NERIS – part 4

Moisture-proof ice rinks – construction and dimensioning

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Summary

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 the last part in a series of four, which will address moisture handling in ice rinks. Together these reports will not only provide with fundamental knowledge on how to design the dehumidification function, but they will also give general recommendations regarding the structures that separate the indoor climate from the outdoor as well as the choice of proper materials for the building envelope. Based on the previous reports of the NERIS-project, this last part gives requirements on how the structures of an ice rink and its dehumidification system should be designed and operated in order to have a well-functioning and energy efficient facility from the moisture perspective.

The main function of the building envelope is to separate the indoor climate from the alternating outdoor weather. This implies that heat and moisture transport should be controlled through the building envelope. Support systems such as heating, ventilation and dehumidification should not work more than necessary in order to maintain the desired climate. To avoid moisture or mold damages in climate separating structures a rule of a thumb is to have a higher vapor resistance on the warmer and more humid side of the structure than on the cooler and drier side. In general, it can be said that in the northern part of Sweden the vapor resistance should be higher on the inner part while in mid- and south- Sweden the vapor resistance should be higher on the outer side of the building envelope.

When the aim is to minimize moisture and heat transport into the arena room, focus should be put on eliminating air leakages through the building envelope. An air barrier can be placed basically anywhere in the envelope structure if it has a low vapor resistance. It is especially important that the installation is done so that the air barrier is continuous at joints between different structures, e.g. walls and ceiling.

Besides from the outdoor climate it is also important that the arena room is well insulated from other climate zones within the ice rink. Climate separating doors should be kept closed to prevent air leakage and moreover be insulated and airtight in order to minimize the risk for moisture related issues.

It is recommended that the ventilation function in the arena room is normally operated only by recirculation, i.e. fresh air is not brought in. As a result, the moisture load is reduced while fresh air still enters the ice rink through the building envelope as air leakage which is often enough to maintain appropriate CO2-levels. Best practice would be to have the supply system controlled by a CO2-sensor, so that necessary fresh air would only be supplied on demand.

The ventilation and dehumidification distribution systems of an ice rink should be separated. The general rule is that warm ventilation air should not be blown towards the ice, meaning that the ventilation ducts should be placed away from the ice slab and directed towards spectators instead, i.e. where the heating demand is really located. The dehumidification supply air should be distributed in a channel centered above the ice, as high to the ceiling as possible, which allows to have a more uniform dry air distribution over the ice. The channel should provide an even flow over the whole length and surface area of the ice.

Sorption type dehumidifiers are recommended to be used in ice rinks and have a suitable capacity, which in the case of many ice rinks in Sweden implies around 20 kg/hour. Regarding the heat source for the dehumidifier regeneration, there are several choices but the most energy efficient way is to always use

recovered heat from the refrigeration system as much as possible. Recovered heat has the potential to cover up to 100% of the regeneration demand and after that electrical energy is only needed for the distribution fans.

Correct control of humidity level is important to achieve good ice quality and a healthy indoor climate. The dehumidifier should be controlled to maintain a specific absolute humidity or alternatively a dew point, where the latter should be kept between 0°C and ca 2°C. If it is lower than 0°C it intensifies the moisture loads and if it is higher than 2°C there is an increased risk of problems related to condensation.

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1 Introduction

1.1 Background and scope of the NERIS project

The project name NERIS is an initial abbreviation for Nordicbuilt: Evaluation and Renovation of Ice halls and Swimming halls. NERIS is led by the Department of Building Science at the Royal Institute of Technology (KTH) in Stockholm, Sweden. Financial support has been received from Formas (The Research Council for the Environment, Land Industries and Community Development) and the Energy Agency. The purpose of the project is to "propose methods to be able to inspect and evaluate the functionality of these types of buildings and report various renovation measures that can improve performance". This means that one wishes to achieve an information bank regarding moisture management in ice rinks and swimming pools. The NERIS project started in 2014 and will be completed in 2018.

This report is the last part in a series of four whose task is to treat moisture in ice rinks. Together, the four reports will analyze and explain the mechanisms of moisture in ice rink facilities. Initially, the ice rink technology will be explained and how the moisture problem in a building can arise with this type of application. The idea is to then build a logical sequence of reports in which moisture-related challenges such as moisture sources and other building physical properties together with dehumidification methods and their energy use impact are described in ice rink applications. The goal is that the various parts of this report series should be able to complement each other and be able to provide practical advice and instructions regarding the dimensioning and planning of dehumidification systems in ice rinks.

1.2 Scope of NERIS - Part 4: Moisture-proof ice rinks - construction and dimensioning

This report is the 4th and last partial report within the framework of the NERIS project, which deals with the moisture problem in ice rinks. This knowledge is very fundamental partly for being able to dimension the dehumidification function but also for how to construct the climate shell and choose its constituent materials.

Based on the content of the previous partial reports, this final report presents the requirements for an ice rink's construction and dehumidification system m.a.p. moisture management. The goal is to be able to create as functional and energy-efficient a facility as possible from a moisture point of view. The information must be applicable to both renovation and new construction of ice rinks.

2 Requirements for the building structure of the ice rink

2.1 The climate shell – roof and walls

In addition to being able to fulfill the requirements placed on its carrying capacity, the climate shell's main purpose is to separate the indoor climate from changing conditions in the surroundings in an energy-efficient way. This means that heat and moisture transport should be able to take place in a controlled manner and that mechanical equipment should not have to work unnecessarily to maintain the climatic conditions necessary for the intended application. The requirements for the layers in the climate shell that are considered most important in terms of heat and moisture transport resistance from the ambient air to the indoor climate of the ice rink are described below.

2.1.1 Thermal insulation

Differences in air temperature are the driving force behind heat transfer between two different climate zones. In warm outdoor climates, heat tries to get into the colder ice rink, which increases the heat load on the ice with an increased cooling demand as a result. In colder outdoor climates, the reverse can happen, i.e. the relatively warmer ice rink emits heat to the colder surroundings. In these cases, the heat demand in the ice rink increases, as you usually try to maintain a constant temperature level in the arena room with an air heating system.

Figure 1. A newly built ice rink with large elements of wood and perforated sheet metal in the walls.

To minimize the cooling and heating needs in an ice rink due to the surrounding climate, its climate shell is usually thermally insulated. The insulation material acts as a thermal barrier between the indoor and outdoor climate, where the aim is to minimize unwanted heat transfer between the climate zones so that thermal comfort can be maintained energy-efficiently throughout the year.

Materials that can be used for thermal insulation must be able to provide sufficiently high thermal resistance under given conditions. There are several different types of solutions, where the choice of insulation material often depends on local prices and availability. Ice rinks in Sweden are generally thermally insulated with mineral wool or polyurethane. The thickness of the insulation layer is dimensioned so that the total thermal resistance can ensure the facility's functionality in a cost-effective manner, i.e. the marginal benefit in energy efficiency must be worth its investment.

2.1.2 Air barrier

Air leakage can cause great strain on the indoor climate of the ice rink, and therefore it is often desired that its occurrence in the climate shell be minimized. Depending on the season, it may be a question of loads that increase the cooling, heating or dehumidification needs in the facility. Especially during warm periods, the operability of an ice rink can become a critical issue if unwanted amounts of warm and humid air infiltrate the facility and the capacity of the dehumidifier is not sufficient.

Different material types have different properties in terms of air permeability, i.e. how easily air can penetrate the material. When several material layers are combined to form a structure in the climate shell, the dimensioned penetration ability of the air through all layers is often low. Unwanted air leakage, however, mainly occurs at cracks, joints, etc. in climate-separating structures that are not sufficiently sealed. To counteract this type of air leakage, an air barrier is installed to prevent air from passing through the small openings in the structure.

Figure 2. Traces of air leakage between wall and ceiling.

When installing an air barrier, it is important to ensure that it is continuous, especially where different types of structure meet (for example, walls and ceilings). Deficiencies in the installation of the air barrier are often discovered later, because the resulting air leakage increases the moisture load on the material layer surrounding the leakage opening and usually leaves visible traces over time. Figure 2 shows a typical case of air leakage in an ice rink where the dark areas reveal air leaking into the joint between the wall and ceiling. The exhaust fan which is often a is a holdover from the days when ice machines had internal combustion engines contributes to the leak. The discoloration is likely a combination of deposited particles and possibly mold. The inside of the ice rink is often relatively cold and when warm and humid air leaks in at the beginning of the season, it will precipitate moisture on the surfaces that are colder than the air's dew point. This is the basis for the discolorations that often appear in the upper parts of ice rinks such as roofs and walls.

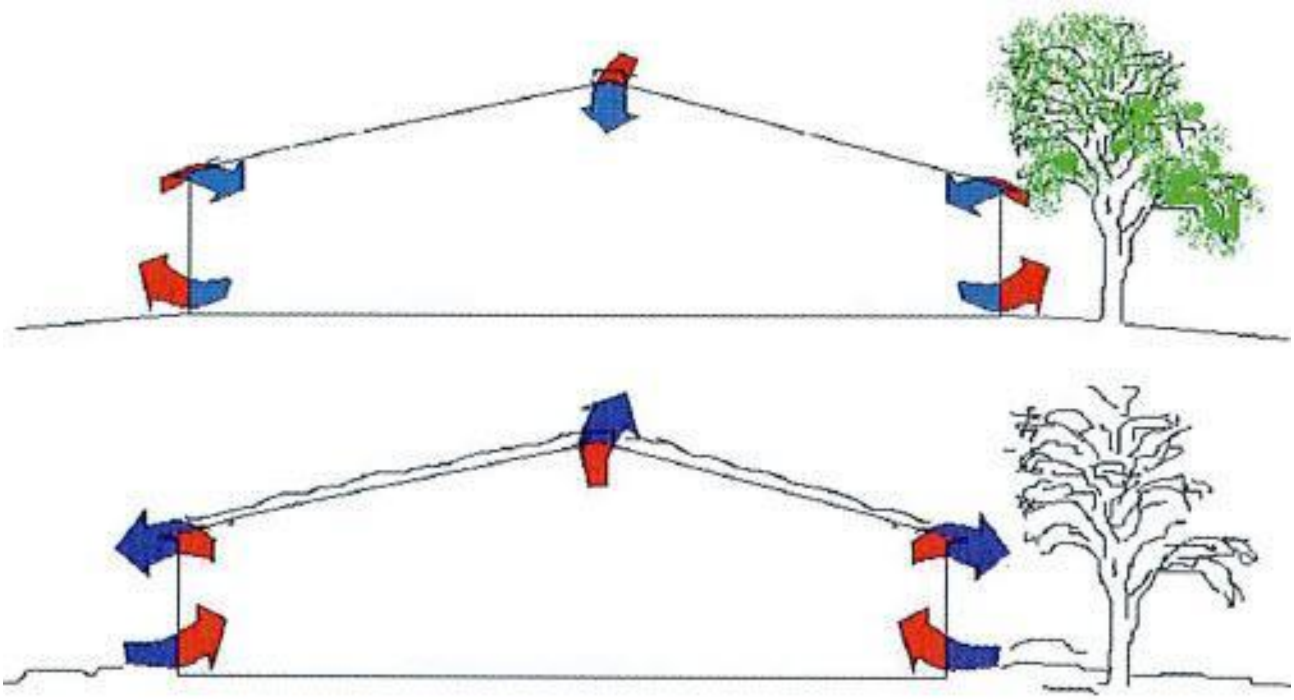

Figure 3. The chimney effect can change direction in an ice rink depending on the season. (Rakennustieto, 2007)

During warm periods, there is a negative pressure difference between the indoor and outdoor air in the upper part of the ice rink, above the neutral pressure line discussed in Part 3 of the NERIS project. Figure 3 shows the consequences of these pressure differences, where warm and moist air infiltrates through the upper part of the ice rink's climate shell. This suggests that traces of air leakage are often observed in the upper part of the ice rink where moisture has condensed on surfaces that are colder than the dew point of the infiltrated air.

On the basis of what has been stated above, it can be concluded that it is not enough to just use airtight materials, but you also have to think about the whole with all the details and especially focus on the connection points.

General requirements for a building's tightness are usually determined by local standards. In Sweden, there are no specific tightness requirements for an ice rink or public building, however, it is mentioned in the Swedish Housing Agency's building regulations that "The building's climate screen must be so tight that requirements for the building's specific energy use and installed electrical output for heating are met". Furthermore, it is stated in the same regulations that "To avoid damage due to moisture convection, the building's climate separating parts should have as good air tightness as possible. Special care to achieve air tightness should be observed at high moisture loads such as in bathhouses or at particularly large temperature differences."

If requirements for a building's airtightness have been set during its design, it should be verified that the set requirements have been met upon handover after construction. This is done in the form of a pressure test according to European standards, where mechanical equipment creates a 50 Pa high overpressure inside the building in relation to the surroundings. Measured airflows are then used to evaluate the climate shell's performance. It should be noted that the method only serves as a diagnostic tool, and does not measure the actual air leakage under normal pressure conditions. Part 3 of the NERIS project describes two methods for estimating the real air leakage in an ice rink.

As an air barrier prevents air from passing through a climate shell, it will be pressurized due to the chimney effect, ventilation system and wind. When choosing materials and installing, you must therefore also take into account the strength requirements of the air barrier.

2.1.3 Vapor barrier

Diffusion of water molecules through a structure is driven by the differences in the partial vapor pressures of the air on each side of the structure. Diffusion is a much slower process for moisture to move than convection, making it a relatively small source of moisture in an ice rink. However, diffusion of moisture can have serious consequences on the structure of the ice rink such as walls and roof under real conditions. When moisture diffuses through the structure's layers and when the relative humidity and temperature become high enough at some point, there is a risk that microbial damage may occur. However, microbial damage also requires time to develop, and in several cases it is expected that dry periods in the surrounding climate can naturally wipe away this moisture load before noticeable damage can occur.

Similar to air permeability, different material types also have different properties in terms of vapor permeability, i.e. how easily water vapor can penetrate the material. To prevent the diffusion of moisture through a structure, a material with low vapor permeability is often installed, a so-called vapor barrier. While a vapor barrier and an air barrier should be seen as separate functions, it is not rare that these are fulfilled by the same material layer in the structure where the vapor barrier can also be an air barrier.

If you choose to install a vapor barrier, it is important that it is placed correctly in the climate shell of the ice rink, taking into account the climate conditions on each side of the structure and the choice of materials. Classically, in ordinary buildings in Sweden, the vapor barrier is placed on the inside of the structure, because the indoor climate is usually warmer and more humid than the outdoor climate, and moisture tends to diffuse outwards through the climate shell. In the case of ice rinks, however, the opposite is normally the case, i.e. if you have a vapor barrier, place it on the outside of the structure. From a Swedish perspective, the ice rinks are located in different climate areas - from north to south - where the surrounding climate varies between being significantly more humid to being drier. This means that moisture migration can go in both directions during a season.

In summary, it can be said that a vapor barrier should absolutely not be placed on the inside of an ice rink! If you can show that the vapor content is always higher on the outside, which is basically the case in southern Sweden, then you could imagine a vapor barrier on the outside. In practice, it is recommended not to have a vapor barrier and to use wall materials in the wall construction that cannot absorb moisture. The importance of the materials is further discussed below.

2.1.4 Typical wall structures

Typical wall structures in ice rinks have been analyzed in a study carried out at KTH in terms of performance in different climate areas and seasons in Sweden (Yousif & Douglah 2017). The main purpose has been to assess the risk of moisture damage and mold growth in these structural solutions.

A general rule regarding vapor transport resistance in a climate separating structure is that the resistance on the warmer and wetter side of the wall core should be higher than on the colder and drier side. The vapor transport resistance in a material layer is determined by the vapor permeability of the material and the thickness of the layer. In cases where a vapor barrier is placed in the structure, it should be done on the warm and moist side of the thermal insulation material. However, the structural solution must always be carefully analyzed in order to ensure its functionality in the local climate conditions.

Figure 4 shows a suitable wall solution according to the analyzes for a typical ice rink in Stockholm's climate. In this solution, the sheet metal panel acts as weather protection with a ventilated air gap to the surrounding climate. The wall core consists of a wooden board that acts as a windbreak, mineral wool as a thermal insulation layer, and a wooden board on the inside. Since the humidity level in the surrounding climate is often higher than in the ice rink during most of the year in Stockholm's climate area, the vapor transport resistance on the outside of the thermal insulation should be higher than on the inside, which in this wall solution has been achieved with a thicker wooden board on the outside than on the inside in the wall core.

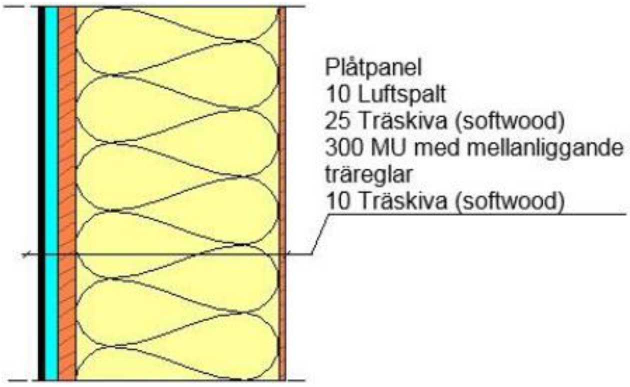

Figure 4. Example of a wall structure suitable for Stockholm's climate.(Yousif & Douglah, 2017)

Figure 5 shows a suitable wall solution according to the analyzes for a typical ice rink in Kiruna's climate. In this solution, the wooden panel acts as weather protection with a ventilated air gap to the surrounding climate. The wall core consists of a wooden board that acts as a windbreak, mineral wool as a thermal insulation layer, and a plywood board on the inside. During a large part of the year, Kiruna has a climate that is drier than in the ice rink, which means that the vapor transport resistance on the inside of the thermal insulation must be higher than on the outside to prevent the diffusion of moisture through the wall to the outside. In this case, a thicker plywood board has been chosen for the inside because the material is more resistant to vapor transport than the narrower wooden board on the outside of the wall core.

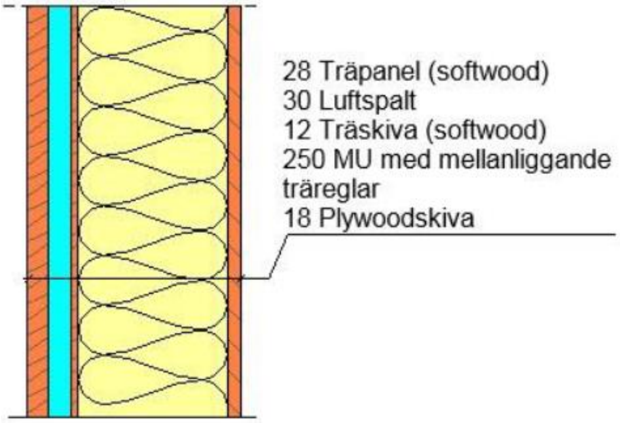

Figure 5. Example of wall structure suitable for Kiruna's climate.(Yousif & Douglah, 2017)

In the analyzed wall solutions, it has been assumed that moisture storage is a necessary and important function in a climate-separating structure. The reason is that it is assumed to be able to be used as a buffer between damp and dry periods, and therefore mineral wool has been used exclusively as thermal insulation material in the analyzed wall solutions. In the case of ice rinks, however, there is not full agreement as to whether moisture storage is necessary, good, or bad. Therefore, other alternatives to insulation materials that have low moisture retention properties should not be ruled out, e.g. polyurethane.

Plastic or sheet-covered sandwich panels have recently become increasingly common solutions for climate shells in ice rinks due to their good heat and moisture insulation properties and that they are practical to install. Figure 6 shows an example of a panel where the insulation material is packed between two layers of plastic or sheet metal. Since plastic and sheet metal are impermeable materials in terms of air and moisture, they act as air and vapor barriers, respectively, and thus make the sandwich panels air- and diffusion-tight. There is, however, the risk that moisture can begin to be stored in the insulation material if it manages to enter the structure through openings via convection, which increases the demands on the panels' installation, where you should ensure that they are well connected to each other and that the joints are sealed so that neither air nor moisture can get through. Furthermore, it is recommended that the insulation material is not of a type that absorbs moisture, e.g. mineral wool. For e.g. cold and freezer storage, insulation materials based on polyurethane or polyisocyanurate are often used.

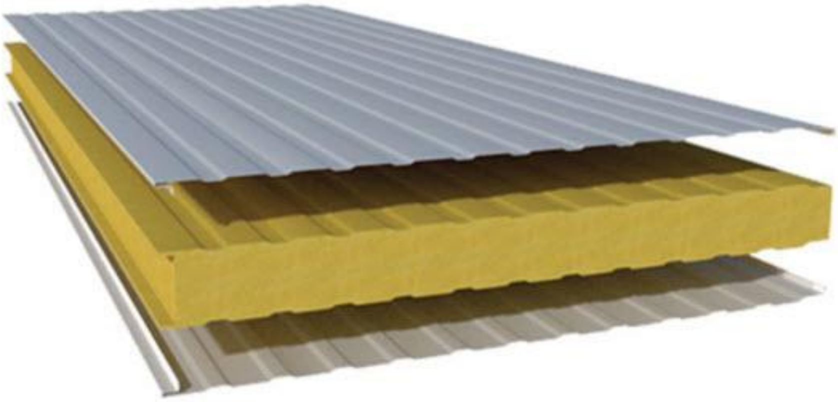

Figure 6. Sandwich panel with polyurethane as insulation material.

Whether or not a vapor barrier should be used in an ice rink's climate shell remains a somewhat open question. As a source of moisture, diffusion of moisture through an ice rink's climate-separating structures is almost unimportant, however, it should be ensured that the structures themselves are functional and that diffusing moisture cannot lead to moisture damage and mold growth. Due to from the special indoor climate in an ice rink and its relationship to the varying outdoor climate, it can be stated that moisture should either not be able to diffuse through the climate shell at all or the structure should be made so that any moisture that gets into the structure can also get out of it. In cases where you choose to place a vapor barrier in the structure, it should be done on the warm and moist side of the thermal insulation material in the structure, which may depend on the climate area in which the ice rink is located. Exact placement of the vapor barrier also depends on the choice of other materials in the structure, and should be carefully analyzed to ensure that there is no risk of moisture damage.

In general, however, it can be stated that a vapor barrier should not be necessary in Sweden's climate, but it is sufficient that the moisture transport resistance in the climate shell layer has been dimensioned correctly so that any moisture that has diffused into the structure can also get out on the other side. If the climate shell consists of diffusion-proof sandwich panels, you should make sure that the joints are tight, or ensure that any moisture that convectively enters the structure via openings, cracks, etc. can also get out so that harmful moisture loading is prevented.

When it comes to minimizing moisture and heat load on the indoor climate of the ice rink, the greatest focus should be placed on preventing air leakage through the climate shell. An air barrier can in principle be placed anywhere in the wall core if it has low vapor transport resistance. From an installation point of view, it is usually easier to place the air barrier on the outside of the wall core, as the inside is more often in contact with other structural elements.

Figure 7. Air barrier/windscreen as part of a wall's construction (www.isola.se).

The vapor transport resistance in an air barrier should be as low as possible so as not to affect the moisture balance of the structure in terms of diffusion. Table 1 compares the vapor transport resistance of an air barrier with other typical building materials. For a material of given thickness, an Sd value is given which represents the vapor transport resistance in comparison with air, i.e. 0.4 mm sheet metal has the same vapor transport resistance as 1500 m of air. With this information, you can conclude that tin and polyethylene are effective vapor barriers, while i.a. plywood's effect on vapor transport resistance can also be applied in structures. The air barrier material can be chosen so that it has such a low Sd value that it does not affect the moisture balance in a structure in terms of diffusion, and can therefore be placed anywhere in the climate shell. Versions of air barrier materials exist where the vapor transport resistance is higher, and then its effect on the moisture balance must be considered.

Table 1. Vapor transport resistance in typical wall construction materials.

Material	**Thickness (mm)**	**Sd value (m)**
Metal plate	0.4	1500
Polyethylene	0.2	70
Plywood	18	12.6
Wood	28	5.6
Mineral wool	200	0.26
Gypsum board	13	0.11
Air barrier/windscreen	0.2 – 0.3	0.05 – 0.7

2.2 Ispists

The ice rink plays an important role in the ice rink's energy use as it must be used to remove heat from the ice throughout the ice season. Since a coolant circulates in the track pipes located in the piste, the heat transfer properties of the piste should be optimized to obtain the most functional and energy efficient facility possible. The surface layer in which the track pipes are located must have the highest possible thermal conductivity to promote heat transfer between ice and coolant, while the layer under the track pipes must be as thermally insulated as possible to minimize unnecessary heat loads and the risk of problems with frost. In practice, an ice slope can be divided into two types: covered and uncovered.

2.2.1 Covered piste

The most common type of piste is covered with a layer of concrete or asphalt in which the track pipes are located. This solution is considered advantageous as it is practical to lay ice and the piste surface does not contaminate the ice. To prevent the uncontrolled spread of meltwater at the end of the season, the solution requires a drainage system placed around the piste to collect that meltwater and then lead it to the sewer system. The ice pist itself absorbs very little moisture, which naturally dries outside the ice season.

Figure 8. Drainage chute outside the ipiste to handle meltwater.

Due to its function, the piste will have different temperature levels throughout the year, which also differ from surrounding structures. This results in the concrete or asphalt layer shrinking and expanding, which causes pressure conditions that, in the worst case, can cause damage to surrounding structures or the track itself. The covered piste must therefore be separated from the surrounding floor structures through a so-called expansion joint to prevent this.

2.2.2 Uncovered piste

A cheaper investment solution is to lay the track pipes in a gravel layer, see example in Figure 9 where the pipes can also be seen in the gravel. In this piste solution, the pipes lie freely in the gravel layer, which facilitates installation compared to a covered piste. However, maintenance of the pistes becomes somewhat more difficult and gravel pistes also contribute to dirtying the ice rink's other spaces.

Figure 9. Gravel rink where even the surrounding surfaces in the ice rink are completely or partially "open", i.e. they have no covering layer.

One aspect that affects the operation and maintenance of a gravel piste is that it absorbs and emits moisture. When the ice season is over and the ice melts, the water sinks down through the gravel surface. This amount of moisture is stored to some extent in the gravel and then begins to be released (evaporated) into the indoor climate of the ice rink when it gets warmer in the rink. This creates a significant moisture load. Figure 10 shows an example where the dehumidifier in an ice rink with a gravel rink had been left in operation even after the ice season. The high energy consumption during the summer months (April – August) - even though the hall is not in operation - shows that the dehumidifier has to work "hard" to dehumidify the indoor climate. The source of moisture is both moisture that had been stored in the screed but also infiltrating ambient air. The consequence is a sky-high electricity bill to no avail!

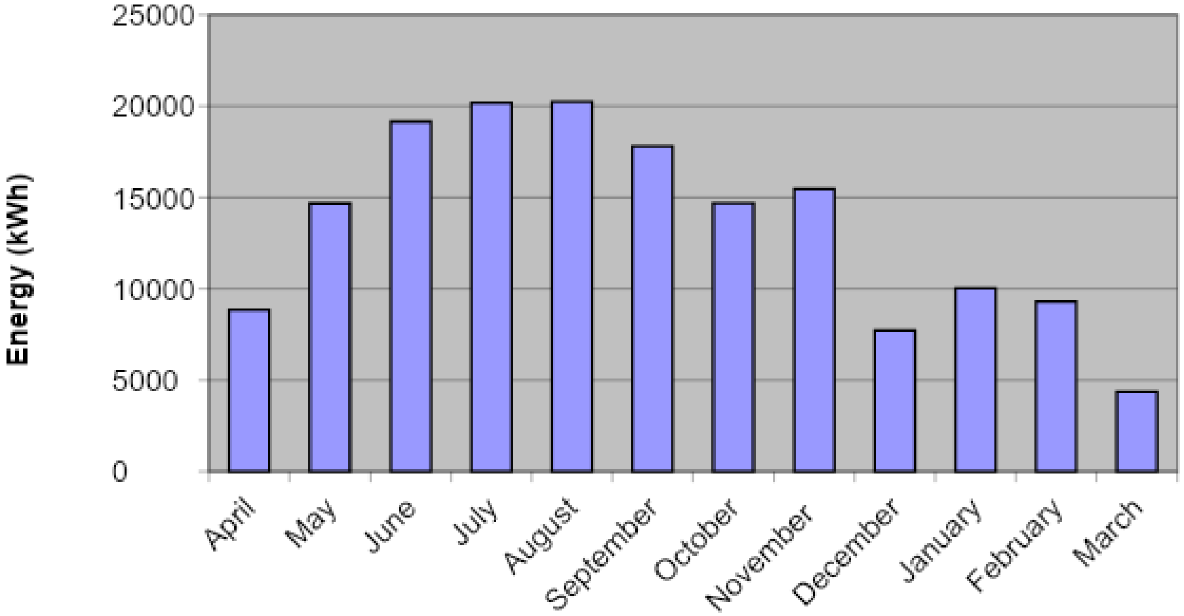

Figure 10. The dehumidifier's energy use in an ice rink with a gravel rink.

The humidity in an ice rink needs to be managed in the off-season but running the dehumidifier is probably the best solution. Above all, the moisture release from the ice rink and other parts of the floor that are not covered must be aired out so that the relative humidity is nominally kept below 70%, where the limit for mold growth is, otherwise moisture damage in the ice rink can occur. This shows that gravel pistes from a moisture point of view will increase the load out of season. If you then have floor surfaces that are not covered, i.e. open gravel or equivalent, this will contribute to the moisture load both during and out of season. It is therefore recommended that you at least cover floor surfaces around the piste with asphalt or equivalent to avoid the ground as a source of moisture in the hall.

2.3 Climate zones

Air leakage through an ice rink's climate shell is considered to be the biggest source of moisture and has therefore been the focus of the NERIS project. However, there are spaces within the ice rink whose indoor climate is noticeably different than in the arena room, such as changing rooms, showers, cafeteria etc. These spaces have higher temperature and humidity levels and should therefore be treated as separate climate zones from the arena room in the ice rink building. This means that the arena room should be kept separate from the other climate zones with insulated walls and doors, have separate air treatment systems, and that air leakage between the spaces should be as low as possible. Figure 11 shows an example of unwanted air leakage through intentional openings, where toilet doors have been left open so that warmer and more humid air can enter the arena room of the ice rink. To prevent these types of scenarios, doors and gates should be fitted with shut-off features, door pumps. Furthermore, it is recommended to minimize the number of intentional openings to other climate zones, e.g. via by applying the so-called airlocks discussed in the 3rd interim report.

An important addition regarding the separation of climate zones is that the separating doors must also be sufficiently insulated, otherwise the risk of unnecessary heat loads and condensation problems increases. In the example below with the open toilet doors, it turns out that the doors themselves are of the simple and uninsulated variety, which is not favorable.

Figure 11. T.V. Open toilet doors towards the ice rink's arena room. T. H. Non-insulated doors are not suitable for separating climate zones.

Another case is the ice machine garage, which is often connected to both the arena room and the surrounding climate. This is to be able to treat the ice with laying water and remove ice scraps that are dumped outside the ice rink. This happens several times during the day to be able to maintain the ice quality and there is a risk that the gates between the arena room, the ice machine garage and the outside are kept open at the same time, which creates direct air leakage from the surroundings into the arena room of the ice rink. The garage should therefore be equipped with automatic doors that can be operated by the ice machine driver so that these are never open at the same time.

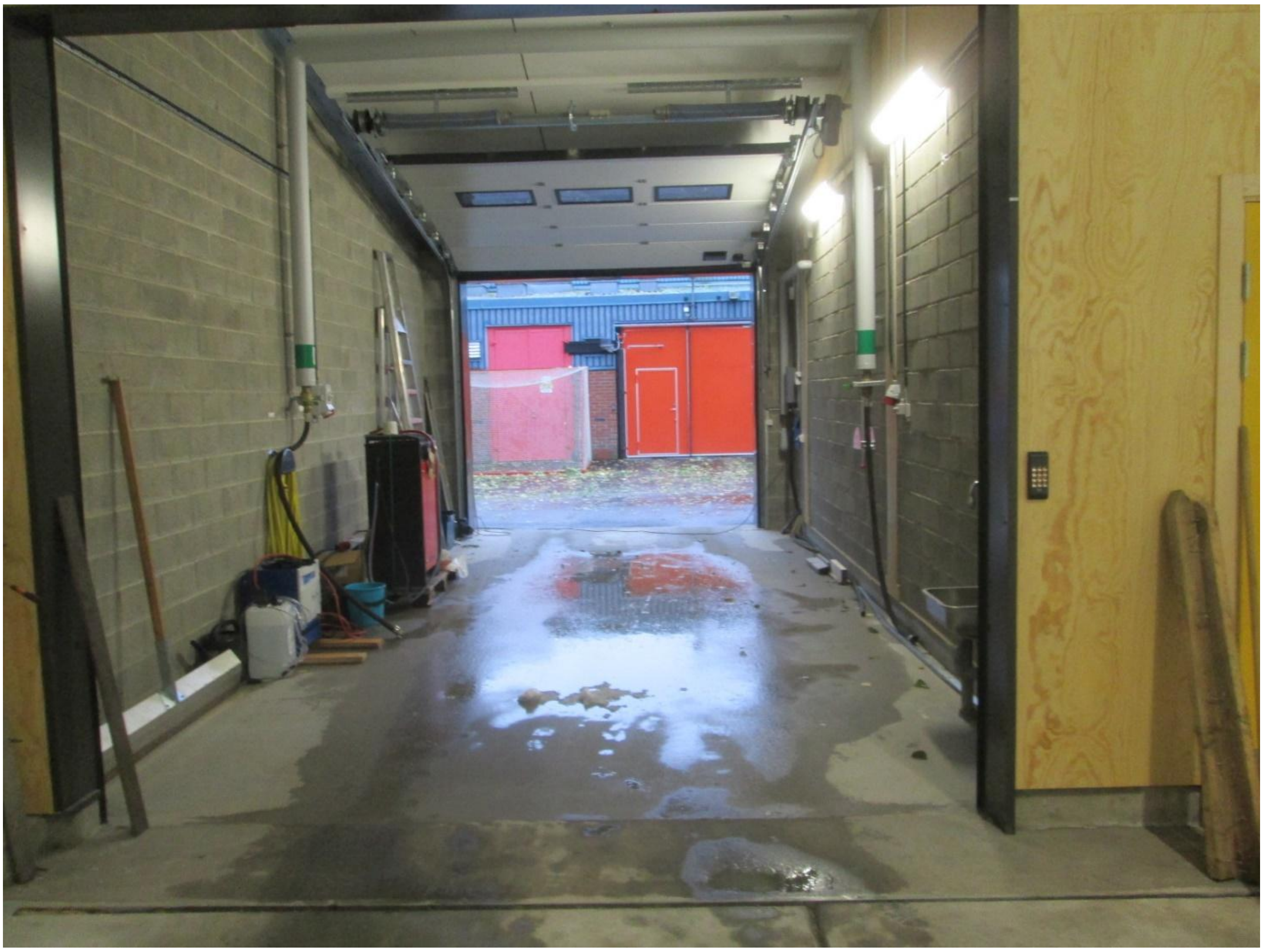

Figure 12. Example of an ice machine garage with roller doors at both ends, both of which are open!

The picture above shows a transport corridor/ice machine garage where both doors are designed as roller doors which can also be operated remotely. This is a good solution where the spaces in question can act as a lock. Unfortunately on this occasion both gates were open!

3 Requirements for the ventilation function

Fresh air is a prerequisite for maintaining a satisfactory indoor climate, which makes its availability mandatory in buildings. Without access to fresh air, the levels of CO2 content and other pollutants in the indoor air are raised, which are proven to have negative consequences for human performance and, in worse cases, also for health. Therefore, local building codes prescribe a minimum fresh air flow, which in Sweden is 0.35 l/s/m^2 in a space that is also normally supplemented with 7 l/s/person depending on the purpose of use of the space (e.g., schools, office environments, etc.).

Figure 13. The distribution system of the ventilation function in an ice rink.

A more advanced method that is applied nowadays is demand-controlled ventilation, i.e. capacity-regulated fresh air flow to maintain the air quality at a certain level. The CO2 content is often used as an indicator, the level of which also usually correlates with the concentrations of other pollutants in the indoor air. For an 8-hour long working day, 5000 ppm has been set as the limit value for the CO2 content in several countries in order to avoid negative physiological effects. However, this is a high level in itself that is rarely achieved under normal conditions in ice rinks.

A current limit value used in Sweden for offices, schools and the like is what is considered the comfort limit, i.e. as the air quality is sufficient and should not affect a person's well-being or mental performance. According to several standards, this limit is 1000 ppm, however, there seems to be no obvious reason why it is at this particular level and there are arguments that point to the fact that one should instead have more flexible limit values that take into account the building type and its use profiles (Persily, 2015). As an example, it can be mentioned that schools in Great Britain have set a limit value of 1500 ppm on the average CO2 value during the school day (Department of Education and Skills, 2006). The same limit value can also be found in schools in i.a. Germany and Switzerland (Deutsches Institut für Normung, 1994), (Schweizerische Normen Vereinigung, 1992).

Compared to schools, offices and other public buildings, an ice rink is of course a completely different case. This type of facility is rarely in full use, i.e. so that the maximum personal load is achieved, and in cases where it is full, it is usually a question of exposure for relatively short periods of time - normally 2–3 hours. The activity in an ice rink is also significantly different from other buildings such as offices and schools. It can be argued that the type of users that players and spectators make up in the facility are less dependent on CO2 levels than e.g. office workers or school students when they are exposed to the indoor climate for 8 hours per day.

CO2 measurements have been carried out in a larger ice rink with approx. 4000 spectators and the results can be seen in Figure 14. The comfort limit of 1000 ppm is exceeded during the match period of approx. 2.5 hours, however it is kept below 5000 ppm by a good margin. Furthermore, it can be observed that after its use, the CO2 content drops during the night to the normal level due to air leakage. Since this form of use does not happen very often in an ice rink, it can be debated whether it is necessary for such a facility to invest in an air treatment system that should be able to cover the maximum need for fresh air (to keep the CO2 level below 1000 ppm). The people/spectators will hardly experience any comfort problems during this short-term exposure, so the need for fresh air is in practice considerably less than is dimensioned for in many cases. This means that in many facilities one would have to manage with a lower capacity of the ventilation than what is actually installed.

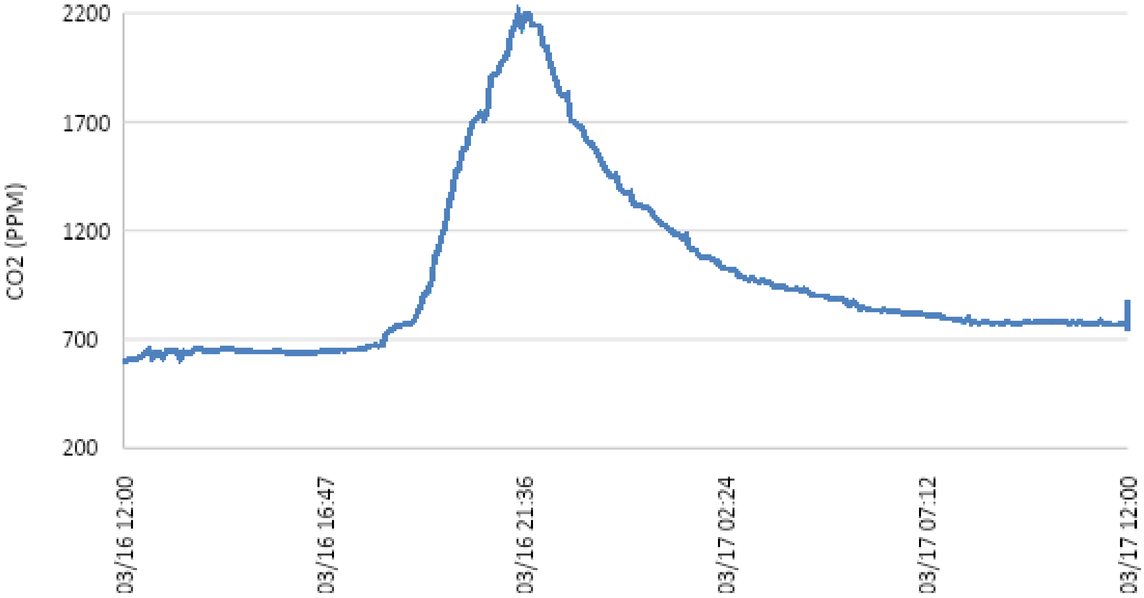

Figure 14. The CO2 concentration measured over 24 hours in a larger arena during a match.

Figure 15 shows the measured CO2 content in an average-sized ice rink in Sweden over a six-day period. Here you can see that the comfort limit of 1000 ppm is never exceeded, even though the facility does not actively take in fresh air. Measurements in other facilities of the same type and size show maximum values of approx. 1200 ppm, which indicates that active intake of fresh air in these existing facilities does not seem to bring any real benefit, but only causes unnecessary strain on the facility's energy system. Most facilities have so much accidental fresh air ventilation that they do not need active ventilation, i.e. fresh air intake. If, on the other hand, these facilities were more airtight, i.e. had less involuntary ventilation, demand-controlled fresh air intake could be more relevant.

Figure 15. The CO2 content in a typical ice rink without controlled fresh air intake over a six-day period.

The main task of the ventilation system in ice rinks is often rather to distribute heat, as the ventilation unit is typically connected to a heat source. From an energy saving point of view, recovered heat from the cooling system is an excellent heat source, as it is a matter of "free" heat whose temperature level in several cooling system types satisfies the requirements to be used in this form of heating the arena room.

However, heating the ice rink's arena room should not be used as a method to counteract the moisture problem, that is taken care of by the ice rink's dehumidification system. To avoid unnecessary heat stress on the ice, it is therefore important that warm air is distributed correctly in the arena room. Requirements for the distribution of warm air are dealt with in connection with the distribution of dehumidified air in section 4.4.

4 Requirements for the dehumidification function

The need for dehumidification in an ice rink depends on how big the moisture sources (moisture loads) are. The moisture load is controlled by the amount of moisture that enters an ice rink through the air and moisture transport resistance of the climate shell and the ventilation's minimization of fresh air intake. Requirements for these and other methods to minimize air leakage have been explained earlier in this interim report.

In order to further reduce the moisture level in an ice rink so that it becomes functional, active dehumidification is required, i.e. a dehumidification system. The previous interim reports in the NERIS project have shown strong arguments for the need for active dehumidification in an ice rink, and in this last interim report, general requirements for a dehumidification system will be explained, e.g. in terms of design, size and use.

4.1 Capacity

The dehumidifier's capacity requirements are a fairly complex issue that depends on several factors. The most important are:

- The volume of the ice rink
- Use of the ice rink and crowd
- Ice season length and time of year
- Geographical location, i.e. local climate conditions
- Airtightness of the climate shell

Ice rinks can vary in size depending on audience demand, which in the event that it is high increases the volume of the ice rink significantly. The volume of the ice hall does not in itself affect the humidity level, but as the area of the climate shell becomes larger, there are more opportunities for air leakage, which increases the humidity load. Even ice rinks that cover more or less the same area and have the same high audience capacity can have very different volumes due to differences in ceiling height. The most common ice rinks in Sweden have an audience capacity of between 500 and 1000. The arena rooms of these facilities cover a ground area of around 2200–2800 m^2 and has a volume of approximately 16,000 to 25,000 m^3. Dehumidification requirements will vary greatly in different ice rinks, and each ice rink must therefore be analyzed separately.

Figure 16. Activity in an ice rink in central Sweden.

In addition to the size of the ice rink, the length of the ice season and when it falls in the year also play an important role. The need for dehumidification increases significantly if the ice season starts in August compared to October, and even more so if you want to operate the ice rink all year round. The local climate also plays a noticeable role in the dehumidification requirement and was analyzed in the 1st interim report of the NERIS project. In Sweden, it could especially be noted that the need for dehumidification drops noticeably in the northern part of the country, when three different climate areas were compared.

To give a general indication of the dehumidification requirement in a typical ice rink in central and southern Sweden, calculations can be performed based on available data from an existing facility that has an ice season from late July to mid-March. The dehumidifier's capacity is 20 kg/h at a process air intake with a 2°C dew point (8°C warm air with a relative humidity of 65%). When the indoor climate was analyzed, it could be observed that the capacity of the dehumidifier was not sufficient to cover the dehumidification demand during the most humid period of the season. The designed dew point level of 2°C was exceeded on 10% of the days of the season, which still indicates that the capacity was sufficient for most of the season.

Figure 17 shows collected data on the capacity level of the dehumidifier in the ice hall when the designed dew point level in the indoor climate could be maintained. Based on this data, a linear trend line could be calculated indicating the capacity requirements of the dehumidifier in relation to the moisture level in the ambient climate. According to this calculation model, the capacity of the dehumidifier in this ice rink would be increased from 20 to 28 kg/h in order to be able to maintain the dew point level in the ice rink during 100% of the days of the season, instead of the 90% that is the situation today. It is assumed here that the highest possible moisture content in the ambient air could amount to 12 gH2O/kg air, which is very high by Swedish standards but still possible. This is quite a large increase in capacity, and whether it is really necessary is something that also needs to be investigated on a case-by-case basis. Far from all technical systems are dimensioned for the "worst case" and dehumidifiers in an ice rink are likely one of these applications.

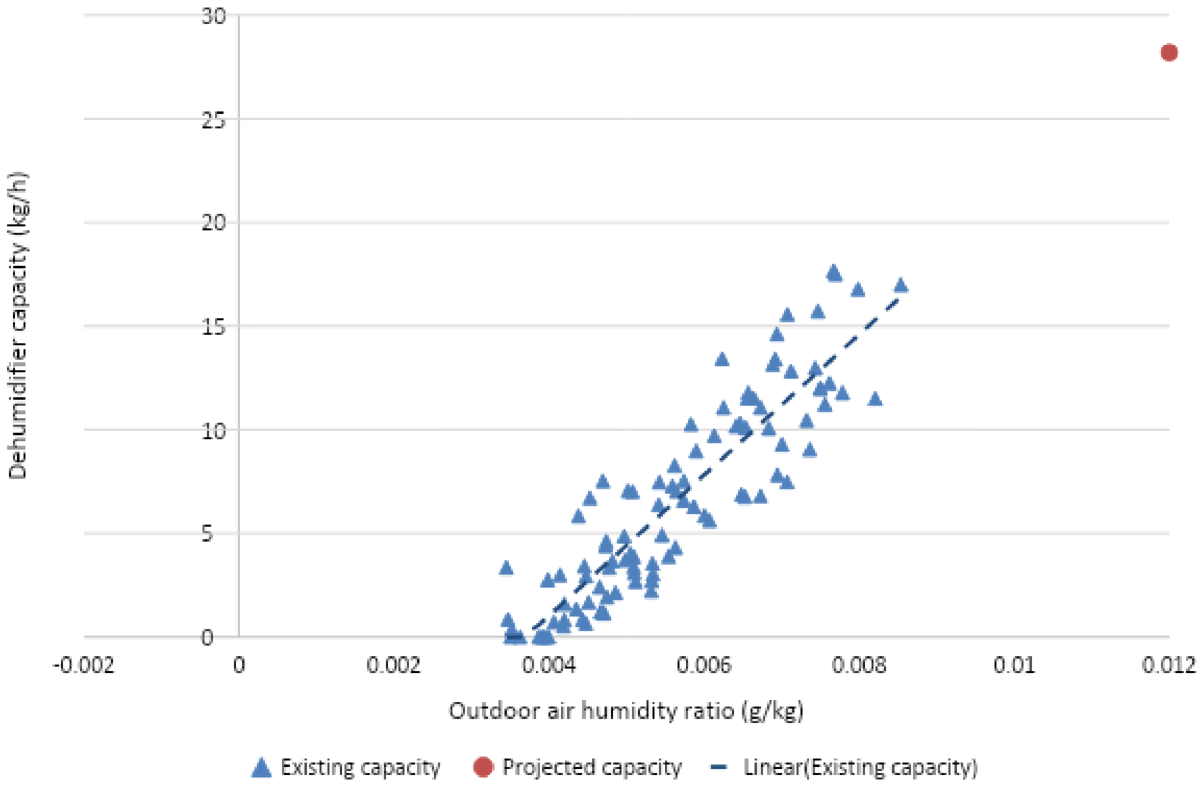

Figure 17. Existing dehumidifier capacity in an ice rink and estimated capacity requirement to be able to maintain the dimensioned indoor climate.

In summary, Table 2 shows the specifications of a sorption dehumidifier that should be able to meet the dehumidification needs during most of the season in a typical ice rink in Sweden. However, these specifications must be seen rather as a general rule of thumb, and the real dehumidification need needs to be further analyzed in specific cases.

Table 2. Dimensioning of dehumidifiers for a typical ice rink in Sweden.

Dehumidification capacity	20 kg/h
Processluft, in	4.3 g H2O per kg of air (e.g. temperature = +7°C and RH = 70%)
Ambient climate	10 g H2O per kg of air (e.g. temperature = +20°C and RH = 65%)

4.2 The heat source of the regeneration air

Most of a sorption dehumidifier's energy use goes to heating its regeneration air, which is used to create dry air. The heat source can vary, the important thing is that the capacity is sufficient and is at a sufficiently high temperature level to be able to cover the need for dehumidification. To achieve energy-efficient and profitable operation, it is recommended to choose a heat source according to the priority list below:

1. Recovered heat from the cooling system
2. District heating
3. direct

where recycled heat is generally the cheapest option and district heating in most cases tends to be cheaper than electricity. One can also imagine combinations of these where, for example, electricity or district heating can be used as a supplement or back-up to recycled heat. These solutions and what they mean in terms of energy were covered in Neri's interim report 2, which is why we refer to it for further details. Below follows a short rehearsal.

4.2.1 Recovered heat from the cooling system

One solution is to use the heat emitted from the ice rink's cooling system, which is otherwise released into the environment if it is not reused as a heat source for something else. However, the heat must be of a sufficiently high temperature level to be used in the dehumidification process, which makes it a challenge to heat the regeneration air only with heat recovered from the cooling system. Most traditional dehumidifiers require up to 120°C hot regeneration air, but in recent years adaptations have made it possible to lower the requirements. Today, there are sorption dehumidifiers that can cope with around 55°C, which opens up the possibility of being able to cover the entire heat requirement in the dehumidification process with recovered heat from the cooling system. The disadvantage of these models is that the fan power often increases slightly when the regeneration air flow increases, which in the context is often acceptable because it is the question of using "free" heat that still makes the solution a profitable alternative.

The cooling system needs to be able to deliver 30-50 kW of heat at around 60°C to be able to cover the needs of the sorption dehumidifier. In recent times, cooling systems based on CO2 as a refrigerant have become more popular, and these can emit heat that meets exactly these requirements. Another solution is to connect a heat pump to the heat carrier side of the cooling system which can raise the temperature of the heat emitted from the cooling system to the required level.

4.2.2 District heating

Many ice rinks in Sweden use cooling systems whose heat output does not reach the temperature levels required for dehumidification. For example. ammonia systems emit most of the heat at temperature levels up to 35°C, which is not enough.

District heating is a very common heat source in many applications in Sweden. The advantage is usually its availability and price in many cases. In ice rinks, the need for dehumidification is highest during the warm period of the year, which is optimal as the price of district heating during this time of the year is often the lowest.

4.2.3 direct

Direct heating is often considered a waste of energy to produce heat when there are more efficient solutions. However, in Sweden it is often considered an acceptable solution, because electricity prices are relatively low in the country, but should only be used if the more profitable alternatives mentioned earlier are not available.

If you choose to use direct heat as a heat source in a sorption dehumidifier, the importance of optimizing the operation of the dehumidifier itself increases. Units with low fan power, preferably EC fans, are recommended and preferably the fans should also be capacity regulated, for example with frequency control.

There are additional functions such as internal recycling called purge which also help to make operations more efficient.

4.2.4 Hybrid

If the recovered heat from the cooling system is not sufficient to its temperature level and capacity to cover the heat demand of the dehumidification system, it can still be applied in a hybrid solution with another heat source as the tip. This means that the regeneration air is preheated in the recovery heat exchanger and then finally heated in a heat exchanger connected to the supplemented heat source. In this way, you have at least utilized free heat emitted from the cooling system and can save on energy costs. As a tip, district heating or direct heating is recommended.

4.3 The control and regulation strategy of the dehumidification system

Correct control of the moisture level is, as stated in Neris part 3, important to be able to achieve good ice quality and a healthy indoor climate in the building. When the humidity of the air in ice rinks is discussed, it is often assumed, as stated earlier, that the relative humidity. The problem is that it varies with the air temperature, which in turn often varies during the season in ice rinks. Therefore, humidity should be discussed in "absolute terms" to get the right picture. This can also be done by using the concept of "dew point".

It turns out that the dew point in an ice rink should be somewhere between 0°C and about 2°C. If the dew point is lower than 0°C, the moisture load increases because, for example, the bed water evaporates to a greater extent. If, on the other hand, the dew point is higher than approx. 2°C, the risk of unwanted condensation on the siding and other building parts that are mainly cooled by the ice increases. The condensation on the edge creates ice build-up, which in turn means that the ice has to be "knocked" off, which creates a lot of extra work.

With this knowledge and knowledge that existing control systems can often be converted to the correct control principle, the savings appear as "low-hanging fruit", i.e. with minimal investment, a relatively large saving can be made. Even if a new control unit were needed, in this context it is a small investment to upgrade.

4.4 The distribution of the dehumidification system

In addition to the unit and the control strategy, it is also important that the distribution of the dehumidification system is sized well so that dry air is brought to where it is needed in the ice rink in order to make the facility functional in the most energy efficient way.

4.4.1 Location

The main task of the dehumidification system is to ensure that water vapor in the air does not condense on the structures of the ice rink, which usually happens on the roof, or on the ice itself. To minimize these risks, it is recommended that the distribution of dry air takes place in the center of the ice near the roof. Figure 18 shows the distribution principle for a typical ice rink's ventilation and dehumidification system, where it also appears that these are recommended to be kept separate.

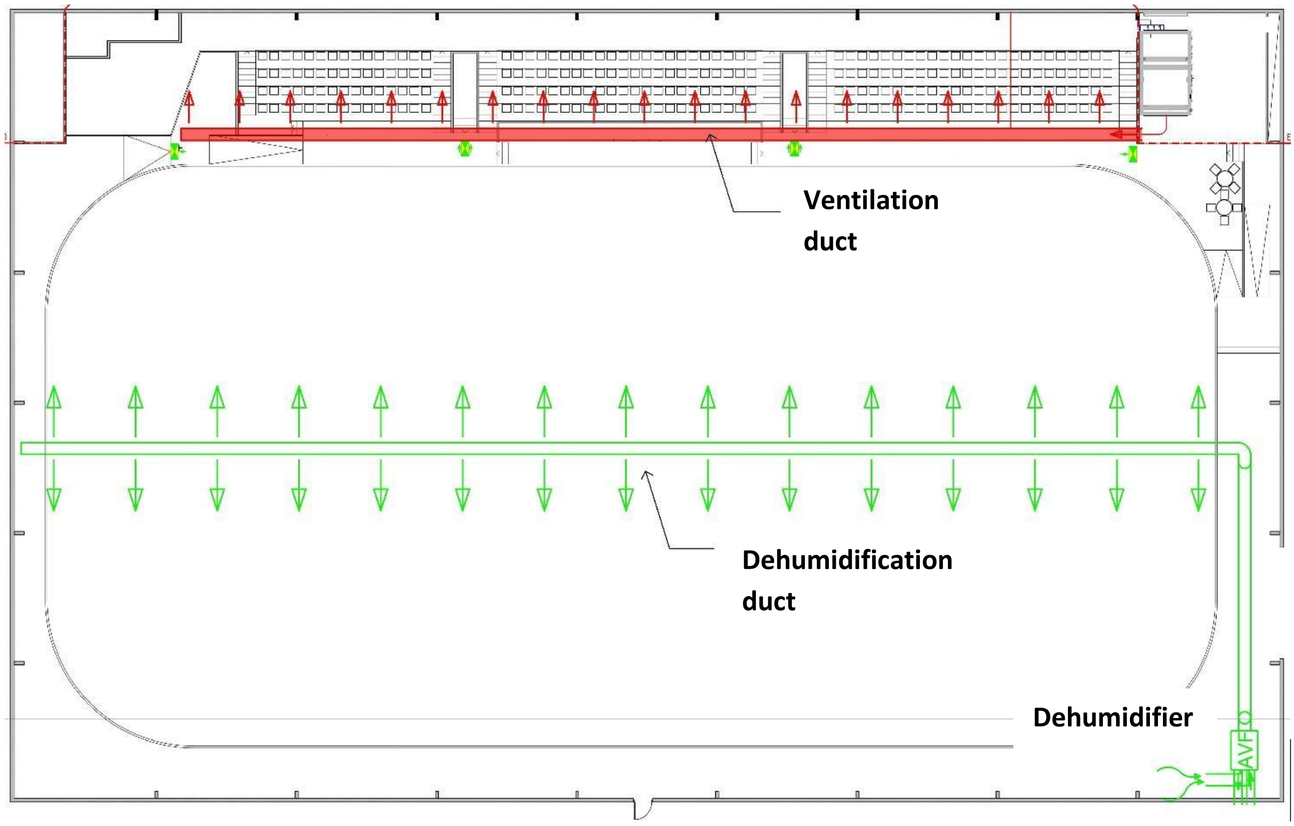

Figure 18. The distribution principle for a typical ice rink's ventilation and dehumidification system.

Warm air in the ice rink's arena room should not be used as a method to counteract the moisture problem, which is managed by the ice rink's dehumidification system, but only to cover the heat needs in the arena room. To avoid unnecessary heat load on the ice, it is therefore important that warm air from the ventilation system is directed where it is needed, i.e. the stands. This means that warm and dry air should be distributed in separate channels in order to create an optimal indoor climate in the arena room in an energy-efficient way.

Figure 19 shows a section of the recommended principle solution, where it can be noted that the bleachers and the ice form two separate climate zones. By the stands the air is warmer, while above the ice it is cooler and drier. In order to maintain the cool and dry climate zone above the ice, the dehumidification system duct should be placed in the middle above the ice as close to the roof as possible.

By spreading dry and cool air high above the ice, the natural temperature gradient that forms in the air above the ice is counteracted. This results in the surfaces of the roof construction being kept cooler and drier, which reduces the heat load from the roof to the ice via radiation and also the risk of condensation forming on the surfaces of the roof that most easily fall victim to moisture damage. In order to deliver cool dry air, the intake of the process air should take place close to the floor surface where the air is the coolest. If the dehumidifier is placed at a higher level than the ice surface, a duct for the process air should be drawn down to floor level from the dehumidifier.

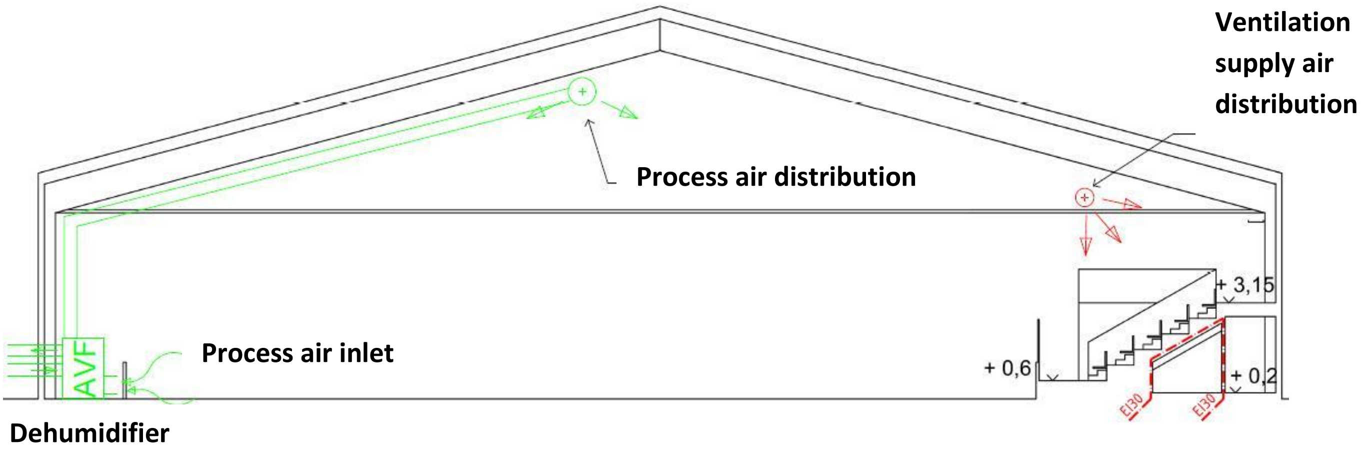

Figure 19. Principle solution regarding placement of ventilation and dehumidification ducts in an ice rink.

4.4.2 Channel types

Distribution of air where needed should be done evenly and at low speeds to create the best results. Two types of channels can be used for this purpose, made of sheet metal or of textile.

Distribution channels made of sheet metal are the most common option, where the flow is regulated by dampers. The strength of the roof structure must be taken into account when installing this type of ducts as they are relatively heavy. Furthermore, air blows from the ducts via locally connected nozzles, which increases the risk that the air is not distributed evenly. Maintenance of the ventilation ducts is also labor-intensive as it is often done locally with a boom lift or equivalent work platforms.

Textile ducts are a more modern option with many advantages. They can be delivered as nozzle channels, which is well suited for even distribution of air, see example in Figure 20. Installation of its channels is quite simple, where they are connected to each other with zippers, and their light weight makes the work even easier. The light weight can also be advantageously used for maintenance work, as it is easy to disassemble the channels for maintenance and then assemble them back when the work is finished.

Figure 20. Textile channel for both ventilation and dehumidification in an ice rink.

The installation shown in the picture above is a good example of how the distribution systems for both ventilation and dehumidification can be solved in a functional and aesthetically pleasing way. The facility has bleachers around the entire arena room and therefore the ventilation duct is designed as a ring. The duct is of the textile type and has nozzles that direct the air towards the stands so that the overheated air gets to where it needs to be, i.e. to the spectator seats. In the middle and high up in the construction is the dry air channel, which distributes the dry air over the ice zone. In this way, as far as possible, different climate zones are created in the arena room which are adapted for the ice and the spectators respectively.

5 discussion

The purpose of the report is to summarize the knowledge from the previous partial reports within Neris and transfer these into concrete dimensioning and construction instructions. The goal is for the reader to be able to create a functional and energy-efficient plant from a moisture point of view.

In addition to being able to fulfill the requirements placed on its carrying capacity, the climate shell's main purpose is to separate the indoor climate from changing conditions in the surroundings in an energy-efficient way. This means that heat and moisture transport should be able to take place in a controlled manner and that mechanical equipment should not have to work unnecessarily to maintain the climatic conditions necessary for the intended application.

To avoid moisture or mold damage in a climate separating structure, a general rule is that the vapor transport resistance on the warmer and wetter side of the wall core should be higher than on the cooler and drier side. This is connected to the geographical location of the ice rink and in a previous study it has been established that in northern Sweden the vapor transport resistance should be greater on the inside of the climate shell, while in central and southern Sweden the vapor transport resistance should be greater on its outside.

When it comes to minimizing moisture and heat load on the indoor climate of the ice rink, great focus should be placed on preventing air leakage through the climate shell. An air barrier can in principle be placed anywhere in the wall core if it has low vapor transport resistance. It is especially important during installation to ensure that the air barrier is kept continuous at the connection points between different structures, e.g. walls and ceilings.

The ice slope is usually either covered with concrete or gravel. A gravel run is generally a cheaper solution, but from an operational point of view somewhat more difficult because moisture is absorbed in the gravel layer. When the ice is melted away after the ice season, the moisture load in the facility increases because the moisture is released to the interior of the ice rink when the air temperature increases. Floor surfaces should generally be covered so that soil moisture is not supplied to the interior of the ice rink, which applies both during the ice season and outside of it. During the non-ice season, the ice rink should be ventilated with fresh air to control the humidity, especially in the arena room.

In addition to the surrounding climate, it is also important that the arena room of the ice rink is well insulated from other climate zones (toilets, changing rooms, ice machine garage, etc.) preferably with airlocks. Climate separating doors, gates, etc. should be kept closed as much as possible to prevent air leakage, and also be insulated and airtight to minimize the risk of moisture problems and unnecessary heat loads.

The arena room's ventilation is recommended to normally operate with air recirculation only, i.e. the outside air inlet must be closed. This reduces the moisture load in the ice rink, while natural air leakage through the structure of the ice rink is often sufficient to maintain the necessary CO2 levels. In the best of worlds, any supply air is controlled at the arena room's CO2 level so that fresh air is only taken in if needed.

The distribution of the ice rink's ventilation heat and dehumidification must take place in separate systems. The general principle regarding ventilation is that you want to avoid warm air blowing towards the ice, which means that ventilation ducts should preferably be placed outside the ice surface and blow towards the spectators etc. who needs it, not the ice. For dehumidification, a more suitable distribution is with a central channel in the roof ridge above the ice, which provides a more even distribution of dehumidified air above the ice. The channel must provide an even flow over the entire length and surface.

When choosing a dehumidifier for an ice rink, a sorption dehumidifier with the required capacity and of so-called hot water regenerated model. This means that heat recovered from the cooling system can potentially be used for up to 100% of the dehumidification process. With an adapted cooling system that has a good heat recovery function, the heat is available and a large saving is then possible.

Correct control of the humidity level is important in order to achieve good ice quality and a healthy indoor climate in the building. When the humidity of the air in ice rinks is discussed, it is often assumed that the relative humidity. The problem is that it varies with the air temperature, which in turn often varies during the season in ice rinks. Therefore, humidity should be discussed in "absolute terms" to get the right picture. This can also be done by using the concept of "dew point". Accordingly, dehumidifiers must be controlled to maintain a specific absolute humidity or perhaps something easier to communicate, dew point. It turns out that the dew point in an ice rink should be somewhere between 0°C and about 2°C. If the dew point is lower than 0°C, the moisture load increases because, for example, the bed water evaporates to a greater extent. If, on the other hand, the dew point is higher than approx. 2°C, the risk of unwanted condensation on the siding and other building parts that are mainly cooled by the ice increases.

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