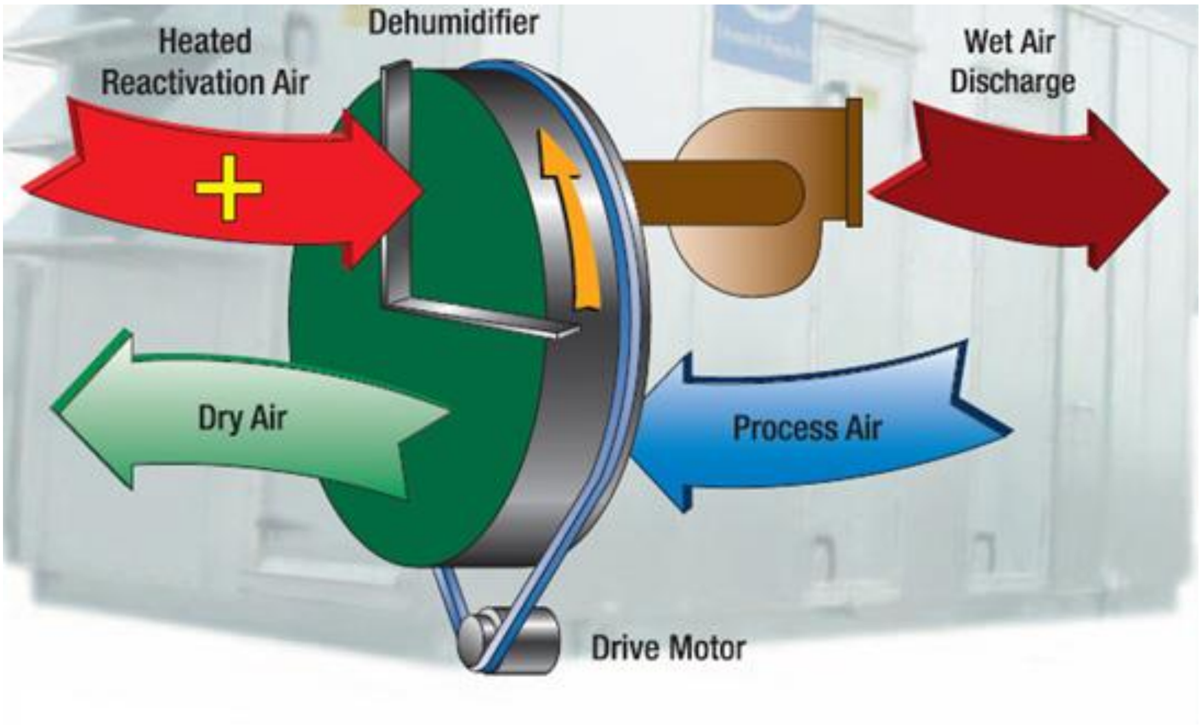

NERIS - Part 2

Methods and energy use for dehumidification in ice rinks

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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 part two in a series of four, which will address moisture in ice rinks. Part two reviews different dehumidification methods that are typically used in ice rinks including their functions. One such method is refrigeration dehumidification which aims to condense the moisture out from the air. The drawback with this method is that it becomes challenging to achieve the low humidity levels that are required in an ice rink. The most common method is desiccant dehumidification, where moisture is removed from the air by a humidity-absorbing material that needs to be reactivated with high-temperature heat. The method is in terms of dehumidification effective, but the amount of high-temperature heating energy required is often quite significant. The yearly demand in a typical ice rink lies between 50 and 150 MWh, where the heat source is often electricity.

The surrounding climate affects highly the dehumidification energy demand since air leakage through the building envelope is the biggest moisture source in an ice rink. The control strategy plays big role in the energy use as well, and it has been found that the traditional strategy based on relative humidity can lead to very bad results. During the warm period of the year the RH-strategy can allow too high levels of humidity in the arena room, while the opposite becomes true during the colder periods where the ice rink gets “over dried”. In a studied ice rink, it could be concluded that 30% of the dehumidification energy had gone to waste due to the used control strategy, which in this case meant that 44 MWh of electricity could be saved on a yearly basis.

The energy use of different ice rinks can also be compared by using so called energy signatures. This is a good way to compare the performance in different conditions and to understand what drives the energy use. Air leakages are the main cause for the dehumidification energy demand and will be discussed further in the latter parts of the NERIS-project.

An interesting field is alternative heat sources for the reactivation of the sorption dehumidifier, since it can potentially lead to significant savings in energy use. In the first generation of the technology recovered heat from the refrigeration system or district heating are typically used in combination with the electric heating, which can save up to 40% in the electricity use in the dehumidification system. In the second generation of the technology it becomes possible to use water-based heat of 60°C to reactivate the dehumidifier, which makes it possible to lower the electricity demand even further. Results and experiences show that more than 80% of the dehumidification energy demand can be covered by recovered heat from the refrigeration system.

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1 Introduction

1.1 Background and scope of the NERIS project

The project name NERIS is an initial abbreviation of Nordicbuilt: Evaluation and Renovation of Ice halls and Swimming halls. NERIS is led by the Department of Civil and Architectural Engineering at the Royal Institute of Technology (KTH) in Stockholm, Sweden. Financial support has been received from Formas (the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning) and the Swedish 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 present various renovation measures that can improve performance". This means that they want to achieve an information bank regarding moisture management in ice rinks and swimming pools. The NERIS project took place in 2014 and will be completed in 2018.

This report is the second 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 hall plants. Initially, the ice hall technique will be described and how moisture problems in a building can arise in this type of application. The idea is to then build a logical order 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 hall applications. The goal is that the different parts of this report series should be able to complement each other and be able to provide practical advice and instructions regarding dimensioning and planning of dehumidification systems in ice rinks.

1.2 Scope of NERIS - Part 2: Methods and energy use for dehumidification in ice rinks

Part 2 of NERIS will deal with different dehumidification methods in ice rinks and their function together with technical possibilities and limitations. An interesting area is what form of energy and not least how much energy the dehumidification process actually uses. From current field measurements, the order of magnitude of the energy demand is presented on a seasonal and monthly basis for different ice rinks.

The surrounding climate is the factor that intuitively should affect the need for dehumidification and thus energy use the most. As will be highlighted here, there are also other factors that affect energy use where, for example, it turns out that the control principle can also play a decisive role. This discussion began in Part 1 and will be made concrete here by examples from ice rinks with different control principles and the difference it makes to energy use. You can also illustrate and compare energy use in different plants by producing so-called energy signatures. This is a tool to understand how plants can be compared and what factors drive energy use. Mechanisms that affect moisture transport, such as air leakage, will be introduced and studied in more detail in part 3.

2 Dehumidification methods in an ice rink

The task of a dehumidifier is to reduce the amount of water vapour in the air to an acceptable level determined by the user. The absolute humidity is normally always higher at the dehumidifier's inlet than at its outlet because it removes moisture from the air. There are different types of dehumidifiers and their respective technologies are defined by the physical process applied. In ice rinks, dehumidifiers usually use sorption or cooling technology.

2.1 Cooling dehumidification

When a surface has a temperature lower than the dew point of the air, water vapor in the air will condense on the surface upon contact, resulting in the air becoming drier. Cooling dehumidifiers (or condensate dehumidifiers) work according to this principle, where a heat exchanger with a cold surface "attracts" the water vapor of the air. To bring about the cold surface, a cooling system is needed and thus a cold medium. Depending on how the cooling systems are configured, these can be classified as a direct or indirect system. However, dehumidifiers are not very common in ice rinks, as technical challenges have been encountered regarding their application in the conditions normally found in ice rinks. These challenges will be discussed later in the report.

2.1.1 Direct cooling dehumidification system

Figure 1 basically shows how a dehumidifier with direct expansion works. First, moist air (process air enters) the evaporator, where water vapor is removed from the air via the condensation process. Then the air is heated again to minimize the load on, for example, the ice rink's heating system. To eliminate the need for an external heat source, the cooling system's condenser heating is often used for this purpose.

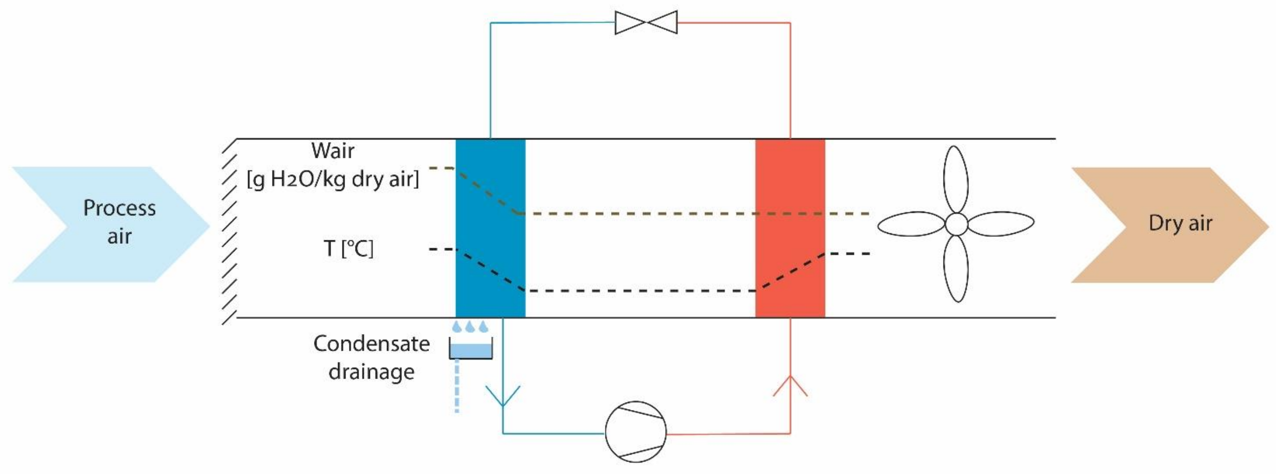

Figure 1. Principle diagram of dehumidifiers with direct expansion.

2.1.2 Indirect system

Indirect dehumidification works according to the same principle as the direct in terms of the physical process involving the dehumidification of the air. However, the dehumidifier's cooling and heat transfer works in a different way. In Figure 2 You see that an ice hall's cooling system's coolant side delivers the cooling needed for the dehumidification process, while its coolant side delivers the heat needed to reheat the dehumidified air. However, the question can be asked whether this is a cost-effective solution, as it increases the capacity requirement on the ice rink's cooling system with higher investment costs as a result. The reason for the increased capacity requirement is that the loads on dehumidification and ice cold reach their respective peaks at the same time, i.e. when the outdoor climate is at its warmest and most humid, which means that the requirements placed on the chiller to meet both needs stack on top of each other rather than complement each other.

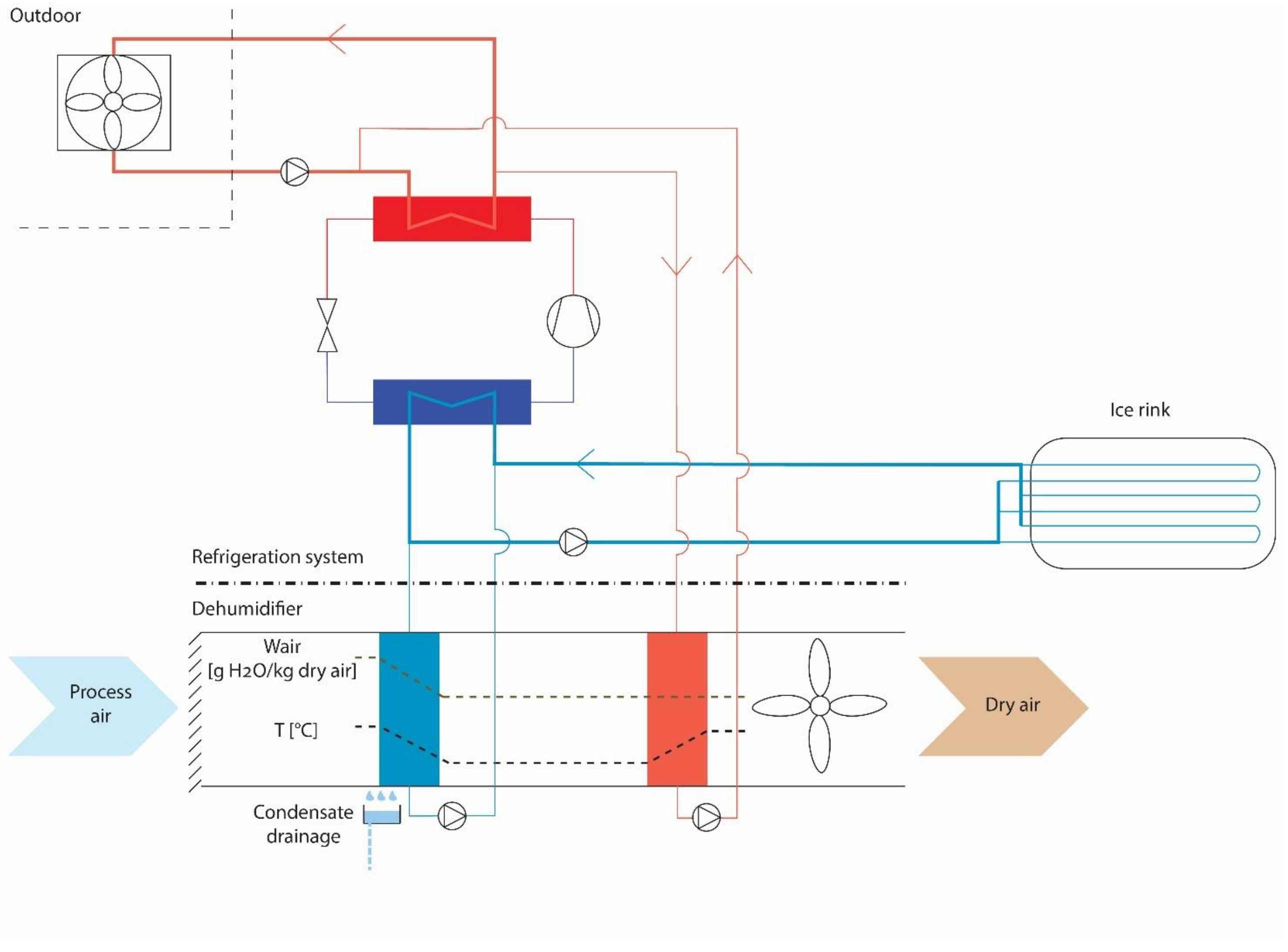

Figure 2. Principle sketch of indirect dehumidifier.

2.2 Desiccant dehumidifier

Desiccant dehumidifiers apply a technology based on moisture-absorbing materials, i.e. materials with chemical properties that allow them to absorb moisture without involving condensation or freezing. Desiccant dehumidifiers are today the most common dehumidifiers found in ice rinks, which much depends on their capacity and performance even at low dew point levels. The picture below shows a larger desiccant dehumidifier in a Swedish ice hall arena.

Figure 3. A larger desiccant dehumidifier in a Swedish arena facility.

The most important part of a desiccant dehumidifier is a rotating desiccant wheel, the so-called rotor. The frame from which the rotor is built is fiberglass, which consists of flat and a pleated layer. The pleated layers are designed so that many channels and a large surface area are created where air can pass through. Today, silica gel is used to a greater extent as an adsorbing layer in the rotors, which means that the moisture thus "sticks". The rotor is often divided into two distinct sectors that separate the two different air flows apart, see Figure 4. About 75% of the wheel's area usually forms a sector where moist air (process air) is passed through and its water content is "captured" by the moisture absorber, resulting in dry and slightly warmed air that can be passed on to, for example, the ice rink. The wheel is rotated by means of a drive motor at a low speed, which results in negligible energy consumption. Over time, the moisture absorber in this sector becomes saturated and cannot absorb more water vapor. To remove the moisture from the rotor, warm regeneration air is allowed to blow through the remaining part of the wheel, about 25%, forming its own sector. In this sector, the warm regeneration air raises the temperature of the moisture absorber, which evaporates its moisture content, which is then carried out into the open air. It is the rotor that determines the capacity and service life of the dehumidifier unit and is thus a key component of the system.

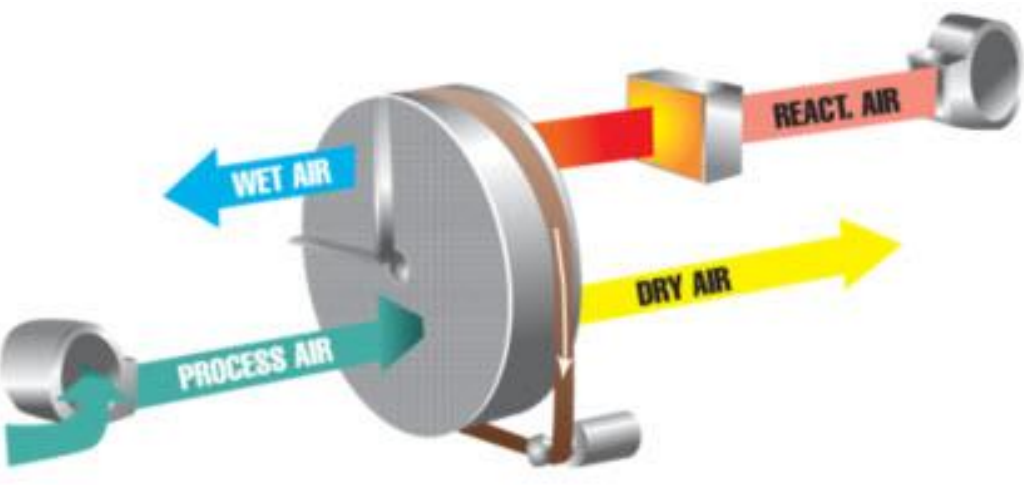

Figure 4. Sorptionsavfuktarens arbetsprincip.

Thanks to the physical process that this technology applies, desiccant dehumidifiers can work efficiently, i.e. with good capacity, even at very low dew point levels, below 0°C, without the risk of frost formation, which is not possible with dehumidifiers. Furthermore, the requirements for the airflow needed for the process also decrease. Most of the desiccant dehumidifier's energy use goes to heating its regeneration air, which means that the most significant savings potential is here. One potential solution is to use heat released from the ice rink's cooling system, which is otherwise released into the surroundings 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 recovered heat from the cooling system.

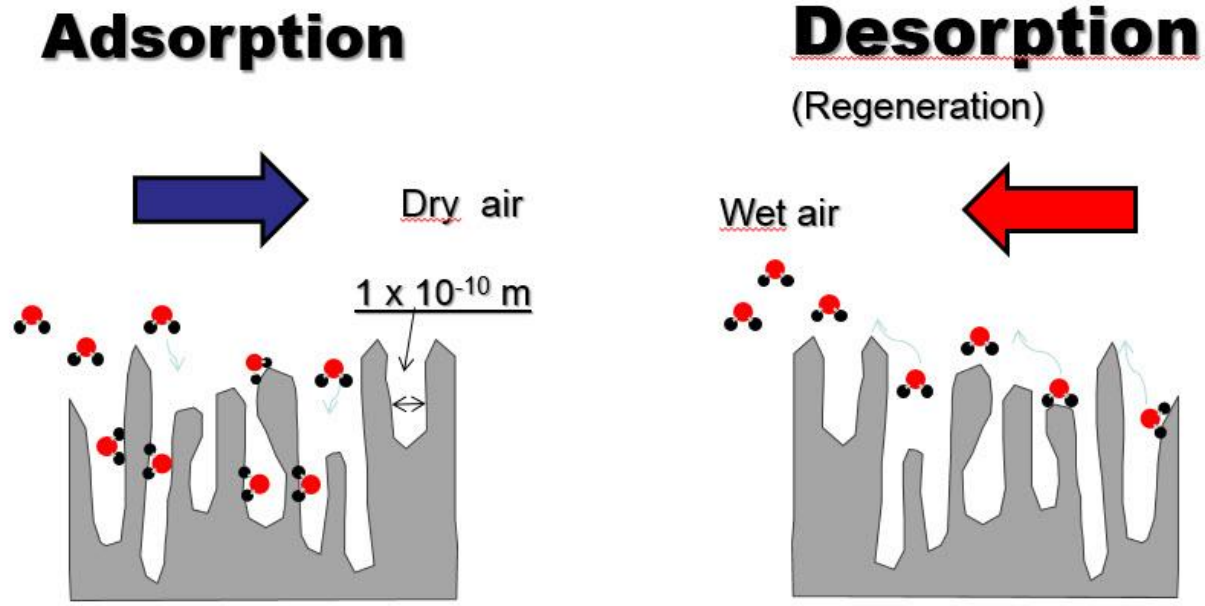

Figure 5. Illustration of adsorption and desorption on a microscale (Moisture control).

As a small in-depth addition to the function of the sorption process, the figure above illustrates how the moisture (water molecules) are "captured" (adsorbed) by the rotor surface layer. As previously described, this leads to drying of the incoming process air. In order to in the next mode, during regeneration, similarly expel the moisture (desorption) from the material, the surface layer is heated by allowing warm air to pass over the surface of the rotor. When the temperature increases in the material (silica gel), the water molecules "release" and follow the regeneration air out to the surroundings.

3 Energy use of the dehumidification system

The dehumidification system is one of the so-called "big five" energy systems in an ice rink and accounts for about 5-15% of the total energy use. However, its proportion is often underestimated because the capacity of the dehumidifier in many cases is insufficient. This usually results in further dehumidification rather being achieved via the ice rink's cooling system because water vapor in the air to a greater extent condenses on the ice surface, which is not optimal as it increases the load on the cooling system unnecessarily. On the other hand, a flawed control strategy can also result in the dehumidifier running when it is not needed, leading to energy waste. The dehumidifier should therefore be used appropriately and only when necessary.

3.1 Dehumidifier performance

Achieving sufficiently dry air in an ice rink with a dehumidifier has proven to be difficult and therefore desiccant dehumidifiers are normally used. Below is an explanation of the problems with using dehumidifiers in ice rinks.

To avoid condensation problems on the ice surface and ice rink structures, the dew point in the ice rink arena room should be kept between 0°C and no more than 2°C. In practice, this means that the surface temperature of the heat exchanger in a dehumidifier must be below or significantly below 0°C. This leads to frost formation which causes high pressure drops in the heat exchanger, and finally defrosting is needed to be able to get the air flow going again. A classic solution has been to use hot gas from the hot side of the cooling system to defrost the heat exchanger, which means that the dehumidification process is interrupted in the meantime. Although it is technically possible to reach dew point levels below 0°C with a dehumidifier, its energy efficiency will suffer greatly from the continuous defrost requirement. A dew point of about 5°C is considered to be the limit for a reasonably efficient operation of a dehumidifier, if this dew point limit is exceeded, the air cannot be dehumidified efficiently to the recommended level. Furthermore, the need for airflow increases if the moisture level of the process air to the ice rink cannot be lowered sufficiently, which in turn increases the fans' energy use. On the whole, cooling dehumidification practically leads to slightly too high moisture levels and the total energy use for the process is relatively high. For the time being, we will confine the discussion to this conclusion, but the issue will be dealt with in the following reports.

3.2 Desiccant dehumidifier's annual energy use

The first interim report of the NERIS project analysed the indoor climate in eight ice rinks in the Stockholm region during the 2015–2016 season (all with about eight months season), as well as the dehumidification system's energy use per season as shown in Figure 6. As can be seen, there are variations in energy use, which may be due to the moisture load, the control strategy or the length of the season. However, this is not possible solely on the basis of: Figure 6 to determine the extent of the impact of each factor on energy use. Since it is known that the analysed ice rinks have insulated building envelopes, and that they are of similar size and built for similar purposes, Figure 6 that the sum of the factors can still affect the energy efficiency of an ice hall at a noticeable level, since the energy use of the dehumidification system in the various ice rinks is in as wide a range as between 55 and 158 MWh per season.

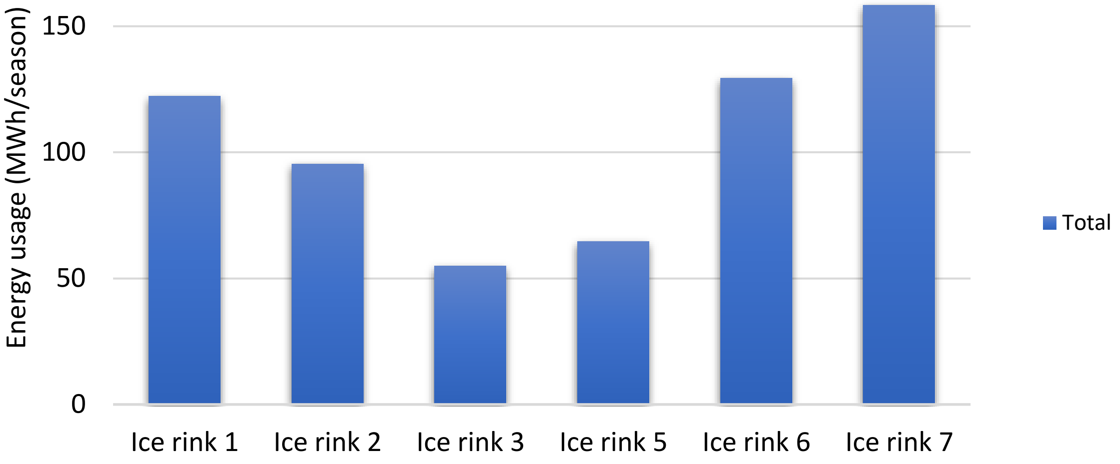

Figure 6. The dehumidification system's energy use in analyzed ice rinks.

3.3 Seasonal variations

Air leakage turns out to be by far the largest source of moisture, where leaks in the building envelope cause outside air to enter the ice rink due to the differences in air pressure inside and outside. The geographical conditions will thus affect the need for dehumidification to a great extent. In part 1 of the NERIS project, the climatic conditions in three cities in Sweden were analysed, where the monthly average steam ratio in Stockholm was noted to vary between 2.5 and 9.0 g $H2O$ per kg of dry air, which means that the dew point typically varies between -5°C and 12°C during the year. Many ice rinks are now in operation from 8 and up to 12 months per year, which indicates that variations in the energy use of dehumidification systems during the season can be large.

Figure 7 shows the dehumidification system's monthly energy use in different ice rinks. Although the differences between the ice rinks can be large, it can be seen that they all follow a similar trend, i.e. that the peak of energy use occurs at the beginning of the season when the outdoor air is humid and that energy use decreases as the outdoor air becomes drier. Most of the halls are started in the July/August range and closed in the March/May range. The fact that there is an "uphill battle between July and August is due to the fact that most are started up at the end of July and then only part of the month's potential energy use for dehumidification is included. For the same reason, some plants seemingly "dive" at the end of the season, but this is explained by the fact that they are not operational throughout April or May. Something that helps to keep the levels up at the end of the season is that you often let the dehumidifiers continue to work to dry up when melting the ice. Theoretically, based on the moisture content in the air reported in Neris 1, there is generally a minimum in the ambient moisture content during January/February after which it increases again. This should lead to a minimum in energy use for these months and then start to increase again. For some of the facilities in the figure below, this trend can be discerned.

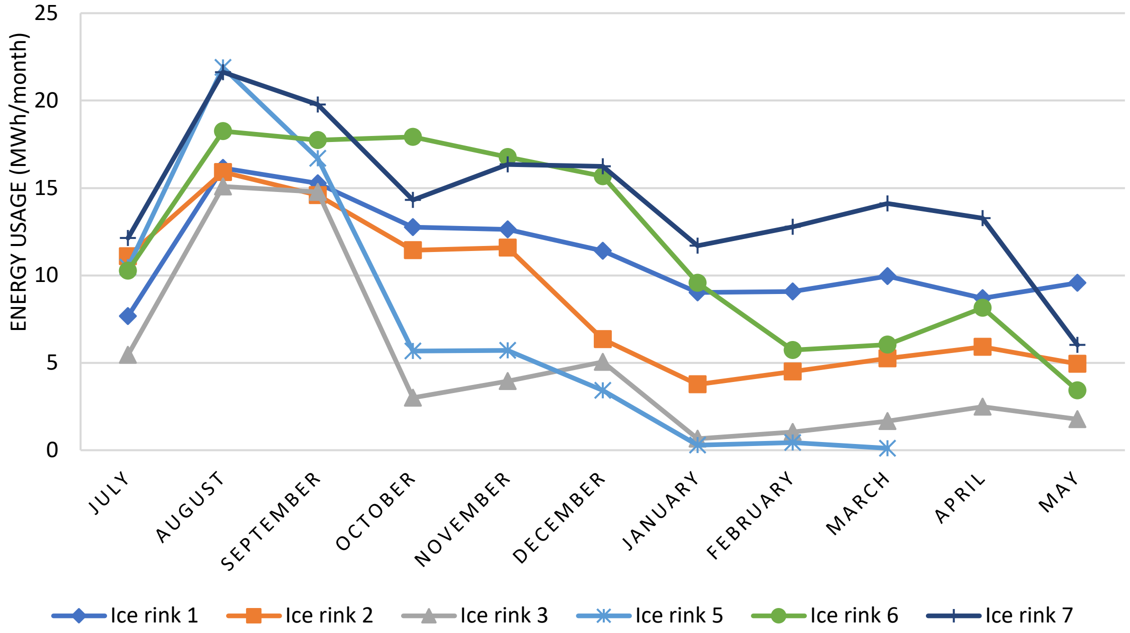

Figure 7. The dehumidification system's monthly energy use in various ice rinks.

The cooling demand in ice rinks has been observed in several studies to be linked, in ways that it increases, with increasing outdoor temperature. This means that a rising outdoor temperature increases both the cooling demand and the dehumidification requirement. Figure 7 strengthens arguments that the need for dehumidification is increasing and thereby confirms what was previously mentioned that indirect cooling dehumidification systems are not so well suited for ice hall use. The consequence is that the dehumidification system adds load to an already high cooling capacity requirement to the ice. The plant's cooling system must therefore cover both needs when they simultaneously reach their respective peaks. In the long run, it also leads to greater heat release from the cooling system when it is least needed, which makes it difficult to get the heat from a possible heat recovery system.

3.4 Avfuktningssystemets energisignatur

A building envelope separates climatic conditions with different air characteristics from each other, however, complete separation is in practice never possible. The main driving force behind the leak-air flow is the temperature difference, which in turn contributes to a pressure difference in the building. This phenomenon will be developed in future parts of the Neris project. A useful and important parameter that the NERIS project uses to show moisture transport is the so-called vapour ratio. Ambient air of higher temperature often naturally has a higher moisture content, so one could express it as the vapor ratio that is proportional to the air temperature. In addition, moisture moves in the direction of the lowest vapour ratio – analogous to heat transported from higher to lower temperature. Relative humidity, which today is still widely used to describe the humidity level, cannot be used for this purpose. In homes, offices and other typical indoor climates, moisture usually moves from the indoor climate towards the outdoor climate, while in ice rinks it is usually the other way around as the outdoor air usually carries more moisture than the indoor air. This type of moisture level difference can be called the vapor ratio difference and can be calculated according to the following formula:

$$\Delta W = W_{ut} - W_{in}$$

Available data from ice rinks have been used to calculate their respective vapour ratio differences, as in Figure 8 I is compared with the dehumidification system's energy use in each ice rink. The linear trend lines all show similar patterns, where a higher vapour ratio difference leads to an increased dehumidification requirement. This confirms once again that the outdoor climate is a significant source of moisture that puts a strain on the dehumidification system.

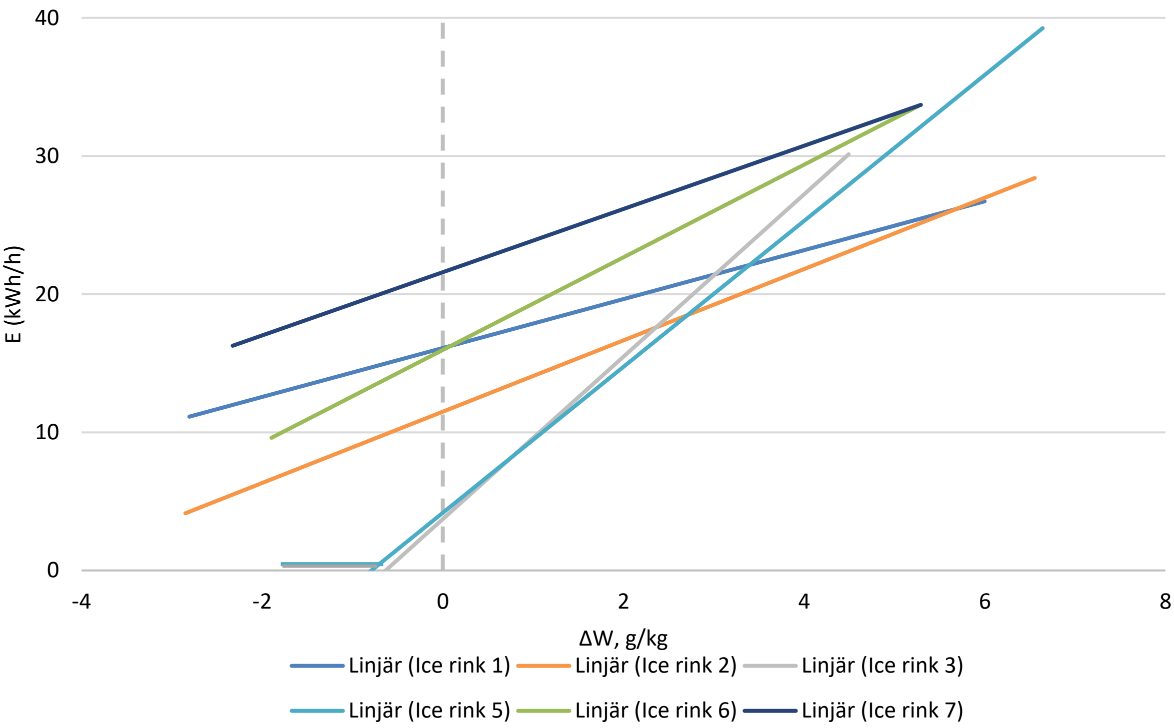

Figure 8. The energy use of the dehumidification system in relation to the vapour ratio difference.

Theoretically, the outdoor air has a vapour content that is acceptable for the indoor climate as the vapour ratio difference is at zero, since there is then no noticeable moisture exchange between the different climatic conditions. This means that air leakage is no longer a source of moisture for the ice rink and that remaining sources of moisture should only be internal in that case (e.g. user, audience, etc.). If the outdoor air is drier than the indoor air, the vapour ratio difference becomes negative, which reverses the direction of moisture exchange and in connection with this, the indoor air is partially dehumidified via a natural process of air leakage or ventilation. In Figure 8 It can be seen that the dehumidification systems in ice rinks 1, 2, 6 and 7 use 5 - 22 kWh on average per hour despite a negative vapour ratio difference, which indicates that there are either internal moisture sources and/or a flawed control strategy that still keeps the dehumidifier operating. Ice rinks 3 and 5 show much lower activity in the dehumidification system on the negative side, and that the dehumidifier is taken out of operation when the negative difference has reached a certain limit. This indicates that moisture from internal sources is discharged via the natural air/moisture exchange and that the dehumidifier is then not needed. In ice rink 5, the dehumidifier is controlled according to absolute humidity, which avoids the risk of "overdrying" the ice hall space, which otherwise makes an unnecessary contribution to energy use.

Exactly how much impact internal moisture sources have on the energy signature is still unclear as it cannot be determined whether a negative vapour ratio difference only represents the load from internal moisture sources or whether a flawed control strategy also plays a role. This will be discussed further below.

The question also arises as to how necessary it really is to operate a dehumidifier in the event of a negative vapour ratio difference. To examine that question further, illustrate Figure 9 The vapour ratio between indoor and outdoor air in two ice rinks.

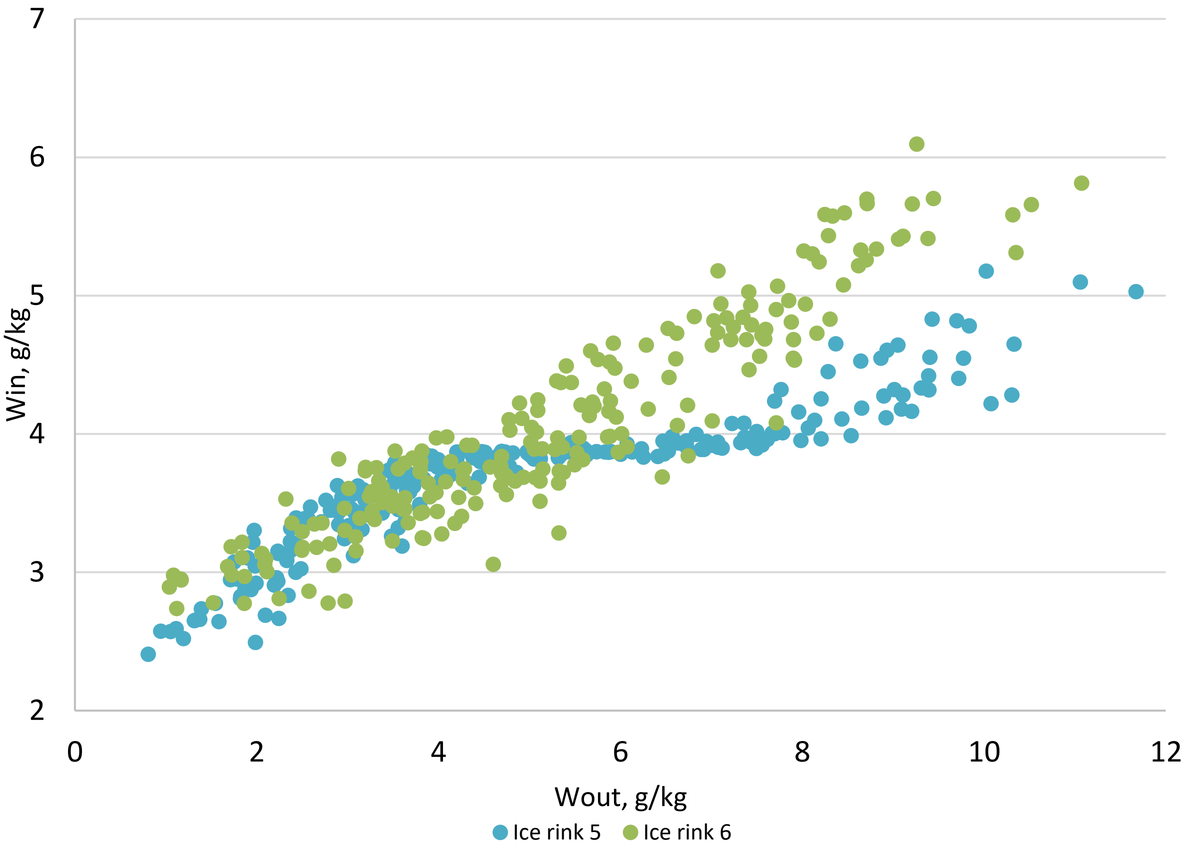

Figure 9. The vapour ratio between indoor and outdoor air in two ice rinks.

When studying the indoor air vapour ratio (Win), it is seen that the ice rinks follow a similar pattern up to about 4 g of water per kg of dry air. After that, the dehumidifier in ice rink 5 maintains a more or less constant level until the point when the capacity is no longer enough to effectively remove the high amounts of moisture from the outdoor air. Furthermore, it helps Figure 8 also to indicate whether internal moisture sources play a major role in the energy signature at a negative vapour ratio difference. The negative vapour ratio difference ends at around 3,8 g of water per kg of air in Figure 9. Up to this point, both ice rinks have a very similar pattern in terms of steam ratio ratios. However, in these conditions one can observe differences in the operation of each ice hall dehumidifier, where in ice rink 5 it is practically stationary and in ice rink 6 is running with an electrical output higher than 10 kW on average.

If an acceptable steam ratio has been reached inside the ice rink under these outdoor climate conditions, there should be no reason to continue running the dehumidifier as the "natural air leakage process" can do the job instead. Especially Figure 8 The above illustrates in a very clear way how the principle of humidity control affects energy use. Ice rink 6 continues to use energy even though the "moisture target" has been reached, i.e. it thus overdries the air to no avail. Ice rink 5, which is controlled on the moisture content (or dew point), stops running at a negative moisture content difference of about 0.5 g of water per kg of air.

3.5 Energy use for different control principles

Proper control of the moisture level is, as has been noted, important in order to achieve good ice quality and a healthy indoor climate in the building. When discussing the humidity of the air in ice rinks, as previously stated, 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".

It turns out for reasons, which will be discussed here further, 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 by, for example, the laying water evaporating to a greater extent. If, on the other hand, the dew point is higher than about 2°C, the risk of unwanted condensation on the edge and other building parts that are mainly cooled by the ice increases. The condensation on the boards creates ice growth, which in turn means that the ice has to be "knocked" away, which creates a lot of extra work.

Figure 10 illustrates the dehumidifier's energy use in ice rinks 5 and 6, which have also been used in the examples above, under three different indoor climate conditions with respect to dew point level: dry (dew point lower than 0°C), nominal (between 0°C and 2°C) and wet (above 2°C).

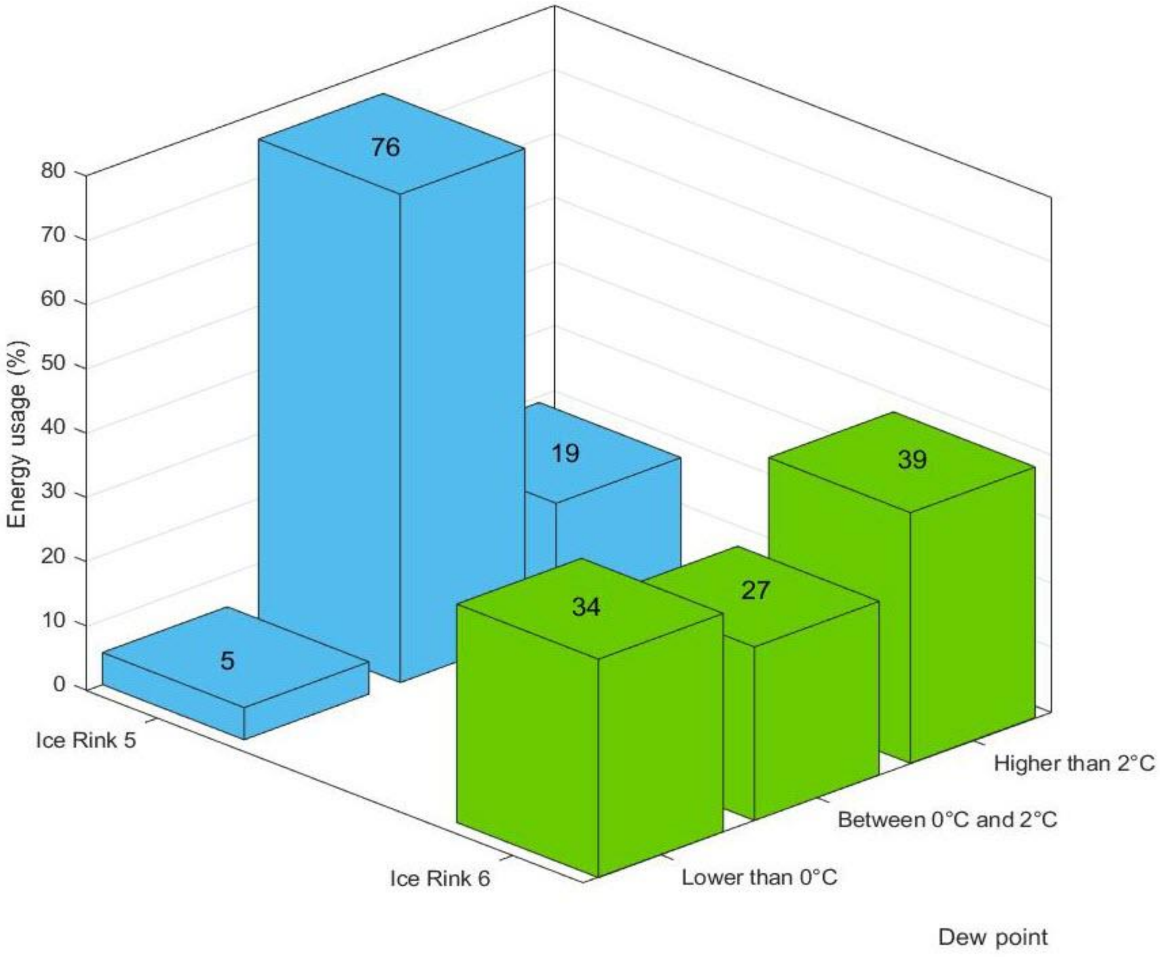

Figure 10. The dehumidifier's energy use as a % of total annual energy in relation to the dew point.

The operation of the dehumidifier in ice rink 5 takes place mainly at "nominal", i.e. desired conditions, which is explained by the applied control strategy based on regulation against the absolute humidity. Only 5% of the operation (about 3 MWh) takes place in dry conditions, which is due to internal moisture sources, since most of the indoor air is then dehumidified via air leakage to the drier outdoor air, and that the dehumidifier is not used at lower moisture levels. In Figure 9 it could be noted that the dehumidifier's capacity was not sufficient as the outdoor steam content reaches high levels and in Figure 10 It is seen that 19% of the drive energy is used in these, i.e. "wet" conditions. This illustrates the need for slightly higher dehumidification capacity in the plant, even if the existing capacity is sufficient for most of the year.

Ice rink 6 shows markedly different results in Figure 10. The dehumidifier's energy use is relatively least under nominal conditions (i.e. when the dew point is 0-2°C), which can lead to moisture problems even if the dehumidifier is in operation. It is thus in operation but works at too low capacity, i.e. it should be directed towards a lower dew point than it does in practice. High energy use in humid conditions could indicate a lack of capacity, but since energy use is also high in dry conditions, it is more a question of the energy waste that occurs due to the control strategy based on relative humidity. Relatively speaking, the dehumidifier in ice rink 6 uses 34% of its annual energy use unnecessarily – ie it overdries the air due to incorrect control principle. In absolute terms, the dehumidifier's "unnecessary" energy use is about 34% of 129 MWh (see Figure 6) = 44 MWh.

With this knowledge and knowledge that existing control systems can often be converted to the right control principle, the saving appears as "a low-hanging fruit", ie with minimal investment, a relatively large saving can be made. Even if a new controller is needed, it is a small investment to upgrade.

4 Energy saving measures

According to the reasoning above, desiccant dehumidification has proven to be normally the technology best suited for ice rinks. The technology can dehumidify air to very low dew point levels (in °C) without technical problems and also leads to a smaller airflow compared to cooling dehumidification. Most of a desiccant dehumidifier's energy use goes to heating its regeneration air, which means that the most significant savings potential can also be achieved here. However, heating must achieve a sufficiently high temperature level, often around 110°C, which is challenging if you look at alternative heat sources that usually have a low temperature. What can be of great potential interest in an ice rink is the possibility of using recycled heat and below we will look at a couple of different options for doing just that.

4.1 Generation 1 – hybrid heating with recycling

A desiccant dehumidifier can use any available heat source that can deliver the required capacity at the right temperature level. In Sweden, electric heating is most often used for this purpose, while in other countries it may be natural gas that is the heat source. In an ice rink where the cooling system emits heat of 60°C, attempts have been made to utilise this heat according to the principles illustrated in Figure 11 where the regeneration air is taken from the environment. To reduce the load (power requirement) on the electric heater, recovered heat from the cooling system is used to preheat the regeneration air.

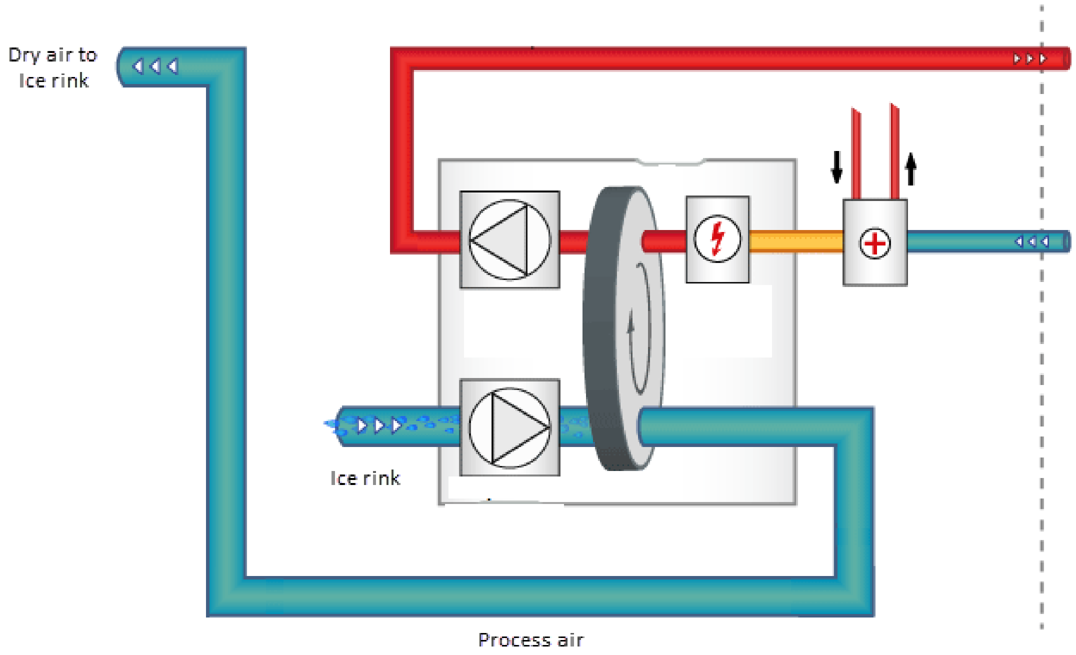

Figure 11. The working principle of the first generation desiccant dehumidifier with recovery heating.

The additional hardware required is a heat exchanger with connection to the heat recovery system of the cooling system. Figure 12 shows the dehumidifier and its preheating function which is a relatively small unit. The electric heater is installed in the dehumidifier itself, while the heat recovery coupling is an option that in this case can be installed outside the dehumidifier unit. Instead of recovered heat, it is also possible to use district heating or any other heat source as a supplementary heat source.

Figure 12. First generation hybrid dehumidifier (TV) - the connection to the heat recovery (TH).

The energy savings depend mainly on how high the temperature level the preheating can achieve, which then leads to less heat output having to be supplied with the electric heater to raise the temperature to the required level. In this case, the preheater raises the air temperature from outdoor level to around 55°C, while the electric heater stands for the rest where the temperature is then raised from 55°C to a maximum of 110°C. The distribution between used recovered heat and electricity when operating the dehumidifier for this installation is shown in Figure 13. The results show that almost 40% electrical energy can be saved in this type of dehumidifier solution when using recovered heat that would otherwise be released to the outdoor air via the cooling system's heat release system.

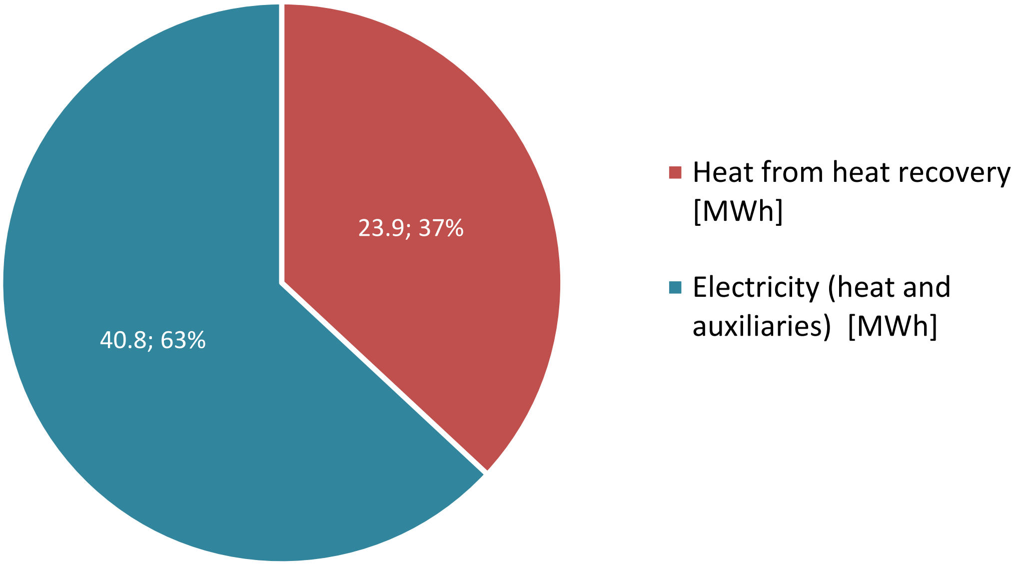

Figure 13. Dehumidifier energy use - first generation recycling technology.

The monthly energy consumption for the installation above can be studied in Figure 14. At the beginning of the season, when the outdoor air is warmer/more humid, electricity consumption is more than twice as high as the amount of recovered heat, while the distribution between the two becomes increasingly even as the outdoor air becomes cooler. This is because the heat output that can be extracted from the recycling system increases as the ambient temperature decreases, i.e. the temperature difference increases in the recycling exchanger.

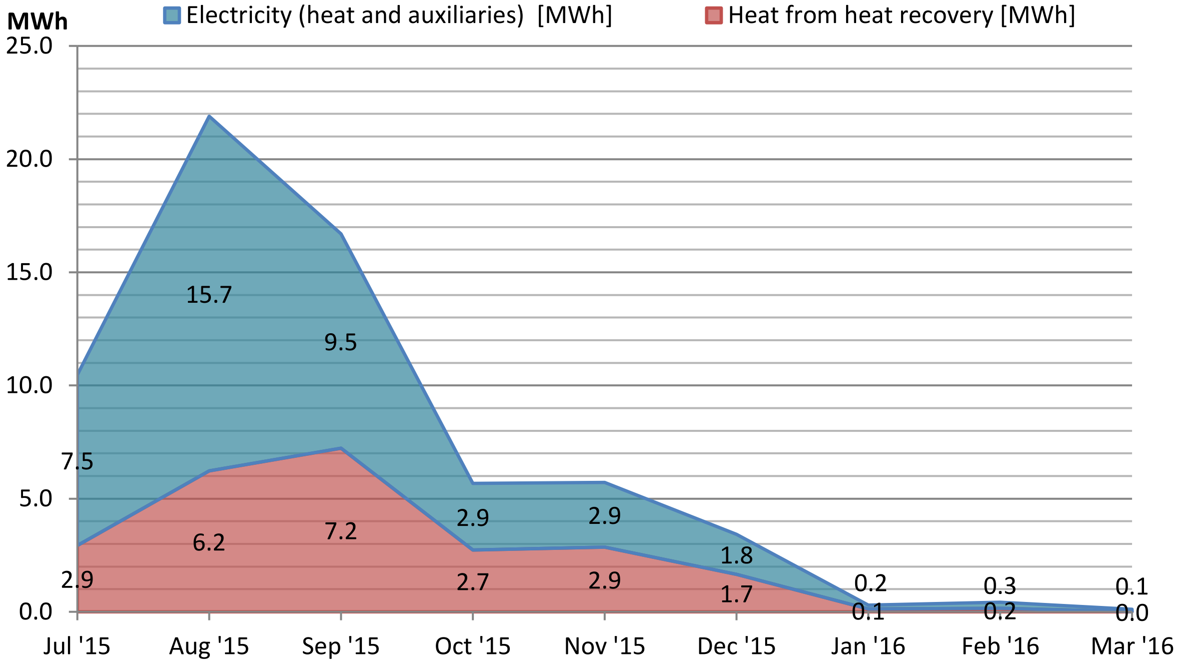

Figure 14. The dehumidifier's monthly energy use in ice rink 5.

When, later in the season, the need for dehumidification decreases with lower moisture levels in the ambient air, the relative share of recycling in the energy supply increases, although the absolute contribution also gradually decreases until the dehumidifier is basically no longer used.

4.2 Generation 2 – complete regeneration with recovered heat

The limitations of the first generation are linked to the temperature level of the recovered heat. To make the dehumidification system less dependent on a supplementary heater, one solution would be to control the cooling system so that the temperature level of its emitted heat is higher. However, this would lower the energy efficiency of the cooling system to a level where its losses would be higher than the potential gains that would be achieved in a more efficient dehumidification process. Thus, there is a technical and economic limit to how high a temperature can be extracted from a heat recovery system.

Another possibility is to increase the rotor's area, with its moisture absorber, so that the regeneration air can work against a larger active surface, but at the same time with a smaller temperature difference between heating air and rotor. This makes it possible to achieve a sufficient dehumidification capacity with heat of a lower temperature level. A dehumidification system has been developed according to this principle and is illustrated in Figure 15. The goal was to cover the dehumidifier's heating needs only with recovered heat from the cooling system. In a traditional desiccant dehumidifier, the regeneration air passes through a quarter of the rotor's surface, while the rest is used by the process air. In this case, the distribution has been changed to 50/50 while as indicated above the total adsorbing area has been increased.

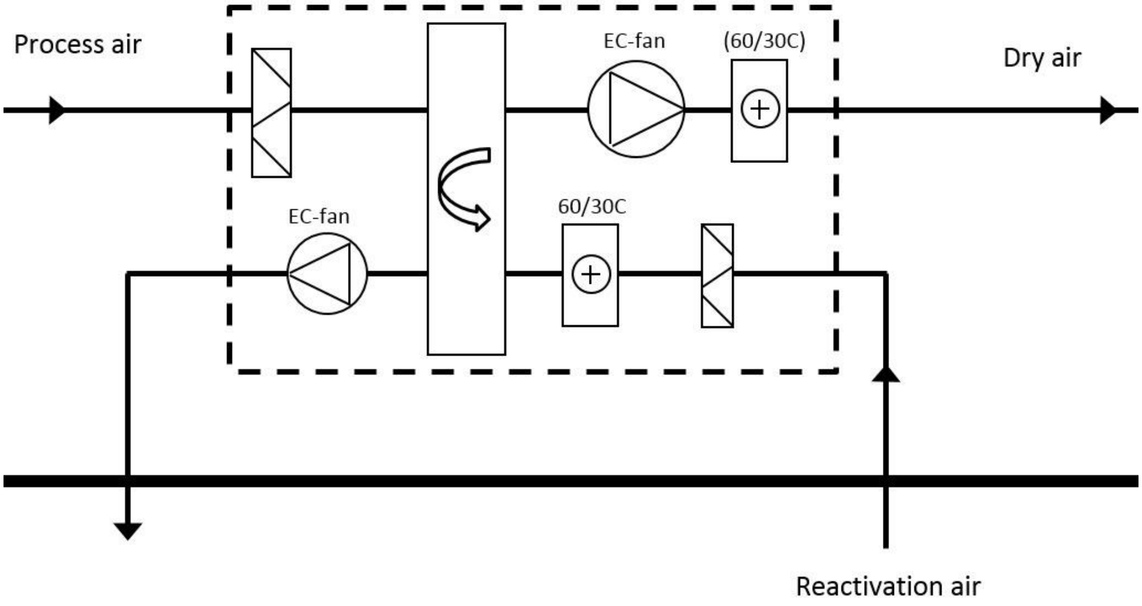

Figure 15. The working principle of the second generation desiccant dehumidifier powered by recovery heat (Moisture control).

Since a lower temperature level is used for heat regeneration, the moisture level of the process air is not as low as in cases where higher temperatures are used. In classic desiccant dehumidifiers, the vapour ratio can be as good as 0 g of water per kg of dry air, i.e. in principle completely dry air, while in the second generation of desiccant dehumidifiers it can be noted that the corresponding figure is around 2 g of water per kg of dry air. Therefore, slightly higher air flows are needed to achieve the same moisture levels in the ice rink, which in turn leads to slightly higher fan powers.

Figure 16. Second generation heat recovery regenerated dehumidifiers.

This sacrifice in the form of higher fan outputs is made in order to cover the heat needs of the dehumidification process with only recovered heat from the cooling system. At the same time, this means that a balance between the size of the rotor and the dehumidification capacity of the heat recovery must be found. In return, suppliers have to a greater extent begun to regulate the capacity of the included fans, which to some extent compensates for the increased need for airflow and in turn distribution effects.

The distribution of the dehumidifier's energy use with second-generation technology is visible for a specific installation in Figure 17. In this case, energy data refers to the results for an entire season. The results show that investing in higher fan outputs nevertheless provides a good saving, as the majority of energy use is still covered by recycled heat, which is also close to "free" or at least very cheap. It should be added that the system shown in the picture above does not have "internal recovery", which is an option that can be added to internally in the machine recover some of the heat in the wet air to the incoming regeneration air. The benefit of an internal recycling is that the heat requirement can be reduced by about 40%, which can be interesting if you have a market for a large amount of (all) recycled heat.

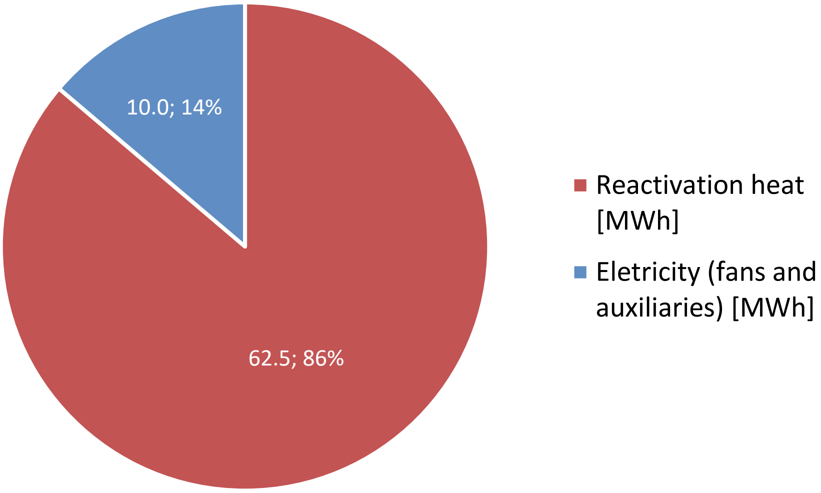

Figure 17. The distribution of the dehumidifier's energy use with second-generation technology.

When it comes to the amount of heat released from the ice rink's cooling system during the season, it can be stated that more heat is released when the outside temperature is higher, which is normally at the beginning of the ice season. How much heat is available under different conditions is discussed further in the reference Rogstam et al 2015. Figure 18 shows the second generation of recycling-driven desiccant dehumidifiers' monthly energy use, where it can be noted that the amount of recovered heat is sufficient throughout the season to cover the dehumidifier's heating needs. Electricity use moves at a level that is on the order of 16% of total energy supplied, while heat obviously makes up the rest ie about 84%.

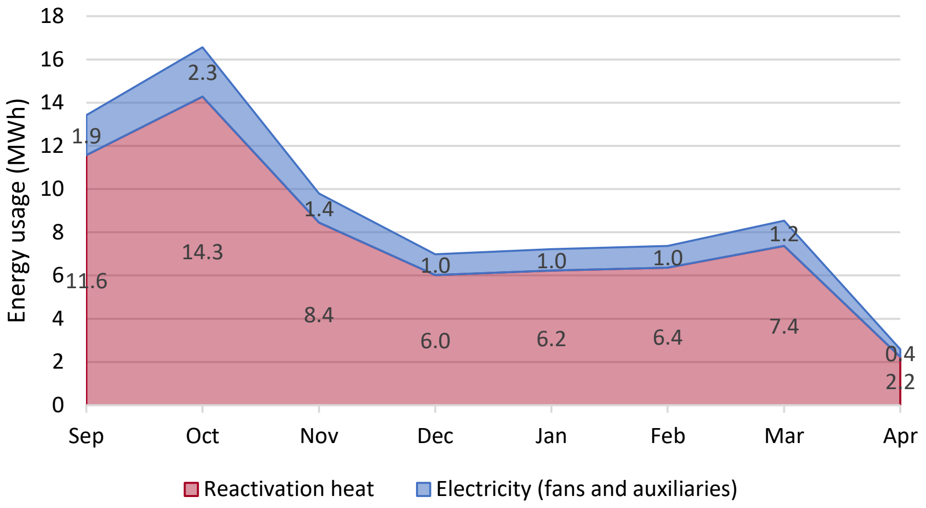

Figure 18. Second generation recycling-driven desiccant dehumidifiers' monthly energy use.

To get an idea of how well this dehumidification technology performs energy-wise in relation to other traditional dehumidifiers, the energy use of dehumidification systems in different ice rinks in Figure 19, where ice rink 9 uses second-generation recycling desiccant dehumidifiers. Even if in this case different seasons are compared, the results should be comparable in principle. It turns out that, as expected, second-generation technology does not reduce the total energy use of dehumidification. However, the savings come from the fact that the recovered heat from the cooling system in this system solution is "close to free".

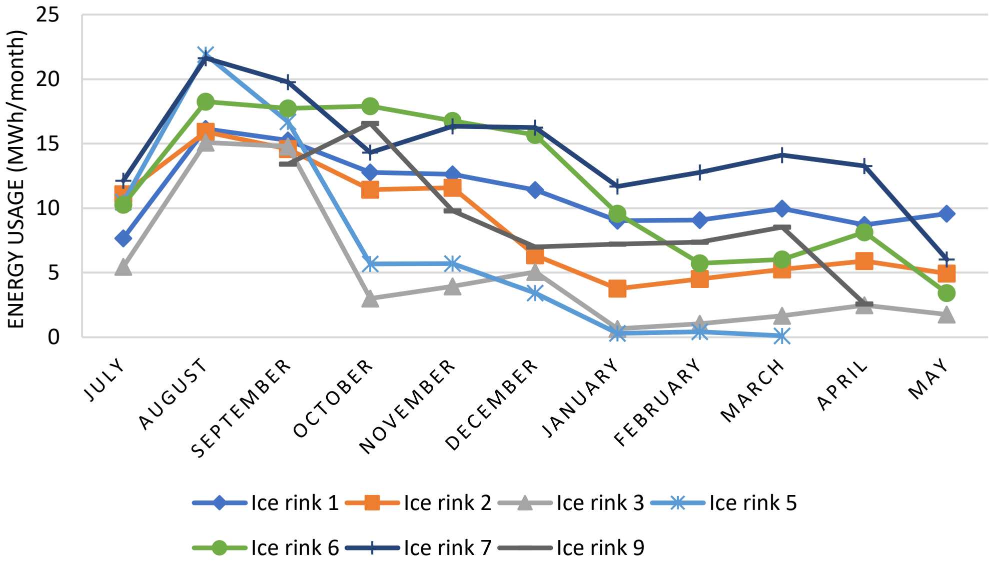

Figure 19. The dehumidifier's monthly energy use in various ice rinks.

The cost of recycled heat is a separate chapter that the interested reader can delve into through Bolteau et al 2016. To make a long story short, it can be said that if the plant still recovers heat and / or that said heat is used when it is hot outside, the cost is close to 0! If the recovery system is activated, the marginal cost of additional heat use is very small. In hot climates, the cooling system normally still works at a high temperature and then the additional cost of the recycling function is also negligible.

5 Conclusions

Interim report 2 within the research project NERIS - Methods and energy use for dehumidification in ice rinks - has dealt with different dehumidification methods in ice rinks and their function together with technical possibilities and limitations. One method discussed is so-called cooling dehumidification, which involves condensing the moisture out of the air. The limitation of this particular method is that it is difficult to get involved in the low moisture levels required in an ice rink. Furthermore, this method drives the cooling demand, often from the cooling system, at the time of year when the cooling demand from the ice is still greatest. This leads to a mismatch of power requirements. The most common dehumidification method is desiccant dehumidification, which is based on moisture being trapped in a rotating wheel and then driven out by high-temperature heat. The method is dehumidification efficient but also requires large amounts of heat energy of high temperature – often in the form of electricity. The annual requirement is generally between 50 and 150 MWh for a small or medium-sized plant.

The surrounding climate is the factor that intuitively most affects energy use, but it turns out that the control principle can also play a decisive role. It turns out that the traditional way of controlling dehumidification based on relative moisture can be severely punished. Not only can you get excessively high moisture levels when the air temperature is high, as at the beginning of the season when it is hot outside, but it often also leads to so-called over-dehumidification when it gets colder - both inside and out. In a current example, it is shown that over 30% of the dehumidification energy is used to no avail, which in the case studied here meant that 44 MWh of electricity was wasted on an annual basis.

You can also illustrate and compare energy use in different plants by producing so-called energy signatures. This is a tool for understanding how plants can be compared with each other and what factors drive energy use. The impact and significance of air leakage has been discussed and will be studied in more detail in future interim reports.

An interesting area is how to save energy and which alternative forms of energy can be used in the dehumidification process. Through what we call 1st generation recycling-driven technology, you combine heat from recycling, district heating or something else with the usually built-in electric heating in the dehumidifier for regeneration. This is a good start and can save the order of 40% electricity for the dehumidification function. In the second generation unit, only liquid-borne heat of about 60°C temperature level is used, which is well suited for, for example, recovery heat from the cooling system - provided that you have enough heat! The experience is good and the savings can be great. The results show that over 80% of the energy requirement for dehumidification can be met with, for example, recovered heat.

6 References

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