

Jens Andreas Rustad  
Christian Fredrik Bryhn Nøstvik

## **Energy use in Norwegian ice rinks**

A key figure analysis

Master's thesis in Real Estate Development and Management

Trondheim, June 2015





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Norwegian University of Science and Technology  
Faculty of Architecture and Fine Art  
Department of Architectural Design and Management



**NTNU – Trondheim**  
Norwegian University of  
Science and Technology



## **Abstract**

This thesis address energy efficiency in ice rinks. The great variation, complexity of the facilities, and the lack of a fitting key figure, have made it difficult to evaluate and compare the energy performance of ice rinks. Several building assessment methods have gained foothold in Norway in recent years, and as these methods only conduct a static evaluation of the building, this thesis investigates measures for the operational phase of the building to improve and evaluate energy performance. As the operational costs in an ice rink in most cases exceeds the investment costs, this highlights the importance of good energy performance.

Through four case studies of different categories of ice rinks in Norway, key figures from energy use data in addition to technical installations, usage patterns and hours of operation have been analysed. The thesis focus on analysing the energy data in accordance to climatic and operational factors and constructing a common basis for comparison of ice rinks within each category.

The Energy Performance Indicator (EPI) is proposed as a basis for comparing ice rinks on equal terms. Working from the assumption that ice rinks can be regarded as process buildings, as they are built to provide a product in the form of an ice pad, and the energy use largely depends on the processes in the building. The elements in the calculation are the productive area, number of available hours, and the final annual energy use (FAEU). Comparing the average values, the arena-sized rinks use 67.9 % more energy per square meter available ice pad throughout the year than the normal-sized ice rinks.

Temperature and humidity are the two most significant climatic factors, as fluctuations in temperature and high levels of humidity in the outdoor air require constant surveillance of the indoor climate. The findings indicate that the climate's impact on the energy use in the rinks is equal, regardless of the studied ice rinks' location.

The interaction between the technical solutions, the construction of the facility, the operations, and a view of the quality of the facility as a whole is important to avoid counteracting processes. This to ensure the right environment that enable focus on a rational and effective operational phase with low energy use. Optimal design of constructions, correct use of building materials and technical equipment adapted to the main use of the facility is required to achieve this.



## **Sammendrag**

Denne avhandlingen adresserer temaet energieffektivitet i ishaller. Den store variasjonen og kompleksiteten i anleggene, samt fraværet av et passende sammenlikningsgrunnlag, har gjort det vanskelig å evaluere og sammenlikne energiytelsen i ishaller. Flere energiklassifiseringsmetoder har opplevd økt popularitet i Norge i de senere år, og da disse metodene kun utfører en statisk evaluering av bygningen, utforsker denne oppgaven tiltak i den operasjonelle fasen for å forbedre og evaluere energibruken. Ettersom driftskostnadene i en ishall i de fleste tilfeller overstiger investeringskostnadene, retter dette søkelyset på viktigheten av energibruken i denne bygningstypen.

Gjennom case-studier av fire ishaller i Norge i forskjellige ishallskategorier, er energidata, informasjon om tekniske installasjoner, bruksmønster og driftstimer analysert. Oppgaven fokuserer på å analysere energidata i forhold til klimatiske- og operasjonelle faktorer, og etablere et grunnlag for sammenlikning av ishaller innenfor hver kategori.

Et måltall for energiytelse (EPI) er foreslått som et grunnlag for å sammenlikne ishaller på like vilkår. Med utgangspunkt i antagelsen om at ishaller er å betrakte som prosessbygg, da de er bygget for et spesifikt formål, og bruken av energi i bygget avhenger av prosessene som skjer i bygget. Utregningen baserer seg på produktivt areal, antall tilgjengelige timer og justert energibruk (FAEU). Ved sammenlikning av gjennomsnittsverdier kommer det frem at kategorien “arena” bruker 67.9 % mer energi per kvadratmeter tilgjengelige isflate gjennom året enn kategorien “normal-hall”.

Temperatur og relativ fuktighet er de to mest signifikante klimatiske faktorene, da svingninger i temperatur og høye fuktighetsverdier i uteluften krever konstant overvåking av inneklimate. Resultatene i denne oppgaven indikerer at klimaets innvirkning på energibruken i ishallene er lik, uavhengig av de studerte ishallenes beliggenhet.

Samhandlingen mellom tekniske systemer, selve konstruksjonene, driften, og å se kvaliteten på fasilitetene i en helhetlig tankegang er viktig for å unngå motvirkende prosesser. Dette for å sikre et miljø som bidrar til fokus på en rasjonell og effektiv driftsfase med lavt energibruk. Helhetlig design av konstruksjonene, riktig bruk av materialer og tekniske installasjoner tilpasset hovedbruken av fasilitetene er nødvendig for å oppnå dette.





## **Preface**

This thesis is the final assignment at the Masters in Real Estate Development and Management, spring 2015. The thesis constitutes 30 ECTS credits. Masters in Real Estate Development and Management is a study program at the Department of Architectural Design and Management, under the Faculty of Architecture and Fine Art, at the Norwegian University of Science and Technology (NTNU) in Trondheim.

The authors of this report have their background from entrepreneurship and economy at BI Norwegian Business School and Structural Engineering at Sør-Trøndelag University College. The diverse backgrounds give a solid foundation for the thesis. The topic of the thesis however, is a subject that both authors have little experience with, and the process of working with this thesis have therefore provided new and interesting knowledge.

The aim for this master thesis is to contribute to the development of energy efficient ice rinks. The focus is on evaluating the operational phase of ice rinks, as this is the main cost driver in sports facilities. The thesis discloses a key figure analysis of four Norwegian ice rinks as a part of the development towards more energy efficient ice hockey rinks in Norway.

We would like to thank supervisor Dr.-ing. Antje Junghans at the Centre for Real Estate and Facilities Management, NTNU, for valuable ideas and comments throughout the period of working on this thesis. Many thanks to Assistant supervisor Chief Engineer Bjørn Aas and Ph.D. Candidate Wolfgang Kampel at the Centre for Sports Facilities and Technology, for extraordinary assist and contribution to this thesis and topic. We would also like to thank the representatives at the studied cases for their invaluable help and commitment.

Trondheim, June 2015

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Jens Andreas Rustad

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Christian Fredrik Bryhn Nøstvik



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## Abbreviations

|                   |   |
|-------------------|---|
| BREEAM            | Building Research Establishment Environmental Assessment Method |
| CaCO <sub>3</sub> | Calcium carbonate   |
| CaO               | Calcium oxide   |
| CO <sub>2</sub>   | Carbon dioxide  |
| EPI               | Energy Performance Indicator                                    |
| FAEU              | Final Annual Energy Use   |
| FMEU              | Final Monthly Energy Use  |
| IIHF              | International Ice Hockey Federation                             |
| kWh               | Kilowatt hours  |
| kW                | Kilowatt  |
| m <sup>2</sup>    | Square meters   |
| m/s               | Meters per second   |
| MET               | Meteorologisk Institutt (Norwegian Meteorological Institute)    |
| MOM               | Management, Operation and Maintenance                           |
| MWh               | Megawatt hours  |
| NH <sub>3</sub>   | Ammonia   |
| NIF               | Norges Idrettsforbund (Norwegian Confederation of Sports)       |
| NIHF              | Norges Ishockeyforbund (Norwegian Ice Hockey Federation)        |
| NS                | Norsk Standard (Norwegian Standard)                             |
| Ra                | Index of colour rendering                                       |
| TEK               | Byggeteknisk forskrift (Technical regulations)                  |
| ua                | Usable area   |



# 1 Introduction

## 1.1 Background for the thesis

The housing and construction sector account for nearly 40 % of the energy use and 40 % of materials used in Norway. It is therefore a relevant topic to promote sustainable quality in buildings that can reduce environmental impact and improve the quality of life for future generations (Kommunal og moderniseringsdepartementet, 2014). The Norwegian Confederation of Sports states in the strategy document “Miljøstrategi for Norsk idrett” (“Environmental strategy for Norwegian sports”) that all sports facilities should fulfil the governmental requirements to environmental standard. This applies to both the construction of new facilities and refurbishment of older facilities (Norges Idrettsforbund, 2011). With ever-increasing demands for reduced energy use through technical regulations, it is important that new solutions, technical and organisational, are utilised in sports facilities.

This thesis is focused on the indoor ice rinks, which officially counts 45. This number does not include rinks with natural cooling. The thesis’ focus is solely on indoor ice rinks and the accompanying facilities, but it is a goal that the methodology and findings in this thesis can be applied in some extent to other sports facilities in the future.

Enova is an organisation owned by the Norwegian Ministry of Petroleum and Energy, and was established in 2001 to impel an environmentally friendly restructuring of energy use and production. Every year Enova publishes a report presenting supplied energy use for different building types for the past year. “Byggstatistikk for 2012” (Building statistics for 2012) shows that sports facilities had an area-weighted, temperature and location corrected specific energy use of 263 kWh/m<sup>2</sup>, usable area (ua). Energy performance of sports facilities are not directly comparable with other types of buildings because of the complexity of the buildings and varying size in relation to the ice surface area. Measurements of energy use per square meter of heated area in an ice rink, and comparisons with corresponding figures for other building types, gives an incorrect picture of the situation. In many aspects a sports facility, and specifically an ice rink, is more similar to a production plant or process building where one uses a key figure for energy, as a factor of the building’s output. In a production plant this factor may be kWh per item produced or per productive area.

The Norwegian Confederation of Sports (NIF) is the largest voluntary movement in Norway, and it is important that sports shows a social responsibility in relation to environment and climate (Norges Idrettsforbund, 2014). NIF want to focus on the possibility of environmental and energy saving standards in energy-intensive sports facilities and other types of facilities. As of today, it does not exist an agreed assessment method or guideline in terms of energy efficient planning and operations for sports buildings in general. Through this thesis, the goal is to contribute to this work for ice rinks. Looking at this through a productive area perspective, a performance assessment of an ice rink should be considered with regard to the pattern of use and availability hours. Of the assessment tools used in Norway today, none possess such an operational phase component.

### **1.1.1 Subject**

The field of research for this master thesis is Real Estate Development and Facilities Management. The researched subjects are energy use and energy efficiency in a selection of Norwegian ice rinks. The thesis is concentrated on design and energy management in ice rinks, to contribute to an energy efficient operational phase. The aim is to establish a factor for comparison of ice rinks, increase knowledge about and evaluate energy saving measures based on the findings in the case study and key figure analysis.

## **1.2 Problem to be addressed**

The problem to be addressed in this master thesis has its basis in the fact that the operational phase in an ice rink is not taken into consideration in existing energy assessment methods, where only a static analysis of the finished building is emphasised, and no agreed common factor suitable for comparing the rinks on equal terms exist.

There are several environmental assessment methods available for use in buildings that, within multiple categories, evaluate the buildings' energy and environmental performance. They offer different sets of criteria for assessing both residential buildings and office buildings, but these sets are not directly transferable to other building types, and it is not appropriate to use these criteria sets when assessing an ice rink. Because this is a commercial product and tool, it does not offer the same value to government-owned facilities, because they are not built with a future resale in mind contrary to commercial participants with greater financial motivations.

As things stand today, it is impossible to compare the energy performance of different ice rinks on the same basis. As a part of the development of a tool for energy savings in the operational phase of the ice facilities, a parameter useful for comparing facilities with each other is investigated.

With ice rinks demanding great insight into the complexity and dynamics of the building in the operational phase, facilitating for increased knowledge and dedication for the personnel to familiarise themselves with the challenges of a rational operation is important.

With basis in the lack of an agreed practice or standard for assessing ice rinks' energy performance and establish a common factor for comparison of ice rinks, the thesis' problem to be addressed is the following:

*Development of management tools for use in the operational phase to promote knowledge and energy efficiency through a key figure analysis of Norwegian ice rinks.*

The objectives of the problem is to develop a management tool or a guide to lay the foundation for energy savings in ice rinks in the operational phase and increase awareness in the design and acquisition-phase. The guide is thought to be an independent tool, or a supplement to assessment methods that only perform a static evaluation of the building regarding the environmental and energy perspective.

The problem to be addressed in this thesis indicates development of rational parameters for energy usage and energy performance in the rinks. A guide to efficient energy management can contribute to a reduction in the energy use in ice rinks, which is very high compared to the remaining agglomeration of buildings in Norway, even though it is difficult to see different building typologies in comparison because of the varying key figures (Enova, 2014).

Details of what the tools and guide contains is not given by the problem to be addressed, but this is a question that shapes the rest of the thesis as a recurrent topic (Olsson, 2011).

### **1.3 Research questions**

To answer the problem to be addressed, the following research questions are formulated to together constitute the final management tool.

#### **1.3.1 Research question 1**

*Is it possible to establish a mutually agreed parameter for measuring energy use and output to make ice rinks comparable?*

This research question is based on the fact that it is not possible to compare different ice rinks with each other or any sports facility. This is because the “area” term used in the denominator (kWh/m<sup>2</sup>) varies between the different building types. In case of comparisons between ice rinks, this parameter causes great difference in the key figures for energy use and performance. To be able to compare ice rinks with each other a new parameter for measuring the energy performance is investigated.

#### **1.3.2 Research question 2**

*Which standard minimum requirements should act as a basis for ice rinks to achieve a rational energy performance?*

This research question aims to elucidate the conditions for an optimal energy efficient operational phase, and is by that directly related to the problem to be addressed. The question is based on research question 1, as a parameter for measuring energy performance is needed to understand what requirements that can be set for an energy efficient ice rink.

#### **1.3.3 Research question 3**

*To what extent do the external conditions affect the energy use and in turn the energy performance?*

The question seeks to answer how climate, nature, landscape and building plot conditions can affect the energy use and performance of the building. Especially the weather and temperature conditions at the rinks’ location is taken into account.



#### **1.3.4 Research question 4**

*How does the energy use in ice-hockey facilities depend on the building materials used?*

The focus is in this question on structural material and properties of these structural materials for use in ice rinks. Different materials affect the building performance in different ways, regarding both indoor climate and energy use. It is relevant to assess characteristics of different materials in relation to areas of application.

### **1.4 Scope and limitation**

The thesis addresses the development of a management tool to contribute to an energy efficient and rational operational phase in ice rinks. The thesis will consider three different types of ice rinks: training rinks, normal-sized rinks and arena-sized rinks. Other types of sports facilities are not assessed; however, the results of this research may be adapted to fit other types of sports facilities. An explanation of the different rink types is found in chapter 2.2.

As the thesis focuses on the operational phase, the measures taken in the planning and building period will not be considered. However, the aim through the analysis of the operational phase is to increase the understanding of the buildings energy use in order to raise the level of knowledge for future design and procurement.

Modern sports facilities are buildings with many and advanced systems. The thesis will not go deep into details and solutions related to this, as this is covered on a superficial level only. The topic of technical systems is brought up at some point due to its relevance for a buildings environmental and energy performance. However, the focus lies instead on seeing the system interaction and totality to determine how this affects the energy performance.

The case study is limited to four objects of interest. To be able to draw more specific conclusion, it would be desirable with a larger selection. On the other hand, the time frame for the thesis is short, and the process of collecting and analysing data is time consuming. By having several objects, it is presumed that it would not be possible to delve into the objects as it is done with the four presented in this thesis.

## **1.5 Structure of the master thesis**

### **Chapter 1: Introduction**

The introduction chapter describes the background for the choice of subject, a presentation of the problem to be addressed, and the research questions, which is the basis for the thesis. In addition, the scope and limitations are presented in this chapter.

### **Chapter 2: Theory**

The theory chapter includes the chosen literature and the theory grounding this thesis. The literature presented is a result of the accomplished literature and document study. Theories describing the different categories of ice rinks, patterns of use and technical equipment are central, as well as theory on materials, climatic conditions and energy classification methods.

### **Chapter 3: Method**

Chapter 3 describes the choice of method and relevant research methodology. The applied method is presented chronologically, as well as the validity and reliability of the method.

### **Chapter 4: Results**

Chapter 4 presents the case study organised after rink classification. First is general information, climatic conditions, technical specifications and operation and use presented. Further is the collected energy use data presented and supplemented with tables and graphs giving a clear view of the information.

The presentation of the rinks and the collected data is followed by the analysis of the data. The presentation is shown according to year and season, and actual and climate adjusted energy use figures. The results also include the background and formulation of a parameter for comparison of ice hockey rinks.

### **Chapter 5: Discussion**

Based on the findings from the theory, case studies and analyses, the problem to be addressed and questions formulated in chapter 1.3 is discussed.

### **Chapter 6: Conclusions and future work**

The final chapter contains the conclusions from the thesis and suggestions for future work.

## 2 Theory

### 2.1 State of the art

In this chapter, the state of the art of ice rinks is explained. For a key figure analysis to have a baseline for comparison, a brief look will be taken on status and practices in term of ice rinks in Norway and in other parts of the world.

#### 2.1.1 Norway

The national average of sports facility density per inhabitant in Norwegian municipalities with over 40,000 inhabitants is just over 2 facilities per inhabitant (Norges Idrettsforbund, 2013). Oslo, the capitol of Norway, comes out worst with a density of 1.4 facilities per inhabitant. Extensive development and construction is needed for increasing the density in order to comply with The Norwegian Confederation of Sports' (Norges Idrettsforbund, NIF) vision of “Sport For All” (Norges Idrettsforbund, 2014). According to the Municipality of Oslo - City Council (2014), the plans that were prepared for upgrading and construction of sports facilities for Oslo's bid for the Olympic winter games in 2022 will be continued through construction of energy efficient and environmental friendly sports facilities (Oslo Kommune - Byrådet, 2014).

According to the Norwegian Ice-hockey Federation (NIHF), there are 45 official ice-hockey rinks in Norway with an average age of approximately 24 years (in 2015) (Norges Ishockeyforbund, 2015). This goes to show, that new rinks are far apart. Constructing facilities for ice related sports is very expensive due to the complexity of the buildings and the required technical systems. They have to be treated as special buildings, which they are often not. When a new rink is designed and built, it is often without the input of specialists. The organisations behind the project are often novices and lacking the required experience, because in most cases they are only involved in this one project. This may be because in Norway, the building of new ice rinks is a public investment, with only a few exceptions. So the expertise one acquires when building a rink in one municipality is rarely transferred to the next project in another municipality. Another problem associated with this is that one tends to base design decisions on the investment costs only, and not the operating costs (Operations Manager, 2015b). This leads to ice rinks with bad energy performance and which have to be improved in the future.

As stated above, the average age of the official ice rinks in Norway is 24 years, although this figure does not tell the whole truth. Many of the ice rinks were built earlier and were outdoor arenas prior to having roof installed. This means that many of the rinks have older facilities than the official age maintains, because the official age is in this case from when the roof was built. As an example, one can look to Jordal Amfi in Oslo that was completed for the Winter Olympics in 1952 as an outdoors ice arena. Officially, this rink was reopened in 1971, when the roof was built. However, everything but the roof was built before the Olympics and therefore still maintains this standard (Bryhn, 2009).

According to the Technical Regulations (Teknisk Forskrift) of 2010 (TEK10) the net total energy demand in a sports facility in Norway is set not to exceed 170 kWh/m<sup>2</sup>, heated usable area, per year (Kommunal og moderniseringsdepartementet, 2010). This implies that all facilities built according to this regulation must satisfy the requirements given in the TEK10. This requirement does not however specify the different types of sports facilities. With different needs for heating and cooling, facilities across different sports cannot be directly compared, which makes the requirements difficult to implement in practice.

### **2.1.2 Rest of the world**

Canada and the USA are both frontrunners when it comes to number of, and standard of ice rinks. Both countries have a vast number of ice rinks and it would be impossible to generalise the state of the art of all the rinks. According to The Edmonton Journal (2007) all the arenas of the 30 National Hockey League (NHL) teams have over 16,000 seats, the biggest over 20,000 seats (The Edmonton Journal, 2007).

In 2005, The Canadian Recreational Facilities Council (CRFC) in cooperation with Hockey Canada conducted a National Arena Census through a survey distributed to 2,486 ice arenas across Canada. Although the response rate was only 48 %, they were able to draw the following conclusions: 47 % of the arenas being over 26 years of age, 32 % being over 36 years old. The oldest arena where constructed in 1921. 86 % of the arenas in Canada are municipally owned and operated and 65 % of the arenas use an NH<sub>3</sub> and water solution as the primary refrigerant. It also becomes visible from the survey that in a 10-year period (2005-2015) major renovations are planned for an amount exceeding 3.7 billion Canadian dollars (22.5 billion NOK) (Canadian Recreation Facilities Council, 2005).

In 2010, the NHL in the United States started the NHL Green Initiative that focuses on the environmental impact of the ice hockey sport. In 2014, the first sustainability report was launched, which address the connection between ice hockey and the environment. From the web page of the report one can read that; “...it is our objective to raise the level of environmental consciousness among our fans and arena operators, and encourage improvements within our Clubs’ buildings, our operations, employees, partners, vendors, fans and communities” (NHL, 2014).

In Sweden, ice hockey has also been an important activity that gathers big crowds and many athletes. Ice hockey was introduced in Sweden in the 1920’s, and the first national ice hockey team was put together by former bandy-players that wanted to try something new. The sport has gained massive interest and attention since its introduction, and is today one of the most popular team sports in the country. Sweden can boast of having 602 ice hockey clubs, 84,000 players and judges, and 9 World Championship gold medals. In addition Sweden have 354 official ice rinks, where the first modern ice rink Rosenlundhallen was built in 1958 (Svenska Ishockeyförbundet, 2015).

A research project collaboration between Energi & Kylanalys AB and Svenska Ishockeyförbundet resulted in a four parts report called “Stoppsladd”. From the 345 official ice rinks in Sweden over a 100 where assessed in “Stoppsladd” which released the first report in 2010. The results show that a typical Swedish arena uses 1,185 MWh energy each year. 43 % of the total energy use is accounted for by the refrigeration system, where the compressors are the largest part. Energy for heating is the second largest post with 26 %, and lighting is the third largest energy user, with 10 % of the total use. In phase one, the project presents a saving potential of 218 MWh per year, or 18 % of the average Swedish ice hockey arena (Rogstam and Hjert, 2010). In phase two of the project, the report published in 2011 states, among other important key elements, that the human factors such as knowledge and incentive are the key to future energy savings as well as more detailed measurement equipment or incentives for measuring (Rogstam et al., 2011). Reports from the projects phase three and four, build on the conclusions presented in phase one and two. They continue to stress the importance of the need for information distribution and development of competence as a key to future savings in coherence with energy saving measures within the different technical areas of an ice rink (Rogstam et al., 2014).

## **2.2 Categories of ice-hockey rinks**

Ice rink facilities share much of the same concerns: the operating costs, energy usage and indoor climate being very different from any other facility, building or process building. The different groups of ice-hockey facilities are all highly dependent on advanced technology to control the indoor climate and energy use (International Ice Hockey Federation, 2015). The Norwegian Ice-hockey Federation (NIHF) has defined the categories of hockey rinks in Norway, and the requirements that follow. It is the number of spectators the facility can hold, and its purpose of use that determine the category. The following three groups of ice rinks is what this thesis is based on.

### **2.2.1 Training rink**

The training rink is described as a facility that provides the most necessary functions to play hockey. Basically, this means providing an ice-pad to play hockey and other activities that involve skating. The training rink is often built as a simple construction, as there are no, or limited number of seating for audience. This reflects the need for advanced heating and ventilation, as this is not much compared to the bigger rinks and arenas. The basic technical equipment needed in a well-working facility is insulated walls and ceiling, efficient refrigeration and heating plant, mechanical ventilation and air dehumidification. On the other hand, many rinks of this category do not have proper insulation and effective heating/ventilation systems, which can lead to indoor air quality problems and energy loss (Norges Ishockeyforbund, 2014).

### **2.2.2 Normal-sized rink**

The normal-sized ice rink (Norwegian: Arrangementshall B) is in size in between the training rink and the arena, and is the most common ice-hockey facility in Norway. Facilities of this classification can hold up to 3,000 spectators and must because of this include all the facilities to meet the needs of the audience, players and employees. This includes changing rooms, showers, cafés, offices and other areas designated for players, audience or media (Norges Ishockeyforbund, 2014).

Even though a normal-sized ice rink needs all the above-mentioned additional facilities, there is no guarantee the ice rink can host hockey matches in top division in Norway. The facility has to meet certain criteria to host these events, e.g. there have to be special areas designated and

adapted for media crew including wireless network and telephone lines as well as a specific VIP-room with a view over the arena (Norges Ishockeyforbund, 2014).

### **2.2.3 Arena-sized rink**

The ice-hockey arena (Norwegian: Arrangementshall A) is defined to be a rink that can house audiences from 3,000 and above. The minimum number of seated audience is 2,000 (Norges Ishockeyforbund, 2014). Many ice-hockey arenas are designed and built for use by multiple types of sport. This means that different sports can be practiced in the arena, and the ice-pad can be converted to use for concerts, exhibitions and various sports like basketball and handball.

## **2.3 Patterns of use in ice rinks**

To understand the energy use figures of an ice rink, it is important also to understand how an ice rink is used. The utility model of an ice rink, and many other sports facilities, differs a great deal from residential and commercial buildings.

The theory and information presented in this chapter is partially based on information that was acquired during field research for this thesis. The majority of information was acquired in unwritten dialogs, meetings and interaction with management, operation and maintenance personnel (MOM-personnel) and visitors in the ice rinks.

### **2.3.1 Training and match situations**

In a typical ice rink, the daily activity can be high, with professional teams, local teams, figure skaters, municipal use like schools and kindergartens in addition to the time the rink is rented to private persons, groups or companies.

Depending on how the individual rink is organised, the activity often peaks in the afternoon with youth teams being the majority. It is important to be aware of the fact that the majority of all activity in an ice rink, whether it is a training rink or a top division arena sized rink, consists of training activities. The hallmark of a training activity is that contrary to matches there are no attendances, mostly just athletes and coaches (Oslo Kommune - Kultur og idrettsbygg, 2015). The conflict in relation to this pattern of use is apparent in the planning phase of a new rink or refurbishment of an old rink. When planning the building of a new rink or refurbishment of an old rink, the design has to fulfil the requirements in the technical regulations. Using the

## Chapter 2 – Theory

ventilation systems as an example, the TEK10 has strict requirements for the ventilation systems in a public building. The regulations are formulated in a way that accommodates the needs for ventilation in a match situation with a capacity crowd.

A match situation with a crowd near full capacity rarely occurs more than every other week, with a few exceptions (playoffs or cups). In Norway, this does not represent the dominating use of the rink. This in turn often leads to a ventilation plant delivering mostly recirculated air. This solution is not ideal for the average rink because a higher degree of recirculating air is less effective. Low degree of air replacement can lead to higher concentrations of chemical pollution and lead to condensation and moisture problems (Norges Astma- og Allergiforbund, 2015). Large canals, placed in the ceiling, with lower airflow rate results in lower pressure and the air throw too short to have any effect. In many cases, one can uphold that to cover the need of ventilation in situations outside full crowd capacity, the air leakages through doors, hallways and similar around the ice surface is sufficient air renewal.

Jordal Amfi in Oslo is an arena completed ahead of the 1952 Olympic Games. Today, a new rink is under planning in the same plot of land. The new arena will house the Vålerenga elite ice-hockey team, with a capacity of 4,000-5,000 seats. This will make it comparable to Rink C and D studied in this thesis. The rink was originally a part of the plans for the Oslo 2022 Winter Olympics bid. The plans for the new sports arenas were future oriented and had high goals for energy efficiency and BREEAM certification. After the Olympic bid were turned down the plans are more conservative, but an energy efficient rink is still a top priority (Oslo Kommune - Byrådet, 2014).

When planning the new rink the usage pattern and hours are an important part of the programming and design, and a matrix displaying the expected use was made. The rink will be used as an arena for an elite ice-hockey team, but the majority of the use is practices followed by weekend cups. The match days are found, with under 1/10<sup>th</sup> of the usage hours of practices (Oslo Kommune - Kultur og idrettsbygg, 2015). When viewing the overall usage one can see practices with twenty persons are assumed to take up 84.9 % of the available hours in the rink. Cups and match days follows at 7.9 % and 7.2 %, respectively (Oslo Kommune - Kultur og idrettsbygg, 2015).

This goes to exemplify the importance of the rinks' pattern of use before one decides on the design and technical solutions. It confirms that even arena-sized rinks are used "as intended"



barely 7 % of the time. Finally it raises a question about the design, as the rinks are designed to accommodate the extreme situations, which is the matches, and not the dominating situation, which is the everyday use of the rink at over 84 % of the time (Oslo Kommune - Kultur og idrettsbygg, 2015).

In order to address this paradox, one have looked into alternative methods of cooling and heating the ice rink in the extreme situations in the planning of the new Jordal Amfi. A new proposal is the “chef’s hat-principle”, which includes a convex roof to separate the climate zones (Rangul and Andersen, 2015). This way they can be able to design the rink after the dominating use, which in turn will make it more efficient.

### **2.3.2 Illustration of daily activity-plan**

Below, an average weekday and an average Saturday or Sunday is illustrated, as it would look like in a normal ice rink. On a typical weekday, the day starts with ice preparation early in the morning before morning practice. Furthermore, the ice is not used until the afternoon, when different youth teams and private sports clubs and/or company sports teams use or rent the rinks’ facilities. This type of activity draws no crowd, and the demand for heating and ventilation is non-existent other than providing air to the players on the ice. The illustration to the right shows a typical weekend (Saturday or Sunday), which includes an A-level match and kids ice-hockey school. One can see that the match only takes a total of 2.5 hours, which is only 20 % of the total opening hours this day. In weekends without A-level matches the rink is often open to public, albeit only 1 to 2 hours of the total opening time that day.

The illustration presented below is based on information gathered from the site visits of the case objects, and statements from management and operational personnel at the site. It must therefore be considered as an example of use.

| Weekday example - normal rink |       |       |                   | Weekend example - normal rink |       |       |                    |
|-------------------------------|-------|-------|-------------------|-------------------------------|-------|-------|--------------------|
| START                         | END   | TIME  | DESCRIPTION       | START                         | END   | TIME  | DESCRIPTION        |
| 07:00                         | 07:15 | 00:15 | Ice preparation   | 08:30                         | 08:45 | 00:15 | Ice preparation    |
| 07:15                         | 08:15 | 01:00 | Practice          | 08:45                         | 09:45 | 01:00 | Practice           |
| 08:15                         | 08:30 | 01:00 | Ice preparation   | 09:45                         | 10:00 | 00:15 | Ice preparation    |
| 08:30                         | 11:00 | 01:00 | -                 | 10:00                         | 11:00 | 01:00 | Kids hockey school |
| 12:00                         | 13:00 | 01:00 | -                 | 11:00                         | 11:15 | 00:15 | Ice preparation    |
| 13:00                         | 14:00 | 01:00 | -                 | 11:15                         | 13:45 | 02:30 | Y-20               |
| 14:00                         | 15:00 | 01:00 | -                 | 13:45                         | 14:00 | 00:15 | Ice preparation    |
| 15:00                         | 16:00 | 01:00 | -                 | 14:00                         | 16:45 | 02:45 | Practice/warmup    |
| 16:00                         | 17:00 | 01:00 | Y-12              | 16:45                         | 17:00 | 00:15 | Ice preparation    |
| 17:00                         | 17:15 | 00:15 | Ice preparation   | 17:00                         | 19:30 | 02:30 | Match - elite      |
| 17:15                         | 18:15 | 01:00 | Y-10/11           |                               |       |       |                    |
| 18:15                         | 18:30 | 00:15 | Ice preparation   |                               |       |       |                    |
| 18:30                         | 19:30 | 01:00 | Y-18              |                               |       |       |                    |
| 19:30                         | 19:45 | 00:15 | Ice preparation   |                               |       |       |                    |
| 19:45                         | 21:15 | 01:30 | Y-15              |                               |       |       |                    |
| 21:15                         | 21:30 | 00:15 | Ice preparation   |                               |       |       |                    |
| 21:30                         | 22:30 | 01:00 | Old Boys practice |                               |       |       |                    |

Figure 1: Example of typical use of an ice rink (Operations Manager, 2015a, Operations Manager, 2015b, Site Manager, 2015, Sports Facility Manager, 2015).

Hours of use can vary from as early as 7:00 AM to as late as 11:00 PM. When the rink is used, the ice is resurfaced as often as once per hour. To keep the ice in top condition after resurfacing and during use, the cooling systems run at high effect. Partly because it has to freeze rapidly after the resurfacing process, but also because the temperature in the rink increases when there are people and activity in the rink.

### 2.4 Technical equipment in ice skating rinks

Ice skating rinks can be large buildings where de refrigerated area, if the purpose of the rink is ice hockey, is approximately 1,800-2,000 m<sup>2</sup>. Depending on the type of rink, there are heated areas of the building in addition. Regardless of this, even the simplest of ice skating rinks use more energy than most other indoor sports facilities of the same standard. The reason for this is the complexity of the ice rinks compared to other facilities, as they are more like processing plants than regular housing when assessing the energy performance.

#### 2.4.1 Refrigeration

The refrigeration unit is the heart of the facility. It is normal that the electricity use for the refrigeration unit accounts for over 50 % of the total energy use (International Ice Hockey Federation, 2015). When planning the refrigeration system, one has to consider energy usage, environment, operation, maintenance and costs. The refrigeration system is needed to make and maintain the ice in the rink, where it consist of compressors, condensers, evaporators and rink pipes. The heat from the rink is sucked by the compressor, via the rink pipes and transferred to

the surrounding via the evaporator and the condenser. Ideally, this system should be used to transfer heat from the condenser to the other climatic zones of the facility that require a higher temperature. The most common refrigeration system is an indirect system, which include a separate heat exchanger, and where the ice is indirectly cooled in a closed circulation loop system that contains a special brine (International Ice Hockey Federation, 2015).

For the operational aspect of the refrigeration system, it is necessary to have an automated system to the extent that it does only cover the demand. Such automation can help reduce the operational costs, by reducing energy usage and the need for regularly maintenance. To reduce energy use further it is recommended to install a compressor that is as efficient as possible. The function of the compressor unit is to keep the pressure and temperature in the evaporator low enough for the brine to boil off at a temperature below that of the medium surrounding the evaporator, so that heat is absorbed. The unit pumps heat from the ice rink to where it is needed, e.g. the support functions in the arena (International Ice Hockey Federation, 2015). It is important to remember that it is not a single component itself that needs focus, it is the entire system as a unit, that needs to be as efficient as possible.

In a simulation model of the refrigeration system of an indoor ice rink, Seghouani and Galanis (2009) found that by using a strategy that limits the number of simultaneously operating compressors they could reduce the energy consumed by the compressor motors with 10 % and decrease the peak power demand by 20 %. On the other hand, this led to a 0.5 °C increase in the exit-temperature of the brine during short periods following the ice resurfacing (Seghouani and Galanis, 2009).

Ferrantelli, Melóis, Räikönen and Viljanen (2012) found that when assessing the energy use in the refrigeration system of an ice rink, it is the brine pumps, chillers, condensers and compressors that need focus, as they represent over 90 % of the total refrigeration energy use. The results show that choosing an optimal secondary refrigerant brine fluid is crucial to achieve better performance, and that an ammonia-solution is to be preferred in any case. Typically this solution consist of 17 % NH<sub>3</sub> and water to gain optimal viscosity, better heat transfer coefficient and resulting in better performance. In addition it becomes clear that the pipe size and depth inside the concrete slab is irrelevant to the system performance, but when increasing the number of pipes with 1/3<sup>rd</sup> it provides a more uniform temperature profile on the ice (Ferrantelli et al., 2012).

### **2.4.2 Ventilation**

Ventilation and air conditioning provides ventilated air delivered to the ice rink and other areas of the facility. Fresh air intake is necessary to ensure good indoor air quality and climate. Those who have visited a dressing room realise the necessity of a proper ventilation system, as the smell from the outfit of the hockey players is bad. A satisfying indoor climate in an ice rink is often difficult as there are different climate zones in the building; the ice rink and the public areas, as well as the air quality is affected by the emissions of the people, the building materials and the outside temperature.

Stobiecka, Koper and Lipska (2013) explains that the required functions of an indoor ice rink ventilation system are maintaining adequate thermal and humidity conditions for the users, and removing excess moisture above the ice surface. In addition, they mention the specific indoor air parameters in an ice rink should be the following: indoor air temperature should be in the range between 10-12 °C during practice and 12-14 °C during competition. Air temperature in the spectator area should be slightly higher, around 14-15 °C, and the air speed above the ice should be 0.25 m/s or less (Stobiecka et al., 2013).

The Swedish “Stoppsladd” report, mentions the importance of an airtight enclosure of the building. This is to eliminate air-leakages through doors, windows or joints in the construction. This can increase energy use in the warmer seasons and cause trouble related to dehumidification, refrigeration and heating (Rogstam et al., 2011).

The energy-saving factor in ventilation is likely to be found in installing demand-controlled fresh-air intake and optimising the airflow rates according to the needs, for minimising the fan power (International Ice Hockey Federation, 2015).

### **2.4.3 Heating**

Heating is needed to maintain comfortable thermal conditions both for the players and the spectators inside the facility. Again, there are conflicting conditions, as the players on the ice wants as much fresh air as possible, the audience prefers warm comfortable temperatures, and the ice-pad itself thrives best in cold stagnant air. These different climatic zones have to compromise to be able to deliver heating to where it is needed to please the players, spectators and the ice. Heating is also utilised to control the humidity in the ice rink and to avoid fog and ceiling dripping problems.

The heating systems of today rely in great extent on heating through convection. This means that heat transfer from one place to another by the movement of fluids. This is an inefficient method as the heated air is often supplied through air vents below the ceiling, and presents a great heat load on the ice itself. The heat load on the ice is dependent on the three factors convection, conduction and radiation, where the heat load from convection is around three times higher than from the other two (Bergsagel, 2014). As a result of this, in an ideal situation the demand for heating is covered by the recovered heat from the refrigeration process and delivered through conduction.

A comparative study of three ventilation systems in typical Canadian indoor ice rinks performed by Piché and Galanis (2010), shows that the use of a heat exchanger to heat the ventilation air results in energy use reductions throughout the year. They found that these gains could be as high as 60.8 % of the heating energy used by the existing system. Depending on actual price and the price of the heat exchanger, it is established that the cost savings over the life cycle of the product is at least three times higher than the investment cost (Piché and Galanis, 2010).

#### **2.4.4 Dehumidification**

The moisture load in the ice rink is due to the people inside the facility, outside air moisture and evaporating water on the ice pad from the ice resurfacers. These factors influence the indoor climate and the humidity a great deal and this moisture have to be controlled at a certain level. The biggest moisture load is the water content of the outdoor air, which enters the facility through ventilation air intakes and through leakages in the building envelope (International Ice Hockey Federation, 2015). Excess humidity can cause rot in wooden structures, corrosion of metals, mould and fungus that gives a contaminated indoor climate.

According to the International Ice Hockey Federation (IIHF) Arena Guide (2015), there are two primary ways to remove moisture from the air: cool the air below its dew point to condense the water vapour, or pass the air over a material that absorbs water. The most common method is, when using mechanical ventilation, to install dehumidifiers that cool the air below its dew point and delivers dry air to the ice rink (International Ice Hockey Federation, 2015).

The relative humidity in an ice rink must be within 40-65 % (Stobiecka et al., 2013).

### 2.4.5 Lighting

Lighting is classified according to their operational principles and the source of the emitting light. Incandescent lamps are generally used in household lighting and have a high electricity demand compared to the illumination. Other types of lighting is fluorescent light and LED lighting, which gives more light per watt and long life expectancy compared to the incandescent lights (International Ice Hockey Federation, 2015).

The luminous intensity are measured in lux and the ice rinks (in Norway) have to meet certain criteria when it comes to intensity, colour temperature and re-striking time (planned or unplanned, the time it takes to turn the lights back on). Average luminance has to be between 1000 and 1400 lux with a colour temperature in the range Ra 70-85. This means it also satisfies the criteria for TV-production from the rink (Norges Ishockeyforbund, 2014).

**Table 1: Types and characteristics of lighting for use in an ice rink (International Ice Hockey Federation, 2015).**

| Type                       | Applicability         | Power range | Life             | Info                                 |
|----------------------------|-----------------------|-------------|------------------|--------------------------------------|
| Compact fluorescent lamps  | General lighting      | 5-55 W      | 8,000-12,000 hr  | Good energy efficiency               |
| Standard fluorescent       | General/rink lighting | 30-80 W     | 20,000 hr        | Good energy efficiency               |
| Light-emitting diode (LED) | General/rink lighting | <200 W      | 15,000-50,000 hr | Good energy efficiency and long life |
| Metal halide lamps         | Rink lighting         | 35-2000 W   | 6,000-20,000 hr  | Good for rink lighting               |
| High pressure sodium lamps | Rink lighting         | 50-400 W    | 14,000-24,000 hr | Poor colour rendering                |
| Induction lamps            | Rink lighting         | 55-165 W    | 60,000 hr        | Long life                            |
| Halogen lamps              | Special lighting      | 20-2000 W   | 2,000-4,000 hr   | Good colour rendering                |

Caliskan and Hepbasli (2010) explain that lighting is a major source of radiant heat to the ice sheet. Dependant of the type of lighting installed the actual quantity of heat radiation can vary. The direct radiant heat can be 60 % of the kilowatt rating of the luminaires (Caliskan and Hepbasli, 2010).

An analysis of the lighting in the “Stoppsladd” project shows that the illumination per installed kilowatt lighting can be divided with a factor of two. This shows a considerable saving potential for the installations with poor performance, and on average the installations deliver 26 lux/kW (Rogstam et al., 2011).

#### 2.4.6 Ice pad structure

The International Ice Hockey Federation (IIHF) describes the most commonly used ice pad structure in their Arena Guide (2015). The ice pad is the most special structure in the ice rink, and is normally constructed in several layers of different material to balance the need for cooling, isolation and heating. It consists of ground layers below the actual ice pad, thermal insulation, piping that leads cooling liquid, and the ice pad itself (International Ice Hockey Federation, 2015).

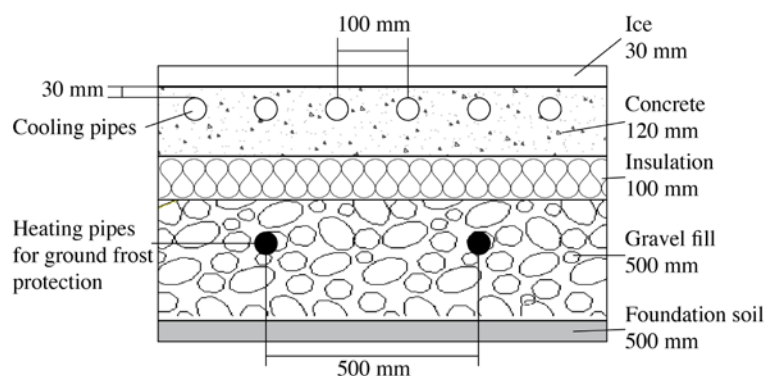


Figure 2: Ice pad structure (International Ice Hockey Federation, 2015).

The Arena Guide states that the most common surfacing material is concrete, as this enables multi-function use also in the off-seasons. Other regularly used materials are sand, as this is cheap and energy economical because of its good heat-transfer characteristics. Asphalt surfaces are also used, as this is cheaper than concrete but require more energy for refrigeration (International Ice Hockey Federation, 2015).

To cool the ice to its desired temperature, piping is laid underneath the ice. The rink pipe material is plastic or metal and is mounted near the surface in the concrete slab. The rink pipes are connected to the distribution and collection mains, which are laid along the short or long side of the rink. The rink piping contains special coolant brine that helps keep the ice-bearing slabs temperature to the temperature level where the water spread onto it can freeze (International Ice Hockey Federation, 2015).

### **2.4.7 Building envelope**

The concept of the building envelope relates to design and construction of the exterior of the building. A good envelope refers to the qualities of the exterior elements, as they should be climate-appropriate, structurally sound and aesthetically pleasing (Oral et al., 2004).

The building envelope primary function in an ice rink is to secure air tightness, as air leakages in the construction can lead to higher moisture loads inside the facility. The exterior wall structure also focuses on air tightness, and the simplest of constructions is several layers of different metal sheet panels. Insulated sandwich elements allow flexibility in the building structure for later conversions or changes (International Ice Hockey Federation, 2015). Oral, Yener and Bayazit (2004) states that the most important function of the building envelope is to control physical environmental factors such as heat, light and sound in order to realise the defined comfort conditions for the user with a minimum of energy use. Therefore it is recommended to develop, establish and follow standards and regulation which take account of all aspects of the problem (Oral et al., 2004).

Most ice rinks are built with an envelope of sandwich-elements, but recent years have seen increased use of laminated timber structures (Wihlborg, 2012). This type of envelope demands extra attention and maintenance of the exterior, but offers excellent attributes indoor in return (Martinsons, 2015). Laminated timber structures are ideal for constructing envelopes for wide spans and open halls because of its high strength to weight ratio (Martinsons, 2011).

A great challenge for ice hockey facilities is the complexity of the building, and the heat transfer through the building envelope (Daoud et al., 2008).

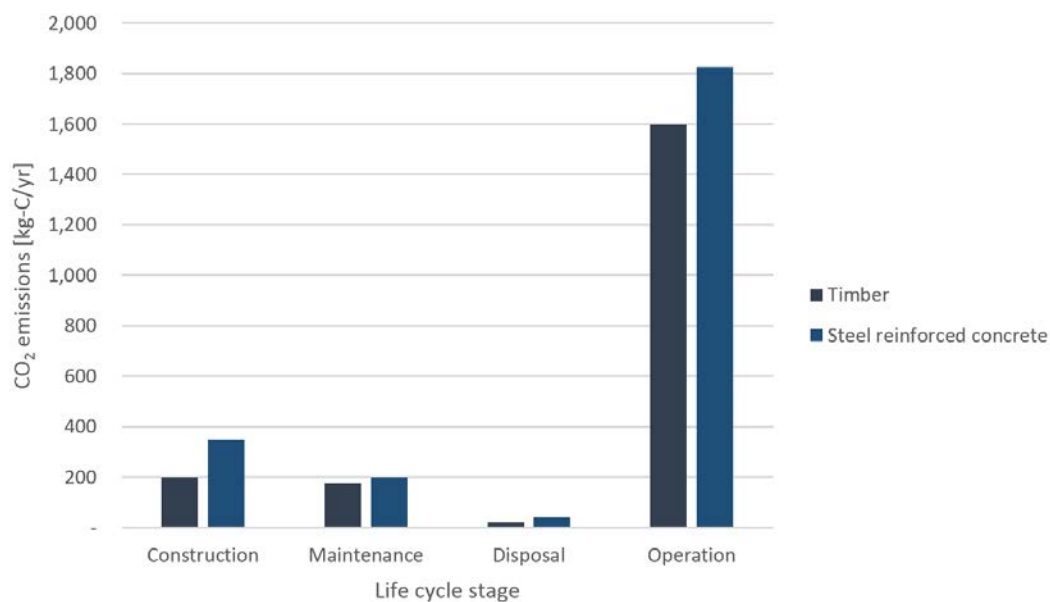
## **2.5 Materials**

Construction materials affect the energy use in a sports facility, just as they affect the energy performance in other building types. With the correct use of building materials, one can optimise the functionality of the building, cost efficiency and sustainability. The focus on preserving the environment in the construction industry is growing each day, as well as the focus on energy use. A topic of current interest is the influence from the materials on the climate, and its qualities as suitable construction material. In this thesis, the focus is on the two most expected relevant construction materials: timber and concrete.



### 2.5.1 Timber

Timber as a building material can be found in both loadbearing structures, floors, interior- and exterior panels, and in doors and windows. Gerilla, Teknomo & Hokao (2007) shows, in their research, how they compare timber and reinforced concrete and how they claim that the materials climatic impact in a life-cycle perspective are at its highest in the usage phase, when it is working as a construction material in a building. This phase alone gives more than 79 % of the materials greenhouse gas emission, while maintenance and disposal only emits 9 % of total emissions (Gerilla et al., 2007). Figure 3 below illustrates this.



**Figure 3: Total CO<sub>2</sub>-emissions through the materials life cycle, divided on the different stages in the life cycle (Gerilla et al., 2007).**

The climatic influence from a building material is largely affected by the materials influence on the buildings total energy use in the operational phase, and because of this, the climatic impact in a life cycle perspective will be on its highest during this phase. However, in recent years, new constructed buildings have become very energy efficient, and the operational phase in these buildings often present a great reduction in the climatic impact. In such buildings, the choice of materials will have greater significance, as production and disposal of the material itself will have greater significance in relation to the life cycle perspective (Rønning et al., 2011).

Timber is a natural and renewable building material, and used the correct way it is also a sustainable material. Peterson and Solberg (2002), referenced in Wærp et. Al. (2008), analysed the greenhouse gas emissions by using laminated timber instead of steel constructions in their

case study of Oslo Airport. The results showed that steel require more energy and cause greater emissions than the laminated timber. The study was based on both time, energy-source during production and waste management.

By using wood as the preferred building material, it can replace the CO<sub>2</sub>-intensive alternative materials, when wood is the only building material that, through its life cycle gives a negative CO<sub>2</sub>-emission. Energy use in production of wooden building materials is mostly based on reusable energy sources, and the by-product from this production process is used for energy intensive processes that do not influence the environment (Svanæs, 2004).

The shape of the building, the choice of materials, furnishing, ventilation and the method of use affect indoor climate. Timber has a positive affection on the indoor climate as it has qualities for absorbing moisture (Martinsons, 2011). In addition, it has the ability to absorb harmful gasses, if treated in correct ways (Svanæs, 2004). The use of laminated timber is environmentally friendly, as for every cubic meter timber used instead of other materials, two tons less of CO<sub>2</sub> emissions is saved in total, with the timber binding it in its entire life cycle as well (Martinsons, 2011).

### **2.5.2 Concrete**

Concrete is the world's most widely used building material, and the benefits of concrete are numerous. It is very strong, has great durability, low maintenance needs, does not rot and is not flammable. In addition, concrete can be utilised as a heat storing material in buildings, which may reduce the need for heating and cooling (Norcem, 2014). As the focus on low-energy buildings gradually increase, the focus on the building materials' attributes and climate impact increases. This is because this factor affect the buildings' total climate overview to greater extent than before. Simultaneously with the requirement for documenting the materials' environmental attributes has been introduced, the need for documenting greenhouse gas emissions and absorption through the lifespan of the material has been increased (Lyng et al., 2014).

Approximately 90 % of the CO<sub>2</sub>-emissions from concrete production comes from the production of cement (Kjellsen and Jähren, 2008). Over half of the carbon dioxide emissions from the cement production originate from the calcination process. The calcination process is where limestone is burned and releases CO<sub>2</sub> (Lyng et al., 2014). In a lifecycle perspective, it is

therefore in the production phase that concrete is the greatest burden on the environment, the opposite of timber. Depending on the method of disposal timber will emit CO<sub>2</sub> after use, for example through combustion. If you look at concrete on the other hand and its total influence on the environment, it is important to consider that concrete absorbs large amounts of CO<sub>2</sub> through a carbonation process. Carbonation is a chemical process where carbon dioxide in the atmosphere reacts with CaO (calcium oxide) and becomes CaCO<sub>3</sub> (calcium carbonate or lime). Concrete surfaces in direct contact with air will carbonate fast and therefore absorb more CO<sub>2</sub> than a concrete surface that is treated. If viewing concrete in a lifecycle perspective this will lead to negative greenhouse gas emissions in the operational phase and also after use (Kjellsen et al., 2005). Concrete that is crushed and later used as, for example fill mass in road construction, will have the ability to continue absorbing CO<sub>2</sub> years after its primary use.

When it comes to indoor climate, buildings made of concrete have good environmental attributes. The concrete's thermal mass and reservoir abilities are highly effective when controlling indoor temperature, in addition to being sound insulating (Heidelberg Cement, 2014). Unfortunately, these capabilities cannot be fully utilised when concrete is used in a rink. This is due to the acoustic insulation needed on the inside, which inhibits the properties related to the thermal mass of the concrete.

## **2.6 Climate**

Climate is defined as a description of the average weather at a location or territory, as it appears when single observations are processed statistically following international guidelines (Meteorologisk Institutt (MET), 2015b). This chapter seeks to present the theoretical basis for the part of the thesis that treats the climate topic.

### **2.6.1 External factors**

External factors are a generic term for both climate and geographic location of the facility. Although there are limited amounts of research carried out on this topic, one can look towards other similar building typologies and research papers that touch on this important angle of the assessment of an ice rink.

Sports facilities are not directly comparable with other types of buildings, e.g. residential or commercial buildings, concerning energy usage. The usage pattern in a sports facility differs

considerably from other building types, which in turn demands other and special needs for heating and cooling. The energy use in a sports facility is affected by usage pattern, opening hours, design, structures and materials, size and heating systems (Anfinsen, 2014). In addition to the aforementioned, there are a number of external conditions, which has impact on energy use. Solar and wind conditions, temperature and topography are important factors.

The research program “Klima 2000” (“Climate 2000”) by SINTEF Byggforsk (2007) institute a search for better acclimatisation of the built environment. The climate in Norway is varied, and every year this leads to extensive damages on the built environment. The coherence between the characteristics of materials, the constructions manner of operations, design of the building and geographical location, and the climate stress they are exposed to is very complex (Kvande, 2007). The research program carried out an extensive analysis of empirical data related to research of process-induced building damages. The results show that 3/4<sup>th</sup> of the damages are related to effects of moisture, 1/4<sup>th</sup> of the damages are related to precipitation alone and 2/3<sup>rd</sup> of the damages are related to the buildings climatic buffer (Kvande, 2007).

The “Stoppsladd” project assessed the energy use in over 100 Swedish ice rinks and parts of this project assessed the variations in energy use between the rinks in different provinces of Sweden. The result from this shows that the specific heating energy use is six times higher in the north than in the south of Sweden. From 0.15 kWh/day/m<sup>2</sup> in the south (Götaland) to 0.93 kWh/day/m<sup>2</sup> in the north (Norrland). This can be attributed to the climatic differences between the north and south as the need for heating is higher in the northern part of the country (Rogstam et al., 2011). When assessing the total specific energy use in the rinks, and all rink categories together, it is visible that the difference in energy use is as much as 36 % between the lowest (Götaland) and the highest (Norrland) consuming province. These variations can be the result of climatic differences between the north and the south of Sweden (Rogstam et al., 2011).

### 2.6.2 Climatic zones

The most frequently used climatic classification map is the map of Wladimir Köppen presented in 1900, and later updated in 1961 by Rudolf Geiger (Kottek et al., 2006). The map shows the different thermal zones of the earth according to the duration of hot, moderate and cold periods and of the impact of heat on the organic world (Rubel and Kottek, 2011). The map is based on five main categories; the equatorial zone (A), the arid zone (B), the warm temperate zone (C), the snow zone (D) and the polar zone (E). A second letter in the classification consider the precipitation, e.g. “f” for fully humid, and a third letter considers the air temperature, e.g. “c” for cool summers (Kottek et al., 2006).

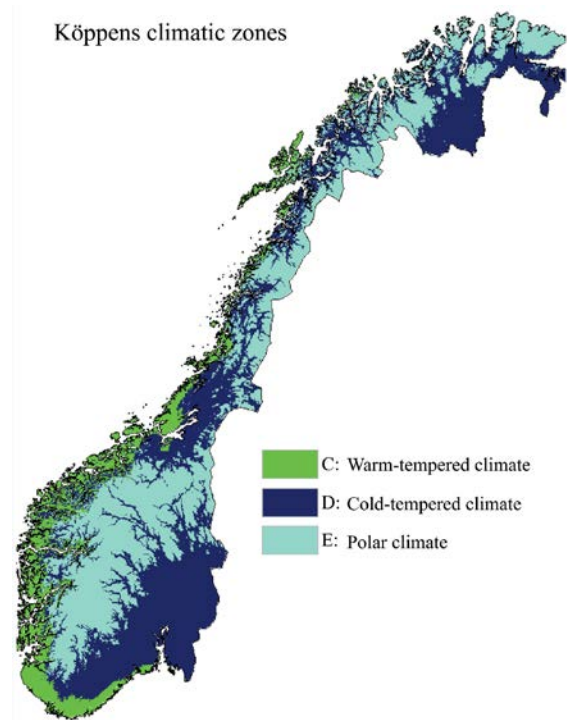


Figure 4: Köppen's climatic zones (Meteorologisk Institutt (MET), 2010).

The map from Norwegian Institute of Meteorology (MET) shows the different climatic zones in Norway. One can see that the coastal areas from the outer Oslofjord to Troms in the north are characterised as a warm-tempered climatic zone (C), while Eastern and Southern Norway, and parts of Trøndelag have a continental cold-tempered climate (D).

According to MET, most parts of Norway are under the category D, the snow zone. This is described as the cold-tempered climate zone where the temperature in the coldest month of the year is below  $-3\text{ }^{\circ}\text{C}$  and the hottest above  $10\text{ }^{\circ}\text{C}$ . The coastal areas are category C, and parts of northern Norway and many mountain regions are under category E, the polar zone (Meteorologisk Institutt (MET), 2010). From the map presented in Kottek et al. (2006), Oslo can be classified in the category *Dfb*, which means cold tempered climate, humid precipitation and warm summers (Kottek et al., 2006).

### 2.6.3 Heating degree-days

To be able to compare energy figures from different locations and periods, the figures have to be adjusted to the same reference location and normal period according to the heating degree-days method from Enova. This method corrects for bias in the figures caused by external factors (geographical and climatic) (Enova, 2015).

Enova defines heating degree-days as the number of degrees the mean temperature throughout a day is below 17 °C. The temperature of 17 °C is set as the minimum temperature where there is no need for additional heating (Enova, 2015). This leads to all days where the mean temperature is equal to, or higher than 17 °C, is given a value of 0 in the statistics.

Figures for each month should be obtained to calculate the adjustment factor depending on the temperature, time and location. The factors found for each month is then used to adjust the energy use. As the statistics varies with the climate at different places in the country, this can be used to adjust the energy use figures to make them comparable to each other, regardless of the climate at the location and time period.

The formula for calculating the adjusted energy use is as follows, when Oslo is set as the location for adjustment (Enova, 2014):

$$Energy\ use_{Oslo} = Energy\ use_{Actual\ facility} * \left( (1 - f) + f * \left( \frac{Degree-days_{Oslo}}{Degree-days_{Actual\ facility}} \right) \right)$$

The second part of this formula yields a factor for correcting the energy use concerning the location of the facility. The formula splits the energy use in two parts, the unaffected  $(1 - f)$  and the adjusted, and adding them together for the summed adjusted use.

- Degree-days (actual facility) = degree-days for the facility in the year one wishes to adjust.
- Degree-days (Oslo) = heating degree-days normal period (1981-2010) for Oslo.
- $f$  = the factor defined by Enova in connection to heat loss and temperature dependent energy use (see below).

When adjusting the energy use for time and location, one cannot adjust the entire energy use (more in chapter 3.2.2). Only an assumed portion of the energy use is to be adjusted, known as

the temperature dependent portion. This percentage vary between different building types and is given in the Building statistics report from Enova (Enova, 2014).

## **2.7 Energy assessment and sports facilities**

In recent years there have been greater focus than ever before on energy savings and environmental impact. Norway is no exception and different brands of energy certifications have gained foothold. There are many reasons behind this, with the main being economic savings, gain or savings and marketing/image reasons. The same exact reasons are why this has yet to be modified for use in non-commercial buildings, like most Norwegian sports facilities.

Norway have strict technical regulations on how a building must be constructed, along with this comes an energy labelling system to inform on how energy efficient the building is. Complying with the technical regulations will gain you a grade in the middle of this energy efficiency scale, and it is an emerging trend where building owners, companies and entrepreneurs acknowledges the value of going one step further with energy assessment certificates. Some of the energy assessment methods that have increased in popularity the past years is BREEAM (British Research Establishment Energy Assessment Method) and MINERGIE® (BREEAM-NOR, 2015, MINERGIE, 2010).

The purpose of the energy assessment methods is to both contribute to a more environmentally friendly building stock through extensive evaluation criteria in several categories and help the owners and users to save money in the day-to-day running of the building. The assessment tools only do a static evaluation of the buildings and therefore only facilitates for a good operational phase without actually having a direct influence in the day-to-day operations or giving guidelines to what requirements should be the basis for a good operating procedure (Norwegian Green Building Council, 2012). This is what can be regarded as the advantage of MINERGIE® in comparison to BREEAM, among others, that it operates with a lean-approach to the energy assessment in the buildings.

The assessment methods operate based on the buildings' calculated need for energy (Norwegian Green Building Council, 2012). There are several ways to proceed when a buildings need for energy is to be determined. Some look at the calculated net total energy need, or the calculated need for delivered energy, while others measure the energy usage in day-to-day operations. If a new building is constructed it is often so that the building produces some of the needed energy

themselves through heat pumps, solar panels or wind turbines. Both calculations of net energy need and need for delivered energy will be the same in this case, however, the performance in regards to energy usage is often misleading due to the fact that one does not distinguish between the two definitions of required energy. This performance is not to be confused with calculations for energy performance in accordance with NS 3031, which to be quantified must contain how the energy is treated outside the building, environmental stress and cost (Standard Norge, 2014b). In this thesis, the term energy performance is sometimes used concerning the difference between the real world performance and an ideal systems performance.

Standards Norway publishes standard documents and guidelines for how net total energy demands and need for supplied energy is to be calculated. The calculation of a building energy performance may be done following the NS 3031:2014 (Standard Norge, 2014b). In this standard, two different calculation methods are found: monthly fixed calculation (following NS-EN ISO 13790) and dynamic method (following NS-EN ISO 13790 and/or NS-EN 15265). The standard specifies regulations for calculation of heat loss, net total energy demand, supplied energy distributed among different energy commodities, primary energy demand, CO<sub>2</sub>-emission and weighted supplied energy and energy cost (Standard Norge, 2014a). The NS 3031 is also used for considering if the building satisfies the energy requirements given in the technical regulations, documenting theoretical energy demand and documenting the theoretical energy performance in connection with certifications. In addition to this, it may also be used when evaluating alternative designs and energy measures by calculating the energy demand both with and without these designs and measures (Standard Norge, 2014b).

BREEAM is the most frequently used classification system for environmental assessment of buildings. It is a comprehensive classification system for buildings and property which documents differences in environmental and health burdens, and makes it easier to make right decisions in a building process or refurbishment process (Norwegian Green Building Council, 2012). Currently 115,000 buildings have been certified and nearly 700,000 buildings have been registered (Norwegian Green Building Council, 2012). BREEAM-NOR is the Norwegian adaptation, with affiliation to relevant standards and regulations within energy and environment, and it is developed by the Norwegian Green Building Council (NGBC). This development of a Norwegian version is based on existing requirements given in TEK10 and the vision of passive-house level by 2015 and nearly zero emission building by 2020 (Kommunal- og regionaldepartementet, 2012).



The aim of BREEAM is to reduce the buildings' impact on the environment, enable the possibility to recognise a building from its environmental standard, offer a credible environmental assessment and certification for buildings, and stimulate the demand for environmental friendly buildings (Norwegian Green Building Council, 2012). The purpose of BREEAM, as it is presented in BREEAM-NOR technical manual is to:

- Give recognition in the market to buildings with low burden on health and environment.
- Secure that the best environment practice is incorporated.
- Determine criteria and standards that exceed those required by regulation and challenge the market to develop innovative solutions that minimize building's environmental impact.
- Increase awareness of owners, users, designers and operating personnel about the advantages of buildings with high environmental standard.
- Support organisations prioritising social responsibility and documenting progress in relation to the environment.

(Norwegian Green Building Council, 2012)

A BREEAM-classification in Norway is carried out based on the BREEAM-NOR technical manual (ver. 1, 2012). Classification of a building can be done either by 1; design and planning phase, which gives a preliminary BREEAM certificate, or 2; as-built, which is done after the building is finished. When classifying by phase 1, a second assessment is required after the building is finished to obtain a final certificate. This classification process evaluates the building in ten main categories organised in their own chapter in the manual, where each chapter has several sub-chapters.

MINERGIE® differs from BREEAM in the approach to the evaluation. MINERGIE®-standard emphasises the importance of comfort for the user living or working in the building. Through focus on the building envelope and the continuous renewal of air by using an energy efficient ventilation system, it aims to reduce the specific used energy use for the building (MINERGIE, 2015b, MINERGIE, 2015a). With basis in this, the specific energy use is the main indicator to quantify the required building quality. In practice, it means that there are no pre-approved or preferred components, materials, procedures or installations that the building have to make use of. This approach gives the building designers complete freedom in their choice of materials

and technical installations, just as long as the finished product meet the MINERGIE® maximum energy use requirements (MINERGIE, 2015b).

The standard is based on the SIA 380/1:2009 “Termische energie im Hochbau” which is developed by the Swiss Society of engineers and architects (Kanton Zürich Baudirektion, 2015). Within this framework, there are different products that represent different levels of energy efficiency. These are MINERGIE®, MINERGIE®-P, MINERGIE®-A and MINERGIE®-ECO. The MINERGIE®-ECO can be added to one of the other labels if the requirements are met. The ECO-label is only available to administrative buildings, schools and small residential buildings with a maximum of 500 m<sup>2</sup> of energy reference area (MINERGIE, 2015a). The basic level focus on efficient use of water, energy and primary requirements for the building envelope. Ventilation is important in terms of efficiency and heat exchanging for thermal comfort in all four seasons to improve the quality of life (MINERGIE, 2015a).

The MINERGIE® standard takes basis in the heated area in the building when the energy performance is assessed. As a minimum requirement, the energy demand must be lower than 90 % of the requirement in the Swiss building regulations, but to achieve recognition one must also comply with the requirements varying with building type. For example, a sports facility must not consume more than 25 kWh/m<sup>2</sup>, heated area (MINERGIE, 2015a). The requirements are stricter with each label with MINERGIE®-A as the most stringent, demanding biomass, solar panels, solar collectors or heat pumps (as long as the electricity is from renewable sources) for heating the building. In addition, as much as 50 % of the heating demand has to be met with solar thermal panels, to keep the energy balance of zero in the building.

These two assessment methods have some obvious differences, the MINERGIE® focus on buildings with low energy demand and BREEAM spanning from waste, planning, transport and more. The different MINERGIE® versions are based on calculated energy demand, and not actual energy use during the operation of the building. This means that the building is given a quality-label based on calculations and pre-construction drawings. As opposed to BREEAM, MINERGIE® does not rank the labelled buildings. It only indicates whether the requirements are fulfilled or not (Schiess, 2011). The operational phase is considered in limited to no extent in either these energy assessments methods.

The annually published Enova-report “Byggstatistikk” (building statistics), have been studied to address the operational phase of the buildings’ lifecycle (Enova, 2014). The report is a tool

to contribute to planning, operation and development of buildings. The main goal of this publication is to create an energy figure benchmark for every year through analyses and statistics. The data is obtained through an online service where building owners and managers can report the energy use.

The report contains information about energy use and theory behind different technical solutions in different building types. It explains the relationships between building components to contribute to increased knowledge for the building managers in the operational phase. Due to the greater focus on the operational phase in this report compared to the energy assessment schemes, it is an important source for documenting the characteristics of this phase.

### **2.7.1 Energy assessment methods in relation to ice rinks**

As BREEAM is a tool for energy assessment that is highly detail oriented, and MINERGIE® a tool with high focus on energy demand, neither has been applied to any sports facility in Norway thus far. In the Oslo 2022 Olympics bid there were extensive plans for the use of BREEAM in the sports arenas. After this bid was shut down, the development of a guide for sports facilities died with it. As things stand present day, none of the assessments are relevant in their current form to apply to a sports facility because BREEAM focus on the commercial side of sustainable development and MINERGIE®'s narrow focus.

The methodology and principles behind is an interesting perspective in relation to sports facilities, and this is why they are included in this thesis. Sports facilities, in general, are in most cases government/municipality owned, neither of which have a great focus on energy efficiency. From the building statistics report, one can see that the sports facilities in Norway consume on average 255 kWh/m<sup>2</sup> (delivered energy, heated area) (Enova, 2014). The savings potential is likely to be massive, and the energy assessment methodologies that already exist could be utilised in this regard. The energy performance is not just determined by the technical equipment, design and planning of the facility, but also the management in the operational phase (Kampel et al., 2012). The lack of this is the biggest weakness and needs to be addressed to have relevance for any sports facility and in particular ice rinks.



### 3 Method

#### 3.1 Method and research design

The method specifies which procedures that are to be used to survey reality (Jacobsen, 2005). The method is shaped with basis in the thesis' problem to be addressed, and it functions as a tool to give an accurate description of reality. There are many disputes regarding what is the best method and procedure to study reality, and one is presented with many choices when choosing the method best suited for one's thesis (Jacobsen, 2005).

One must decide whether the thesis prerequisites deductive or inductive data acquisition. Deductive data acquisition means going from theory to empiricism. In other words, one acquires knowledge and make up one's mind or expectations about a phenomenon, and collecting empirical data later to see if the opinions or expectations match reality. Inductive approaches means going the opposite direction by collecting all relevant information, and then systemise and analyse the collected data. There are positive and negative sides to both approaches. By choosing the deductive approach, one is in danger of shaping the results of the research because of expectations to reality and may find that one tend to look for results supporting this and overlook other important information. The inductive approach is based largely on the actual reality, without any preconceived attitudes, and will secure a genuine reflection of reality in a better manner (Jacobsen, 2005).

Going forward it is important to evaluate the degree of closeness in the research scheme. For a long time the desire has been to minimise the researchers effect on the subjects. One must not disturb reality, and one must have duly distance between the researcher and the research object. The foundation for this is the need for the research results to be verifiable. In principle one should achieve the same results if a different researcher conducts the project. Something that suggests a degree of closeness in the research project is that the researcher will always affect the research with their preferences and values. For example through whom one chooses to interview and the choice of problem to be addressed, this may affect the outcome of the study (Jacobsen, 2005).

Finally, the question if the research project is directed towards a quantitative or qualitative orientation has to be addressed. Quantitative methods provide information in the form of

numerical data, often acquired through surveys. This method demands that the researcher have sufficient knowledge about the subject of the research, and that the phenomenon can be structured.

The qualitative method is based on collecting information through fieldwork and interviews. These are flexible methods where the gathering of information can be adapted to the reality the subject of research exists in (Jacobsen, 2005). The qualitative methods aims to intercept meaning and experience that does not easily quantify (Dalland, 2007).

### **3.1.1 Research design**

Research design is an overall plan for the procedure to solve a given task. There are three different kinds of research design: explorative, descriptive and causal design. The three types each have their area of use depending on the character of the task at hand (Olsson, 2011).

#### *Explorative design*

Explorative design is used when the task at hand or problem to be addressed is unclear and one has little or no information and knowledge about the subject of the study. Being flexible in relation to what information to be acquired and how it is acquired distinguish the method. The flexibility comes from the procedure for gathering information about the problem, which includes interviews, processing of secondary data or different forms of surveys and observation. In this way the researchers themselves control the information being collected and it allows them to focus more on the actual problem (Selnes, 1999).

Explorative design is often a part of case studies or as a method for obtaining new knowledge about topics or phenomenon's, like preparatory work for developing a hypothesis. The method is useful, as a hypothesis cannot be formulated easily if the theory is too specific or general. Because this research method is used when the problem to be addressed is unclear or when one has little knowledge about the topic for further research, it is commonly used for building a framework for the continued research (Babbie, 2007).

#### *Descriptive design*

Descriptive design is used when the problem to be addressed is clear and the goal is to describe the coherence between variables, e.g. purchase behaviour and purchase criteria. There is often a conviction as to which variables that affects or explains the task that is researched, and a

frequently used methodology is hypotheses. This type of research design is flexible and gives the researchers the opportunity to test all hypotheses in approximately all situations. The most common type of descriptive design is when the situation is described at a certain point in time (Jacobsen, 2005).

The downside with this flexibility is that there is no access to consider irrelevant variables and that the cause-effect relation is rarely analysed, as it is difficult to analyse changes over time. This means that if the two variables are related, there is no evidence to tell why these are related (Mitchell and Jolley, 2009). Despite that descriptive design does not allow allegations to be raised concerning cause-effect relations, there is no reason that this design not can take action regarding cause-effect relations that can be claimed as hypotheses.

### *Causal design*

Causal design is a form of explanatory design. When the problem to be solved is a cause-effect type of problem, it is natural to make use of causal designs. This type of research design often consists of a very systematically method and offers limited amount of flexibility within the collection of information (Selnes, 1999). What you expect to be the cause must correlate with what you presume to be the effect, which means that two examined phenomena must correlate. If the above is not the case, it is impossible to conclude and separate the cause from the effect (Jacobsen, 2005).

Even though an event always occur as a consequence of another event, you cannot state that the effect is a direct result of the cause, this can only be assumed (Vaus, 2001). Because of this, it is not possible to prove the claimed cause-effect problem with full certainty, i.e. it can only be made probable through for instance regression analysis. To substantiate the existence of a causal relation, the following requirements must be met: 1. it must be positive correlation between cause and effect. 2. The statement that claims that a variable affects the other must be true (the order of the factors are indifferent) (Vaus, 2001).

## **3.2 Applied method**

In this chapter, an account is given of the methods applied in the thesis. With basis in the problem to be solved, research questions and topic, the expedient design is the explorative design, where the thesis develops in relation to what information is being acquired. The explorative research design is largely based upon unstructured interviews as process of continuous learning. Through this method one get a linear learning process that increase gradually as the researchers acquire deeper knowledge of the subject.

When using the explorative research design one must choose a method that differentiate the problem, which require few objects to be researched. These methods call for a qualitative approach to the researched object (Jacobsen, 2005). Qualitative methods imply a triangulation of methods through the use of unstructured interviews, observations, document analysis and case studies.

The problem to be addressed in this thesis appears as relatively diffuse. This means that the authors have less prescience about the researched topic. This can be classified as a theory and hypothesis-developing problem, where the intention is to develop new knowledge about a phenomenon by discovering what the phenomenon consists of, and develop theories to explain the phenomenon (Jacobsen, 2005). This can be directly related to this thesis where the intention is to develop a management tool for use in the operational phase in energy efficient and sustainable ice hockey facilities.

The explorative research design and the qualitative method require a wish to concentrate the research around only a few research-units. This is what Jacobsen (2005) name an intensive situation. In this case, it is common to prioritise having several variables instead of several units. This is the opposite of an extensive method, which imply more units and fewer variables, and therefore point towards the quantitative method. The qualitative data is data that characterise different phenomenon's attributes. As quantitative methods is about what is measurable in numbers, like the use of statistics, qualitative methods comprises direct relation to the informant or to the observations (Repstad, 1993).

The process started with a thorough document and literature search, where the first step is mapping the already existing research on the topic. When the relevant sources are found, one must classify this in categories for future use. A systematic examination of the literature through



academic search engines with specific search words was performed. The case study was initiated by creating an overview of the different categories of ice rinks in Norway and which ice rinks it was possible to establish contact with. Important factors were location, possibilities of receiving a valid set of data, and size/classification. After the selection process, contact was established with each object, and site visits and amount of data available was discussed. The case study is described as a method of triangulation as the study itself is a qualitative study, with few objects, and the collected material is a quantitative data set of information, that required extensive data processing. The unstructured interviews carried out in context with the case studies represent a third dimension of the study, as this was a way of receiving first hand information and were carried out at the same time as the site inspections.

### **3.2.1 Document and literature studies**

Document and literature studies were initiated with a process of mapping the already existing research and literature on the relevant topics for this thesis. All findings was classified and sorted in categories for future use and reference. Systematic examinations of the literature through academic search engines with specific keywords were performed.

It is of great importance to perform a document and literature study, especially in the initial stages of the thesis, where the collection of primary data is not yet implemented. Document studies are secondary data collected and processed by other, and of this reason it is important to be specific of the selection in the study. One can risk that the collected data may have been collected and used with a different intention than the one for this work, and therefore may contain several sources of error (Jacobsen, 2005).

The objective of the document and literature study is to acquire an overview of the former work on the subject, and to give an orientation of what is known in relation to the topic that is being researched, as well as clarify important concepts as a basis for the thesis (Dalland, 2007). It is a preparatory activity, even if on is going to use other methods to retrieve information. Through a systematic and critical approach on the existing data, one can establish a basis for new research and view the problem to be addressed in a larger perspective. When performing this study, it is important to know how the collected data is produced, what they will be used for and strengths and weaknesses (Olsson, 2011).

Relevant document and literature studies were conducted with regards to the field of theories that this master thesis comprises. These fields are energy classification, ice rinks, sports facilities, and energy calculation, as well as materials, climate, and the methodical theory this thesis is based upon. Web-based search engines are many, but the most frequently used are the following:

### ***Bibsys***

Bibsys is a shared database used by over one hundred different research and science libraries in university colleges and universities throughout Norway. Bibsys Ask offers searches in this database. Here you can find everything from books, master theses, doctoral theses and electronic literature, to CD's, cassettes and journals (BIBSYS, 2015, BIBSYS Ask, 2015).

### ***Google Scholar***

Google Scholar is a search engine for scientific work provided by Google. Here one can search and find articles, publications, books and reports. The hits are ranked after relevance to the keyword and one can retrieve summaries or full texts. In addition to this it is possible to locate the documents or the publications you are after through your local library or online (Google, 2014).

### ***Scopus***

Scopus is a comprehensive database, administered by Elsevier. The database contain research articles, journals and publications within the topics of technology, medicine, art and the humanities (Elsevier, 2014). Scopus contain to a great extend international publications and are relevant when you aim to research international practice within in example energy and energy efficiency.

### ***eKlima***

eKlima is a web portal which gives free access to the climate database of the Norwegian Meteorological Institute (MET). The climate database contains data from all present and past weather stations in Norway. From eKlima one can generate simple lists or advanced analysis, where the content of the reports can be specified after the need (Meteorologisk Institutt (MET), 2015a).

### 3.2.2 Case study

A case study is a study where the object are restricted in time and space (Jacobsen, 2005). The case study is utilised when the focus of the research is context and consists of few units. The goal is to collect primary data that can constitute a basis to analyse and evaluate the studied case, with the objects to enlighten the problem to be addressed in the thesis.

The case study is typically carried out in eight steps: 1; assessing the appropriateness and utility value, 2; ensuring the accuracy of the results, 3; preparations, 4; choice of case(s), 5; collection of information and data material, 6; analysing data, 7; interpretation of data, and 8; presentation of results (Gagnon, 2010). During the preparations for choosing the right case study objects for the thesis, the different alternatives' relevance concerning the problem to be addressed must be evaluated. A case study can be utilised to build theories, validate theories or a combination of these (Gagnon, 2010).

The case study is an important tool for the development of a management tool for in-use ice hockey facilities and to increase the knowledge both when designing and operating ice rinks. The results from the research contribute to form the basis for the continuing work with the management tool, and to develop a common factor for evaluation of energy use in these facilities.

Assessing the objectives for the study, and its utility value, initialised the process. The result is wanted to reveal and confirm or disprove what energy-related measures that can form the basis for development of criteria that can be employed by an operational phase management tool for ice hockey rinks in Norway. To ensure the accuracy of the results, it was necessary to establish the selection criteria, as well as the criteria for the information and data material. The criteria for the examples that are presented in this thesis are, amongst others that they coincide with the Norwegian ice hockey federations categorising of ice hockey facilities, the objects location, and the expected possibilities of collecting a valid set of data.

Prior to contacting the objects, it was important that the researchers had good knowledge about the objects, which lead the study into the preparation phase. During this period, all available information was collected, in addition to composing schemes, guides and plans. The point of initial contact is the most important, and critical, as this often determine the relationship between the researcher and the informant (Gagnon, 2010). To invite the informant to contribute

with data and information of higher relevance and quality for the researcher, it is important to be well prepared. The following processing and analysis of the collected material and data can be characterised by reducing data to a system and methodically sort out the irrelevant information. This process was time consuming, as one had to return to the informant to clarify or seek out additional information.

Presentation of analysis and results is the final stage in Gagnon's (2010) case study research method, and is also where the main findings and the analysed material that is of importance to the problem to be addressed in this thesis is presented.

### *Collecting data*

Robert Yin (2009) lists six sources of evidence from a case study. This study have made use of documents, archival records, interviews, direct and participant observation. The final source, physical artefacts (Yin, 2009), is not employed during the collection of material for this study.

The collection of information and data material was extensive and carried out through both field research visiting the case objects and current conversations throughout the period of data collection. Some material was sent via e-mail, as the location of the case objects did not allow frequent visits. Site visits were conducted to map out the design of the rinks and all the supporting functions, if there were any present. In addition, it was important to observe the technical systems and components in the buildings. To get an impression of the state of the facilities and the layout a general assessment was conducted, in addition to studying floor plans and diagrams.

Documents and archival records were collected through e-mail correspondence as well as during the site visits. During consecutive exchange of information over a longer period of time, the information received could be discussed and assessed in close collaboration with the representatives for the studied objects. Collected material includes in great extent statistical data of historical energy use figures (kWh), in addition to floor plans, running time and usage time. Other information regarding special attributes for the given case object was also relevant to collect. The extensive data material concerning energy use was collected through accessing the central control and monitoring system if this system was present. Other ways of collecting the relevant data material were to examine invoices and statements from the service provider manually.

As one important factor when assessing the case objects is climate, relevant information about the local climate conditions were needed. This information was collected from online databases including Enova heating degree-days statistics and MET.

During site visits, direct observation was used to collect information. This gives advantages in terms of real time information and one get an insight into personal behaviour and organisation of the studied object (Yin, 2009). The observations were initiated with a guide around the facilities and in all the relevant technical areas, such as ventilation and cooling rooms. All observations and noticeable distinctive characteristics were written down. The direct observations phase of the case study are a very time consuming activity, and require extensive planning and coordination. It is also a source of bias due to the representative observers manipulation the events, and providing one-sided information (Yin, 2009).

#### *Analysing collected case study material*

The analysis of the collected material is one of the most challenging aspects of the case study. The analysis consists of examining, categorising and recombining evidence to draw empirically based conclusions (Yin, 2009). When starting the process of analysing the collected data material it was important to have a clear vision of what to do with the material and how to work with the data to make it “readable” for both the researchers and for the readers of the thesis.

The collected data material has been methodical decomposed and systematised into readable and comparable charts. The quality and the setup of the collected data differ from each case object and the systems used to measure and monitor the objects energy use are different from each object. This requires a thorough examination of the data to get a detailed understanding. The analysis of the collected material is what forms the key figure analysis in the thesis, as the process of analysing the data material and information from the case objects is contributing to developing a key figure parameter as well as establishing a guide for minimum requirements and operation routines in an ice rink facility.

The aim of the analysis of the data is to investigate the energy performance in connection to the management and operation of the facility. The analysis of the actual data is seen in combination with the information acquired during site visits as to what type and quantity of equipment that is present, running hours, operating hours and categories of users. The analyses are conducted with the available data, which include:

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- Electric energy
- Energy, cooling systems
- Energy, heating systems
- District heating
- Mean temperatures
- Hours of availability and operation

In addition to the above, the process of mapping the rinks design and layout has provided information about the different technical systems deployed. Floor plans and information provided by management personnel have been used to support the discussion and results.

### *Adjusting collected energy use data material*

To be able to compare the collected energy use data material, all data is adjusted for this purpose. The method of adjustment is based on Enova heating degree-day method and is explained in chapter 2.6.3.

In this thesis, figures for each month have been obtained to calculate the adjustment factor depending on the temperature, time and location. The factors for each month are then used to adjust the energy use. The adjusted figure for the monthly use is furthermore in the thesis referred to as FMEU (Final Monthly Energy Use). This is not to be confused with the FAEU (Final Annual Energy Use), as the monthly figures are most suitable concerning the presentation of the data collected.

Oslo is chosen as the baseline for comparison of energy figures when presenting the results from the case study. This means that the data from the rinks for the years 2010 to 2014 are adjusted to the climate levels of the normal period in Oslo from 1981 to 2010. Overall, this leads to comparable figures, but it is important to note that this is not the actual energy use of the case objects.

It is the temperature dependant portion of the energy use that are to be adjusted. In a sports facility this portion of the energy use is set to 60 %, while e.g. a swimming hall has a portion of 40 % (Enova, 2014). The statistics offer no dedicated factor for ice rinks, and the thesis will therefore assume the same value as swimming halls, as both are special buildings dedicated to fulfil one need (mainly) and similar to process buildings in this manner. In other sports facilities like i.e. athletics halls, indoor football fields or handball halls, the main portion of the energy

use is dedicated to heating the facility; ergo the energy use is highly climate dependent. In an ice rink the biggest portion of the energy use goes to the processes in the facility e.g. compressors and pumps, equipment that runs regardless of the outdoor temperature. Kampel et al. (2014) use a 40 % climate correction in swimming halls, but argues that the percentage is hard to verify as it is expected to vary between different facilities. Variations in age, management and usage patterns may affect the climate dependent share (Kampel et al., 2014).

Because of the lack of research on this specific topic, and the limitations of this thesis, choosing a different factor for calculating the adjustment would be pure conjecture. As an ice rink have to deliver a specific set of conditions to maintain the ice at all times, and with modern day technology, building materials and methods, the external conditions impact on the indoor climate can be minimised. Even so, with the climate in Norway, which is somewhat similar to the desired conditions in an ice rink, one can argue that the portion of the climate dependent energy use may be even lower than the 40 % used for the calculations in this thesis.

### *Presentation of analysis and result*

The results from the case study is presented in bar charts to see the development in energy use over a specific period of time. Results from each case object show a bar chart illustration of the actual energy use in coherence with the mean temperature, before a final adjusted energy use (FAEU) chart. The adjusted energy use data is then presented according to season, to easier see the development through the ice-hockey season as a whole. Energy performance indicators (EPI) are arranged in tables for each rink. A group table and a scatter chart show the development and compare the key figures for each rink.

The information about the studied rinks and the results from the case study has been made anonymous. This is to create a distance to the case-objects and to prevent identification of persons, objects and advertisement of sensitive information.

### **3.2.3 Interview**

There are two different ways of approaching the interview, qualitative and quantitative. The quantitative approach is best suited when there are large amounts of data to be collected, often when one are going to research a group of people or a specific environment. The tools for this type of research may be a survey with check boxes. This type of survey gives little to no flexibility as you cannot change the questions during the interview or adapt these to a particular

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informant. Qualitative interviews are more of an unstructured exercise, as you rely on an interview-guide prepared before the actual interview. The informants are interviewed individually and the questions can be adapted during the interview as to make sure the researcher receives as much information possible, and to get a grip of the informants own understanding, motives and way of thinking (Repstad, 1993).

Retrospective interviews are a type of interview where the informant looks back on the past. There are several methodical problems attached to this type of interviews as the interview is based on the informant to portray what a person feels and thinks at a certain point in time and in a certain context (Repstad, 1993). There are therefore sources of error by using this type interviews, as the informants may or may not cite the episode correctly or does not remember what they felt at that time. Maybe the informants also have different meanings and opinions today, compared to what they had at the time the episode occurred. Because of the mentioned, informants can deliberately give false information to the interviewer.

A group interview is often valuable to unite the expertise and receive comprehensive information and reflections from more than just one informant. On the other hand, there are several sources of error related to this method. Repstad (1993) mention sources of error to be presentations of only one perspective of the case, in addition to restrictions in communication between the participants, tactical statements during conflicts, and dominating participants with strong personalities and meanings (Repstad, 1993). Despite the mentioned sources of error, it is a method where you can get great results if the group is coordinated through well functioning group dynamics and a balanced conversation.

Interviews conducted for this thesis was done in connection to the site visits, and objects of interest were management personnel and persons in positions related to the operation and maintenance of the rink. A simple guide was developed to form a template to provide the same level of information from the different interviews, and this guide was differentiated depending on the object of the interview. It was seen as important to encourage supplementary answers and reflection through probing and exemplifications, as well as focusing on reading the body language of the informant and create a relation to the informant. By doing this, one was able receive as much information as possible from the informant.

The semi-structured interviews were conducted in an informal setting, at the location of the case objects. This was to have the informant in known settings, as this acts as a comforting



factor. It was also the most practical, as the site inspections involved travelling long distances. The questions were carefully worded, as to not imply any negative qualities about the subject of the interview. This may lead to a negative outcome, as the corroboratory purpose of the interview would not have been served (Yin, 2009). Questions posing a “how” were encouraged, as one must seek to keep the interview at a non-threatening level. Questions posing a “why” may seem hostile, and the informant may react negative, hence the reason they were avoided.

### **3.3 Validity and reliability**

Validity and reliability have to be considered in regard to the chosen research design, as one should assess what is needed for the results from the thesis to be valid and reliable. Qualitative research methods emphasise validity, while quantitative methods emphasise reliability. Validity relates to the results being valid and if the surveys or data material measure what they are supposed to. Reliability can relate to the results being consistent over time and that the data are re-creatable and verifiable (Mitchell and Jolley, 2009). It is a target that both are highly present.

There are two types of reliability, internal and external. Internal reliability relates to how other researchers are able to use the method for analyses of data, and external reliability is to what extent other researchers are able to obtain the same results (Storsul, 2008). The same is for validity, where you have internal and external validity. The internal validity relates to the degree of how valid the results are in regards to the subject of the survey. External validity relates to the possibility of transferring the results to other surveys and phenomenon (Storsul, 2008). A survey or experiment without reliability can have no validity, but if the survey has a high degree of reliability it is not given that the degree of validity is high as well. For a survey to achieve this, it must have a certain degree of reliability and not be biased, from both the researchers and the informers side (Mitchell and Jolley, 2009). Low reliability can be caused by the observer (researcher), the tested environment, irregularities from presenting the survey, or the informer (Mitchell and Jolley, 2009).

When doing measurements of energy use data in the same building over a period of time, one will obtain results that vary around an average value. These variations are called random errors. If the results have a tendency to either higher or lower values over time, the error is systematic.

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This is highly relevant for quantitative methods dealing with large sets of data, and will be practically difficult in use of quantitative methods (Mitchell and Jolley, 2009).

In this thesis, there is a probability that the studies conducted may be biased to some extent. Multiple experts and operational and maintenance personnel have been interviewed, and the risk for the informants to be biased in their answers are present. According to Mitchell & Jolley (2009), there are two main categories of informant bias, the wish to satisfy the researcher and a predisposed and subjective attitude. The wish to satisfy the researcher theory was introduced by Martin Orne (1962), where he stated that the informers were more interested in giving the researchers the answers they wanted rather than the correct answers (Orne, 1962). The informers would make use of any hints about answers supporting the researcher's hypotheses and thus give incorrect answers. An even bigger problem is the informer's desire to look good for the researcher through being predisposed and subjectivity. This problem is relevant for this thesis by the interview objects, different organisations and companies only being positive about themselves and their cause. Through a thorough and critical review of the process after each collection of data and conversation with informants, one can minimise the source of error. The final source of error regarding the validity is the researchers themselves. This is the most severe form of bias because the consequence is that one only sees the results one wants to see. It has therefore been important to remain objective in method and approach so the results have relevance and can be re-examined by others.

## 4 Results

In this chapter, the chosen cases for the analysis are thoroughly presented followed by a detailed analysis of the energy use. The four cases chosen for further study are different in many ways.

For the cases, four ice facilities from each of the official NIHF rink categories have been chosen. Rink A and Rink B represent the normal rink category, and Rink C and Rink D represent the arena category. Rink B consists of two rinks, a training rink in addition to the normal rink.

From each case key figures related to energy use, energy usage, operation time and usage schedules is investigated. To make use of these data they are compared to each other and seen in connection with the structure of the rink.

The analysis part is split in two: annual and seasonal. The first part presents the actual energy use with the mean temperature followed by the FAEU. The second part consist of the seasonal overview. The reason for this is to identify if the climate may be responsible for any deviations in the energy use. The final part of the chapter presents the calculation of the EPI for each of the rinks based on the internal conditions. Essential factors for evaluating an ice rink is used to calculate a key figure for assessing the energy performance of each rink.

The seasonal energy use is based on a standard Norwegian ice-hockey season starting in August and ending in March/April. The figures in this part of the chapter are all adjusted to make it possible to compare the different seasons' energy use with each other.

## 4.1 Rink A (Normal-sized rink)

### 4.1.1 General information


|                              |                      |  |
|------------------------------|----------------------|--|
| Name:                        | Rink A               |  |
| Location:                    | Oslo, Norway         |  |
| Owner:                       | Municipality         |  |
| Operator:                    | Local Sports Club    |  |
| Year of build:               | 1978                 |  |
| Ice-surface:                 | 1,800 m <sup>2</sup> |  |
| Capacity (total spectators): | 2,000                |  |

Figure 5: General information Rink A.

Rink A is the chosen example of a normal-sized ice rink. The rink is located in Oslo Municipality, Norway, and is the home of a Norwegian top division hockey team.

The ice rink was the tenth ice rink built in Norway when it opened in 1978. The rink can hold up to 2,000 spectators, divided into 980 seats and 1,020 standing places, and is a part of a sports centre, which is owned by the municipality of Oslo, but operated by the local sports club (Sports Facility Manager, 2015). The sports centre consists of the ice rink and an indoor artificial football pitch. The two facilities are connected through a joint area with vestibule, staircases, elevators, canteen and two cafés.

When the rink first opened in 1978, it had no changing rooms, cafeteria or restrooms. This has later been added to satisfy the requirements and needs of both users and spectators. The refurbishing of the rink in 2004 was extensive, and the roof constructions, foundations and walls was reinforced and re-insulated to meet modern regulations.

### *Climate*

Oslo has a temperate climate with four clearly defined four seasons. The mean temperature is -4.5 °C in January, 16.4 °C for July and 5.7 °C for the year as a whole. Average annual precipitation is 763 mm (Store norske leksikon, 2009).

Mean temperature is a measure of the average temperature over a given period of time. The method of calculation is dependant of the available data, where the simplest calculation is based on the average of maximum and minimum temperature. This means that when presenting monthly mean temperature, this is a product of the maximum and minimum temperature that month (Harstveit, 2009).

#### **4.1.2 Design and building specific information**

Rink A is a normal-sized ice rink with one ice pad of 1,800 m<sup>2</sup>. The spectator stands are located on one side of the pad.

The shared area between the football facility and the ice rink was built in 2004. This building was necessary to accommodate the needs for more changing rooms and spectator needs like canteen and restrooms. During the building of these areas, the changing rooms were also refurbished.

There are nine changing rooms allocated to the football hall and ice rink. They are located in the basement, which is the same level as the ice surface. The gates to the ice rink is located on the backside of the facility, granting easy access for the ice preparation machines and removal of the surplus ice. The surplus ice is stored in a heap outside for melting. Basins for snow melting are not used.

#### ***Construction***

The main substructure consists of concrete elements, and steel beams. The roof is supported by arched laminated girders and holds a retrofitted reflective layer to reduce the heat load on the ice. Skylight windows give natural light in the rink. The walls in the rink are covered with horizontal wooden panels. This gives a different experience than metal sheet covered walls, and may have a positive effect on the experienced indoor climate. In addition, the concrete grandstand-area is covered with wooden panels, which also make up the seating for audience.

#### ***Technical equipment***

For heating the rink, two methods are used. In the changing rooms and restrooms, electrical heating cables are used. Ovens in the ceiling heat the rest of the building.

## Chapter 4 – Results

Sensors that monitor the air pressure in the canals control ventilation. In reality this means that whenever the air temperature is high or the CO<sub>2</sub>-level reaches a certain point the ventilation effect will be upped to improve the air flow. When the rink is not in use, the airflow is reduced to save energy. The rink has its own air treatment systems, which regulates this. The canals for the spectator's area is mounted in the ceiling and pointed down at the stands. This principle for heating is the same as in the case of Rink B (chapter 4.3.2), where it has been proved through experiments that it does not function effectively (Bergsagel, 2014). Despite this, the users have not reported any problems with the climate in the rink. When there is no activity on the ice the ventilation system distributes recirculated air. This saves energy compared to heating fresh air (International Ice Hockey Federation, 2015).

Excess heat from the cooling system for the ice is utilised in a heat recovery unit and is distributed to a heat exchanger to preheat air for the ice rink and tap water. The recovery unit for the exhaust air is a rotating type. This maintains an air temperature in the rink at 12 °C while the ice temperature is -4 °C. Naturally, the temperature in the rink is higher when there is a lot of activity and people in the rink.

Lighting consist of metal-halogen lamps. There is 52 lamps of this type hanging only a few meters over the ice, in addition to fluorescent lamps over the spectator stands. During training hours the brightness of the lights is turned down to under half of what is in hockey matches, to save energy. Match-day brightness is normally 1,200 lux, while training brightness is 500 lux.

As for the slab of the rink, there is quite a few problems. First, the slab is not straight, which leads to the ice being thicker in some areas. The ideal ice thickness is approximately 2.5-3.0 cm for a hockey rink (Vancouver 2010, 2010). It must be thick enough to prevent the skaters from going through to the slab and thin enough to display the adverts, in addition thinner ice demands less energy from the cooling system. In Rink A, the thickness of the ice varies from 3 cm up to approximately 8 cm. The consequences of this is that the cooling system consumes more energy than necessary and that the thickest areas of the ice is often soft or wet.

The second issue is the lack of inspection hatches for the cooling pipes. The cooling system is the original from construction in 1978 and demands continuous maintenance. However, the problems are not that easy to identify because it is not possible to check any of the pipes for leakages without using a scanner and drilling the slab. Modern facilities have inspection hatches in one short side of the rink for problem searching.

The cooling systems make use of brine to cool the pad. As the compressors and pumps, the pipes in the pad have never been changed since opening. The pipes are made of plastic.

### **4.1.3 Operation, use and management**

Traditionally the rink has ice from august to the Easter holidays, later if the top division hockey team reaches the playoffs in the national series. In 2014, laying of the ice started in august to accommodate the demand from local clubs, groups and associations. The facilities are owned by the Municipality of Oslo, and operated by the local sports club. It is a joint responsibility concerning daily management and technical maintenance. The sports club provide an operations manager that together with municipal representatives forms the operations and management organisation. Currently the sports club have a demand matching the need for approximately 1.2 rinks, which means they have to rent ice-time from other rinks in the area.

A typical week of use consists of approximately 60 hours of different ice activities. Of this, about 47 hours are recurring appointments, while about 14 hours of the rinks' weekly use is schools, school care programs and kindergartens. In between every session from 3:00 PM in the weekdays and all day in the weekends, the ice is resurfaced. One session is normally 1 hour, except for matches, which takes 2 hours. Over an entire week, this amounts to a total of about 10 hours of ice resurfacing. The ice is not resurfaced in the weekdays before 3:00 PM because children use the rink.

### **4.1.4 Collected data**

Rink A does not have an advanced SCADA-system (Supervisory Control And Data Acquisition) for monitoring energy use. All data obtained is gathered from invoices from the power company (Hafslund ASA). The energy use figures presented are therefore the bought energy. The monthly energy use is presented first, followed by the seasonal energy use and compilations in both categories.

#### ***Monthly energy use***

All figures are given in kWh, unless otherwise is specified. The annual figures are presented individually before a compilation diagram is shown for easy comparison.

## Chapter 4 – Results

### 2011

**Table 2: Energy use Rink A - 2011.**

| Monthly energy use (kWh) - Rink A - 2011 |      |      |      |     |      |      |      |      |         |          |          |
|--|------|------|------|-----|------|------|------|------|---------|----------|----------|
| Jan.                                     | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct.    | Nov.     | Dec.     |
| -  | -    | -    | -    | -   | -    | -    | -    | -    | 221,904 | 232,803* | 232,843* |

*\*Note that the energy use for these months is not accurate as figures from selected measuring points could only be obtained quarterly. The quarterly figures were then divided equally over the corresponding months to be able to give an estimate of the use, and to be able to present diagrams of relative energy usage trends.*

The 2011-data from Rink A are not complete, as seen in the table above. The three last months of the year are the only months where energy use historic values are archived.

### 2012

In 2012, the month with the highest energy use is March with 241,063 kWh. Total use in 2012 was 2,023,815 kWh. The trend this table shows, with significantly less energy use during summer, is what one can expect from a facility that is mainly in use during the winter half of the year.

**Table 3: Energy use Rink A - 2012.**

| Monthly energy use (kWh) - Rink A - 2012 |          |          |         |         |         |         |          |          |         |         |         |
|--|----------|----------|---------|---------|---------|---------|----------|----------|---------|---------|---------|
| Jan.                                     | Feb.     | Mar.     | Apr.    | May     | Jun.    | Jul.    | Aug.     | Sep.     | Oct.    | Nov.    | Dec.    |
| 240,843*                                 | 234,515* | 241,063* | 90,670* | 59,370* | 55,563* | 91,819* | 176,267* | 180,926* | 223,386 | 206,770 | 222,616 |

### 2013

Below is the monthly energy use for 2013 shown. As one can see, the 12/13 season probably ended in April, while the production of new ice most likely started in September, as the increase in energy use from August is significant.

**Table 4: Energy use Rink A - 2013.**

| Monthly energy use (kWh) - Rink A - 2013 |         |         |         |        |        |        |        |         |         |         |         |
|--|---------|---------|---------|--------|--------|--------|--------|---------|---------|---------|---------|
| Jan.                                     | Feb.    | Mar.    | Apr.    | May    | Jun.   | Jul.   | Aug.   | Sep.    | Oct.    | Nov.    | Dec.    |
| 222,176                                  | 200,756 | 189,966 | 121,921 | 64,138 | 51,113 | 41,524 | 42,833 | 153,833 | 215,356 | 207,518 | 227,827 |

The total energy use this year was 1,738,967 kWh.



## 2014

Table 5: Energy use Rink A - 2014.

| Monthly energy use (kWh) - Rink A - 2014 |         |         |         |        |        |        |        |         |         |         |         |
|--|---------|---------|---------|--------|--------|--------|--------|---------|---------|---------|---------|
| Jan.                                     | Feb.    | Mar.    | Apr.    | May    | Jun.   | Jul.   | Aug.   | Sep.    | Oct.    | Nov.    | Dec.    |
| 225,982                                  | 219,211 | 229,967 | 115,326 | 95,006 | 55,823 | 52,363 | 95,498 | 170,474 | 204,228 | 213,604 | 221,825 |

In 2014, the total annual energy use was 1,899,312 kWh. The months with the highest energy use are January and March, followed by December. The low energy use in June and July indicates that there were no “summer-ice” this year.

### Summed energy use

Below, the summed annual energy use is compiled in one table. 2012 is the first year with a total energy use from all twelve months. 2011 is not complete.

Table 6: Annual energy use Rink A (total).

| Summed annual energy use (kWh) - Rink A - 2010-2014 |          |           |           |           |
|---|----------|-----------|-----------|-----------|
| 2010  | 2011     | 2012      | 2013      | 2014      |
| -   | 687,551* | 2,023,815 | 1,738,967 | 1,899,312 |

\*Energy figures from 2011 was not obtainable for the entire year.

### Seasonal energy use

In the following part, graphs and illustrations similar to the annual illustration is presented. However, the illustration starts in August and ends in July. This gives a better overview of an entire season without having to view different years together.

### 2011/2012 season

As noted above, the monthly figures for 2011 is not complete. Despite the lack of complete data to illustrate the full season, it is presented below to give an impression of the overall seasonal energy use. The two months, August and September, are normally not the months with the highest energy use, depending on when the production of ice is set to start.

Table 7: Seasonal energy use Rink A - 2011/2012.

| Seasonal energy use (kWh) - Rink A - 11/12 |      |         |          |          |          |          |          |         |         |         |         |
|--|------|---------|----------|----------|----------|----------|----------|---------|---------|---------|---------|
| Aug.                                       | Sep. | Oct.    | Nov.     | Dec.     | Jan.     | Feb.     | Mar.     | Apr.    | May     | Jun.    | Jul.    |
| -  | -    | 221,904 | 232,803* | 232,843* | 240,843* | 234,515* | 241,063* | 90,670* | 59,370* | 55,563* | 91,819* |

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One can see from the illustration above that the highest energy use is found in the beginning of 2012. From there, the energy use gradually decreases towards the summer, only to see a quite significant increase in July.

### *2012/2013 Season*

In Rink A, they tend to start the ice-season later than other ice rinks in Norway. As seen in the presentation of the year 2012, the laying of the ice is estimated to have started in August, when interpreting the figures. When looking at the 12/13 season, the energy use figures does not reveal any extremes in any way, as the energy use is following the trend with a high during winter and low in the summer.

Table 8: Seasonal energy use Rink A - 2012/2013.

| Seasonal energy use (kWh) - Rink A - 12/13 |          |         |         |         |         |         |         |         |        |        |        |
|--|----------|---------|---------|---------|---------|---------|---------|---------|--------|--------|--------|
| Aug.                                       | Sep.     | Oct.    | Nov.    | Dec.    | Jan.    | Feb.    | Mar.    | Apr.    | May    | Jun.   | Jul.   |
| 176,267*                                   | 180,926* | 223,386 | 206,770 | 222,616 | 222,176 | 200,756 | 189,966 | 121,921 | 64,138 | 51,113 | 41,524 |

### *2013/2014 Season*

The 2013/2014 season is the season with the highest energy use of the two seasons reviewed. From the table one can assume that the production of ice started in September, hence the large increase in energy use from August to September.

Table 9: Seasonal energy use Rink A - 2013/2014.

| Seasonal energy use (kWh) - Rink A - 13/14 |         |         |         |         |         |         |         |         |        |        |        |
|--|---------|---------|---------|---------|---------|---------|---------|---------|--------|--------|--------|
| Aug.                                       | Sep.    | Oct.    | Nov.    | Dec.    | Jan.    | Feb.    | Mar.    | Apr.    | May    | Jun.   | Jul.   |
| 42,833                                     | 153,833 | 215,356 | 207,518 | 227,827 | 225,982 | 219,211 | 229,967 | 115,326 | 95,006 | 55,823 | 52,363 |

As the season normally ends around Easter, it is expected that energy use is reduced from April to May, which also can be seen in the table above.

### *Summed energy use*

Summed up, the overview of the energy use gives a different view than the annual summaries presented earlier. Because of the limited amounts of data available, the 2011/2012 season does not represent a valid basis for comparison. Despite this, it is chosen to include the season in the table below to give an illustration of the figures.

Table 10: Seasonal energy use Rink A (total).

| <b>Summed seasonal energy use (kWh) - Rink A - 2010-2014</b> |            |           |           |  |
|--|------------|-----------|-----------|--|
| 2010/2011  | 2011/2012  | 2012/2013 | 2013/2014 |  |
| -  | 1,701,399* | 1,901,564 | 1,841,050 |  |

## 4.2 Rink A results

In the following chapters, the data gathered from Rink A is analysed in regards to discovering irregularities and to establish a basis for comparison, as well as seeing the energy use in connection to the addressed research questions.

First, it is important to understand what the different power meters measure. Improving the energy performance is difficult if one does not know what is measured and it is a point to be made about understanding what one pays for as well. Second, this is where one first encounter the suspicious effect of the heating degree-days adjustment formula, in July 2014. This deviation can be addressed to Enova's formula and is not to be confused with the difference seen in August in the seasonal overview, as this particular difference is caused by the earlier start of the ice-season.

### 4.2.1 Annual energy use

The energy data for the rink is divided in three blocks. This is because it is three power meters measuring the energy use and effect. The technical equipment connected to each power meter has not been possible to identify. However, from the development and trend lines one can make assumptions based on the level of, and development in the energy use.

#### *2012*

The equipment connected to the designated power meters are unidentifiable, but from the figure below the likely conclusion that power meter 3 is measuring the cooling system is drawn. From the information gained at the site visit it was known that the cooling system in the rink today is the original from the construction year (1978). This explains the high energy use of this power meter compared to the other two.

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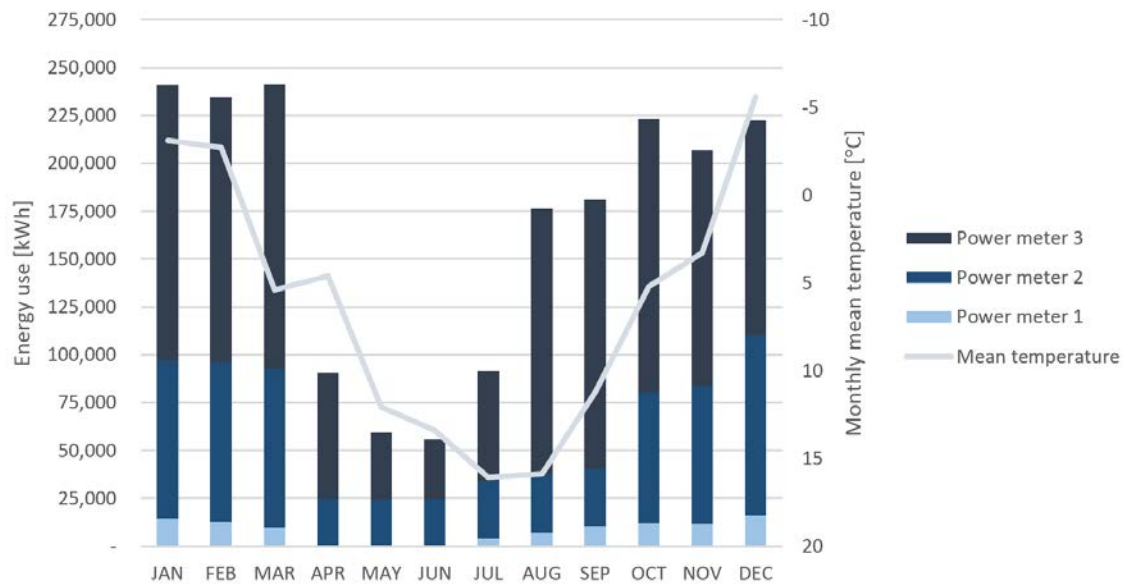


Figure 6: Actual energy use with mean temperature, Rink A - 2012.

The climate in Oslo where the rink is located is a typical coastal climate, as can be seen in the figure above. Only three months have mean temperatures below zero. It is difficult to ascertain to what extent the climate affect the energy use in the rink when one does not know what the power meters measure. What can be seen from the figure above is that power meter one seems to follow the temperature curve. Power meter two on the other hand seems to follow the ice-season in the rink. The energy use measured by this power meter decreases to about a third after the ice is removed (April), while it increases gradually when the ice is laid over the summer.

When viewing the climate adjusted energy use the autumn months in total adjusts to the same level. The one deviation that can be seen is in March, although the level is not drastic. This relatively small deviation of about 40,000 kWh can be explained by increased use, for example a weekend hockey cup.

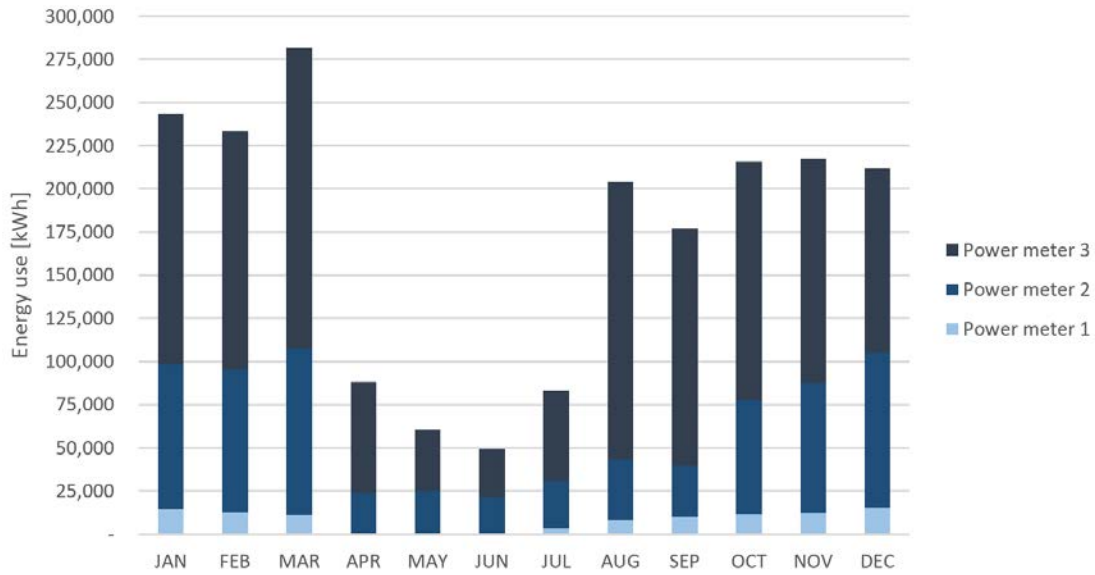


Figure 7: FMEU, Rink A - 2012.

**2013**

This year displays the same characteristics as pointed out in the figures for 2012. The temperature in 2013 is cooler at the coldest and warmer at the warmest, without one seeing any major effects of this in the graph of the energy use.

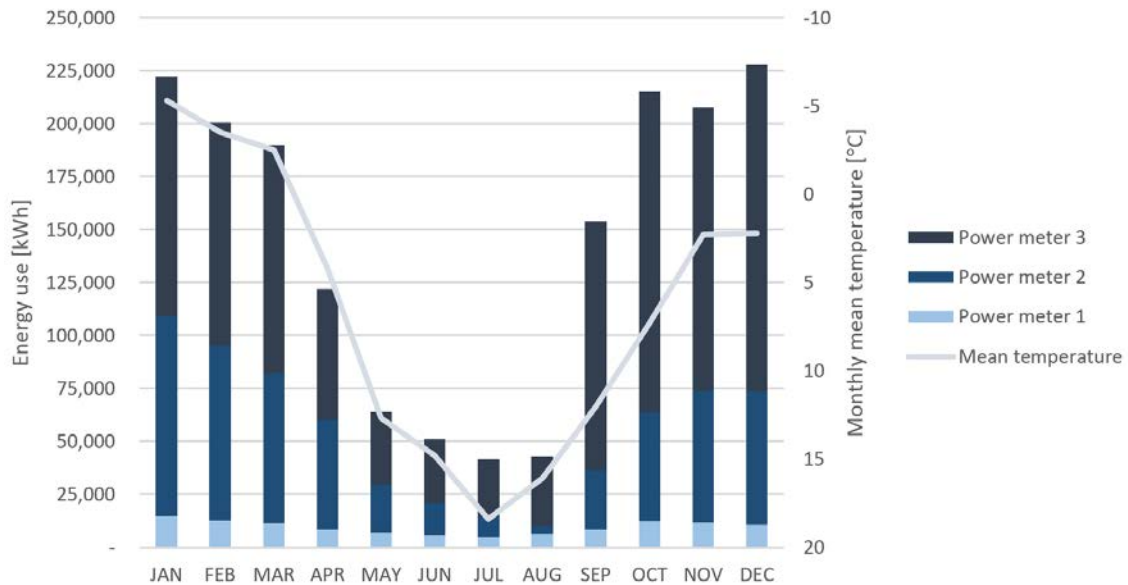


Figure 8: Actual energy use with mean temperature, Rink A - 2013.

The ice was removed in mid-April and laid in September the following season. The FMEU shows a steady decrease in the energy use from January to June, while the increase during the autumn months is uneven with a difference of about 65,000 kWh between September and

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October as the maximum. In November, the use decreases with about 12,000 kWh, before increasing with about 43,000 kWh in December.

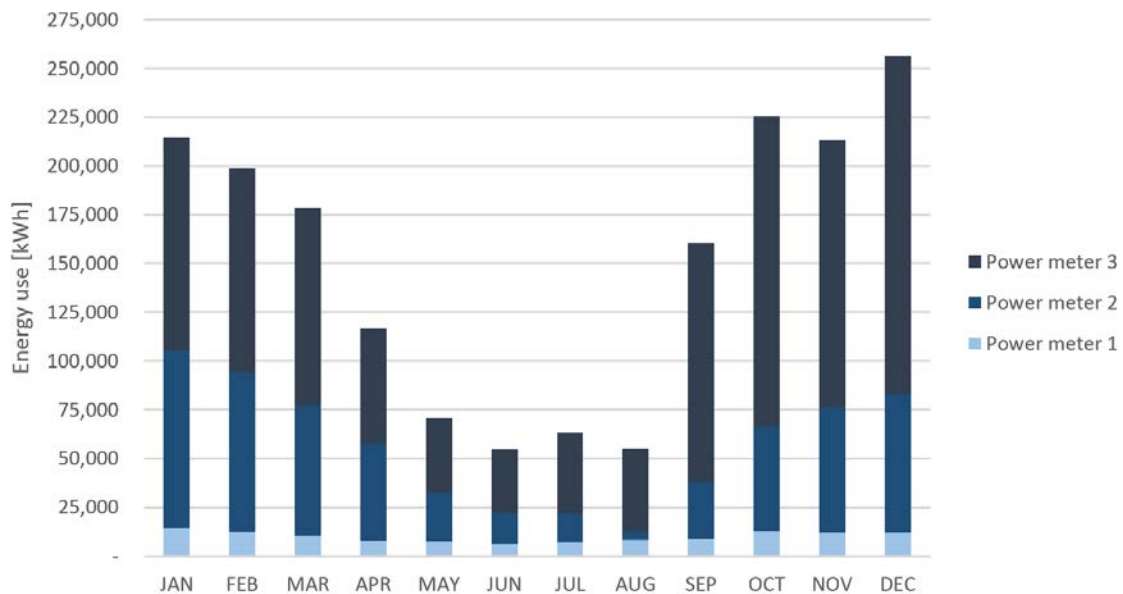


Figure 9: FMEU, Rink A - 2013.

### 2014

In 2014, just as with 2013 and 2012, one can see that the likely cooling system power meter is registering use throughout the summer months, despite there not being any ice during the summer in any of these years. If so, this is a common method to keep the pad cool throughout the summer to avoid the need for massive cooling at the start of a new season.

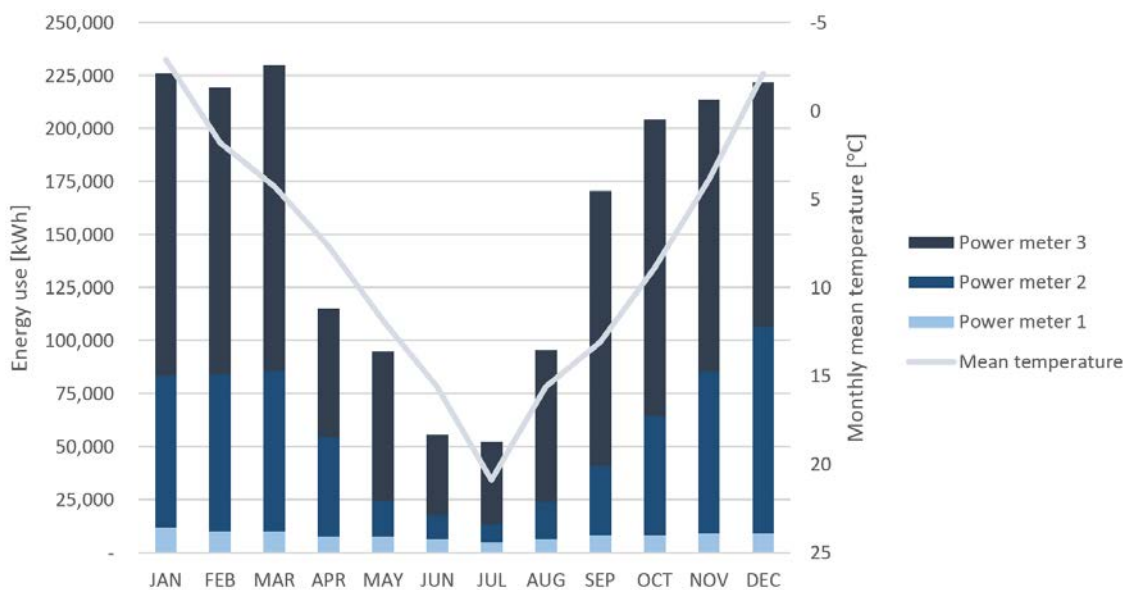


Figure 10: Actual energy use with mean temperature, Rink A - 2014.

From the temperature graph above, one can see that in July the mean temperature is 20.9 °C. Compared to the normal period, July had 21 fewer heating degree-days. Based on the Enova methodology this should give the rink a theoretical advantage due to the temperature, which should lead to lower actual energy use, and the adjusted to the same level as the adjacent months, presuming equal use of the rink.

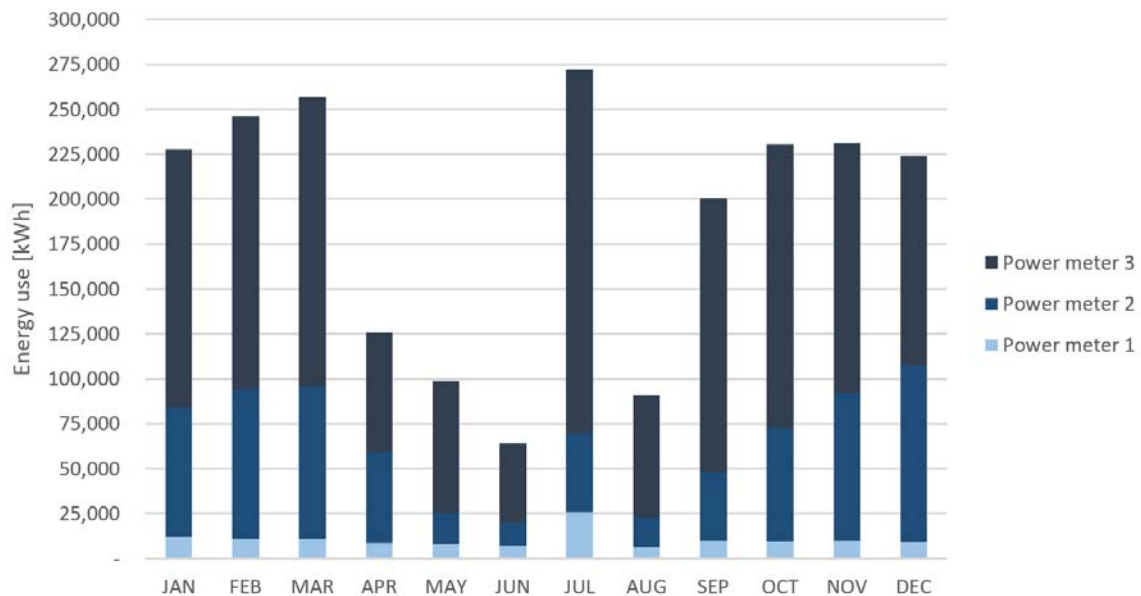


Figure 11: FMEU, Rink A - 2014.

The reason for this month being at the high level it is, can be addressed to the heating degree-day formula by Enova not being customised to fit ice rinks specifically. A typical ice rink does not have an ideal temperature at 17 °C, as it is a building designed for a cold sport. Generally, the indoor air temperature in an ice rink should be in the range between 10-12 °C during practice, and 12-14 °C in a match situation (Stobiecka et al., 2013). This also weighs in to the discussion of the percentage of energy use regarded as climate dependent.

#### 4.2.2 Seasonal energy use

Below, the energy use is organised into two complete ice-hockey seasons in the rink. The figures are adjusted to be comparable.

It is clear to see that the energy use is higher in the 2013/2014 season, especially because of the extreme deviation in July. Because this month hardly represents the level of energy use, but rather the temperature's effect, it is not representative. When overlooking July, the energy use sums up to about the same level.

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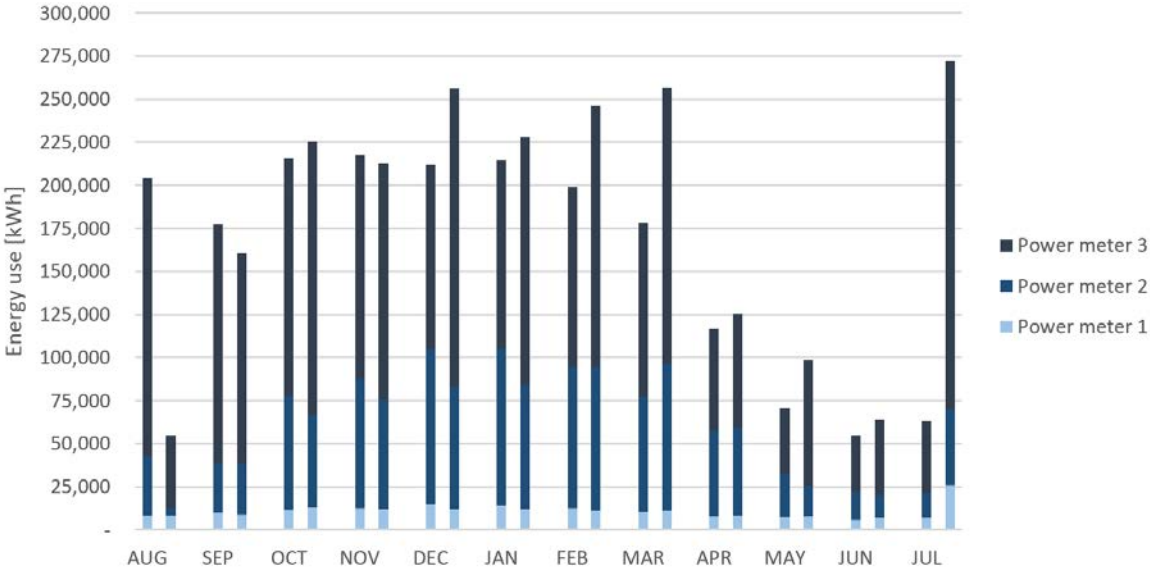


Figure 12: Seasonal energy use (FMEU), Rink A. From left to right: seasons 12/13 and 13/14.

The impact of July is especially visible in the total energy use for the seasons in the figure below. The entire difference in the total adjusted energy use between the past two seasons is made up by the increase in July 2014.

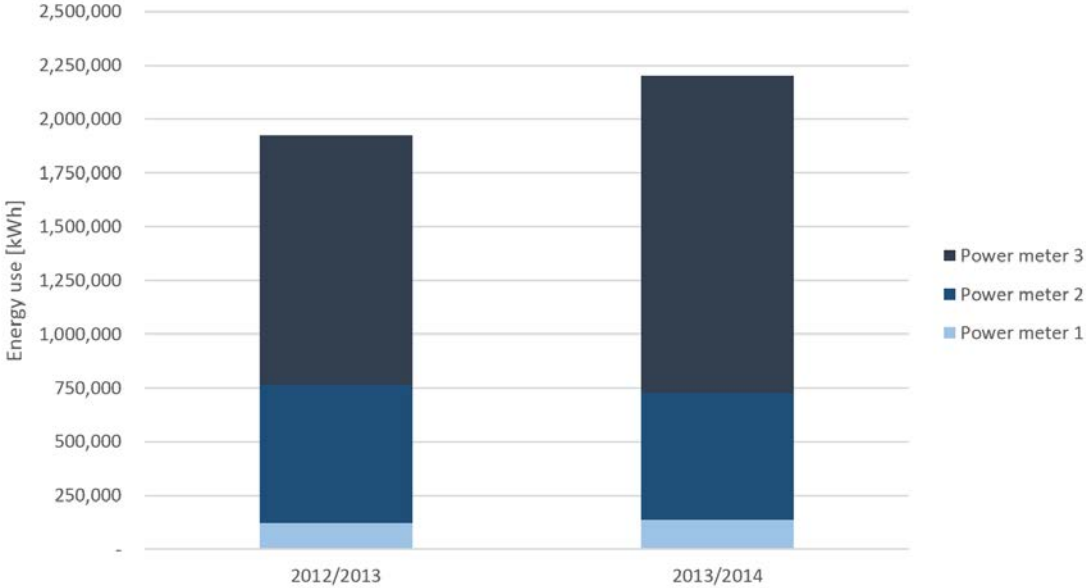


Figure 13: Seasonal energy use, Rink A (total).



### 4.3 Rink B (Normal-sized and training rink)

#### 4.3.1 General information


|                              |  |  |
|------------------------------|--|--|
| Name:                        | Rink B                                   |  |
| Location:                    | Sør - Trøndelag, Norway                  |  |
| Owner:                       | Municipality                             |  |
| Operator:                    | Municipal services                       |  |
| Year of build:               | 1977                                     |  |
| Ice-surface:                 | 2*1,800 m <sup>2</sup>                   |  |
| Capacity (total spectators): | 3,000 (main rink)<br>100 (training rink) |  |

Figure 14: General information Rink B.

Rink B is the chosen example of a normal-sized rink and training rink. The rink is located in Sør-Trøndelag, Norway, and is home to a former top-division hockey team.

Rink B is a part of a sports centre, which consists of the two ice rinks, an outdoor ice speed skating track, indoor exercise hall, a provisional exercise hall made of plastic, a curling rink and a football field. When referring to Rink B, both the main rink and the training rink are included in this term, while the sports centre includes all facilities in addition to the ice rinks.

The main indoor rink, which can accommodate 3,000 spectators, was built in 1977, and was opened as the eighth ice hockey facility in Norway. In 2009, a training rink was built in direct connection to the main rink. The training rink is a simple construction without any seating for spectators. The sports centre has undergone several modifications throughout the years. The latest project consisted of changing three ventilation systems in the exercise hall and changing rooms, in addition to some structural adaptations.

It is the municipal services that administrate the facility and rent out the rink to i.e. company sports teams and private teams. Local sports clubs, schools and day care facilities use the ice rink and other indoor facilities free of charge.

### *Climate*

The climate in Sør-Trøndelag is mild and humid, and strongly affected by its location in the outskirts of the Brave West Winds in the northern hemisphere. Cold polar air from the north meets warmer air mass from the south, which leads to a very unstable climate. During winter, mild temperatures and downpour as snow, sleet or rain characterises the climate (Trondheim Kommune, 2015).

The annual mean temperature is measured to 5.3 °C (1961-1990). Mean temperature in January is -3.1 °C and in June to August mean temperature is 13.7 °C (Trondheim Kommune, 2015).

#### **4.3.2 Design and building specific information**

Both the normal-sized rink and the training rink at the sports centre are of international size, 60\*30 meters, which equals 1,800 m<sup>2</sup>. The normal-sized rink has seating for spectators on both straights and short sides, while the training rink has little for spectators. Concrete and timber are the two most commonly used construction materials as the foundation and basis for the tribunes are made of this material. Benches of wood provide seating for spectators on the short sides of the rink, while plastic seats is used on the straights.

The logistics in the arena shows signs of being built in the 1970's. With one kiosk/café, a limited number of restrooms for the spectators and one entry/exit-point, it can be argued that the arena does not support big crowds.

Behind the tribune, in the outer part of the arena, there is a running track, to further encourage multi use. Both professional athletes and exercisers often use the running track in the winter months. There are six locker rooms connected to the main rink in addition to referee's room and other storage facility. These are basic equipped lockers in a generous size. Technical rooms are not given a great amount of space compared to new builds, and are placed underneath the spectator stands, as in most other facilities. The ice resurfacers has easy access both to the rink and to the outdoors speed-skating rink.

Between the rink and the connecting area, doors are installed to minimise air leakages from the rink. This helps stabilise the climatic circumstances in the rink and makes it easier to maintain a given temperature and humidity.

### *Construction*

The rink is constructed with a concrete foundation and metal sheets as walls and roofing. The upper parts of the wall consist of metal sheets supported by steel beams anchored in the concrete. Massive arched laminated wood girders hold up the roof. The ceiling is covered with reflective material to reduce the heat load on the ice and the need for lighting, as well as condensation issues in the ceiling.

The training rink was built in 2009 and provided a 100 % increase of the ice-area in Rink B. The training rink is attached to the other facilities at the sports centre and is a steel construction with inner walls made of LECA (Light Expanded Clay Aggregate). The roofing consist of steel, and with no reflective material. Around the ice rink, there is limited space and no seating for spectators although this was originally planned as doors were built in the wall at a higher level (1<sup>st</sup> floor) for entry and exit.

### *Technical equipment*

Heating and ventilation is supplied from the same air stream, where air is distributed through channels along the ceiling over the tribune area. The air supplied in the rink is ventilated from exhaust valves underneath the seating area. Two ventilation plants delivering a maximum of 30,000 m<sup>3</sup> and 20,000 m<sup>3</sup> supply the air. These plants mostly run on recirculated air, depending on activity in the ice. They also include a rotating heat exchanger unit, which is estimated to have 85 % power efficiency, as it was installed in 2012-2013. The locker rooms are provided with their own ventilation plant, and are heated by heating panels in the ceiling.

Dehumidification is accommodated with separate dehumidifiers placed in each short-end of the rink. These dehumidifiers have a capacity of 6,000 m<sup>3</sup>/h. The dehumidifiers deliver the dry air back to the rink through air ducts underneath the ceiling (Bergsagel, 2014).

The cooling system in the rink was renewed between 2011 and 2013 and has seen minor upgrades in the electronic equipment such as cyclo-inverters in addition to periodic maintenance. The ice slab is made of concrete and the rink pipes contains special brine as coolant. The slab was reconstructed in 2009-2010. The closed refrigeration circuit is automatically controlled, and operates on the basis of a fixed value of -5 °C as a reference value for the ice-temperature. The cooling system keeps the ice thickness in the range between

3-5 cm. Thicker ice is needed when figure skating is practiced on the ice, but when ice hockey is played the ice thickness is reduced to a minimum.

To keep the ice in perfect condition and even in thickness, the ice resurfacers operate on laser technology, which measure the ice thickness and adjust the scraper accordingly. In addition to this, it helps prevent ice building up in the corners along the sideboards, which is a common problem in many ice rinks.

The training rink is heated with five air heaters placed on one side of the rink underneath the ceiling. The air heaters have an effect of 5 kW each, and supply air horizontally from underneath the ceiling. The cooling system is identical to the system in the arena, and they operate with the same temperatures and ice-thickness. There is however, no integration between the separate systems and they operate individually.

The lighting in the arena consists of eighty-two metal halide lamps. The lighting is arranged in zones with three scenarios, so one can adjust the light according to the activity on the ice. Each lamp consists of four individual light bulbs, and during matches, all eighty-two lamps with all four bulbs are lit. When the ice is used for practice, only two of the four bulbs in each of the eighty-two lamps are lit. The third scenario is when younger players and kids use the rink for practice. They require less lighting and therefore only two out of four bulbs in forty-one of the eighty-two lamps are lit.

### **4.3.3 Operation, use and management**

The sports centre is owned and operated by the municipality as they have an operational liability by maintaining the sports centre. There is one permanently employed site manager, provided by the municipality, to ensure proper management.

The ice rinks are used by a variety of clubs, organisations and schools. Primary school, lower secondary school and upper secondary school all use the rinks from time to time, as well as private and company sports teams. The municipality hire the hours in the rinks weekdays until 3:30 PM. In the time after this, and in the weekends, the rinks are used by Sør-Trøndelag ice-hockey district. Local sports clubs, municipal schools and day care facilities use the rinks free of charge. Non-local sports clubs, company sports teams are charged 470 NOK pr. Hour (Site Manager, 2015).

As for most other rinks in the country, that does not provide ice during summer, the season starts in September, and ends around Easter-time. This is normally in the turn of the month between March and April. This equals an estimated season of 28 weeks.

#### 4.3.4 Collected data

The energy use in the Sports Centre is monitored by a SCADA-system named Entro. The main monitoring happens on site, but it is possible to access the system on the Internet from anywhere.

In the presented figures in the following chapters the district heating energy use for the air-house football hall, outdoor speed skating rink and the athletics hall are excluded. The electricity figures for the ice rink include both the main rink and the adjacent training rink, as it is not possible to distinguish the energy use between the two.

The figures presented in this chapter are the consumed electricity (lights, electric ovens etc.), energy for the cooling systems (ice cooling) and district heating.

#### *Annual energy use*

Annual energy use figures have been obtained from the annual reports created in Entro, dating back to January 2010.

The years are presented individually with a summary of all the years at the end. Each year consist of the actual energy use table (monthly total), while the specific energy use is illustrated in the analysis chapter (4.4.1).

#### **2010**

In 2010, the total energy use in Rink B was 2,579,601 kWh, not including the use in certain facilities, as explained above.

**Table 11: Energy use Rink B - 2010.**

| <b>Monthly energy use (kWh) – Rink B - 2010</b> |         |         |         |        |        |        |         |         |         |         |         |
|---|---------|---------|---------|--------|--------|--------|---------|---------|---------|---------|---------|
| Jan.  | Feb.    | Mar.    | Apr.    | May    | Jun.   | Jul.   | Aug.    | Sep.    | Oct.    | Nov.    | Dec.    |
| 330,089   | 311,265 | 293,435 | 121,156 | 93,818 | 82,113 | 93,938 | 166,888 | 231,432 | 263,653 | 272,922 | 318,892 |

The year starts in January with the level of energy use at about 330,000 kWh. The season ended in late March this year, as the tradition in Norway for removing the ice at Easter also applies

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here. When viewing the specific energy use one can see that the energy use is only distributed in general electricity, which includes all used energy not related to the cooling system for the ice or district heating. Individual power meters measure electricity for the cooling system and district heating.

**2011**

In 2011, one can see that the trend with a gradually decreasing energy use towards the summer is present and the significant increase in August marks the start of the ice-season. The total energy use this year was 2,251,922 kWh.

**Table 12: Energy use Rink B - 2011.**

| <b>Monthly energy use (kWh) - Rink B - 2011</b> |         |         |         |        |        |        |         |         |         |         |         |
|---|---------|---------|---------|--------|--------|--------|---------|---------|---------|---------|---------|
| Jan.  | Feb.    | Mar.    | Apr.    | May    | Jun.   | Jul.   | Aug.    | Sep.    | Oct.    | Nov.    | Dec.    |
| 312,347   | 271,377 | 207,986 | 147,001 | 85,363 | 68,273 | 63,286 | 185,625 | 235,243 | 213,294 | 223,103 | 238,924 |

Looking at the specific energy use, it is found that district heating was not yet introduced, as it is only cooling systems and electricity that is present.

**2012**

In 2012, the energy use was below 300,000 kWh in all months with the exception of November and December, and below 250,000 kWh if January is overlooked as well.

The total energy use this year was 2,159,150 kWh.

**Table 13: Energy use Rink B - 2012.**

| <b>Monthly energy use (kWh) - Rink B - 2012</b> |         |         |        |        |        |        |        |         |         |         |         |
|---|---------|---------|--------|--------|--------|--------|--------|---------|---------|---------|---------|
| Jan.  | Feb.    | Mar.    | Apr.   | May    | Jun.   | Jul.   | Aug.   | Sep.    | Oct.    | Nov.    | Dec.    |
| 266,726   | 229,700 | 206,892 | 80,285 | 55,406 | 38,413 | 44,776 | 85,476 | 161,309 | 248,437 | 417,521 | 324,209 |

The cooling system represent the majority of the increase in energy use throughout the year, with a significant rise in November.

**2013**

The energy use this year was 3,188,397 kWh. The first months of the year follows a similar trend from the past years. This year saw the introduction of district heating in February, and the portion of energy use related to cooling systems are considerably higher than it has been the past years.

Table 14: Energy use Rink B - 2013.

| Monthly energy use (kWh) - Rink B - 2013 |         |         |         |         |        |        |         |         |         |         |         |
|--|---------|---------|---------|---------|--------|--------|---------|---------|---------|---------|---------|
| Jan.                                     | Feb.    | Mar.    | Apr.    | May     | Jun.   | Jul.   | Aug.    | Sep.    | Oct.    | Nov.    | Dec.    |
| 364,697                                  | 350,748 | 337,322 | 240,415 | 148,336 | 97,855 | 67,679 | 184,501 | 278,198 | 329,343 | 391,145 | 398,158 |

## 2014

In the year 2014, the energy use in the ice-months varies between 300,000 kWh to nearly 450,000 kWh. The total energy use in 2014 was 3,447,085 kWh.

Table 15: Energy use Rink B - 2014.

| Monthly energy use (kWh) - Rink B - 2014 |         |         |         |         |         |         |         |         |         |         |         |
|--|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| Jan.                                     | Feb.    | Mar.    | Apr.    | May     | Jun.    | Jul.    | Aug.    | Sep.    | Oct.    | Nov.    | Dec.    |
| 416,630                                  | 382,731 | 440,324 | 275,393 | 173,108 | 154,396 | 140,063 | 161,744 | 229,774 | 304,846 | 380,118 | 387,958 |

From the specific energy use, it is evident that the portion of district heating relative to the total energy use has increased, while the cooling energy use has decreased slightly.

### *Summed energy use*

Compiled together, the development of the energy use from 2010 to 2014 is shown below. Here, the massive increase in energy use in 2013 and 2014 becomes apparent, which is further examined in chapter 4.4 to determine whether it is caused by climatic factors (external) or internal factors, as the figures are not comparable on equal basis in their current form.

Table 16: Annual energy use Rink B (total).

| Summed annual energy use (kWh) - Rink B - 2010-2014 |           |           |           |           |
|---|-----------|-----------|-----------|-----------|
| 2010  | 2011      | 2012      | 2013      | 2014      |
| 2,579,601   | 2,251,922 | 2,159,150 | 3,188,397 | 3,447,085 |

### *Seasonal energy use*

In the following chapter, the illustrations are arranged according to season to give a better overview of an entire season without having to view different years together.

#### *2010/2011 Season*

Looking at Table 17, the laying of the ice probably started mid-August and the removal probably in early April. The energy use reaches its top in December with a monthly use of 318,892 kWh.

The total energy use this season was 2,409,420 kWh.

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**Table 17: Seasonal energy use Rink B - 2010/2011.**

| <b>Seasonal energy use (kWh) - Rink B - 10/11</b> |         |         |         |         |         |         |         |         |        |        |        |
|---|---------|---------|---------|---------|---------|---------|---------|---------|--------|--------|--------|
| Aug.  | Sep.    | Oct.    | Nov.    | Dec.    | Jan.    | Feb.    | Mar.    | Apr.    | May    | Jun.   | Jul.   |
| 166,888   | 231,432 | 263,653 | 272,922 | 318,892 | 312,347 | 271,377 | 207,986 | 147,001 | 85,363 | 68,273 | 63,286 |

The electricity use is the dominant part of the total energy use. The electricity has a smooth development while the energy for the cooling systems vary a bit more.

### *2011/2012 Season*

The total energy use this season was 2,018,487 kWh.

**Table 18: Seasonal energy use Rink B - 2011/2012.**

| <b>Seasonal energy use (kWh) - Rink B - 11/12</b> |         |         |         |         |         |         |         |        |        |        |        |
|---|---------|---------|---------|---------|---------|---------|---------|--------|--------|--------|--------|
| Aug.  | Sep.    | Oct.    | Nov.    | Dec.    | Jan.    | Feb.    | Mar.    | Apr.   | May    | Jun.   | Jul.   |
| 185,625   | 235,253 | 213,394 | 223,103 | 238,924 | 266,726 | 229,700 | 206,892 | 80,285 | 55,406 | 38,413 | 44,776 |

When viewing the entire season, one can see that the level of energy use is stable in the entire season from August to March. The month with the lowest use is June with about 1/7<sup>th</sup> of the opposite month, January.

### *2012/2013 Season*

The total energy use this season was 2,844,004 kWh. This season saw the introduction of district heating in the facilities, or at least the individual measuring of this.

**Table 19: Seasonal energy use Rink B - 2012/2013.**

| <b>Seasonal energy use (kWh) - Rink B - 12/13</b> |         |         |         |         |         |         |         |         |         |        |        |
|---|---------|---------|---------|---------|---------|---------|---------|---------|---------|--------|--------|
| Aug.  | Sep.    | Oct.    | Nov.    | Dec.    | Jan.    | Feb.    | Mar.    | Apr.    | May     | Jun.   | Jul.   |
| 85,476  | 161,309 | 248,437 | 417,521 | 324,209 | 364,697 | 350,748 | 337,322 | 240,415 | 148,336 | 97,855 | 67,679 |

From the specifics, the peak in November is due to a high figure for the cooling system. District heating barely makes an impact with the exception of February and March.

### *2013/2014 Season*

The total energy use this season was 3,563,990 kWh. This season saw the energy use peak at 440,324 kWh in March.

**Table 20: Seasonal energy use Rink B - 2013/2014.**

| <b>Seasonal energy use (kWh) - Rink B - 13/14</b> |         |         |         |         |         |         |         |         |         |         |         |
|---|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| Aug.  | Sep.    | Oct.    | Nov.    | Dec.    | Jan.    | Feb.    | Mar.    | Apr.    | May     | Jun.    | Jul.    |
| 184,501   | 278,198 | 329,343 | 391,145 | 398,158 | 416,630 | 382,731 | 440,324 | 275,393 | 173,108 | 154,396 | 140,063 |



The district heating and the cooling systems are the main energy carriers. For example in March, the facilities used 158,167 kWh in district heating alone.

*Summed energy use*

Table 21: Seasonal energy use Rink B (total).

| Summed seasonal energy use (kWh) - Rink B - 2010-2014 |           |           |           |  |
|---|-----------|-----------|-----------|--|
| 2010/2011   | 2011/2012 | 2012/2013 | 2013/2014 |  |
| 2,409,420   | 2,018,487 | 2,844,004 | 3,563,990 |  |

When summed and put together, the impression given in the individual seasons becomes even more evident, with highly varying monthly values and a development in the wrong direction. These figures are not directly comparable in their current form, but gives an impression of the development.

**4.4 Rink B results**

Rink B is a rink that does not stand out in either a negative or a positive sense. Overall, the rink performs evenly in all the years data was obtained. An interesting observation is that instead of turning all cooling systems off in the summer, Rink B runs them on low effect to keep the pad surface cool.

**4.4.1 Annual energy use**

*2010*

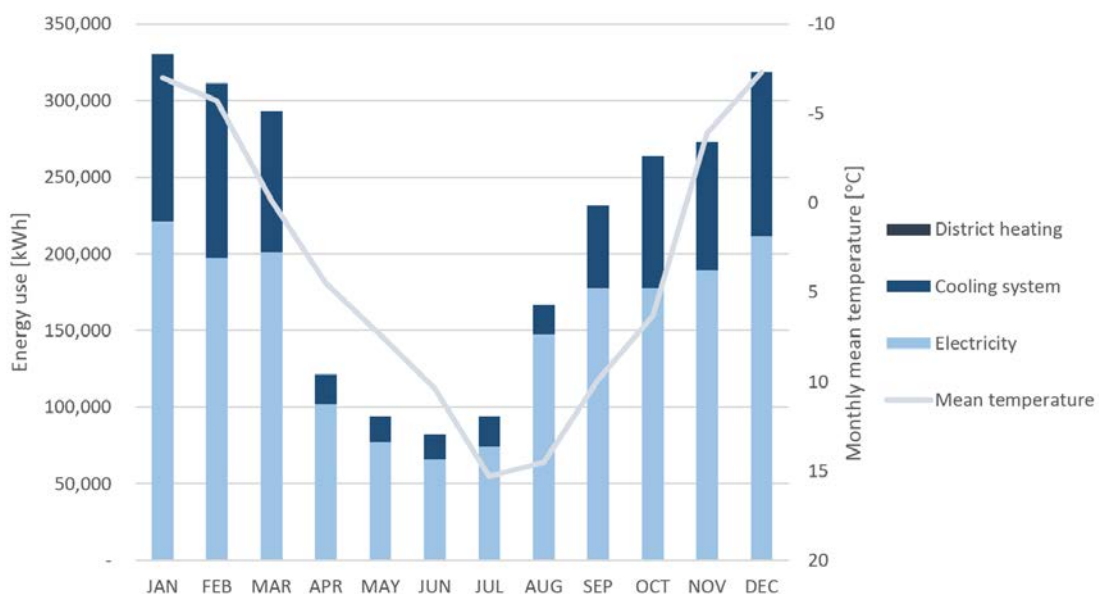


Figure 15: Actual energy use with mean temperature, Rink B - 2010.

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The figure above (Figure 15) shows the specific energy use along with the mean temperature in 2010. The energy use decreases towards the summer months as the facilities are not in regularly use during this period, with the ice being removed in April this year. One can see that June has the lowest energy use of the year. Rink B usually starts laying the ice in early September, which explains the increase in August and September.

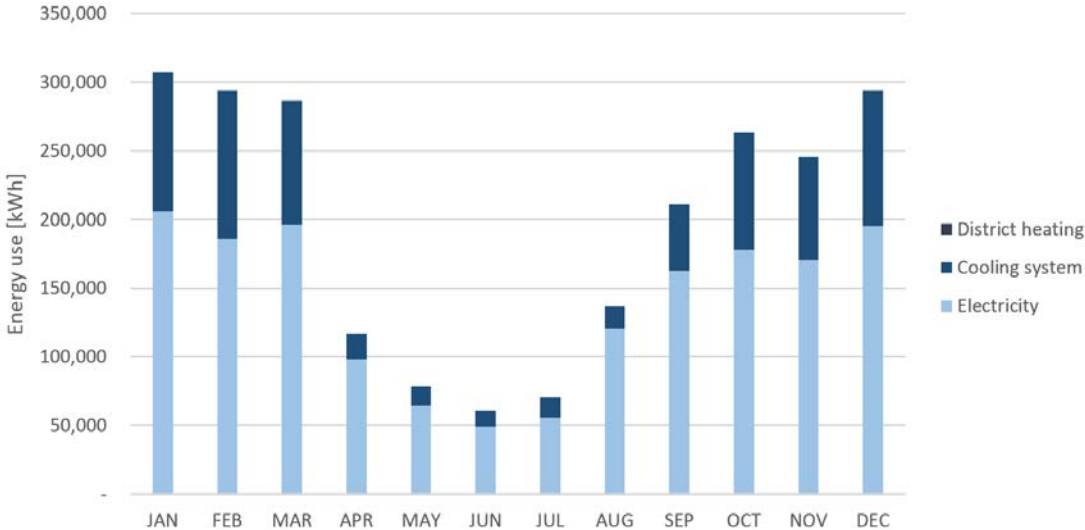


Figure 16: FMEU, Rink B - 2010.

The figure above displays the climate adjusted energy figures for Rink B. One can see that the figures are generally lower through the year, which means that the climate in general was colder than the normal period this year. The FMEU level is lower in the first months of the season (August-November) compared to the last months of the past season (January-March), but increases in the last month of the year.

2011

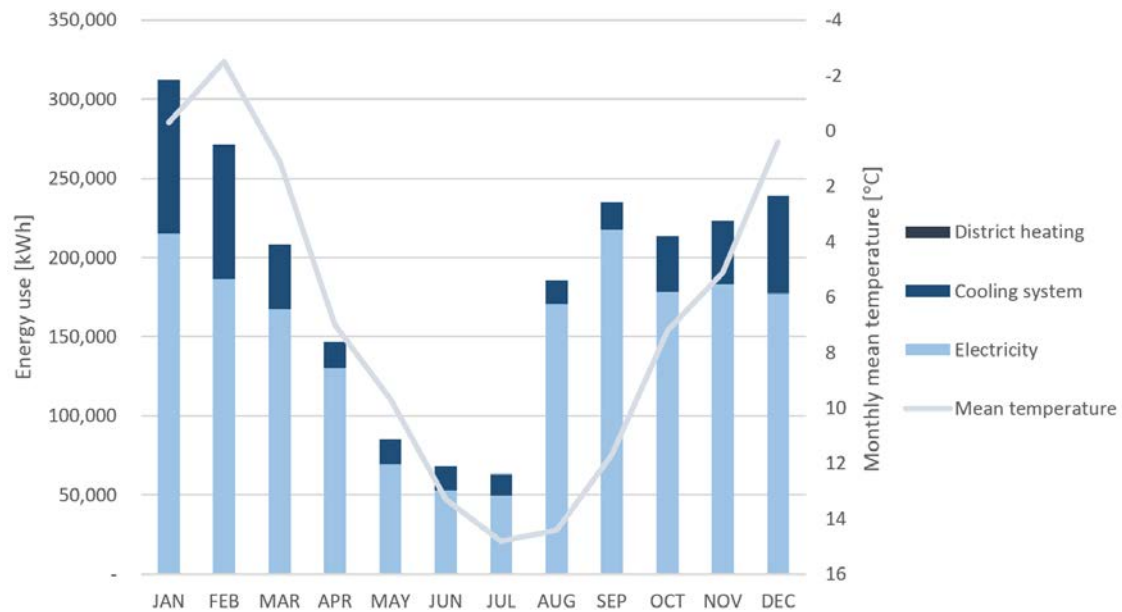


Figure 17: Actual energy use with mean temperature, Rink B - 2011.

2011 sees a steady decrease from January to June, with the mean temperature matching the normal period temperature fairly well as the adjustments are minimal. The cooling system is running on low effect throughout the summer months, which is a strategy employed by several rinks. The reason is that in total, it is cheaper to run the cooling system on low effect when the rink is not in use, compared to the cost of cooling down the slab after it has been heated in the summer. Cooling down a warm slab often demands more energy in a short period of time, compared to the sum of energy needed to maintain a steady temperature with the cooling system. This is an assessment each rink has to make as it depends on the indoor temperature in the summer, and the number of weeks the rink is not in use and planned used, among other factors to consider.

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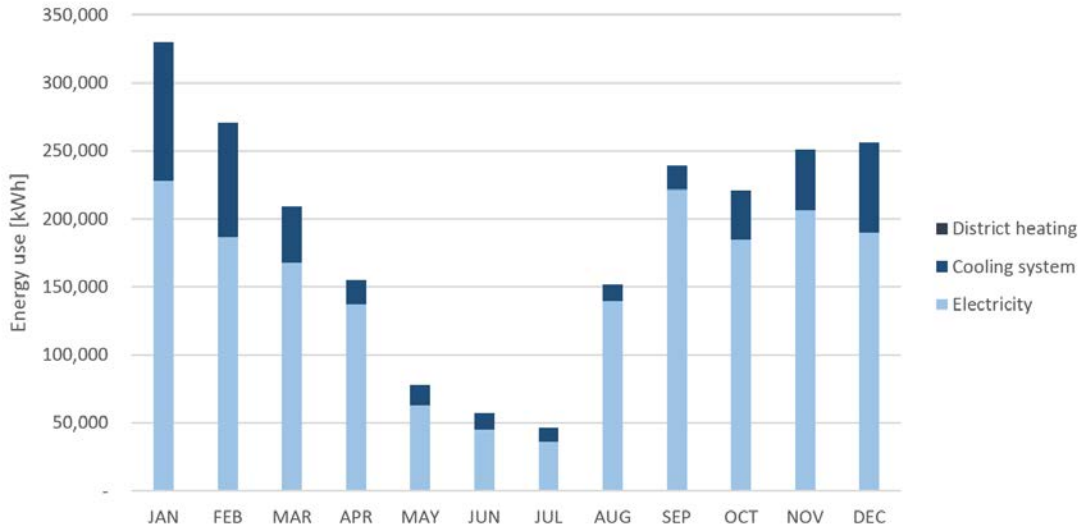


Figure 18: FMEU Rink B - 2011.

Even with the climate consideration taken out of the picture, one can see that the cooling system in Rink B draws more energy in January and February compared to the autumn months of September, October and November. The reason behind this is most likely increased activity in the rink with local schools, youth teams and the elite team.

2012

The year of 2012 follows the same pattern seen the past years. The interesting aspect is what happens in November this year, where the energy use for the cooling system represents over half of the total energy use this month.

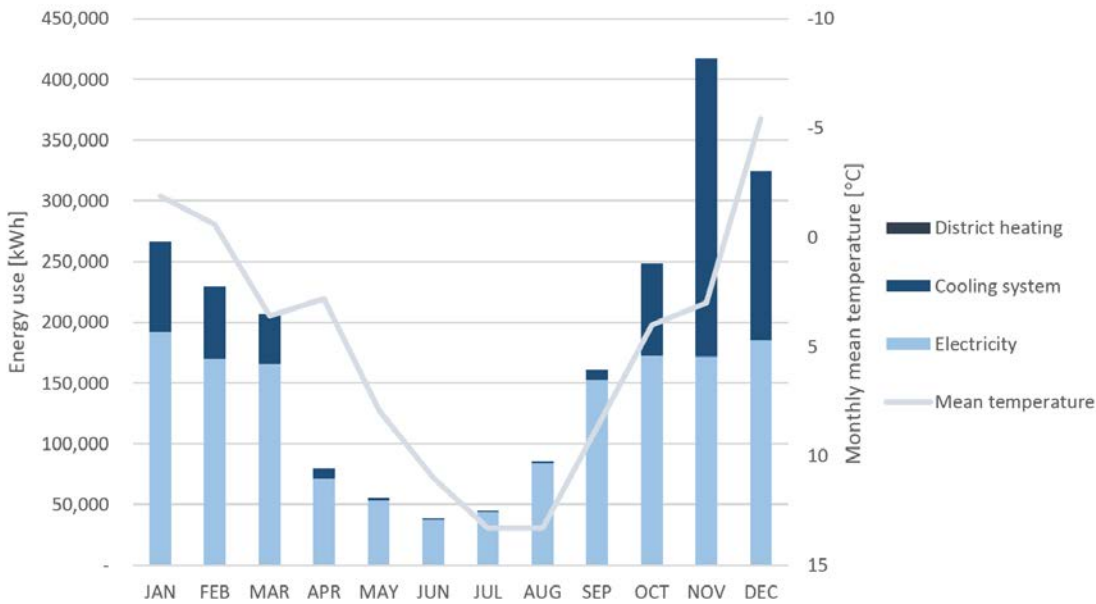


Figure 19: Actual energy use with mean temperature, Rink B - 2012.

As one can see, the ice was laid in late September, with moderate use of the rink in October. From the figure of the adjusted energy use below, one can see that the cooling system in November uses almost twice as much energy as in December.

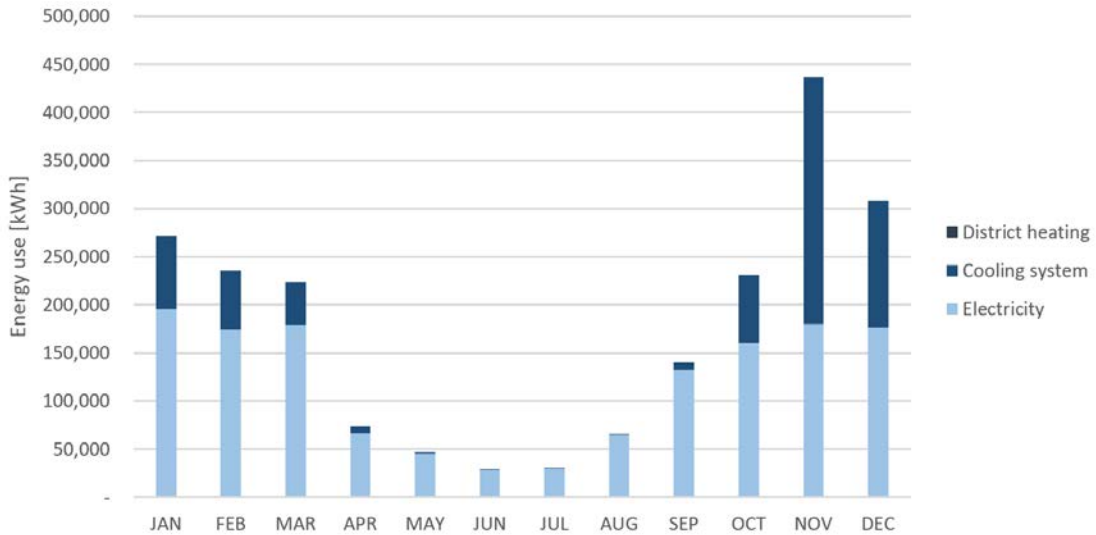


Figure 20: FMEU, Rink B - 2012.

**2013**

2013 saw the introduction of district heating in Rink B. The first year the use of this was quite low, however when one look at the adjusted energy use in the figure below the total energy use has increased.

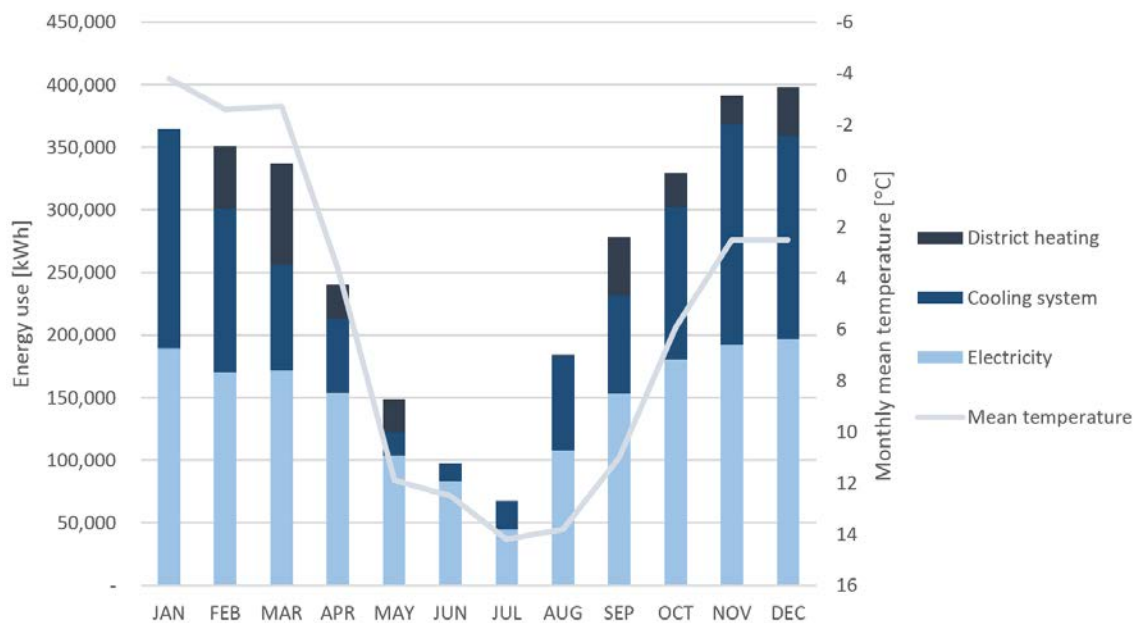


Figure 21: Actual energy use with mean temperature, Rink B - 2013.

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The season with ice ended in April and the next started in late August. The cooling system energy use is increasing towards the end of the year, which is normal as the use of the rinks also increases in these months.

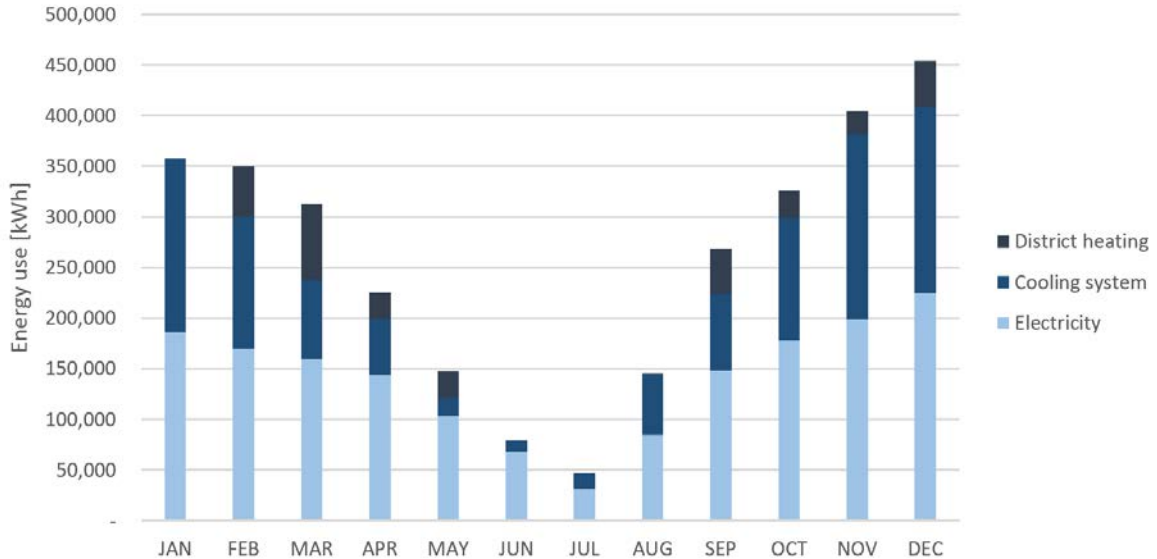


Figure 22: FMEU, Rink B - 2013.

### 2014

This was a warmer year than the previous years, but still one can see the increase in use of district heating.

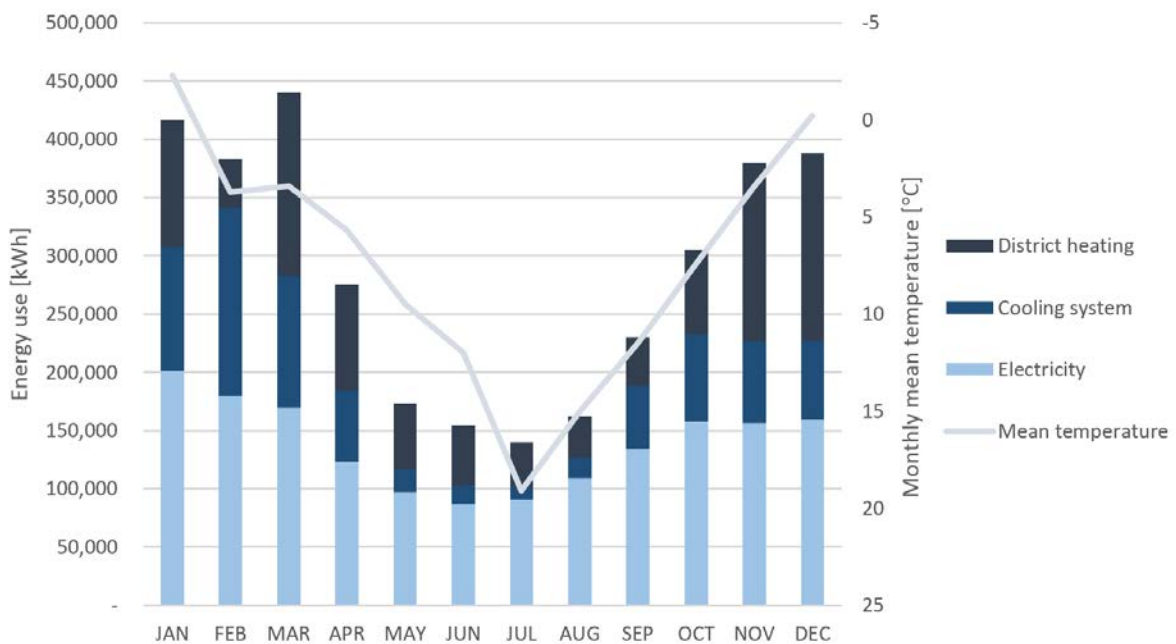


Figure 23: Actual energy use with mean temperature, Rink B - 2014.

Looking past the first three months of the year, the energy used for the cooling system is reduced drastically. What caused this is unknown, but a reduction in use can be ruled out as the rink is used just as much despite not having an ice-hockey team in the top division anymore.

The biggest decreases in cooling system energy is found in November and December, however these are also the months with the biggest increases in district heating energy.

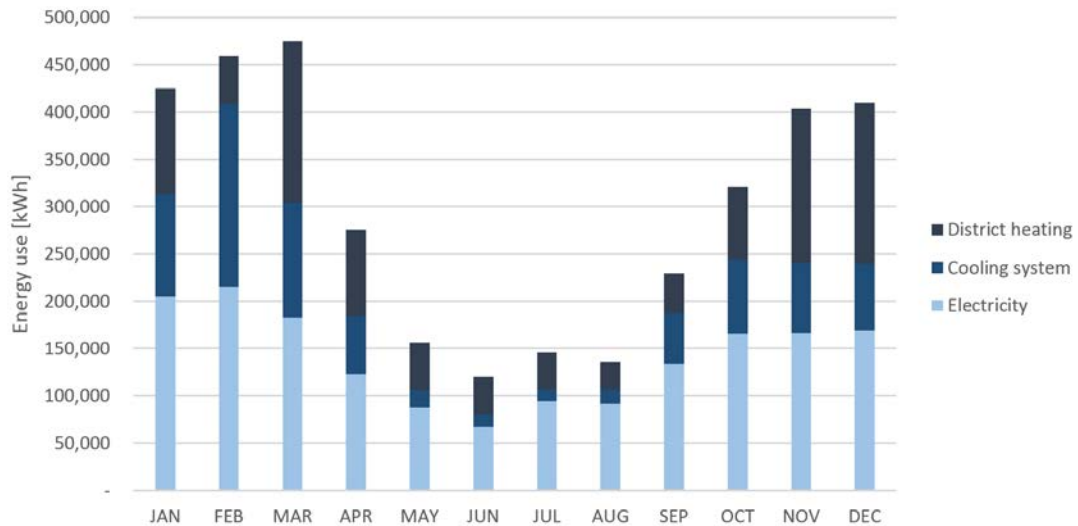


Figure 24: FMEU, Rink B - 2014.

#### 4.4.2 Seasonal energy use

When sorting the annual energy data in seasons, it is clear to see that the last two seasons, the 2012/2013 and 2013/2014, uses the most energy. The 2013/2014 season is by far the season in Rink B with the highest energy use.

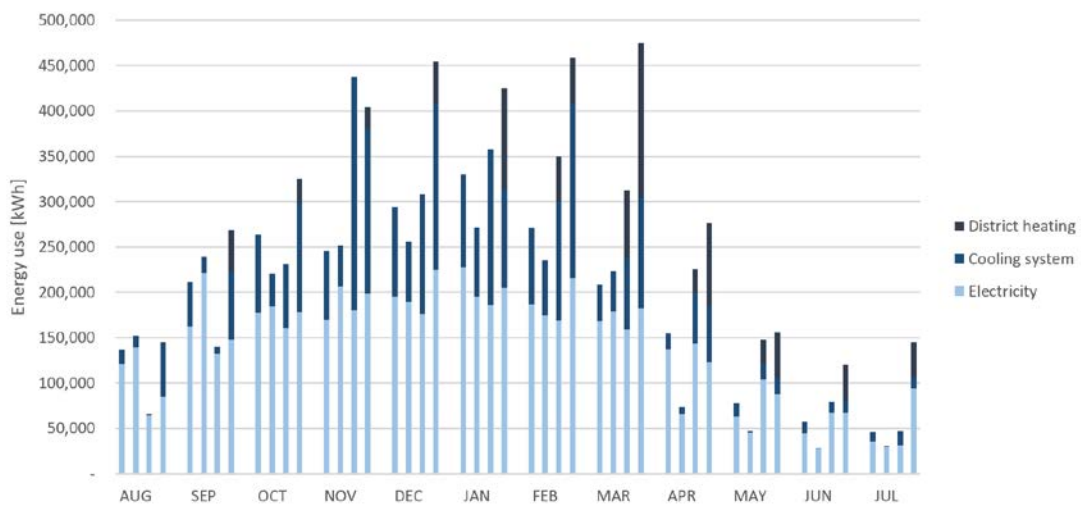


Figure 25: Seasonal energy use (FMEU), Rink B. From left to right: seasons 10/11, 11/12, 12/13 and 13/14.

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From the figure below, the specific energy use can be seen clearly. Overall, the electricity use has been steady at the same level, but the cooling system energy use has increased along with the district heating energy use.

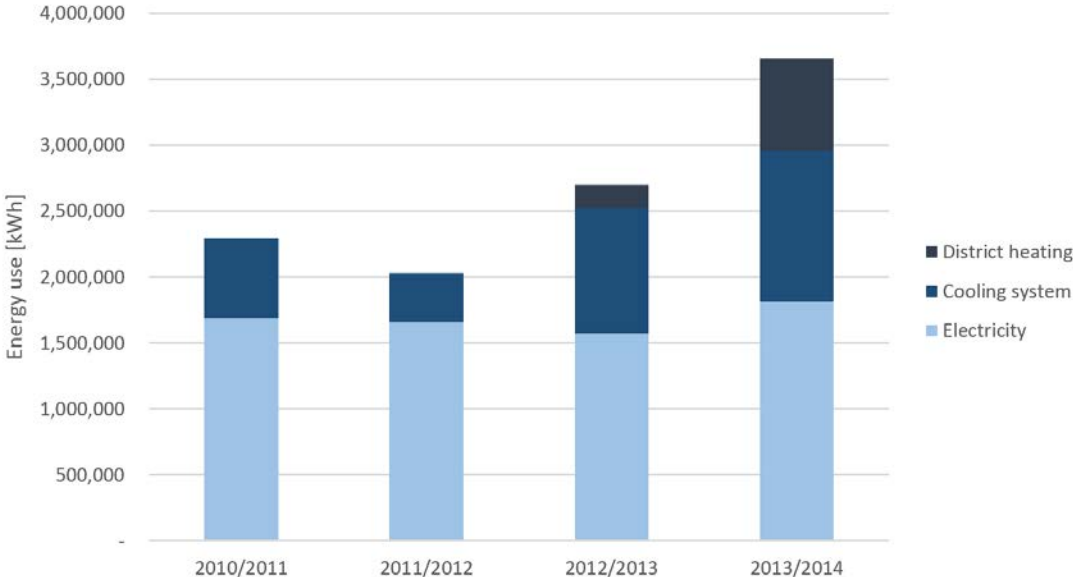


Figure 26: Seasonal energy use, Rink B (total).



## 4.5 Rink C (Arena-sized rink)

### 4.5.1 General information


|                              |                                   |  |
|------------------------------|-----------------------------------|--|
| Name:                        | Rink C                            |  |
| Location:                    | Hedmark, Norway                   |  |
| Owner:                       | Municipal owned operating company |  |
| Operator:                    | Municipal owned operating company |  |
| Year of build:               | 1992 - 1994                       |  |
| Ice-surface:                 | 1,800 m <sup>2</sup>              |  |
| Capacity (total spectators): | 6,500<br>(5,500 seated)           |  |

Figure 27: General information Rink C.

Rink C is one of the chosen examples of an arena-sized ice rink. The arena is located in Hedmark, Norway. The arena is the home to one of the Norwegian top division ice-hockey teams.

According to the owners, Rink C is the biggest sports arena in the world constructed in timber. The arena is built in close proximity to a training rink and arena for hockey-matches for the younger players. The two rinks are built together by a connecting hallway. Total capacity of the arena is 6,500 visitors in total with 5,500 seated audience, and the training rink provides seating for approximately 1,500 people (HRTB Arkitekter AS, 2015). The arena is owned and operated by a facility services provider that also took part in designing, building and developing arenas for the 1994 Winter Olympics. The company is municipality owned and are responsible for the operation and maintenance in several sports arenas in the county (Operations Manager, 2015a).

Rink C was originally constructed as an arena for figure skating and short track speed skating. The construction period started in 1992 and the rink was finished in 1994.

#### *Climate*

The climate in Hedmark can be characterised as a typical continental climate. Winds do not tend to reach high speeds, and the direction follows the elongated valleys main route. During

winter, there is often inversion, which means higher temperatures on higher altitudes (Dannevig, 2009).

The mean temperature in Hedmark for January is normally between -6 °C and -8 °C in the southern areas, and between -10 °C and -13 °C in the northern dales. Mean temperature in July is around 16 °C in the south of Hedmark. Annual rainfall is 600-800 mm, which is about the same as the capital in Norway, Oslo (Dannevig, 2009).

### **4.5.2 Design and building specific information**

The Norwegian architectural firm HRTB Arkitekter AS and the facility service provider designed the arena, and the contractor for the building of the arena was Martin M. Bakken AS, a company in the Backe group (Operations Manager, 2015a).

Total size of the arena is 8,000 m<sup>2</sup> and the ice pad is standard European size 60\*30 meters, which equals 1,800 m<sup>2</sup> of ice surface. The building has an oval shape that seeks to attach different spaces and building typologies in the neighbourhood. The dark coloured facade is thought to counteract the surroundings many different colours (HRTB Arkitekter AS, 2015). The arena provides VIP-facilities for 50 people and a café with seating for 120 people. There are also facilities for business meetings for up to 50 people and a studio for AV-production (Operations Manager, 2015a).

#### ***Construction***

The main substructure consists of concrete columns with lattice girders in laminated wood that spans the entire width of the hall. Between these girders, light shaft segments span in a “sandwich” construction in 1.2 meter widths, with plates above and below. Roofing is felt roof.

The in-situ concrete stand are stabilising the construction, together with the facade made of cantilevered laminated timber girders, which rests on the stand. Between these girders there are built prefabricated non-load bearing wall elements, that are slightly rhombic shaped.

The facades are inspired by the Northern lights, common in Norway in the wintertime. During the design-period, the focus was on timber and to use Norwegian timber. The roof construction was originally planned made of steel, but was changed to wood after a central decision that this change was going to be sponsored.

### *Technical equipment*

The central control and monitoring system is located off site, in the maintenance offices in a collaborative sports centre. As it is the facility service provider that owns and operates both arenas, it is more convenient to have a joint solution where you can supervise both arenas. The control and monitoring system software is Entro.

Heated air is delivered through ventilation ducts placed up under the ceiling and nozzles directed towards the seating area. The heated air is provided by a heat pump installation, which nearly covers the full need of heat. On extra cold days, district heating is used to fill in the gaps to cover the extra need for heating. District heating is also used to preheat the domestic hot water. The vast ceiling height is often a problem in ice-rinks as the heated air rises and is stored just below the ceiling. To take advantage of this air, it is installed large ventilation “cannons” that blow the hot air down on the tribune. When the need for heating is greater than during a hockey-match, for example when hosting concerts and exhibitions, additional heating coils are rented from external providers to cover the extra need.

The air-handling unit has an airflow rate of 45,000-50,000 m<sup>3</sup>/h. This includes the attached training rink. The ventilation plant contains a heat exchanger unit with 55 % power efficiency. The heat exchanger is a heating coil that works after the liquid to air-principle. Temperature in the arena is between 8 °C and 10 °C on training days, and around 15 °C on match-day. This is measured on the seating area for the audience.

The cooling system consist of original parts from the year of build. Two piston-compressors drive the system, which demands more maintenance than a screw-compressor, but are more efficient when not running on full power. The ice slab is made of concrete and the rink pipes contains special brine as coolant. The closed refrigeration circuit is automatically controlled, and there is inspection hatches located on the short side of the rink. The average temperature on the ice surface is -4 °C, and the ice thickness is 3.5-4.0 cm.

There are little to no problems regarding dehumidification in the arena. This is mainly because of its location inland, where the climate presents no challenges concerning indoor humidity. Even so, the ventilation plant does incorporate a dehumidification system. This is to keep the humidity in a certain level.

The lighting in the arena consists of ca. 460 PT5 lamps, each one with an effect of 2 kW. Lighting is from the year of build, and more efficient lighting sources can probably be found today. Pre-programmed scenarios, where the light automatically turns on when there is activity on the ice, control the lighting. All the lamps are normally only used when there are hockey-matches in the highest division. Lower levels, juniors, and training does not require the same amount of lighting, as the speed of the game is not as fast as the professionals.

### 4.5.3 Operation, use and management

In addition to being the home of an elite ice-hockey team, the arena can also host different cultural events, such as concerts, fairs and exhibitions.

Like many other ice-rinks in the country, day-care facilities, after-school programmes, figure skaters, middle schools and high schools in the area use Rink C. This call for well-incorporated routines for the maintenance-personnel as the ice is in use many hours of the day.

Traditionally the rink has ice from week 27 (July) to mid-April depending on the playoff-matches in the national series. Rink C tends to lay the ice earlier than many other rinks. They call it “summer-ice” and arrange figure skating camp and hockey-schools for the juniors in July/August.

### 4.5.4 Collected data

The energy use in Rink C is monitored by a SCADA-system. All figures presented in the following chapters are obtained from this program. Figures concerning the energy use are presented both in annual form and seasonal.

#### *Monthly energy use*

#### **2010**

Starting with 2010, the total energy use was 3,571,719 kWh. As seen from the table below, the month with the highest energy use is over 650,000 kWh in January, and the lowest in June with nearly 50,000 kWh.

**Table 22: Energy use Rink C - 2010.**

| <b>Monthly energy use (kWh) - Rink C - 2010</b> |         |         |         |        |        |         |         |         |         |         |         |
|---|---------|---------|---------|--------|--------|---------|---------|---------|---------|---------|---------|
| Jan.  | Feb.    | Mar.    | Apr.    | May    | Jun.   | Jul.    | Aug.    | Sep.    | Oct.    | Nov.    | Dec.    |
| 667,083   | 441,195 | 386,644 | 163,700 | 78,656 | 45,377 | 209,848 | 302,197 | 283,905 | 305,142 | 277,605 | 410,367 |

The trend this table shows is what one can expect from a facility that mainly is in use during the winter half of the year.

### 2011

The month with the highest use is January, with 366,983 kWh. The total energy use this year was 2,833,094 kWh. The autumn months' energy use is notably lower than the winter months this year.

Table 23: Energy use Rink C - 2011.

| Monthly energy use (kWh) - Rink C - 2011 |         |         |         |        |        |         |         |         |         |         |         |
|--|---------|---------|---------|--------|--------|---------|---------|---------|---------|---------|---------|
| Jan.                                     | Feb.    | Mar.    | Apr.    | May    | Jun.   | Jul.    | Aug.    | Sep.    | Oct.    | Nov.    | Dec.    |
| 366,983                                  | 309,447 | 301,525 | 147,776 | 90,469 | 83,320 | 121,631 | 306,435 | 300,696 | 286,392 | 260,131 | 258,289 |

### 2012

The trend for 2012 looks similar to 2011; however, where 2011 had a decreasing energy use trend towards the end of the year, 2012 is showing an increase. The total energy use this year was 2,724,857 kWh.

Table 24: Energy use Rink C - 2012.

| Monthly energy use (kWh) - Rink C - 2012 |         |         |         |        |        |         |         |         |         |         |         |
|--|---------|---------|---------|--------|--------|---------|---------|---------|---------|---------|---------|
| Jan.                                     | Feb.    | Mar.    | Apr.    | May    | Jun.   | Jul.    | Aug.    | Sep.    | Oct.    | Nov.    | Dec.    |
| 298,855                                  | 255,377 | 272,037 | 132,972 | 65,640 | 58,448 | 208,317 | 293,339 | 270,463 | 294,170 | 277,105 | 298,134 |

### 2013

Table 25: Energy use Rink C - 2013.

| Monthly energy use (kWh) - Rink C - 2013 |         |         |        |        |        |         |         |         |         |         |         |
|--|---------|---------|--------|--------|--------|---------|---------|---------|---------|---------|---------|
| Jan.                                     | Feb.    | Mar.    | Apr.   | May    | Jun.   | Jul.    | Aug.    | Sep.    | Oct.    | Nov.    | Dec.    |
| 374,729                                  | 383,930 | 291,853 | 78,219 | 44,605 | 51,410 | 211,759 | 275,989 | 263,882 | 282,883 | 283,341 | 279,691 |

The total energy use this year was 2,822,291 kWh. The first months of the year sees considerably higher numbers than the months in the end of the year.

**2014**

2014 seems to be the most stable year with almost equal amount of energy use in the winter and autumn. The total energy use this year was 2,585,299 kWh.

**Table 26: Energy use Rink C - 2014.**

| <b>Monthly energy use (kWh) - Rink C - 2014</b> |         |         |         |        |        |         |         |         |         |         |         |
|---|---------|---------|---------|--------|--------|---------|---------|---------|---------|---------|---------|
| Jan.  | Feb.    | Mar.    | Apr.    | May    | Jun.   | Jul.    | Aug.    | Sep.    | Oct.    | Nov.    | Dec.    |
| 299,012   | 257,577 | 267,479 | 148,032 | 51,188 | 36,806 | 239,743 | 277,060 | 258,187 | 247,215 | 246,422 | 256,558 |

**Summed energy use**

In the table below (Table 27), the summed energy use for each of the years can be viewed. Although the energy use figures are not climate adjusted for comparison, the decrease from 2010 to 2014 with approximately 1 million kWh is substantial.

**Table 27: Annual energy use Rink C (total).**

| <b>Summed annual energy use (kWh) - Rink C - 2010-2014</b> |           |           |           |           |
|--|-----------|-----------|-----------|-----------|
| 2010   | 2011      | 2012      | 2013      | 2014      |
| 3,571,719  | 2,833,094 | 2,724,857 | 2,822,291 | 2,585,299 |

**Seasonal energy use**

**2010/2011 Season**

In Rink C, they usually have the ice ready for August because of skating classes arranged by different organisations. As seen in the presentation of the year 2010, laying of the ice started in July.

When looking at the 10/11 season, one can see a noticeable increase in the energy use at the turn of the year.

**Table 28: Seasonal energy use Rink C - 2010/2011.**

| <b>Seasonal energy use (kWh) - Rink C - 10/11</b> |         |         |         |         |         |         |         |         |        |        |         |
|---|---------|---------|---------|---------|---------|---------|---------|---------|--------|--------|---------|
| Aug.  | Sep.    | Oct.    | Nov.    | Dec.    | Jan.    | Feb.    | Mar.    | Apr.    | May    | Jun.   | Jul.    |
| 302,197   | 283,905 | 305,142 | 277,605 | 410,367 | 366,983 | 309,447 | 301,525 | 147,776 | 90,469 | 83,320 | 121,631 |

The total energy use this season was 3,000,367 kWh.

**2011/2012 Season**

In the 11/12 season the energy use is varying little throughout. The amount of use is stable between 250,000 kWh and 300,000 kWh each month.

Table 29: Seasonal energy use Rink C - 2011/2012.

| <b>Seasonal energy use (kWh) - Rink C - 11/12</b> |         |         |         |         |         |         |         |         |        |        |         |
|---|---------|---------|---------|---------|---------|---------|---------|---------|--------|--------|---------|
| Aug.  | Sep.    | Oct.    | Nov.    | Dec.    | Jan.    | Feb.    | Mar.    | Apr.    | May    | Jun.   | Jul.    |
| 306,435   | 300,696 | 286,392 | 260,131 | 258,289 | 298,855 | 255,377 | 272,037 | 132,972 | 65,640 | 58,448 | 208,317 |

As seen above, the preparation of ice started in July, where the energy use is just over 200,000 kWh. The total energy use this season was 2,703,589 kWh.

**2012/2013 Season**

Table 30: Seasonal energy use Rink C - 2012/2013.

| <b>Seasonal energy use (kWh) - Rink C - 12/13</b> |         |         |         |         |         |         |         |        |        |        |         |
|---|---------|---------|---------|---------|---------|---------|---------|--------|--------|--------|---------|
| Aug.  | Sep.    | Oct.    | Nov.    | Dec.    | Jan.    | Feb.    | Mar.    | Apr.   | May    | Jun.   | Jul.    |
| 293,339   | 270,463 | 294,170 | 277,105 | 298,134 | 374,729 | 383,930 | 291,853 | 78,219 | 44,605 | 51,410 | 211,759 |

There is a steady increase from November, peaking in February at just over 380,000 kWh. The ice was removed in late March.

The total energy use this season was 2,869,716 kWh.

**2013/2014 Season**

Table 31: Seasonal energy use Rink C - 2013/2014.

| <b>Seasonal energy use (kWh) - Rink C - 13/14</b> |         |         |         |         |         |         |         |         |        |        |         |
|---|---------|---------|---------|---------|---------|---------|---------|---------|--------|--------|---------|
| Aug.  | Sep.    | Oct.    | Nov.    | Dec.    | Jan.    | Feb.    | Mar.    | Apr.    | May    | Jun.   | Jul.    |
| 275,989   | 263,882 | 282,883 | 283,341 | 279,691 | 299,012 | 257,577 | 267,479 | 148,032 | 51,188 | 36,806 | 239,743 |

The 2013/2014 season sees the peak in energy use in January at 299,012 kWh. The ice was removed in early April.

The total energy use this season was 2,685,623 kWh.

**Summed energy use**

Table 32: Seasonal energy use Rink C (total).

| <b>Summed seasonal energy use (kWh) - Rink C - 2010-2014</b> |           |           |           |  |
|--|-----------|-----------|-----------|--|
| 2010/2011  | 2011/2012 | 2012/2013 | 2013/2014 |  |
| 3,000,367  | 2,703,589 | 2,869,716 | 2,685,623 |  |

Summed in Table 32, the overview of the season gives a different impression than the annual summaries. However, one cannot judge the performance of the rink with basis in this without first adjusting for climate impact.

**4.6 Rink C results**

The overall energy use decreases from the first to the second year, but then increases for two consecutive years. It is important to note that the operation of the rink was changed from the ice-hockey club to a professional facility services provider in this period. The full effect of this can be viewed in the chapter 4.9 about the Energy Performance Indicator.

Similar to the results from the Rink A analysis, the heating degree-days formula yields some strange results in Rink C as well. This further underlines the need for investigating this formula in relation to ice rinks.

**4.6.1 Annual energy use**

**2010**

The monthly energy use in combination with the mean temperature for Rink C is presented below. The data have been arranged in bar and combination charts to easier see trends and developments.

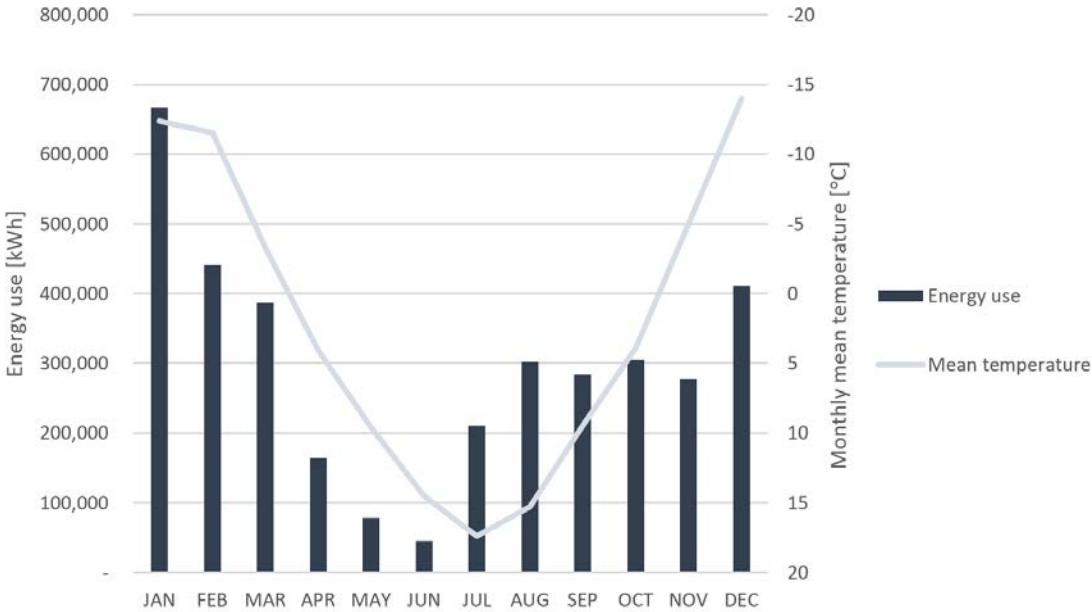


Figure 28: Actual energy use with mean temperature, Rink C - 2010.



The illustration above shows that a significant part of the annual energy use occurred in the first winter-months of the year. Furthermore, the energy use decreases towards the summer months as the facilities are not in regularly use during this period. One can see that June has the lowest use of the year at 45,377 kWh. As described in chapter 4.5, Rink C tends to lay the ice earlier than other rinks in the country. This can explain the sudden increase in July and the gradually increasing figures towards the end of the year.

When viewing the energy use in coherence with the mean temperature, one can see that there is a valid basis for claiming a certain degree of correlation between the two. However, grounds for claiming that the temperature has a major effect cannot be found from this single example.

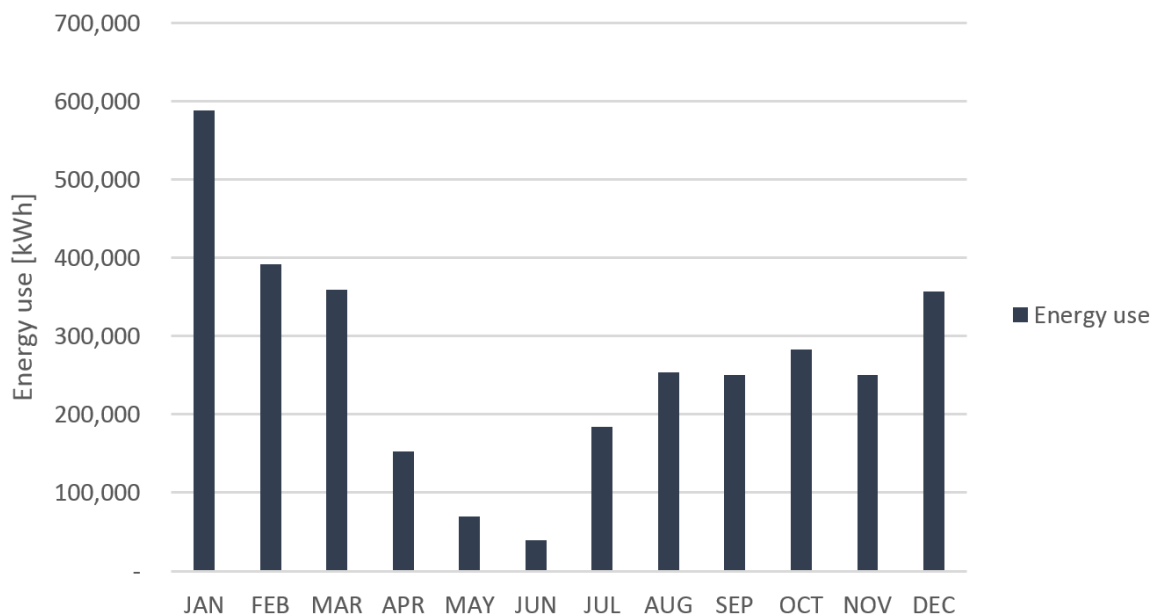
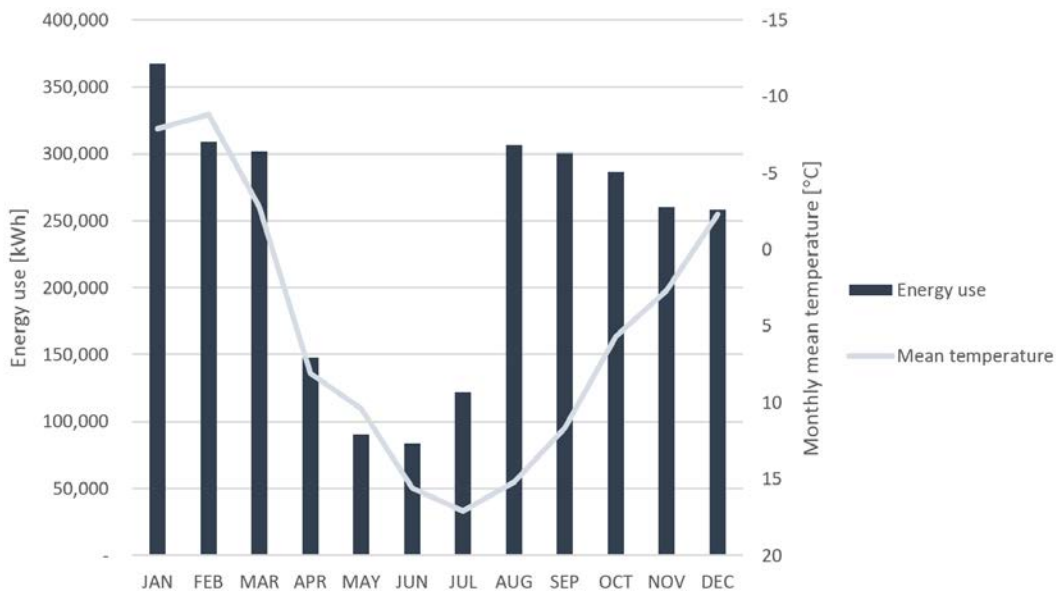


Figure 29: FMEU, Rink C - 2010.

The adjusted total energy use for 2010 is 390,887 kWh lower than the actual energy use. This means that the climate of the rink's location in Hedmark was warmer in 2010 than the heating degree-days normal period for Oslo. In theory, the level of energy use after the climatic adjustment should be fairly equal in the months of the ice-hockey season. As mentioned earlier, there are basically three variables that affect the energy use after this adjustment: activity level, management and technical equipment/systems.

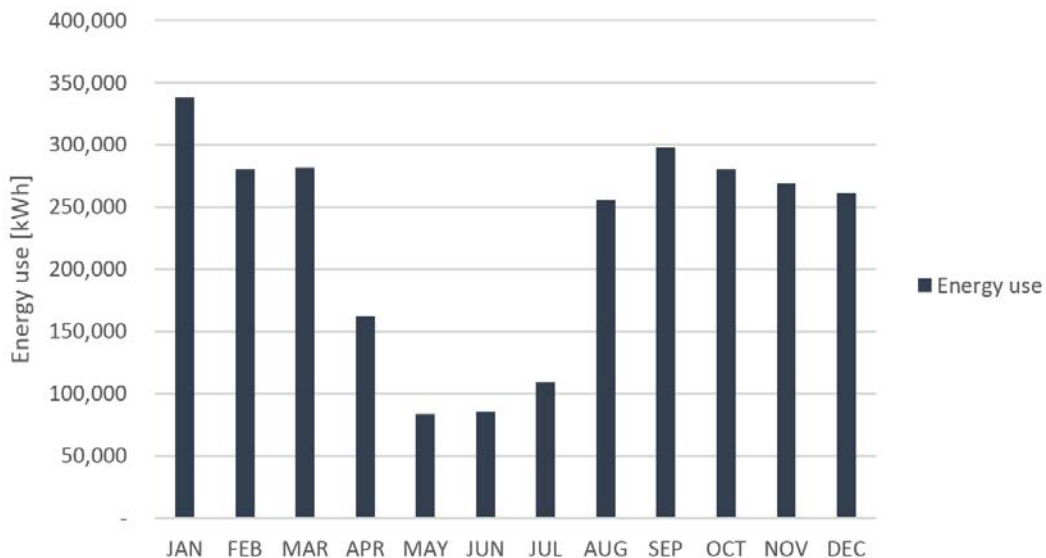
**2011**

2011 has no extreme peaks in the energy use during the year. The peak came in January with 366,983 kWh of use. Rest of the ice-season months are stable from 250,000 kWh to about 300,000 kWh. One can see a correlation between the energy use and the temperature that might indicate that the energy use goes down slightly when the temperature approaches ca. -2 °C.



**Figure 30: Actual energy use with mean temperature, Rink C - 2011.**

This year one can see a dramatic reduction of the energy use in the first winter months January through March compared to 2010, when viewing the adjusted use below. The year overall shows the equal trend as in 2010, where the season ends in mid-April and low use during summer. The production of “summer-ice” can be seen as a slight increase in energy use in July.

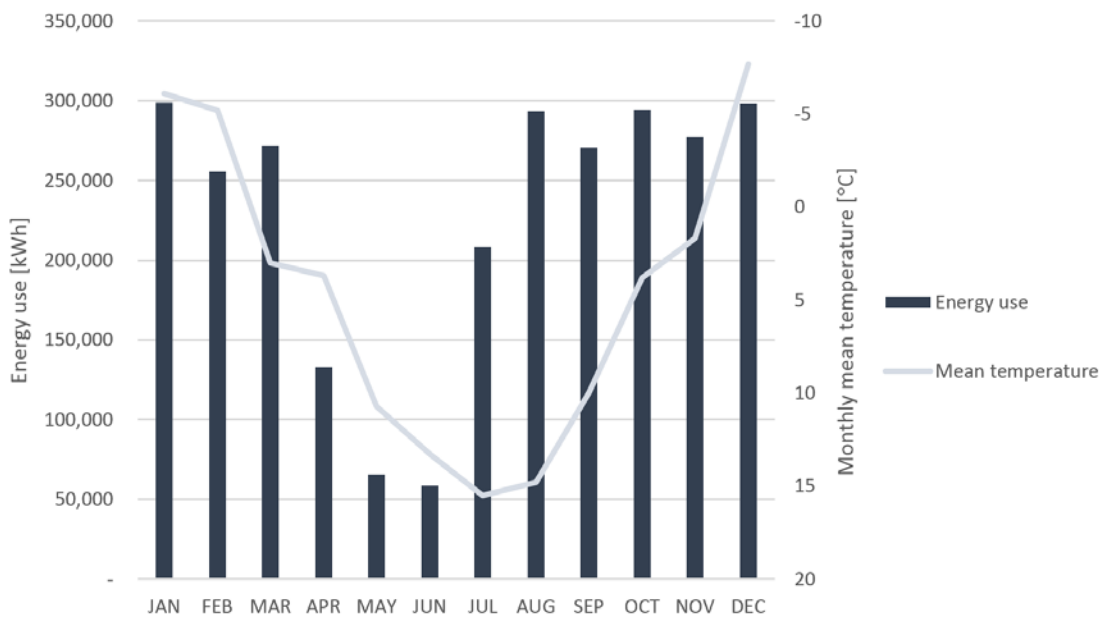


**Figure 31: FMEU, Rink C - 2011.**

After the end of the 09/10 ice-hockey season, the responsibility for maintenance and operations was handed over from the local ice-hockey club to the municipal facility services provider. This meant that the municipality was now responsible for the maintenance and daily supervision, and could implement their already well-functioning monitoring systems to easier make visible changes in the energy use. The higher attention to energy use may be the cause for the decrease in use in the first quarter of 2011 compared to 2010.

**2012**

2012 sees an energy use trend similar to the one from the past year. The energy use varies between 250,000 kWh and 300,000 kWh in the ice-season. The season ended in April and the next started in August, with the “summer ice” program in July for ice-hockey schools and start of practices the last week of the month for the elite team.



**Figure 32: Actual energy use with mean temperature, Rink C - 2012.**

The adjusted energy use was 199,311 kWh lower in 2012 than in 2011. Moreover, as one can see from Figure 33, there are no months with major deviations from the assumed energy use.

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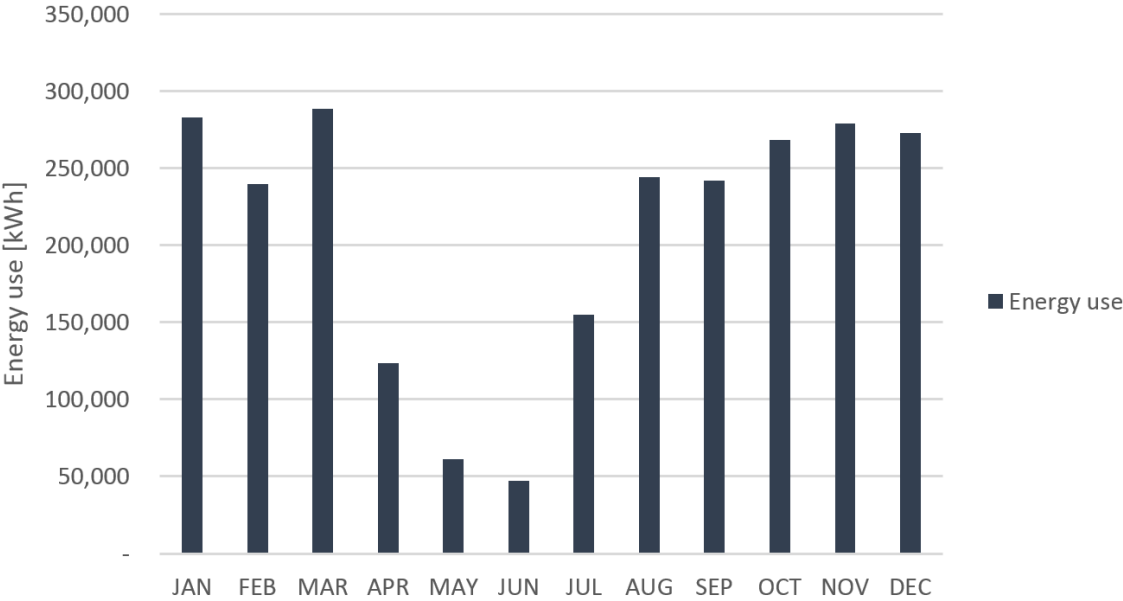


Figure 33: FMEU, Rink C - 2012.

The increase in July this year was caused by the earlier start to the cooling systems for laying ice earlier that season.

2013

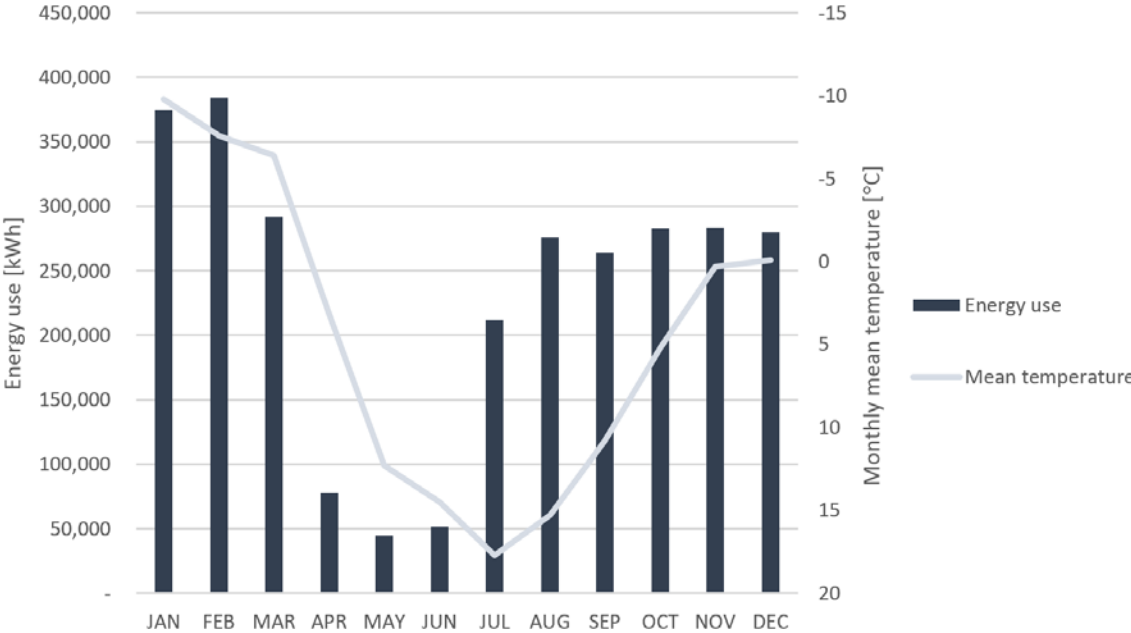


Figure 34: Actual energy use with mean temperature, Rink C - 2013.

From last year, one can see an increase in the adjusted energy use as well as in the actual energy use in the two first months of 2013. The sudden increase from December to January can be

explained by a major public event that took place in Rink C in January this year. This does not however explain the further increase in February.

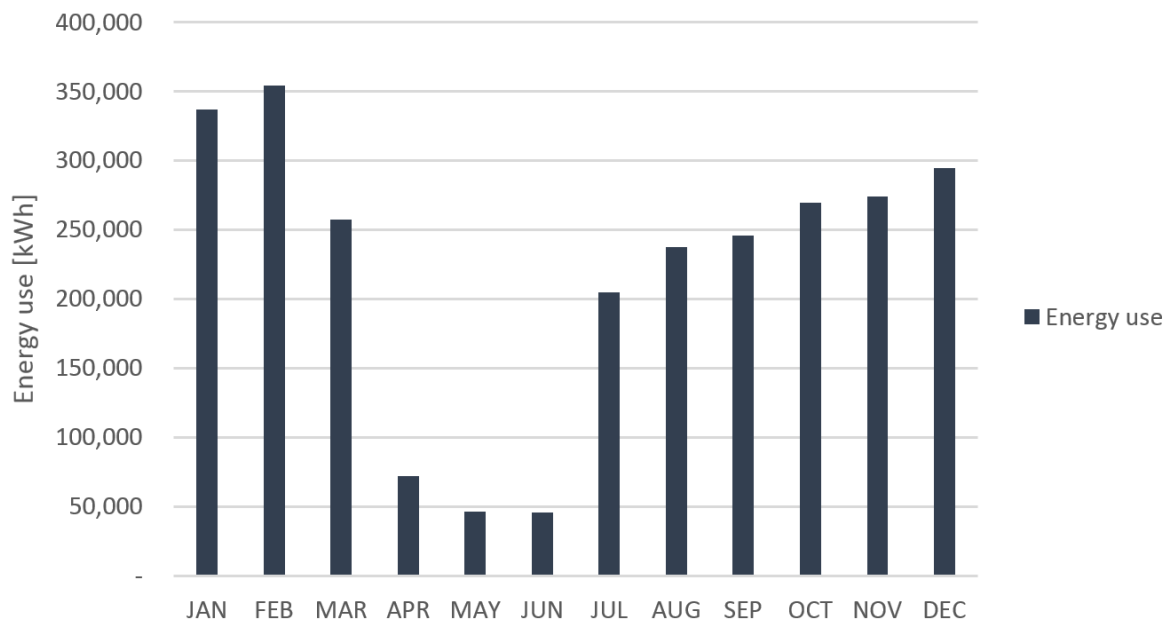


Figure 35: FMEU, Rink C - 2013.

As the previous years, the ice was prepared and laid in July. There is a steady increase in the FMEU from the season's start and towards the year's end. This is likely due to increased activity like training and matches during the autumn.

## 2014

2014 was a considerably warmer year than the past years, which can be seen in the figure below. Interestingly this displays a believed weakness with the use of Enova's heating degree-days adjustment method in ice rinks.

When viewing the actual annual energy use with the mean temperature, one can see that July is similar to the energy use in the following months. When viewing the adjusted graph however, the energy use is 149,173 kWh higher than the actual energy use.

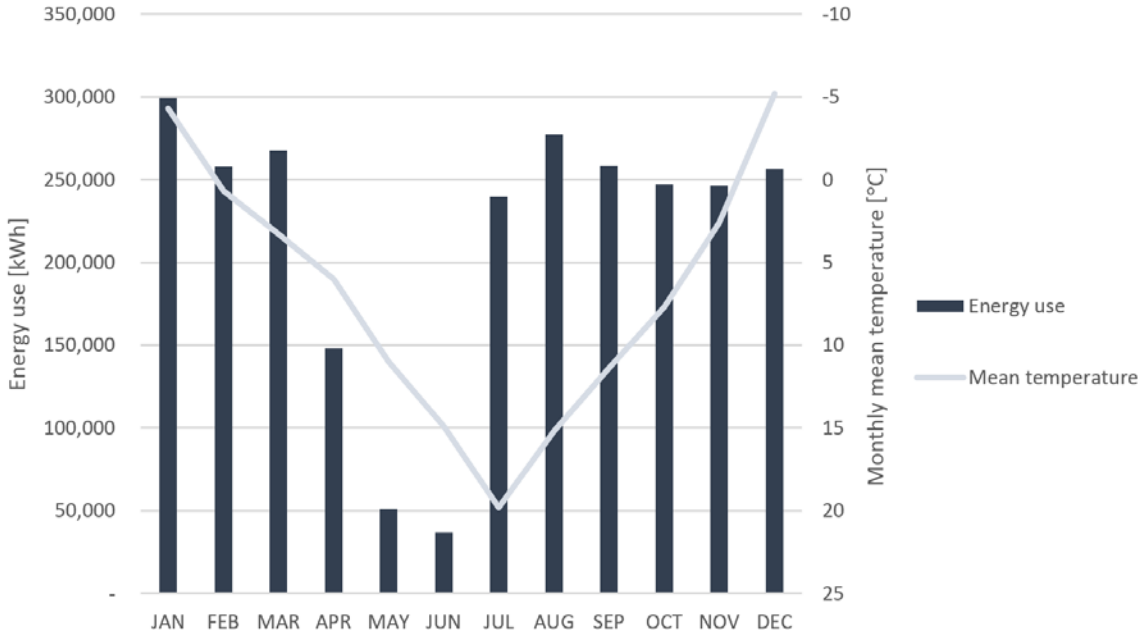


Figure 36: Actual energy use with mean temperature, Rink C - 2014.

The reason for this high deviation between the actual and adjusted FMEU lies in the formula for adjusting the energy use to make the figures comparable to each other. Enova operates from a basis that the ideal temperature where there is no need for additional heating is 17 °C and that the portion of climate dependent energy use is 60 % (in this thesis 40 % is used in the calculations). As seen above, the temperature decreases steadily from the maximum in July, at 19.8 °C.

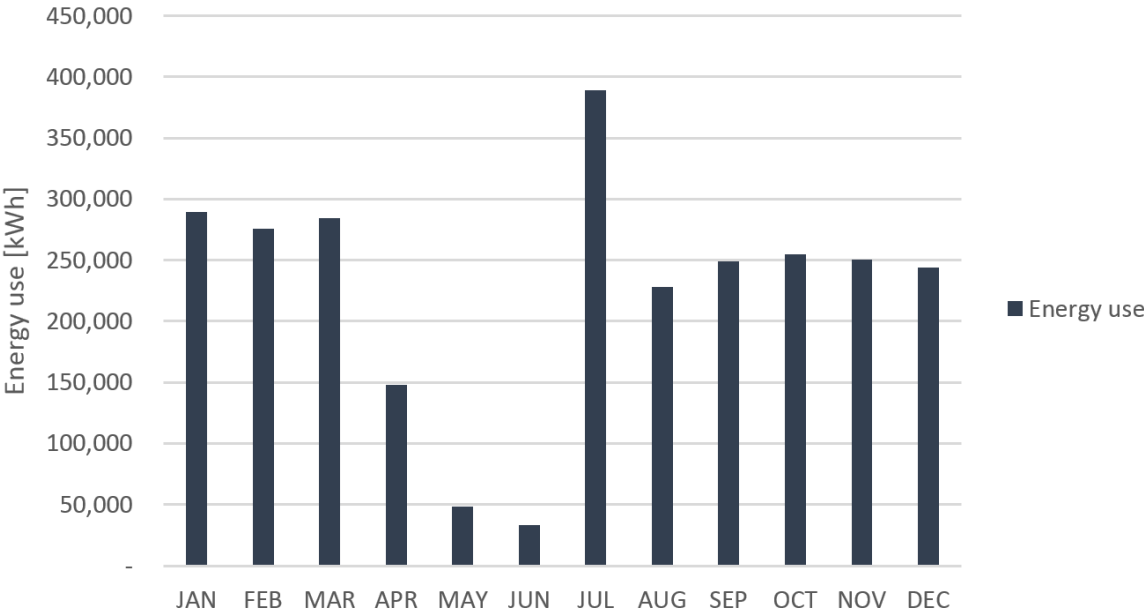


Figure 37: FMEU, Rink C - 2014.

In July, the rink's location had a total of 9 heating degree-days, whereas the normal period value for July is 23. This yields an adjustment factor of 1.62 with a climate dependent energy use percentage of 40. It is difficult to suggest what the ideal temperature for this calculation would be for an ice rink, but probably lower than 17 °C as the normal temperature inside a typical ice rink is around 10-15 °C (Stobiecka et al., 2013).

What then can be argued from this observation, is that the percentage of climate dependent energy use is lower than the 60 % used by Enova and probably the 40 % used in this thesis (Enova, 2014). Seeing as one consumes far less energy in relation to heating when the set temperature for when heating is needed in an ice rink is perhaps as much as 5-7 °C less than the current definition, who is most suited for residential housing, with an optimal temperature of 18-20 °C.

#### 4.6.2 Seasonal energy use

In Figure 38 a compilation of all the seasons is presented. The energy use is rearranged to visualise the start and end of the season when the rink is in use continually rather than the calendar year.

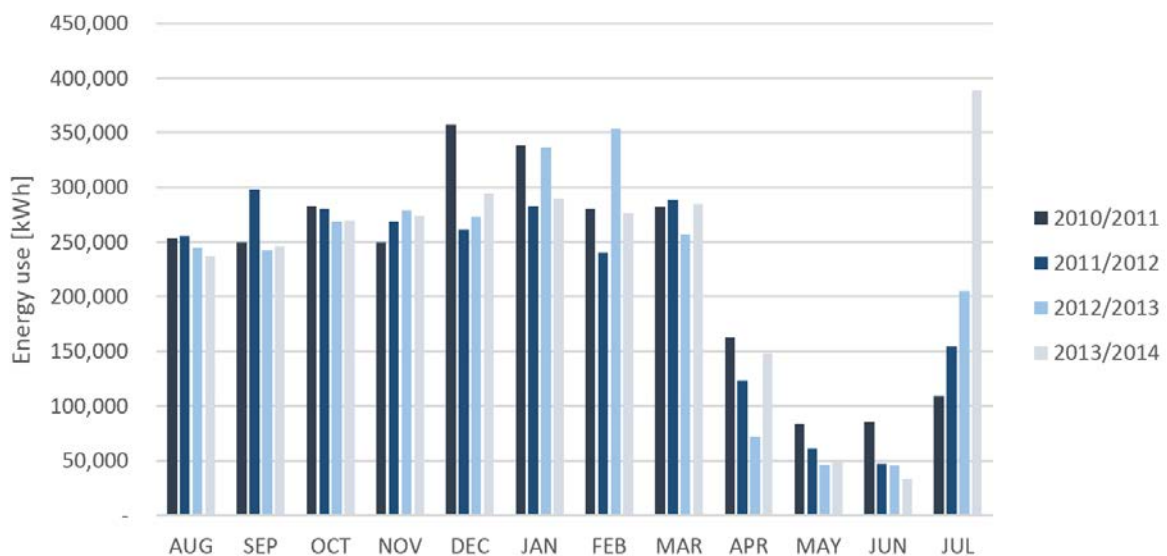


Figure 38: Seasonal energy use (FMEU), Rink C.

This illustration clearly shows the normal level of energy use in the rink. Note that the bar graphs presented in this chapter is the adjusted FMEU, so the deviations are clear to see. As stated earlier, the reasons behind this could be that the formula for calculating the adjusted

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energy use is biased towards residential housing, or possibly that one or more of the internal factors are affecting the energy use.

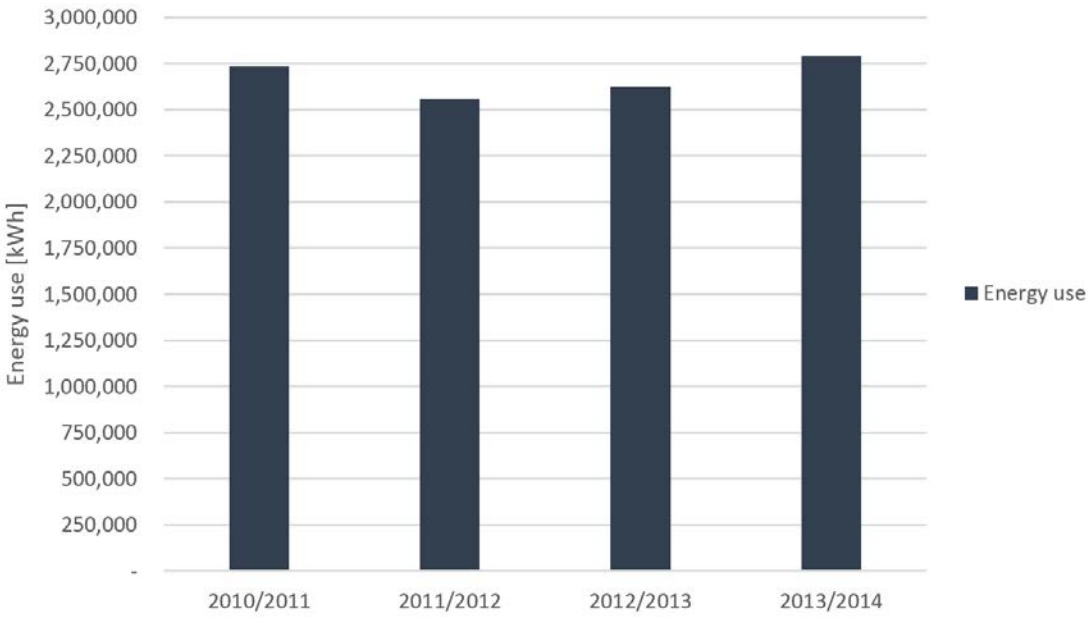


Figure 39: Seasonal energy use, Rink C (total).



## 4.7 Rink D (Arena-sized rink)

### 4.7.1 General information


|                              |                            |  |
|------------------------------|----------------------------|--|
| Name:                        | Rink D                     |  |
| Location:                    | Rogaland, Norway           |  |
| Owner:                       | Private investment company |  |
| Operator:                    | Private investment company |  |
| Year of build:               | 2012                       |  |
| Ice-surface:                 | 1,586 m <sup>2</sup>       |  |
| Capacity (total spectators): | 4,250                      |  |

Figure 40: General information Rink D.

Rink D is an example of an arena-sized rink. The rink is located in Rogaland, Norway and is one of the most modern ice arena in Norway, opened in October 2012. The arena is the home of one of the elite ice-hockey teams in Norway.

The arena can hold up to 4,250 spectators on a game day. This includes 4,100 sold seats and 150 volunteers/personnel. Of the 4,100 sold seats, 3,850 are seated and the rest is standing places. Prior to the arena being built, hockey teams from the area played in an ice rink across the road from where the Rink D is today. Recently another new ice rink has been opened adjacent to the old one, with two ice pads and four curling rinks (Operations Manager, 2015b). Together with Rink D they make up the ice facilities offered for the local population and sports teams.

#### *Climate*

The climate in Rogaland is typical Atlantic climate with large amounts of rain through the year. The coastal areas are exposed to the elements and the storms from the North Sea during autumn and January. The winter is mild with temperatures rarely below -4 °C. Summer temperature is above the national average, but only occasionally exceed 24 °C.

#### **4.7.2 Design and building specific information**

The architects designed the arena in collaboration with Swedish experts on ice rinks. The arena's total area is 16,400 m<sup>2</sup>, which took about one and a half years to construct. The arena has a modern look with the walls being concrete and sandwich-elements, with part glass facades.

When designing the arena, the architects cooperated closely with the users of the building to ensure that the building was suited to their needs, as the building is not only home to the elite ice-hockey team, but also the private company who own the arena (Operations Manager, 2015b).

Inside the arena, the ice surface is designed after National Hockey League (NHL) standards, which is 61\*26 meters. This is uncommon in the Nordic countries, who usually have one meter shorter and four meters wider ice pads. The crowd capacity of 4,250 spectators is all seats in addition to 36 VIP-lounges. Each of the lounges have reserved seats in the arena as well. Facilities for the spectators also include a meeting area, three pubs, six kiosks and a restaurant for up to 200 guests (Operations Manager, 2015b).

#### ***Construction***

The main substructure consists of concrete elements, and the roof is partially flat and partially arched. In the arched part of the roof there are sinus-shaped steel sheets thatched with foil. 60-meter long steel truss girders support the roof, while hollow core slabs support the flat part of the roof. Facades consist of concrete elements and sandwich elements. The eastern end wall is made of glass.

The walls and ceiling only have 150 mm and 180 mm insulation to keep the temperature inside the rink optimal. This is mainly because of the climatic conditions in Rogaland.

The building was constructed in two main parts. When part two was under construction, part one was closed, which helped reduce moisture in the construction. The building has largely maintenance-free facades, and is constructed with universal design according to TEK10.

### *Technical equipment*

The ventilation plants in the arena supply air to the rink/public areas i.e. locker rooms and adjacent areas such as entrance, hallways and offices. The air is both supplied and ventilated from vents underneath the ceiling. The main vents are concentrated above the tribune-area to prevent hot air from affecting the climate on the ice. Because of the arena's multi-use capacity, an additional ventilation plant is installed and used in the off-season, for use during exhibitions and concerts. This delivers ventilated air to the rink-area from vents underneath the ceiling. The ventilation plants are mostly run on recirculated air to reduce the energy use as heating the outside air consumes more energy than using return air. During matches with, or close to, a capacity crowd the temperature in the rink can go as high as 20 °C, but they are able to maintain freezing temperature on the playing field because the ventilation system does not blow hot air down onto the playing field. Because the air movement over the ice is kept to a minimum, dehumidifiers are used in addition to air recycling (Operations Manager, 2015b). Wanted temperature in the arena (spectator area) is 17 °C, measured in level three (where level one is on the ice, and level two is mid-section tribune).

Other rooms, such as lounges, meeting rooms, and locker rooms are, in addition to the automated HVAC systems, heated with an automated radiator system or separate fan coils delivering heat or air when the temperature in the room falls below the wanted temperature. These rooms normally have a set value of 20 °C.

The restaurant in the south end of the arena overlooks the ice rink, and offer a bar and tables for guests. This area causes challenges because of the two climatic zones, where the restaurant guests want hot air, and the players on the ice want cooler air. Heating the area with radiators close to each table solves this. In addition, heating panels in the roof radiates heat concentrated on the guests around the table.

The arena receives its cooling from a district central. This plant delivers a solution of brine used for cooling of the ice for the playing field. The brine is delivered to the arena with a temperature of -12.4 °C. Return temperature is -10.6 °C. The system keeps the ice frozen and between -5 °C to -6 °C. Ice thickness is kept on 3.5 cm, but because of wear and tear the ice tends to be thinner around the goal-area. Excess heat from the cooling system is not made use of.

Because of the humid climate in Rogaland, dehumidification systems are installed to keep the humidity stable. The humidity in the arena is measured to 35 % in mid-section tribune-level and 47 % on rink-level. The humidity is kept around 50 % to prevent fog.

The lighting in the entire arena is made up of light-emitting diode lamps (LED-lamps). This type of lighting consumes less energy and transmits less heat than traditional light sources like incandescent, halogen or fluorescent lamps. The lifespan of these lamps is considerably longer than the average bulbs as the LED-lamps can run for 50,000 hours, some types even longer (Edison Tech Center, 2015). The lighting in the rink is normally turned off when there are no activities on the ice. It can also be dimmed to accommodate the level of activity. In addition to the LED-lamps, metal-halide lamps are used during matches to satisfy the need for bright lighting.

### **4.7.3 Operation, use and management**

Being a modern arena, technical systems like heating, ventilation and lighting is pre-programmed by the management staff. In the day-to-day operation, this means that the events taking place in the rink is programmed in a calendar. The events then gets a designated scenario depending on the type of activity.

The hockey season in the arena last from July to mid April, as the elite team begins practice on ice late July. The arena is used by teams with players from 14 years of age, and up to 20 years of age. In addition, schools with top-level athletics teams makes use of the ice. Sponsors of the hockey teams also have the opportunity to practice on ice two days a week.

Average opening hours is 10 to 11 hours every day, and between 3 and 5 hours in the weekends. The municipality require that the arena is also available for use to recreational sports activities and other activities at least 1,400 hours per season.

The restaurant in the arena is normally open to the public, but only when the top division team are on site. On regular weekdays, there are not enough visitors to keep the restaurant open.

The only month during summer with no ice is June. In this period, other indoor activities are practiced in the arena.

Average attendance is 4,250 per game. Actual ticket sales are just below this, as the amount of volunteers, players are also counted. During handball games, there is extra seating for audience as the sideboards are removed, and the capacity increases to around 5,500 spectators.

Three janitors that work different shifts maintain the arena.

#### 4.7.4 Collected data

Rink D makes use of an advanced SCADA-system for monitoring and controlling the arena's energy use. The system both registers the consumed energy for the different systems in the building in addition to function as a tool to control temperature, airflow rate and more.

There have been some technical issues in regards to measuring the individual energy use for the different systems. This is why this thesis only presents the total energy use for each month.

The numbers presented in this chapter include general electricity, cooling, water heating, and district heating. Cooling and water heating usage numbers were only available as a grand total over a period of several months. To be able to incorporate these numbers in the illustrations that follow, the total energy use figures from cooling and water heating have been distributed across all twelve months of the year, and therefore represent an average. This does not give a 100 % accurate account of each individual month, but in total, it shows the correct situation of the energy use in Rink D.

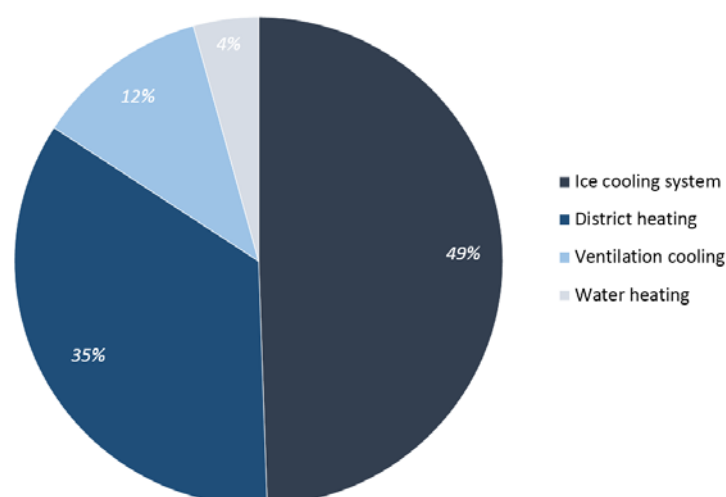


Figure 41: Distribution of specific energy carriers (excluding general electricity), Rink D.

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The diagram presented above represent the different energy carriers' specific energy use percentage of the total. It is important to be aware of the deficiency of general electricity in this diagram.

Since the arena is quite new (2012), energy figures are not available as far back as the other examples in this thesis. In the following chapters, all relevant data that was available to obtain in April 2015 is presented.

### *Monthly energy use*

Monthly energy use figures have been obtained dating back to 2013. All figures are given in kWh, unless otherwise specified.

### **2013**

2013 is the first full year of operation for the arena, and is therefore the point of departure for the data analysis. One can see that the energy use numbers are following the expected trend for a winter-facility, where the energy use is at its highest in the winter-months and decreases towards the summer.

**Table 33: Energy use Rink D - 2013.**

| <b>Monthly energy use (kWh) - Rink D - 2013</b> |         |         |         |        |        |        |         |         |         |         |         |
|---|---------|---------|---------|--------|--------|--------|---------|---------|---------|---------|---------|
| Jan.  | Feb.    | Mar.    | Apr.    | May    | Jun.   | Jul.   | Aug.    | Sep.    | Oct.    | Nov.    | Dec.    |
| 136,243   | 139,029 | 137,246 | 137,715 | 83,834 | 75,716 | 86,878 | 140,972 | 169,823 | 174,003 | 156,344 | 155,515 |

### **2014**

The total energy use this year was 1,918,896 kWh. The energy use through the year is stable, but higher towards the end of the year.

**Table 34: Energy use Rink D - 2014.**

| <b>Monthly energy use (kWh) - Rink D - 2014</b> |         |         |         |         |         |         |         |         |         |         |         |
|---|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| Jan.  | Feb.    | Mar.    | Apr.    | May     | Jun.    | Jul.    | Aug.    | Sep.    | Oct.    | Nov.    | Dec.    |
| 165,426   | 142,636 | 172,872 | 150,068 | 103,870 | 121,342 | 126,695 | 192,661 | 206,179 | 203,291 | 179,957 | 153,893 |

**2015**

The only available data from 2015 is presented in the table below. Even though this is only two months, it can help visualise a trend.

Table 35: Energy use Rink D - 2015.

| <b>Monthly energy use (kWh) – Rink D – 2015</b> |         |      |      |     |      |      |      |      |      |      |      |
|---|---------|------|------|-----|------|------|------|------|------|------|------|
| Jan.  | Feb.    | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
| 147,445   | 122,174 | -    | -    | -   | -    | -    | -    | -    | -    | -    | -    |

**Summed energy use**

The summed annual energy use is compiled in one table. The energy use has increased from the first full year of operation to the second.

Table 36: Annual energy use Rink D (total).

| <b>Summed annual energy use (kWh) – Rink D – 2010-2015</b> |      |           |           |         |
|--|------|-----------|-----------|---------|
| 2011   | 2012 | 2013      | 2014      | 2015    |
| -  | -    | 1,593,324 | 1,918,896 | 269,619 |

**Seasonal energy use****2012/2013 Season**

The 2012/2013 season does not represent a full season of energy use data, as the acquired data only goes back to 2013. Nevertheless, it is included in this overview for illustration purposes.

Table 37: Seasonal energy use Rink D - 2012/2013.

| <b>Seasonal energy use (kWh) – Rink D – 12/13</b> |      |      |      |      |         |         |         |         |        |        |        |
|---|------|------|------|------|---------|---------|---------|---------|--------|--------|--------|
| Aug.  | Sep. | Oct. | Nov. | Dec. | Jan.    | Feb.    | Mar.    | Apr.    | May    | Jun.   | Jul.   |
| -   | -    | -    | -    | -    | 147,333 | 147,522 | 136,494 | 134,196 | 79,621 | 61,039 | 65,448 |

**2013/2014 Season**

The only complete season from Rink D is the 2013/2014 ice-hockey season. As illustrated below, one can see an increase in the energy use at the turn of the year.

Table 38: Seasonal energy use Rink D - 2013/2014.

| <b>Seasonal energy use (kWh) – Rink D – 13/14</b> |         |         |         |         |         |         |         |         |         |         |         |
|---|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| Aug.  | Sep.    | Oct.    | Nov.    | Dec.    | Jan.    | Feb.    | Mar.    | Apr.    | May     | Jun.    | Jul.    |
| 140,972   | 169,823 | 174,003 | 156,344 | 155,515 | 165,426 | 142,636 | 172,872 | 150,068 | 103,870 | 121,342 | 126,695 |

The total energy use this season was 1,779,572 kWh.

**2014/2015 Season**

The 2014/2015 season does not represent a full season of energy use data, and thus the basis for comparing the seasons is absent.

**Table 39: Seasonal energy use Rink D - 2014/2015.**

| <b>Seasonal energy use (kWh) - Rink D - 14/15</b> |         |         |         |         |         |         |      |      |     |      |      |
|---|---------|---------|---------|---------|---------|---------|------|------|-----|------|------|
| Aug.  | Sep.    | Oct.    | Nov.    | Dec.    | Jan.    | Feb.    | Mar. | Apr. | May | Jun. | Jul. |
| 192,661   | 206,179 | 203,291 | 179,957 | 153,893 | 147,445 | 122,174 | -    | -    | -   | -    | -    |

**Summed energy use**

In the case of Rink D, none of the illustrated seasons is comparable, as it is only the 2013/2014 season that contains a full year of data. To be able to use the same format for illustrations in all case-object presentations, it is chosen to illustrate the summed seasonal energy use as seen below.

**Table 40: Seasonal energy use Rink D (total).**

| <b>Summed seasonal energy use (kWh) - Rink D - 2010-2015</b> |           |           |           |           |
|--|-----------|-----------|-----------|-----------|
| 2010/2011  | 2011/2012 | 2012/2013 | 2013/2014 | 2014/2015 |
| -  | -         | 771,655   | 1,779,572 | 1,205,600 |

**4.8 Rink D results**

The conclusion that can be drawn from the following analysis is that this rink needs to evaluate further in a few years time to achieve a broader base of data. It is also vital that the problems with the detailed metering, addressed in chapter 4.7.4, is resolved.

**4.8.1 Annual energy use**

**2013**

The monthly energy use in combination with the mean temperature for the rink’s location is presented below. The data have been arranged in bar and combination charts to easier see trends and developments.



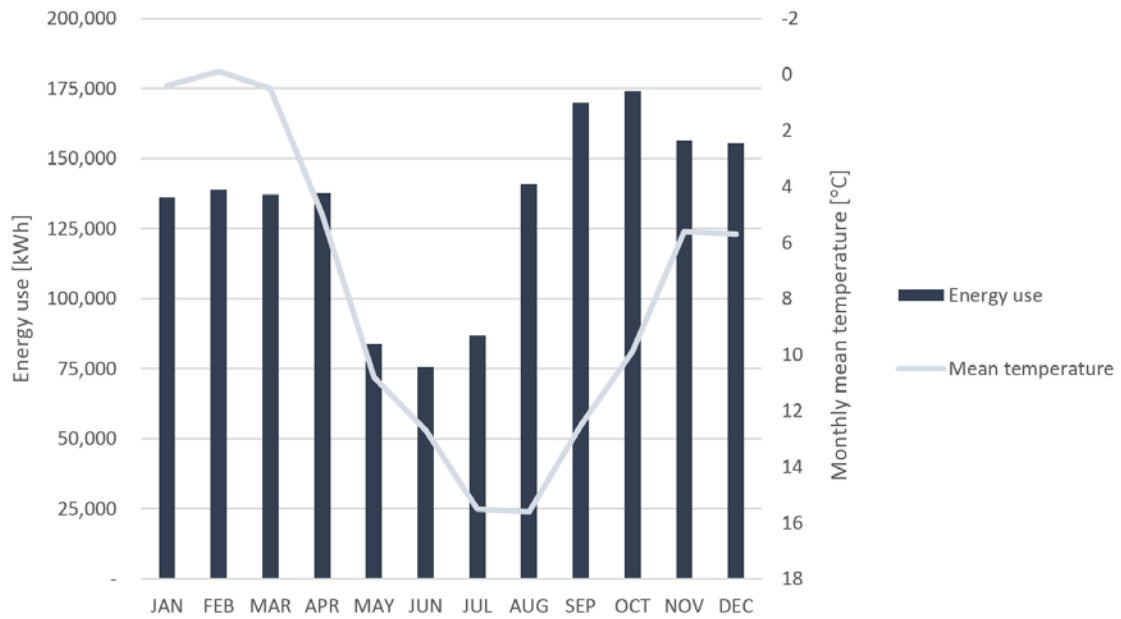


Figure 42: Actual energy use with mean temperature, Rink D - 2013.

The figure above shows a very stable energy use in the first months of the year, with almost even numbers from January through April. The summer months represent the lowest consuming months, but from August, there is a significant increase, which increases further into September and October. The mean temperature graph shows that 2013 was a very warm year, with mean temperatures above zero throughout the year.

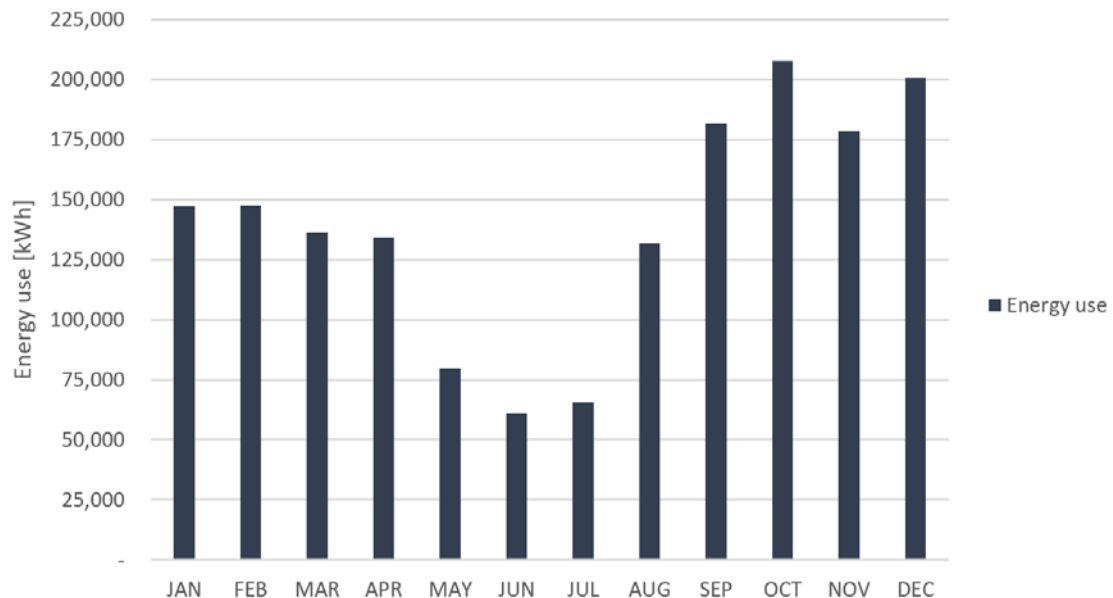
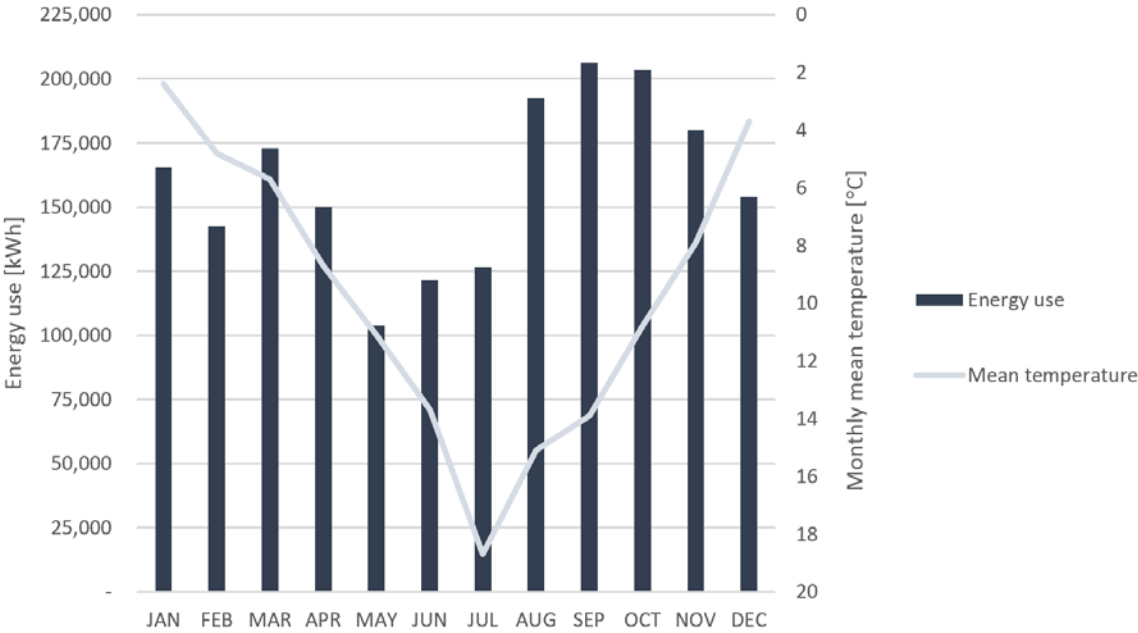


Figure 43: FMEU, Rink D - 2013.

The FMEU for 2013 is shown in the figure above. One can see that the adjusted energy use fluctuates in great extent, which means that after adjusting for the climate as a factor, other relevant parameters must be considered to have great affection on the energy use.

**2014**

2014 shows energy use with a similar trend as the previous year, although the actual use is slightly higher in almost every month of the year. The mean temperature this year was much like the previous year, a warm period with temperatures above zero throughout the year.



**Figure 44: Actual energy use with mean temperature, Rink D - 2014.**

The actual annual energy use figure above shows that the month with the lowest energy use was May, with just over 100,000 kWh. This is an increase from 2013, where the lowest consuming month was June with nearly 80,000 kWh. As the temperature in the two months is relatively similar in both years, the reason for this must be found in either alterations in use, technical equipment or operations and management.

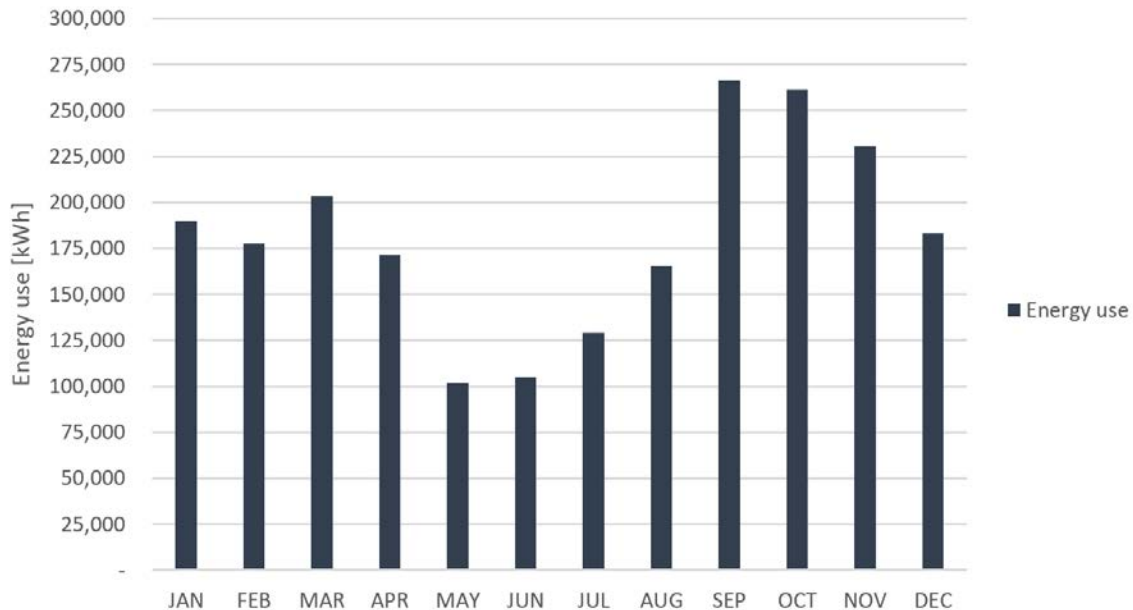


Figure 45: FMEU, Rink D - 2014.

Total adjusted energy use in 2014 is 2,185,032 kWh (FAEU). To put this in perspective, the amount of energy used by Rink D this year is enough to cover the total energy use of 108 typical Norwegian households for an entire year (Statistisk sentralbyrå, 2014).

Rink D tends to keep the ice longer towards the summer than other ice rinks presented in this thesis, which may be the reason for the increase in energy use in 2014, in the summer months from 2013. It is also worth considering that the arena is new, and only has two full years of operation as a reference, which is 2013 and 2014 presented in this chapter. It may take some time to regulate, adjust and calibrate the different technical system, to both work together towards the same goal, and to optimise the effect in relation to the wanted climatic conditions in the arena.

#### 4.8.2 Seasonal energy use

Below, the overview of the 2013/2014 season presented. This is the only season that can be viewed as a whole, as the 2012/2013 season does not provide complete data. One can see from the illustration below that the energy use through the season is relatively even during the months of the season from September to April.

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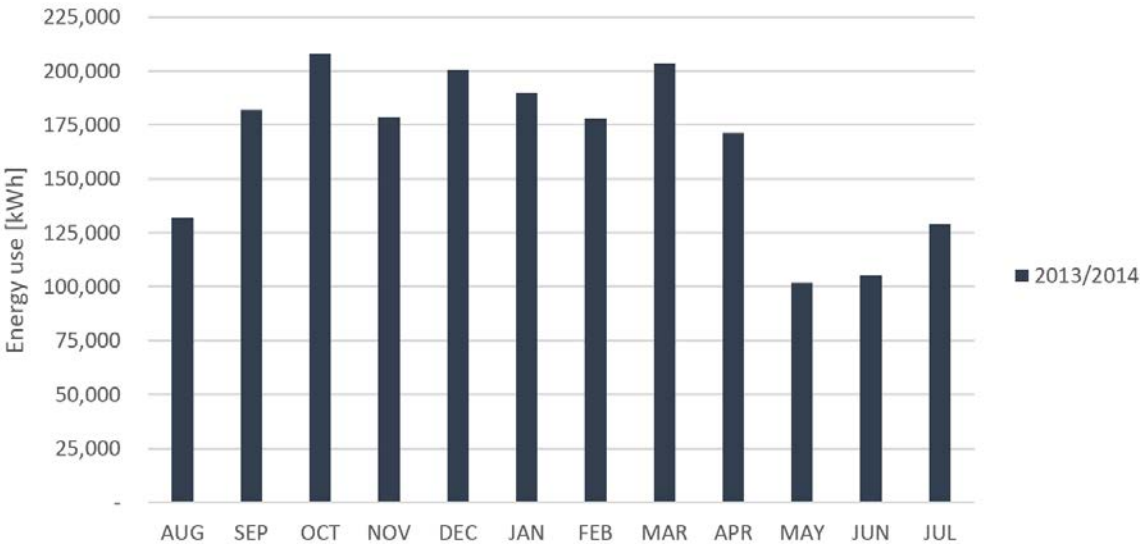


Figure 46: Seasonal energy use (FMEU), Rink D - 2013/2014.

The lowest consuming month during this season was May, closely followed by June with just above 100,000 kWh. As described in chapter 4.7.3 operation, use and management, in Rink D, the top division ice-hockey team begins their practice on ice in July. The only month during the year/season with no ice in the arena is June. Although May was the lowest consuming month of the season, it is to expect that there were indoor activities in the arena during June, which demands e.g. ventilation cooling. As presented earlier, ventilation cooling, district heating and water heating represents around 51 % of total energy use in the rink (chapter 4.7.4), and major parts of this are used during the summer.

## 4.9 Energy performance indicator for comparison of ice rinks

As stated earlier in this thesis, comparison of different ice rinks is difficult to achieve with good results for a number of reasons. The rinks vary in size, technical installations, ice pad size, heated area, opening hours and season length.

This chapter calculates performance value based on a unified factor that make ice rinks comparable within their size category. The justification for the choice of parameters is discussed in chapter 5.1.

### 4.9.1 Calculation of the indicator

The formula for calculating the energy performance indicator (EPI) is presented below. The *Adjusted energy use<sub>year</sub>* is the total adjusted energy use (kWh) the chosen year (FAEU), or an average value for a multiple years. *Prod. area* or productive area is the purpose area of the facility, which for an ice rink is the size of the ice pad (m<sup>2</sup>). The *Annual hours open<sub>year</sub>* is the total number of hours the ice rink is open and available for use.

$$\text{Energy performance indicator}_{\text{year}} = \frac{\text{Adjusted energy use}_{\text{year}}}{\text{Prod. area} * \text{Annual hours open}_{\text{year}}}$$

The unit for this indicator is  $\frac{kWh}{m^2 * h}$ .

One has the possibility to calculate the performance through this key figure for a single year or a period of several years by using the average energy use. In the following parts of this chapter, both the annual factors and a rink-average figure are calculated. The key figure from the average energy use is better suited for comparison of several rinks as it gives a more accurate picture of the use by spreading deviations over a longer period.

**Rink A**

Rink A has one Nordic-sized ice pad at 1,800 m<sup>2</sup>. The rink is open 78 hours a week and 31.3 weeks a year on average.

In 2012, the rink was open for 33 weeks, a total of 2,574 hours. The FAEU was 2,066,067.14 kWh. The calculated EPI this year was 0.4459 kWh/m<sup>2</sup>,h.

In 2013, the rink was open for 30 weeks with an energy use of 1,807,392.32 kWh, which yielded an EPI of 0.4291 kWh/m<sup>2</sup>,h.

The energy use in 2014 increased to 2,267,867.46 kWh. The rink was open for 31 weeks, which resulted in an EPI of 0.5211 kWh/m<sup>2</sup>,h.

On average, the rink is open 31.3 weeks a year and has an energy use of 2,047,108.97 kWh. This results in an average EPI of 0.4653 kWh/m<sup>2</sup>,h.

Table 41: EPI, Rink A.

| Rink A                             |            |            |
|------------------------------------|------------|------------|
| Size of rink: 1,800 m <sup>2</sup> |            |            |
| Average opening hours: 78 pr. week |            |            |
| Year                               | Weeks open | Energy use |
| 2010                               | -          | -          |
| 2011                               | -          | -          |
| 2012                               | 33         | 2,066,067  |
| 2013                               | 30         | 1,807,392  |
| 2014                               | 31         | 2,267,867  |
| Average:                           | 31,3       | 2,047,108  |

**Rink B**

Rink B have two ice pads with a total area of 3,600 m<sup>2</sup>. The rink is in use most of the week with an average of 85 hours. The ice-hockey team that is housed in Rink B have not been of the best the past few years and the season have not been prolonged because of playoffs. The number of weeks the rink is open on average (the past five years) is 28.8.

In 2010, the rink was open for 28 weeks with an FAEU of 2,364,588.99 kWh. This resulted in an EPI of 0.2760 kWh/m<sup>2</sup>,h.

Table 42: EPI, Rink B.

| Rink B                             |            |            |
|------------------------------------|------------|------------|
| Size of rink: 3,600 m <sup>2</sup> |            |            |
| Average opening hours: 85 pr. week |            |            |
| Year                               | Weeks open | Energy use |
| 2010                               | 28         | 2,364,588  |
| 2011                               | 30         | 2,266,230  |
| 2012                               | 26         | 2,092,905  |
| 2013                               | 31         | 3,116,797  |
| 2014                               | 29         | 3,556,337  |
| Average:                           | 28,8       | 2,679,371  |

2011 saw a reduced energy use to 2,266,230.25 kWh despite the rink being open for two additional weeks. The EPI this year is lower than in 2010 at 0.2469 kWh/m<sup>2</sup>,h.

In 2012, the opening weeks was shortened to 26, when the rink was closed in April and August. The energy use was reduced accordingly, to 2,092,905.01 kWh. The EPI was 0.2631 kWh/m<sup>2</sup>,h.

2013 saw an increase in the number of open weeks to 31, but also an increase in the energy use with over one million kilowatt hours to 3,116,797.80 kWh. The EPI naturally increased to a value of 0.3286 kWh/m<sup>2</sup>,h.

In 2014, the increase in energy use increased further to 3,556,337.17 kWh, while the number of open weeks decreased to 29. This yielded the EPI value 0.4008 kWh/m<sup>2</sup>,h.

On average, the past five years the rink has been open for 28.8 weeks with an adjusted energy use of 2,679,371.84 kWh. The average EPI the past years is 0.3040 kWh/m<sup>2</sup>,h.

### ***Rink C***

Rink C has a Nordic-sized ice pad at 1,800 m<sup>2</sup>. On average, the rink is available for use 70 hours a week.

The rink was open 34 weeks in 2010 and had a FAEU of 3,180,831.35 kWh. The EPI for this year is 0.7425 kWh/m<sup>2</sup>,h.

2011 saw the rink open for 33 weeks with the energy use at 2,703,466.77 kWh. The ratio was better than the past year equalling an EPI of 0.6502 kWh/m<sup>2</sup>,h.

The best performing year in terms of the EPI came in 2012 when the rink was open for 36 weeks. The EPI was 0.5521 kWh/m<sup>2</sup>,h, with the lowest adjusted energy use for the time period at 2,504,154.94 kWh.

In 2013, the rink was open 34 weeks and had a total energy use of 2,636,746.50 kWh. This resulted in the EPI at 0.6155 kWh/m<sup>2</sup>,h.

In 2014 the rink was open for 38 weeks, which improved the EPI to 0.5628 kWh/m<sup>2</sup>,h. the total energy use was 2,694,616.69 kWh.

**Table 43: EPI, Rink C.**

| Rink C                             |            |            |
|------------------------------------|------------|------------|
| Size of rink: 1,800 m <sup>2</sup> |            |            |
| Average opening hours: 70 pr. week |            |            |
| Year                               | Weeks open | Energy use |
| 2010                               | 34         | 3,180,831  |
| 2011                               | 33         | 2,703,154  |
| 2012                               | 36         | 2,504,154  |
| 2013                               | 34         | 2,636,746  |
| 2014                               | 38         | 2,694,616  |
| Average:                           | 35         | 2,743,963  |

From the average figures for these five years, one learns that the rink is open 35 weeks a year, which equals 2,450 hours. The average total energy use is 2,743,963.25 kWh and the EPI is 0.6222 kWh/m<sup>2</sup>,h. Compared to the other arena-sized rink in this thesis, one can see that this EPI is higher than the EPI of Rink D, but is mostly caused by the high energy use in 2010. If 2010 is not counted in the average the EPI drops to 0.5932 kWh/m<sup>2</sup>,h which is only marginally higher than the average EPI for Rink D.

**Rink D**

The rink’s ice pad is sized after the NHL standard with a total area of 1,586 m<sup>2</sup>, which is smaller than the Nordic-sized pads. The rink is available for use on average 62 hours every week. In both 2013 and 2014 the rink was open 34 weeks which equals a total figure of open hours of 2,108 hours. Note that this does not include hours when the rink was in use for e.g. handball matches and other non-ice activities.

Table 44: EPI, Rink D.

| Rink D                             |            |            |
|------------------------------------|------------|------------|
| Size of rink: 1,586 m <sup>2</sup> |            |            |
| Average opening hours: 62 pr. week |            |            |
| Year                               | Weeks open | Energy use |
| 2010                               | -          | -          |
| 2011                               | -          | -          |
| 2012                               | -          | -          |
| 2013                               | 34         | 1,672,276  |
| 2014                               | 34         | 2,185,032  |
| Average:                           | 34         | 1,928,654  |

In 2013, Rink D had a total adjusted energy use of 1,672,276.19 kWh, which yields an EPI of 0.5002 kWh/m<sup>2</sup>,h.

In 2014, the FAEU was 2,185,032.38 kWh, with an EPI of 0.6536 kWh/m<sup>2</sup>,h. The EPI for 2013 is lower than the EPI for 2014, which means that 2013 was the better year in regards to the energy input versus output. This is evident as the rink was open on average the exact amount of time with the energy use being lower in 2013.

The average adjusted energy use for the two years the rink has been open is 1,928,654.28 kWh. This yields an EPI of 0.5769 kWh/m<sup>2</sup>,h.



### 4.9.2 Annual EPI scatter chart

The annual EPI values are inserted in a scatter chart below, to see any relations between the rinks.

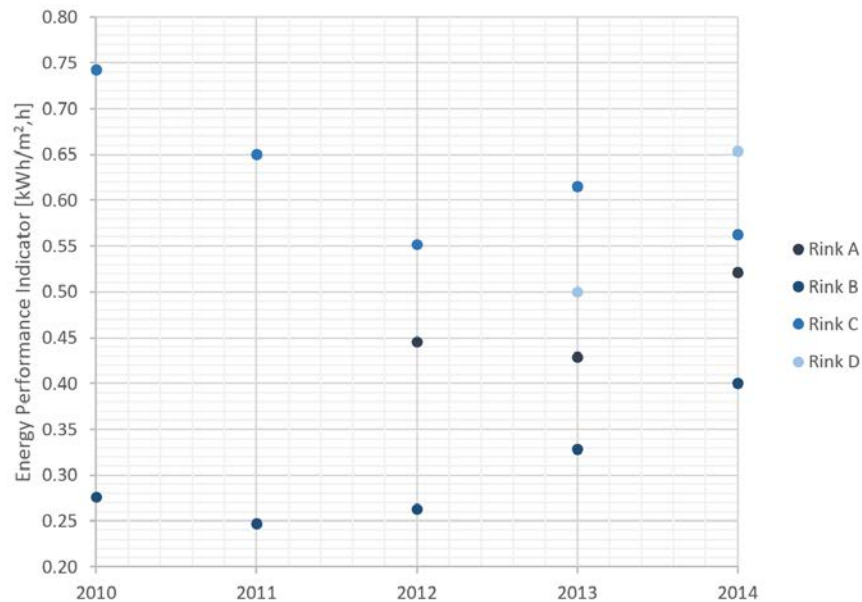


Figure 47: Annual EPI-value scatter chart.

From this graphical presentation the conclusions can easier be drawn:

- Rink A is represented with EPI values for two years only. From the chart, it is obvious that this is too few and the trend shown is misleading due to this.
- Rink C sees a positive trend and it is looking to be the most energy efficient arena-sized rink. It is thought that Rink D should stabilise on a higher value than Rink C due to the higher number of support functions (“unproductive area”).
- Rink A is the second most energy efficient ice rink when measured by this indicator. The trend is increasing and given that it continues, the rink will be at the same level as the arena-sized Rink C.
- Rink B is the rink that, according to the EPI, performs the best. The rink sees an increasing trend from 2012, but the fact that the technical systems were renewed in this period could be the reason behind this.

Before calculating the EPI for each of the rinks, it seemed logic that the rinks should group together with the other rinks of the same type. When examining the results of the EPI-

calculation, one can see that this is not the case for these four rinks. Considering the data obtained in this thesis, with fifteen data points, this was however not unexpected.

Rink D has only two data points, because only the full years of energy use are plotted. This contributes to the situation looking rather bad regarding the trend line. As stated above, more EPI-values are required in the coming years to determine the correct level of performance.

The deviations between the rink types are relatively large, spanning from average values of 0.3040 kWh/m<sup>2</sup>,h (Rink B) to 0.4653 kWh/m<sup>2</sup>,h (Rink A) for the normal rinks and 0.5769 kWh/m<sup>2</sup>,h (Rink D) to 0.6222 kWh/m<sup>2</sup>,h (Rink C) for the arena rinks. The difference between the arena-sized rinks is not much, but as stated above, Rink D is misleading due to the lack of data. The difference between the normal-sized rinks is greater as Rink A on average consumes 53.1 % more energy per available productive square meter than Rink B. This underlines the advantage in energy efficiency when having a larger productive area available and connected to shared facilities, as changing rooms.

Below, an illustration of the EPI-values plotted per rink category with the average EPI-values. The average of the arena-sized rinks is 0.612 kWh/m<sup>2</sup>,h, while the normal-sized rinks are at 0.364 kWh/m<sup>2</sup>,h. From this, one can see that the arena-sized rinks on average use 67.9 % more energy per available square meter ice pad in a year.

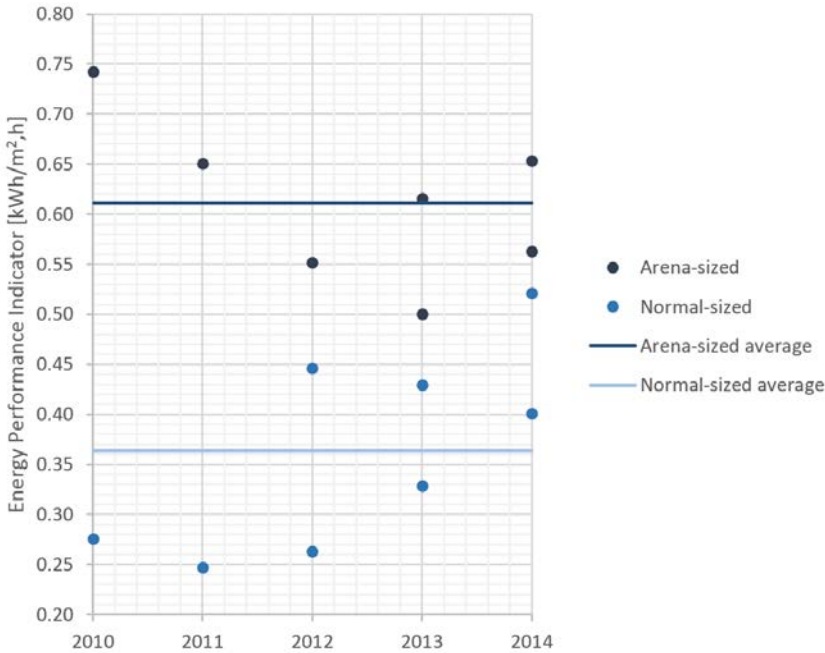


Figure 48: EPI-value scatter chart with averages.

It is a common perception that the critical periods for operating an ice rink are the start of the season in the autumn and the end of the season in the spring. This is because the rink have to operate in higher outdoor temperatures in combination with high relative humidity. The autumn months is in this context regarded as the worst because the relative humidity is higher than in the spring. When examining these months concerning the EPI, one finds that the adjusted energy use presents an inconclusive picture.

Rink D exhibit deviations in September and October in both the studied years, which effect the EPI value negatively. The other rinks in this thesis exhibit deviations as well, but in different months in the years in question. In Rink C, the stated months are January and February, in Rink B, March and November, and in Rink A, March, December and July.



## 5 Discussion

With basis in the lack of an agreed practice or standard for assessing ice rinks and other sports facilities' energy performance, the thesis's problem to be addressed is the following:

*Development of management tools for use in the operational phase to promote knowledge and energy efficiency through a key figure analysis of Norwegian ice rinks.*

The objective of the problem above is to develop a guide to rational energy use and a way to measure the energy performance in ice rinks. This guide is thought to be utilised as a tool to raise awareness in the design and acquisition phase and in the operational phase. It is designed as a standalone tool, but could also supplement existing assessment methods that perform a static energy evaluation of the building.

The chapter discusses the research questions in relation to the findings in the key figure analysis carried out on the four ice rinks and the relevant theoretical foundation. Together this comprises the management tool the addressed problem seeks to develop.

### 5.1 Factor for comparison of ice rinks

*Is it possible to establish a mutually agreed parameter for measuring energy use and output to make ice rinks comparable?*

When dealing with complicated and custom buildings like ice rinks, the unit kWh/m<sup>2</sup> is far from accurate, and the results could differ enormously from one rink to another. The area used for this calculation is the total useable area of the ice rink. The main source of the variations is the variations in size of the non-ice specific areas. Because the different rinks are difficult to compare based on the definitions one operates from today, a review of the common features in ice rinks is given to understand how rinks can be comparable.

An ice rink is built for a specific purpose, and the ice area is the only area that for is common between ice rinks, regardless of standard and type. Some rinks are European sized or North American sized and many have multiple ice pads. Even so, this is constant compared to public areas, changing rooms, cafeterias and more. The ice is the most important factor in an ice rink regardless of the total size and can be compared whether it is an arena or training rink. Seeing as it is the single most important feature in an ice rink, the relationship between the ice surface

and the energy use must be investigated. This thesis supports the view of the Swedish research report “Stoppsladd” when using the ice pad areas as the essential area (Rogstam and Hjert, 2010). This means looking at the ice rink as a process building, much like a production plant in theory, where the ice is the productive area. The term *productive area* initially comes from the forest industry, where productive area is a technical definition of an area that produces a given number of cubic wood per hectare per year. When using this designation for sports facilities, the productive area can be interpreted as the space that fulfils the facilities’ purposes. In an ice rink, the ice surface must be regarded as the productive area. The motivation behind the use of ice surface as a denominator is that a typical ice rink uses about 61 % of the total energy use for cooling of the ice, according to the IIHF Arena Guide (International Ice Hockey Federation, 2015).

The climate can be a factor, (e.g. chapter 4.2); there are sometimes huge deviations because of it. However, the goal is to examine the rinks’ performance in a unified comparable manner regardless of location and external factors. The climate’s influence is eliminated through the adjusted energy use figures, and one is left with the internal factors only.

The internal factors affecting energy use is the design of the rink, technical equipment and systems, use of the rink and management. Due to the nature of the data that was obtainable in this research, a quantification of the technical equipment and design of the rink is difficult as only one of the case studies have detailed figures for energy use. Information about the usage of the rinks have been obtained, with the start and end of each season, opening hours in an average week as well as use outside the season months. Hours when the rink is in use for other activities, such as concerts, affect energy use during the season to a limited extent. The rink that is most used for non-ice related activities is Rink D, where they have a separate energy measuring system for these instances. When it comes to the energy management in the rink, it is difficult to put a specific number on the impact from good management or bad management, as there is no benchmark for any of the rinks and they all have different prerequisites.

One have to evaluate what the end product of an ice rink actually is when trying to quantify how good or bad a rink is performing. For the arena-sized rinks, an argument can be made that the output the energy use must be seen in connection with is the number of spectators in a season as this is the main source of income. However, the case with most ice rinks is that they have next to no income because they are built by the municipalities to support the local

community. The ideal context to evaluate the energy use is in relation to the total number of users, like athletes, spectators and the public. Apart from match attendance, it has not been possible to obtain this information as it is an impossible task for the rinks to gather correct figures dating months and years back in time. When this cannot be utilised, the next best thing is the time the rink is available and open for the users. The total number of operation-days is another factor that could be used to evaluate the performance of a rink, but as stated above the total hours the rink can be used for its purpose is regarded as the output.

The “Stoppsladd” report is made up of extensive surveys from over one hundred ice rinks in Sweden. When evaluating the rinks, the research group makes use of both the ice area and the number of days the rink is open (operation days) in a season (Rogstam and Hjert, 2010). In this thesis, the season days are taken one step further to opening hours every week, as it is believed that this will increase the accuracy of the parameter.

The energy figures is the numerator in the calculation of the key figure parameter. The energy usage figures are adjusted to eliminate the climatic influence. Due to the availability of data for this thesis, all the figures are the energy the rinks actually pay for, obtained from either invoices or power meters. Therefore, it does not take into account the use of equipment like heat pumps who have higher energy output than input.

Below, the factors calculated in chapter 4.9.1 is presented in a table.

**Table 45: EPI-value results for all rinks.**

| Energy Performance Indicator (EPI - kWh/m <sup>2</sup> ,h) |        |        |        |        |
|--|--------|--------|--------|--------|
| Year   | Rink A | Rink B | Rink C | Rink D |
| 2010   | -      | 0.2760 | 0.7425 | -      |
| 2011   | -      | 0.2469 | 0.6502 | -      |
| 2012   | 0.4459 | 0.2631 | 0.5521 | -      |
| 2013   | 0.4291 | 0.3286 | 0.6155 | 0.5002 |
| 2014   | 0.5211 | 0.4008 | 0.5628 | 0.6536 |
| Average:   | 0.4653 | 0.3040 | 0.6222 | 0.5769 |

The table displays the rather large difference from the larger Rink C and Rink D to the smaller Rink A. This suggests that to compare the large arenas with the smaller rinks is still not appropriate. The main differences between these rink types (chapter 2.2) are the extra facilities that come with the arena-sized rinks. In addition to more changing rooms, restrooms, press area and kiosks, the total heated area increases. The spectator stands requires a certain temperature

for people to come watch the games, bigger hallways and common areas are also required, and in many cases restaurants and lounges (International Ice Hockey Federation, 2015). Although the extra areas in an arena generate income on game days it is mostly surplus the days when there are only training in the rink.

Rink B comes out of this calculation with the lowest factor, which is positive, and means that it is the most effective rink out of the four. The reason behind this is that Rink B has two ice pads that double the productive area. As the two ice pads share facilities as changing rooms, technical rooms, restrooms and a kiosk, the energy demand is far less than the demand of two separate rinks. This becomes clear when viewing the EPI for Rink B which is 0.1613 kWh/m<sup>2</sup>,h lower than the similar Rink A.

This performance indicator paints a picture of the performance of the building when viewed in the context of productive area size and hours of availability for use. In this sense, it works as an indicator to how much output one receives from the actual input, which is the energy use. As a further development of the parameter originally launched in the “Stoppsladd” report, this thesis has refined parameter to include number of opening hours. This increases the accuracy of the key figure, but demands that data for the average opening hours during a week and the number of weeks the rink is open.

The key figure for comparing ice rinks have been established as usable when comparing multiple rinks. The correctness of the availability hours and season length is especially important if the rinks are compared with each other. In addition, rinks could be evaluated more in depth if there were a greater availability of specific energy figures. This was not available from the rinks studied in this thesis and therefore, only the total annual energy usage was the basis. Frankly, this only shows half the picture and joins in the necessity of more measuring of energy use in ice rinks.

Another important factor when creating a key figure for comparing ice rinks is the adjustment of the energy use. The adjustment formula should, after the findings in this thesis, be reviewed to meet the characteristics of ice rinks. What one can see is that in its current form the formula has major impacts when the temperature deviates from the normal period. The deviations could suggest that either the climate dependant percentage of the energy use is smaller or that the ideal temperature in an ice rink should be set lower than the 17 °C currently used today (Enova, 2015). This question is covered in the discussion of research question 3 in chapter 5.3.



## 5.2 Minimum requirements for a rational energy performance

The second research question address the energy performance of the facility, requirements and important factors within this topic.

*Which standard minimum requirements should act as a basis for ice rinks to achieve a rational energy performance?*

After finding a key figure for comparing ice rinks, this research questions seeks the answer to what is a good level of performance for each of the rink types, and what is needed to achieve the desired level. As the case study in this thesis consist of four cases; two arena sized and two standard sized where one also has a training rink, conclusions of what the EPI should be for each of the rink types can hardly be drawn. With this possibility of comparing rinks on an equal basis, one should proceed to examine even more rinks in the future and conduct the calculations. This would give a broader statistical basis on which to conclude on the energy performance levels. The building statistics-report by Enova, where building owners and managers report energy use, is a service that could be seen in connection to the benchmarking index presented in this thesis. As the report already present energy use numbers, the benchmarking index presented in this thesis could act as a valuable addition to this statistics report, and provide a separate factor for ice rinks.

Rink A was completed in 1978, Rink B in 1977, Rink C in 1994 and Rink D was completed in 2012. In addition, the average age of the official ice rinks in Norway is 24 years (Norges Ishockeyforbund, 2015). This implies that the standard of the Norwegian ice rinks is far from modern. If one should look to any rink for inspiration, it should be Rink D, as it is the newest and one of the most modern in Norway. From the site visit performed in the case study, it was discovered that even in this rink, there were problems in the operational phase caused by the focus on reducing the initial investment cost (e.g. air leaks around the stands).

As discussed in chapter 2.7 “Energy assessment and sports facilities”, the use of energy assessment methods could be the way to go. There is an opportunity to make use of the methodology from several of these methods, specifically BREEAM and MINERGIE®, and angling the focus over to sports facilities and ice rinks. The categories in the assessment methods span over a wide spectre of energy saving and optimising measures (Norwegian Green Building Council, 2012, MINERGIE, 2015a). The possibility of structuring this into a manual

for ice rinks to facilitate a rational and well-managed operational phase should be investigated further, as they currently are biased towards commercial and residential buildings (Schiess, 2011). Although as BREEAM is focused on the commercial side of sustainable development, and to give recognition to the market through ranking of achievement, the methodology of assessing all the different factors that make an impact on the energy performance of the building is a focus that can be kept when planning and operating ice rinks. MINERGIE® operates with a lean approach, and focuses on the importance of comfort for the user through effective technical systems. Even though the standard takes basis in the heated area, which has been established as an inappropriate denominator, it is the user that also should be in focus in the ice rink as the rink acts as a process building where its main function is to provide an ice pad for the users.

Good management and staff is difficult to put into terms of minimum requirements, but is just as well a very important part of a rational energy use through the life of the building. In Rink C one could see a significant improvement when the operation of the rink were left to a professional management organisation. Because the majority of the ice rinks and sports facilities in Norway are funded and owned by the government and run by divisions in the municipalities, they are in many cases left to a manager with a real estate portfolio (Regjeringen, 2015). This leads to fewer specialists in sports facilities and ice hockey rinks, and a lack of knowledge concerning the extra demands in this building stock.

When setting the requirements for the technical systems in an ice rink it comes down to the size and use of the rink as mentioned in chapter 2.1 and 2.3. As the majority of Norwegian ice rinks are old, and with the assumption that many of the technical systems are from the time of construction, there is reason to believe that the potential for energy savings is as large as presented in the “Stopppladd”-report, where they estimate the possible savings to between 20 % and 40 % (Rogstam et al., 2011). There is no doubt, that savings can be achieved by upgrading the technical equipment in the rinks, but one of the issues related to this, which were experienced at Rink B is the lack of space. Modern equipment requires more space and this leads to problems during the installation when the rinks’ technical rooms were designed twenty to thirty years ago.

When planning or refurbishing an ice rink, flexibility should be in the back of one’s mind. During the site visits on the different case objects, it was discovered that the newest built rinks

were designed with the possibility to further expand the technical rooms. This is not possible in the older rinks as the existing rooms are already filled completely. The technical development is a dynamic process and it is important to have long-term perspective and goals when planning and operation an ice rink. The usage pattern should be weighted according to its influence on the energy use, as the majority of the use in all of the studied rinks was training activities. A rink used for training does not have the need for large-scale technical systems as an arena-sized rink. This implies that if one has the opportunity to find alternative solutions to cover the extreme situations, e.g. match days, much of the technical equipment can be scaled down, closer to a training rink, to reduce energy use. This in particular relates to the ventilation, heating and air-cooling systems, as they have to be designed to fulfil the technical regulations who demand that they can handle a worst-case scenario, in this case a capacity crowd (Kommunal og moderniseringsdepartementet, 2010).

The aforementioned focuses in great extent on the different subjects that needs to be addressed to achieve a rational energy performance in an ice hockey rink.

As the standards of the rinks differ, one cannot determine fixed requirements that are applicable to all rink classifications. The focus should be on existing and future use of the facility, and that the technical installations are appropriately scaled. In attachment 1, recommended requirements for the main technical installations in an ice hockey rink is described, in addition to focus areas, which have great influence on the energy performance. This acts as a simplified guide for energy efficient and rational operation of ice rinks in Norway, and as a supplement to this research question.

### **5.3 Energy use and the external conditions**

The third research question seeks to answer how external conditions, such as climate, nature, landscape and building plot conditions can affect the energy use and performance of the building.

*How does the external conditions affect the energy use and in turn the energy performance?*

As stated in Anfinsen, (2014) the energy use in a sports facility is affected by usage pattern, opening hours, design, structures and materials, size and heating systems (Anfinsen, 2014). In addition to this, for ice hockey rinks, one can add all the other technical solutions that are

present in a facility are this type. The varied climate in Norway lead to extensive damages on the built environment, and the majority of the damages can be related to moisture in the construction (Kvande, 2007). Structural weaknesses can further lead to inefficient overall energy performance of the building or facility. Rogstam et al. (2011) found that the specific energy use in ice hockey rinks is influenced by the location of the rink, as the rinks in the northern province of Sweden consumed around 36 % more energy than rinks in the southern province. These differences can be related to the climatic differences between the north and the south of Sweden (Rogstam et al., 2011).

With basis in the climatic zone classification map by Köppen and Geiger (Kottek et al., 2006) in context with the climatic descriptions and mean temperature of the location of the four case objects in this thesis, it can be argued that the climatic differences between the studied objects are not as obvious as in the “Stoppsladd” report. As the mean temperature in Oslo (Rink A) is  $-4.5\text{ }^{\circ}\text{C}$  in January (Store norske leksikon, 2009),  $-3.1\text{ }^{\circ}\text{C}$  in Sør-Trøndelag (Trondheim Kommune, 2015), rarely below  $-4\text{ }^{\circ}\text{C}$  in Rogaland and between  $-6\text{ }^{\circ}\text{C}$  and  $-8\text{ }^{\circ}\text{C}$  in Hedmark (Dannevig, 2009), and the geographical diversification of the objects is not as great as in the Swedish report. On the other hand, when reviewing the specific energy use for the case objects one can, in some periods, see a certain degree of correlation between the energy use and the temperature, although this is not representative to prove with certainty.

When adjusting the energy use and calculating the FMEU, it is only an assumed portion the energy use that is adjusted, known as the temperature dependent portion. In this thesis the amount of climate dependent energy use is set to 40 % as the Enova statistics offer no dedicated factor for ice rinks (Enova, 2014). In addition the method is based on a heating degree-day count with  $17\text{ }^{\circ}\text{C}$  as minimum temperature as the formula is biased towards residential housing (Enova, 2015). When performing this adjustment of the energy use data, one can see from the results that in some cases this leads to great fluctuations (Rink A and Rink C). It can be argued that these fluctuations are the result of the inaccurate formula regarding both the minimum temperature heating degree-day count and the amount of dependent energy use. It would be appropriate to suggest a further review of the basis for heating degree-days to adapt this to the type of facility studied in this thesis. The deviations seen in this thesis could still be isolated instances. Either way, the question of the heating needs in an ice rink and if one should rather examine the cooling needs is raised. After all, the ideal temperature is lower and only certain areas are in need of heating on a regular basis. An angle could be to investigate if the cooling

energy need increases in locations with warmer climates where perhaps the need for heating is non-existing.

Meanwhile, after performing this adjustment, the three remaining factors are usage, management and technical equipment/technical systems. The results presented in chapter 4, illustrate both the actual monthly energy use and the adjusted, FMEU. These results support the basis that the triggering factor for changes in the energy use is the use of the productive area in the facility, but also the exterior temperature as an important climatic condition. A relevant question to address is the frequency of the need for extra heating of the facility, and the indoor temperature set point. The need for heating is often controlled by the comfort of the audience, as they require stagnant air in heated conditions, while the ice rink itself needs cold stagnant air and the players on the ice want a constant fresh air supply (Bergsagel, 2014).

Based on the available research and the findings in this thesis, it is reason claim that a colder climate affects the energy performance in an ice rink in a negative way, as the energy for heating then is increased, which represent a significant amount of the total energy use through the year. Temperature and humidity are the two most significant climatic factors, as fluctuations in temperature and high levels of humidity in the outdoor air require constant surveillance of the indoor climate set points to keep this at an even level. It is important to focus on the interaction between the technical solutions and the construction and design of the building, to avoid counteracting processes, as the quality of the facility as a whole is important to ensure the right environment that enable focus on, and reduction of energy use.

#### **5.4 Energy use and building materials**

The fourth research question focuses on structural materials and the properties of the materials for use in ice-hockey facilities. Different materials affect the building performance in different ways, regarding both indoor climate and energy use.

*How does the energy use in ice-hockey facilities depend on the building materials used?*

The construction materials focused on in this thesis are timber and concrete, as these are presumed to be the two most common construction materials in ice rinks. Timber is claimed to have its highest climatic impact in a life cycle perspective in the usage phase, as the material in this phase emits more than 79 % of its total greenhouse gas emission over a life cycle (Gerilla

et al., 2007). It is only natural that the highest impact is in the operational phase, as the qualities of the material influence the buildings total energy use during the operational phase of the building. What is particularly interesting in terms of ice rinks and timber is the material's influence on the indoor climate, as it has specific thermic and climatic qualities. The qualities for absorbing moisture and harmful gasses (Svanæs, 2004) and the environmentally friendly use of laminated timber (Martinsons, 2011), should be emphasised when addressing the design and energy use of ice hockey rinks.

Concrete is a strong, low maintenance and inflammable construction material, and is the world's most widely used structural building material. As timber, concrete also possess energy saving qualities as a heat reservoir which may reduce the need for heating and cooling (Norcem, 2014). The material's thermal mass and reservoir abilities are highly effective when controlling the indoor temperature, in addition to being sound insulating (Heidelberg Cement, 2014). These capabilities however, are not utilised to their full potential in an ice rink, because of the need for acoustic insulation.

The majority of the cases in this thesis are constructed with a combination of the mentioned materials and steel as a third main construction material. Rink A has a substructure of concrete elements and steel beams, arched laminated girders that support the roof, and a grandstand of concrete covered with wooden panels. Rink B is very similar, with concrete foundation, and laminated wood girders supporting the roof. In addition, the training rink at Rink B, built in 2009, is a steel construction with LECA inner walls. Rink C is constructed with concrete and laminated wood girders that span the entire width of the hall. One of the newest additions to ice hockey arenas in Norway, Rink D is also constructed of concrete elements and 60-meter wide steel trusses that support the roof. Here it is also used steel sheets as roofing and concrete and sandwich elements as facade. The eastern wall is made of glass.

The energy use in the assessed ice hockey facilities do vary in great extent. This is mainly because of its size as an arena or a normal or training rink, and the use of the facility. From the results of the case study, the construction materials impact on the total energy use cannot be verified, but one can assume that the materials in connection to the outdoor climate do affect the overall energy use to some extent. It is only natural to believe that a facility constructed with focus on quality in materials is going to perform better than the opposite. The combination of construction materials in an ice hockey facility, where you combine the span length of timber,

the pre-fabricating options of concrete, and the good fire protection and low costs of both materials may be the most appropriate solution as the goal of reducing the energy use implies thinking of the actual construction and its installations as a whole.

The energy use fluctuates between the case objects in this thesis, even though the principles of construction are somewhat similar in each category. It can therefore be said that the building materials used do affect the energy use in relation to damages in the construction, the technical and structural qualities of the construction and the material itself, and the sustainability of the material.

The building materials used in an ice hockey facility is dependent on qualities that contribute to the air tightness of the building envelope and that support the indoor climate in a positive manner. Seen in a different way, to keep the energy use at an acceptable level, the facility must be designed according to its function, where the construction materials have an important role.

The research question may be interpreted in different ways, as whether to focus on the carbon footprint of the actual material in a life cycle perspective, or the performance of the building in an operational perspective. Often do these two aspects coincide, but the focus should be on how the building materials perform during the operational phase of the facility.

Based on the findings in this thesis one can claim that the energy use in an ice rink is affected by the construction of the facility as a whole, but the state of dependence on the specific building material cannot be concluded. It is evident to assume that minor improvements in material quality and construction through design and planning constitutes marginal gains that contribute to better overall performance of the facility. By exploiting the different materials' attributes and strong points i.e. timber's strength to weight ratio, moist capacity and span lengths, concrete's thermal attributes and low maintenance, combined in different parts of the facility and in collaboration with technical equipment one can achieve synergy effects that improves the building's energy performance.





## 6 Conclusions and future work

### 6.1 Conclusions

The thesis set out to explore the energy efficiency in Norwegian ice rinks, through a key figure analysis to develop a guide to energy efficient ice rinks. The energy use in the selected case objects was examined to understand the energy use and correlations between internal and external factors, as well as the complexity of the buildings.

Given that the relationship between the complexity of the ice rinks and the energy usage unit ( $\text{kWh}/\text{m}^2$ ) was established to be highly inaccurate, a unit usable for comparing the ice rinks was found ( $\text{kWh}/\text{m}^2, \text{h}$ ). The EPI shows substantial variations between the assessed rinks, with the arena-sized rinks being the worst and the normal-sized rink with two ice pads being the best. For creating a tool for both assessing and improving an ice rink, a mutually agreed benchmark is needed. As such, the EPI is a necessary addition. To determine a suitable level for each of the ice rink categories it is appropriate to study a larger amount of ice rinks. This can be used to create a base of information to compare ice rinks and create greater awareness around the energy use in ice rinks. In a long-term perspective, this would have great socio-economic benefits.

An important part of the energy management in an ice rink is the monitoring and measuring of the energy use. In the studied cases, this proved to be of variable quality, leading to difficulties understanding the performance of the facilities. With the assumption that the status is not any better in other ice rinks from the same period, there is much potential for improvement. This fact can be seen in connection with the need for increased knowledge about the complexity and all the systems in an ice rink among the operations personnel. It is to address this that the guide in the attachments was developed as a part of this thesis (Attachment 1).

During the course of examining the data obtained from the objects, it became apparent that the formula for climate-adjustment of the energy figures yielded major deviations in certain cases. When investigated it was uncovered that the formula is not suited for use in ice rinks, as the parameters of adjustment is based on residential buildings.

It was discovered in the site visits, that the use of an ice rink is special compared to many other types of buildings. As stated, the majority of use in Norwegian ice rinks is training activities,

while the rinks have to be designed for the extreme situations that occur at maximum every other week. This is both in regard to the technical systems running constant through the season and the use of the ice itself. The findings underline the need for a holistic approach to planning, building and managing ice rinks. This approach should apply to the design of the rink, with choice of materials, technical systems, layout and size, all to accommodate the actual need of the rink.

## **6.2 Future work**

Throughout the work of this thesis, one has touched some interesting topics that was not, due to the limitation of time, studied further. Therefore, in this final part of the thesis, topics that one believe should be examined further are mentioned.

As stated on numerous occasions in this thesis, the need for more detailed measuring of energy use is stressed. An aspect that was not considered in this thesis because of the availability of data, was the water use and related energy use. In an ice rink with multiple changing rooms, restroom facilities and ice resurfacing multiple times each day, the water use is naturally high. Although not considered here, it is acknowledged as an important piece in the total energy use in an ice rink and should be considered to greater extent in future works.

Knowledge, and incentives of gaining knowledge, is an important factor in terms of energy management. Methods of finding, gaining and distributing knowledge should further be investigated, as the holistic approach is vital to achieve optimal energy performance.

The method of adjusting the energy use data is biased towards residential housing. It is encouraged to further investigate this method of adjustment, as adaptations towards sports facilities or ice hockey rinks are needed to improve precision of the data when adjusted.

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# ENERGY EFFICIENT ICE RINKS

A guide for energy efficient and rational operation of ice rinks in Norway

## INTRODUCTION

Ice rinks can be large buildings where the refrigerated area, if the purpose of the rink is ice hockey, is approximately 1,800 – 2,000 m<sup>2</sup>. Depending on the type of rink, there are heated areas of the building in addition. Regardless of this, even the simplest of ice skating rinks use more energy than most other indoor sports facilities. The reason for this is the complexity of the ice rinks, as they are more similar to processing plants than regular housing when assessing the energy performance of the facility.

The energy performance of the facility is not only determined by the technical equipment, design and planning of the facility, but also the management in the operational phase. The lack of this leads to inefficient facilities. This guide presents key factors for ice rinks as a common thread. Topics of relevance are design, technical installations and operation and maintenance.



## DESIGNING AN ICE RINK

### CONSTRUCTION

The construction of an ice rink relates to the focus on the building envelope and the exterior of the building. A good envelope refers to the qualities of the exterior elements, as they should be climate-appropriate, structurally sound and aesthetically pleasing. The primary function of the building envelope is to secure air-tightness to minimize the moisture loads inside the rink and to realize the defined comfort conditions for the user with a minimum of energy use. When planning and designing an ice rink, it is important that the design of the facility supports the primary activity in the rink. Whether it is a training rink or an arena with 6,000 seats, the purpose of the construction must be clarified early in the process. One must constantly aspire the most efficient layout based on the activities in the rink.

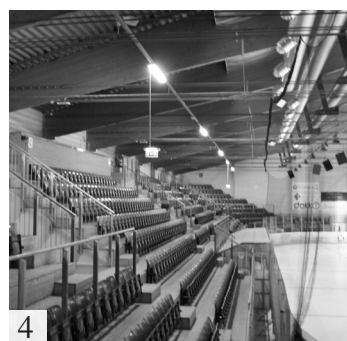
### MATERIALS

With the correct materials and the correct use of the materials, one can optimize the functionality of the facility, cost efficiency and sustainability. The focus on preserving the environment and reducing the energy use is growing each day, and the materials influence on the climate and its qualities is a topic of current interest.



Timber is a natural and renewable building material, and used the correct way it is also a sustainable material. Timber has a positive affection on the indoor climate as it has qualities for absorbing moisture, and abilities to absorb harmful gasses if treated the correct ways. The use of laminated timber is environmentally friendly, as for every cubic meter timber used instead of other materials, two tons less of CO<sub>2</sub> emissions is saved in total, with the timber binding it in its entire life cycle as well.

Concrete is the worlds most widely used building material, and the benefits of concrete are numerous; strong, great durability, low maintenance needs, does not rot and is inflammable. The concrete's thermal mass and reservoir abilities are effective when controlling the indoor temperature, in addition to being sound insulating. On the other hand, these capabilities cannot be fully utilised when concrete is used in a rink. This is due to the acoustic insulation needed on the inside, which inhibits the properties related to the thermal mass of the concrete.



## PLAN FOR FUTURE IMPROVEMENTS

When refurbishing an older ice rink, it is often seen that the lack of space limits the possibilities of upgrading to more energy efficient solutions. Modern equipment requires more space, which can lead to problems getting new solutions installed in the facility. Older ice rinks have technical rooms designed according to often thirty-year-old systems. Flexibility is a keyword, as newer ice rinks often are designed with the possibility to further expand the technical rooms. The technical development is a dynamic process and it is important to have a long-term perspective and goals when planning and operating an ice rink.

## OPERATION AND MAINTENANCE OF ICE RINKS

The utility model of an ice rink differs a great deal from residential and commercial buildings. In a typical ice rink, the daily activity can be high, with professional teams, local teams, figure skaters, and municipal use in addition to rented time by private groups or companies. It is important to be aware of the fact that the majority of all activity in an ice rink consists of training activity. The hallmark of training activity is that contrary to matches, there are no attendances, mostly just athletes and coaches. Rinks should be planned according to usage pattern, as hours of use are an important part of the operation and maintenance of the rink. An arena-sized rink is used “as intended” only 7 % of the time, as the everyday use, including training is 84 % of the rinks time in use.

When planning technical equipment and installations, maintenance routines and frequencies must be considered. Well-incorporated routines for maintenance are a must in a complex facility like an ice rink. Automated central control and monitoring systems are encouraged. Such automation can help reduce the operational costs, by reducing energy usage and the need for regularly maintenance. The responsibility for maintenance should be placed with the supplier that can deliver continuous presence and with the best overall knowledge of ice rinks. This is often the user of the rink. Knowledge is an important factor, as special skills are required to perfect and tune the different technical installation to work together and deliver the best possible output with the lowest possible input.

## TECHINCAL INSTALLATIONS

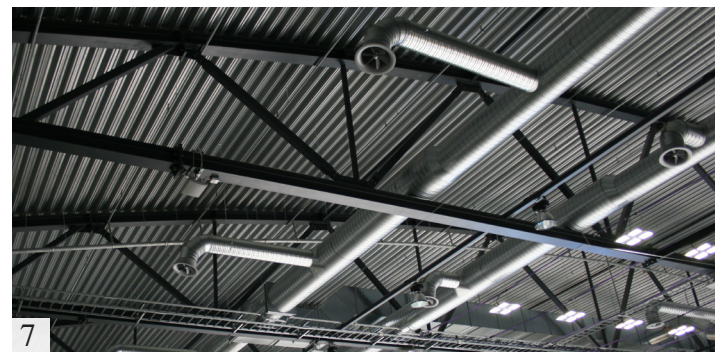
### HEATING

Heating is needed to maintain comfortable thermal conditions both for the players and the spectators. The different climatic zones have to compromise in order to deliver heating where it is needed. Heating is also used to control the humidity in the rink and to avoid fog and ceiling dripping problems. In an ideal situation, the demand for heating is covered by the recovered heat from the refrigeration process and delivered through conduction. By using a heat exchanger to heat the ventilation air, one can reduce the heating energy use by 60 %. Depending on the price of the heat exchanger, the cost savings over the life cycle of the product at least three times higher than the investment cost.

### DEHUMIDIFICATION

The moisture load in the rink is due to people inside the facility, outside air mixture and evaporating water on the ice pad from the ice resurfer. The biggest moisture load is the water content from the outside air, which enters the facility through ventilation air intakes and through leakages in the building envelope. There are two primary ways to remove moisture from the air: cool the air below its dew point to condense the water vapour, or pass the air over a material that absorbs water. The most common method is, when using mechanical ventilation, to install dehumidifiers that cool the air below its dew point and delivers dry air to the rink. The most efficient dehumidification is done through installing cooling coils in the ventilation plant instead of se-

parate electricity driven dehumidifiers. This will also reduce the operating costs of the installation. The relative humidity in an ice rink must be within 40 – 65 %.



### COOLING

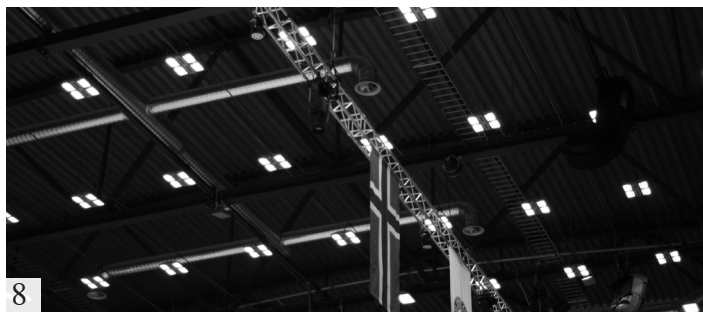
The electricity use for the refrigeration unit accounts for over 50 % of the total energy use in the rink. The system is needed to make and maintain the ice, where it consists of compressors, condensers, evaporators and rink pipes. One should utilize the excess heat from the condenser to heat other climatic zones of the rink that require higher temperature. The most common system is the indirect system, where the ice is indirectly cooled in a closed circulation loop that contains special brine. Choosing an optimal secondary refrigerant brine fluid is crucial to achieve better performance, and that an ammonia-solution is to be preferred in any case. This solution consists of 17 % NH<sub>3</sub> and water to gain optimal viscosity, better heat transfer coefficient and resulting in better performance. The rink pipe size and depth is irrelevant to the system performance, but by increasing the number of pipes with 1/3 it provides a more uniform temperature profile in the ice. By limiting the number of simultaneously operating compressors one can reduce the energy used by the compressor motors with 10 % and 20 % decrease of the peak power demand.

## VENTILATION

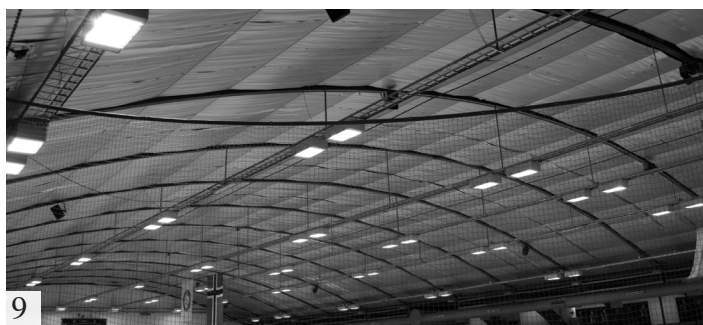
A satisfying indoor climate in an ice rink is difficult as there are different climate zones in the building. The required functions of an indoor ice rink ventilation system are; maintaining adequate thermal and humidity conditions for the users, and removing excess moisture above the ice surface. Indoor air temperature should be between 10-12 °C during practice and 12-14 °C during matches. Air temperature in the spectator area should be slightly higher, around 14-15 °C, and the air speed above the ice should be 0,25 m/s or less. The energy saving factor in ventilation is to be found in demand-controlled fresh-air intake and optimizing the airflow rates according to the needs, for minimizing the fan power.

## LIGHTING

Lighting is a major source of radiant heat to the ice sheet. Dependant on the type of lighting installed, the actual quantity of heat radiation can vary. The direct heat can be 60 % of the kilowatt rating of the luminaires. In average, the installation of lights delivers 26 lux/kw. Lighting is classified according to their operational principles and the source of the emitting light. Incandescent lamps are generally used in household lighting and have a high electricity demand compared to the illumination. Light-emitting diodes (LED) are the preferred lighting source, as this gives more light per watt and long life expectancy (up to 50,000 h) compared to incandescent lights.



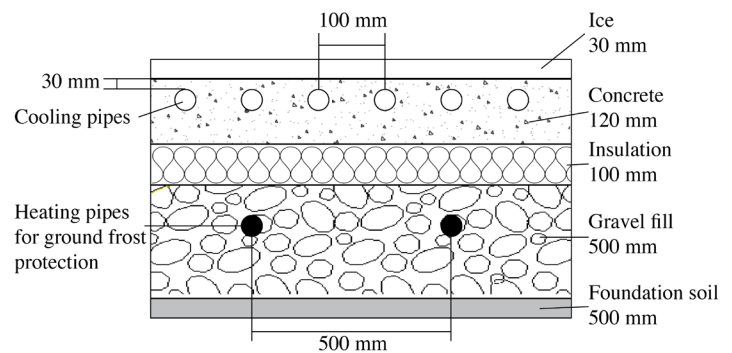
8



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## ICE PAD STRUCTURE

The ice pad is the most special structure in the ice rink, and is normally constructed in several layers of different material to balance the need for cooling, isolation and heating. It consists of ground layers below the actual ice pad, thermal insulation, piping that leads cooling liquid, and the ice pad itself. The most common surfacing material is concrete, as this enable multi function use. The rink pipe material is plastic or metal and is mounted near the surface of the concrete slab. The rink pipes are connected to the distribution and collection mains, which are laid along the short or long side of the rink. Inspection hatches should be mounted over these connections.



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## CLIMATE

The varied climate in Norway lead to extensive damages on the built environment, and the majority of damages can be related to moisture in the construction. The specific energy use in ice rinks is influenced by the location of the rink, as the outside temperature and humidity to great extent affects the indoor climate. Colder climate affects the energy performance in an ice rink in a negative way, as the energy for heating then is increased, which represent a significant amount of the total use through the year. Temperature and humidity are the two most significant factors, as fluctuations in temperature and high levels of humidity in the outdoor air require constant surveillance of the indoor climate set points to this at an even level. It is important to focus on the interaction between the technical installations and the construction and design of the building, to avoid counteracting processes, as the quality of the facility as a whole is important to ensure the right environment that enable focus on, and reduction of energy use.

## ENERGY PERFORMANCE INDICATOR (EPI)

The EPI is a unified parameter for comparing the energy performance of ice rinks within their size category. The energy use figures must be adjusted to eliminate the climatic influence. One has the possibility to calculate the performance through this key figure for a single year or a period of several years by using the average energy use. The formula is presented below. The *Adjusted energy use<sub>year</sub>* is the total adjusted energy use (kWh) the chosen year, or an average value for multiple years. *Prod.area* or productive area is the purpose area of the building, which for an ice rink is the size of the ice pitch (m<sup>2</sup>). The *Annual hours open<sub>year</sub>* is the total number of hours the ice rink is open and available for use.

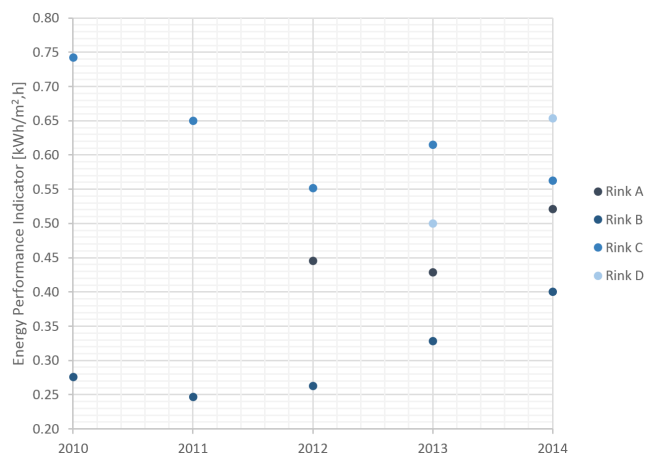
$$EPI_{year} = \frac{Adjusted\ energy\ use_{year}}{Prod.\ area * Annual\ hours\ open_{year}}$$

The performance indicator paints a picture of the performance of the building when viewed in the context of productive area size and hours of availability for use. In this sense, it works as an indicator to how much output one receives from the actual input, which is the energy use.

The table below displays the large difference from the larger Arena 1 and Arena 2 to the smaller Normal rink. This suggests that to compare the large arenas with the smaller rinks is difficult.

| Energy Performance Indicator (EPI - kWh/m <sup>2</sup> ,h) |        |        |        | 11     |
|--|--------|--------|--------|--------|
| Year   | Rink A | Rink B | Rink C | Rink D |
| 2010   | -      | 0.2760 | 0.7425 | -      |
| 2011   | -      | 0.2469 | 0.6502 | -      |
| 2012   | 0.4459 | 0.2631 | 0.5521 | -      |
| 2013   | 0.4291 | 0.3286 | 0.6155 | 0.5002 |
| 2014   | 0.5211 | 0.4008 | 0.5628 | 0.6536 |
| Average:   | 0.4653 | 0.3040 | 0.6222 | 0.5769 |

The main differences between these rink types are the extra facilities that come with the arena-sized rinks. In addition to more bathrooms, press area, and kiosks, the total heated area increases. The spectator stands require a certain temperature for people to come watch the games, bigger hallways and common areas are also required, and in many cases restaurants and lounges. Although the extra areas in an arena generate income on game days, it is mostly surplus the days when there are only training in the rink.



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The annual EPI values are inserted in a scatter chart above, to see any relations between the rinks. Exponential regression lines are also drawn for each of the rinks to view the trends. When examining the results of the EPI-calculation one can see that the rinks do not group together with the other rinks of the same type, which was the expected outcome. The deviations are relatively large, spanning from average values of 0.3030 (Normal+training) to 0.4654 (Normal) and 0.5769 (Arena 1) to 0.6246 (Arena 2). The difference between the normal sized rinks is the greatest as the rink “Normal” on average consumes 53.6 % more energy per available productive square meter than the “Normal + training” rink. This underline the advantage in energy efficiency when having a larger productive area available and connected to shared facilities, as changing rooms.

## MAIN POINTS OF IMPORTANCE

A recurrent theme in terms of operating an ice rink is the need for information distribution and development of competence as a key to future savings in coherence with energy saving measures within the different technical areas of the rink. More precise measuring on component level is also a topic of interest, as this will contribute to better operation and energy use data in the rink. It is important to focus on the interaction between the technical installations and the construction and design of the building, to avoid counteracting processes, as the quality of the facility as a whole is important to ensure the right environment that enable focus on, and reduction of energy use. The different technical installations need to work together, e.g through enabling the use of excess heating from the cooling system, installation of heat pumps, and the use of district heating. One should continuously search for ways of improvements, as to design the rinks after the main use, which is training activities, and look for alternative solutions to handle the extreme situations that occur during matches.

The expenditures in an ice rink depend on the structural and technical quality of the facility, staff, and the various energy, water and disposal charges. The income side is affected by location, population, interest, admission pricing, opening hours and number of users. In relation to this it is important to stress the importance of the quality of the facility as a whole and the various trades. This implies a higher initial investment cost but gives a reduction of operating and maintenance costs.

### Images/tables reference list:

- 1: Rink D/C. Nøstvik 2015
- 2: Rink C/C. Nøstvik 2015
- 3: Rink C/C. Nøstvik 2015
- 4: Rink A/C. Nøstvik 2015
- 5: Rink C/C. Nøstvik 2015
- 6: Rink B/C. Nøstvik 2015
- 7: Rink D/C. Nøstvik 2015
- 8: Rink D/C. Nøstvik 2015
- 9: Rink B/C. Nøstvik 2015
- 10: Ice pad structure/J. Rustad 2015/ based on IIHF Arena Guide 2015
- 11: C. Nøstvik/J. Rustad/Master thesis
- 12: C. Nøstvik/J. Rustad/Master thesis
- 13: Rink D/C. Nøstvik 2015



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FINAL MONTHLY/ANNUAL ENERGY USE

| LOCATION  | HOH | YEAR      | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | SUMI |
|-----------|-----|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
| 0301 Oslo | 66  | 1991-2010 | 621 | 551 | 504 | 337 | 174 | 67  | 23  | 46  | 161 | 327 | 465 | 606 | 3882 |
| MUNICIP.  | HOH | YEAR      | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | SUMI |
| Rink C    | 185 | 2014      | 673 | 468 | 435 | 337 | 203 | 90  | 9   | 82  | 177 | 303 | 448 | 692 | 3917 |
| Rink C    | 185 | 2013      | 832 | 685 | 718 | 425 | 161 | 92  | 25  | 71  | 194 | 372 | 507 | 536 | 4618 |
| Rink C    | 185 | 2012      | 718 | 650 | 437 | 411 | 212 | 132 | 64  | 79  | 218 | 418 | 458 | 769 | 4566 |
| Rink C    | 185 | 2011      | 774 | 722 | 603 | 270 | 214 | 63  | 31  | 79  | 165 | 346 | 430 | 589 | 4286 |
| Rink C    | 185 | 2010      | 879 | 765 | 613 | 401 | 239 | 98  | 33  | 77  | 230 | 400 | 619 | 894 | 5248 |
| Rink A    | 66  | 2014      | 609 | 421 | 391 | 276 | 159 | 49  | 2   | 52  | 112 | 247 | 387 | 592 | 3297 |
| Rink A    | 66  | 2013      | 679 | 563 | 595 | 376 | 139 | 57  | 10  | 27  | 145 | 293 | 436 | 462 | 3782 |
| Rink A    | 66  | 2012      | 605 | 557 | 355 | 361 | 166 | 92  | 30  | 33  | 170 | 358 | 412 | 689 | 3828 |
| Rink A    | 66  | 2011      | 642 | 614 | 510 | 225 | 170 | 39  | 9   | 45  | 126 | 286 | 372 | 508 | 3546 |
| Rink A    | 66  | 2010      | 782 | 655 | 526 | 327 | 185 | 49  | 7   | 41  | 167 | 347 | 574 | 825 | 4485 |
| Rink D    | 72  | 2014      | 453 | 341 | 350 | 249 | 183 | 101 | 22  | 71  | 93  | 191 | 273 | 411 | 2738 |
| Rink D    | 72  | 2013      | 516 | 478 | 511 | 360 | 199 | 130 | 60  | 55  | 137 | 220 | 343 | 351 | 3360 |
| Rink D    | 72  | 2012      | 445 | 433 | 350 | 344 | 227 | 157 | 94  | 61  | 177 | 298 | 322 | 510 | 3418 |
| Rink D    | 72  | 2011      | 468 | 455 | 431 | 238 | 208 | 128 | 56  | 67  | 118 | 217 | 266 | 407 | 3059 |
| Rink D    | 72  | 2010      | 596 | 505 | 418 | 312 | 263 | 147 | 47  | 67  | 144 | 264 | 456 | 596 | 3815 |
| Rink B    | 93  | 2014      | 592 | 368 | 421 | 335 | 231 | 150 | 21  | 77  | 162 | 289 | 402 | 530 | 3578 |
| Rink B    | 90  | 2013      | 653 | 554 | 617 | 400 | 176 | 130 | 96  | 99  | 176 | 337 | 429 | 448 | 4115 |
| Rink B    | 90  | 2012      | 593 | 518 | 420 | 423 | 278 | 175 | 110 | 110 | 240 | 396 | 416 | 694 | 4373 |
| Rink B    | 90  | 2011      | 543 | 552 | 498 | 297 | 224 | 112 | 72  | 84  | 154 | 300 | 354 | 514 | 3704 |
| Rink B    | 90  | 2010      | 752 | 641 | 536 | 372 | 294 | 190 | 62  | 84  | 206 | 327 | 621 | 753 | 4838 |

% climate dependent EU  
40%

ADJUSTMENT FACTORS

|  | N61-90 | N71-00 | N81-10 | %61-90 | %71-00 | %81-10 |     | JAN   | FEB   | MAR   | APR   | MAY   | JUN   | JUL   | AUG   | SEP   | OCT   | NOV   | DEC   |
|--|--------|--------|--------|--------|--------|--------|-----|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|  | 4907   | 4730   | 4620   | 80     | 83     | 85     | HED | 0.969 | 1.071 | 1.063 | 1.000 | 0.943 | 0.898 | 1.622 | 0.824 | 0.964 | 1.032 | 1.015 | 0.950 |
|  | 4907   | 4730   | 4620   | 94     | 98     | 100    | HED | 0.899 | 0.922 | 0.881 | 0.917 | 1.032 | 0.891 | 0.968 | 0.859 | 0.932 | 0.952 | 0.967 | 1.052 |
|  | 4907   | 4730   | 4620   | 93     | 97     | 99     | HED | 0.946 | 0.939 | 1.061 | 0.928 | 0.928 | 0.803 | 0.744 | 0.833 | 0.895 | 0.913 | 1.006 | 0.915 |
|  | 4907   | 4730   | 4620   | 87     | 91     | 93     | HED | 0.921 | 0.905 | 0.934 | 1.099 | 0.925 | 1.025 | 0.897 | 0.833 | 0.990 | 0.978 | 1.033 | 1.012 |
|  | 4907   | 4730   | 4617   | 107    | 111    | 114    | HED | 0.883 | 0.888 | 0.929 | 0.936 | 0.891 | 0.873 | 0.879 | 0.839 | 0.880 | 0.927 | 0.900 | 0.871 |
|  | 4139   | 3994   | 3882   | 80     | 83     | 85     | OSL | 1.008 | 1.124 | 1.116 | 1.088 | 1.038 | 1.147 | 5.200 | 0.954 | 1.175 | 1.130 | 1.081 | 1.009 |
|  | 4139   | 3994   | 3882   | 91     | 95     | 97     | OSL | 0.966 | 0.991 | 0.939 | 0.959 | 1.101 | 1.070 | 1.520 | 1.281 | 1.044 | 1.046 | 1.027 | 1.125 |
|  | 4139   | 3994   | 3882   | 92     | 96     | 99     | OSL | 1.011 | 0.996 | 1.168 | 0.973 | 1.019 | 0.891 | 0.907 | 1.158 | 0.979 | 0.965 | 1.051 | 0.952 |
|  | 4139   | 3994   | 3882   | 86     | 89     | 91     | OSL | 0.987 | 0.959 | 0.995 | 1.199 | 1.009 | 1.287 | 1.622 | 1.009 | 1.111 | 1.057 | 1.100 | 1.077 |
|  | 4139   | 3994   | 3882   | 108    | 112    | 116    | OSL | 0.918 | 0.936 | 0.983 | 1.012 | 0.976 | 1.147 | 1.914 | 1.049 | 0.986 | 0.977 | 0.924 | 0.894 |
|  | 3488   | 3380   | 3282   | 78     | 81     | 83     | ROG | 1.148 | 1.246 | 1.176 | 1.141 | 0.980 | 0.865 | 1.018 | 0.859 | 1.292 | 1.285 | 1.281 | 1.190 |
|  | 3488   | 3380   | 3282   | 96     | 99     | 102    | ROG | 1.081 | 1.061 | 0.995 | 0.974 | 0.950 | 0.806 | 0.753 | 0.935 | 1.070 | 1.195 | 1.142 | 1.291 |
|  | 3488   | 3380   | 3282   | 98     | 101    | 104    | ROG | 1.158 | 1.109 | 1.176 | 0.992 | 0.907 | 0.771 | 0.698 | 0.902 | 0.964 | 1.039 | 1.178 | 1.075 |
|  | 3488   | 3380   | 3282   | 88     | 91     | 93     | ROG | 1.131 | 1.084 | 1.068 | 1.166 | 0.935 | 0.809 | 0.764 | 0.875 | 1.146 | 1.203 | 1.299 | 1.196 |
|  | 3488   | 3380   | 3282   | 109    | 113    | 116    | ROG | 1.017 | 1.036 | 1.082 | 1.032 | 0.865 | 0.782 | 0.796 | 0.875 | 1.047 | 1.095 | 1.008 | 1.007 |
|  | 4441   | 4337   | 4208   | 81     | 83     | 86     | STR | 1.020 | 1.199 | 1.079 | 1.002 | 0.901 | 0.779 | 1.038 | 0.839 | 0.998 | 1.053 | 1.063 | 1.057 |
|  | 4441   | 4337   | 4208   | 93     | 95     | 98     | STR | 0.980 | 0.998 | 0.927 | 0.937 | 0.995 | 0.806 | 0.696 | 0.786 | 0.966 | 0.988 | 1.034 | 1.141 |
|  | 4441   | 4337   | 4208   | 98     | 101    | 104    | STR | 1.019 | 1.025 | 1.080 | 0.919 | 0.850 | 0.753 | 0.684 | 0.767 | 0.868 | 0.930 | 1.047 | 0.949 |
|  | 4441   | 4337   | 4208   | 83     | 85     | 88     | STR | 1.057 | 0.999 | 1.005 | 1.054 | 0.911 | 0.839 | 0.728 | 0.819 | 1.018 | 1.036 | 1.125 | 1.072 |
|  | 4441   | 4337   | 4208   | 109    | 112    | 115    | STR | 0.930 | 0.944 | 0.976 | 0.962 | 0.837 | 0.741 | 0.748 | 0.819 | 0.913 | 1.000 | 0.900 | 0.922 |

## Attachment 3

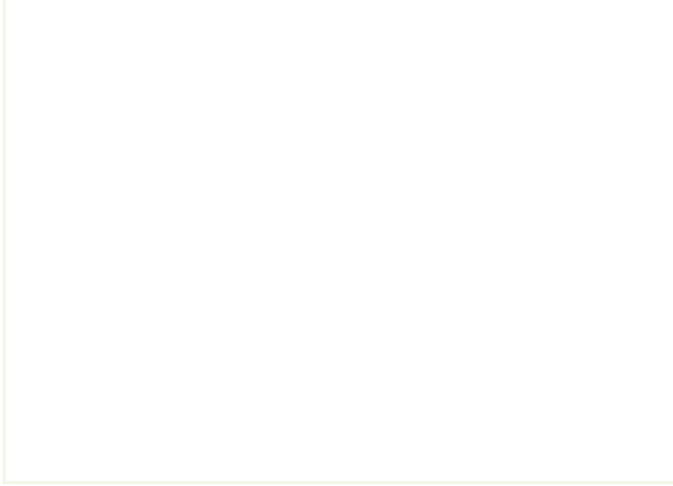
Case study – Template for interview and site inspection information

|           |  |  |
|-----------|--|--|
| 1         | Ice rink name:<br>Year of build:<br>Year of refurbishment: | <b>COOLING:</b>  |
| 2         | Adress:<br>Contactinfo:<br>Tlf / E-mail:                   | Installed year:  |
| 3         | Energy classification:                                     | Compressors:   |
| 4         | Energy use:<br>Monthly/annual                              | Effect:  |
| 5         | Ice-season start:<br>Ice-season end:<br>Activity in hours: | Hours of operation:  |
| 6         | Size of ice pad:   | Capacity regulation:   |
| 7         | Heated area:<br>Airlocks?                                  | Energy use:  |
| <b>8</b>  | <b>ICE</b>   | Handling of excess heat:   |
| 9         | Material – surface:  | Drawings?  |
| 10        | Refrigerant:   | Are there anything that does not work the way it is intended?                |
| 11        | Insulation:  | Works as intended?<br>Processes – Technical installation – operations – use. |
| 12        | Normal ice thickness:                                      | Future plans for improvement?  |
| 13        | Piping:  | Construction of the facility<br>Walls – Roofing – Foundation – ice pad.      |
| 14        | Ice temp. Practice/match:                                  | Different use of the facility  |
| <b>15</b> | <b>HEATING/VENT.</b>                                       | <b>LIGHTING:</b>   |
| 16        | Dehumidifiers:   | Type:  |
| 17        | Temperature:   | Installed year:  |
| 18        | RH:  | Number of units:   |
| 19        | Heat exchanger:  | Time lit:  |
| <b>20</b> |  |  |









**NTNU – Trondheim**  
Norwegian University of  
Science and Technology