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Measurements of indoor climate parameters in the exercise zone of an ice hockey hall

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MASTER THESIS

for

Student Linda Strand Prestmo

Spring 2018

Measurements of indoor climate parameters in the exercise zone of an ice hockey hall

Måling av klimaparametere i utøversone på en ishockeybane

Background and objective

An ice hockey court is in practice in a cold pit, and the air in this pit will have a limited mixing relative to the air in the rest of the hall. The ice hockey players hold a high intensity level and produce a lot of CO_2 during training and match. There has been some research on indoor air quality, and detailed tolerance levels have been developed for acceptable air pollution in different arenas. Nevertheless, there is little research on how different ventilation measures may improve the air quality in the exercise zone of ice hockey halls. It will therefore be very important to identify effective measures to improve the indoor air quality in ice hockey arenas.

The main purpose of this project is to investigate the indoor air quality of an ice hockey arena with and without ventilation in Trondheim. The results of this project will be used in the future to decide whether a new ventilation system is needed.

The following tasks are to be considered:

1. Literature study on ventilation solutions in the exercise zone of an ice hockey arena.
2. Carry out field measurements of indoor air quality in one ice hockey arena in Trondheim.
3. Carry out a survey in the ice hockey arena with ventilation and without ventilation.
4. Evaluate the performance of the ventilation method to improve indoor air quality in an ice hockey arena.
5. Prepare a conference article to disseminate the research results.

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Within 14 days of receiving the written text on the master thesis, the candidate shall submit a research plan for his project to the department.

When the thesis is evaluated, emphasis is put on processing of the results, and that they are presented in tabular and/or graphic form in a clear manner, and that they are analyzed carefully.

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The final report is to be submitted digitally in DAIM. An executive summary of the thesis including title, student's name, supervisor's name, year, department name, and NTNU's logo and name, shall be submitted to the department as a separate pdf file. Based on an agreement with the supervisor, the final report and other material and documents may be given to the supervisor in digital format.

☐ Work to be done in lab (Water power lab, Fluids engineering lab, Thermal engineering lab)
☒ Field work

Department of Energy and Process Engineering, 15. January 2018

Guangyu Cao
Academic Supervisor

Preface

This master thesis is part of a Master of Technology degree Energy Use and Energy Planning at the Norwegian University of Science and Technology in Trondheim. The thesis is worth 30 ECTS and the work is based on a preliminary study performed in the autumn of 2017, worth 20 ECTS, both was written at the Department of Energy and Process Engineering.

The purpose of this thesis was to assess the indoor air quality at Dalgård ice hall. Ice halls are poorly regulated in Norway regarding guidelines for buildings and operation methods. This thesis is one step in assessing how Norwegian ice halls work, and the status of the indoor air quality the hall use.

I want to thank my supervisor, Guangyu Cao, and co-supervisor Snorre Olsen for guidance through this semester. Both have added good ideas and relevant feedback on the way I worked with the research questions. I also want to thank Kyrre Svarva at NTNU who helped a lot in creating the online survey.

From Dalgård I want to thank Henrik Langeng. As the operational leader at Dalgård he has provided valuable knowledge of the ice hall and made sure I was allowed and able to do the measurements I wanted. The local ice hockey team having Dalgård as their home, Astor, as well as other local teams using the ice hall have also been of great help. Especially the team leaders of the Oldboys teams.

I also want to thank Stian Vik, manager for the local referees. Without him it would have been a much harder task to get in contact with the referee before each match and get their approval for attaching the equipment on them. I also want to thank every referee I have been in contact with, and their open approach to my ideas.

At last, I want to thank my parents, my friends and everyone who has supported me through the last five years. A special thanks goes to John-Are for proofreading, support and keeping my spirit high, and Ane for always joining me for snack breaks, afternoon walks and late evening talks.

Linda Strand Prestmo

Linda Strand Prestmo

Abstract

The purpose of this thesis was to assess the indoor air quality at Dalgård ice hall in Trondheim. Ice halls are poorly regulated in Norway regarding guidelines for buildings and operation methods. This thesis will assess how one Norwegian ice halls is operated and the status of the indoor air quality inside the hall.

A literature study was performed and reviewed relevant studies and new research on ice halls and indoor climate. Several studies regarding indoor air quality in ice halls focused on pollution from the resurfacer, while new studies focused more on air distribution since many ice halls have shifted towards electric resurfacer.

Field measurements in order to assess the indoor air quality at the ice hall was conducted in several different ways. CO_2 concentration, temperature and relative humidity was the parameters measured at the ice rink, while the sharpening room also had it's $PM_{2.5}$ measured. CO_2 concentration was measured on the ice rink during ice hockey matches by attaching the measurement equipment on the back of the referee. CO_2 values during an ice hockey match was measured for four different athletic profiles: women, men, teenagers and children. The increase during a match ranged from 92 ppm to 262 ppm, and the concentration increased to above 1000 ppm during all measured matches which is the recommended value by the Norwegian Institute of Public Health.

Two different surveys was created. One was sent out to every Norwegian ice hall and mapped how many had fresh air supply and how many used recirculated air. Only 6 ice halls used only fresh air, while most used a combination between fresh air and recirculated air.

The other survey was sent out to the local ice hockey teams that used Dalgård for training purposes or for matches. This survey mapped how the players perceived the air quality at Dalgård. The majority of the participants were pleased with the air quality at the ice rink, with 98% choosing to describe it as acceptable or better.

The fresh air supply was assessed with measurements during two nights, and based on those results the air change per hour was calculated. The calculations proved that the amount of fresh air supply at Dalgård is dependent on the weather conditions.

Sammendrag

Formålet med denne oppgaven var å vurdere kvaliteten på innelufta ved Dalgård ishall i Trondheim. Ishaller er dårlig regulert i Norge når det gjelder retningslinjer for bygninger og driftsmetoder. Denne oppgven vil vurdere hvordan en norsk ishall opereres og statusen for kvaliteten på innelufta i hallen.

Et littersturstudie ble utført som vurderte relevante studier og ny forskning om ishaller og inneklima. Flere studier som handlet om luftkvalitet i ishaller fokuserte på forurensning fra prepareringsmaskinen, mens nyere studier fokuserte mer på luftdistribusjon siden mange ishaller har byttet til en elektrisk prepareringsmaskin.

Feltmålinger for å vurdere luftkvaliteten i ishallen ble gjort på forskjellige måter. CO_2 konsentrasjon, temperatur og relativ fuktighet var parameterne som ble målt på isbanen, mens det i sliperommet også ble målt $PM_{2.5}$. CO_2 konsentrasjonen ble målt på isbanen under ishockeykamper ved å feste måleutstyret på ryggen til dommeren. CO_2 verdiene under ishockeykampene ble målt med fire ulike utøverprofiler: damer, menn, tenåringer og barn. Økningen i løpet av en kamp varierte fra 92 ppm til 262 ppm, og konsentrasjonen økte til over 1000 ppm i alle kampene som er den anbefalte verdien fra folkehelseinstituttet.

To ulike undersøkelser ble laget. En ble sent ut til hver norske ishall og kartla hvor mange som hadde frisklufttilførsel og hvor mange som brukte omluft. Bare 6 ishaller brukte bare friskluft, mens de fleste brukte en kombinasjon mellom friskluft og omluft.

Den andre undersøkelsen ble sent ut til de lokale ishockeylagene som bruker Dalgård for trening eller kamper. Denne undersøkelsen kartla hvordan spillerne opplevde luftkvaliteten på Dalgård. De fleste deltakerne var fornøyde med luftkvaliteten på isbanen, med 98% som valgte å beskrive den som akseptabelt eller bedre.

Frisklufttilførselen ble vurdert med målinger gjennom to netter, og basert på disse resultatene ble luftbytte per time beregnet. Beregningene beviste at mengden lufttilførsel på Dalgård er avhengig av været.

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Nomenclature

$\Delta\rho_0$	Density difference [kg/m^3]
$\dot{M}$	Strength of indoor sources [m^3/h]
$\dot{V}$	Ventilation rate [m^3/h]
$\frac{dC_r}{dt}$	Change in indoor pollution over time
ρ_{0m}	Mean density [kg/m^3]
ΔT	temperature difference [°C, K]
C_0	Indoor pollution at the beginning of measurements [mg/m^3]
C_d	Discharge coefficient
C_i	Indoor pollution [mg/m^3]
C_r	Pollution concentration of indoor air [m^3/h]
C_s	Pollution concentration of supply air [m^3/h]
G	Pollution [mg/h]
g	Gravitational acceleration [m/s^2]
H	Opening height [m]
n	Number of people
P_p	Pollution from people
Q_d	Total discharge flow [m^3/s^2]
t	time [h]
T_0	reference temperature [K]
T_1	temperature [K]
V	Free volume of the room [m^3]
W	Opening width [m]

Chapter 1

Introduction

In today's society we spend 90% of our time inside a building, whether it is a residential building, school, office or an athletic building. Air quality has had a lot of attention since Fanger started assessing the problem in the 70's. The beginning of this research however started already in the 1700s, with Lavoisier finding a correlation between the number of people in a room and how the air was perceived. [1–3]

Good indoor climate is crucial for maintaining a good health. Bad air quality can decrease productivity, cause irritation and eventually illness [4]. This master thesis focuses on the air quality in ice halls. This is done through measurements, surveys and literature studies.

1.1 Background

Indoor ice arenas offer a challenging environment for energy effective buildings and safe indoor air. The cold air temperatures required to keep a good ice quality can create humidity problems if the outdoor air is warmer. Spectators in bigger arenas expect to be in thermal comfort to a certain extent. These requirements creates a complex situation for ventilation and energy use.

The international ice hockey federation (IIHF) has technical guidelines of ice rinks, and among them are some recommendations for fresh air supply. The manuals and guidelines published by The Norwegian ice hockey association are the same as those from IIHF.

The air quality in ice halls was investigated in the 80's, 90's and 2000s. The resurfacer, the machine used to manage, scrape and re-surface the ice, released several toxic components such as carbon monoxide, nitrogen dioxide, nitrogen oxide and hydrocarbons. After the resurfacers switched to electric rather than fossil fuel the original problems have vanished. Not much has been done since this, so a general description on the temperature, CO_2 concentration and relative humidity can help with information on how the air quality is in an ice hall with an electric resurfacer.

1.2 Objectives

This master thesis is a continuation of a preliminary study performed the autumn of 2017 [5]. The preliminary study contains CO_2 measurements from two ice halls with different ventilation system, one with mechanical ventilation and one with recirculated air. This master thesis will continue to investigate the air quality and the perceived air quality in the ice hall with recirculated air.

The thesis is divided in five tasks, and the first four will be mentioned as research questions:

- Literature study on ventilation solutions in the exercise zone of an ice hockey arena.
- Carry out field measurements of indoor air quality in one ice hockey arena in Trondheim.
- Carry out a survey in the ice hockey arena with ventilation and without ventilation.
- Evaluate the performance of the ventilation method to improve indoor air quality in an ice hockey arena.
- Prepare a conference article to disseminate the research results.

1.3 Limitations

The final results are affected by the accuracy of the measurement equipment and external condition. The number of measurements could have been higher in order to achieve a better understanding of the transient situation for both matches and the decreasing CO_2 concentration during the night.

1.4 Structure

This thesis is structured in 9 main sections. The introduction gives a brief summary of the background and the objective of this thesis. Theory present basic information about ice halls, indoor environment and mathematical models necessary in order to solve the research questions. Case study is a section where information about the case hall, Dalgård, is given. Methodology explains the approach to the research questions, what methods have been used and how they were realised. The literature review examined the current literature available and state of the art concerning studies on ice halls and the effect indoor air quality can have on people. In the result section, the results from all the measurements are presented, and the results are discussed in the discussion section before the conclusion answer the different parts of the research questions.

Chapter 2

Theory

This theory chapter will present general knowledge and background knowledge required in order to complete the research questions. Studies, published papers and articles will be presented later in the literature review. This chapter builds on the work from a preliminary study in 2017, where the air quality of two ice halls with and without a mechanical ventilation system was compared [5].

2.1 Ice halls

Ice related sports used to be limited to the colder periods of the year. Modern ice halls maintain a low temperature and are able to create ice which extends the period of time when ice sports can be played. The international ice hockey federation released a guide to ice rinks in 2002 with extensive information on everything from construction to operation and economics [6]. According to it, a well functioning ice hall should have the following features:

- Insulated building envelope
- Mechanical ventilation
- Efficient refrigeration plant
- Efficient heating system, including heat recovery
- Air de-humidification
- Proper lighting

As of March 2018, NIHF has listed that Norway has 47 different ice halls across the country. Out of these, 4 does not have a designated spectator area and are only considered training halls. Comparing this to neighbouring countries with similar population and climate like Sweden (356 ice halls) and Finland (266 ice halls), Norway lacks some experience operating ice halls. [7]

2.1.1 Building

Ice halls have a different indoor climate compared to normal buildings. The different zones in the ice hall make things a bit more complicated than a building with uniform needs, and in table 2.1 the recommended design values on the rink and ice while playing ice hockey and tribune given from IIHF are listed. If figure skating was the main activity in the ice hall instead of ice hockey, the values would be different. In general, the temperature differences inside the building with different zones might reach 20°C.

Keeping the temperature at both high and low temperatures demands high energy use. The high energy use forces the building to focus on energy saving. Windows are a problem regarding energy use, because they can give unwanted heat and cooling. Heat transfer happen through both convection, conduction and radiation. Infiltration often takes place along the window frame, which will supply the building with fresh air based on the temperature difference. On a clear day, the sun will contribute with heat through radiation. Windows can also cause blinding for people inside the hall, and prevention of this require physical shading either from inside or outside of the building. These two problems has resulted in lack of windows along the walls. [8]

A unique problem to ice hall is fogging. Other buildings can be troubled with condensation, but this rarely manifest in a visual hindrance. This is particularly a problem in countries with warmer climate, as this happens often when outdoor temperatures are warmer than indoor temperatures. Dehumidifiers are used to combat this problem.

Table 2.1: Recommended design values from IIHF [6]

	Temperature			Max. relative humidity	Min. fresh air intake
	Ice	Rink	Tribune	of the rink space	l/s per occupant
Hockey-training	-3	+6	+6 to +15	70	4-8 / spectator 12 / player

These halls are used similar to other big athletic halls. Most users are younger people in school age. There is little activity in the daytime, however in the evening and weekends it has much more traffic. Technical equipment should be adjusted to this change in internal load. How and when these hall are used can vary between countries and climate. In Norway, ice sports are seen as a winter sport and the season goes from autumn to spring. In the summer time the ice is gone, and in some halls the area might be used for other purposes.

Flooring

The ice rink is normally covered in a layer of ice. This requires piping both for heating and for cooling purposes. The floor is subjected to cold temperatures, so a layer of heating pipes and insulation between the ice and the foundation should protect the foundation from freezing. In addition to prevent freezing, the heating pipes will help with the removal of ice once the season is finished. [6]

Board and protective glass

In an indoor ice hall the wall which surrounds the rink consists of several layers. First layer is a kickplate, followed by a board and on top of that is a protective glass. Out of these three layers, only the protective glass is translucent. Because of this, the spectators area is often elevated from the ground floor.

The glass is taller at the short side of the rink than on the long sides. Most places also have a safety net above the protective glass in these areas to catch hockey pucks. The international ice hockey federation has recommended values on the length of each layer. NIHF has accepted these values and uses them, and they are shown in Figure 2.1.[6]

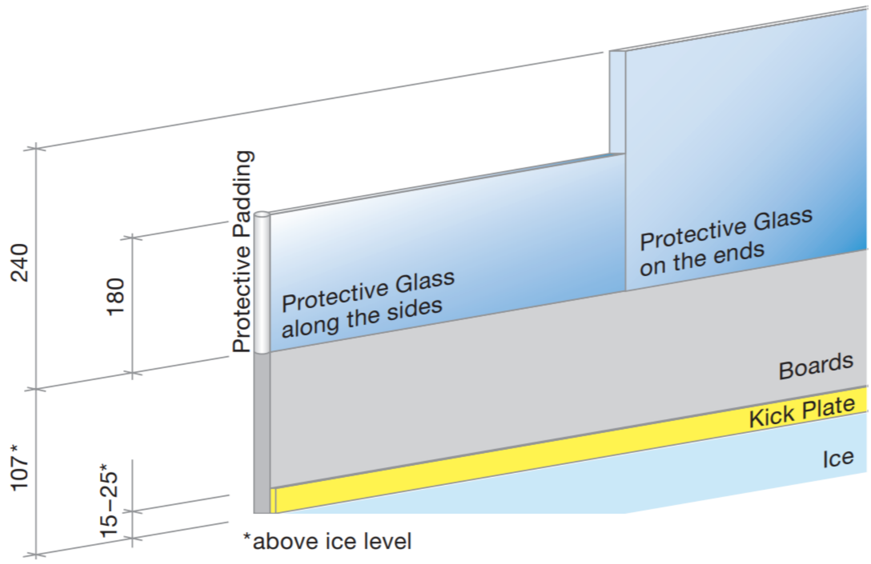


Figure 2.1: Illustration of kick plate, board and protective glass with measurements in cm. Picture is from IIHF's rink guide [6]

2.1.2 Technical installations

Ice halls need most of the same technical installations as normal buildings. The main addition is the need for cooling and de-humidification. Cooling is important in order to maintain the ice at a good quality, while de-humidification is important in order to have a healthy indoor environment without condensation and fogging.

An ice hall operates in the winter half year, but can in Norway experience temperatures from +15°C in September to -30°C in February. Too cold or warm temperatures will cause a problem when using the resurfacer to lay new ice as well as to the users of the ice hall. Ice suitable for ice hockey will have the best quality if the ice temperature is between -4°C and -5°C [6]. A higher temperature will create softer ice with less speed, and is used when laying ice for figure skating. A good heating and cooling system is therefore important in order to maintain a good indoor temperature throughout the season. Heating can either be done through radiators or ventilation system.

Ventilation is often divided in mechanical and natural ventilation. Fresh air is either supplied through an air handling unit as in mechanical ventilation, or opening of doors, windows and infiltration in leaks in natural ventilation. It is also possible to have mechanical ventilation without fresh air supply. A re-circulation system takes air from one area and distributes it in another area, often after heating or cooling the air first. A combination of fresh air and re-circulated air is often used in ice halls to control the relative humidity. The IIHF point out the importance of having mechanical ventilation and fresh air supply and have recommended a minimum fresh air supply of 4-8 l/s per spectator and 12 l/s per player in a small ice hall.

Lack of large window surfaces gives a larger need for good lighting. If the ice hall is big enough to play matches on, the lighting should be good enough for spectators and perhaps even filming for television broadcasting. IIHF suggest 500 Lux on the rink which equals to the requirements for office space.

One big difference compared to normal buildings is dehumidifiers. Usually the humidity indoor is acceptable as long as the building does not suffer from the moisture and starts to rot. The temperature in an ice hall however, is so low that condensation and fog can become a problem when the temperature outside is warmer than inside. An ice hall with recirculated air will have the de-humidifiers standing independent and supplying dry air for the rink, while a mechanical ventilation system with fresh air supply will also have a de-humidifier connected to the air handling unit.

2.1.3 Regulations

All buildings in Norway need to follow a set of regulations concerning health and safety. Those are the regulations on technical requirements for building works (TEK) and guidelines for in-door climate from the Norwegian institute of public health. If the building also ends up being a work place the working environment act must be taken into account.

The regulations on technical requirements for building works was first created in 1924 and has been regularly updated since then, every version adding a number behind the abbreviation and the newest version released in 2017 creating TEK17. Norway have no regulations or official guidelines created specifically for ice halls. The building envelope needs to follow TEK, but the design of ventilation, heating, recommended temperatures and relative humidity can be adjusted to preference. [9]

Normal health and safety precautions need to be taken while designing an ice hall with values from the Norwegian institute of public health [4]. For most people, the ice hall is a temporary place for leisure activities. In that case, the regulations are not as strict as if it had been used for longer periods of time. For example, the yearly averaged values of $PM_{2.5}$ is 8µg/m^3 compared to daily averaged values of 15 µg/m^3. The recommended maximum value of CO_2 is generalised as 1000 ppm because of its indicator properties [4].

Some people have the ice hall as their work place. Because of this, the indoor environment needs to follow the working environment act [10]. This act states the importance of ventilation to keep pollution levels as low as possible. With high temperatures, a higher ventilation quantity is needed because of higher evaporation from building materials.

2.2 Indoor environment in ice halls

Indoor environment is a diverse field separated into several parts. The human perception of indoor environment and air quality is dependent on each and every one of them. The seven elements which make up the indoor environment are explained in table 2.2

Table 2.2: The seven elements of indoor environment explained [11].

Elements of indoor environment	Explanation and some examples
Actinic environment	Levels of daylight, level of light, colour of the light, blinding, radiation,
Acoustic environment	Acoustic environment is decided from sound pressure levels and reverberation time, low frequency noise, infrasound
Aesthetic environment	Perception of how aesthetic the environment is, and individuals have differences in preference
Biochemical environment	Also called atmospheric environment and air quality, is determined by the gasses, smell, and chemical substances and particles in the air
Mechanical environment	Ergonomics, machines and tools
Thermal environment	Determined by air temperature, temperature gradient, radiation, air velocity and relative humidity
Psychosocial environment	Interaction between humans and how well people get along with each other

One basic way of measuring indoor environment is measuring how satisfied people are. If occupants or users of a building or room have problems with the indoor environment, it can have an impact on comfort, health and productivity in addition to affect certain products like food, paper and medicine. [11]

Human comfort can be described as a state where there is no desire to change any environmental parameters. The value of these parameters is difficult to define however, as every human is different and both social and physical aspects must be taken into consideration. Perceived air quality for instance, will be different if you are in the room for a period of time, or entering the room.

Assessing the perception of air quality can be done with different techniques. One way is with the unit decipol. One pol is defined as the perceived air quality with a load of one standard person with a ventilation rate of one l/s. As of yet, no instrument is able to measure decipol directly, so a group of subjects need to assess the air quality with a number from 1 to -1 in order to calculate the decipol of the room. A scale of acceptability, 2.2, is used by untrained people, and by doing this the percentage of dissatisfaction is found. [12]

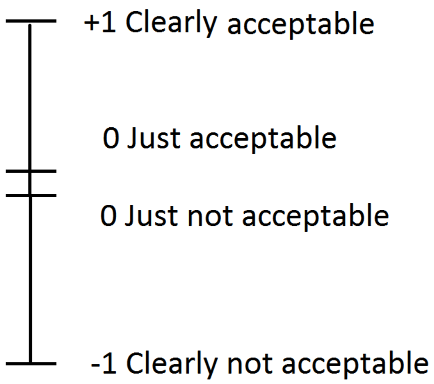


Figure 2.2: A scale of acceptability to use for untrained people [11]

2.2.1 Indoor air quality

Indoor air quality is used to describe the general cleanliness of the air. It is a combination of how it is perceived and what effect it can have on health, processes and products. Good air quality is air that have no harmful concentration of pollutants. There are regulations and standards for what concentrations of certain substances can be accepted, both averaged daily values and averaged yearly values. [2]

The indoor air can be polluted by emissions from materials, humans and processes or from outdoor pollution. TEK17 §13 states that a building should have ventilation which secure a satisfactory air quality. § 13-3 states that because of emission from materials, the minimum fresh air supply when the building is not in use is 0.7 m^3/h per m^2, and 2.5 m^3/h per m^2 when it is in use [9].

Pollutants from humans are mostly water vapour, odour and dust. A large concentration of these might be uncomfortable, but they are not dangerous. Processes and chemicals however, might emit or create substances that are dangerous to inhale. Combustion for instance is a common process where several toxic substances are created. The source of outdoor air pollution is divided into anthropogenic and natural sources [13]. Anthropogenic is pollution caused by human activity, like burning fossil fuels or agriculture. Natural causes of pollution like volcanic eruption or sandstorms are not possible to influence. If a building is in an area with high outdoor pollution, it is important to have a good filter in the air handling unit to clean the air before it gets into the indoor air and possibly make it worse.

One type of pollution is particular matter, PM; airborne particles also known as aerosols. These small particles are categorised after the particular diameter size. Coarse particles have a size above 2.5µm (PM_{10}), fine particles a size between 0.1-2.5µm ($PM_{2.5}$) and ultrafine particles are smaller than 0.1µm ($PM_{0.1}$). Dependent on the size and substance, PM can cause severe damage to lungs and respiratory system. [14]

CO_2 concentration has traditionally been used as an indicator of air quality and how contaminated the room is with bioeffluents [2]. CO_2 is often annotated with ppm, parts per million. Outdoor concentration fluctuates during the year, but the average concentration is around 400 ppm [15]. The Norwegian standard NS-EN-15251 describes the importance of taking the difference between indoor and outdoor concentration into account when assessing the air quality [16]. If a building was to achieve a maximum concentration of 1000 ppm, they should aim to have category 2 according to table 2.3.

Table 2.3: Recommended CO_2 concentrations higher than outdoor concentrations for demand regulation. The table is from NS-EN 15251 [16]

Category	Equivalent CO_2 concentration higher than outdoor concentration in ppm for energy calculations
1	350
2	500
3	800
4	> 800

Perception of air quality can be measured with several methods, but two of them are called Predicted mean vote (PMV) and Predicted percentage dissatisfaction (PPD). PMV is an index which goes from +3 to -3, and with equations it predicts the mean value of votes cast by using heat balance. This method should not be used if the outcomes is higher or lower than +2 and -2. By setting the equation equal to 0, the equation will present which combination of parameters like activity level, clothing and other factors can give thermal balance. [17]

PPD is used in order to find how many people will feel uncomfortable in a specific setting. Uncomfortable in this setting means choosing -2 og +2 on the PMV scale. The combination of PPD and PMV creates a function seen in figure 2.3. Even with optimal design, a 0% dissatisfaction can never be achieved. The reason for this is personal parameters like preference, age, health etc.

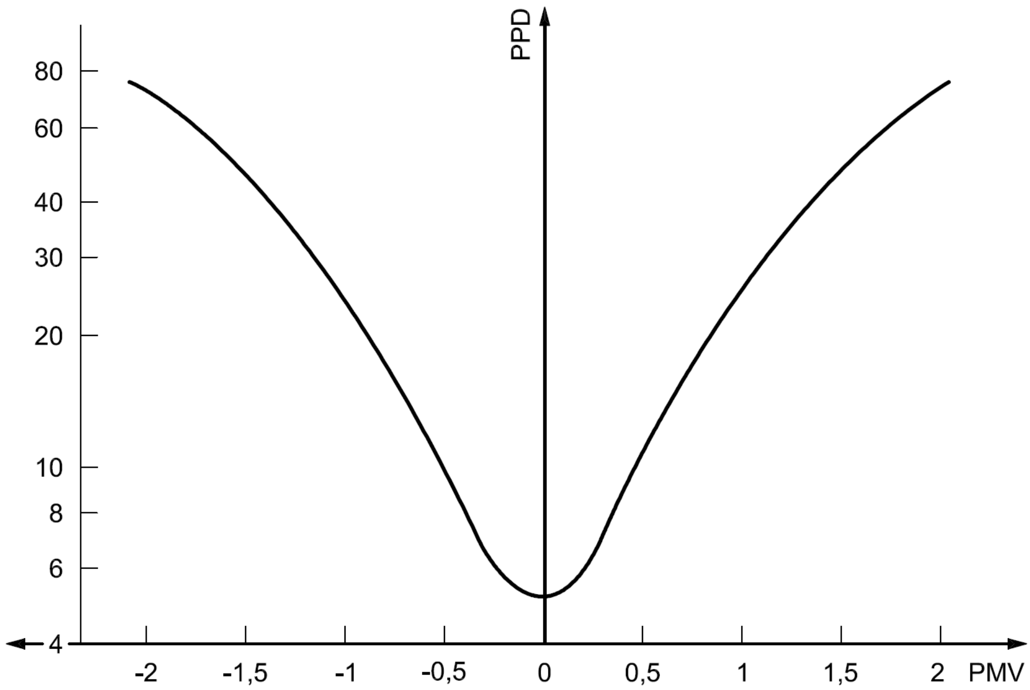


Figure 2.3: PPD as a function of PMV [17]

2.2.2 Temperature

Temperature or thermal environment is often measured with absolute temperature. Absolute temperature is the temperature measured by an instrument such as dry bulb, wet bulb or similar. Thermal environment can also be assessed with perceived temperature. What people perceived the temperature as, depends on both environmental and personal parameters. Personal parameters are often difficult to control for a whole group but can be easy to control on an individual level. The personal parameters are often divided into physical and psychological parameters. Physical parameters are metabolism, clothing level and health, while psychological parameters are stress, social relations and situation and personal preference. [12]

Environmental parameters such as temperature profile, air velocity, humidity and radiation is difficult for each person to control in order to fit their own preferences. Parameters that can be changed individually are metabolic rate and clothing level. The metabolic rate describes how much heat is generated and the mechanical work performed. Activity levels are equal to the mechanical work performed and as table 2.4 shows the energy created pr m^2 increases with higher activity levels. If all other parameters are constant, a person who increases their met from 1 to 2 will become warmer and might over time get uncomfortable.

Table 2.4: Metabolic rate at different activity levels. The table was originally created by Fanger in 1972 [3, 12]. [18]

Activity	Metabolic rate	
	met	W/m2
Seated, relaxed	1.0	58
Sedentary activity	1.2	70
Standing, light activity	1.6	93
Standing, medium activity	2.0	116
Walking 2km/h	1.9	110
Walking 5km/h	3.4	200
Ice hockey	8.0	-

When designing a building, only the environmental parameters can be decided. In order to achieve a well functioning building, the necessary and wanted temperatures must be assessed beforehand. This can lead to the demand for several zones. In an ice hall for example, the ice rink and the spectators area needs different temperatures. These two zones will have different climate with humidity and temperature, which can be a complex situation. If there is a cafeteria, that is yet another zone. Good engineering solution with heating, cooling and ventilation needs to be in place for the facility to have an optimal energy use.

Unless a room is completely sealed off from the outside with no plumes, the air will have some movement. This movement of air is important in order to distribute temperature, pollution and humidity. If the velocity is higher than 0.1 m/s it starts to become sensible to people in the room, and eventually it can be perceived as uncomfortable. Draft is defined as undesirable, local cooling of part of the body [2]. This sensation of draft becomes intensified if the air is turbulent. [12]

Draft is not only uncomfortable, but can create a bad working climate. The common illness cold seems to be easily caught if the feet is cold for 10-15 minutes [12]. The air often rises to the ceiling, go down near windows and reach a high speed along the floor.

It's not only humans that are affected by unwanted air velocity. The ice can also be affected if the velocity is high enough. High velocities across a surface increase the energy transfer [19]. The ice usually has a temperature between 0 °C and -4 °C, so leading warmer air along the surface will heat up the ice and give it a worse quality. This is not a wanted situation, a ventilation system in an ice hall must be design in a way that does not compromise the ice quality.

2.2.3 Humidity

A building envelope in the northern hemisphere is exposed to humidity from the outdoor climate and the indoor climate. Sources of humidity are emission from humans, materials or activities like washing and cleaning. Outdoor humidity is weather based, and different locations have different conditions depending on the climate.

Humidity in air is often mentioned as relative or absolute. Relative humidity is a percentage of how much water is in the air compared to the maximum capacity at a specific temperature. Absolute humidity is given in kg water per kg dry air. Colder air can hold less water than warm air, so air with two different temperatures will have different relative humidity even though the absolute humidity is the same. The Norwegian Labour Inspection Authority does not have a guideline for acceptable relative humidity. Normal variations during a year is 20% to 60%, and keeping the value in this range prevents good conditions for mould and mites [10]. [11]

It is advised that the indoor humidity should be somewhere between 40% to 60% in normal buildings. A high percentage of humidity will lead to condensation and with time, rot damages. Microorganisms such as dust mites, bacteria and viruses thrive in relative humidity above 60%. [2]

Relative humidity has a lower recommended value of 20%. This limit is often broken during the winter, when the outdoor air has a lower absolute humidity. In this period many can complain about dryness in eyes and skin, problem with respiratory organs and allergies. [2]

This indoor humidity has previously been ventilated out of the building through leaks and openings in the building envelope. With time, the buildings energy consumption has been evaluated and addressed. This has lead to a tighter envelope with less infiltration of air. A mechanical ventilation is therefore needed not only for supply air, but also for exporting pollutants and humidity out.

If a large amount of humidity is added to a room that is already saturated, or is allowed to accumulate, it is bound to start to condensate. For ice halls, this is highly problematic as the indoor air is often colder than the outdoor air at the start and end of a season. This has lead to a high demand of dehumidifiers for most ice halls.

2.3 Ventilation

Ventilation is the changing of air in a building or enclosure. Different ventilation methods and systems will serve different purposes, and every building needs to be examined in order to find the best solution.

2.3.1 Ventilation classified by driving force

The three main ventilation methods used in buildings are mechanical ventilation, natural ventilation and a hybrid ventilation. They are classified through their driving force. Natural ventilation is ventilation where infiltration and the openings like doors and windows are the main fresh air supply. It use the stack effect and wind pressure to move the air through the building [2]. The outdoor air is directly provided to the building without any form of treatment. This method is a cheap solution as it doesn't require any energy to run, but it can lead to draft and work best when the temperature difference between indoor and outdoor is large. Since the ventilation system does not have many mechanical components, it is not possible to recover heat. [11]

Mechanical ventilation uses an air handling unit along with fans, dampers and other mechanical constructions in order to supply air to the building. Mechanical ventilation is also known as forced ventilation, and is not dependent on the weather in order to supply fresh air. The mechanical components can demand a lot of electricity and over time be expensive to operate. With the use of an air handling unit it is possible to filtrate and temperate the air supplied to the building. Using ducts to transport the air through the building also make it easier to choose how the air is distributed through a room. Hybrid ventilation combines mechanical ventilation with natural ventilation. [2, 12]

2.3.2 Infiltration

Infiltration is a leak in the building body. Outdoor air unintentionally enters the room, and cause a higher heating or cooling demand depending on whether or not the outdoor air is warmer or cooler than the indoor air. [11]

No building is completely without leaks, and how tight a building have to be is regulated in TEK17. The air leakage rate per hour at 50 Pa pressure difference for small houses is equal to or less than 0.6 h^{-1} [9]. The leakage number have decreased a lot from 1985 when the value was 6 h^{-1} [20].

2.3.3 Air distribution

In different rooms the air will move differently. The way it moves is mainly depends on how the air is supplied to the room, but parameters such as temperature differences, height and room design must be taken into account.

Displacement flow

Displacement flow supplies air long the floor at a low velocity. The air then rises and is extracted near the roof. The temperature of the supplied air must be colder than the temperature in the room, which can lead to draft and uncomfortable low temperature for people near the supply valve. The upwards motion is run by the buoyancy effect, and increases when heat sources like humans or machines which emit heat is present. The air moving upwards along a heat source will be polluted by bioeffluents, heat and humidity. A boundary layer will form near the ceiling where the concentration of contaminated air is higher than in the rest of the room. For displacement ventilation to work as intended, it is important that the room is high enough for this boundary layer to be above the breathing zone. [12]

Mixing ventilation

Mixing flow will supply air at a high velocity in order to move the air. The velocity is often grater than 1 m/s, but is limited by the generation of noise. The placement of the supply valve is of less importance than for displacement ventilation, and can be installed both near the ceiling or side walls. The air jets exiting the supply vent will create a mixing motion in the room, and ideally the pollution in the room will be equally distributed. In reality corners are often areas where the air have not been fully mixed, and have higher contamination than the rest of the room. [12]

2.3.4 Regulations

There is no regulations specifically for ventilation of ice halls, so general regulations must be met when building such a facility. The ventilation requirements in construction works for the general public and work buildings from TEK17 are as following [9]:

1. An average fresh air supply of 26 m^3/h per person should be supplied to the building because of pollution.
2. The minimum fresh air supply should be 2.5 $m^3/h*m^2$ floor when the room is in use, and 0.7 $m^3/h *m^2$ floor when the room is empty.
3. Rooms with polluting activity shall have adequate extraction in order to maintain an acceptable air quality.

2.4 Mathematical models

Every situation can be described as a mathematical model, and often different ones are needed to explain the entire situation or in order to find unknown variables.

2.4.1 Mass balance

A mass balance describing how the CO_2 concentration changes during a time period can be designed. When choosing what kind of mass balance to use, it can either be a steady-state or a non-steady state balance. The difference is whether or not the situation changes throughout the time period. A non-steady state mass balance can look like equation 2.1. [12]

$$\dot{V}C_s + \dot{M} = \dot{V}C_r + V\frac{dC_r}{dt} \tag{2.1}$$

where:
C_s = Pollution concentration of supply air $[m^3/h]$
C_r = Pollution concentration of indoor air $[m^3/h]$
$\dot{M}$ = Strength of indoor sources $[m^3/h]$
$\dot{V}$ =Ventilation rate $[m^3/h]$
V = Free volume of the room [m^3]
$\frac{dC_r}{dt}$ = Change in indoor pollution over time

$\dot{V}$ is ventilation rate [m^3/h], and describes how much air goes in and out of the building body. This could be mechanical ventilation rate, or how much air goes through leaks and infiltration and through open doors and windows.

$\dot{M}$ is the pollution source [m^3/h]. The main pollution sources for CO_2 is human respiration and combustion from machines. At Dalgård, the resurfacer has no combustion as it is electric, humans are the only source of CO_2.

In this case, the equation is divided in four different parts, two before and two after the equality sign. $\dot{V}C_s$ and $\dot{V}C_r$ are similar to each other, and explain the concentration which comes in and goes out of the building. $\dot{M}$ is pollution from a source inside the building. $V\frac{dC_r}{dt}$ describes how the pollution change during a time period and this part has the designation of [µg/h].

Strength of source, $\dot{M}$

The $\dot{M}$ can often vary when the equation is used for a long period of time. When estimating the situation for several days, the ice hall will have periods of time when it is closed and no people are inside the building. If the mass balance is used for several consecutive days with the same opening hours, equation 2.2 can be used to describe $\dot{M}$.

$$\dot{M} = \left\{ \begin{array}{cc} 0 & \text{23:00-14:00} \\ n\,P_p & \text{14:00-23:00} \end{array} \right\} \tag{2.2}$$

where:
n =Number of people
P_p = Pollution from people

The pollution strength of the source depends on P_p, pollution from people, and n, how many people are in the ice hall at the time. The amount of pollution people emit is related to their activity level as shown in table 2.4. In a normal situation at least two pollution groups will be created, spectators which are sitting and athletes which have a high activity.

Ventilation rate, $\dot{V}$

The ventilation rate differs between opening and closing hours. When the ice hall is closed, the only air exchange happens through leaks in the building body. When the hall is open however, air will come through open doors as well as leaks through the building body. One situation in which the openings of doors can have a major impact on the indoor air quality is operation rooms, where the room is practically sterile. This theory on air through doors is therefore gathered from the article by Ljungqvist et al on contamination risk due to opening of doors in operating rooms [21].

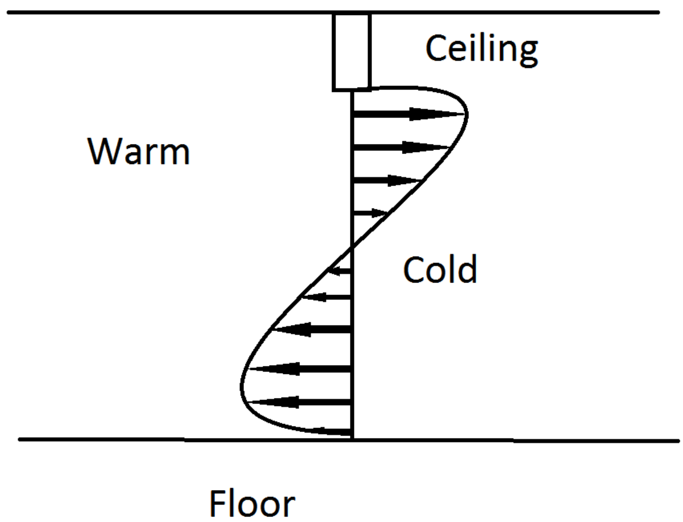


Figure 2.4: Theoretical visualisation of air movement through a door with temperature differences [21]

Air pass through an open door like shown in picture 2.4. Warm air goes through the upper part of the opening, while cold air goes through the lower part of the opening. An equal amount of air goes through both ways as long as the room is not over-pressured or under-pressured. [21]

The total discharge flow can be calculated in each direction with equation 2.3. This equation can be used for steady state conditions and at fixed dimensions.

$$Q_d = C_d \frac{WH^{3/2}}{3} \left\{ g \frac{\Delta\rho_0}{\rho_{0m}} \right\}^{1/2} \tag{2.3}$$

where:
Q_d = Total discharge flow [m^3/s^2]
C_d = Discharge coefficient
W = Opening width [m]

H = Opening height [m]
g = Gravitational acceleration [m/s^2]
$\Delta\rho_0$ = Density difference [kg/m^3]
ρ_{0m} = Mean density [kg/m^3]

The total discharge flow is dependent on mean density and density difference, and a relation to mean and difference in temperature can be derived with the help of the equation for ideal gas, as shown in equation 2.4. A higher temperature difference will create more air exchange through an opening. If the two sides of the door has the same temperature however, no forces will work on moving the air through the door and Q_d will be zero.

$$\frac{\Delta\rho_0}{\rho_{0m}} = \frac{2\Delta T}{(T_1 + T_0)} \tag{2.4}$$

where:
Δ T = temperature difference [°C, K]
T_1 = temperature [K]
T_0 = reference temperature [K]

Opening and closing of doors is not a steady state situation however, and the dimensions of the opening area will change as the door opens or closes. Some of the parameter that should be added to equation 2.3 is how long the door is open, how long the door is fixed in the open position and how long the door takes to open and close as well as the direction the door moves in.

The door at Dalgård moved sideways, and does not open in a circle motion. This has to be taken into consideration when finalising the equation and calculating the ventilation rate at a specific time.

2.4.2 Air change per hour

Air change per hour (ACH), also called air exchange rate, describes the time taken for the entirety of the air in a building to be changed one time. This does not take into consideration possible boundaries or dead zones in the building, but only focuses on air exchange and contamination.

In order to calculate the ACH, the equations must be based on non-steady state conditions. Equation 2.5 explain the situation while considering internal and external pollution, ventilation rate, time and the volume of the room. This equation could be used in order to calculate the CO_2 concentration and compare those results with the measured values.

$$C_i = C_0 e^{(-\frac{\dot{V}}{V}t)} + C_s\left[1 - e^{(-\frac{\dot{V}}{V}t)}\right] + \frac{G}{\dot{V}}\left[1 - e^{(-\frac{\dot{V}}{V}t)}\right] \tag{2.5}$$

Where:
G = pollution [mg/h]
C_0 = indoor pollution at the beginning of measurements [mg/m^3]
C_i =Indoor pollution [mg/m^3]
t =time [h]

If the ACH is going to be calculated based on measurements done during the night, two simplifications can be done. Both G and C_s can be set to zero. That will create equation 2.6

$$C_i = C_0 e^{(-\frac{\dot{V}}{V}t)} \tag{2.6}$$

Changing the equation in order to get the ACH by itself will give equation 2.7. For this equation to work it must be assumed that the ventilation rate is constant during the time, t.

$$ACH = \frac{\dot{V}}{V} = \frac{lnC_0 - lnC_i}{t} \tag{2.7}$$

Chapter 3

Case study

Dalgård ice hall was built in 1989 in Byåsen, a district in the Norwegian city of Trondheim. Along with a football field and an athletics facility as shown in Figure 3.1, this is a popular area for local sport activities. The ice hall is in operation in the winter period with activity starting in September and closing in March/April.

Figure 3.1: Dalgård area, picture: Gulesider.no.

3.1 Zones inside the hall

The ice hall is divided in several areas or zones which have their own climate. In this thesis the measurements will focus mostly on the ice rink, spectators area and sharpening room, but the ice hall in general will be looked at through a survey.

Figure 3.2: The inside of Dalgård ice hall, photo: Linda Strand Prestmo.

This ice hall has a spectator area on the west side, capable of holding up to 1050 spectators. Below this area are the locker rooms, in addition to an outdoor locker room outside on the right side. In the middle towards south is a cafeteria which sells food, beverages and snacks. On the right side is a narrow passage and a place for the ice hockey players to sit during a match. The ice hall has a total of four doors. Two doors on the west side of the building, one near the middle of the ice rink and one in the corner. The other two are up near the spectator area, but is rarely used.

3.1.1 Ice rink

The ice rink has no ventilation of fresh air supply, the only source is opening of doors. The two de-humidifiers are installed in the opposite corners of the ice hall. They are leading dry air along the ceiling.

3.1.2 Spectators area

The spectator area is along the west side of the building and can be seen in Figure 3.2. It can fit up to 1080 people, though it rarely reaches this amount of spectators. The area is one floor higher than the rink, and is heated through warm, recirculated air distributed from the ceiling.

3.1.3 Cafeteria

The cafeteria is run by volunteers from Astor ice hockey club. The opening hours vary depending on the day and week, as the activity level changes throughout the year. It is a warm place where spectators and athletes can buy food, beverages and snacks. The room has no fresh air supply, and relies on opening of the door out to the ice hall for changing the air.

3.1.4 Locker room

The locker rooms are mostly located below the spectators area, and the door can be seen in the middle of figure 3.2. A total of three locker rooms can be found, in addition to a locker room for the referees and one room in a separate building on the east side.

3.1.5 Sharpening room

Dalgård has one room used to sharpen skates. As figure 3.3 shows the room is small and even though there is a duct in the room, it is not connected to a functioning ventilation system.

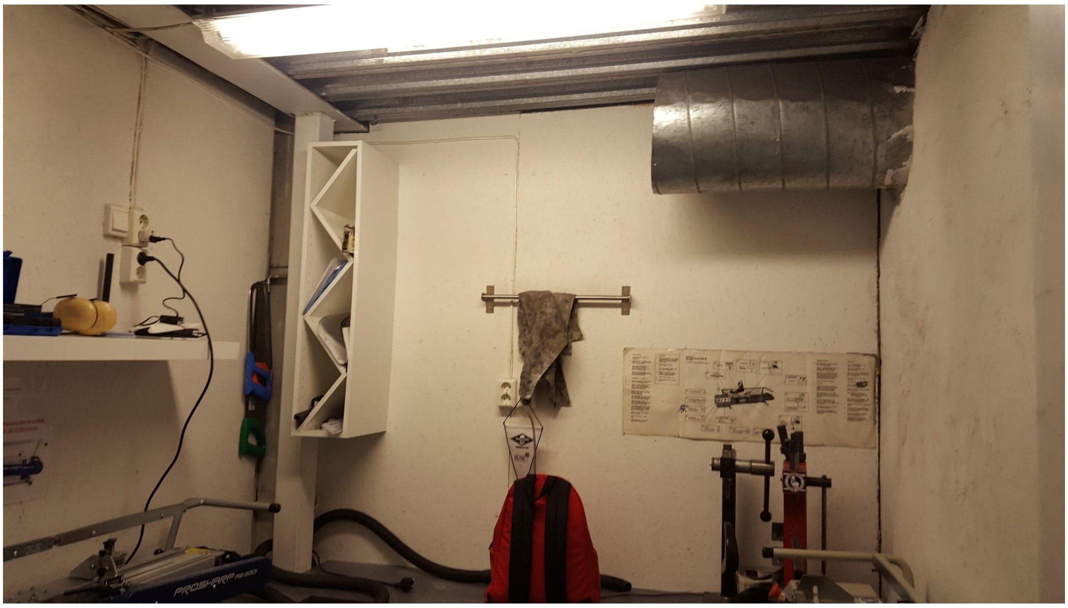


Figure 3.3: Room for sharpening skates, photo: Linda Strand Prestmo.

The room used for sharpening skates originally only permitted club-members to enter and use the equipment with a password protected door, but the password has been shared through social medias so many people have now access to the room. A club member regularly sharpening skates confirmed the safety routines in the room. The safety concerning the sharpening was a priority, with routines in place to not harm the skate or the person in the room, and to create the best skates. Protective items like masks or glasses were available, but not used.

3.2 Ice specific equipment

The ice surface has the dimensions 60 meter long and 29 meter wide, and is following both the recommended values from the Norwegian Ice Hockey Association and the International Ice Hockey Federation [6, 22].

The protective glass is newly upgraded and fits according to the new rules, as NIHF and IIHF demands. Compared to older glass, the new ones are generally lower, more flexible and higher behind the goals. This creates a safer environment to ice hockey players, and has shown to lessen the injuries to the head and shoulders.

The ceiling is layered with an insulated, reflecting material. This keeps the roof cold when the sun is up, and decrease the temperature stratification and the risk of condensation.

The resurfacer used in this ice hall is an electric machine called Olympia IceBear. This machine will scrape the ice while simultaneously adding hot water in order to create a smooth surface.

3.3 Ventilation

Dalgård does have two exhaust ventilation fans and a re-circulation system. They are installed at the south-wall of the building. The fuses attached to the fans are undersized, which has led to them being disconnected. This have resulted in lack of fresh air supply. The re-circulation system heats air from the east side and supply it to the spectators area on the west sidek. The re-circulation system is automatic and start based on a time schedule on what activities are to take place that day. In addition to this, the hall also have two de-humidifiers in order to prevent condensation. These machines start automatically when the humidity reach a certain level.

3.4 Usage

Dalgård is used both for training and for matches by local ice hockey teams. They also have times designated for figure skating. Table 3.1 shows the opening hours through the week. In this period, both organised activity and free time is included. Dalgård is open for everyone every Saturday from 10:00-12:00, and is used for families and other people who want to use the ice.

Table 3.1: Opening hours at Dalgård

	Open	Close
Mon, Tues, Thur	14:00	23:00
Wednesday	16:00	23:00
Saturday	10:00	20:00
Sunday	09:00	23:00

Chapter 4

Methodology

This chapter will explain which methods were used for solving the different parts of the thesis and how they were carried out. The thesis is divided in four five parts. The first four are research questions this report tries to answer, while the last part is a conference article that is handed directly to the thesis' supervisor as agreed.

4.1 Literature review

The first part of the thesis was to find relevant literature. The literature study's main task was to find information on what has been done regarding ventilation solutions in ice halls. It was expanded to also contain work on air quality, the impact CO_2 can have on humans and general technical advancement with equipment in the ice hall.

Relevant literature was found in different ways. The first step was to search for it in databases, using words from table 4.1. When a good article was found, looking through articles they have cited was a second step for finding good literature. The last step was looking at articles which had used them as references. A combination of all these steps were used continuously throughout the work on this thesis.

Literature was searched for in different available databases. The first databases used was ScienceDirect, Oria, and Scopus, as they search through a wide variety of different engineering fields. Wiley, PubMed and Reasearchgate in combination with Google Scholar was later used to search for specific topics. While Pubmed has literature focused on health, Wiley has more on indoor climate. Researchgate was a good site for finding authors and their project, but Google Scholar had to be used to find most of the literature from them.

Table 4.1: Search words

Ice hall	CO_2	Cognitive functions	Ventilation
Ice rink	Air quality	Performance	Air distribution
Sports hall	Indoor air pollution	Learning	Productivity

4.2 Survey

Two surveys were conducted in total. The first one was an electronic survey directed towards users of Dalgård ice hall and how they perceived the air quality. The second survey was conducted through phone calls directed towards employers in charge of operating ice halls in Norway, and what kind of ventilation system they had installed.

4.2.1 Perceived air quality

This first survey was about perceived air quality from the users of the ice halls. The sample which answered the survey was found mainly through the local ice hockey club, Astor and other local ice clubs that either have training or matches at Dalgård. The team leaders for each 4th division team and for the Oldboys teams were contacted, and most agreed to forward the survey to their team.

The questions in this survey focused on air quality in general, air quality in specific area of the ice hall and possible health symptoms of bad air quality.

NTNU offers two different tools for conducting online surveys. The chosen solution was SelectSurvey. This is the university's own system. The answers are gathered and stored at their server. According to NTNU's norms, this survey was registered at the Data Protection Official (NSD. Both the survey and the acceptance letter is attached in the appendix D and C.

4.2.2 Ventilation systems in ice halls

The second survey was a mapping of ventilation systems used in Norwegian ice halls. A list of every ice hall in Norway published from the Norwegian Ice Hockey Association was used to find the sample. Contact information for each hall was found through the halls, or the local ice hockey clubs website. The ice halls were first contacted with a phone call, and those who didn't answer was contacted through e-mail.

The question asked was whether the ice hall had installed a ventilation system which utilised fresh air or recirculated air. If the ice hall had both options available, when were each solution used. In addition they were free to give comments on how they operated the ice hall and why.

4.3 Field measurements

From a preliminary study, it has already been established that the ice rink might have a sub-optimal indoor climate and dead spots. More measurements were necessary in order to get results on how the air quality is in different situations. It was decided to do the following steps:

- Measure the difference between the CO_2 concentration on the rink and the spectator area, with adults and youths on the ice
- Measure the CO_2 concentration in the rink during a night
- Measure the temperature at different heights in order to create a temperature profile

Three different measurement devices were used during the in total three weeks of measuring, with different properties and functions. The EasyLog and Rotornic was borrowed from SIAT and another faculty and therefore had a limited period available for use. The instruments used for the field measurements will now be presented:

4.3.1 EasyLog, EL-USB-2

The EasyLog instrument is one USB stick with sensors for temperature and relative humidity, seen in figure 4.1. Along with the corresponding software, this is a simple device suitable for measuring several points. In total 6 USB sticks were available, and they were used in order to find a temperature and RH gradient. The specifications for the instrument can be found in table 4.2 and the original values come from the producers website [23].

Figure 4.1: EL-USB-2, picture retrieved from producer [23]

Table 4.2: Specificaitons for EasyLog

	Temperature	Relative humidity
Measurement range	-35°C to 80°C	0 to 100%
Accuracy	0.55°C typical (5 to 60°C)	2.25% typical (20 to 80%)

4.3.2 Rotronic, CP11

The CP11 is a handheld device with the possibility to record CO_2 concentration, air temperature and relative humidity. It can be seen in figure 4.2. Two of these were used in order to assess the difference between the ice and the spectators area. The device on the ice was attached to a referee skating over most of the rink area. Specifications are shown in table 4.3 and the values are derived from the producers website [24].

Figure 4.2: Rotornic CP 11, picture retrieved from producer [24]

Table 4.3: Specifications for Rotornic

	CO_2 concentration	Relative humidity	Temperature
Measurement range	0-5000 ppm	0.1% to 99.95%	-20 to 60 °C
Accuracy at 23 ±5 °C	±30 ppm ±5 % of the measured value	<2.5 % (10-90%)	±0.3

4.3.3 Beijing green built environment technology, QD-M1

The QD-M1 is a measurement device able to detect $PM_{2.5}$, HCHO, CO_2, temperature and humidity. Real time data can be displayed and viewed on an app on a tablet or a smart phone, and recorded data can be exported to a computer. This device was used specifically to measure the $PM_{2.5}$ levels in the sharpening room. Since it needs constant power supply, it is not suitable for measuring different part of the ice hall out of reach for a power supply or measuring while moving. The values from table 4.4 were delivered directly from the producer through e-mail, and figure 4.3 is from the producers website [25].

Figure 4.3: QD-M1, picture retrieved from the producers website [25]

Table 4.4: Specifications for QD-M1

	$PM_{2.5}$	CO2 concentration
Measurement range	0-500 µg/m3	0-5000 ppm
Accuracy	±10%	±10%

4.4 Measurement setup

As mentioned earlier, four different parameters were measured through three different instruments. In table 4.5 an overview of the measurements is found. The reason every parameter was not measured every time was largely due to high demand from other students waiting to use them for their work. How the instruments were used and when will be explained in detail later on.

Table 4.5: Overview of when the different parameters were measured

Measurements	CO_2	Temperature and humidity	$PM_{2.5}$
Week 11	X	X	X
Week 14	X	X	X
Week 16	X	-	-

4.4.1 CO_2 concentration

The preliminary study determined that the CO_2 concentration can get too high during a day at Dalgård, with values up to 1400 ppm [5]. It was of interest to further examine how the CO_2 concentration developed during a day, and especially during an ice hockey match.

The measuring techniques and results are divided into day and night. During the day, two instruments were used and the same set up is valid for all four days. One was placed in the spectators area, an elevated part of the ice hall, while the other was attached to the back of a referee. The instrument was placed in a sports belt originally used for a water bottle as seen in picture 4.4, which prevented the referee to be restricted by the device.

(a) Device in the bag **(b)** Securing the device

Figure 4.4: CO_2 logger in the belt

The night measurements were important in order to find how the CO_2 concentration declined during the night, and was performed 18.03 and 08.04. During the night one instrument was used and the instrument was placed on top of some crates in order to get values from 1 meter height. As shown in figure 4.5, the device was located in the middle of the ice rink. Measuring started when the ice hall closed and ended when the hall opened.

(a) A close look on the set up

(b) Location on the rink

Figure 4.5: Placement of the CO_2 logger

Sunday, 18.03

Sunday was a day full of matches from morning to evening. The events during measurements are listed in table 4.6, but several matches were also played later in the evening. During the break from 12:45 to 13:55 both instruments were inside the cafeteria while a national championship finale was played on the ice.

Table 4.6: Events on Sunday, 18th of March

Time	Event
09:25-10:42	Match 1
12:45-13:55	Match X, not measured
14:00-15:13	Match 2
15:17-16:40	Match 3

Each team playing all three matches had between 10 and 20 players ready to play on the bench. During a match, the next two teams used the ground floor to warm up. A total of 10 athletes were at the ice during a match, along with three referees. Each match had two periods of 20 minutes except the final at 12:45 which had three periods of 20 minutes. In the break between two periods, both instruments were brought to the referee's wardrobe.

Friday, 06.04

The U15 team played one match and was a team consisting of teens up to 15 years old, mainly boys but also some girls. Each team had 10 athletes on the ice, and the whole team was changed simultaneously on both sides a couple of times during the match except the goal keeper. The team played two periods with a break in between.

Sunday, 08.04

The Sunday was a day full of matches for children, U11 and U12 teams. These teams had children aged up to 11 and up to 12 years old, and boys and girls played against each other and were on the same team. A total of three matches were played, with a break between the second and third as shown in table 4.7. In the break, there was no activity on the ice. During a match, 10 athletes were in the ice rink at all times. The entire team on both sides were changed every minute except the goal keeper. One period were played, and the changing of the team took a lot of time.

Table 4.7: Matches on Sunday, 8th of April

Time	Match
11.05-12:13	Match 1
12:33-13:45	Match 2
13:45-15:30	-
15:30-16:29	Match 3

Friday, 20.04

The last measurement day focused on adults, the Oldboys team. The Oldboys team consists of older men playing against each other as a hobby and for fun. Each team had 10 athletes on the ice at all time, and they changed the whole team except the goal player a couple of times during the match. Two periods were played with a break in between.

4.4.2 Temperature and relative humidity

Temperature was measured in two period, one period in week 11 and period in week 14. The two periods differs in length, but the placement of the instruments were the same both times. This was important in order to get results which could be used in creating a temperature and relative humidity gradient.

The EasyLog USB data loggers were installed in the ice hall in the evening on Saturday, 17th of Mars. They were installed at three different height: 1 meter, 2 meter and 3 meter. Table 4.8 shows the name of the six loggers and at what height they were installed at.

Table 4.8: Placement of the USB loggers

Installation height	USB point	
1 meter	1	4
2 meter	2	5
3 meter	3	6

At 1m and 2m, the instruments were installed on the inside of the protective glass facing the athlete boxes, as shown in figure 4.6 a). The instrument installed at 3 meters was attached to the net, which resulted in different locations for the three instruments as shown in figure 4.6 b) and c).

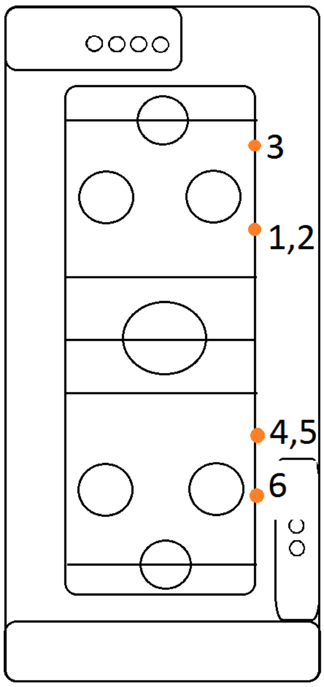
In point 1, 2 and 3 the USB loggers were not disturbed by anything, and experienced normal conditions. The USB loggers in point 4, 5, and 6 however, was installed just below one of the de-humidifiers and could be disturbed by changes in temperature or relative humidity.

In week 11 the loggers were programmed to start recording at 06:00 Sunday morning, every 5 minutes until manually stopped. Starting the recordings this early would give an understanding on how the conditions in the ice hall were before the activities started. The loggers were retrieved on Monday morning, having recorded for about 25 hours.

In week 14 the loggers were programmed to start recording at 06:00 Tuesday morning, every 5 minutes until manually stopped. They were taken down Monday morning the following week, and logged for 6 days in total.

(a) Placement on 1m and 2m

(b) Placement of 3m



(c) The six Easylog was placed on 4 different places. One on the top and bottom, and two on the others

Figure 4.6: Placement of EasyLog

4.4.3 $PM_{2.5}$

The sharpening room was investigated with some concerns about the possibility of high dust values in the air. PM 2.5 was measured twice, and both times the set up was as shown in picture 4.7. During this time, the CO_2 values and temperature values were also recorded.

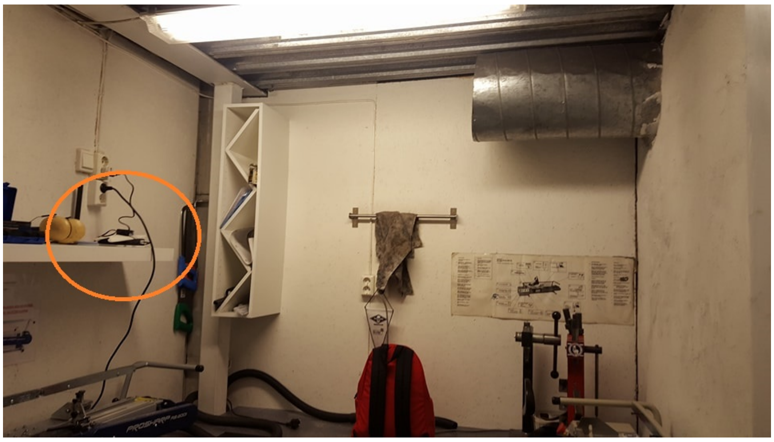


Figure 4.7: Sharpening room, photo: Linda Strand Prestmo

The first measurement was performed in week 11, and lasted from 15th to 17th of March. The second measurement in week 14, and lasted from 3th to 14th of April.

4.4.4 Placement of equipment

The placement of IAQ monitors is important in order to get good results. Dalgård has three zones which will be focused on. Ground floor with an ice rink, first floor with a spectators area and the sharpening room on the ground floor.

A review of measurement procedures by Mahyuddin and Awbi investigated how a group of bachelor degrees, master degrees and PhD's executed measurements [26]. The findings stated that 73% agreed that the positioning of CO_2 sensors affected the assessment of air quality. In the group who answered to the survey, 34% had the sensor positioned in the middle of the room, 15% near occupants, 10% on a shelf and 9% near a wall.

The placement of equipment was for this thesis decided based on recommendations and purpose. The Rotronic which measured CO_2 concentration had restrictions on where it could be placed and was attached to the back of the referee. This height is too low to be in the breathing zone for adults, but will be around breathing height for a lot of children. The QD-M1 was placed in the breathing zone of adults, while the EasyLog was supposed to create a temperature gradient and was not as dependent on where the breathing zone was.

4.5 Citation

Vancouver is the chosen citation style through this thesis, a style that make use of numbers with corresponding entries in the reference list. A large number of references have been used in order to make a thorough understanding of the theory behind the research question as well as the literature search. This style was chosen in order to create a better flow reading through the text.

The citations have been placed in two different places through the thesis. The first place is at the end of a sentence. When this is done, that specific sentence is from the cited source. The second place is at the end of a paragraph. This way cite the whole paragraph, and not only one sentence. This has been used for example when a topic is well covered from a textbook. Both these methods can be used simultaneously, for example when most of a paragraph comes from one source except one sentence.

Chapter 5

Literature review

One of the research question is to perform a literature study. While the theory chapter includes accepted knowledge, this chapter will review what work and studies have been done regarding several themes relevant for this thesis. The literature review is divided into three themes: Indoor climate, ventilation and health effects.

5.1 Indoor climate in ice halls

Air quality and perceived air quality have an important distinction. People might perceive air quality to be better or worse than it actually is, depending on a lot of different parameters. Studies have shown that colder temperatures will make people perceive a better air quality than warmer temperatures if all other parameters are kept constant [27–29]. Similar results could have been seen in ice halls if tested, where players and spectators could perceive the air quality better than it is simply because of the cold temperature.

The indoor air quality of ice halls has had a lot of attention, as an enclosure with combustion needs a good ventilation system in order to keep the people inside from getting sick. An increased breathing frequency reinforces the importance good air quality has, as toxic components would gather up faster for people who exercise.

A paper focusing on the problems created by the exhaust from the resurfacers were published already in 1971 and several papers have been released since then [30]. In that paper, they mentioned illnesses from carbon monoxide and nitrogen dioxide.

A systematic review of published papers investigating the indoor air quality of sport facilities and building used for physical activity was released in January 2018. They found that the most investigated air pollutants were CO, particulate matter and NO_2 with 18, 15 and 14 studies, and these also had the longest history of being monitored. The three parameters following them were temperature, humidity and CO_2 with 11, 9 and 9 studies. Ice halls is the sport facility that have been most investigated. [31]

In 2011 Brauer et al published a paper with an extensive mapping of NO_2 values in international ice halls [32]. 332 ice halls in nine different countries were examined, and among these about 40% had 1-hour NO_2 values that exceeded the recommended values from the World Heath Organisation. Lee et al examined the CO and NO_2 levels in an ice hall with different use of fuel and operation of the ice hall [33]. They concluded that a combination of full operation of ventilation with fresh air and less operation time of the resurfacer is needed in order to reduce the toxic substances in the air.

Both NO_2 and CO are toxic, which means that high concentrations will give immediate symptoms. Particulate matter however builds up over time. For people in high activity this is dangerous, as respiration through the mouth does not filtrate big particles the same way as nasal respiration [31].

Several papers have examined the correlation between particulate matter and decay of pulmonary functions. Athletes who exercises in ice rinks does not experience the same harsh temperatures as other winter athletes. Particulate matter has therefore been assumed to be the source of the high prevalence of airway symptoms like asthma. [34, 35]

5.2 Ventilation

Currently there is a lack of good standards or guidelines on how a ventilation system for ice halls should be designed, and few studies have been conducted in order to examine how different ventilation systems and designs work in a climate such as an ice hall.

Palmowska and Lipska performed in 2016 several experiments to verify their CDF simulation of an ice hall [36]. The CDF model was made in Ansys CFX, and the model was able to map real condition with maximum mean deviation of 0.03 m/s for speed, 1.1 °C for temperature and 15% relative humidity. The same model was later used for a paper by Palmowska and Lipska published in 2018 [37]. Additions to the model for the second study study was air humidity ration comparison, skaters and spectators. This allowed them to investigate the influence humans had on different parameters. One of the conclusions from this was that the main cause of excessive moisture was outdoor air, and they advised to keep the fresh air supply to a hygienic minimum.

Toomla et al. recently published an article investigating the air distribution and ventilation efficiency in an ice rink arena with mixing ventilation [38]. With extensive experimental measurements, an overview of relative humidity, carbon dioxide, air velocity and temperature was made. The ice hall had mixing ventilation and a tracer gas experiment showed that the ventilation system was flawed and did not succeed in mixing the air, creating two layers. The fresh air supply was low, around 4%, and resulted in an ACH of 0.03 h^{-1}.

At least two user groups have different needs in an ice hall, the skaters and the spectators. The two zones of different temperature might get their needs fulfilled if they were supplied by two different ventilation systems. Lestinen et al. investigated the indoor climate in a Swedish multipurpose arena, which had both displacement ventilation and zoning ventilation, with experimental analysis and a CFD simulation [39]. They concluded that a combination of displacement and zoning ventilation was suitable for a multipurpose arena, but the measurements were only conducted in the spectators area.

Stobiecka et al. have done a numerical study on two different kinds of ventilation system [19]. The first system was a traditional integrated system, the second system was a separated system where the spectators and players were supplied with air from two different sources. The results from this study has not yet been validated through an experimental test. In this study they concluded that while the separated system have larger areas where the air velocity is higher than wanted, the traditional system is less effective due to the incapability of removing plumes.

5.3 Health effects

Sport facilities in general are characterised as a place where physical activities are performed. The athletes or people using the facility will be dependent on good indoor condition to enhance the physical and psychological performance.

Over the years, several studies have examined the correlation between air supply and perceived air quality with sick building syndrome and productivity. The focus has been in offices, as a company would lose more money if the employers have a worse productivity because the ventilation system is not good enough.

Wargocki et al. performed a study in 2000 with 29 female subject, and showed that an increase of air exchange rate from 0.6 to 6 per hour in an office space increased the overall productivity by 3.4% [40].

Sick building syndrome is a complex set of symptoms some individuals experience while staying inside a specific building. This illness appears even though the building seems healthy with no moisture damage or certain allergenes in the air. Some of the symptoms are respiratory problems, itchy and sore eyes, irritated nose, cough, drowsiness and headaches. The symptoms go away when leaving the building. Seppänen et al. found that with a ventilation rate above 10 Ls-1 per person the reported symptoms decreased significantly, and kept on sinking until the carbon dioxide levels reached 800 ppm [41]. Tsai et al. supports this conclusion, and found that with a CO_2 concentration above 800 ppm problems with the mucus membrane and upper respiratory problems began to increase [42]. [43]

A correlation between indoor humidity and respiratory problems have been confirmed. Low relative humidity in an office with a reference temperature at 25°C is often associated with an aggravation of asthma, allergies and respiratory infections. Problems identified in such buildings are dry skin, dry eyes, respiratory problems and negative effects on the mucus membrane [44]. Studies have shown that a combination of low temperatures and low humidity is connected with respiratory tract infections [45]. While low temperatures were associated with lower respiratory tract infection, low absolute humidity is associated with upper infection. The mean average daily temperature before a respiratory tract infection was detected in this study as -3.7°C ± 10.6°C.

CO_2 concentration and health

CO_2 is generally seen as an indicator of air quality. Comparing the indoor concentration with the outdoor concentration gives a number on how much contamination is released from humans and equipment as well as how effective the ventilation system is. CO_2 has not been proven to be harmful before it reaches a high level of 10,000 ppm [4].

Newer studies have been debating whether or not CO_2 itself can be seen as a pollutant, and what effect it has on the human brain. Satish et al. released a paper in 2012 raising the question whether or not CO_2 itself could be considered an indoor pollutant, and examined if 9 different decision-making parameters were affected by an increase of CO_2 concentration [46]. The three different pollutant levels used in this study were 600 ppm, 1000 ppm and 2500 ppm, and the participants were exposed for 2.5 hours. At a 1000 ppm, 6 out of 9 parameters decreased moderately, while at 2500 ppm large reductions occurred compared to 600 ppm.

In the years after this paper was published, several other studies have examined how CO_2 pollution can affect the mind of people in a room. This have been especially interesting for people in office areas or schools, where these parameters are affecting their performance and learning.

A paper published in 2016 had 24 participants who spent a working week in an environmentally controlled office space, 8 hours a day for 6 days. The different days had different environment concerning VOC, CO_2 concentration and supply air representative to conventional and green office buildings in the U.S. [47]

Both the paper published in 2012 and the paper published in 2016 were done with the same system for measuring cognitive function, Strategic management simulation (SMS). The results from the paper can be seen in table 5.1.

Table 5.1: Findings from higher CO_2 concentration in the two studies

CO_2 concentration, in paper from 2012 [46]	600	1000	2500
Reduction from mean raw scores from 600 ppm	-	11-23 %	44-94%
CO_2 concentration, in paper from 2016 [47]	550	945	1400
Reduction in cognitive function scores from 550 ppm	-	15%	50%

A study from Denmark in 2016 sought to examine the effects of 5000 ppm on health symptoms, performance on cognitive tasks, sensory comfort and changes in physiological responses. In this study, 10 college students were exposed for 2.5 hours while performing different tasks such as text typing and addition. They failed to conclude that 5000 ppm had a significant impact on cognitive functions compared to 500 ppm. [48]

This study had a different way to test the subjects, and the testing could have an impact on how the end results will be. Further studies needs to be done in order to determine how the CO_2 affects the health and performance in normally found concentrations.

In 2016, Zhang et al. published a paper examining how humans were affected by different CO_2 concentrations. The CO_2 was added in the room in two ways. The first method was by adding chemically clean CO_2 in a room where the ventilation system removed the bioeffluents. The second method was by using only bioeffluents. The ventilation was restricted so the CO_2 concentration rose due to human pollution. The results showed that the amount of CO_2 did not give a significant effect on the perceived air quality when chemically clean CO_2 was added. Pollution through bioeffluents however reduced the perceived air quality and increased the number of health effects reported. [49]

In 2017, 499 female students at a University in Saudi Arabia participated in a study examining the effect temperature and CO_2 had on vigilance and memory tasks. This paper concluded that changes in temperature to 23 °C and 20 °C significantly improved the performance in a memory task and attention task. The results also revealed that CO_2 concentration of 1000 ppm and 1800 ppm deteriorated the accuracy of results for all tasks relative to 600 ppm. [50]

Chapter 6

Results

The results from the measurements in the ice hall are now presented for each type of measurement. Some of the results will be added in the appendix B, only the main findings will be presented in this chapter.

6.1 CO_2

The CO_2 concentration was measured six different times. Four of them was with different demographic using the ice, in order to see if they achieved different outcome. The other two were measured during the night in order to see how fast the CO_2 concentration decreased when no source was in the building. This information was later used to find the air change per hour.

6.1.1 Women

The results given from the two instruments shown in figure 6.1, gave a clear overview of the ice hall this day. The darker background signalise an ice hockey match. During this time both instruments were in the open area of the ice hall, one on the rink and one in the spectator area. In the small gaps between the periods, both instruments were brought to a well ventilated locker room.

In the second period of the first match, 10:10-10:40, the spectator instrument was brought down to the ground floor, while it was kept in the same place for all the other periods. The measurements from the spectators area after the break have stable values just above 1000 ppm, while it varies on the ice rink. The CO_2 concentration on the rink rose noticeably during the first two periods, before it stabilized in the last four. The concentration also rose during the matches and peaked on 1300 ppm, but decreased during the breaks. The average value in the ice rink for the last four periods were all above 1200 ppm. The concentration on the ice rink was always of a higher value than in the spectators area.

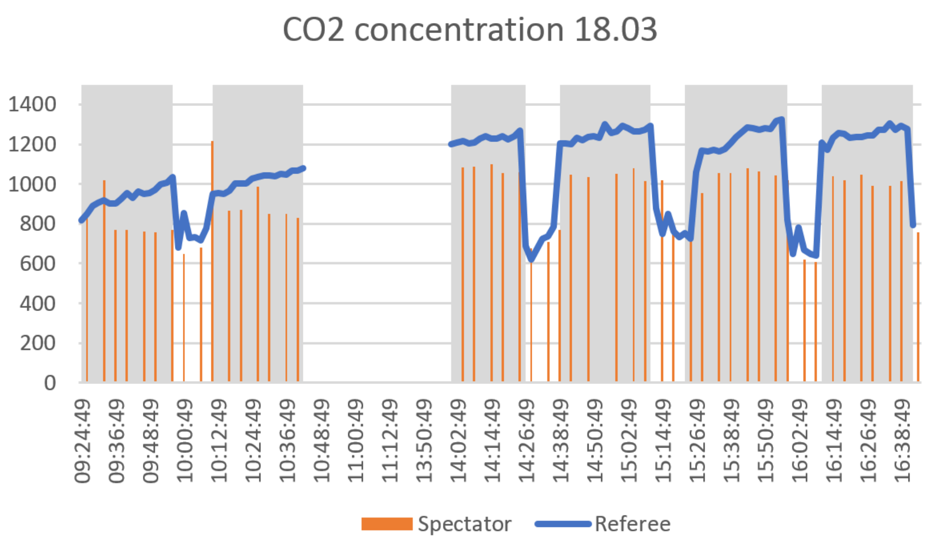


Figure 6.1: CO_2 concentration, grey areas are matches and the white areas between are breaks. In the brakes, both instruments are in the referee locker room.

6.1.2 Teens

The teen match chosen was a U15 match, with teens aged 14-15 years old. At this age, their physics has improved a lot from when they were younger, and they train more structured. This day the match lasted from 19:45 to 20:45. During the first period of the game, the amount of spectators rose from 25 to 40 and stayed constant until the end of the second period.

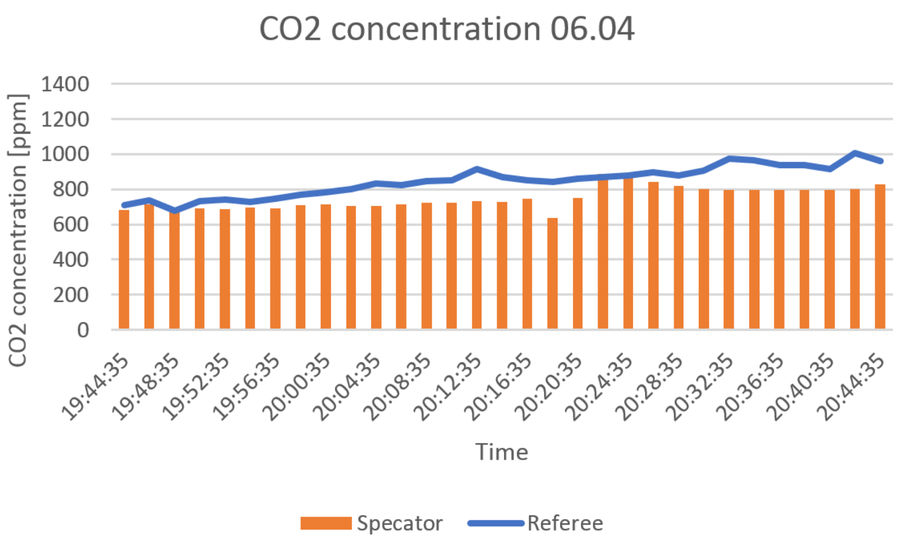


Figure 6.2: CO_2 concentration during a match of youths aged 13-15 years

Figure 6.2 shows the results from this match. The CO_2 concentration among the spectators rose from 700 ppm to 800 ppm. The concentration on the ice rose from 700 ppm at the start to 1000 ppm at the end of the game. The CO_2 concentration proceeded the same way as it did earlier, with the levels on the ice rising noticeably more than the levels near the spectators area.

6.1.3 Children

For the children class, a day with several matches for the U11 and U12 teams were chosen. Children in the age group of 10 to12 years old will have a weaker physics and intensity in their game than the other classes chosen for measurements, so it is assumed that the increase of CO_2 concentration will be slower. Three different matches were played and the CO_2 concentration during these matches is shown in figure 6.3.

In this age class, the game lasts for 18 min and has a short break every minute where the entire team on the ice except the goal keeper is changed. The two periods are separated by a 5 minute break. This day the referees did not go to their locker room during the break but stayed close to the ice, which is why there is no drop in the CO_2 concentration during the break like it was on with the women measurements.

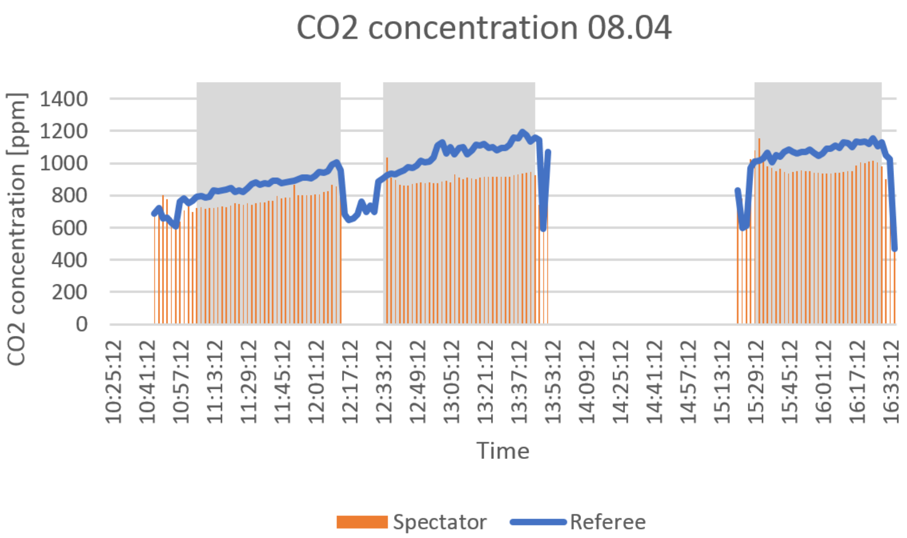


Figure 6.3: CO_2 concentration with a break in the middle of the day. Grey area signifies matches

The average CO_2 concentration rose from the first match to the second match, but the second and third match had similar values. At the most extreme during the second match, the difference between the ice and the spectators area were 300 ppm. During the day the concentration at the spectators area rose from 700 ppm to 900 ppm. The concentration on the ice rink exceeded the recommended values of 1000 ppm in the two last games, and reached as high as 1200 ppm.

6.1.4 Men

The men class chosen for measurements was two Oldboys teams. This is a team of older men playing for fun, and not professionally. It is assumed that they have a worse physics than the women chosen for measurements, and perhaps also worse than the teens chosen. Figure 6.4 shows how the concentration develops during the match.

For the Oldboys match the ice were not re-surfaced in the break between the two periods like it has been with the other measurements, so the referee and measurement equipment stayed on the ice the whole time. The match lasted an hour including a break between the two periods, and was similar to the teens' match.

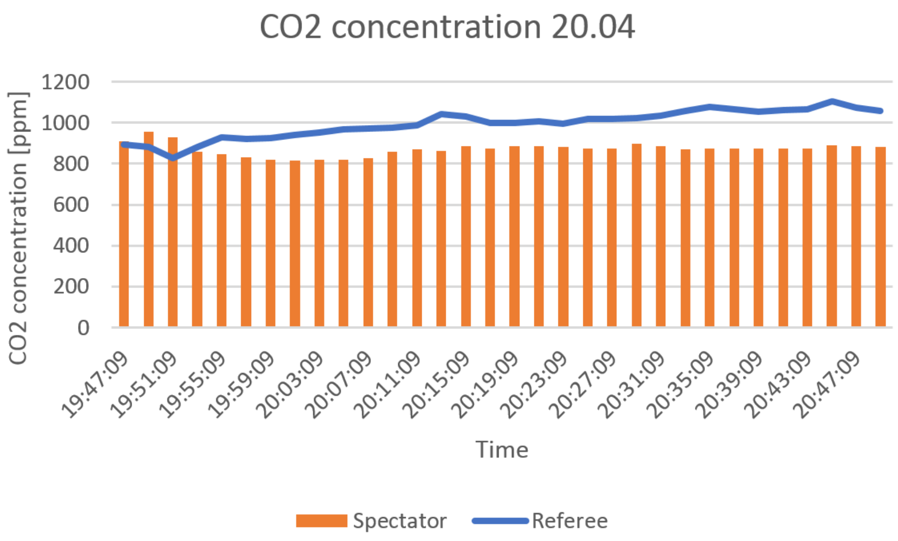


Figure 6.4: CO_2 concentration in the ice hall during an Oldboys match

The CO_2 concentration decreased 10 minutes into the measurement period. The cause of this is unknown, as the values from figure 6.4 are all taken during the match and the values before or after is left out. The CO_2 concentration in the ice rink exceeded 1000 ppm halfway through the match, while the average CO_2 concentration for the spectators area was below 900 ppm.

6.1.5 Night

By measuring during the night it is possible to see how much time is needed for the CO_2 concentration to decrease and stabilise. During the night the operating conditions are the same every time, and the opening of doors and pollution sources are constant.

Week 11

The equipment was set up and measured from when the ice hall closed to when it opened the next morning . Figure 6.5 shows that the decrease of CO_2 in the time period is close to linear. The CO_2 concentration does not seem to stabilize and reach close to outdoor values, as the value at the end is still around 700 ppm. During the night, the CO_2 concentration decreased a total of 452 ppm from start to end.

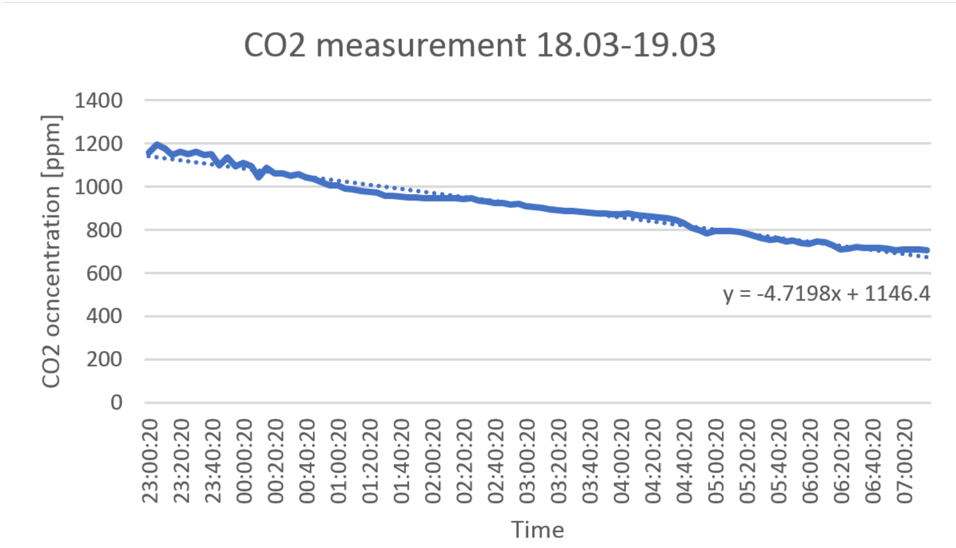


Figure 6.5: CO_2 concentration during the night between 18th of March to 19th of March

Week 14

The instruments were set up at the end of opening hours, but an hour after the last person had left the ice, and placed in the middle of the ice. Compared to the measurement performed the night between 18.03 and 19.03, this time the starting concentration is much lower.

Figure 6.6 shows that the CO_2 concentration slowly decreased and reached a value of 655 ppm, a total reduction of 190 ppm. This measurement also created an almost linear reduction of CO_2, so a longer period of time would still be needed if the concentration would stabilise or reach outdoor levels.

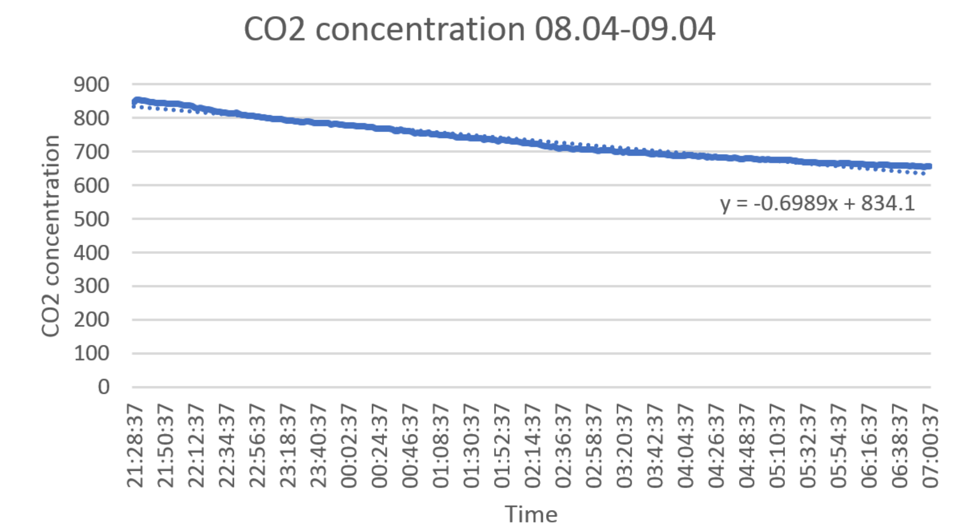


Figure 6.6: CO_2 measurements during the night between 8th of March and 9th of March

6.1.6 Comparison

Table 6.1 was made so the results could be compared more precisely. All the measurements done on one day are grouped together, and the values are listed chronologically.

Table 6.1: Comparison on how the CO_2 concentration has increased through the matches measured

Match day	Athletes		CO_2 increase [ppm]
18.03	Women	Match 1	262
		Match 2	92
		Match 3	219
06.04	Teens		251
08.04	Children	Match 1	165
		Match 2	254
		Match 3	116
20.04	Men		166

6.2 Temperature and relative humidity

Both temperature and relative humidity were measured with the EasyLog, so both of them have results from different height and the possibility to see a profile. A total of 6 locations were used, in three different height.

After retrieving the data from week 11, some of the USB loggers had inaccurate measurements and some stopped recording too early as shown in table 6.2. These differences made it challenging to compare the results from all the USB loggers this day.

Table 6.2: Status of the USB loggers, week 11

USB point	Status
1	Stopped early, wrong measurements
2	Fine
3	Fine
4	Stopped early, wrong measurements
5	Stopped early, wrong measurements
6	Fine

In week 14 the USB loggers were measuring for a much longer period of time with a total of 7 days. They were hung up Tuesday evening and taken down the following Monday. One of the USB sticks stopped early compared to when it was taken down, but managed to measure long enough to make all the measurements acceptable as seen in 6.3.

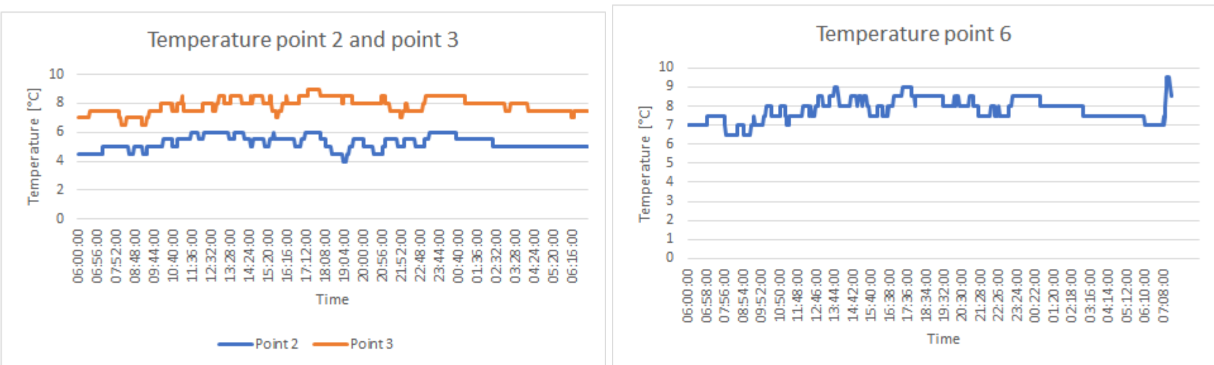
Table 6.3: Status of the USB loggers, week 14

USB point	Status
1	Fine
2	Fine
3	Fine
4	Stopped early, fine measurements
5	Fine
6	Fine

6.2.1 Temperature

Week 11

Figure 6.7 shows that the temperature in point 2, 3 and 6 follow each other during the day. The two USB loggers at point 1 and 5 showed both the same diagram, see figure B.1 in appendix B. These temperatures are undoubtedly wrong and can not be used.



(a) Temperature point 2 and 3 **(b)** Temperature point 6

Figure 6.7: Temperature results for week 11

The results for relative humidity can also be found in appendix B. It is shown that the humidity fluctuate during use, and stabilise when the equipment in the ice hall is turned off at the end of the day. Both loggers installed three meter high have the same values.

Week 14

With a longer period of logging, variations between days are easy to notice. Figure 6.8 has a dark and white background to easily mark different days. The difference between the three different height is also quite clear.

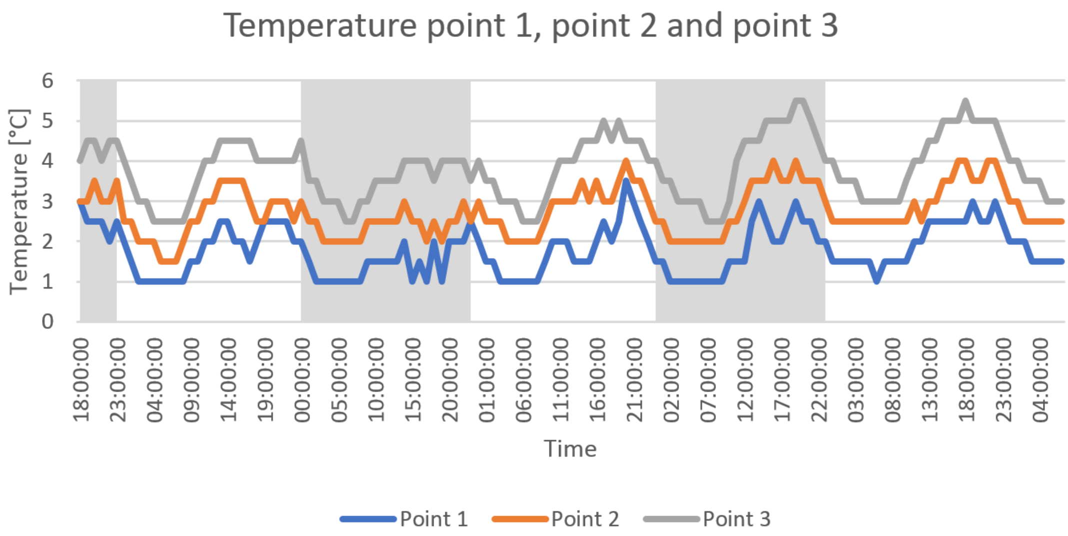


Figure 6.8: Temperature results for point 1, 2 and 3 in week 14

6.2.2 Relative humidity

After measuring the relative humidity in week 11, several errors were found and it was concluded that a larger sample was needed. The measurements performed in week 14 was better, as they last through several days. Figure 6.9 shows the values for point 1, 2 and 3. The rest of the results from relative humidity can be found in appendix B.

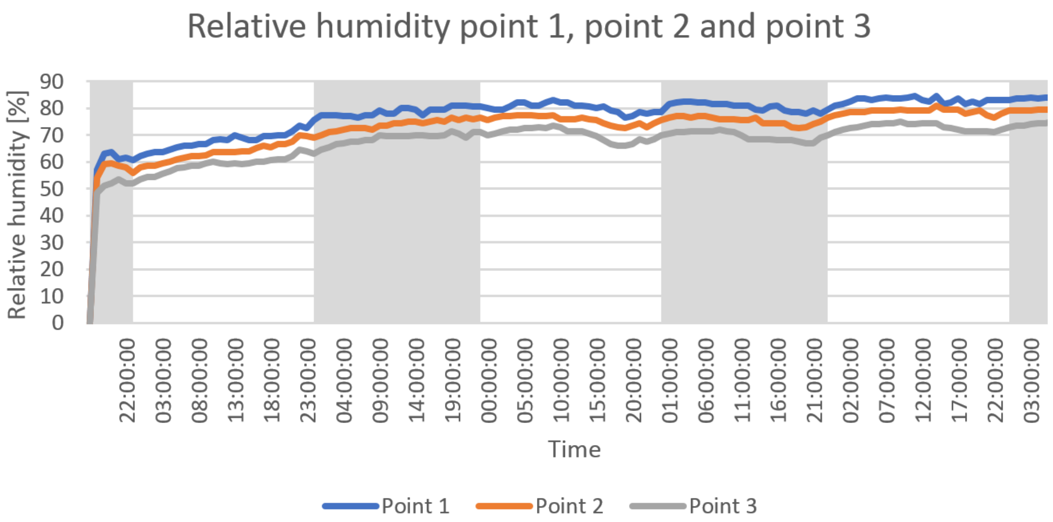


Figure 6.9: Relative humidity in week 14

6.3 $PM_{2.5}$

The particulate matter in the sharpening room was measured twice, with different measurement periods. This was necessary since the room does not have scheduled usage, and measuring through several days would increase the chances of having realistic measurements.

6.3.1 Week 11

The sharpening room was monitored from 15th to 17th of March. The measurement results from $PM_{2.5}$ are found in figure 6.10.

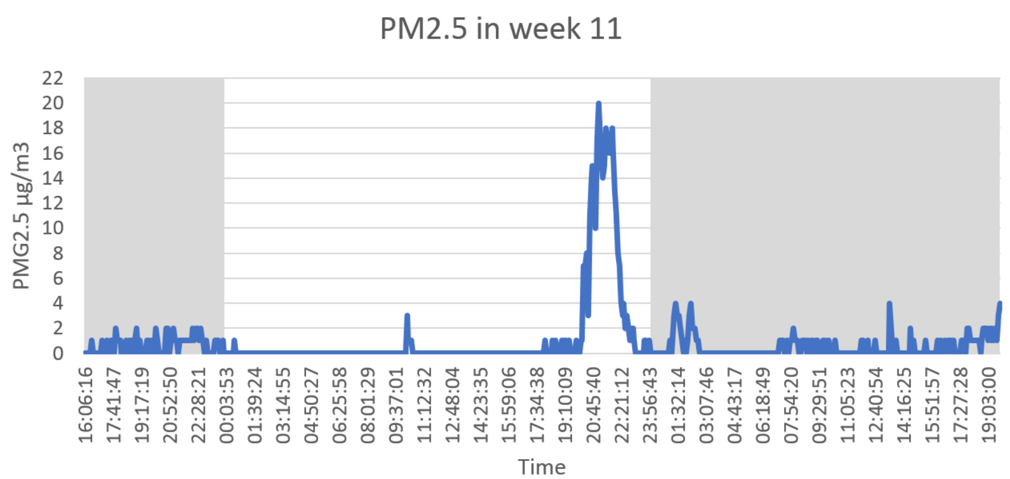


Figure 6.10: Results from the sharpening room, the background colour symbolises different days

The $PM_{2.5}$ in the room reach a maximum level of 20 µg/m^3 during the measurement period. According to the limits from the Norwegian institute of public health and the Norwegian environment agency, this is higher than both the averaged yearly value and the averaged daily value. The amount of time with such a high value of particulate matter is short, the damage from exposure is low as the limitations are averaged throughout 8 hours.

6.3.2 Week 15

At the time of retrieving the data, instrument had been recording for a total of 12 days. The results can be seen in figure 6.11. .

Compared to the first $PM_{2.5}$ measurement, this shows more clearly when the room is being used for sharpening skates. The values does not reach as high as the first measurement, but it seems like they last longer.

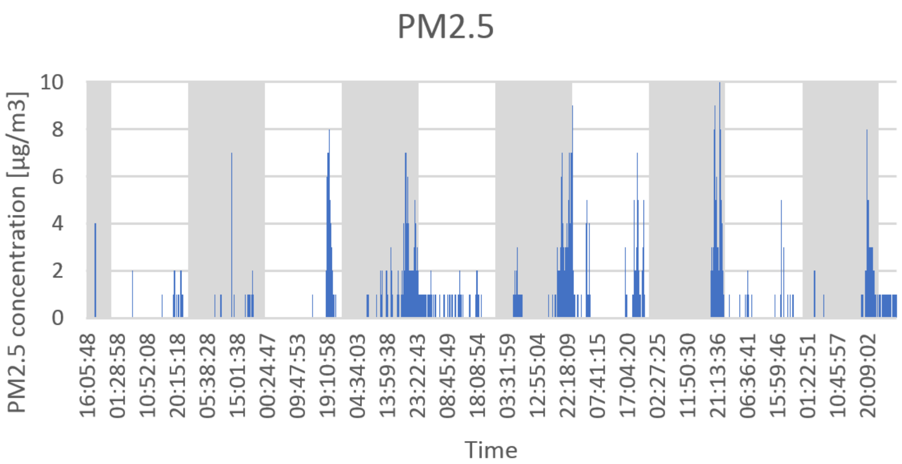


Figure 6.11: $PM_{2.5}$ concentration in the sharpening room during week 14 and 15

6.4 Survey

The two different surveys were conducted in two different ways. The first one was mapping what kind of ventilation system the Norwegian ice halls were using. The second was how the indoor air quality was perceived from the users of Dalgård.

6.4.1 Ventilation system in ice halls

The choice of ventilation system is up to the entrepreneurs who are in charge for building the ice halls. With no regulation concerning this matter, each ice hall will have a different solution. After calling every single ice hall listed at NIHF, 70% answered and their answers are shown in figure 6.12.

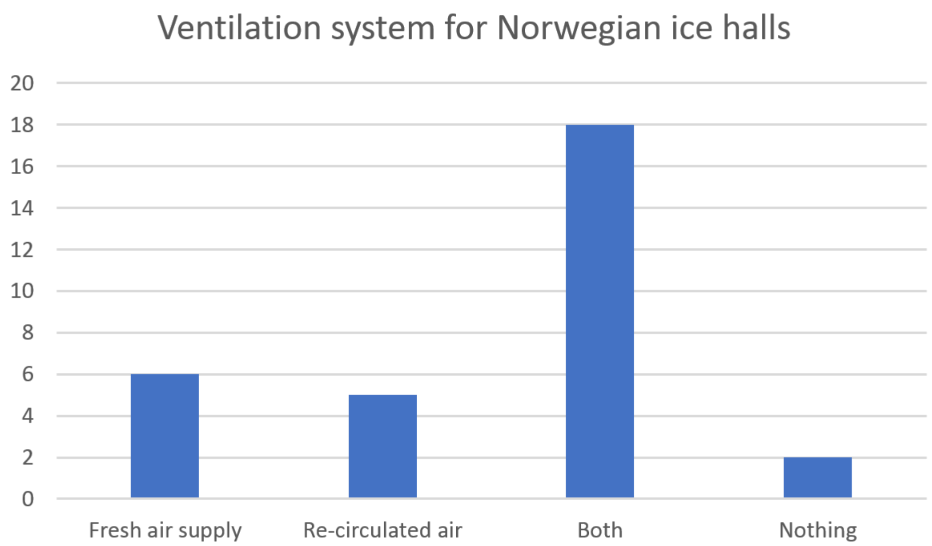


Figure 6.12: Air supply in Norwegian ice halls

It is clear that most ice halls have the opportunity to use both recirculated air and fresh air to ventilate the hall. Two ice halls stated that they did not have a ventilation system at all, and these two ice halls did not have a spectators area. It can be assumed that they are mainly used for practising, and not for matches or by professional players.

Only 6 ice halls said that they had only fresh air supply. This is interesting, as the regulation on technical equipment for construction work gives some specifications on how much fresh air a building should have regarding removal of emissions from materials and humans.

6.4.2 Perceived air quality at Dalgård

The survey sent out to the local Oldboys teams and 4th division teams in the area as well as through Astors social media platform, and can be seen in appendix C. The survey was sent out as a URL-link, and the participants were allowed to answer the questions as they wanted. When the survey was closed after being open for about a month, the response rate was 10 % in total. From when the survey was made and until it was finished, it was sent to four different groups at different times. Astor ice hockey club, the Oldboys and 4th division teams, the referees and the people working at Dalgård. By duplicating the survey and giving the URL-link at different times it was possible to monitor the response rate. The Oldboys and 4th division teams had the highest response rate of just above 30 %.

Figure 6.13 shows how the participants perceived the air in different zones at Dalgård. In general, most people thought the air was acceptable or better. Some differences were found between the zones, as expected. Only 2.0% perceived the air as worse than acceptable on the ice rink, 4.0% thought the same in the spectators area, 10.4% in the cafeteria and 32.0% in the locker room. When combining the answers for somewhat poor and poor, the locker room comes out as the worst zone.

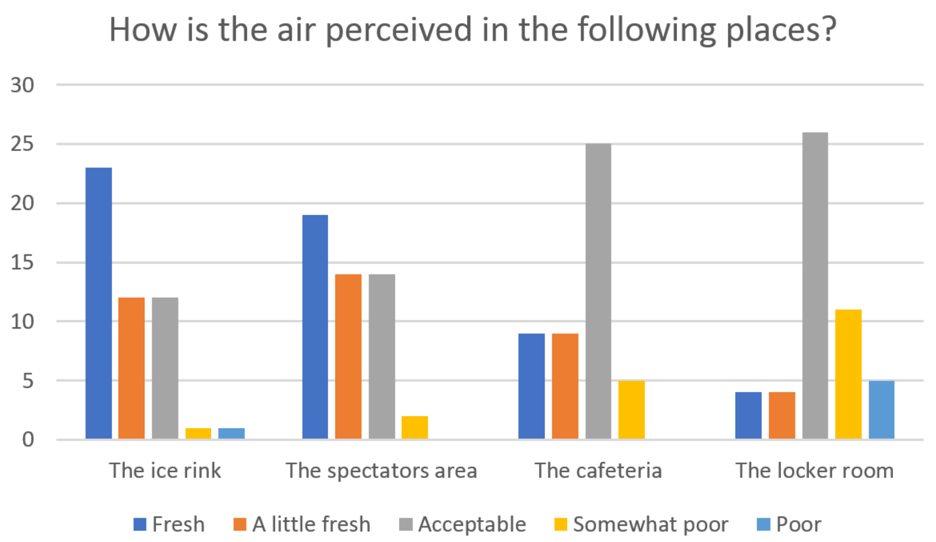


Figure 6.13: Perceived air quality in different zones at Dalgård

In figure 6.14, the responses on how some climate parameters are perceived on the ice rink are shown. While most of the participants are pleased with the air quality, 11% said they have experienced bad air, 13.5 % have experienced unpleasant odour and 29.7% have experienced dry air while on the rink.

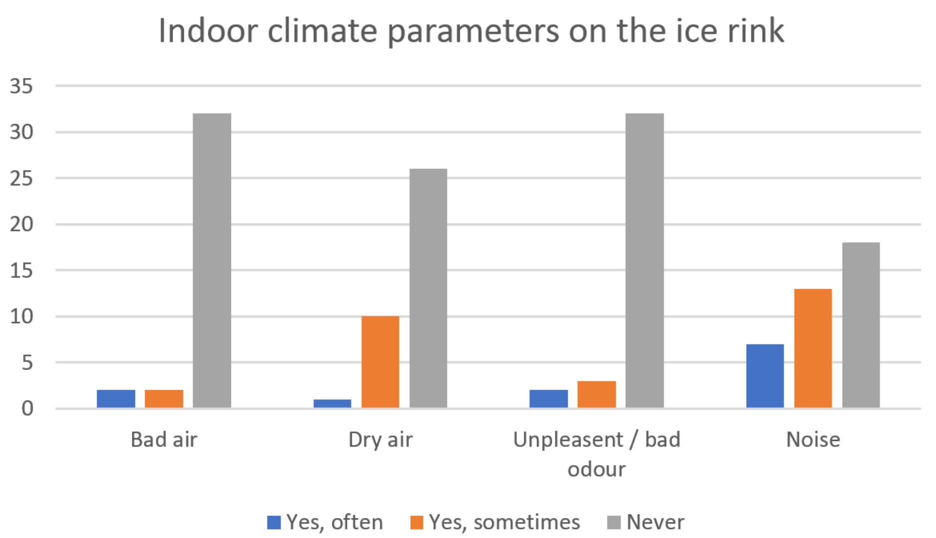


Figure 6.14: Responses on how the participants perceived different indoor climate parameters on the ice rink

6.5 Mathematical models

The mathematical models presented in the theory chapter are now presented here with relevant values. Both air exchange rate and the mass balance could have been used to find the ventilation rate if all the relevant parameters were known.

6.5.1 Air change per hour

The ACH was calculated for two different days, and used the night measurements. This is the only measurements where the parameters that can be controlled are the same. The values used and final results from the calculation can be found in table 6.4.

Table 6.4: Values and results of the ACH calculation

Day of measurement	CO_2 concentration [ppm]		Time period [h]	ACH [h^{-1}]
	CO_2 start	CO_2 end		
Week 11, 18.03-19.03	1145	704	8.25	0.06
Week 14, 08.04-09.04	847	655	9.5	0.027

When the ACH and volume is known, it is possible to calculate the ventilation rate. For Dalgård, the volume is not known. It is therefore assumed that the volume is 13 000 m^3, equal to the volume used the field study published by Toomla et al [38].

Table 6.5: Ventilation rate at different air exchange rates

Air exchange per hour [h^{-1}]	Ventilation rate [m^3/h]	Ventilation rate [m^3/s]
0.027	351	0.10
0.06	780	0.22
0.6	7 800	2.17
1	13 000	3.61
2	26 000	7.22

By using the same total floor area as Toomla et al., 1833 m^2, it is possible to compare these ventilation rates with the requirements from TEK17. The minimum requirement of an empty room is then 1283 m^3/h and a room with people have a minimum ventilation rate of 4582.5 m^3/h.

6.5.2 Mass balance

The mass balance explained in section 2.4 is good for showing the theoretical background on how the air moves and how the CO_2 concentration changes throughout a time period, but is difficult to use because of the unknown variables.

In the original equation 2.1, three parameters are unknown. These are $\dot{M}$, V and $\dot{V}$. If the mass balance is to be used in order to find the ventilation rate, it would make sense to use the same time period as when finding the air exchange rate. The two values gotten from the two equations could be compared. $\dot{M}$ would have been set to 0 as no people would be in the ice hall in this time period. The unknown parameter then would be ventilation rate and volume.

$\dot{M}$ is one parameter which is not fixed, but variable. Since this is the source of CO_2 in the ice hall, it is impossible to continue without this value. Since the number changes throughout the day and not only between opening and closing hours, some kind of surveillance should be in place to estimate the number correctly.

Chapter 7

Discussion

Dalgård can not be seen as an ideal ice hall, but with the result from the second survey it seems like it can be a representative one. It is quite average both in size and age, and the technical equipment installed does not work as originally planned.

Results from the indoor air quality measurements and suggestions on how to make the air quality better can be used as a case for other ice halls to undergo the same treatment. As revealed, many ice halls only use recirculated air, so it can be assumed that their CO_2 concentration will develop the same way during matches.

7.1 Ventilation

The way ice rinks are built is in itself a problem when it comes to ventilation. The ice hall often has a level difference between the rink and the spectators area and the ice rink is surrounded by a wall. In addition to physical barriers, the environment is also a problem with the cold surface of the ice and the temperature stratification.

When choosing air distribution through the ice hall both mixing ventilation and a combination between mixing ventilation and displacement ventilation can work.

Displacement ventilation alone is out of the question. Every ice rink has to follow the regulations from IIHF as described in section 2.1, where every section of the board around the ice rink is fixed. This leaves no room for openings for a supply valve. The cold ceiling is a problem with displacement ventilation, as the warm air is supposed to rise up. Another problem with displacement ventilation could be the ice quality. The ice is sensitive to temperature, and even though the supply air would have to be cold the velocity could still transfer heat between the ice and the air, and make the ice too hard. The spectators area is a zone where displacement ventilation would be useful, and under the seats or near the back wall would be an ideal placement for the supply ducts.

The same problems stand in the way for natural ventilation. With natural ventilation it can be as good as impossible to lead the air where it is needed. Right now the only supply for fresh air at Dalgård is the door and leaks in the building body. The leaks are not possible to control, while the doors are a bit more controllable. The problem with the doors is that they are the only way of going in and out of the building, and they are not necessarily placed in an optimal place for air distribution. Two of the doors are used by the public and lead from the hall to the outside, both at the east side of the building. The first door is most used for traffic, and is placed near the corner of the rink. The second door is placed along the middle of the ice rink, towards an area of the rink where the board is not as high. This door is mostly used by the visiting team during a match, and will supply the ice rink with fresh air.

Mechanical ventilation would supply the building with more stable fresh air, and make the building independent on the weather. A complete mechanical ventilation with an air handling unit and ducts would give Dalgård the option of controlling how the air is distributed in the hall.

The literature review found some work that has been done on ventilation for different zones. In this case, two different ducts will supply air to different parts of a room. The simulations from Stobiecka et al. on zone ventilation looks promising, but it has yet to be tried in a real ice hall. The new ice hall at Jordal have this design of ventilation as one of the alternatives.

When conducting the survey of what kind of air supply Norwegian ice hall used, only 6 were using only fresh air. The vast majority had the opportunity to use both fresh air and recirculated air, and in this case many of them were using fresh air only when needed because of very high CO_2 levels and in emergencies. The mapping also showed differences in how the ice halls were designed and operated. While talking to people with knowledge of each ice halls, some comments were noted. Some of the ice halls were forced to use recirculated air most of the time because they did not have a de-humidifier, while another used fresh air during the night to control the relative humidity level. One ice hall had the resurfacer placed outside of the hall, and received lot of fresh air when the ice had to be prepared.

By the comments made during the phone calls, it seems like there might be some geographical differences in what kind of air is used. The ice hall in Bergen is located on the west coast of Norway and is prone to rain, stated that they never use fresh air as long as the recirculated air can give acceptable indoor air quality in order to keep the relative humidity as low as possible. The ice halls in Kongsberg and Vinterbro, ice halls in the eastern part of Norway, only uses recirculated air while the ice hall is empty in order to keep the air as fresh as possible without increasing the humidity load by having two sources.

It does not seem to be a relationship between which ice halls that uses only fresh air supply and age, as those ice halls was built between 1969 and 2010. For the older ice halls, the ventilation system could have been installed later or have been rehabilitated during its lifetime.

One of the people talked to on the phone was under the opinion that the ice hall was too big compared to the number of people in the ice hall to ever have CO_2 concentrations or other harmful substances at high enough levels to require fresh air, now that they no longer used a resurfacer based on fossil fuel. This was an interesting opinion which could indicate that it is difficult to access good information about indoor air quality on ice halls. Whether or not the ice hall has such a big volume that it can not have bad air depends on how the air moves inside the hall and how the boundary layers develop.

TEK17 clearly stated that buildings for general public and work buildings must have a minimum supply rate of fresh air, as previously stated in section 2.3.4 Regulations. Section 13-3 in TEK17 is not followed by many ice halls, which indicates that the building industry might not consider ice halls as a place for permanent residency or a work place.

7.2 Increased CO_2 concentration during a match

The CO_2 concentration during a match was particularly interesting to examine, as very few, if anyone, have ever looked at this before. In order to have a realistic measurements of the situation, several matches were chosen. It was important to measure when children, women and men played in order to see how different intensity and height might have affected the concentration.

The increase during a match was surprisingly similar for all the games chosen for measurements. The two days with least increase of CO_2 was the last two measurements, with the Oldboys and the youngest children. This is to be expected, as these two groups are assumed to be the ones with the least intensity during a match due to age and physical capabilities.

Both women and children had a day with several matches. Looking at their values, it also look like the CO_2 changes similarly, even though the values are not the same. The concentration for the first two periods rises in both cases, and the break in between does not reduce the concentration enough for the start of the second period to be as low as the start of the first period. The CO_2 concentration also crosses 1000 ppm about half through the second period in both cases.

Men and teenagers had the same kind of day, which means that neither of the two athletic groups had more than one match played at the measurement day. The CO_2 concentration in the spectators area stay around 800 ppm in both cases, and both matches reach 1000 ppm at the ice rink at one point during the match.

During this thesis it has been proven that more wind will supply more fresh air to the ice hall. The professional female players on 18.93 generated the highest increase during a match with 262 ppm. What is interesting is that this day was also the day with most wind and most spectators. More spectators can impact two parameters. First of all, many people and frequent use of the door will supply more fresh air to the ice hall. But more people will also give the ice hall a higher internal pollution source. The temperature difference between indoor and outdoor is also highest this day out of all the four days chosen for measurement, at 7 °C difference. This combined with an average wind speed of 6.8 m/s during the day will supply the ice hall with a lot of fresh air supply.

The effect these recorded CO_2 levels can have on the users of the hall is uncertain. As presented in the literature review, several studies has shown a correlation between high CO_2 levels and performance on cognitive tasks. One of the papers argued that the effect could come from bioeffluents, as they found differences between CO_2 pollution by people and pure CO_2 If this is the case, the users of the ice hall will not be as affected as people in smaller enclosures simply because of the volume.

It can be important for national sport organisations like NIHF to keep a track on how this field is developing. If researchers can conclude that CO_2 levels as low as 1000 ppm can have an impact on cognitive functions and learning abilities, they will need to take action. One way would be to give official recommendation for installation of ventilation systems with scientific reasons.

7.3 Supplied fresh air

Dalgård does not have a ventilation system. The only fresh air supply comes through opening of doors and infiltration and leaks in the building body. Therefore it is reasonable to assume that the amount of fresh air supply will be dependant on weather, specifically wind and temperature.

One parameter which can estimate how much fresh air is supplied during a period is ACH, air changes per hour. By knowing the volume of the hall and how fast the CO_2 concentration decreases, it is possible to find out how many times all the air is changed per hour.

The ACH for Dalgård was calculated to be 0.06 h^{-1} and 0.02 h^{-1}. Toomla et al. did a similar experiment for a Finnish ice hall with mechanical ventilation using recirculated air and a small percentage fresh air, which resulted in an ACH at 0.03 h^{-1}.

The air change per hour measured during the night time can be set as equal to the air leakage rate per hour, since the fresh air comes through leakages in the building body. This is only valid though, if it is assumed that the pressure difference is at 50 Pa. By further assuming the highest air leakage rate to be constant, this can be compared to standards and other buildings.

New buildings should, according to TEK17, have an air leakage rate per hour below 0.6 h^{-1}. Dalgårds value at 0.06 h^{-1} is much lower. Looking at this number alone suggest a very tight building body, but since Dalgård was built in 1989 this is most likely not the case.

In order to understand this low value, the reasons for air exchange need to be examined. Difference in pressure and temperature is a significant force. During the measurements at 18.03, the temperature difference between indoor and outdoor varied between 8°C to 4.9°C during the whole night. The difference between indoor and outdoor temperatures at 08.04 was even less, varying only between 0.3 °C to -0.3 °C. Both these values can be seen in appendix A.

Air change per hour might not be a good way to compare buildings as big as ice halls. In order to change the air one time with such a large volume, a substantial amount of air is needed. As table 6.5 shows, an air exchange rate of 1 would require a fresh air supply of 13 000 m^3/h.

Dalgård is an old building, and does not follow the requirements from TEK17. TEK 17 can still work as a guideline and indicate the state of the building and ventilation system by comparing it to the measured values. Neither the ACH calculated from 18.03 or 08.04 would satisfy the minimum ventilation rate for a room with or without people. The required air leakage rate per hour at 0.6 h^{-1} however, would satisfy both a room with and without people.

7.4 Particulate matter in the sharpening room

When this thesis started, the sharpening room was of interest as the sharpening of skates generates a lot of metal dust. In this room $PM_{2.5}$ measurements were started, and almost two weeks of measurements were conducted. The end results were surprising, as the levels were not as high as expected.

After exploring some more literature on the matter, it seems like the wrong equipment was used for measurement. PM_{10} often contains minerals and metals, which is particles too large to be measured in an instruments for $PM_{2.5}$.

Based on the research questions presented in this master thesis, measurement of particular matter was not a priority. The literature behind it should have been examined closer before the measurements started, and could have given better results.

Further examination on this problem is recommended. The lack of national guidelines on how to ventilate and secure a safe environment regarding the machine which sharpen the skates might result in different practise between the ice halls. Smaller ice halls and ice halls operated through local sport clubs have a tighter budget and can end up neglecting important safety equipment if they are unaware of the potential damage.

By mapping the size of the particles and the effect it can have on the respiratory functions, a draft for safety and health concerns can be created and distributed to all ice halls. Some of the ice halls have sufficient safety procedures, while other ice halls should invest and upgrade their routines. And awareness campaign could make an impact, as most of the people using these machines are normal people voluntary for local sport clubs.

7.5 Improvement on air quality

The overall impression from this thesis is that the CO_2 concentration reaches high levels, although not so high that improvements on the ice hall is urgent. The same conditions of a CO_2 concentration over 1000 ppm and high activity would create a higher amount of discomfort in warmer temperatures compared to what people perceived in the ice hall.

The results from the survey shows that the majority of the participants think the air quality on the ice rink is acceptable, and only 13.5% have experienced the air on the ice as heavy and bad. The area with the poorest results was the locker room. Locker rooms are often characterised with high levels of odour. This room had a high vote on acceptable compared to the others, and the reason for this could be that could be that people are expecting the locker room to smell. The results from the survey raises the question whether or not the air quality should be improved, when the perceived air quality is good.

There is no longer harmful substances in the ice hall like it was before the resurfacer was changed to an electric machine. The CO_2 concentration also never reached the daily limit set by the Norwegian Labour Inspection Authority at 5000 ppm.

The effect low concentrations of CO_2 can have on the mind and cognitive functions however can be a determining factor in the future. If it is proven that levels between 1000 ppm and 2500 ppm can weaken learning abilities and awareness for a short period of time, sport facilities would have to prioritise ventilation in order to create an optimal space for learning and improving. This is a new field and more studies and examinations needs to be performed before any results can be concluded.

If Dalgård were to improve the air supply, the first step should be get the exhaust fan running. The ice hall already have two exhaust fans installed that is not currently running due to problems with the fuses. Operating the fans during the day time would create an under-pressure inside the hall, increasing the infiltration and fresh air supply. The second step could be to investigate the possibilities of mechanical ventilation by installing an air handling unit and ducts to distribute the air. This is a much more expensive alternative, and an analysis of cost and consequences should be made before making such a decision.

7.6 Temperature and relative humidity

One of the research question was how the temperature and humidity profile looked like. Figure 6.8 shows the temperature at point 1, 2 and 3 for several days. In this graph, it can be seen that the difference between 1 and 2 meters are between 0.5°C to 1.5°C, and the difference between 2 and 3 meters are also between 0.5°C and 1.5°C.

The temperature difference between point 4, 5 and 6 is shown in figure B.2 in the appendix. The difference between the points are in the same range as the temperature difference between point 1, 2 and 3 with a minimum difference of 0.5°C and a maximum of 1.5°C.

The pattern of temperature is the same for both those figures, but the figure containing point 4, 5 and 6 is more flat compared to the other figure, and does not have the same peaks. Since point 4, 5 and 6 is installed below one of the de-humidifiers. The reason for this might be that the air have changed the temperature in the air or that the de-humidifier creates enough movement in the air to distribute the temperature more evenly.

The figure which shows relative humidity is identical for both sides in week 14, and from point 1 to point 3 the difference is around 10%. Figure B.3 shows the relative humidity for the three instruments which were working in week 11. In this case the different vertically was also 10%, and the values for point 3 and 6 which are at the same height overlapped completely.

Chapter 8

Conclusion

The literature review found that some work had been done on indoor climate in ice halls earlier, but recent literature on ice halls focused on air distribution. New studies have been made regarding the impact high but acceptable levels of pollution like CO_2, bioeffluents and temperatures in general can have on cognitive functions. Ventilation of ice halls are demanding because of the indoor conditions, and in addition to mixing ventilation one new method that is being explored is zone ventilation. This is a ventilation type with several ducts supplying one zone with a certain temperature and relative humidity, and another zone with other temperatures and relative humidity.

CO_2 concentration was measured during eight different matches distributed on four days. The CO_2 concentration rose during all eighth matches, and the increase ranged from 98 ppm to 262 ppm. Measurements on the ice rink were done during two nights, and both nights the CO_2 concentration failed to reach outdoor values and ended between 600 ppm and 700 ppm.

Two surveys were created and distributed in order to assess the indoor air quality in ice halls. The first survey showed that the majority of the participants perceived the air quality at the ice rink and spectator area as acceptable or better. The second survey mapped the use of fresh air supply and recirculated air in Norwegian ice halls. Very few ice halls in Norway use exclusively fresh air, and most of them have installed a combination between fresh air and recirculated air where recirculated air is used most.

Dalgård ice hall does not have mechanical ventilation, and is dependent on open doors and leaks in the building body for fresh air supply. The air exchange rate was calculated based on the two night measurements when leaks in the building body was the only fresh air supply to be 0.06 and 0.027 h^{-1}.

Chapter 9

Further work

Further work can be done based on the results and experience gathered in this thesis.

For later work, it is advised to do some more CO_2 measurements. The measuring started late this semester, and more matches with high intensity should have been investigated. Matches from the 2nd division for women and men is recommended, as well as longer measurement throughout the day with normal activities. Since the air supply is dependent on the weather and wind, a comparison between two matches of equal intensity would give a clearer picture of how much the air supply affect the increase of CO_2 during a short period. It could also be interesting to study the effect the door in the middle can have on the air quality during a match. When this is used by a team twice, how much air can come through and will it have any effect on the CO_2 concentration.

The investigation of particular matter in this thesis was inadequate. With equipment able to measure PM_{10}, the PM values from the sharpening room could be properly investigated and the health impact established. It would also be possible to test whether or not the assumption that ice hall in general actually is free from PM compared to when fossil fuel was used for the resurfacer is true.

The last result interesting to follow up on would be to do a more extensive mapping of the Norwegian ice halls and gather all this information in one place. How are each hall designed, who have fresh air supply and why doesn't every all follow the TEK17's demand for a minimum ventilation rate. This work could be the beginning of an informational booklet designed to make the differences and similarities clearer, and have a place where this kind of information could be easily accessed. It would also be useful with an estimation of how much it would cost an ice hall to install exhaust fans in order to achieve forced ventilation, and information on how effective this ventilation type would be compared to mechanical ventilation with ducts to distribute the air.

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[50] Ahmed Riham Jaber, Mumovic Dejan, and Ucci Marcella. The effect of indoor temperature and co2 levels on cognitive performance of adult females in a university building in saudi arabia. *Energy Procedia*, 122:451 – 456, 2017. CISBAT 2017 International ConferenceFuture Buildings Districts – Energy Efficiency from Nano to Urban Scale.

[51] Yr.no.

Appendices

Both weather data and results will be given in weeks instead of dates if it lasts over several days. Table .1 shows the correlation between weeks and dates.

Table .1: Overview over weeks and dates

Week	Dates
11	12.03 - 18.03
14	02.04 - 08.04
16	16.04 - 22.04

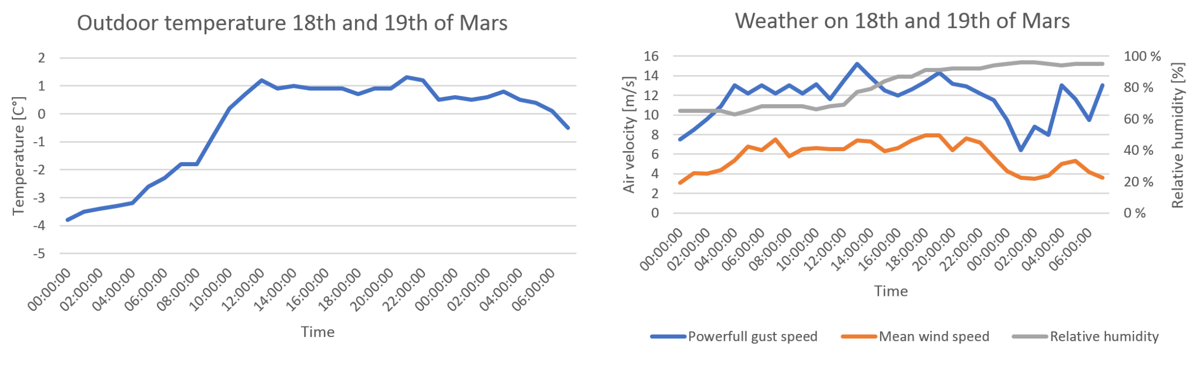
Appendix A Weather data

Dalgård does not have mechanical ventilation. The amount of fresh air supply to the building is therefore directly connected to the weather. A day with more wind will give more fresh air to the building compared to a day with less wind. All the weather data for this thesis was retrieved from Yr.no, a website from the Norwegian Meteorological Institute, and the data was recorded at Voll, Trondheim. This weather station is 6 km east of Dalgård.

A.1 Week 11

The weather for 18th and until the morning of 19th of March can be found in figure A.1. This was a day with varying outdoor conditions. While the CO_2 measurements took place the mean average wind speed was 6.8 m/s while the average gust speed was 12.9 m/s.

Since an overnight measurement also was done this day, the night values are also important. The mean wind speed during the night was a bit lower than during the day, but still high with an average mean wind speed of 4.1 m/s and an average gust speed of 9.9m/s.



(a) Temperature

(b) Wind and relative humidity

Figure A.1: Weather data for 18th and 19th of March [51]

Temperature differences

Figure A.2 shows the temperatures indoor and outdoor during the first night measurement between 18.03 and 19.03.

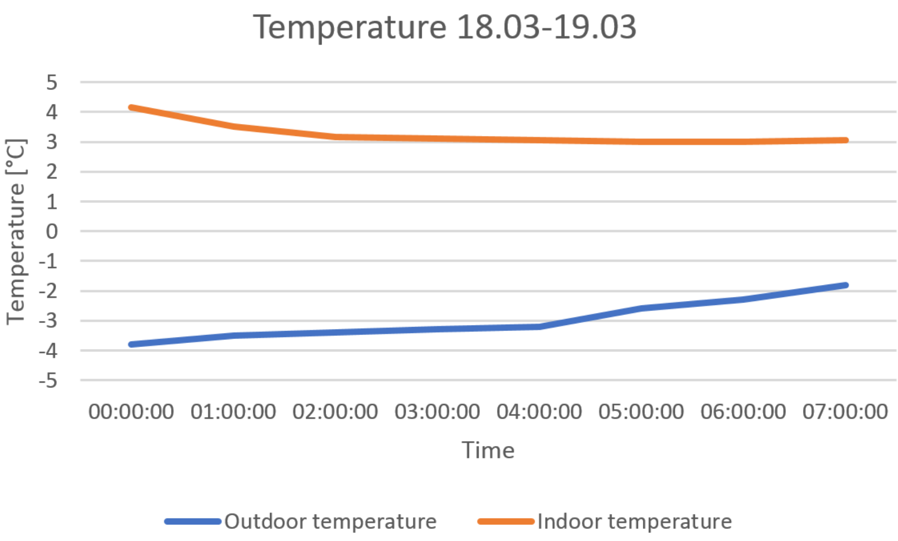
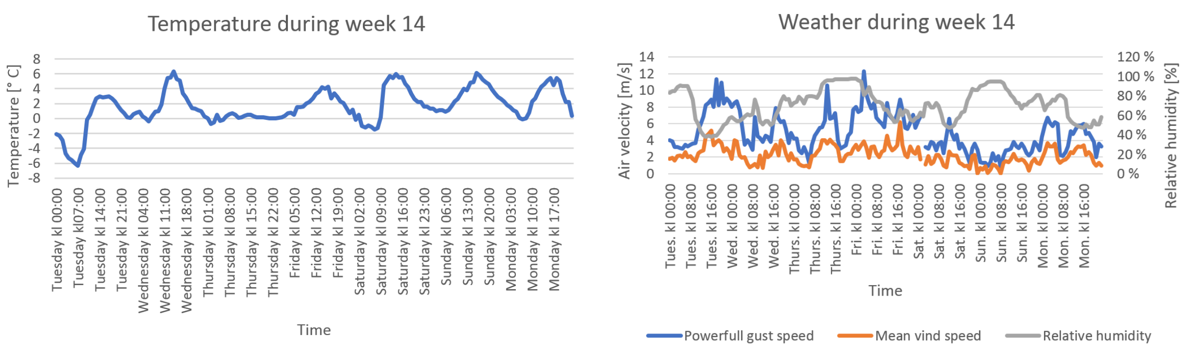


Figure A.2: Temperature indoor and outdoor during the measurements between 18th and 19th of March [51]

A.2 Week 14

Several measurements were performed in week 14, so the period of weather data is longer than in week 11. Temperature measurements were made from Tuesday to Monday, which determined what weather data was needed. In addition to temperature measurements, three CO_2 measurements was also performed this week. Figure A.3 shows the weather for week 14.



(a) Temperature

(b) Wind and relative humidity

Figure A.3: Weather data for week 14 [51]

The first CO_2 measurements this week was done on Friday 06.04. The average mean wind speed during the day was 2.3 m/s and the average gust speed was 4.7 m/s. During the match from 19:45 to 20:45 the outdoor conditions was as following; the average mean wind speed was 2.3 m/s, the average gust speed was 3.3 m/s and the relative humidity was at a constant 97%.

The second CO_2 measurement was done on Sunday 08.04. The average mean wind speed during the day was 1.1 m/s and the average gust speed was 2.4 m/s. A total of three matches were measured this day. During this period, the outdoor condition was as following; the average mean wind speed was 1.7 m/s, the average gust speed was 3.2 m/s. The relative humidity fluctuated between 88% to 67% during the same period.

The third and last CO_2 measurement was performed during the night between Sunday 08.04 and Monday 09.04. The average mean wind speed during this time was 2.3 m/s and the average gust velocity was 4.8 m/s.

Temperature differences

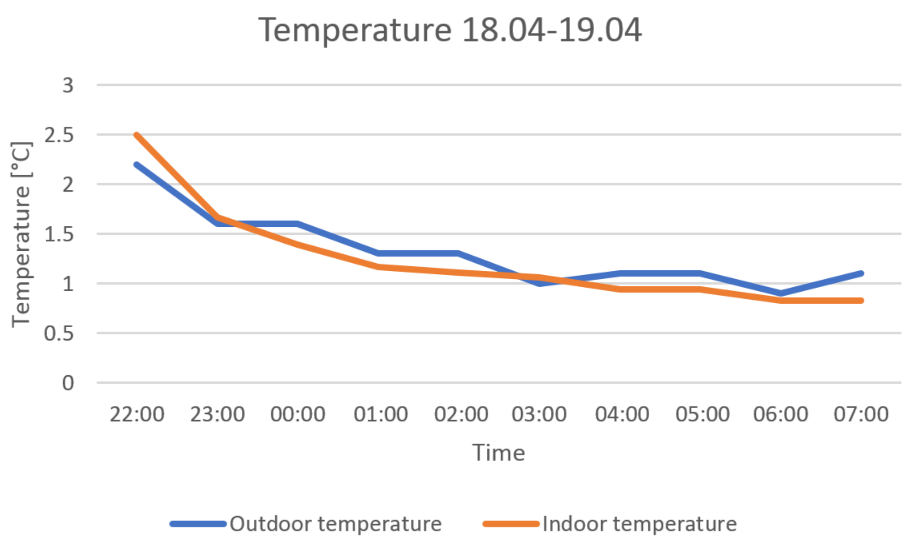
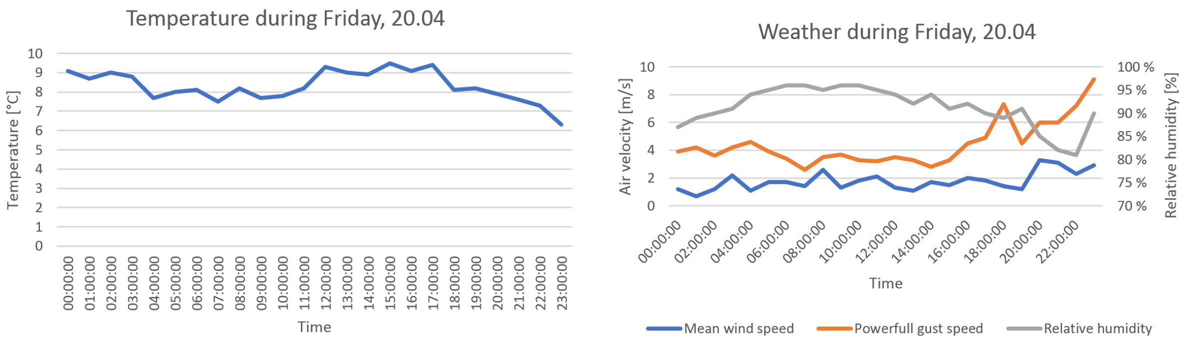


Figure A.4: Temperature inside and outside during the measurement between 08.04 and 09.04

A.3 Week 16

Week 16 contains only one measurement, the last CO_2 measurement. Measurement was done during one match in the time period 19:45-20:45. In this period the average mean wind speed was 2.3 m/s, and the average gust speed 5.3 m/s.



(a) Temperature

(b) Wind and relative humidity

Figure A.5: Weather data for week 16 [51]

Appendix B Results

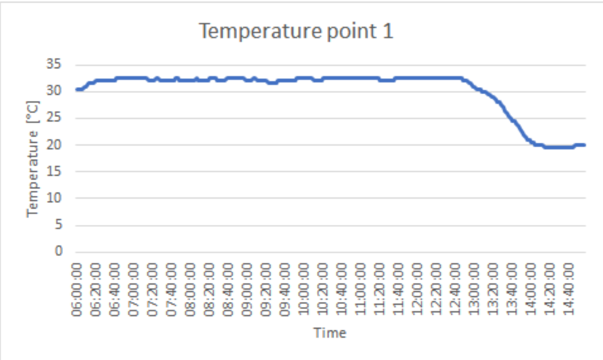
In this section a lot of results are listed in order to create a better order and flow in the original text.

B.1 Temperature and relative humidity

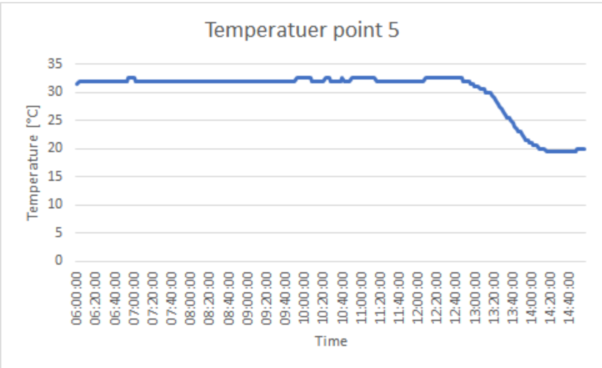
The results from the measurements regarding relative humidity and temperature will be presented here.

Temperature

Figure B.1 shows the results from the USB loggers installed at point 1 and point 5. Them having the exact same curve gives the possibility of them having the same error. Before installing them at the ice hall all USB loggers were in a swimming hall. They are very sensitive to water, so these two loggers might have been exposed to water before use.



(a) Temperature point 1



(b) Temperature point 5

Figure B.1: Temperature results

While figure B.2 is less complete than figure 6.8 as the USB logger in point 4 stopped working, the figure is still showing the expected results. Both figures follows the same pattern, and even point 1 and 4 are close even though they might have been more affected by variations in the rink.

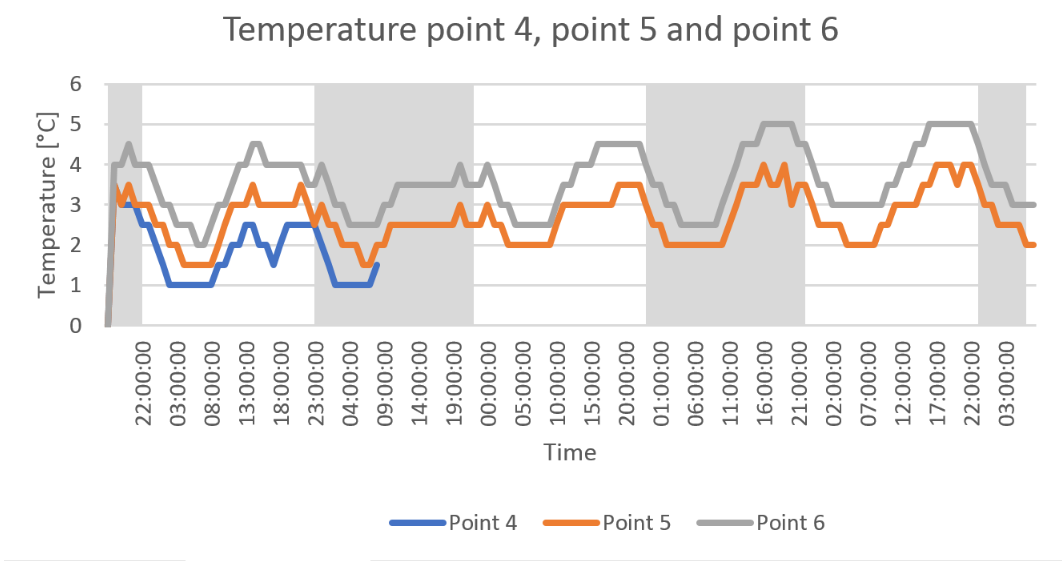


Figure B.2: Temperature results for point 4, 5 and 6

Relative humidity

Figure B.3 shows the results for week 11. The USB loggers with measurement errors are not presented. Point 3 and 6 is overlapping almost the entire time and can be hard to part from each other.

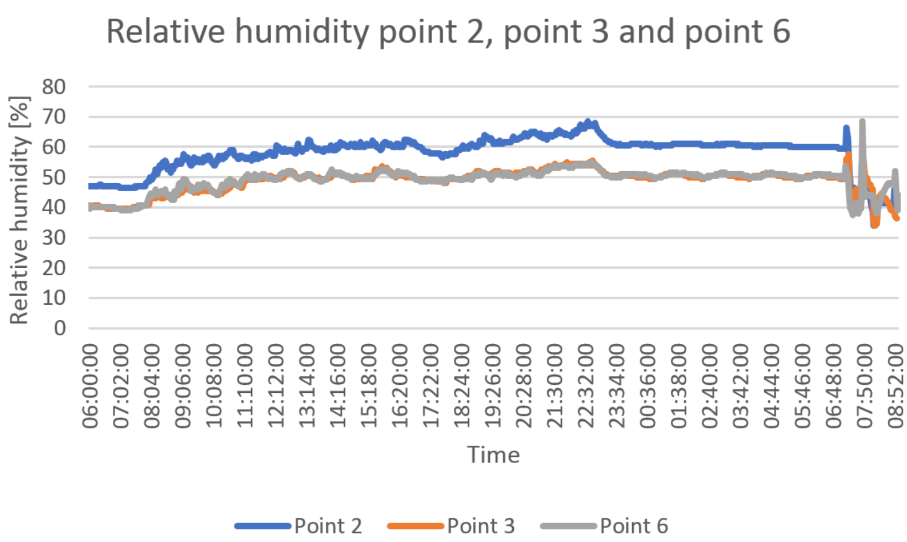


Figure B.3: Relative humidity point 2,3 and 6

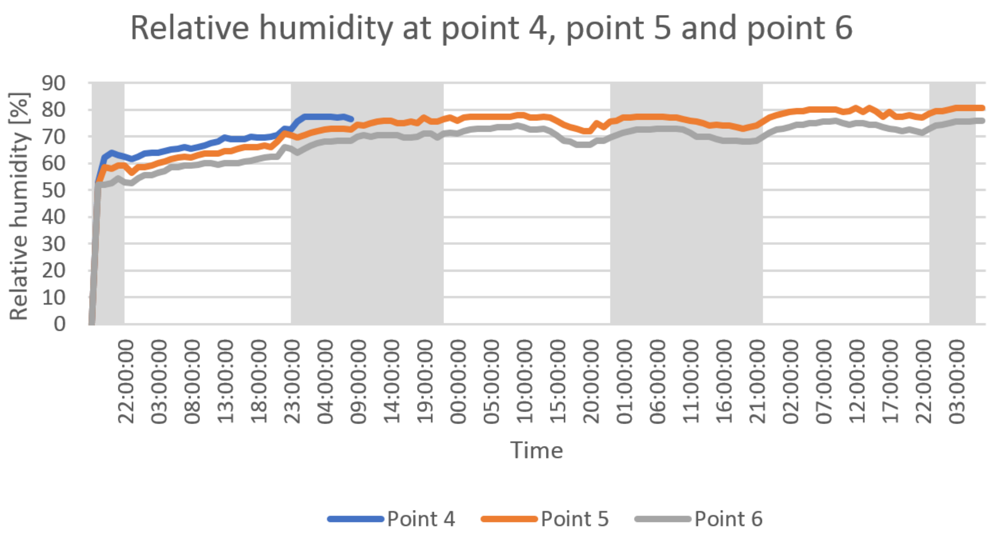


Figure B.4: Caption

Appendix C Survey

The survey is attached here. Since the people participating in the survey was mostly Norwegian, the survey is also written in Norwegian.

NTNU
Kunnskap for en bedre verden

Dalgård inneklima

Informasjon angående spørreundersøkelse-Luftkvalitet i Dalgård ishall

Bakgrunn og formål
Spørreundersøkelsen er en del av en masteroppgave som blir skrevet ved NTNU, Institutt for energi- og prosessteknikk, og skrives i samarbeid med Senter for idrettsanlegg og teknologi (SIAT). Formålet med undersøkelsen er å kartlegge hvordan brukerne av ishallen opplever luftkvaliteten.

De som har blitt valgt til å være med i undersøkelsen er personer som befinner seg i ishallen eller medlemmer av lag som har treninger eller kamper i ishallen.

Hva innebærer deltakelse i studien?
For å delta i undersøkelsen fyller du ut et elektronisk eller manuelt skjema. Spørsmålene vil handle om hvordan du opplever luftkvaliteten i ishallen. Svarene vil bli analysert og sammenlignet med fysiske målinger gjort våren 2018.

Hva skjer med informasjonen om deg?
Alle personopplysninger vil bli behandlet konfidensielt. Alt datamateriale vil anonymiseres ved prosjektets slutt, som etter planen vil være i juni 2018. Kun masterstudent og veileder har tilgang til datamaterialet. Resultatet vil bli fremstilt slik at enkeltpersoner ikke kan gjenkjennes.

Frivillig deltakelse:
Det er frivillig å delta i studien, og du kan når som helst avbryte utfyllingen av spørreundersøkelsen og dermed ikke delta.

Samtykke til deltagelse:
Ved å utfylle og sende inn/levere spørreundersøkelsen regnes dette som samtykke for deltagelse.

Dersom du ønsker å delta eller har spørsmål til studien, ta kontakt med

Masterstudent:
Linda Strand Prestmo
Lindasp@stud.ntnu.no
Tlf: 90266055

Veileder:
Gunagyu Cao
Guangyu.cao@ntnu.no

Studien er meldt til Personvernombudet for forskning, NSD - Norsk senter for forskningsdata AS.

NTNU
Kunnskap for en bedre verden

Dalgård inneklima

Kjønn:

- ◯ Mann
- ◯ Kvinne
- ◯ Annen oppfatning av kjønn

Alder:

- ◯ 18-20
- ◯ 20-25
- ◯ 25-30
- ◯ 30+

Hvilken beskrivelse passer for deg?

- ☐ Bruker av isen (ishockey, frigåring, kunstløp)
- ☐ Tilskuer
- ☐ Trener
- ☐ Dommer
- ☐ Annet, kommenter

Hvor ofte er du på Dalgård ishall?

- ◯ Mindre enn 1 gang i uken
- ◯ 1-2 ganger i uken
- ◯ 3-4 ganger i uken
- ◯ Mer enn 4 ganger i uken

Hvordan opplever du lufta generelt på følgende steder?

	Frisk	Litt frisk	Akseptabel	Litt dårlig	Dårlig
Isbanen	◯	◯	◯	◯	◯
Tribunen	◯	◯	◯	◯	◯
Kafeen	◯	◯	◯	◯	◯
Garderoben	◯	◯	◯	◯	◯

Når du er på tribunen, opplever du noen av disse punktene?

	Ja, ofte	Ja, iblant	Aldri
Innestengt (dårlig) luft	◯	◯	◯
Tørr luft	◯	◯	◯
Ubehagelig/vond lukt	◯	◯	◯
Støy	◯	◯	◯

Når du er i kafeen, opplever du noen av disse punktene?

	Ja, ofte	Ja, iblant	Aldri
Innestengt (dårlig) luft	◯	◯	◯
Tørr luft	◯	◯	◯
Ubehagelig/vond lukt	◯	◯	◯
Støy	◯	◯	◯

Når du er på isbanen, opplever du noen av disse punktene?

	Ja, ofte	Ja, iblant	Aldri
Innestengt (dårlig) luft	◯	◯	◯
Tørr luft	◯	◯	◯
Ubehagelig/vond lukt	◯	◯	◯
Støy	◯	◯	◯

Når du er i garderoben, opplever du noen av disse punktene?

	Ja, ofte	Ja, iblant	Aldri
Innestengt (dårlig) luft	◯	◯	◯
Tørr luft	◯	◯	◯
Ubehagelig/vond lukt	◯	◯	◯
Støy	◯	◯	◯

Har du i løpet av de siste 3 månedene merket noe av følgende plager når du er i ishallen?

	Ja, ofte	Ja, iblant	Aldri
Hodepine	◯	◯	◯
Svimmelhet	◯	◯	◯
Irritasjon, kløe, tørrhet i øynene	◯	◯	◯
Hoste, tørrhet i hals	◯	◯	◯
Kløe, tørrhet på hender	◯	◯	◯

Allergiske symptomer:

	Ja	Nei
Har du eller har du hatt astma?	◯	◯
Har du eller har du hatt allergi?	◯	◯
Har du eller har du hatt eksem?	◯	◯

Opplever du noen sesongvariasjoner når det kommer til luftkvalitet? (forskjell mellom høst, vinter og vår)

◯ Nei
◯ Ja

Hvordan opplever du luftkvaliteten i de ulike årstidene?

	Bra	Greit	Dårlig
Høst	◯	◯	◯
Vinter	◯	◯	◯
Vår	◯	◯	◯

Hvilke endringer merker du i den dårlige sesongen?

	Bedre	Lik/ingen endring	Værre
Luftkvalitet	○	○	○
Helseplager som er nevnt tidligere (luftveisproblemer, hudproblemer, øyeproblemer og lignende)	○	○	○
Lukt	○	○	○

Appendix D Approval from NCD

The approval to distribute the survey without further security actions is attached here.

Guangyu C ao
Jonsvannsveien 82
7491 T RON DH EIM

Vår dato: 25.05.2018 Vår ref: 60502 / 3 / PEG Deres dato:
Deres ref:

Tilrådning fra NSD Personvernombudet for forskning § 7-27

Personvernombudet for forskning viser til meldeskjema mottatt 25.04.2018 for prosjektet:

60502	Measurements of indoor climate parameters in the exercise zone of an ice hockey hall
Behandlingsansvarlig	NTNU, ved institusjonens øverste leder
Daglig ansvarlig	Guangyu Cao
Student	Linda Strand Prestmo

Vurdering

Etter gjennomgang av opplysningene i meldeskjemaet og øvrig dokumentasjon finner vi at prosjektet er unntatt konsesjonsplikt og at personopplysningene som blir samlet inn i dette prosjektet er regulert av § 7-27 i personopplysningsforskriften. På den neste siden er vår vurdering av prosjektopplegget slik det er meldt til oss. Du kan nå gå i gang med å behandle personopplysninger.

Vilkår for vår anbefaling

Vår anbefaling forutsetter at du gjennomfører prosjektet i tråd med:

- opplysningene gitt i meldeskjemaet og øvrig dokumentasjon
- vår prosjektvurdering, se side 2
- eventuell korrespondanse med oss

Meld fra hvis du gjør vesentlige endringer i prosjektet

Dersom prosjektet endrer seg, kan det være nødvendig å sende inn endringsmelding. På våre nettsider finner du svar på hvilke endringer du må melde, samt endringsskjema.

Opplysninger om prosjektet blir lagt ut på våre nettsider og i Meldingsarkivet

Vi har lagt ut opplysninger om prosjektet på nettsidene våre. Alle våre institusjoner har også tilgang til egne prosjekter i Meldingsarkivet.

Vi tar kontakt om status for behandling av personopplysninger ved prosjektslutt

Ved prosjektslutt 11.06.2018 vil vi ta kontakt for å avklare status for behandlingen av personopplysninger.

Se våre nettsider eller ta kontakt dersom du har spørsmål. Vi ønsker lykke til med prosjektet!

Vennlig hilsen

Marianne H øgetveit Myhren

Pernille Ekornrud Grøndal

K ontaktperson: Pernille Ekornrud Grøndal tlf: 55 58 36 41 / pernille.grondal@nsd.no
Vedlegg: Prosjektvurdering
K opi: L inda Strand Prestmo, lindasp@stud.ntnu.no

Personvernombudet for forskning

Prosjektvurdering - Kommentar

Prosjektnr: 60502

Formålet er å kartlegge luftkvaliteten ved Dalgård ishall. Dårlig inneklima kan føre til nedsatt prestasjonsevne. Det er tidligere ikke gjort undersøkelser som viser hvordan luftkvaliteten er i en ishall sett bort fra undersøkelser i utlandet som fokuserer på forgiftning av eksos. Oppgaven skal gjennomføres med målinger av luftparametre som CO_2, temperatur og relativ luftfuktighet og spørreundersøkelse. Spørreundersøkelsen har som formål å kartlegge hvordan brukerne av ishallen opplever luftkvaliteten..

Du har opplyst i meldeskjema at utvalget vil motta skriftlig informasjon om prosjektet, og samtykke skriftlig til å delta. Opprinnelig planla du å intervjue ungdommer, og innhente foreldrenes samtykke til dette. I telefonsamtale med personvernombudet opplyser du imidlertid at du har valgt å kun intervjue voksne over 18 år. Vi har derfor endret meldeskjema i tråd med dette. Vår vurdering er at informasjonsskrivet til utvalget er godt utformet. Vi ber deg imidlertid om å presisere i informasjonsskrivet at utvalget vil bli bedt om å stille enkelte spørsmål om helsetilstand.

Det fremgår av meldeskjema at du vil behandle sensitive opplysninger om helseforhold.

Personvernombudet forutsetter at du/dere behandler alle data i tråd med NTNU sine retningslinjer for datahåndtering og informasjonssikkerhet.

Prosjektslutt er oppgitt til 11.06.2018. Det fremgår av meldeskjema/informasjonsskriv at du vil anonymisere datamaterialet ved prosjektslutt. Anonymisering innebærer vanligvis å:

- slette direkte identifiserbare opplysninger som navn, fødselsnummer, koblingsnøkkel
- slette eller omskrive/gruppere indirekte identifiserbare opplysninger som bosted/arbeidssted, alder, kjønn

For en utdypende beskrivelse av anonymisering av personopplysninger, se Datatilsynets veileder:
https://www.datatilsynet.no/globalassets/global/regelverk-skjema/veiledere/anonymisering-veileder-041115.pdf