio regulates according to actual need, while RH-based control often results in unnecessary operation. The latter occurs because the low temperature in the ice rink leads to high RH values, even though the absolute moisture content and dew point may be low during the colder periods of the year. This leads to "over-drying," which, in turn, results in unnecessary energy consumption for the dehumidification system.

Many modern dehumidifiers have control units that can manage different control strategies discussed in this report, such as relative humidity, absolute humidity (or steam ratio), and dew point. This makes it feasible for many facilities to switch control strategies with the right knowledge.

The next part of the NERIS report will present energy usage in absolute terms and how the control strategies impact it.

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