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# Evaluation of Measures to Improve Indoor Environment in Norwegian Schools

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This thesis is written during the breakout of the pandemic COVID-19, which has been a demanding situation for adaption. The pandemic has influenced the thesis, both by closing the university and the ability to collect the necessary amount of data.

Solveig Askevold Ulsund, MSc Student
Trondheim, 18th of June 2020

# Abstract

The purpose of this study is to examine the indoor environment for three schools in Trondheim municipality. They are reported as schools with known indoor environmental problems. The study is evaluating simple measures to improve the environment. This study will review the chosen measures, and further transfers the learning potential to a national level.

The study have been conducted through field measurements, interviews, questionnaires, and computation. The results have been compared and evaluated per method and in the context of each other. The result of this are compared with an earlier study to evaluate if chosen measures to improve the indoor environment are efficient.

A comparison of the result of this study with earlier study shows that the technical measures implemented in 2020 are efficient, while the behavioral measures are more difficult to follow up. The analysis of the result indicates that Stabursmoen does not have a satisfactory indoor environment, Sunnland has a moderately satisfactory indoor environment, and Sørborgen has a satisfactory indoor environment.

A comparison of the result of this study with earlier studies shows that the technical measures implemented in 2020 are efficient, while the behavioral measures are more difficult to implement, and needs to be anchored in the management to be successful. The analysis of the result indicates that Stabursmoen does not have a satisfactory indoor environment, Sunnland has a moderately satisfactory indoor environment, and Sørborgen has a satisfactory indoor environment.

# Sammendrag

Hensikten med denne oppgaven er å undersøke inneklimaet for tre skoler i Trondheim kommune. De rapporteres som skoler med kjente miljøproblemer innendørs. Studien evaluerer enkle tiltak for å forbedre inneklimaet. Denne studien vil gjennomgå de valgte tiltakene, og videreføre læringspotensialet til et nasjonalt nivå.

Studien er utført gjennom feltmålinger, intervjuer, spørreskjemaer og programmering. Resultatene er sammenlignet og evaluert per metode og i sammenheng med hverandre. Resultatet av dette er sammenlignet med en tidligere studie for å evaluere om valgte tiltak for å forbedre innemiljøet er effektive.

En sammenligning av resultatet fra denne studien med tidligere studie viser at de tekniske tiltakene som ble implementert i 2020, er effektive, mens atferdstiltakene er vanskeligere å følge opp. Analysen av resultatet indikerer at Stabursmoen ikke har et tilfredsstillende inneklima, Sunnland har et moderat tilfredsstillende inneklima, og Sørborgen har et tilfredsstillende inneklima.

En sammenligning av resultatet av denne studien med tidligere studier viser at de tekniske tiltakene som ble implementert i 2020, er effektive, mens atferdstiltakene er vanskeligere å gjennomføre, og må forankres i ledelsen for å lykkes.

# Objective

The aim of the project is to evaluate simple and effective measures for improving the indoor environment in schools that have been put on hold because the building will be rehabilitated or demolished and replaced with new buildings.

- Literature review
- Plan and conduct field measurements of indoor thermal environment and indoor air quality in selected schools
- Plan and carry out survey in three schools regarding the effects of indoor environment on health
- Develop a machine learning model to predict indoor air quality using carbon dioxide as an indicator
- Analysis of measurements results and survey result
- Evaluate the performance of different indoor environment measures for Norwegian schools on hold
- Prepare an article to dissemination the research results

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# Chapter 1

# Introduction

In August 2018, a new project, "Skoler på vent" (English; Schools on hold) was initiated by SINTEF in co-operation with NTNU, NAAF, and Trondheim municipality. The project aims to set focus on the indoor environment and to find and evaluate efficient and simple measures to improve the quality of indoor air in schools on hold for renewal. The project was initiated to acquire knowledge about schools waiting for refurbishment in addition to bu used as learning for comparable projects on a national level. In this project, there are three case-schools which will be investigated by the project group over a predefined time. The case-schools are selected based on age and because they are awaiting either refurbishment or displacement of new construction. All three case-schools are in the new Trondheim municipality, reformed 01.01.2020. The schools are Sunnland secondary school, Stabbursmoen primary and secondary school, and Sørborgen primary and secondary school (old municipality; Klæbu). The location of the three schools are shown in figure 1.1.


Figure 1.1: Map of Trondheim and the location of the three case schools in Trondheim area [35]

The background for the project is the new focus around IAQ outside of residential buildings, and the importance of air quality received by children. They do not have fully developed respiratory systems and have a higher volume of air intake than an adult. The Norwegian Labor Inspection Authority published in 2013, a report after inspecting 301 schools in 280 different municipalities in Norway. [10] The report raised awareness of the lack of resources used to ensure a safe and healthy learning environment. Nine out of ten municipalities were forced to make improvements. Today, there is a high focus on measures for energy savings in public buildings. It is tempting to turn down the heat or provide less ventilation as energy savings measures and cost reduction. However, this can be crucial for pupils' health and learning ability. In Bergen, several schools had to close down the past decade, because the poor indoor environment was endangering for the occupants. Both pupils and employees developed permanent health problems attending the schools, Varden and Landås. In 2018, one in three people associated with Varden school was diagnosed with asthma. [14][15][34]

Only the most necessary maintenance is carried out for schools that are waiting to be demolished, rehabilitated, or where the near future is undefined. It is primarily mitigating measures and organizational measures. Scheduled maintenance is reduced only to maintain emergency measures when necessary. The reduced maintenance causes a backlog that can resolve in high costs when emergency measures must be implemented since users in buildings have become ill. Furthermore, these buildings must have a good cleaning and optimal building operation with a satisfactory indoor climate, where no one gets sick even if the buildings are on hold. Schools, where the further operation is unresolved, will still be in regular use. However, unfortunately, no funds will be set aside for upgrading, and new equipment, unlike newer schools under the municipality's maintenance and school budget. It is common for schools on hold, to be in use for 10-15 years. It indicated that children spend a large part of their entire childhood in an unsatisfactory indoor environment and can affect the children's health, leading to high social costs for society. [34]

The case schools are chosen from an evaluation conducted by Trondheim municipality, which evaluates the state of the schools in Trondheim, every fourth year. The schools are categorized into three categories; red, yellow, and green, where red is the worst category and means that the school needs to take serious action to improve the existing building or replace the school building with a new. From the latest examination in 2017, both Sunnland and Stabbursmoen were marked as red [7]. Today's status for the upgrade of these two schools is that Sunnland will be replaced with a new school in 2023, and Stabbursmoen will be rehabilitated within 2022. Since these schools' are awaiting major upgrades and replacement buildings, there will not be invested a large amount to upgrade the existing building. Therefore, it is vital to study the existing buildings to see which simple measures can be accomplished to improve the quality of the indoor air. In the autumn of 2019, there was developed a plan for different measures to improve the indoor environment, and they were implemented in January 2020. [7] [20]

The goal of this work is to evaluate simple and efficient measures to improve the indoor environment in schools that are awaiting refurbishment, reconstruction, or an uncertain future. The final output of this project is a digital "toolbox," including simple measures that the municipalities can utilize efficiently to improve the indoor environment for schools on hold. The project holds considerable learning potential, which will resolve in knowledge transfer for schools in the same situation, over the whole country.

A field study was conducted in each of the three schools; Stabbursmoen, Sunnland, and Sørbrogen. There were chosen four case-rooms that were equipped with instruments to measure carbon dioxide, temperature, and relative humidity. Pupils attending the schools were invited to participate in a web-questionnaire about indoor environment and health symptoms. Selected employees were interviewed for each school regarding the indoor environment, health problems, and implemented measures. The thermal environment was examined by comparing the predicted percentage of dissatisfaction with the actual percentage of dissatisfaction. The results are presented separately and seen in the light of each other to evaluate which measures implemented are efficient. Last, it was used machine learning to develop a tool to predict indoor air quality based on carbon dioxide concentration.

The thesis divides into six chapters. The first is the introduction, followed by the literature review conducted to perform the study. The literature review consists of ventilation utilized in Norwegian school, hazards of poor indoor air quality, requirements and guidelines from Norwegian authorities, thermal comfort, and a short explanation of machine learning. The various methods used in this study are presented in chapter 3. In chapter 4, a short presentation of the schools and implemented measures are described. chapter 5 presents the results with discussions. Last, the conclusion is presented in chapter 6.

# Chapter 2

# Literature Review

This chapter presents the relevant theory and literature study related to this master's thesis. Parts of the chapter were written in association with the project thesis, which is continued to the master thesis.

## 2.1 Ventilation effectiveness in class rooms

Technical systems in a school's main task are to provide an acceptable environment in an energy-efficient way, without reducing health and performance of pupils and employees. Ventilation is an essential part of the indoor environment.
The ventilation effectiveness can indicate the quality of air and human exposure in a room. In other words, ventilation effectiveness represents how well a room or space is ventilated compared to perfect air mixing conditions. The main object for a ventilation system is to provide fresh air to the occupants and remove present air pollutants. Since a mechanical system accounts for up to half of the energy consumption in a building [38], it is necessary to have a ventilation system that can remove pollutants and provide a safe indoor environment without extraneous high air supply rate. [30]

Air exchange rate ($\varepsilon^a$) has been evaluated by research to be one of the most efficient indicators to measure how the supplied fresh air can remove indoor airborne contaminants[29]. The parameter can describe the quality of the distributed supplied air for space by reviewing the age-of-air in different locations across a room or space. The effectiveness of air exchange is defined by the ratio of age-of-air for perfect mixing conditions and the average age-of-air for the current zone. This relationship gives the effectiveness of ventilation compared to perfect mixed conditions. [30]

For school buildings, one of the challenges regarding ventilation is that they are old and often outdated, especially the technical systems. Also, how the building is utilized has changed.

Today, the number of pupils per square meter has increased, which implies that the internal heat load increases equivalently. Therefore, there is a need for a new ventilation strategy for Norwegian school buildings. [19]

### 2.1.1 Mixing ventilation

Mixing ventilation is the most common ventilation system in old school buildings. The fresh air is supplied by air terminals in the ceiling, by air jets. The jets are important to generate re-circulation of air in the room. It is because the momentum of flow from the supply opening is only partially maintained by the buoyancy force. This principle is illustrated in figure 2.1 The jets can be formed as free jets or wall jets. When maintaining thermal comfort in the room, there is important to keep a low velocity level and small temperature gradients. [23]

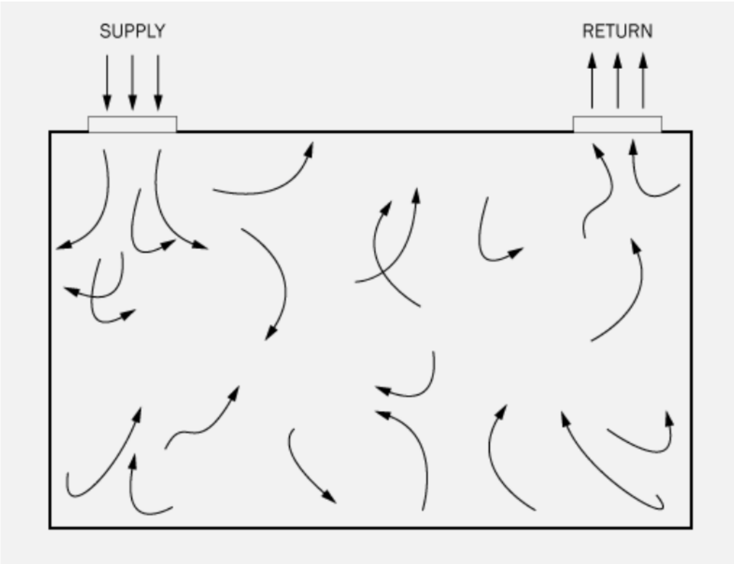


Figure 2.1: Illustration of thermal plum for Mixing ventilation [1]

When absorbing contaminants from different sources with mixing ventilation, the general principle is to create re-circulation flow, for instance, the local concentrations are low everywhere in the room. It means that the contaminant removal must involve convection and turbulent diffusion, leading to a rise to concentration gradients. Sunnland and Stabbursmoen school is mainly equipped with this type of ventilation.[23]

### 2.1.2 Displacement Ventilation

The principle for displacement ventilation is to replace the old air with new fresh air. Displacement ventilation has different design forms, and the main principle for displacement ventilation to form air movement in the space is to take advantage of the physics behind air density. Cold air has a lower density than warm air. Therefore, by supplying fresh air by terminals near the floor, the fresh cold air will replace the warm old air and keep the occupant zone clean and fresh while the old air is circulating to the higher zone where the air extract is located. Buoyancy is the main driving force. This is illustrated in figure 2.2. [39]

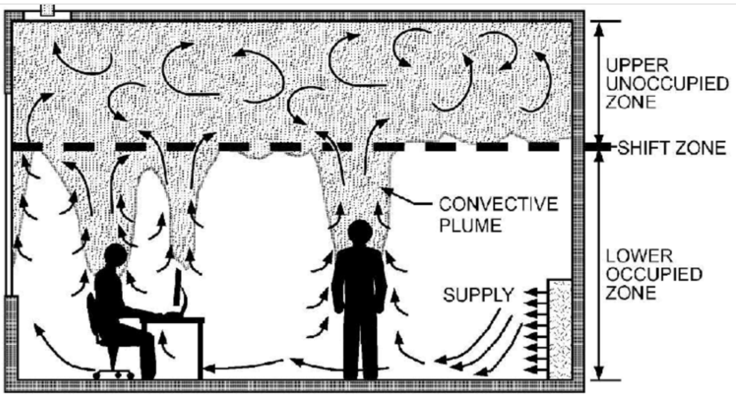


Figure 2.2: Illustration of thermal plum for displacement ventilation [21]

For the principle of buoyancy forces to work, the vertical temperature gradient in the room should be at least 1-2°C. Therefore, displacement ventilation can not be used for heating a room. Sørborgen school is mainly equipped with this type of ventilation. [39]

### 2.1.3 Requirements for ventilation in educational buildings

The ventilation in a building shall fulfill requirements that ensure satisfactory air quality. The ventilation shall adapt to the rooms' design, intended use, pollution, and humidity loads. It shall provide an efficient airflow which can remove odor to provide a satisfactory air quality. Besides, the ventilation shall provide indoor air that does not contain harmful concentrations of pollutants that can provide health issues or cause irritation of the eyes, nose, and throat. The following requirements are applied for educational buildings according to TEK 17 §13-3 [11]:

1. *An average supply of fresh air at a minimum rate of 26 $m^3$ per hour per person shall be supplied due to the pollution caused by people performing light activities. If activities other than light activities are to be performed, the supply of fresh air shall be adapted such that the air quality is satisfactory*

2. *The minimum supply rate of fresh air due to pollution from materials, products and systems shall be:*

   (a) *2.5 $m^3$ per hour per $m^2$ of floor space when the housing unit or rooms are in use*

   (b) *0.7 $m^3$ per hour per $m^2$ of floor space when the housing unit or rooms are not in use*

### 2.1.4 Consequences of insufficient ventilation and risk of airborne transmission estimated from concentration of carbon dioxide

Poor indoor environment is a known problem for schools in Norway. Children are more sensitive to exposure to air pollutants than adults because the airways, immune and digestive systems, and neural systems are not fully developed. This may lead to easier entrance for toxic gases and can affect the bodies organs. The health consequences of the poor indoor environment include airways, infections, headaches, dry skin, mucous, and rapid colds. [5]

Exhaled breath is the primary source for emission of airborne particles. Exhaled breath contains a concentration of carbon dioxide of nearly 40 000 ppm, and the concentration outdoors contains around 400 ppm. In a classroom, the primary source of carbon dioxide comes directly from the occupants, when it seldom exists other significant sources inside. Therefore, it can be possible to estimate the risk of transmission of airborne infections in a school, based on the Wells-Riley equation, the total amount of carbon dioxide inside a room, and a carbon dioxide-based risk equation. This gives the following model for the reproduction number of how contagious a disease can be inside a building, assuming there exist at least one carrier inside the room: [31]

$$R_{A0} = (n-1) * [1 - exp(-\frac{\bar{f} q t}{n})] \tag{2.1}$$

$R_{A0}$ = Reproduction number of a contagious disease in a room

n = number of persons in the ventilated room

$\bar{f}$ = Fraction of indoor air which is exhaled breath

q = quanta-generation rate for infects [quanta/person]

t = Total exposure time [s]

Further, this model can be used to risk evaluation for various scenarios of different types of airborne viruses with different values for $q$. The infectiousness for a disease increases with the value of $q$. Measles has a high $q$-value, influenza has a medium $q$-value, and the Rhinovirus has a low $q$-value. Predicted reproduction number can be calculated by assuming there is one infected person among a group of people in the room, the number of occupants, ventilation rate, and the average concentration of carbon dioxide in the room. [31]

Figure 2.3 a) shows the reproduction number for measles as a function of the number of occupants in a room. The calculated reproduction rate for measles, with a quantum generation rate of 570/h and the exposure time of 10h (approximately two school days), will have a nearly linear growth with the number of occupants in the room when there are high concentrations of carbon dioxide (2000 ppm). The growth is not as significant for low concentrations of carbon dioxide. However, the reproduction number is still higher than 1, which means that it is still reasonable to assume that spread of the infection can occur in well-ventilated rooms.[31]

Figure 2.3 b) shows the reproduction number for influenza as a function of the number of occupants in a room. The calculated reproduction rate for influenza, with a quantum generation rate of 100/h where the exposure time is 4h, the risk of infection will solely be critical with high concentrations of carbon dioxide. Compared to the risk of getting infected outdoors, the reproduction rate will be almost five times higher, with concentrations above 1000 ppm and almost ten times as high for concentrations above 1500 ppm. In buildings with well-ventilated rooms and low concentrations of carbon dioxide, the reproduction number will be less than 1 and therefore be in reduced risk of infections. [31]

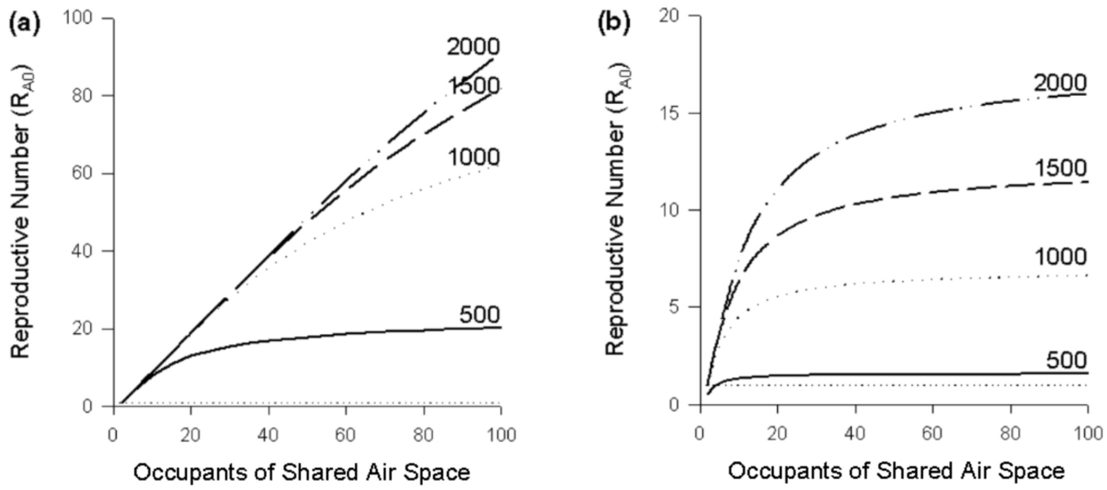


Figure 2.3: $R_{A0}$ for airborne disease as a function of number of occupants in a room and concentration of $CO_2$ (ppm). a) Measles (q=570 quanta/h, t=10 h, $C_0$=350 ppm, $C_a$ =37 500 ppm), b) Influenza (ppm) (q=100 quanta/h, t=4 h, C0=350 ppm, Ca =37 500 ppm) [31]

A review from the Building Ecology Research Group, including 27 papers regarding the relationship between ventilation rates and health effects, there was found consistency across multiple investigations and different epidemiology designs and divergent population. The review has shown that higher ventilation rates will reduce sick building symptoms and short term sick leave, caused by inflammation, respiratory infections, and short term sickness. [41]

## 2.2 Thermal comfort in buildings

Since the 1930s, thermal comfort has been on the agenda. When the developing the concept of thermal comfort, the integration of several sciences put together is necessary. The research must include physiology, building physics, mechanical engineering, and psychology. The standard ASHRAE 5-74 has defined thermal comfort as follows "*That condition of mind which expresses satisfaction with the thermal environment*"[2]. The sensation can be individual, and which state of mind a person will find as satisfying will vary from person to person. To understand the importance of thermal comfort, there are three main reasons. First of all, it is the importance of providing a satisfactory indoor environment for people. Second is to control the energy consummation and last, to suggest and set standards. [32] [36]

For years, there have been two general strategies to evaluate thermal comfort; (1) Climate chamber studies and (2) field studies. [36]

1. Climate chamber studies are conducted in a chamber which can vary the different climatic parameters. The task determines personal parameters, such as metabolic rate and clo (clothing insulation). This test aims to determine the steady-state thermal comfort model

2. Field studies are conducted in real conditions, where there is no attempt to control the environmental conditions. Therefore, this method aims to study thermal comfort in the real world. In addition to the environmental parameters, metabolic rate, and clo, the subjects are influenced by cultural and psychological factors.

### 2.2.1 Thermal comfort standards

The most applied standards regarding thermal comfort is ASHRAE 55 and ISO 7730. They have both formed standards for comfortable thermal environments. ASHRAE determines the comfort zone for occupants. If the environment is thermally uniform, 90 % of the occupants should find the thermal environment acceptable. ISO 7730 utilizes PMV (predicted mean vote) and PPD (predicted percentage of dissatisfaction) indices to specify acceptable thermal comfort conditions. PMV is based on the thermal sensation scale, a 7-point scale, seen in table 2.1. The PPD predicts the percentage of occupants to likely feel "too warm" (-3, -2) or "too warm" (2, 3). [9][28]

Table 2.1: Thermal sensation scale and comments about scale [9]

| Scale | Thermal Sensation | Comment |
|---|---|---|
| 3 | Hot | Intolerably warm |
| 2 | Warm | Too warm |
| 1 | Slightly warm | Tolerably uncomfortable, warm |
| 0 | Neutral | Comfortable |
| -1 | Slightly cool | Tolerably uncomfortable, cool |
| -2 | Cool | Too cool |
| -3 | Cold | Intolerably warm |

The relationship between PMV and PPD is illustrated in figure 2.4. The relationship is based on Fanger's PMV-PPD equation, in which the comfort criteria are defined by theoretical, experimental, and statistic studies. Fanger's equation and belonging physical parameters is embroidered in appendix A. For occupants with the sensation "thermal neutral" (PMV=0), there is predicted that 5 % will be dissatisfied with the environment. For the thermal sensations "Hot" and "Cold" (PMV=3 and PMV=-3), there is predicted that 100 % of the occupants will be dissatisfied with the thermal environment. [9]

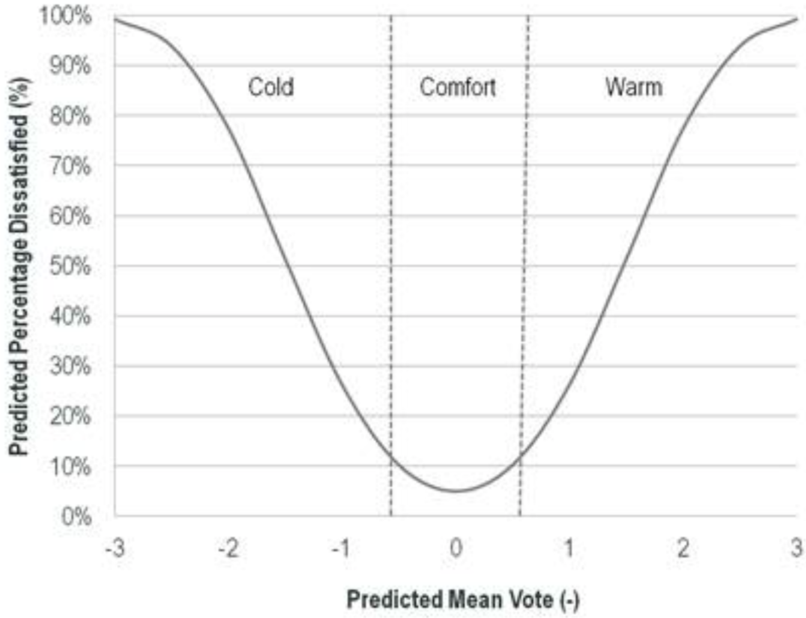


Figure 2.4: Relationship between PPD and PMV [6]

### 2.2.2 Recommendations and guidelines for indoor environment and consequences of default

**Carbon Dioxide**

A child consumes 10 to 15 kg of air per day, varying with size, age, and physical activity. The air the child is exposed to consist of different chemicals and air pollutants, like carbon dioxide. In many ways, the air quality is dependent on the quality of the ventilation in the school, and health, well-being, and function are highly dependent on the air consumed. If the air inside a building is insufficient with a high concentration of carbon dioxide, numerous health issues can affect pupils and teachers. The hazards are sleepiness, headache, decreased concentration, irritation in mucous and increased frequency of respiratory infections. For Norway, the authorities have decided that the maximum level of carbon dioxide inside in schools and kinder gardens is 1000 ppm [3]. [26]

**Thermal environment**

For schools in Norway, the major thermal obstacle is too high room temperature. It can cause the following health effects; fatigue, dry skin, and dry mucous membrane [27]. There has been proven a significant relation between air temperature above 22°C and the occurrence of indoor environment problems by several studies [44]. From the Norwegian regulation, TEK17, he recommendation regarding temperature during the heating season should be below 22°C and higher than 19°C for light activity level (classroom activity)[12].

**Relative Humidity**

Through several studies, there are associations between dampness and respiratory diseases, mainly cough, wheezing, and, to a lesser extent, asthma. Children are in the risk group of people who are more sensitive to dampness in buildings. Thereby, to avoid dampness in schools are essential to remaining healthy. Moisture damage that evolves will make indoor environment unsatisfactory and may result in sick pupils and employees. Therefore, measures should be taken early to reduce the scope of the damage. This will have a great significance for the user's health. Relative humidity indoors should be higher than 20% and below 50 %.[25]

**Summery of Recommendations and guideline values**

In table 2.2, a summary of recommendations and guideline values to behold a satisfactory indoor environment set by Norwegian authorities, is presented. The table includes the maximum and minimum values for the following parameters; carbon dioxide, temperature, and relative humidity. [3][12][4]

Table 2.2: Recommendation and guideline values for carbon dioxide, temperature and relative humidity in Norwegian schools [3][12][4]

| **Parameter** | **Recommendation and guideline value** |
|---|---|
| Carbon dioxide | Below 1000 ppm |
| Temperature | Above 19°C<br>Below 22°C |
| Relative Humidity | Above 20 %<br>Below 50 % |

## 2.3 Machine learning as a tool to predict carbon dioxide indoors

Machine learning (ML) is an application of artificial intelligence which trains computers to work in a certain way without being expressly programmed, based on statistical algorithms. The received output value predicts the program in the algorithm by the use of a specific statistical method. This is the main difference between ML and traditional programming. An illustration of the difference between traditional programming and ML is seen in figure 2.5 ML is mainly used for creating intelligent machines which can work and think like a human being. [40]

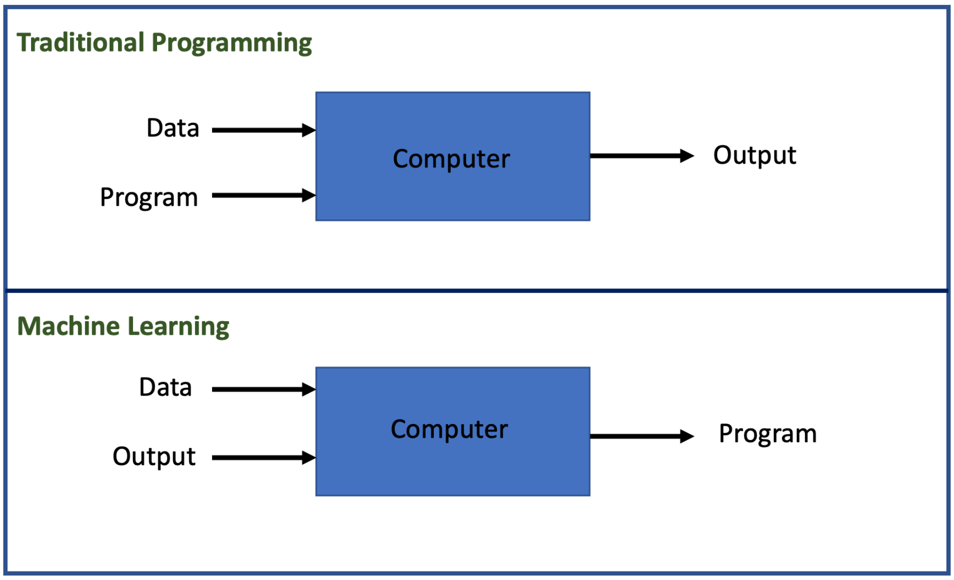


Figure 2.5: Illustration of a simplified flow chart for traditional programming and Machine Learning

ML can be separated into two categories, supervised, and unsupervised. Unsupervised learning is a method that already have quantum variants [42]. When predicting carbon dioxide, it will be used supervised ML, which means that the program is "trained" on a predefined set of "training-examples." When given new data, the ability to predict an accurate prediction will be in range for the model. When new data is introduced to the ML algorithm, the output is based on the training examples. If the output is unsatisfying, the algorithm is trained over and over until the prediction reaches an acceptable accuracy. In figure 2.6, a flow chart for a typical ML process is illustrated. [40]

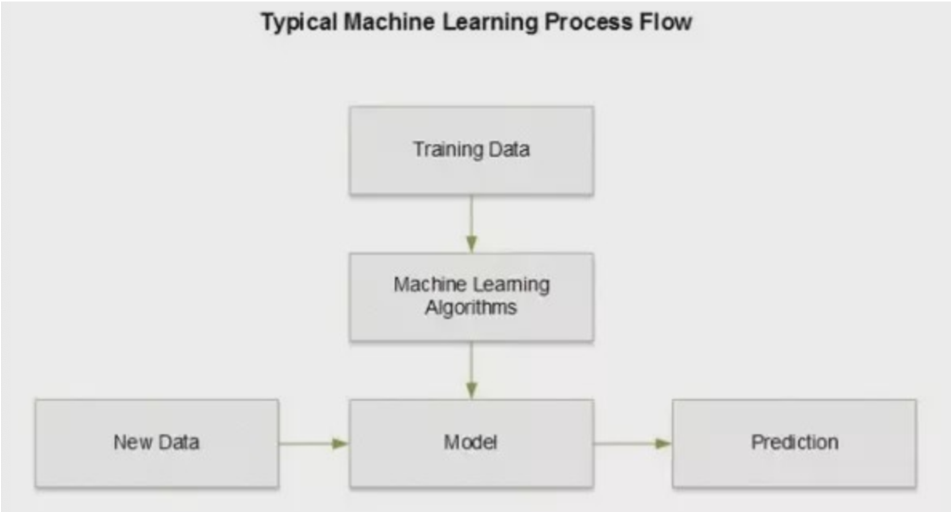


Figure 2.6: Illustration of a flow chart for a typical machine learning flow [40]

To build a model that can predict the carbon dioxide level inside a room, there are several requirements. Perhaps the most important requirement is access to enough labeled training data in order to train the machine learning model which can determine the data patterns. Further, automation, which gives the system ability to operate automatically, an iteration to repeat the process, scalability, which is the capacity of the machine to increase or decrease size and scale and the model created to fulfill the demand by the process of modeling. When predicting carbon dioxide, the output can be based on the following parameters as input; occupants, temperature, relative humidity, and weather conditions. [40]

A study from Sogang University in Seoul, Korea proved to use deep learning as a tool to predict indoor air quality. The model received input data from six sensors measuring six atmospheric factors: carbon dioxide, fine dust, temperature, humidity, light quantity, and volatile organic compounds (VOC). The deep learning model was proven to be more efficient than in prediction ability than a single linear regression method. [18]

## 2.4 Prediction methods

There are a wide range of different predefined algorithms which can be used in ML, two of the algorithms will be explained briefly. The two methods are Random Forest prediction (RF) and AdaBoost prediction (AB)

### 2.4.1 Random Forest prediction

Random Forest is a supervised learning tool, where the outcome is based on the learned patterns. The algorithm is based on the principle of decision tree, where the prediction follows several branches of "if" and "then" decision splits. The data starts on the bottom of the three and follows upwards to the first branch with regulation data and splits the data to the fitted path until it reaches the "leaf," where the output data is presented. The final prediction is a result of several output data from individual trees, which is why the algorithm is called Random Forest. Figure 2.7 is an illustration of the principles for Random Forest algorithm, using decision trees to predict. [13]

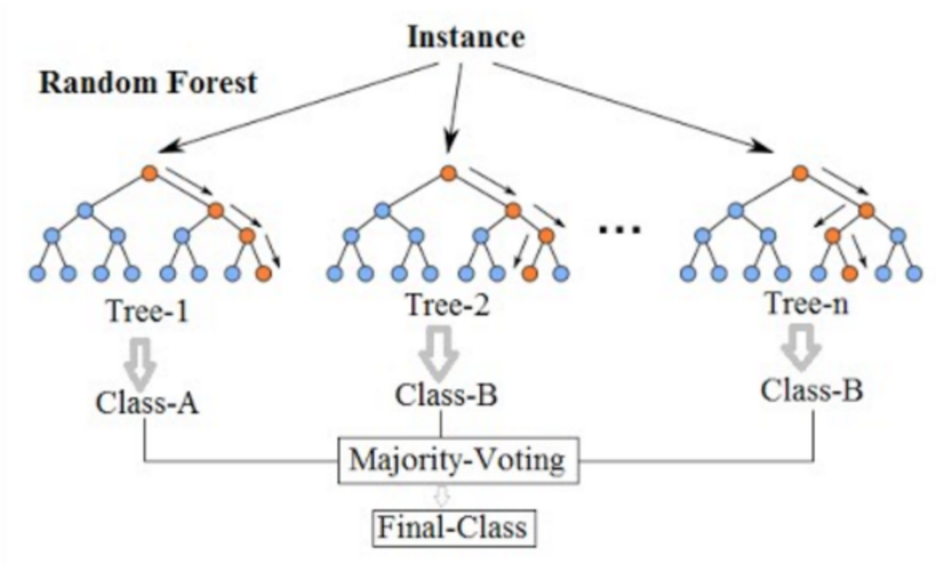


Figure 2.7: Illustration of the construction of a decision tree [13]

### 2.4.2 AdaBoost Prediction

AdaBoost prediction is an algorithm that boosts the method by creating a robust classifier from several weak classifiers. For this to succeed, there is build one model for training data, and further, a second model is created to attempt to correct the errors which occurred in the first model. This continues until the model predicts the training set satisfactory or until the maximum number of models are added. An illustration of a simplified flow chart is seen in figure 2.8. The flow chart illustrated that a number of models, until $M_n$ will be added and combined. Further, new data will be integrated, before the prediction is estimated. [8]

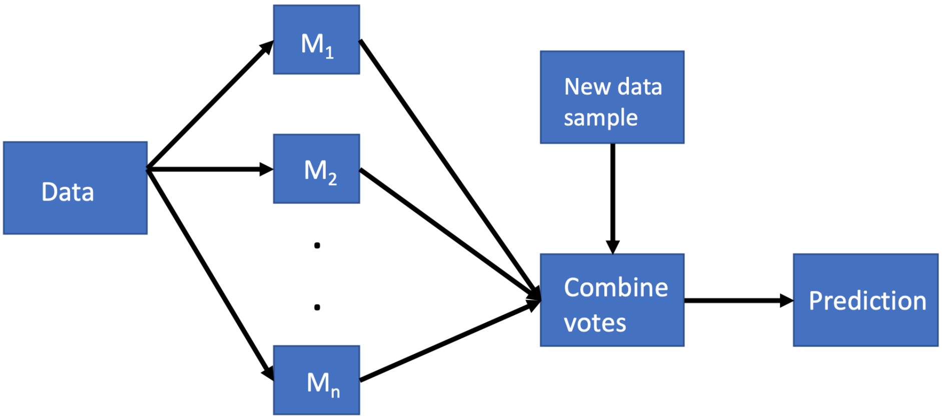


Figure 2.8: Illustration of a simplified flow chart for AdaBoost prediction. M=model

# Chapter 3

# Methodology

In this chapter, a description of the work conducted in the study will be described. Both qualitative and quantitative methods have been used. The work consists of a combination of field measurements, interviews, questionnaires and machine learning. An overview of the work conducted during this study is provided in table 3.1, in the form of a timeline. The timeline is provided with dates and what has been accomplished.

Table 3.1: Timeline with dates for when different tasks are conducted during the study

| Timeline | What is accomplished |
|---|---|
| 06.02.20 | Installation of measurement equipment at all three case-schools |
| 14.02.20-23.03.20 | Interview with employees of the three case-schools |
| 24.02.20 | Survey regarding thermal comfort, Stabbursmoen |
| 24.02.20 | Replacement of batteries for indoor environment sensors, Stabbursmoen |
| 24.02.20-16.03.20 | Questionnaire regarding indoor environment and health symptoms,pupils |
| 26.02.20 | Survey regarding thermal comfort, Sørborgen |
| 04.03.20 | Retrieve all measurement equipment, Sørborgen and Sunnland |
| 10.03.20 | Retrieve all measurement equipment, Stabbursmoen |

## 3.1 Field Measurements

For the field measurements, each room in the three schools are equipped with similar instrumental set up. The instrumental set up includes instruments that measures the following parameters; air temperature, carbon dioxide, relative humidity, supply, and extract temperature and outdoor temperature. When measuring the three first parameters, there are used to different types of sensors; ELMA DT-802D [ELMA] and CA.1510 [CA], both from the same manufacturer (Elma instruments). The supply, extract, and outdoor temperature are measured using a device called iButton DS1922L [iButton]. The different instruments used are displayed in figure 3.1.


Figure 3.1: Instruments used in the field measurements. CA.1510 (in front, left), iButtons (back, left), and ELMA DT-802D (right)

The collection of data is handled by using the associated program from each instrument, distributed by the manufacturer. The following programs are used; ELMA: "Multiple Datalogger," CA: "Datalogger," and iButton: "OneWire-Viewer." The set-up for the instruments is handled in the same programs. Each instrument is set to a logging interval of 2 minutes. When analyzing the results, the program Microsoft Excel is used. The analysis of the results and comparison of the field measurements are based on the range of operating hours (school hours) for each room. According to the schedule, the rooms will be unoccupied by a part of the time during the operation hours, but this is not taken into account in the analysis, reasoning it is unpredictable. There is a high probability that there will be changes to the original schedule. The school hours for each room in each school is shown in table 3.2.

Table 3.2: School hours, when the rooms are in use

| School hours | Start | End |
|---|---|---|
| **Stabbursmoen** | | |
| Room Bl\r{a}sal | 08:00 | 13:45 |
| Room 321A | 08:00 | 13:45 |
| Room SFO | 13:00 | 16:30 |
| Teacher's lounge | 08:00 | 16:00 |
| **Sunnland** | | |
| Room 104 | 08:15 | 14:35 |
| Room 108 | 08:15 | 14:35 |
| Room 203 | 08:15 | 14:35 |
| Room 207 | 08:15 | 14:35 |
| **Sørborgen** | | |
| Room 0217 | 08:15 | 13:15 |
| Room 0222 | 08:15 | 13:15 |
| Room 0273 | 08:15 | 13:15 |
| Music room | 08:15 | 13:15 |

It has been attempted to copy the set-up and placement of instruments from the study [35] executed in conjunction with the project, winter 2019.

### 3.1.1 Testing and set-up of instruments

For this study, there is supplied in a total of 9 ELMA-sensors, 5 CA 1510-sensors, and 27 iButtons. Most of them are tested in a room with steady and controlled climate conditions before they are used in the field study. From the test, one ELMA-sensor is excluded, reasoning missing measuring values for carbon dioxide. Ideal, one more should be excluded because the measured carbon dioxide level had a high deviation compared with the other instruments. However, due to the lack of instruments, it is decided to use the sensor. All the results from the test can be viewed in appendix B.

From the test of the instruments, it can be seen that several of the ELMA-sensors could be in need of a calibration; however, in shortage of resources, the standard deviation is calculated and used further in the results. The ibuttons showed a significant correlating result from the test. All the instruments have been given their own unique name composed by the type of instrument and a number; ELMA-X, CA-X, and iButton-X. Table 3.3 gives an overview of the instruments and their location.

Table 3.3: Location of instruments used during the field measurement

| Location | ELMA-X | iButton supply | iButton extract |
|---|---|---|---|
| **Stabbursmoen** | | | |
| Blåsal | CA-3 | 15 | 14 |
| 321A | CA-4 | 12 | 11 |
| SFO | CA-5 | 18 | 17 |
| Teachers lounge | CA-2 | 16 | 9 |
| **Sunnland** | | | |
| 104 | ELMA-4 | 2 | 1 |
| 108 | ELMA-7 | 4 | 3 |
| 203 | ELMA-6 | 6 | 5 |
| 207 | ELMA-1 | 8 | 7 |
| **Sørborgen** | | | |
| 0217 | ELMA-8 | 27 | 26 |
| 0222 | ELMA-5 | 25 | 24 |
| 0273 | ELMA-2 | 23 | 21 |
| Music room | ELMA-3 | 19 | 20 |

### 3.1.2 Experimental setup: Stabbursmoen

The rooms chosen for Stabbursmoen school has a wide spread of both location and use. There are chosen two rooms located on the second floor, which are the room "Blåsal" and classroom 321A. The SFO-room is located on the 1st floor, and the last room is the teacher's lounge located on the ground floor. For a more descriptive understanding of where the rooms are located, see figure 3.2 and 3.3. The placement of the instrument in each room are market with the following colour coding:

- Black: ELMA-sensor
- Blue: supply-temperature
- Orange: extract temperature

In Sunnland school, the CA-sensors is utilized. The placement of the sensors is based on the earlier study, to strive to receive as similar conditions as possible.

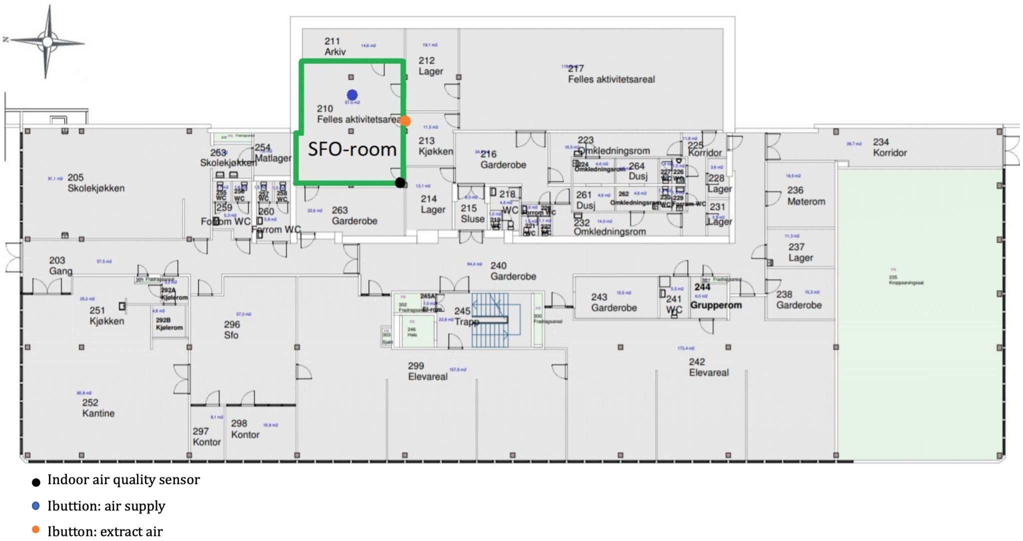


Figure 3.2: Floor plan of first floor of Stabbursmoen school. The rooms included in the field measurements are marked with a square. The measurement tools are marked with a dot; black is the indoor environment sensor, blue is the iButton measuring supply air and orange is the iButton measuring extract air [35]

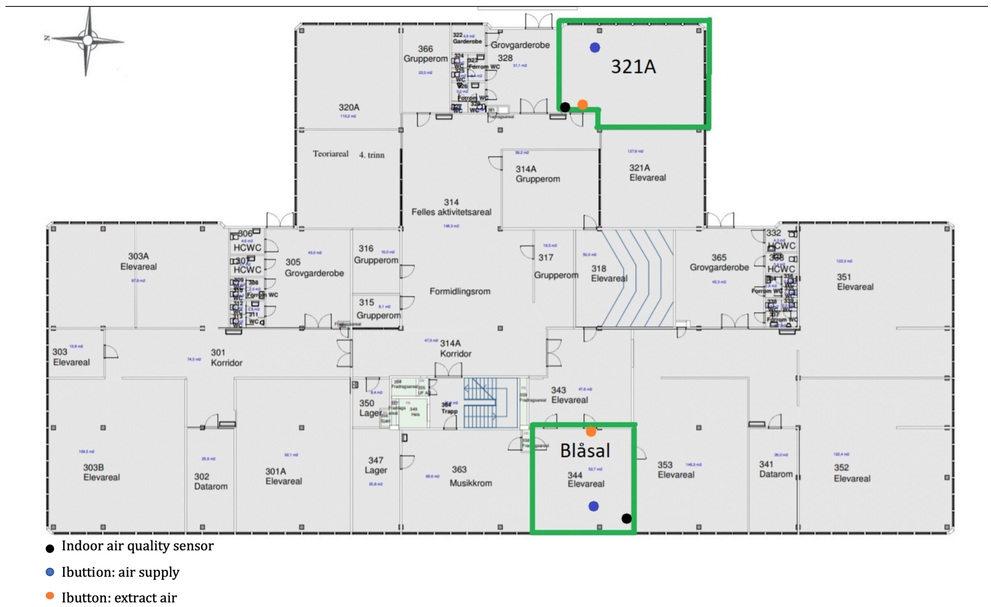


Figure 3.3: Floor plan of the second floor of Stabbursmoen school. The rooms included in the field measurements are marked with a square. The measurement tools are marked with a dot: black is the indoor environment sensor, blue is the iButton measuring supply air and orange is the iButton measuring extract air [35]

### Blåsal

The room Blåsal is a small auditorium, located on the west side of the school. The area is 52,7 $m^2$, and there are roughly 60 seatings in the room, but there are rarely more than 20 pupils in the room at the same time. In January 2020, the air supply from the central ventilation unit is replaced with a classroom aggregate, which is currently supplying fresh air to the room. The CA-sensor is taped to the wall in the back of the classroom. The initial idea of the placement for the sensor is probably to keep it out of sight for curios pupils, as well as avoid external heating and cooling loads. The iButtons for supply air is placed on the grill from the central ventilation unit, and the iButton measuring extract air is placed on the outlet above the door, which is not utilized*. The placement of the sensors are seen in figure 3.4

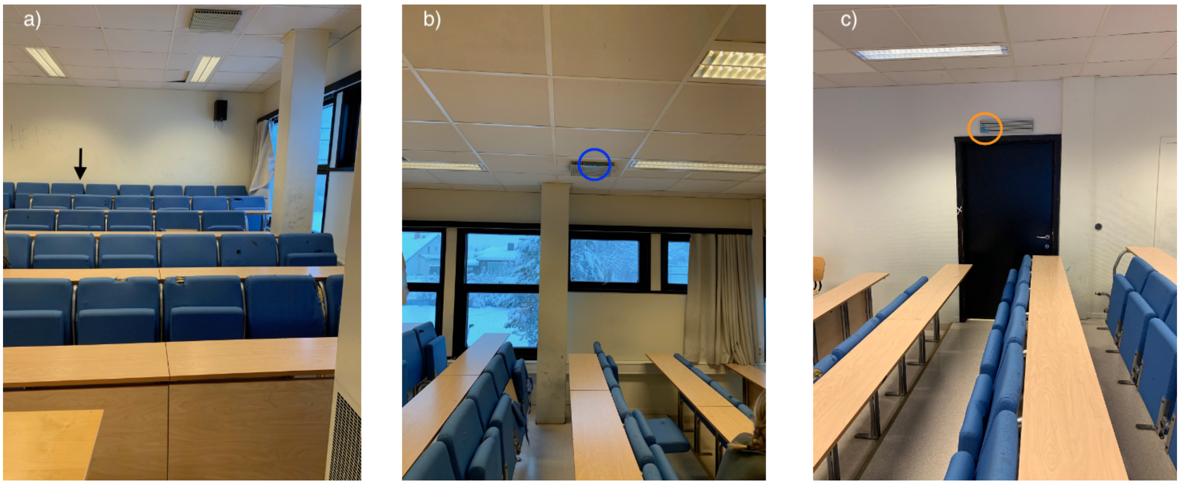


Figure 3.4: Location of placement of sensors in the room Blåsal. a) Sensor, measuring air quality b) Sensor measuring temperature of supply-air, and c) Sensor measuring temperature of extract-air

**Teacher's lounge*It has been discovered that the placement of the iButtons measuring the temperature of supply and extract air is incorrect according to the wanted outcome. They should have been placed on the new classroom aggregate in the room and not in the same location as the earlier study.*

**Teacher's lounge**

The room teacher's lounge is located on the ground floor for the school. It has an area of 73.8 $m^2$. The room is used as a multipurpose room for the teachers and administration of the school. Here they eat lunch, take breaks, and holds meetings, depending on the day. It is not connected to the central ventilation system, but a newer system, installed in 2008. There are four mechanical extracts. The IAQ-sensor's placement is along the long side, opposite the entrance of the room, on a lectern. The iButton measuring supply air-temperature is placed on the side of the air terminal in the middle of the room. The iButton measuring the extract air is placed inside the extract terminal in the middle to the left. Placement of the sensors are displayed in figure 3.5.

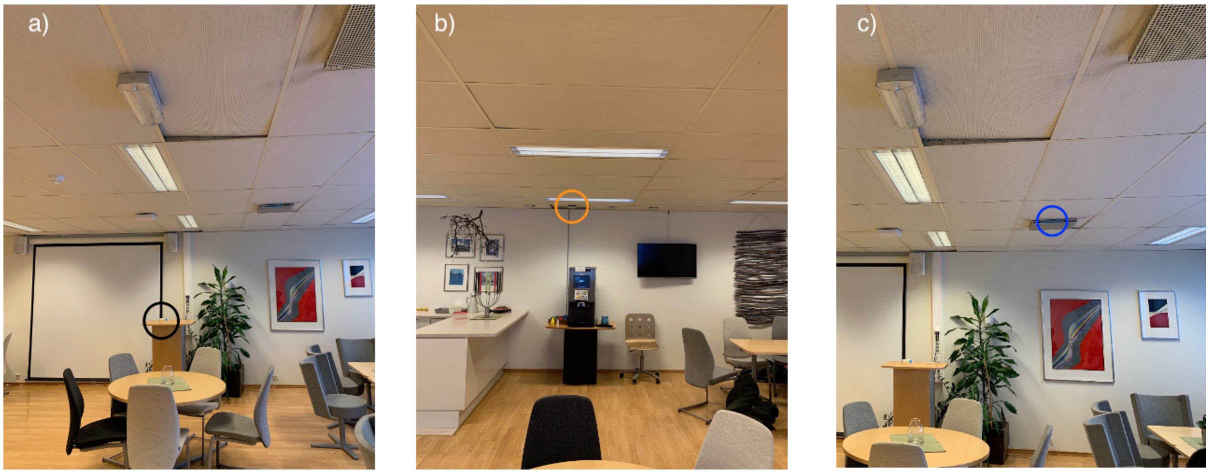


Figure 3.5: Location of placement of sensors in Teacher's lounge. a) Sensor, measuring air quality b) Sensor measuring temperature of extract-air, and c) Sensor measuring temperature of supply-air

### SFO-Room

The SFO-room has an area of 50 m$^2$ and is used as playroom during the after-school program (SFO). It is located on the second floor and in the core of the building, which implies that there is no window and thereby no source to natural lighting. It is also functioning as the school's emergency room. The room is supplied with air through two air terminals, the iButton measuring the supply air-temperature is attached to the air terminal which is nearest the exit door. There are no extracts at all, neither grids nor mechanical extracts. The sole approach for the exhaust air to leave the room is through the door opening. Therefore, there is no source to measure the extract temperature. The CA-senor's placement is on top of a bookshelf, a central location of the room. Sensor-placement are seen in figure 3.6.

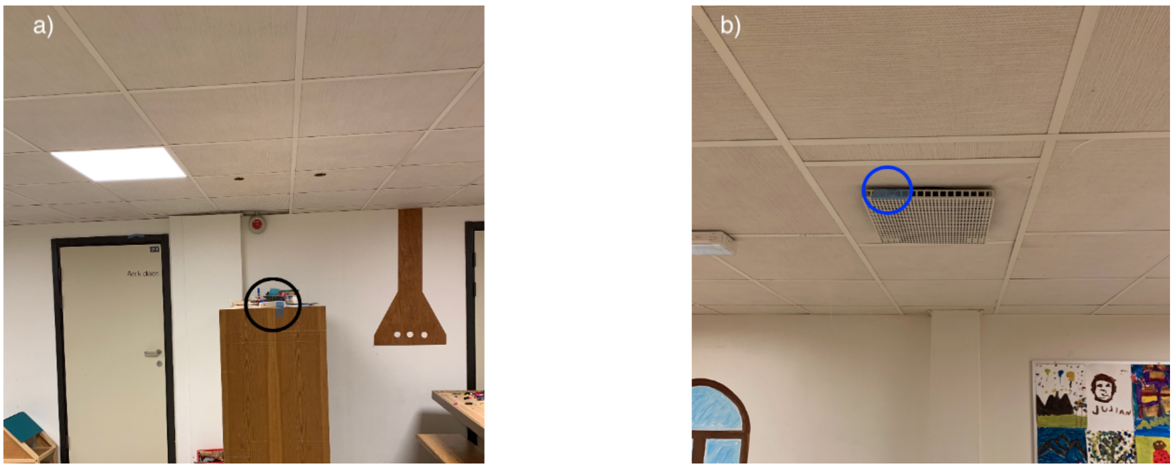


Figure 3.6: Location of placement of sensors in the SFO-room. a) Sensor, measuring air quality b) Sensor measuring temperature of supply-air

**Classroom 321A**

This classroom is a corner classroom on the second floor, facing the external surroundings to the east and south. The room area is unknown but estimated to approximately 175 $m^2$, where the assumption is based on rooms with known areas and similar size. The classroom is equipped with 28 desks and four benches. For the walls facing the external environment, there are windows along the entire walls. The CA-sensor's placement is in front of the classroom on a table near the smartboard. Supplement of air appears through six air terminals, which are evenly distributed in the ceiling. The iButton measuring supply is placed on the side of one in the middle. The iButton measuring the extract air is placed inside of the single extract in the classroom. The placement of the sensors are displayed in figure 3.7.

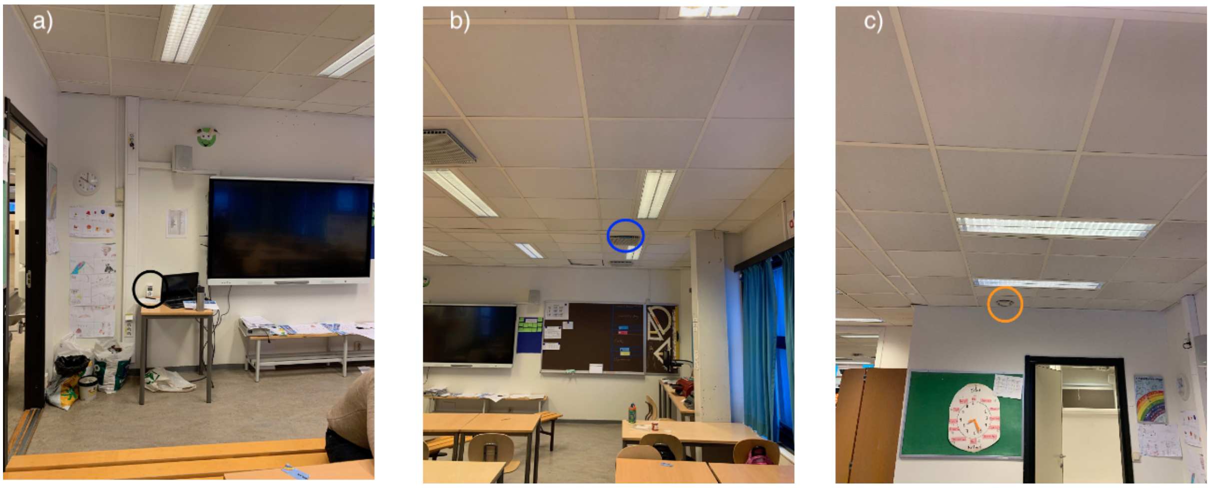


Figure 3.7: Location of placement of sensors in classroom 321A. a) Sensor, measuring air quality b) Sensor measuring temperature of supply-air, and c) Sensor measuring temperature of extract-air

### 3.1.3 Experimental setup: Sunnland

The four rooms which are selected by the represents from the school and the researcher team for Sunnland school are exclusively classrooms. All the rooms are facing east. Two of the rooms are located at ground floor and the other two are located on the first floor. Repetitive for all the rooms is that they have windows along the east wall. For a descriptive location of the rooms, the floor plan with markers of the chosen rooms are shown in figure 3.8. The placement of the instrument in each room are market with the following colour coding:

- Black: ELMA-sensor
- Blue: supply-temperature
- Orange: extract temperature


Figure 3.8: Floor plan of ground floor (right) and second floor (left) for Sunnland school. The rooms included in the field measurements are marked with a square. The measurement tools are marked with a dot; black is the indoor environment sensor, blue is the iButton measuring supply air and orange is the iButton measuring extract air [35]

For Sunnland school, the ELMA-sensors are utilized. The placement of the sensors are based on the earlier study, to strive to receive as similar conditions as possible.

**Room 104**

Classroom 104 is a corner room on the ground floor of the north-east side of the building. It has a total floor area of 69.9 $m^2$ and holds a number of 27 single standing desks spread across the room.The room is equipped with a Swegon compact classroom aggregate, which is independently supplying air to the room and is located in the back of the classroom in the north-east corner. The room is heated by radiators mounted to the wall facing the exterior.

The ELMA-sensor's placement is in front of the classroom, on a small table near the smart-board. The height of the table is approximately the same as the breathing zone for the pupils. The iButton for supply air is placed on the air outlet facing the exterior wall. The iButton measuring the extract air is taped on top of the ventilation unit, where the extract grill is located. The placement of the sensors are seen in figure 3.9.


Figure 3.9: Location of placement of sensors in classroom 104. a) Sensor, measuring air quality b) Sensor measuring temperature of supply-air, and c) Sensor measuring temperature of extract-air

**Room 107**

Classroom 107 is a corner classroom located on the ground floor of the south-east side of the building. The area of the room is 88.8 $m^2$ and holds 28 single placed desks for pupils., which makes it the largest classroom taking part in the field study from Sunnland school. The central ventilation unit ventilates the room. It has a modified duct system that runs across the classroom before splitting into two arms running over the widows. Wall-mounted electric radiators run the heating of the room. The ELMA-sensor is placed in front (south wall, facing the outdoors) of the classroom on top of a small table, between the smart board and blackboard. The iButton for supply air is placed on the middle inlet-grill (east wall, facing the outdoors), upper side of the grill. The iButton for extract air is placed on the lower side of the outlet-grill (north wall, facing indoors),The placement of the sensors are seen in figure 3.10.

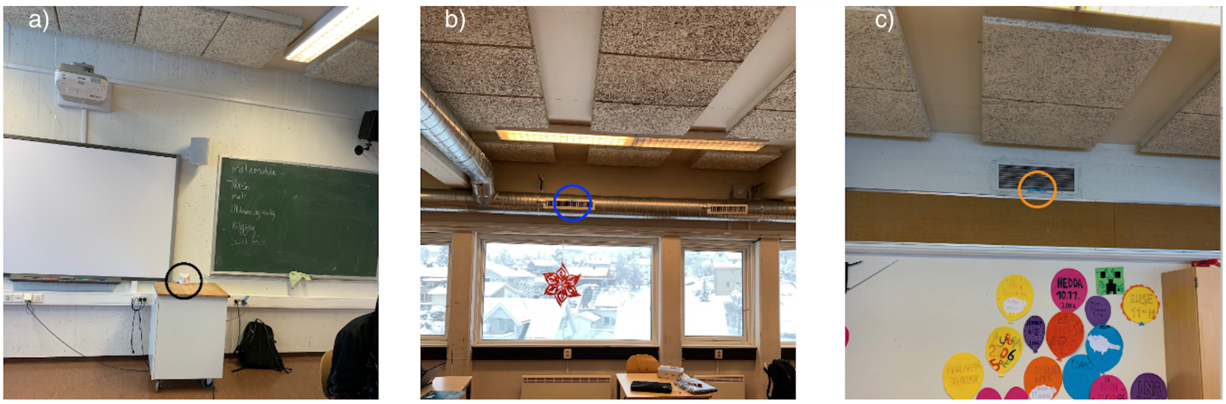


Figure 3.10: Location of placement of sensors in classroom 107. a) Sensor, measuring air quality b) Sensor measuring temperature of supply-air, and c) Sensor measuring temperature of extract-air

### 203

Classroom 203 is a corner classroom in the north-east side of the building on the $1^{st}$ floor. It has a total floor area of 58.7 $m^2$ and holds 27 single standing desks spread across the room. The room is equipped with a separate Swegon compact classroom aggregate, which independently supplies the room with air and is located in the back of the classroom in the north-east corner. The room is heated by radiators mounted to the wall facing the exterior.

The ELMA-sensor's placement is in front of the classroom, on a small table near the smartboard. The height of the table is approximately the same as the breathing zone for the pupils. The iButton for supply air is placed on the air outlet facing the exterior wall. The iButton measuring the extract air is taped on top of the ventilation unit, where the extract grill is located. The placement of the sensors are seen in figure 3.11.

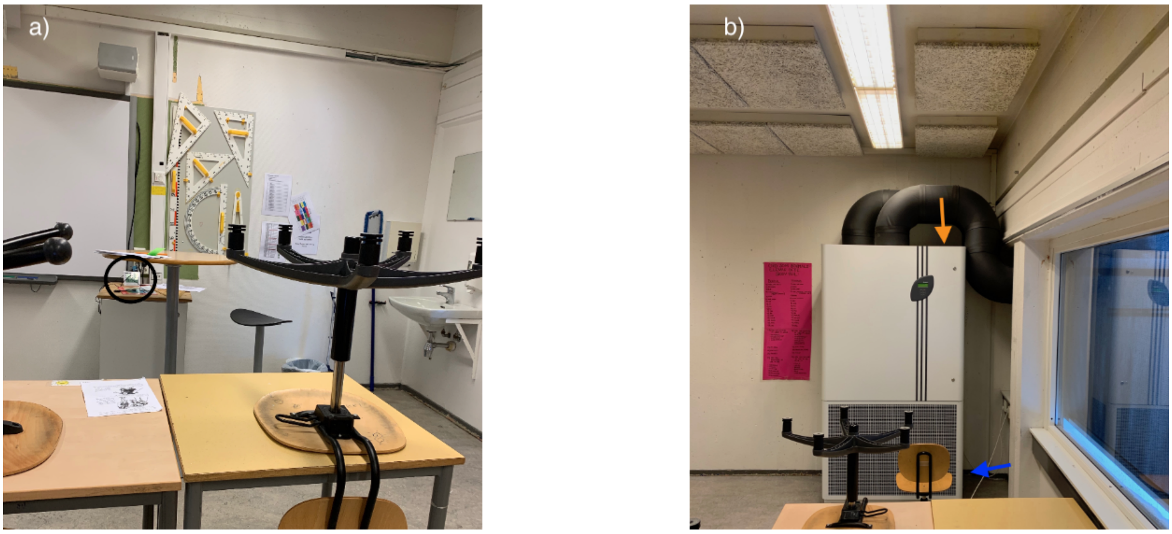


Figure 3.11: Location of placement of sensors in classroom 203. a) Sensor, measuring air quality b) Sensor measuring temperature of supply-air, and sensor measuring temperature of extract-air

### 207

Classroom 207 is a corner classroom located on the ground floor of the south-east side of the building, with an area of 58.6 $m^2$ and holds 24 single placed desks for pupils. The room is the smallest classroom taking part in the field study from Sunnland school.

The room is ventilated by the central ventilation unit. It has a modified duct system that runs across the classroom before splitting into two arms running over the widows. Wall-mounted electric radiators run the heating of the room.

The ELMA-sensor is placed in the back (south wall, facing the outdoors) of the classroom. It is taped on the cable tray running across the back wall. The cable tray is approximately in the height of the breathing zone for the pupils. The iButton for supply air is placed on the middle inlet-grill (east wall, facing the outdoors), upper side of the grill. The iButton for extract air is placed on the lower side of the outlet-grill (north wall, facing indoors). The placement of the sensors are seen in figure 3.12.

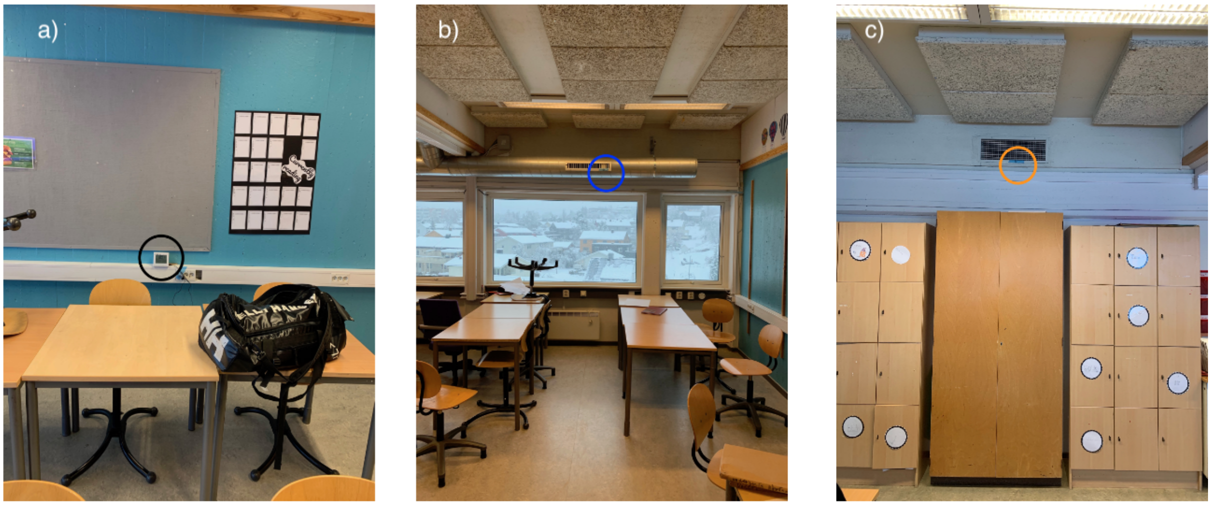


Figure 3.12: Location of placement of sensors in classroom 207. a) Sensor, measuring air quality b) Sensor measuring temperature of supply-air, and c) Sensor measuring temperature of extract-air

### 3.1.4 Experimental setup: Sørborgen

The four rooms chosen at Sørbrogen school are spread across the area in the new school building where mainly the lower grades are occupied. The rooms investigated thoroughly is the music room, which is located in the cellar of the building and three classrooms in different sizes, spread across the main floor. Figure 3.13 is a sketch of the floor plan, where the investigated rooms are marked with a square. The placement of the instrument in each room are market with the following colour coding:

- Black: ELMA-sensor
- Blue: supply-temperature
- Orange: extract temperature

**Room 0217**

Room 0217 is a classroom at the end of wing E. It has three walls that are entirely or almost

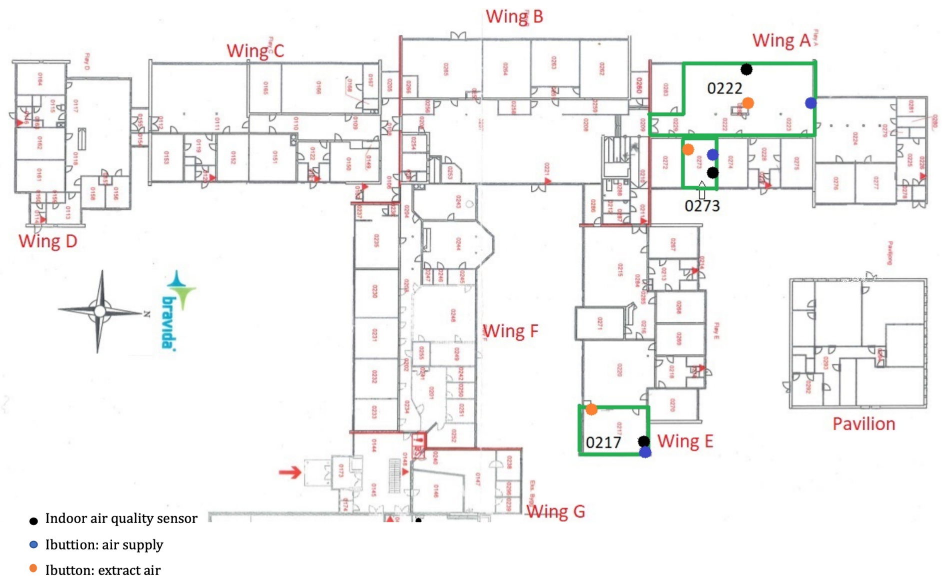


Figure 3.13: Floor plan of the ground floor of Sørborgen school. The rooms included in the field measurements are marked with a square. The measurement tools are marked with a dot; black is the indoor environment sensor, blue is the iButton measuring supply air and orange is the iButton measuring extract air [35]

entirely exposed to the external environment, the North, the east, and the south wall. The ELMA-sensor's placement is in front of the classroom on a commode, roughly in the same height as the pupils' breathing zone. The air supply terminal is located right in the north-east corner, and the iButton is placed on top of the air outlet. The placement of the sensor and the iButton can be seen in figure 3.14 a)

The extract vent for the room is several meters above the floor and is therefore inaccessible. The iButton is therefor taped on the wall behind the desk furthest away from the fresh air outlet, which is a similar placing as last field study, as seen in figure 3.14 b). The justification for the placement given is the following: *"The principle of thermal layers would ensure that the temperature closer to the roof would be higher than the occupant zone." [33]*

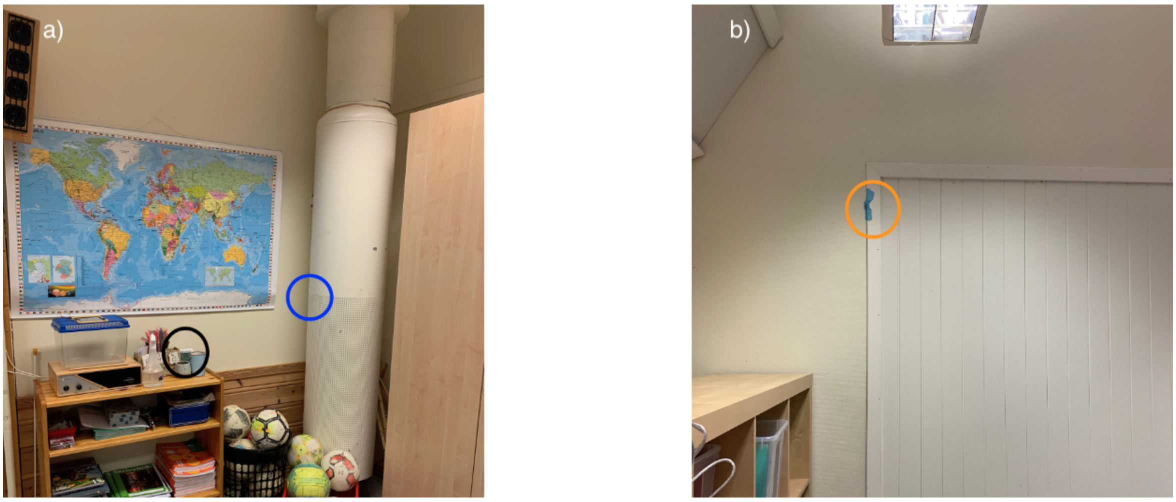


Figure 3.14: Location of placement of sensors in classroom 0217. a) Sensor, measuring air quality and Sensor measuring temperature of supply-air, and b) Sensor measuring temperature of extract-air

**Room 0222**

The ELMA-sensor is placed on top of a shelf in the middle of the room. Reasoning that the sensor requires electric power by a socket, the placement is not ideal regarding external heating and cooling sources. The placement is near a radiator and a window. The inlet air terminal is in the corner, furthest away from the entrance to the room. The iButton is placed above the inlet vent. The iButton measuring extract air temperature is placed on the extract located in the ceiling, in the middle of the classroom. The placement of the sensors are displayed in figure 3.15.

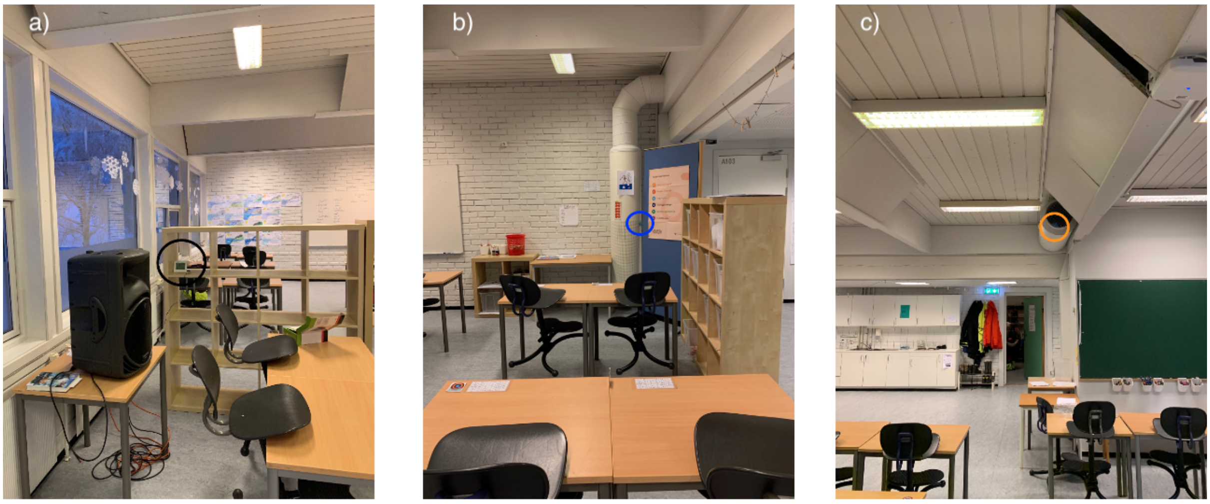


Figure 3.15: Location of placement of sensors in classroom 0222. a) Sensor, measuring air quality b) Sensor measuring temperature of supply-air, and c) Sensor measuring temperature of extract-air

### Room 0273

The ELMA-sensor's placement is in front of the classroom on a small table, roughly in the middle of the wall. The iButton is placed above the inlet vent. The iButton measuring extract air temperature is placed on the extract located in the ceiling, in the middle of the classroom. The placement of the sensors are seen in figure 3.16.

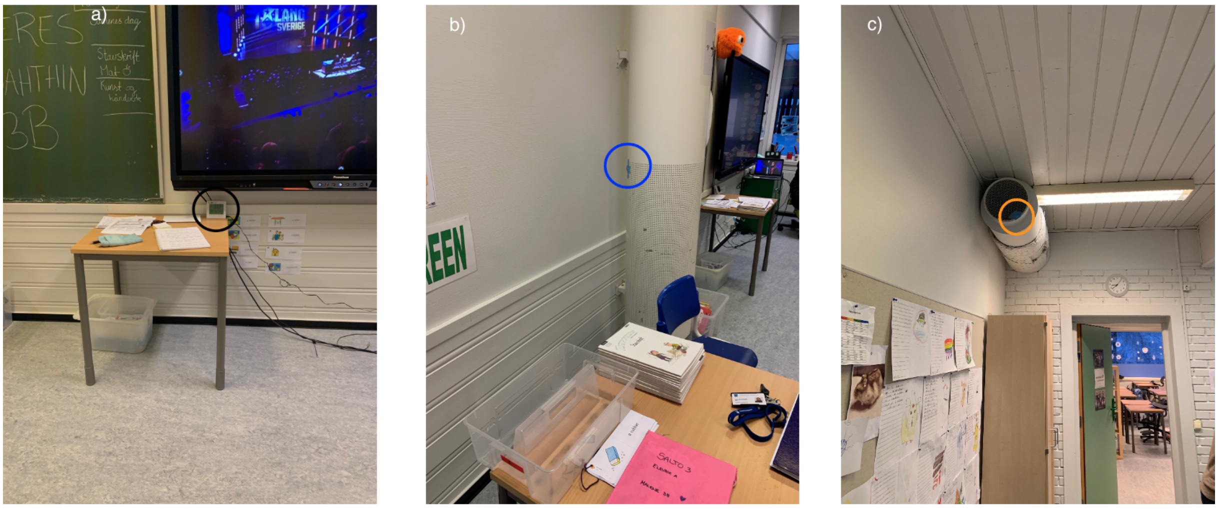


Figure 3.16: Location of placement of sensors in classroom 0273. a) Sensor, measuring air quality b) Sensor measuring temperature of supply-air, and c) Sensor measuring temperature of extract-air

### Music room

The ELMA-sensor is placed on top of a table in the corner in front of the classroom. The height of the table is about the same height as the breathing zone for a seated pupil. The iButton for supply air is placed in the corner of the central inlet terminal, and the iButton for extract air is placed in the corner of the single extract. The placement is shown in figure 3.17.

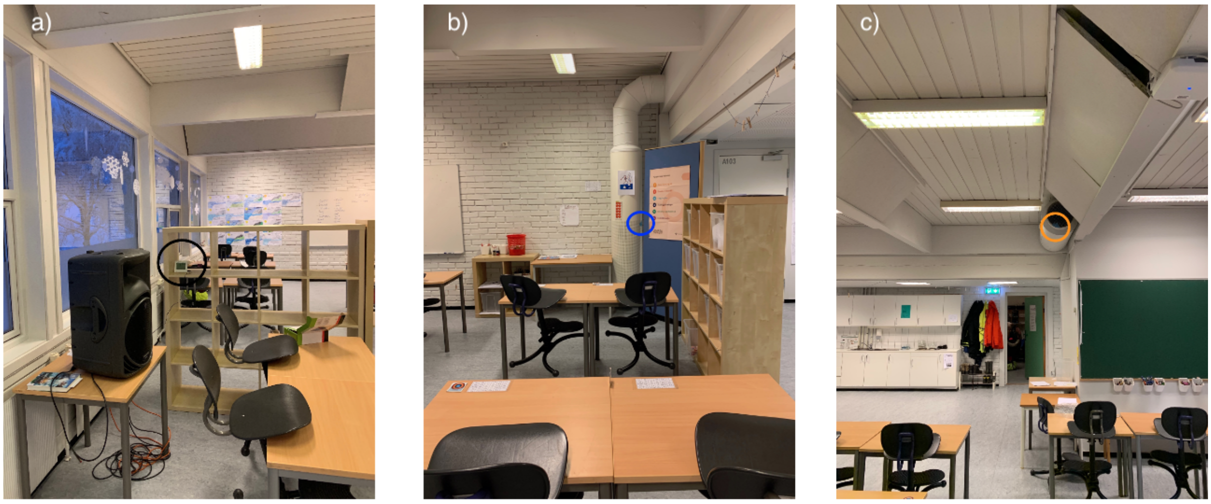


Figure 3.17: Location of placement of sensors in the Music room. a) Sensor, measuring air quality b) Sensor measuring temperature of supply-air, and sensor measuring temperature of extract-air

### Instruments

The three instruments used is described in table 3.4, 3.5 and 3.6. They are presented with the instruments' accuracy and range. [17][16][22]

Table 3.4: Technical specifications for instrument ELMA DT-802D [17]

| ELMA DT-802D | Measuring range | Accuracy at 23 ± 5°C | Resolution |
|---|---|---|---|
| **Temperature** | - 5°C to 50°C | ± 1°C | 0.1°C |
| **Carbon dioxide** | 0 to 9999 ppm | ± 100 ppm ±5% of the measured value | 0.1% |
| **RH** | ≤ 90% | ± 5% RH | 0.1% RH |

Table 3.5: Technical specifications for instrument C.A 1510 [16]

| C.A 1510 | Measuring range | Accuracy at 23 ± 5°C | Resolution |
|---|---|---|---|
| **Temperature** | -10 to 60°C | ± 0.5°C | 0.1°C |
| **Carbon dioxide** | 0 to 5000 ppm | ± 50 ppm ± 3% of the measured value | 1 ppm |
| **RH** | 5 to 95% RH | ± 2% RH | 0.1% RH |

Table 3.6: Technical specifications for iButtons [22]

| IButton DS1922L | Measuring range | Accuracy [-10°C , 65°C] | Resolution |
|---|---|---|---|
| **Temperature** | -40°C to 85°C | ± 0.5°C | 0.5°C |

## 3.2 Questionnaire of indoor environment and health symptoms

To evaluate the user sensation of the pupils, the pupils have been asked to answer a Questionnaire, developed by Norges Astma og allergiforbund [NAAF] (English; Norwegian association for asthma and allergies). The Questionnaire has been developed, reasoning the increased focus on indoor environment in schools, the past decades. The general insight gain through this questionnaire is subjective user observation of the indoor environment by the occupants. Also, it will be possible to discover health issues experienced amongst the pupils and indicate which type of issues are experienced with the indoor environment. [24]

The schools participating in this project are instructed to order the Questionnaire from NAAF and conduct the Questionnaire during school hours. The response rate from both Stabbursmoen and Sørnorgen are quite good, where 73 % of the pupils ansared. For Sunnland, the response rate is less satisfying, where 37 % of the pupils responded.

The questions carried out in the questionnaire addresses factors regarding the indoor environment, such as sound, air quality, temperature, and air pollution. Further, it addresses health issues, like asthma and allergy, as well as physical discomfort, which can occur from poor indoor environment. The full Questionnaire is given in appendix D. [24]

### 3.2.1 Analysis of the Questionnaire

The analysis of the data from the Questionnaire is carried out by NAAF. The result is calculated to a total score per question, given in percent. The result from the respective schools is compared with a reference. The reference is material collected from similar questionnaires from schools without any known indoor environment problems. Also, the results will be compared to last year's result from the same Questionnaire. The result is illustrated with a rose model, figure 3.18 is an example of the model. The red line is the reference value, and the blue line is the result of the respective school. [24]

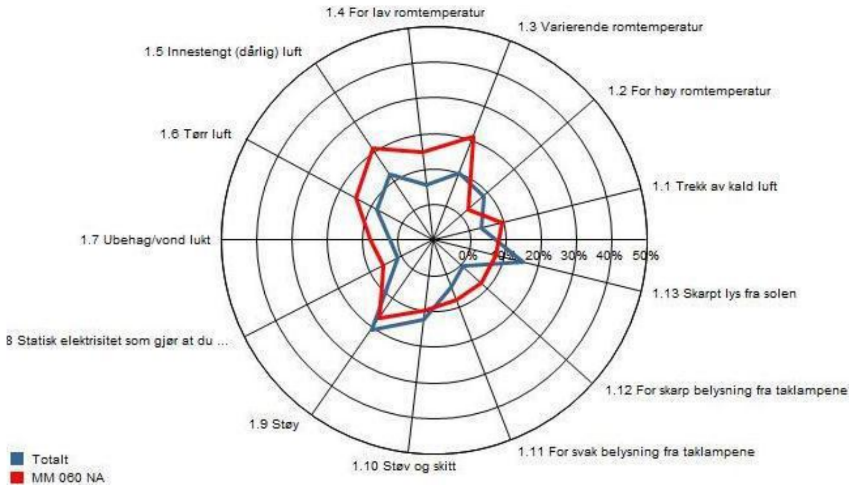


Figure 3.18: Example of presentation of the result given as a rose model [24]

For each question, there is calculated an uncertainty. The answers from the respective schools, reference value, and deviation will also be presented in a spider graph. From this result, it is possible to analyze and reveal indications of which indoor environment problem may be an issue for the schools.

## 3.3 Survey: Thermal Comfort

To be able to gain insight of how the occupants perceive the physical indoor environment parameters, there has been carried out a survey directed to actual mean vote, to compare it with the predicted mean vote.

Too develop the survey for the children, there is used inspiration from different surveys. The main inspiration is taken from a field study in the UK; "Field study on thermal comfort in a UK primary school" written by Jentsch, James, and Bahaj. The circumstances for the study conducted in the report is very much alike the circumstances in this study. However, this study has a smaller scope. [37]

The biggest concern for the execution of the survey for thermal comfort is to make it simple enough for children to understand the question. The range of age in different schools varies from 5 - 16 years. For this reason, the survey is simplified by many variables, compared to a study with adult objectives. In the end, the survey consisted of 5 questions, where ASHRAE's

7-point scale is used as the preference for thermal sensation. The number scale is exchanged with text, describing the thermal sensation. Instead of asking the objects to write down each garment they are wearing to collect the clothing insulation factor (clo), it is asked if the object is wearing a sweater. When estimating the clothing insulation factor, there are taken notes of the clothing for each object during the investigation. Besides, it is noted for the activity level to be able to make assumptions about the objects' metabolic rate. The full version of the survey is provided in appendix E.

The objects are asked to fill out the survey at the start of the school hour and the end of the school hour. Each question is explained thoroughly to the objects. Each object have a significant number based on the placement in the classroom.

This experiment is only conducted at Stabbursmoen and Sørborgen. It was not possible to plan a visit to Sunnland, reasoning no response from the principle. At Stabbursmoen, the room Blåsal is used, and the object is $10^{th}$ grade. At Sørborgen school, the classroom 0222 is used, and the object is $2^{nd}$ grade.

## 3.4 Interviews

Similar to last year's study, it is performed interviews with employees at the respective schools. It is striven to interview the same persons as earlier, but due to some changes, some of the objects are new in this study. The intention is to conduct all interviews in the period week 7 - 9. Nevertheless, it is delayed reasoning poor response and difficulties scheduling meetings with the employees, and the outbreak of the virus COVID-19. All of the interviews are conducted within week 14. In table 3.7, the participants for each school and position has been listed, in addition to missing interviews.

Table 3.7: Number of employees interviewed in each school

| School | Number of interviews |
|---|---|
| Stabbursmoen | 4 |
| Sunnland | 7 |
| Sørborgen | 5 |

For the interviews, it is used an interview-guide developed by SINTEF Community and Solvår Wågø. She also held a share of the interviews. A small amount of the interviews are held in person at the respective schools. The main part of the interviews is done by telephone. The interviewer wrote the answers of the object directly in the interview guide while providing the interview. The questions aim to map the users' experience of the sensation of, amongst other, indoor air quality, thermal comfort, and physical and psychological health of employees and pupils. The scope of the interview is the school's current status. Also the interview objects are asked to evaluate if the indoor environment and health had improved. The full interview is given in appendix C.

## 3.5 Machine learning model: $CO_2$ Prediction

To predict carbon dioxide level for a classroom, machine learning is used. There has been used two different supervised algorithms to predict the carbon dioxide level, Random Forest and AdaBoost. The model is programmed in Jupyter Notebook, a software which uses Python programming language.

### 3.5.1 The model

The model is interpreting data with the Panda package as a foundation. The model imports the desired data and executes a check to find if the data is incomplete. If the the file has gaps, the model will discover how many, and the location of the gap in the file. This needs to be restored manually. In the next step, when the model is provided with a complete data set with no missing values, it splits the data. 75 % is used to training and 25 % is test data. The split data is shuffling according to the index. Next, the prediction model is built, where Random Forest and AdaBoost are imported and training of data executed. The last step is to use the test data and predict the output. The model gives feedback if the result is good or if there is a need for more training to make a better prediction. The full code is provided in appendix F.

The two algorithms utilized for the prediction is further described in chapter 2.3, section 2.4.

### 3.5.2 Data collecting

It is important to have as accurate data as possible. The parameters needed to predict the carbon dioxide level inside a classroom with this model are air temperature, relative humidity, occupants, and carbon dioxide. Temperature, relative humidity, and carbon dioxide are collected from the measurements from the field study. Data regarding occupants are collected manually by counting occupants inside a room for a set time frame, preferably 1-2 days for different rooms to collect a proper amount of training data.

Due to COVID-19, the collected data is limited. During the survey study regarding thermal comfort, the pupils are counted while the study is ongoing, for two hours. It is intended to use this data as test data before the real data is collected later on. As a consequence of the lockdown of Norwegian schools in mid-Mars due to the pandemic, it is not possible to collect the desired amount of data in April-Mai as planned initialed. Besides, the data collected at Stabbursmoen could not be utilized due to technical issues with the CA-sensor, which are described in section 3.1. This makes the data set used in the model quite limited, with one set with a time frame of 2 hours with 2 minutes interval.

# Chapter 4

# Presentation of Case Schools and implemented measures

In this chapter, the case schools will be introduced shortly. The essential information regarding the schools' design and technical systems is described. Additionally, the measures implemented in January 2020, formed by the project group is presented. This study is one part of the whole project. The main task in this report is to review the implemented measures, which are further presented. Small parts of the information in this chapter is collected from the project assignment.

## 4.1 Stabbursmoen School

Stabbursmoen, seen in figure 4.1, is both a primary and secondary school and is located at Heimdal. Residential buildings are surrounding the school. The main building was built in 1979 and has later been supplied with a pavilion that contains several specialized classrooms. The net area of the school is 5183 m2. Today, the school holds around 430 pupils and 50 employees. The main building consists of three floors, where a technical room occupies the third floor. [35]
Initially, the school was built as an open area school, but it was later reconstructed by separating the classrooms with dry-walls without doors. The technical systems have not been adjusted regarding the new structure for the floor area, neither the light fixtures. It is no doubt that parameters like temperature, airflow, and lighting conditions are affected by the new structure. [35]

In 2013, the school was categorized as yellow, and later in 2017, the school was degraded into the critical red category. The report from 2017 stated that the building is in need of extensive rehabilitation, both indoors and outdoors. The roof, windows, doors, elevator, ventilation,

Figure 4.1: Stabbursmoen school

electrical, and plumbing needs to be replaced. The foundation, exterior walls, and the building's drainage also needed rehabilitation. The inside would need to be renovated afterwards. Today, the situation has aggravated. Trondheim municipality has planned a total rehabilitation for Stabbursmoen school to be finished in 2022. [7][20]

### 4.1.1 Technical systems

In the main building, there are three separate ventilation systems. The main system supplies the whole building, except the gymnasium and teacher's office space, which has its own separate ventilation system. The ventilation system supplying the gymnasium is outworn. This and the main system were installed in 1979 and there has not been any major upgrades except from ordinary maintenance. The ventilation system supplying the teacher's space is rather new and was installed in 2008.[35]

The main ventilation system is designed with a rotating heat exchanger, and the system was initially designed to reuse air as an energy savings measure. Today, this is not in use, and the damper is completely closed. The system is operating with a constant air volume (CAV). An example of the air terminal and air extract at Stabbursmoen school is seen in figure 4.2. [35]

Figure 4.2: An example of the ventilation distribution system at Stabbursmoen school. A typical extract is seen left in the picture and a typical air supply grill is seen to the right

The building is supplied with heat from the ventilation system and convector heaters. Due to complaints from the occupants, there have been several fan coil units in chosen classrooms, because of cold temperatures. A climate control system manages the temperature. [35]

### 4.1.2 Implemented measures, January 2020

From the field study executed winter and autumn 2019 [35] the result showed that Stabbursmoen is the school with the most problematic indoor environment. It was discovered that the main reason that Stabbursmoen can not satisfy today's standards and requirements is the ventilation system's performance and the inner diameter of the ducts leading to the air terminals. The diameter is 200 mm and can not efficiently provide a high enough airflow rate without compromising with the noise level. Also, lightning is experienced as problematic. For improvement of the indoor environment, the following measures are implemented at the beginning of January 2020, by the project.

- Cut of setback of set-point temperature for ventilation and heating system, for night and weekends
- Replace old incandescent fixtures to new led fixtures
- Implementation of external classroom aggregate for the room "Blåsal"
- Control measurements and troubleshooting parts of the ventilation system to detect whether or not fire dampers are closed or other faults.

- Detect if exiting blinds which have not been used for years can be utilized to reduce the radiance from the sun rays
- Establish the possibility to open all the windows associated with a utilized area

The following measures are suggested by the project group to be implemented by the school:

- During all types of breaks, all pupils should leave critical rooms, so full venting of rooms is possible
- In the end of a school day, teachers should look over that radiators are not manually turned off
- During the day, radiators with a thermostat should be controlled if they are set to the right temperature

As the last suggestion, if the areas utilized for education is experienced as too cold, it can be implemented radiators if Stabbursmoen school requests it. In appendix G, the full table with the school's problems, suggested solutions, and chosen solutions can be seen. Additionally, it is developed a poster with five simple measures. The school is encouraged to present it to the teachers and students and apply the measures in their daily routines. The poster is seen in appendix I.

## 4.2 Sunnland School

Sunnland school, seen in figure 4.3 is a secondary school with pupils from 8 – 10th grade. The school enrolls approximately 320 pupils and 35 employees. It consists of two buildings and a pavilion, where the net area of the main buildings area 4250 m2 [20]. The school is located at Nardo, surrounded by office buildings to the west and residential buildings to the east. The main road, E6, passes 150 m away from the school, and thereby leads to some polluting of the air.


Figure 4.3: Sunnland School school

Sunnland is currently one of the oldest existing secondary schools in Trondheim. The oldest building is from 1956 and is today functioning as the administration building. Also, there are teacher offices, gymnasium, and other specialty rooms located in the building. The main building was constructed in 1978 and is the building where most of the classrooms are located. This building has had major upgrades that conducted over time. [35]

### 4.2.1 Technical systems

The main building's central ventilation unit is a high-velocity system, operated with a constant air volume, from 1977. The airspeed in the main ducts lies between 10 – 15 m/s and operates at maximum capacity during operation hours. The central ventilation system has had an upgrade since it was installed. Instead of its original design, where the fresh air and extract air vents grills were placed on the same wall opposite the window wall, the duct runs across the classroom and splits into two arms above the window and supplies the classroom with fresh air. The upgrade increases the distribution of fresh air. Also, for four of the classrooms, the ducts to the central ventilation system have been removed and replaced with their respective classroom ventilation handling unit from Swegon. The unit has a maximum capacity of 1300 m3 per hour, and the model is called Swegon Compact Air [43]. In figure 4.4, one of the implemented classroom aggregates is shown. The unit default setting for the classroom aggregates is 850 m3/h. [35]

Figure 4.4: An example of a classroom ventilation aggregate from Swegon. This type of ventilation unit supplies to four classrooms at Sunnland school

Originally, the ventilation unit was designed to use recycled air, by a recycling unit. Today the unit is completely shut down, and there is exclusively fresh air supplied to the classrooms. Seemi Lindtorp, an HVAC engineer for Trondheim municipality and a participant of the project group, has stated that the ventilation for the main building at Sunnland school is running at its maximum capacity.

The heating for the main building is supplied by the ventilated air and separately placed electrical heaters in the classrooms. The electrical heaters were installed after complaints of the thermal comfort because the heated, ventilated air could not manage the heating load by itself. All permanent electrical heaters are connected to the central controller system, which regulates the classrooms' temperature by integrated temperature sensors.

### 4.2.2 Implemented measures, January 2020

Regarding Sunnland school, which was listed as the most critical school in 2018, it is noteworthy to mention that measures were taken already before the first field measurements which were conducted in affiliation with this project. There were placed external classrooms aggregates from Swegon in four classrooms rooms, including two of the case rooms included in this study. The main problem at Sunnland is that the rooms are highly sensitive to the outdoor conditions, and the heating is hard to regulate. The heating system is old and worn out. For improvement of the indoor environment, the following measures were implemented at the beginning of January 2020, by the project:

- Cut of setback of set-point temperature for ventilation and heating system, for night and weekends
- Rearrange the placements of pupil's desks to avoid local thermal discomfort (heat from radiators, draught, and similar)
- Actively use blinds to prevent classrooms from overheating during the cooling season

The following measures are suggested by the project group to be implemented by the school:

- During all types of breaks, all pupils should leave critical rooms, so full venting of rooms is possible
- At the end of a school day, teachers should look over that radiators are not manually turned off
- During the day, radiators with a thermostat should be controlled if they are set to the right temperature

If necessary, the school can be supplied with more classroom aggregates and electric radiators on the school's request. In appendix G, the full table with the school's problems, suggested solutions, and chosen solutions. Additionally, it is developed a poster with five simple measures. The school is encouraged to present it to the teachers and students and apply the measures in their daily routines. The poster is seen in appendix I.

## 4.3 Sørborgen School

Sørborgen school, seen in figure 4.5 is a primary- and secondary school located in the old Klæbu municipality, which was merged with Trondheim municipality, January 2020. The school is located in rural surroundings, nearby a football field, forest, and residential buildings. The school hosts around 420 pupils. [35]

Figure 4.5: Sørborgen school

The reason Sørborgen is included in this project has a different background than the two other case schools. Unlike the other schools which are awaiting upgrades, Sørborgen was rehabilitated and expanded with a new section in 1996. Later on, the school has been supplemented with an extension to the main building, which was finished in 2018. The school thereby consists of one old part and a new part, that are connected. The status quo today is that the school is not waiting for any major upgrades or refurbishments. The new building has no known indoor environment problem today. However, the old building still does. [35]

The known indoor environment problems which have thoroughly been inspected are troubled with noise and lightning. [35]

### 4.3.1 Technical systems

The old section of the school is supplied with a CAV ventilation system, and the new section has three ventilation units. The older section has a mix of mixing ventilation and displacement ventilation. In the newer section, there is one unit that covers all the classroom and one unit which covers the gymnasium. The unit covering the classrooms are of the type displacement ventilation. In figure 4.6, an example of the air terminal and air extract of the displacement ventilation at Sørborgen school is shown. [35]

Sørborgen is connected to a local district heating plant that uses biomaterial from local forestry as fuel. The plant supplies heat to hydronic radiators. Besides, there are electrical heaters installed in the school. The radiators have a dynamic regulation based on the

Figure 4.6: An example of the displacement ventilation distribution system at Sørborgen school. A typical extract is seen left in the picture and a typical air supply grill is seen to the right

outdoor conditions. [35]

### 4.3.2 Implemented measures, January 2020

Sørborgen was classified as a school with satisfying indoor environment, hence earlier results [33]. Therefore it was decided not to make any improvements for Sørborgen, but it will still be a part of the study. It it is developed a poster with five simple measures. The school is encouraged to present it to the teachers and students and apply the measures in their daily routines. The poster is seen in appendix I.

# Chapter 5

# Results and Discussion

## 5.1 Field Measurements

The results and analysis from the field measurements from winter 2020 will be presented and discussed in the following sections. Furthermore, the data collected during winter 2019 has been analyzed with the same base and will be presented together with the new result to present a comparison regarding if the status quo has been improved by the new measures implemented in January 2020. In conjunction with the pandemic of COVID-19, an article was written regarding the concern of reopening schools with poor indoor environment too early. The article is found in appendix J.

There is analyzed if the measured values of carbon dioxide, temperature, and relative humidity are outside range of the guidelines for a good working indoor environment, mentioned in table 2.2, section 2.2.2. The results and analysis in this section are based on the hours the rooms are occupied (school hours) by pupils and employees. It applies to the period mentioned in table 3.2, section 3.1. The values presented in the tables in this section is thereby calculated from the significant school hours for each room, and the recommendations and guidelines, set by Norwegian authorities.

To gain a perspective of how the overall result is to be interpreted, the mean has been calculated with three different prerequisite, within school hours. This is applicable for the tables in section 5.1.3, 5.1.4, and 5.1.5. The three prerequisite are as follows;

- Mean of the values which are found outside range of recommendations and guidelines (within school hours)
- Mean for the values according to recommendations and guidelines (within school hours)
- Total mean (within school hours)

There is one exception to the mentioned prerequisites. For temperature, the mean temperature, according to guidelines, is excluded from the table because it did not contribute to interpreting the results. The calculated mean from 2019 is used as the reference value.

The following result will be presented per school and per measured parameter (carbon dioxide, temperature, and relative humidity). When interpreting the result, color coding has been used to evaluate the status of the room. The column showing the difference between the mean of 2020 and 2019 is given with the color code, seen in table 5.1. Green color means that the parameter improved in 2020, red color means that the parameter is worse in 2020, and black means that the status is neutral.

Table 5.1: Description of interpretation of colors in tables

| Color | Status |
|---|---|
| Green | Improved conditions |
| Red | Deteriorated conditions |
| Black | Neutral |

### 5.1.1 Uncertainties

During the field measurements, there were several mistakes with the instruments. The ELMA-sensor in room 104 at Sunnland was unplugged the first day of measuring, which led to no results. Therefore, room 104 is not mentioned in the results. For Stabbursmoen, during a visit in the measuring period, it was discovered that the C.A 1510 sensors were out of battery. The date of battery replacement is noted in table 3.1, with the timeline, in chapter 3. Reasoning the COVID-19 pandemic, the instruments had to be collected before the school closed. Therefore, the measuring period is shorter for Stabbursmoen school. The instrument placed in the SFO-room did not record due to technical issues with the sensor. Therefore, the SFO-room is excluded.

The air quality sensors displayed irregularities, hence the test that can be found in appendix B, and the instruments were not calibrated.It makes the measurements uncertain, even though the measurements are regulated according to the calculated standard deviation, seen in table B.1 in appendix B. The data collected from earlier work [33] had a missing file for the room 0273 at Sørborgen. Due to this, the room is only presented with the results from 2020. The measurements from the supply and extract air is not used, it was not seen as relevant for the results nor the discussion.

For the comparison of the field measurements conducted in 2020 and 2019, there is important to have in mind that the weather conditions are not the same. The period for measurements in 2019 was colder than the period in 2020.

### 5.1.2 Presentation of deviating values for the included room in the study

In table 5.2, a summary of the data analysis from the field measurement is presented, together with the data analysis from 2019, which are used as reference values. The table presents the percentage of time a parameter is outside the set limits, presented in table 2.2, section 2.2.2. If the analysis indicates an improvement of a parameter from the field measurement, the value is colored green. If the analysis indicates deterioration of a parameter from the field measurement, the value is colored red.

Table 5.2: Presentation of the percentage of deviation from the limit values for 2020 and 2019 for the three schools with the associated room (school hours)

| | **$CO_2$>1000 ppm [%]** | | **Temp<19°C [%]** | | **Temp>22°C [%]** | | **RH <20% [%]** | |
|---|---|---|---|---|---|---|---|---|
| | ***2020*** | ***2019*** | ***2020*** | ***2019*** | ***2020*** | ***2019*** | ***2020*** | ***2019*** |
| **Stabbursmoen** | | | | | | | | |
| Blåsal | 15 % | 24,6 % | 17 % | 48 % | - | - | 54 % | 3,5 % |
| 321A | 30,5 % | 17 % | 6,7 % | 9 % | 22 % | 15 % | 38,5 % | 12 % |
| Teachers lounge | 12 % | 8 % | - | 4 % | 58 % | 49 % | 51 % | 22 % |
| **Sunnland** | | | | | | | | |
| 108 | 5 % | 11 % | 9 % | 0 % | - | - | 21 % | - |
| 203 | MD | MD | - | 1 % | 34 % | 65 % | 6 % | 10 % |
| 207 | 33 % | 11 % | 10 % | 45 % | - | - | 51 % | 3 % |
| **Sørborgen** | | | | | | | | |
| 0217 | - | - | - | 8 % | 39 % | - | 58 % | 26 % |
| 0222 | - | - | - | - | 99 % | 59 % | 58 % | 17 % |
| 0273 | - | MD | - | MD | 38 % | MD | 57 % | MD |
| Music room | 1 % | 8 % | - | - | 98 % | 12 % | 42 % | 22 % |

**MD symbolizes that there is missing data, the file does not exist.*

*—symbolizes that there does not exist any deviating values (most wanted result)*

### 5.1.3 Stabbursmoen

Stabbursmoen is the school with the worst results in 2019 and is therefor the school where most measures are implemented. In table 5.3, the mean values for carbon dioxide are presented. The values are measured in ppm. In table 5.4, the mean temperatures for Stabbursmoen school are presented. The table is containing both temperatures below 19°C and temperatures above 22°C. The mean temperature is common. Table 5.5 presents the mean for relative humidity.

Table 5.3: Mean values of carbon dioxide, Stabbursmoen. The following mean values are presented: Mean of the values which are exceeding 1000 ppm, mean for the values below 1000 ppm, and the total mean of the sample (school hours)

| | **2020** | **2019** | **Improvement/ deterioration ($\triangle$2020-2019)** |
|---|---|---|---|
| | ***$CO_2$ [ppm]*** | ***$CO_2$ [ppm]*** | ***$CO_2$ [ppm]*** |
| **Blåsal** | | | |
| Mean $CO_2$ outside range | 1343,9 | 1280,7 | 63,2 |
| Mean $CO_2$ within range | 577,9 | 570,0 | 7,8 |
| Mean $CO_2$ | 692,5 | 744,6 | 52,0 |
| **321A** | | | |
| Mean $CO_2$ outside range | 1146,4 | 1133,6 | 12,8 |
| Mean $CO_2$ within range | 644,5 | 715,2 | 70,8 |
| Mean $CO_2$ | 797,4 | 792,4 | 5,0 |
| **Teachers lounge** | | | |
| Mean $CO_2$ outside range | 1146,9 | 1480,0 | 333,1 |
| Mean $CO_2$ within range | 675,6 | 579,5 | 96,1 |
| Mean $CO_2$ | 732,3 | 648,7 | 83,5 |

*—symbolizes that there does not exist any deviating values (most wanted result)*

Table 5.4: Mean values of temperature, Stabbursmoen. The following mean values are presented: Mean of the values which are below 19°C and exceeding 22°, and the total mean of the sample (school hours)

| | **2020** | | **2019** | | **Improvement/ deterioration (△2020-2019)** | |
|---|---|---|---|---|---|---|
| | *T<19°C* | *T>22°C* | *T<19°C* | *T>22°C* | *T<19°C* | *T>22°C* |
| | *[°C]* | | *[°C]* | | *[°C]* | |
| **Blåsal** | | | | | | |
| Mean temp outside range | 18,2 | - | 17,7 | - | 0,5 | - |
| Mean temperature | 20,1 | | 18,9 | | 1,2 | |
| **321A** | | | | | | |
| Mean temp outside range | 17,9 | 22,5 | 18,0 | 22,3 | 0,1 | 0,2 |
| Mean temperature | 21,1 | | 20,8 | | 0,2 | |
| **Teachers lounge** | | | | | | |
| Mean temp outside range | - | 22,6 | 17,6 | 22,7 | - | 0,1 |
| Mean temperature | 22,1 | | 21,8 | | 0,3 | |

Table 5.5: Mean values of relative humidity, Stabbursmoen. The following mean values are presented: Mean of the values which are below 20 %, mean for the values exceeding 20 %, and the total mean of the sample (school hours)

| | **2020** | **2019** | **Improvement/ deterioration (△2020-2019)** |
|---|---|---|---|
| | *RH [%]* | *RH [%]* | *RH [%]* |
| **Blåsal** | | | |
| Mean RH outside | 17,2 | 18,2 | 1,0 |
| Mean RH within range | 22,6 | 29,8 | 7,2 |
| Mean RH | 19,7 | 29,4 | 9,7 |
| **321A** | | | |
| Mean RH outside | 18,1 | 17,9 | 0,2 |
| Mean RH within range | 23,5 | 31,4 | 7,9 |
| Mean RH | 21,4 | 29,6 | 8,2 |
| **Teachers lounge** | | | |
| Mean RH outside | 17,6 | 16,9 | 0,7 |
| Mean RH within range | 22,1 | 28,0 | 5,9 |
| Mean RH | 19,8 | 25,6 | 5,8 |

**Blåsal**

The room Blåsal, is the most troubling room regarding high carbon dioxide levels from previous results [35]. It was set restrictions for the use of the room, to maximum 20 occupants. Therefore, in January 2020, an external classroom aggregate was implemented to ease the load from the central ventilation system.

The level of carbon dioxide exceeded a level of 1000 ppm 24.5 % of the school hours in 2019. This decreased in 2020 to 15 %. All though, the mean carbon dioxide levels exceeding 1000 ppm were shown to be higher than in 2020. The overall mean for carbon dioxide has decreased and shown that the measure has improved the conditions. One reason for why the result is not more significant is that the aggregate was still under adjustments during the measurement period. The operator of the school said it was turned off in periods due to unpleasant draught. This uncertainty makes it difficult to conclude the total effectiveness of this measure.

For the temperature, the critical problem was temperatures below 19°C, this has shown to be improved drastically. The new results show a decrease from 48 % to 17 % deviation. Also, the mean temperature is found to be significantly better. For the temperatures below 19°C, the mean temperature has increased from 17.7°C to 18.2°C, and the overall mean temperature has improved for appearance below 19°C to being within limits. This is a significant improvement for the room. The temperature has no incidences for temperatures exceeding 22°C neither in 2020 nor in 2019.

The results from 2020 shows that the deviation of relative humidity has increased significantly in the room. In 2019, it was barely below 20 %, but the new result displays that the relative humidity is too low over 50% of the time. The mean for the remaining half, which is above the limit, is remarkably low, with its 22.6 %. The total mean is below the guideline with 19.7 % in 2020.

**321A**

The amount of time when the carbon dioxide level is exceeding 1000 ppm has increased from 17 % to 30.5 %. Also, the mean levels, presented in table 5.3 are indicating that the situation has deteriorated. Both the mean carbon dioxide outside the range, and the total mean increased according to the new results.

In this room, the problem lies with temperatures raising above 22°C. There is a small deviation of 7 %, which has improved since 2019 with 9 %. Temperatures above 22°C have deteriorated from 15 % to 22 %. By looking at the mean temperature in table 5.4, it can be seen that the temperature below 19°C, and above 22°C are marked in red, which indicates deteriorated conditions. Because this goes both ways, it is assumed that there is interference with the radiators' regulation.

The parameter with the worst development is relative humidity. Relative humidity has increased from 22 % to 38.5 %. The overall mean values show deteriorated conditions as well, except for the mean outside range, which has improved by 0.2 %. The total mean has decreased from 29.6 % to 21.4 %. With this, it can be concluded that the mean relative humidity is too low, barely above the limit.

**Teachers' lounge**

The teachers' lounge is supplied with fresh air from a newer and separate ventilation system than the previous rooms. The teachers' lounge has had moderate carbon dioxide levels by history, except for lunch hours, almost every day, and meeting hours, once a week. The results showed that this is accurate, and is still the standing situation. The room can keep satisfying levels of carbon dioxide for daily use, but not when the load is maximized. Although it can be seen that levels exceeding 1000 ppm have decreased quite a lot. From 2019 to 2020, the mean level outside range has decreased from 1480 ppm to 1146 ppm, which is an improvement of 333 ppm, seen in table 5.3. This can indicate that routines of venting the room have improved.

The temperature in the teachers' lounge has shown improvement for temperatures below 19°C, where there are no incidences. For temperatures above 22°C, there has been a slight deterioration, from 49 % in 2019 and 58 % in 2020. This has resulted in a mean temperature of 22.1°C, which is 0.1°C above the limit. The result can be seen in table 5.4.

The relative humidity has increased for the teachers' lounge as well as the other rooms. It went from 22 % in 2019 to 51 % in 2020. The mean measured values falling below the limit is higher in 2020 than in 2019, with respectively 17.6 % and 16.9 %. However, the overall mean is 19.8 %, which is below the limit, the values are presented in table 5.5.

### 5.1.4 Sunnland

In this section, mean values for Sunnland school will be presented and compared for 2020 and 2019. It will be seen in the perspective of the values presented in table 5.2. Carbon dioxide, temperature and relative humidity are presented respectively in table 5.6, 5.7 and 5.8.

Table 5.6: Mean values of carbon dioxide, Sunnland, The following mean values are presented for carbon dioxide: Mean of the values which are exceeding 1000 ppm, mean for the values below 1000 ppm, and the total mean of the sample (school hours)

| | **2020** | **2019** | **Improvement/ deterioration (△2020-2019)** |
|---|---|---|---|
| | ***$CO_2$* *[ppm]*** | ***$CO_2$* *[ppm]*** | ***$CO_2$* *[ppm]*** |
| **108** | | | |
| Mean $CO_2$ outside range | 1715,4 | 1142,4 | 573 |
| Mean $CO_2$ within range | 593,5 | 680,6 | 87 |
| Mean $CO_2$ | 703,8 | 730,7 | 27 |
| **203** | CO2 | CO2 | |
| Mean $CO_2$ outside range | - | - | - |
| Mean $CO_2$ within range | 531,6 | 541,4 | 10,3 |
| Mean $CO_2$ | 531,6 | 541,4 | 9,8 |
| **207** | CO2 | CO2 | |
| Mean $CO_2$ outside range | 1325,4 | 1080,3 | 245 |
| Mean $CO_2$ within range | 764,5 | 632,9 | 131 |
| Mean $CO_2$ | 950,3 | 681,9 | 268,4 |

*—symbolizes that there does not exist any deviating values (most wanted result)*

Table 5.7: Mean values of temperature, Sunnland. The following mean values are presented: Mean of the values which are below 19°C and exceeding 22°, and the total mean of the sample (school hours)

| | **2020** | | **2019** | | **Improvement/ deterioration (△2020-2019** | |
|---|---|---|---|---|---|---|
| | ***T<19°C*** | ***T>22°C*** | ***T<19°C*** | ***T>22°C*** | ***T<19°C*** | ***T>22°C*** |
| | ***[°C]*** | | ***[°C]*** | | ***[°C]*** | |
| **108** | | | | | | |
| Mean temp outside range range | 18,6 | - | - | - | - | - |
| Mean temperature | 20,0 | | 20,4 | | 0,4 | |
| **203** | | | | | | |
| Mean temp outside range range | - | 22,4 | 18,6 | 22,8 | - | 0,3 |
| Mean temperature | 21,6 | | 22,3 | | 0,7 | |
| **207** | | | | | | |
| Mean temp outside range range | 18,7 | - | 18,5 | - | 0,2 | - |
| Mean temperature | 19,5 | | 19,0 | | 0,4 | |

Table 5.8: Mean values of relative humidity, Sunnland. The following mean values are presented: Mean of the values which are below 20 %, mean for the values exceeding 20 %, and the total mean of the sample (school hours)

| | **2020** | **2019** | **Improvement/ deterioration (△2020-2019)** |
|---|---|---|---|
| | ***RH [%]*** | ***RH [%]*** | ***RH [%]*** |
| **108** | | | |
| Mean RH out of range | 18,9 | - | - |
| Mean RH within range | 27,9 | 33,9 | 6,0 |
| Mean RH | 27,4 | 33,9 | 6,5 |
| **203** | | | |
| Mean RH out of range | 16,3 | 13,7 | 2,6 |
| Mean RH within range | 25,1 | 25,7 | 0,6 |
| Mean RH | 21,8 | 24,4 | 2,6 |
| **207** | | | |
| Mean RH out of range | - | 18,5 | - |
| Mean RH within range | 30,3 | 30,5 | 0,2 |
| Mean RH | 30,3 | 30,2 | 0,1 |

### Room 108

Room 108 is supplied with fresh air from the central ventilation unit of the school. It has improved during the past year. It decreased from measuring above 1000 ppm 11 % of the time in 2019 to only 5 % in 2020. Although the level of carbon dioxide exceeding 1000 ppm has a higher mean, thus the overall mean shows an improvement by decreasing from 745 ppm in 2019 to 693 ppm in 2020. This is found in table 5.6. It might be a result of routines by venting the room during breaks, that causes the improvement.

Temperatures falling below 19°C has had a negative development from 0 % to 9 %. There are no measured incidences of too high temperatures neither in 2020 nor in 2019. For the 12 % of time when the temperature is falling under the limit, the mean temperature is 18.6°C. Although, the total mean temperature is still within the interval with a score of 20°C, seen in table 5.7. The reason for the temperature fall might be due to venting routines, which is in coherence with the measured carbon dioxide levels.

The incidence of relative humidity dropping below 20 % has increased from 0 % to 21 %. Additionally, the mean relative humidity in total and within limits has decreased by around 6 %, seen in table 5.8.

**Room 203**

Room 203 is supplied with fresh air from a separate classroom aggregate. The result shows that the carbon dioxide level is acceptable for this room, which it also was in 2019. Besides, the total mean carbon dioxide has decreased by 10 ppm, as seen in table 5.6. Good routines of venting the room might be the reason for the positive result.

The temperature conditions have been improved significantly. In 2019, the temperature was exceeding 22°C 65 % of the time, but the new results show a deviation of only 34 %, which is an improvement of nearly 50 %. The calculated mean, in table 5.7, can also justify the statement that the temperature conditions have improved for the room. The mean temperature exceeding 22°C decreased from 22.8° to 22.4°C. In 2019, the total mean temperature was 22.3°C, which is too high, according to the guidelines. New results can display a total mean temperature of 21.6°C, which is within the recommended values. This might be reasoning the high focus regarding temperature regulations and the point of not touching the radiators' regulation.

### 5.1.5 Sørborgen

In table 5.9, the mean values for carbon dioxide are presented. The values are measured in ppm. In table 5.10, the mean temperatures for Sørborgen school are presented. The table is containing both temperatures below 19°C and temperatures above 22°C. The mean temperature is common. Table 5.11 presents the mean for relative humidity.

Table 5.9: Mean values of carbon dioxide, Sørborgen, The following mean values are presented for carbon dioxide: Mean of the values which are exceeding 1000 ppm, mean for the values below 1000 ppm, and the total mean of the sample (school hours)

| | **2020** *$CO_2$ [ppm]* | **2019** *$CO_2$ [ppm]* | **Improvement/ deterioration ($\triangle$2020-2019)** *$CO_2$ [ppm]* |
|---|---|---|---|
| **Musicroom** | | | |
| Mean $CO_2$ outside range | 1196,2 | 1185,5 | 10,7 |
| Mean $CO_2$ within range | 447,1 | 550,5 | 103,4 |
| Mean $CO_2$ | 451,6 | 598,4 | 146,8 |
| **0273** | | | |
| Mean $CO_2$ outside range | - | Missing data | - |
| Mean $CO_2$ within range | 457,2 | Missing data | - |
| Mean $CO_2$ | 457,2 | Missing data | - |
| **0222** | | | |
| Mean $CO_2$ outside range | - | - | - |
| Mean $CO_2$ within range | 468,2 | 547,2 | 78,9 |
| Mean $CO_2$ | 468,2 | 547,2 | 78,9 |
| **0217** | | | |
| Mean $CO_2$ outside range | - | - | - |
| Mean $CO_2$ within range | 429,8 | 439,5 | 9,7 |
| Mean $CO_2$ | 429,8 | 439,5 | 9,7 |

*—symbolizes that there does not exist any deviating values (most wanted result)*

Table 5.10: Mean values of temperature, Sørborgen. The following mean values are presented: Mean of the values which are below 19°C and exceeding 22°C, and the total mean of the sample (school hours)

| | **2020** | | **2019** | | **Improvement/ deterioration (△2020-2019)** | |
|---|---|---|---|---|---|---|
| | *T<19°C* | *T>22°C* | *T<19°C* | *T>22°C* | *T<19°C* | *T>22°C* |
| | *[°C]* | | *[°C]* | | *[°C]* | |
| **Musikkrommet** | | | | | | |
| Mean temp outside range range | - | 22,7 | - | 22,2 | - | 0,4 |
| Mean temperature | 22,6 | | 21,7 | | 1,0 | |
| **273** | | | | | | |
| Mean temp outside range range | - | 22,4 | | | - | - |
| Mean temperature | 21,9 | | Missing data | | - | |
| **222** | | | | | | |
| Mean temp outside range range | - | 23,9 | 18,3 | 22,7 | - | 1,2 |
| Mean temperature | 23,9 | | 22,2 | | 1,7 | |
| **217** | | | | | | |
| Mean temp outside range range | - | 22,3 | 17,9 | - | - | - |
| Mean temperature | 21,8 | | 20,4 | | 1,5 | |

Sørborgen is proven to be in the best condition of the three case-schools. Also, it is not expecting any major upgrades in the near future. All the rooms are supplied with fresh air by displacement ventilation, except for the music room. The conclusion from 2019, regarding Sørborgen, was that the indoor air quality was satisfying, and there was no need for technical measures. The school was still encouraged to focus on routines to optimize the indoor environment. In appendix I, there is presented a poster with five simple measures to improve the indoor environment. The management for each school was encouraged to inform employees and students about the poster.

The result of this field study revealed quite consistent results for all the rooms. Therefore, the school will be discussed as one unit and not discussed room by room. In table 5.2, the summery of measure points exceeding the recommended values are listed. From the table, it is seen that carbon dioxide levels are satisfying for all the test rooms. In table 5.9, the mean for carbon dioxide is presented. The mean is 450 ppm ± 20 ppm. There is one exception, which is the music room, which has a level of 1196 ppm mean, measured outside the range, but this is insignificant because it is only applicable for 1 % of the time. The conditions are satisfactory, and the ventilation system at Sørborgen school is working as it should be. The

Table 5.11: Mean values of relative humidity, Sørborgen. The following mean values are presented: Mean of the values which are below 20 %, mean for the values exceeding 20 %, and the total mean of the sample (school hours)

| | **2020** | **2019** | **Improvement/ deterioration (△2020-2019)** |
|---|---|---|---|
| | ***RH [%]*** | ***RH [%]*** | ***RH [%]*** |
| **Musicroom** | | | |
| Mean RH outside range | 16,1 | 15,0 | 1,0 |
| Mean RH within range | 24,3 | 25,7 | 1,4 |
| Mean RH | 20,8 | 23,4 | 2,5 |
| **0273** | | | |
| Mean RH outside range | 15,7 | Missing data | - |
| Mean RH within range | 23,9 | Missing data | - |
| Mean RH | 19,2 | Missing data | - |
| **0222** | | | |
| Mean RH outside range | 16,2 | 14,5 | 1,7 |
| Mean RH within range | 24,1 | 27,4 | 3,3 |
| Mean RH | 23,8 | 25,2 | 1,4 |
| **0217** | | | |
| Mean RH outside range | 14,4 | 15,4 | 1,0 |
| Mean RH within range | 22,7 | 26,9 | 4,2 |
| Mean RH | 17,9 | 24,0 | 6,1 |

pupils are receiving a perfectly fine amount of fresh air.

There are no incidences of temperatures that fall below 19°C. Although, the amount of time, while the temperature is exceeding 22°C, is critical for each of the case rooms. The worst cases are for room 0222 and the music room, where the temperature exceeds 22°, respectively 99 % and 98 % of the time. The two other rooms have a deviation of around 40 % of the time, seen in table 5.2. When mean temperatures are taken into account, seen in table 5.10, it is more evident that room 0222 is the most troubled room, with a mean temperature of 23.9°C. This is almost 2°C higher than the top limit for the recommended temperature and is most likely to cost an uncomfortable thermal environment for the pupils. However, the placement of the instrument might conflict with a local heating source. The ELMA-sensor was placed on top of a shelf, near the radiators, since it required a power outlet. When it was collected, the sensor had been moved to the windowsill, right above a radiator. The placement has probably had an impact on the result. For the music room, the same issue applies. There was a radiator underneath the table where it was placed. Nevertheless, there is still reason to believe that the temperature is too high for the case rooms.

The relative humidity has a higher occurrence of values below 20 % in 2020 than in 2019. It is believed that it is because of the direct influence of high temperatures in the rooms, which leads to dry air.

## 5.2 Questionnaire

This section will discuss the questionnaire sent out to all the pupils in each case school. The new results from 2020 will be presented, together with the responses from 2019 and the response from the reference schools. The focus area for the questionnaire was health symptoms and experienced indoor environment problems. The amount of respondents is presented in table 5.12. Sørborgen and Stabbursmoen school had both a response rate of 83 %, which is evaluated to be satisfying. Sunnland, on the other hand, had a response rate of 37 %, which is acceptable. The questionnaire was answered more or less in the same period as the field measurements were executed.

The responses are presented per school in a spider diagram. The red line represents the reference value, the green line represents the responses from 2019, and the blue line represents the result from 2020.

Table 5.12: Response rate from the questionnaire at Stabbursmoen, Sunnland and Sørborgen, 2020

| | **Responserate** | **Respondents** | **Pupils invited to respond** |
|---|---|---|---|
| **Stabbursmoen** | 37 % | 123 | 332 |
| **Sunnland** | 83 % | 247 | 298 |
| **Sørborgen** | 83 % | 193 | 233 |
| **Total** | 65 % | 563 | 863 |

### 5.2.1 Uncertainties

In 2019, Sunnland experienced technical issues, which led to no answers. Therefore, the result from Sunnland will just be compared to the reference. The reference are based on results from similar questionnaires from schools with no known indoor environment problems. The uncertainty of the reference is dependent on the number of pupils who participated. For the following four parameters, there are no reference values of the parameters, there does not exist any reference value: Poor lightning from ceiling, Uncomfortable light from ceiling and uncomfortable light from the sun.

### 5.2.2 Stabbursmoen

In figure 5.1, the responses from the questionnaire regarding health symptoms are presented. In appendix K, the full result from the questionnaire is presented (in Norwegian), together with the uncertainty of the reference.

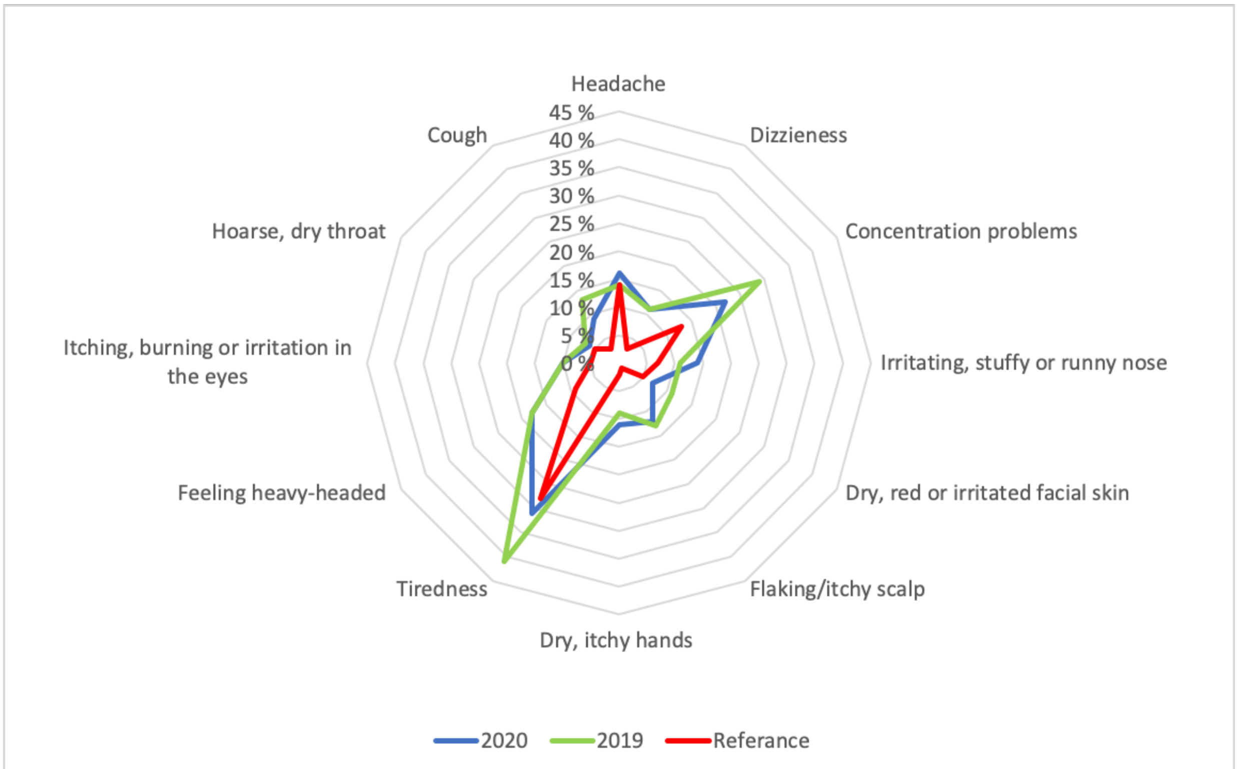


Figure 5.1: Experienced health symptoms, Stabbursmoen School

From the analysis, it can seem like the school's air quality has improved, which is comprehensive with the indications from then field measurements. The amount of students who have reported concentration problems and tiredness has decreased. The number of pupils reported tiredness as a health symptom in 2020 is near to be on the level with the reference and has decreased by 10 %, since 2019. The amount of students who reports concentration problems has decreased by around 7 % but is still 11 % higher than the reference, and therefore not a satisfying result. This can be seen in line with the improvements discussed in section 3.1. There are fewer incidences of temperatures falling below the lower limit of temperatures. Therefore, it is reasonable to think the pupils are experiencing less freezing, which is energy-consuming and has conflicts with the energy to be used for learning. Also, the change of fluorescent has most likely had a positive impact on the sensation of tiredness and concentration.

The health symptoms deviating the most from the reference, and has the same rate or higher than in 2019, is the following; Dry, itchy hands, flaking itchy scalp, itching, burning, or irritation in the eyes. It is all health symptoms related to dry air, which occurs when there is low relative humidity. The amount of time for when the relative humidity is below the recommended limit has decreased a lot, and the consequences are reveled in the questionnaire.

In figure 5.2, the response to the questionnaire regarding experienced indoor environment problems is presented. The issues that pupils find the most problematic is the following and have the highest deviation from the reference is the following; poor air quality, too hot, noise or unease from co-pupils and dust or dirt. In 2019, the following problems were included as a high deviation from the reference; fluctuations between hot and cold and disturbing noise from external sources.

The amount of pupils who answered that it is too hot has decreased, additionally, the number of pupils experiencing fluctuations between too hot and too cold. The result from the field measurements indicates that the temperature is higher than last year, but there are fewer cases where the temperature is too low. It can be discussed that more stable temperature conditions lead to a more comfortable indoor climate. When there is less fluctuation, the pupils may be less sensitive to high temperatures. With this, it can be assumed that temperature regulations have improved and that the temperatures are more consistent today.

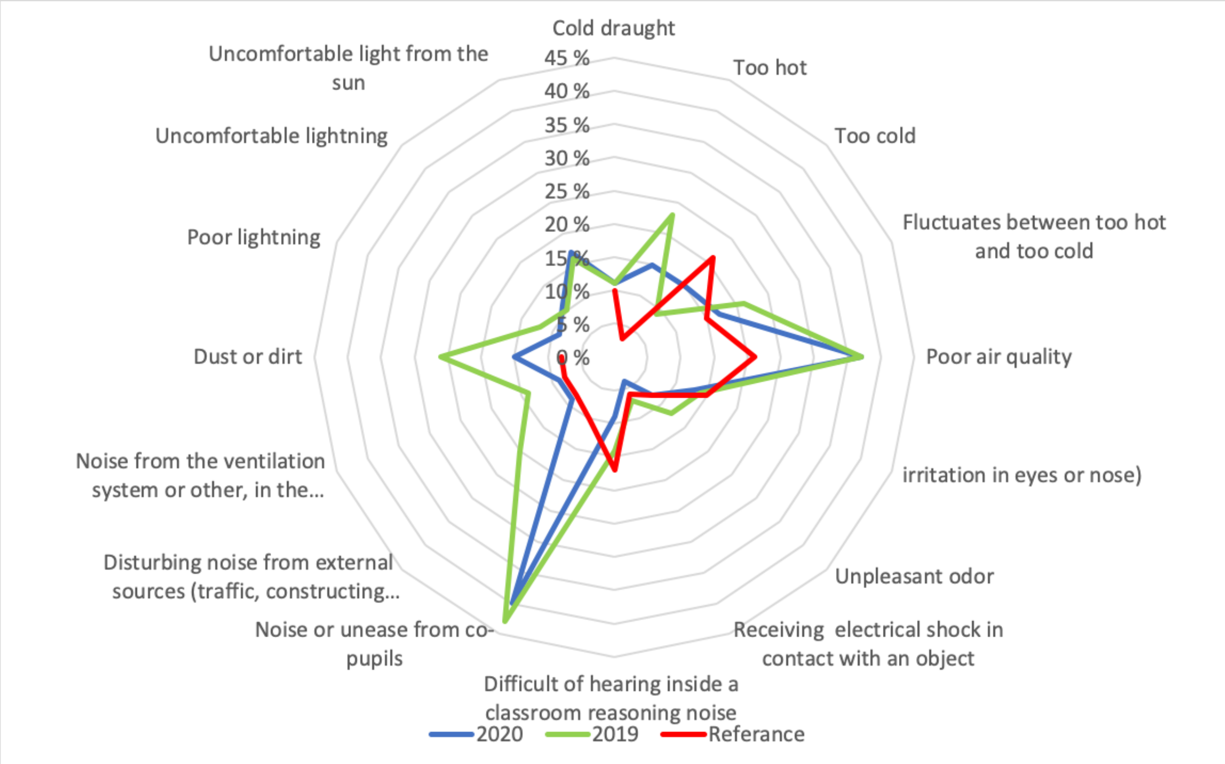


Figure 5.2: Experienced indoor environment problems, Stabbursmoen School

For the experienced indoor environment problem, dust or dirt, there is still a deviation from the reference value. It has decreased by 9 % since 2019. There has been a sincere focus on the sanitation of the school. Not only for cleaners but as well among the pupils and employees of the school. There have been implemented routines for environmental service in the learning plan, where all pupils see to their desks and try to keep all surfaces clean and tidy, and the sanitation workers can better clean the area.

The last environmental problem is noise. Noise among co-pupils is similar for 2020 and 2019. It is around 30 % higher than the reference value. It might be due to the design of the school. The school is built as an open area school, where the rooms are separated with thin partition walls with little insulation, and few rooms are equipped with doors. It leads to disturbing noise from neighboring rooms and pupils walking outside the classrooms. Nevertheless, noise from external sources has decreased with 11 % and is within the reference value.

### 5.2.3 Sunnland

As mentioned, Sunnland did not participate in the questionnaire in 2019. In figure 5.3, the blue line represents the result from 2020, and the red line represents the reference. In appendix L, the full result is presented with uncertainty for the reference.

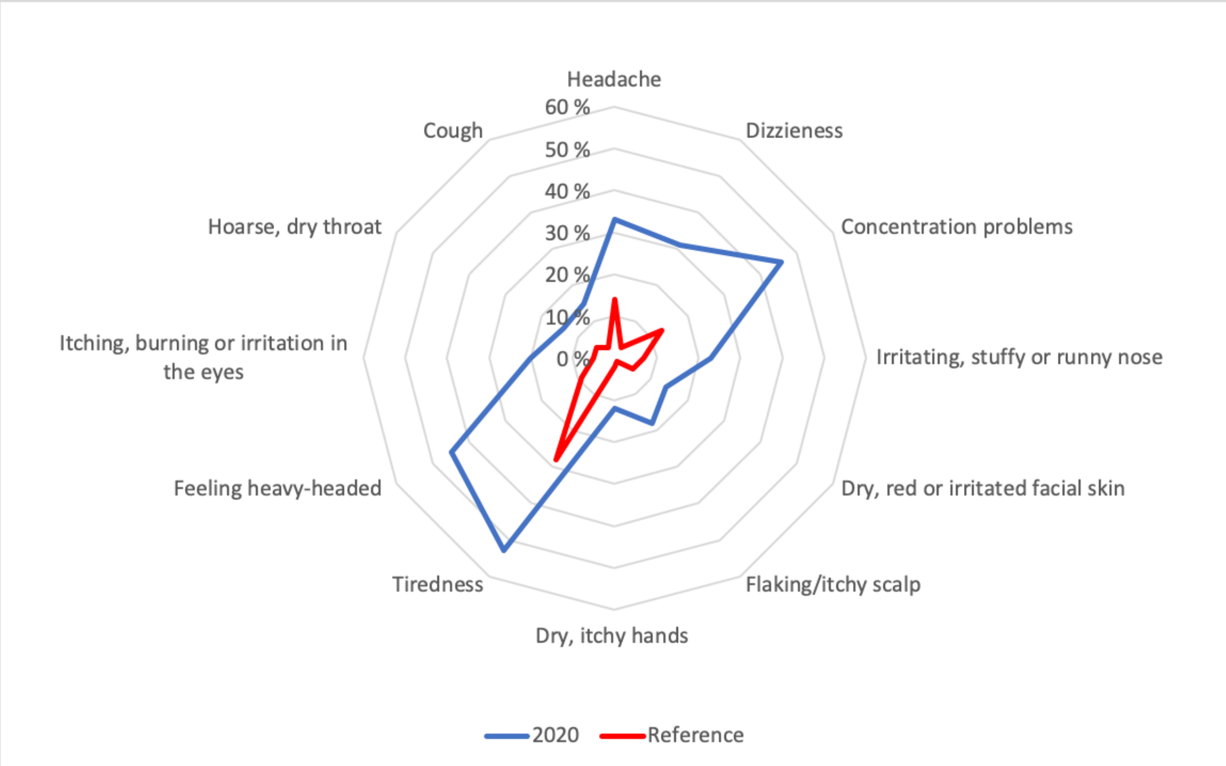


Figure 5.3: Experienced health symptoms, Sunnland School

For the pupils who answered the questionnaire, there is a high amount of health symptoms reported. In short lines, all of the factors are higher than the reference value with the given uncertainty. The health symptoms which report the highest deviation are dizziness, concentration problems, feeling heavy-headed, and tiredness. They have a deviation of 30 % from the reference. A common denominator is that each of these symptoms can arise from poor air quality. In general, it can be stated that students are aware of the poor indoor environment, and it is affecting their daily health in a high scale matter.

In figure 5.4, the result (blue line) from the questionnaire regarding indoor environment problems are presented, together with the reference (red line). Several factors are exceeding the reference with uncertainty, which are the following; Too hot, Fluctuations between too hot and too cold, poor air quality, dry air, unpleasant odor, noise or unease from co-pupils, and dust or dirt.

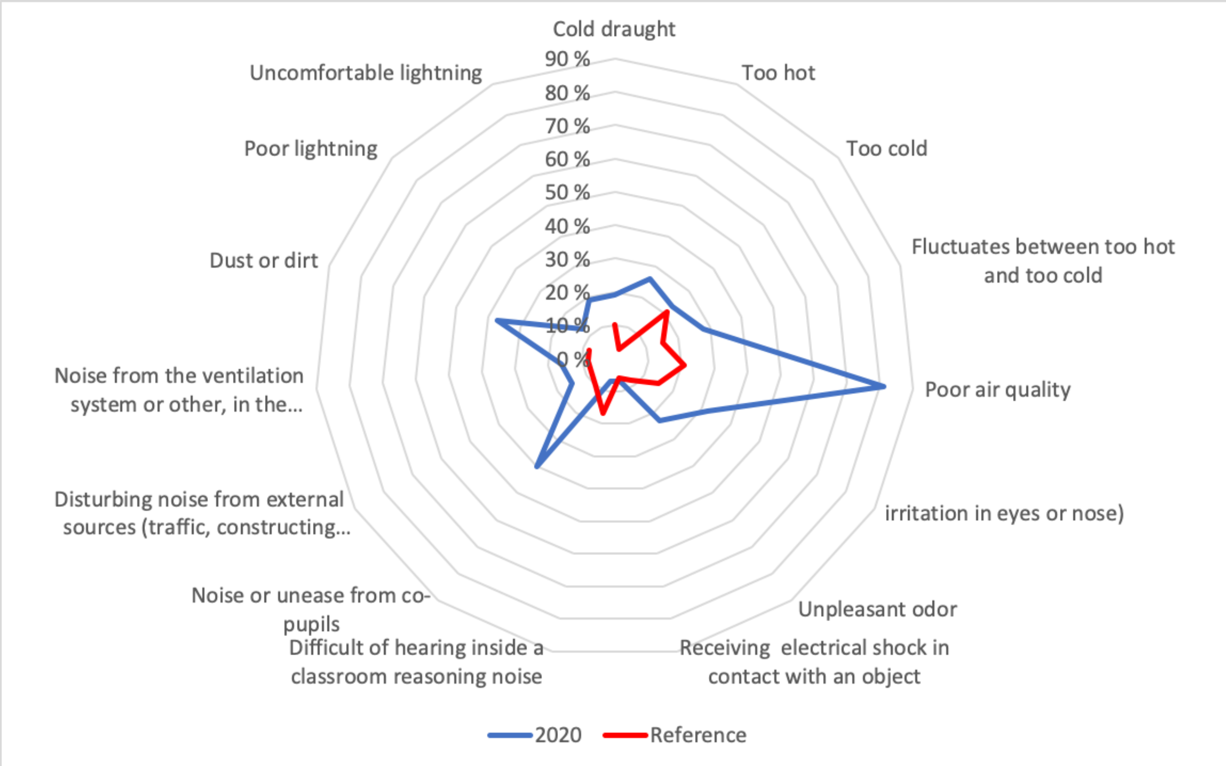


Figure 5.4: Experienced indoor environment problems, Sunnland School

There was 81 % of the respondents who answered for poor air quality. It is a deviation of approximately 60 % from the reference. This, in addition to the number of pupils who answered it was too hot and fluctuating temperatures, are quite coherent to the answers to the health symptoms. Dizziness, Concentration problems, tiredness, and feeling heavy-headed are symptoms which can occur whit poor air quality and high temperatures. Nevertheless, it does not have a high correspondence with the field measurements, but this will be discussed in section 5.6.

### 5.2.4 Sørborgen

The result from the questionnaire regarding health symptoms is presented in figure 5.5. The blue line is the result from 2020, the green line is from 2019, and the red line is the reference. For Sørborgen, there are no health symptoms that are deviating from the reference value with the uncertainty. There is a small improvement from the responses from 2019 to 2020. It is very satisfying results and compiles well with the result from the field measurement. There was not detected any prominent indoor air quality problems in the test room. The questionnaire strengthens the indication. The full result is presented in appendix K

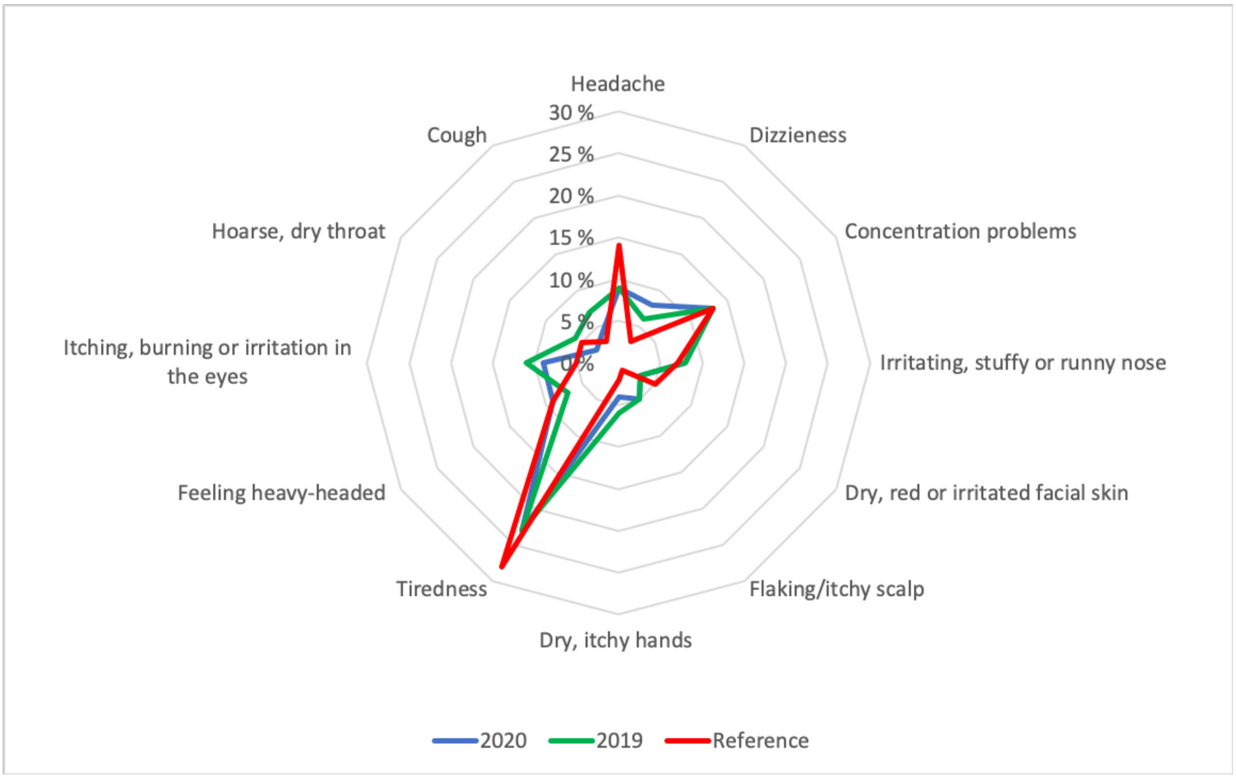


Figure 5.5: Experienced health symptoms, Sørborgen School

Figure 5.6 presents the result from 2020 (blue line), responds from 2019 (green line) and the reference (red line). As seen in the figure, most of the factors have a lower appearance than the reference, with one exception; noise or unease from co-pupils. This is a very satisfying result and compiles well with both the answers to health symptoms and the field measurements. The result from 2020 and 2019 is quite coherent, and there has not been a significant change.

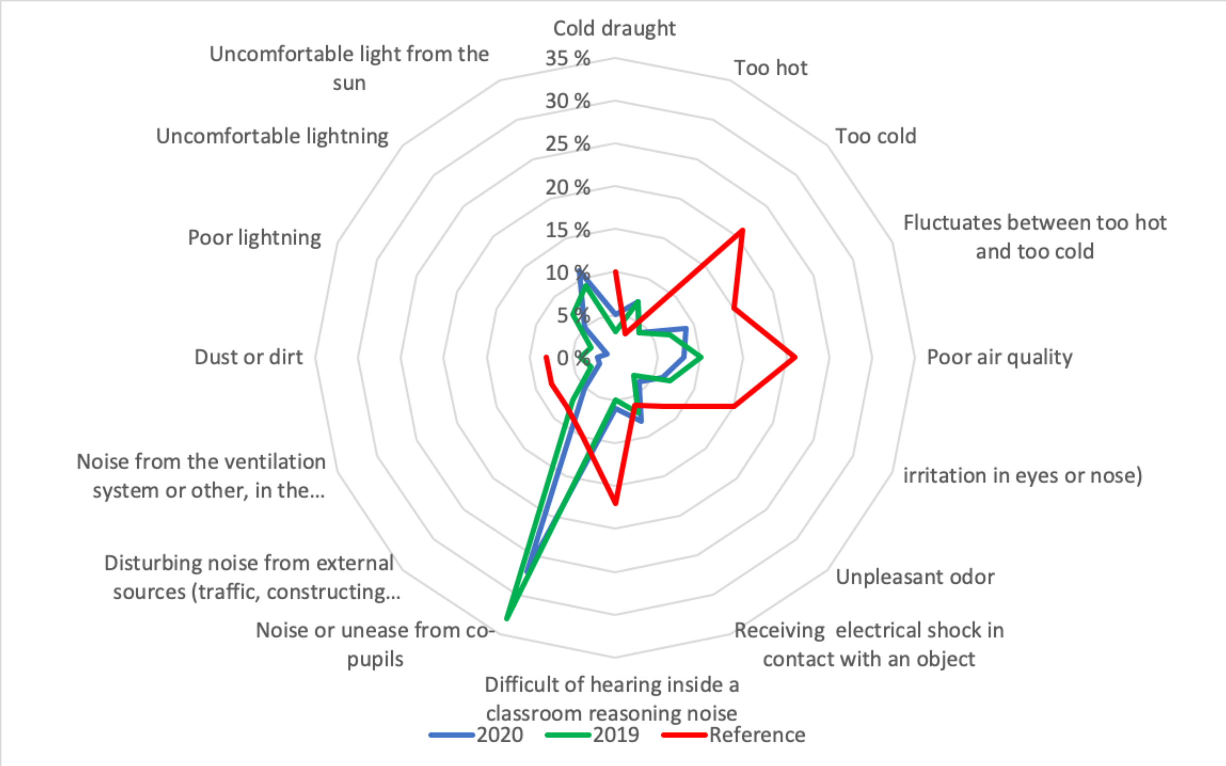


Figure 5.6: Experienced indoor environment problems, Sørborgen School

## 5.3 Interviews

In this section, the interviews with employees at the case-schools will be presented and compared to the interviews from 2019. It is sought to interview the same objects as last year rather than users of the case rooms. This has led to that the objects thus not necessarily represent the indoor environment for the included rooms. However, it still paints a picture of the indoor environment conditions for the school. Table 5.13 presents the number of interviews conducted for each school in 2020 and 2019.

Table 5.13: Number of interviews conducted for each school, in 2020 and 2019

| **School** | **Number of interviews** | |
|---|---|---|
| | **2020** | **2019** |
| Stabbursmoen | 4 | 5 |
| Sunnland | 7 | 9 |
| Sørborgen | 5 | 7 |

The questions in the interview differ between text, multiple-choice, and number rating questions. The questions which categorize as multiple choice will be presented in bar charts, where the green bar represents 2019, and the green bar represents 2020. Considering that the number of interview objects is incompatible for the two years, the chart will be presented in percentages. The following questions will be presented as a bar chart:

- Interview object's health symptoms the past two years
- Interview object's impression of factors affecting the indoor environment
- Interview object's impression of the health of employees
- Interview object's impression of the health of students

The text questions will be summarized, and the number rating is presented in a table with the calculated average. In appendix C, the full interview guide for 2020 is provided.

The interview objects were asked to rate their quality and thermal conditions on a scale from 1 to 10, where 1 is the best and represents perfect conditions, and 10 is the worst. In table 5.14, the calculated average score of perceived air quality and thermal conditions is presented, for 2020 and 2019. Stabbursmoen has the worst result regarding air quality, with an average score of 7, and Sunnland has the worst result for thermal conditions, with an average of 8.4. The average score for the two factors are presented in table 5.14.

Table 5.14: The calculated average for 2020 and 2019, given by the objects on a scale from 1 to 10, where 1 is the best

| | **Air quality [Average]** | | **Thermal conditions [Average]** | |
|---|---|---|---|---|
| | ***2020*** | ***2019*** | ***2020*** | ***2019*** |
| **Stabbursmoen** | 7.0 | 5.8 | 7.0 | 7.0 |
| **Sunnland** | 6.5 | 7.1 | 8.4 | 6.8 |
| **Sørborgen** | 4 | 5.5 | 3.8 | 4.7 |

### 5.3.1 Uncertainties

When discussing the interviews, it is essential to state that the statistical foundation is low and not too comprehensive. The interviews can not be used to conclude, but they function as a substitute material to strengthen or weaken assumptions and conclusions based on the field measurements and questionnaire. It is not possible to compare the schools with each other either. It is because the response rate differs from school to school. For instance, Sørborgen had the lowest rate with four respondents in 2020, and Sunnland had the highest rate, with nine respondents in 2019, and if one person answers yes to one factor, it will give an output of respectively 25 % and 11 %. It gives misleading statistics if the statistical background is not considered.

### 5.3.2 Stabbursmoen

In total, four employees were interviewed at Stabbursmoen, including the operator, school nurse, and the principal. The average score, presented in table 5.14 for the air quality and thermal conditions were 7. It is a deterioration of 1.2 for air quality and steady for thermal condition, compared to 2019. In figure 5.7, the answers for whether or not the object had experienced health-related symptoms the past two years are presented. The green bars represent 2019. The new result reveals that the objects are not contested with any health symptoms related to the indoor environment. This is an improvement from 2019.

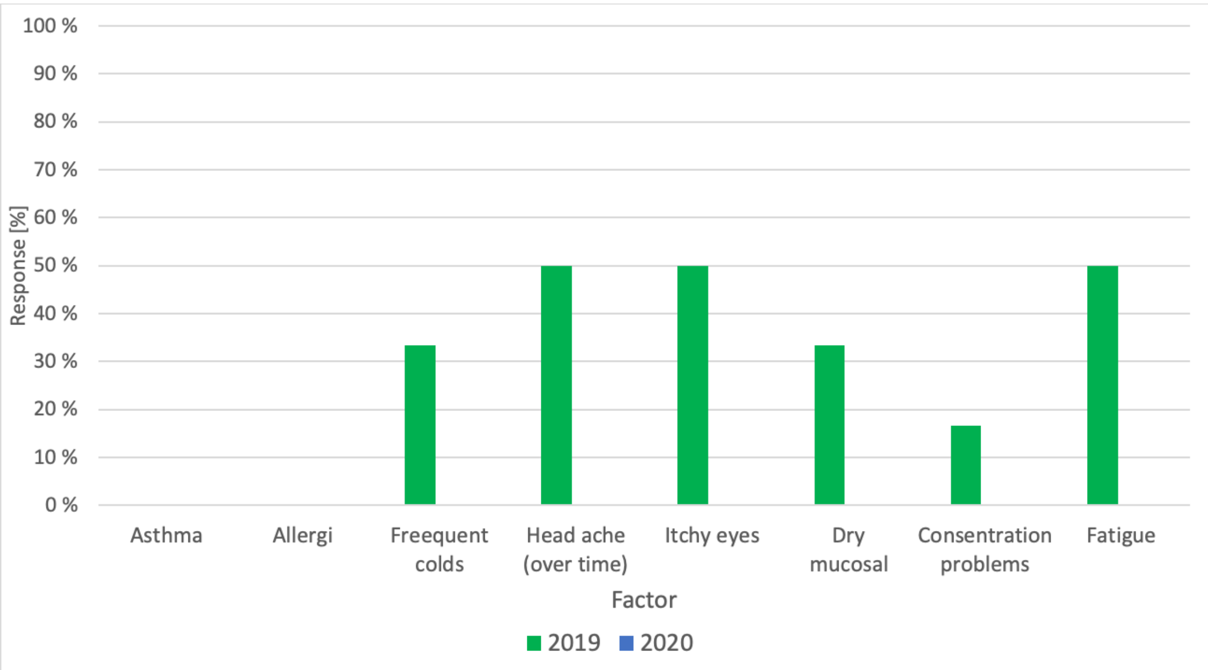


Figure 5.7: Interview object's health symptoms, Stabursmoen School

Figure 5.8 presents the subjective meaning of which factors are important for the indoor environment in the school. The green bar represents 2019, and the blue bar represents 2020. The new result shows that the heating system has the highest increase, and sanitation has the highest decrease.

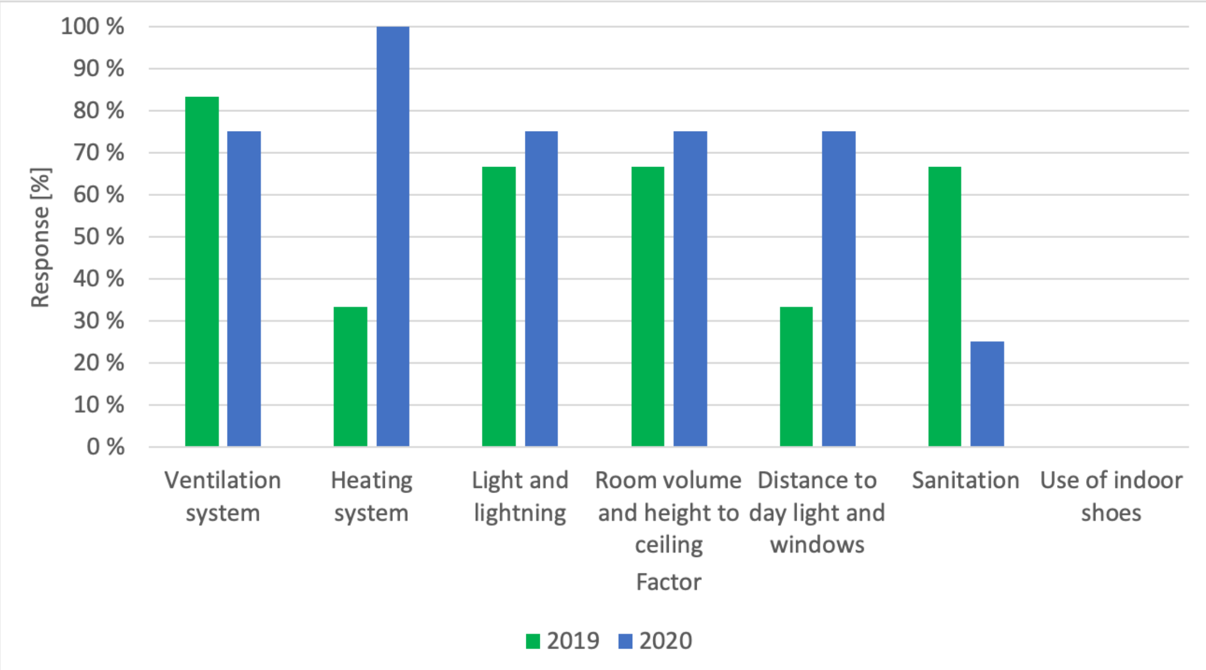


Figure 5.8: Interview objects impression of factors affecting the indoor environment, Stabbursmoen School

Figure 5.9 and 5.10 represents the interview objects' subjective perception of how the indoor environment affects the employees' and pupils' health. The green bar represents 2019, and the blue bars represent 2020. The bar which has increased the most for the employees is thermal comfort, where the new result reveals that 100 % of the objects interviewed are affected by the thermal comfort, compared to 33 % in 2019. The bar which has had the highest decrease is fatigue, which decreased from 66 % in 2019 to 25 % in 2020. For students, all the bars have had an increase except for learning, which has decreased.

In the interviews for 2020, there was asked if they had noticed any improvements after the new measures were implemented. The general feedback was that the classroom aggregate had improved the air quality in the room Blåsal. They noticed less fatigue and heavy-headed sensation after staying inside the room for too long. However, the implementation of the classroom aggregate has impacted the thermal conditions of the room. The feedback has been that the aggregate generates uncomfortable draught if the pupils are placed too near.

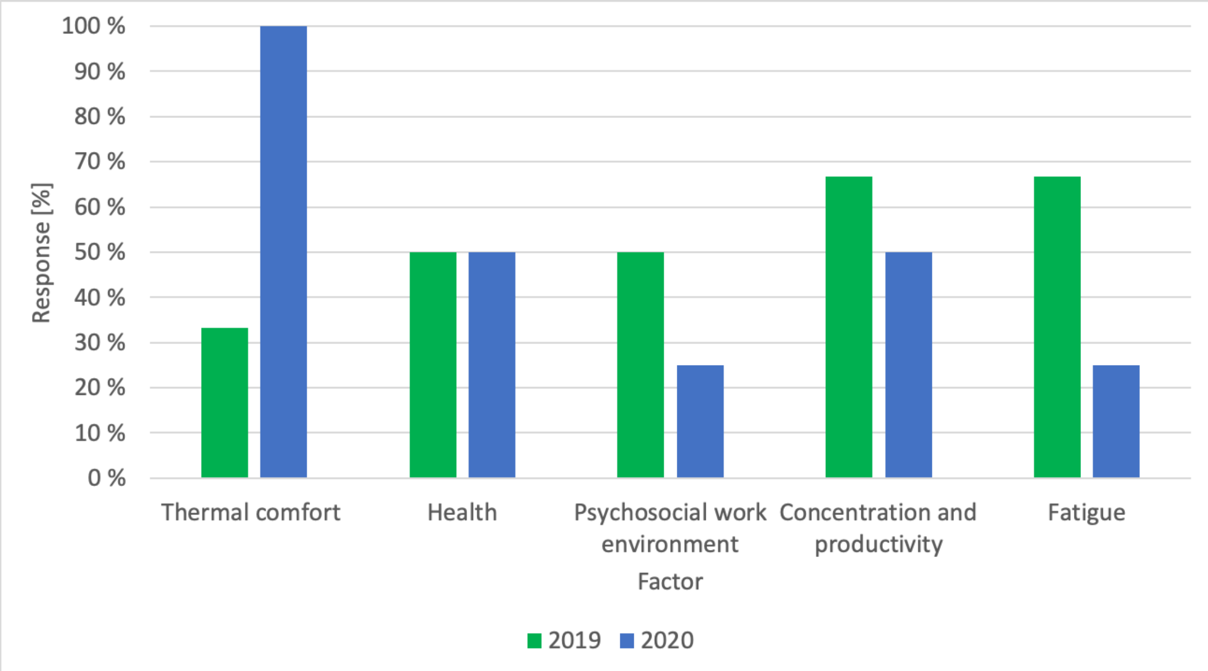


Figure 5.9: Interview objects impression of health of employees, Stabbursmoen School

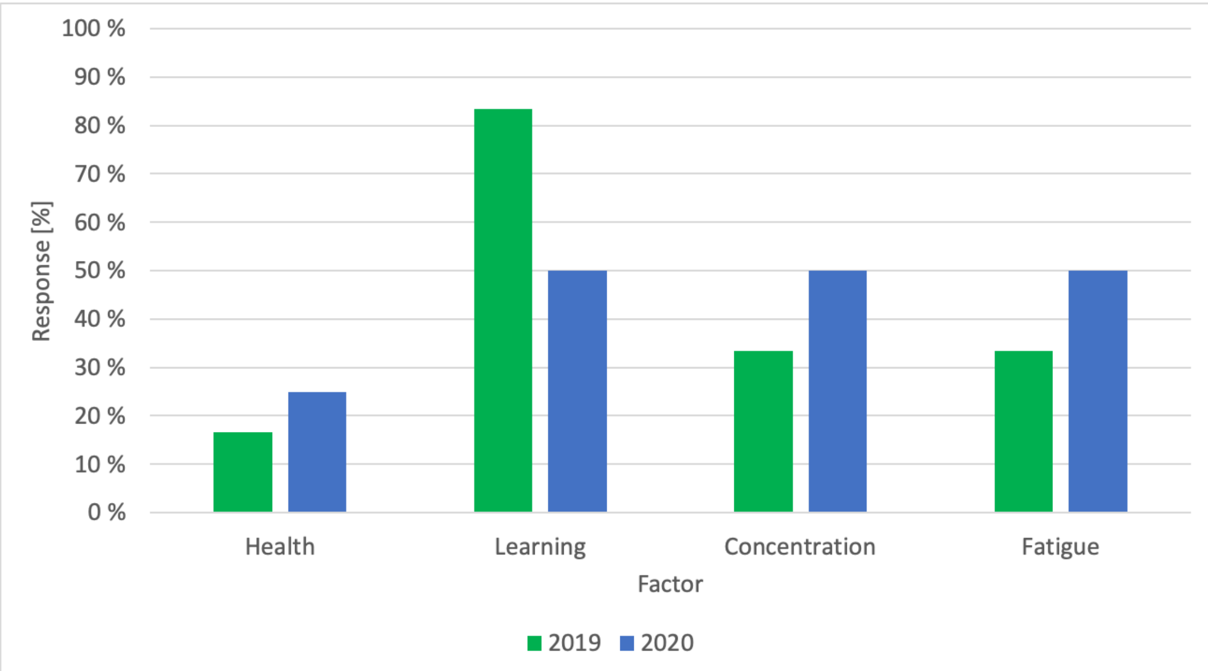


Figure 5.10: Interview objects impression of health of pupils, Stabbursmoen School

The measure of upgrading the fluorescent has had a positive impact. It was mentioned in every interview. It is assumed that the reason the impact of lightning has a higher response rate in 2020 is that the employees are more aware that lightning has impacted the conditions of the indoor environment after the conditions are improved.

The number of responses was quite low for Stabbursmoen, with only four participants. It does not give a comprehensive statistical foundation to make any conclusion, but it gives indicators for the school's condition.

### 5.3.3 Sunnland

Sunnland had the highest rate of respondents to the interview, with seven representatives, including the principal, school nurse, and operator, in 2019, there were 9 respondents. The average score, introduced in table 5.14, the average score of the air quality has had an improvement from 7.1 in 2019 and 6.5 in 2020. The subjective opinion regarding the thermal conditions has deteriorated from 6.8 in 2019 to 8.4 in 2020.

In figure 5.11, the health symptoms the interview objects has experienced the past two years is presented. There are several significant changes to the experienced symptoms. In 2020, almost 30 % of the respondents had experienced more extended periods with headache, compared to 70 % in 2019. Almost 60 % responded that they experienced itchy eyes and dry mucosal in 2020, which is a significant increase compared to 2019, with a percentage of around 10 %. Also, the percentage of experienced concentration problems has increased by 30 %.

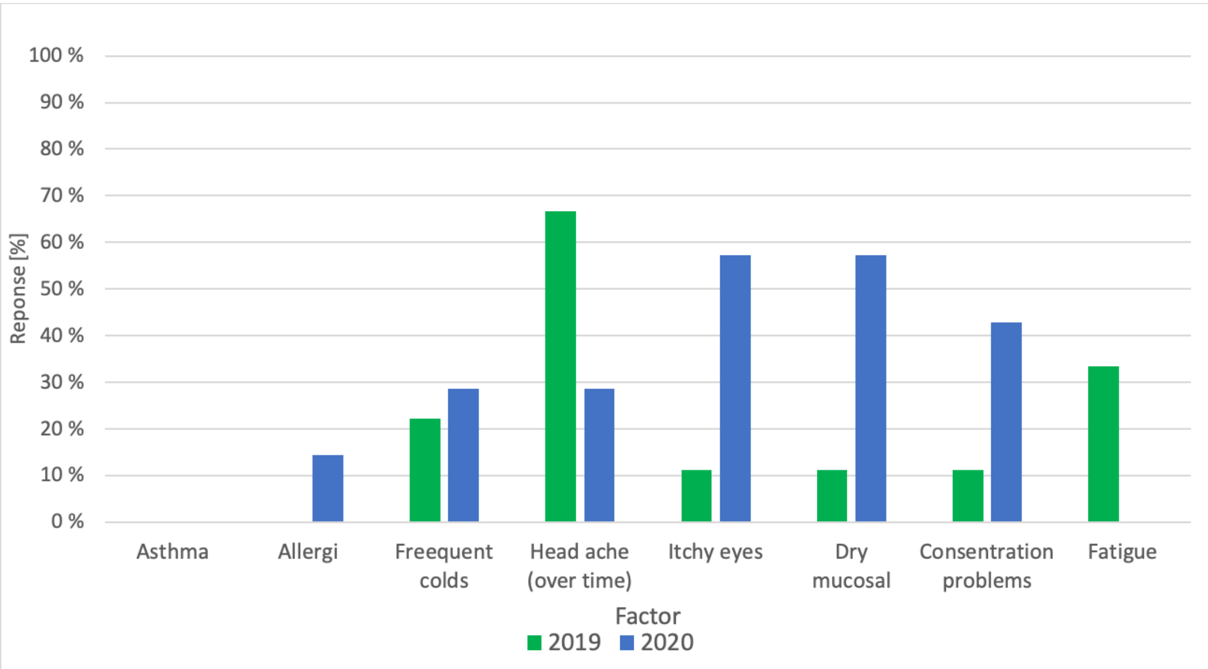


Figure 5.11: Interview object's health symptoms, Sunnland School

Figure 5.12 presents the subjective meaning of which factors are important for the indoor environment in the school. The green bar represents 2019, and the blue bar represents 2020. The new result shows that all the factors except ventilation system and room volume and height to ceiling have increased in 2020.

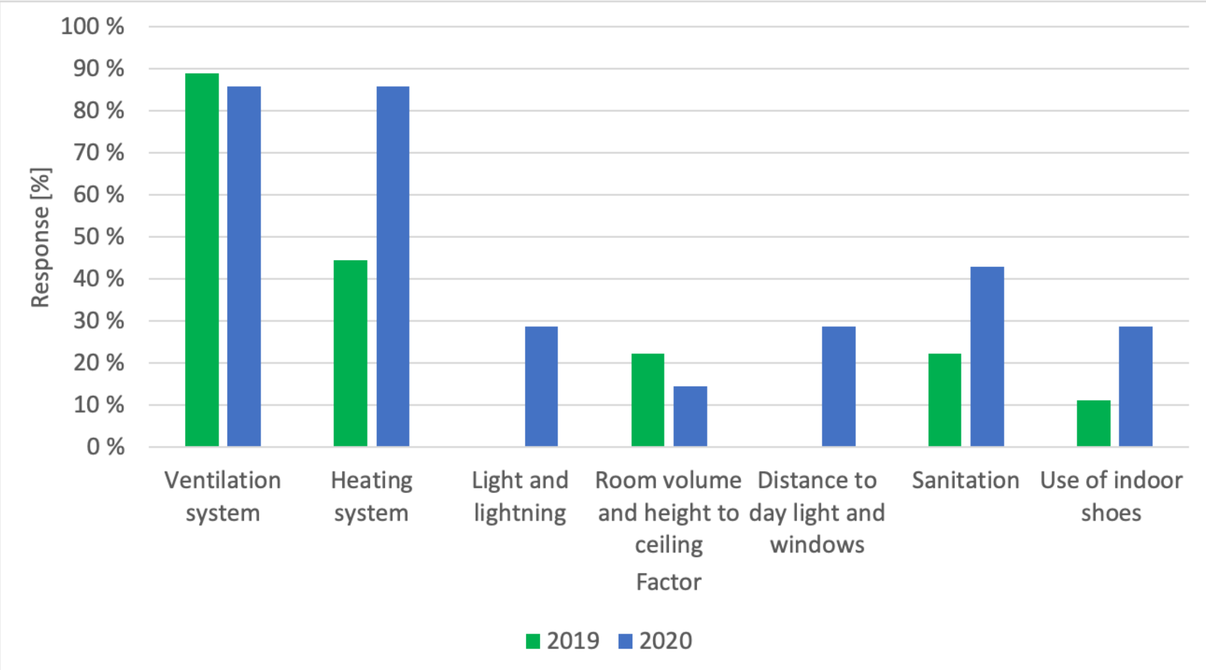


Figure 5.12: Interview objects impression of factors affecting the indoor environment, Sunnland School

Figure 5.13 and 5.14 presents the interview objects' impression of how the indoor environment affects the employees and the pupils. The green bar represents 2019, and the blue bar represents 2020. As seen in the bar chart, all the bars have increased in 2020, compared to 2019. The bar with the highest increase is "psycho-social work environment," which has increased with over 60 %.

Sunnland had the highest response rate, both in 2019 and 2020, and therefore has the most reliable statistics. It has been noticeable that Sunnland is the school with the most pessimistic frame of mind. The general feedback was regarding the thermal conditions. There is much frustration directed to the radiators and the problems of regulating the thermostat to the right temperature. The teachers feel it is either too hot or too cold and that the temperature fluctuations are perceptible. They have noticed that the implementation of the classroom aggregates has improved the air quality, but several states are at the expense of thermal comfort. Pupils placed near the aggregates have stated that they are shivering.

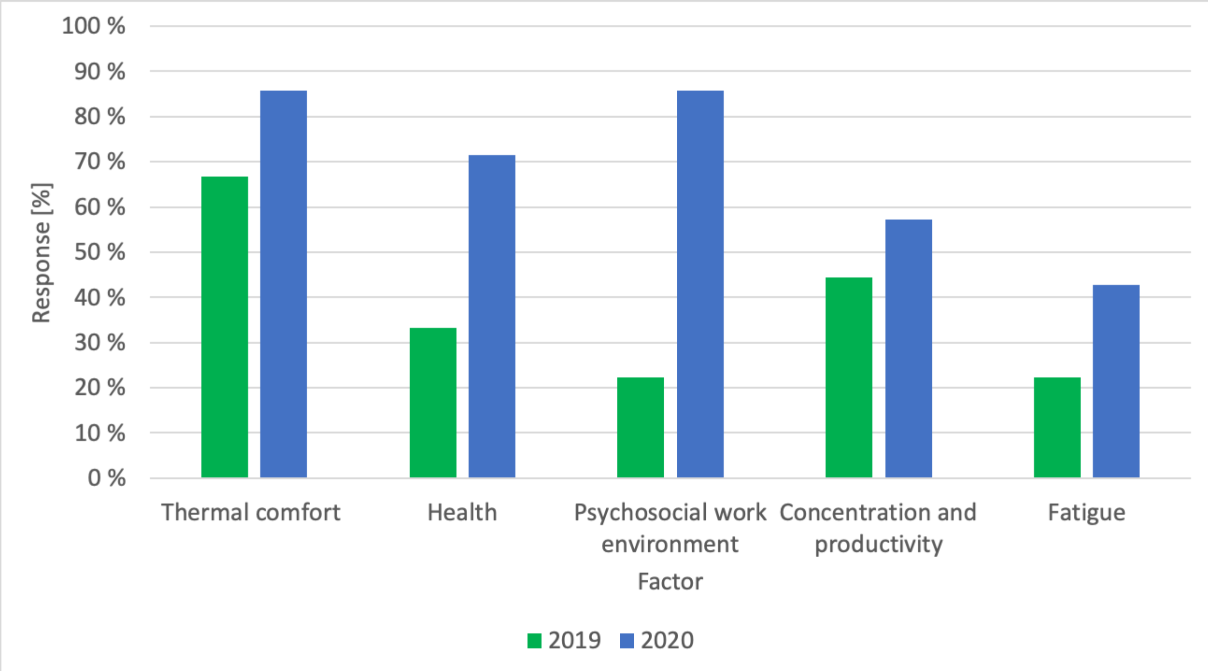


Figure 5.13: Interview objects impression of health of employees, Sunnland School

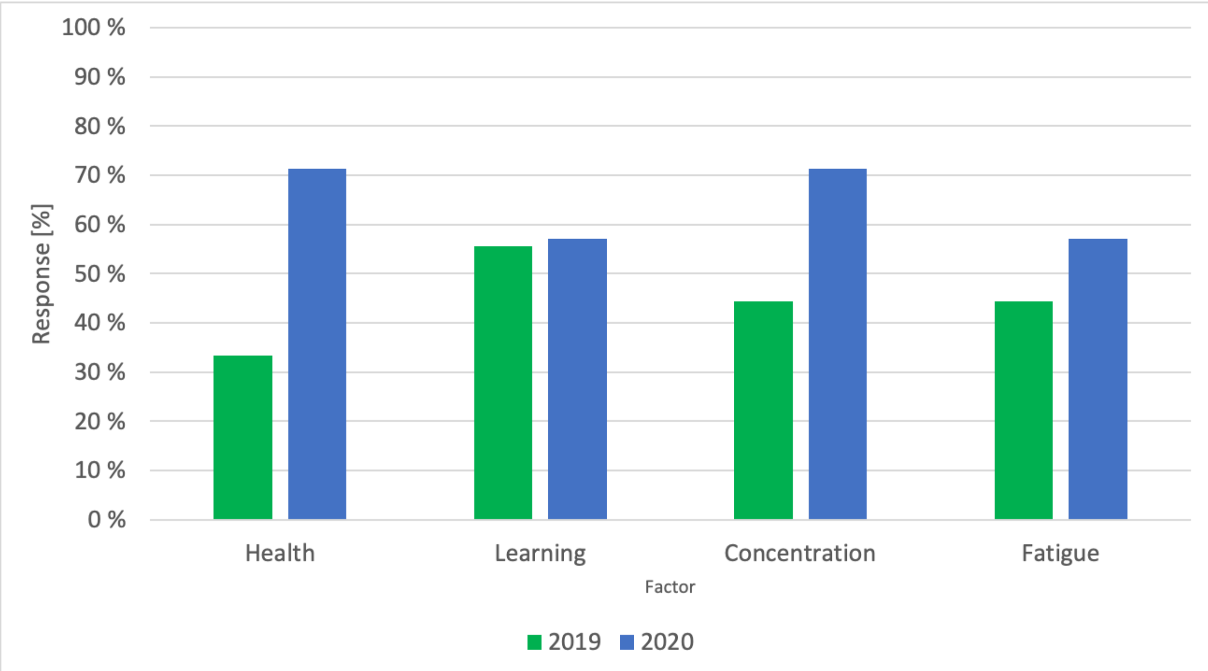


Figure 5.14: Interview objects impression of health of pupils, Sunnland School

There was asked if conditions for the school had improved after implementation measures. There was noticed that the temperature was better due to the cut of setpoint temperature for ventilated air. However, most of the respondents answered; no noticeable change or that the time frame from the implementation of measures to the interview was too short of making an evaluation.

### 5.3.4 Sørborgen

In total, there were five employees interviewed at Sørborgen, including the operator, school nurse, and the principal. In 2019, there were 7 employees interviewed. The average score, presented in table 5.14 for the air quality, was 4. It is an improvement of 1.5. The average score for the thermal condition was 3.8, which is an improvement of 1.2 compared to 2019, making Sørborgen the only case school where the employees rate the indoor environment to have had an improvement from 2019 to 2020.

In figure 5.7, experienced health symptoms in the past two years are presented. The green bars represent 2019, and the blue bars represent 2020. The new result reveals that the symptoms, concentration, and fatigue have diminished, but itchy eyes, dry mucous, eczema, and frequent colds have appeared in 2020. Also, the rate of experienced headache has increased by 30 %.

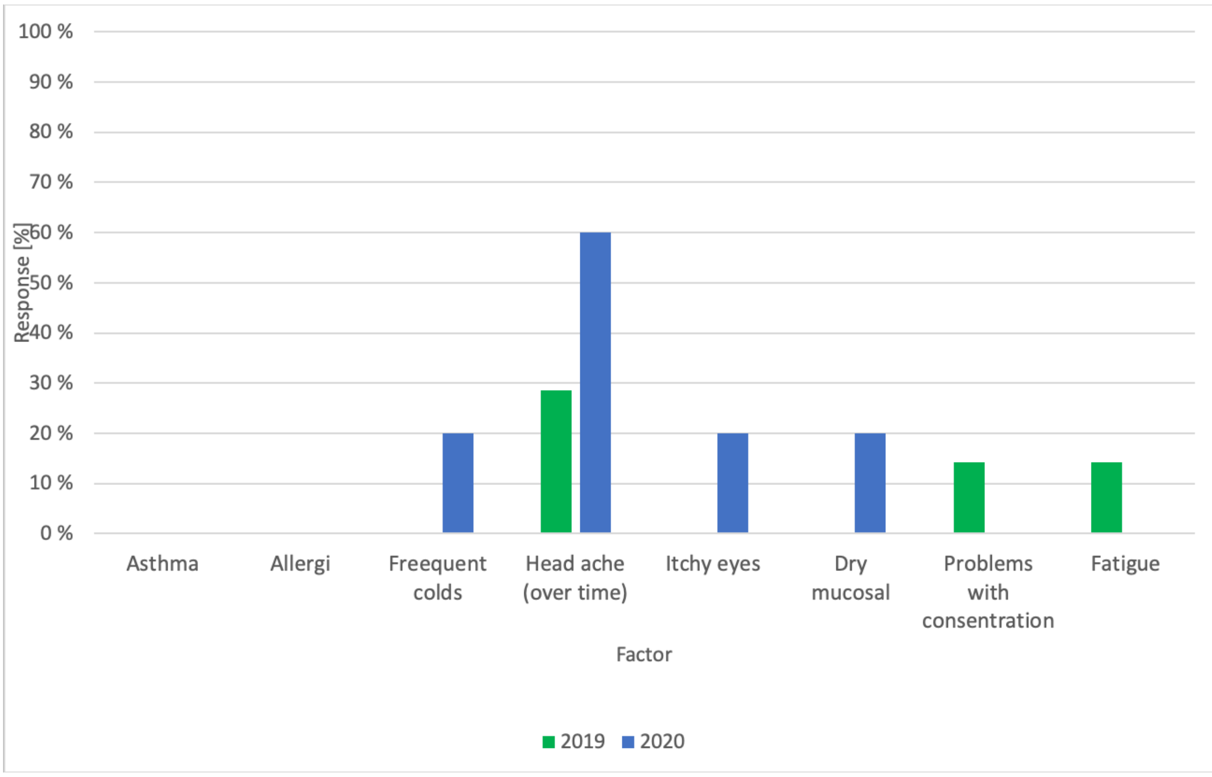


Figure 5.15: Interview object's health symptoms, Sørborgen School

Figure 5.6 presents the subjective meaning of which factors are important for the school's indoor environment. The green bar represents 2019, and the blue bar represents 2020. The new result shows that the factors; heating system, room volume, and ceiling height have increased by over 30 % each. Furthermore, light and lightning and sanitation have appeared as a troubled area in the new result.

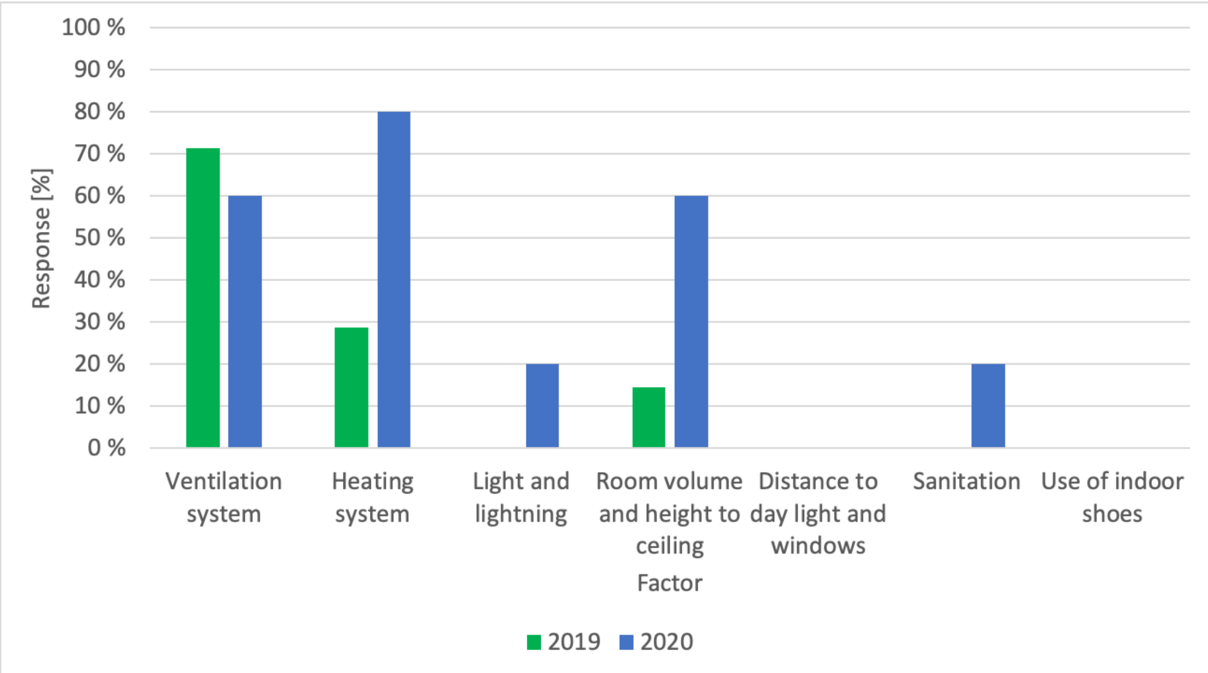


Figure 5.16: Interview objects impression of factors affecting the indoor environment, Sørborgen School

Figure 5.17 and 5.18 presents the interview objects' impression of how the indoor environment affects the employees and the pupils. The green bare represents 2019, and the blue bar represents 2020. Regarding the employees, thermal comfort, concentration, and productivity seem to be less occurrent in 2020 than in 2019. However, health and psycho-social work environments have had a higher occurrence. The bar chart describing the pupils indicates that the indoor environment affects the pupils on the same scale for both years.

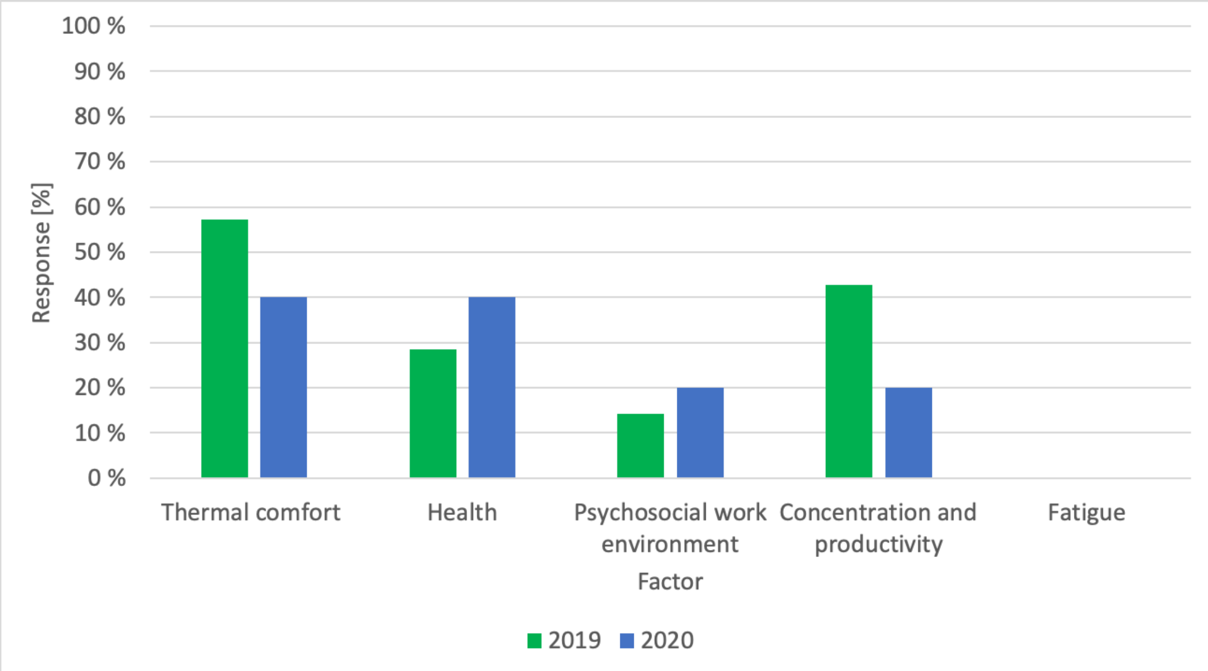


Figure 5.17: Interview objects impression of health of employees, Sørborgen School

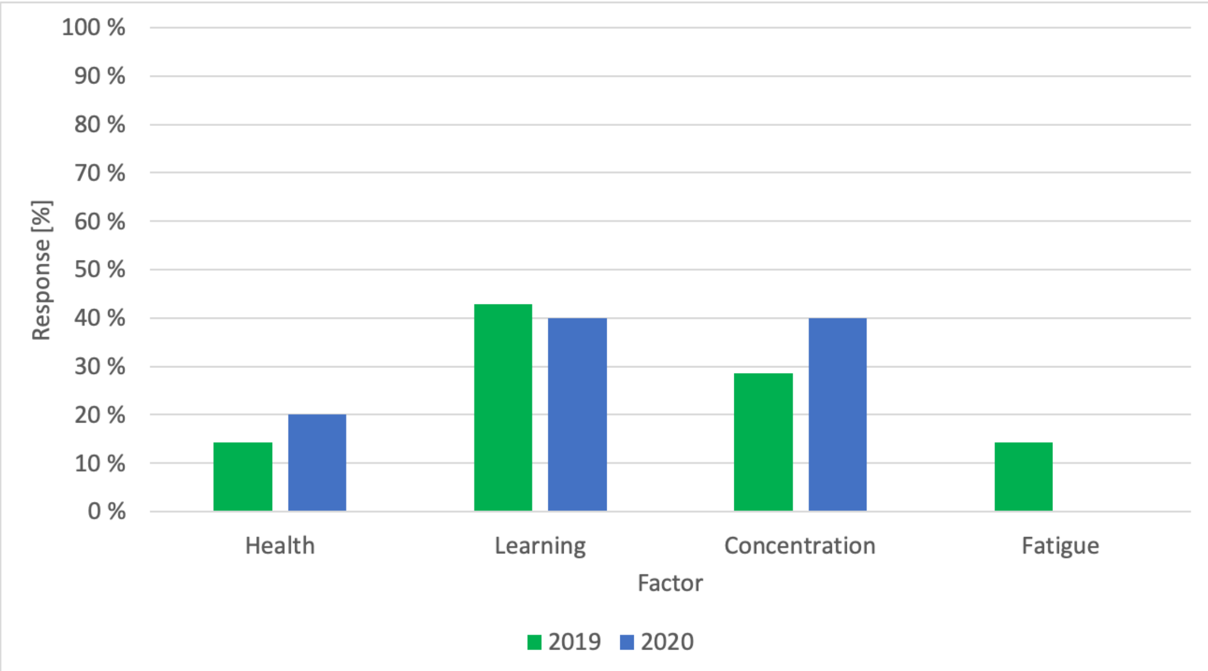


Figure 5.18: Interview objects impression of health of pupils, Sørborgen School

### 5.3.5 General discussion of the interviews

According to the statistic, there have been deteriorating conditions for several fields. The worst category is where there was answered what impacts the environment. Even though the respondents often answered that the conditions had improved. Take Stabbursmoen as an example; 100 % of the respondents answered that the lights had improved the indoor environment significantly, but there was still a higher percentage who stated the lightning as a problem in 2020. Further, this applies to several other responses. After the project started, it is believed that there has been more focus and learning for the employees, targeting the indoor environment, which has made them more aware and knowledgeable around the subject and has had an impact on the responses in 2020.

## 5.4 Thermal comfort

The study of thermal comfort includes two classrooms, one at Stabbursmoen school, with 23 $10^{th}$ graders and on at Sørborgen school, with 21 $2^{nd}$ graders. It was not possible to conduct this study at Sunnland school before the schools locked down. For each room, the pupils answered the survey two times, at the start of the lecture and in the end (The number of pupils varied for the two different surveys because a few pupils were late to class). The four surveys made a total of 85 answers.

### 5.4.1 Uncertainties

The objects answering the survey are young, and there were uncertainties directed to the understanding of the survey. The understanding was that the pupils participating in the investigation understood the simplified thermal comfort survey. If uncertainties regarding the questions occurred, it was explained more thoroughly. There were measured radiant temperature, air temperature, and velocity, and taken notes regarding the clothing insulation level and activity level to investigate the thermal environment based on the adaptive thermal comfort model. However, this was not completed due to a shortage of time.

### 5.4.2 Correlation between Thermal Sensation Vote and Thermal Preference Vote

Figure 5.19 and 5.20 is presenting the collection of the entire sample of the surveys for thermal sensation vote (TSV) and thermal preference vote (TPV). The TSV and TPV are centered around 0 (neutral and no change), with a shift towards cold thermal sensation for TSV, and a TPV is shifting towards wishing for a warmer temperature, which is consistent results. Overall, the pupils evaluated their thermal sensation to be mostly cold, and the thermal preference to wish for a warmer environment.

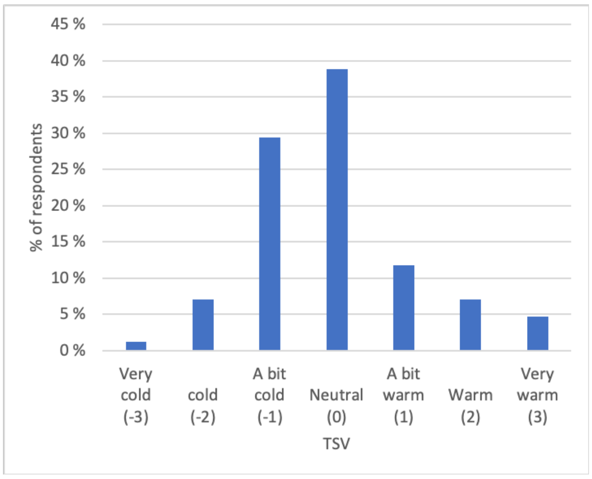


Figure 5.19: Relative frequency of Thermal Sensation Votes (TSV) from the four surveys, in total of 85 responses

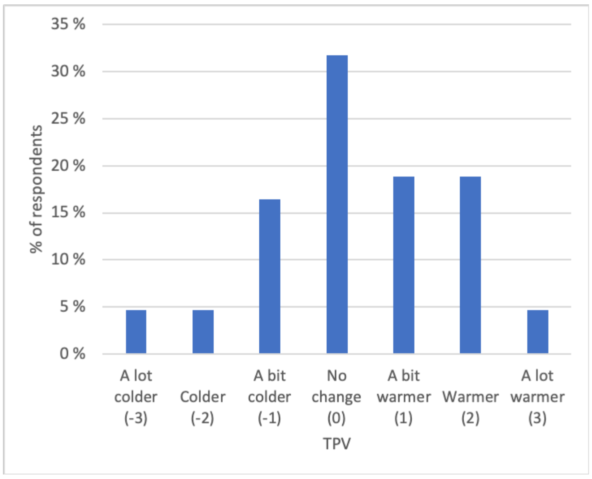


Figure 5.20: Relative frequency of Thermal Preference Votes (TPV) from the four surveys, in total of 85 responses

The pupils where asked if they feel satisfied with the thermal conditions or not. In figure 5.21, the percentage of pupils feeling satisfied with the environment per thermal sensation vote is presented. The question is asked to identify the impact of perceived thermal sensation and satisfaction. According to Fanger's PMV-PPD equation, There is always a certain percentage that will feel unsatisfied with the thermal environment. For the thermal neutral sensation (0), there is predicted that 5 % of the occupants will feel unsatisfied. If the actual percentage deviates significantly from Fanger's equation, it indicates that there are other factors than the thermal environment, which influences the pupil's comfort, like high carbon dioxide level or low relative humidity. The result from the survey shows that 100 % of the pupils, which feels thermal neutral is satisfied with the conditions.

### 5.4.3 Predicted Mean Vote vs. Actual Mean Vote

Figure 5.22 compares the PMV with the calculated AMV from the survey. The PMV cure for adults is used because there does not exist a developed model for children. APD is calculated from the pupils' thermal sensation votes. The result indicates that the actual percentage of dissatisfaction is coherent with the predicted percentage of dissatisfaction.

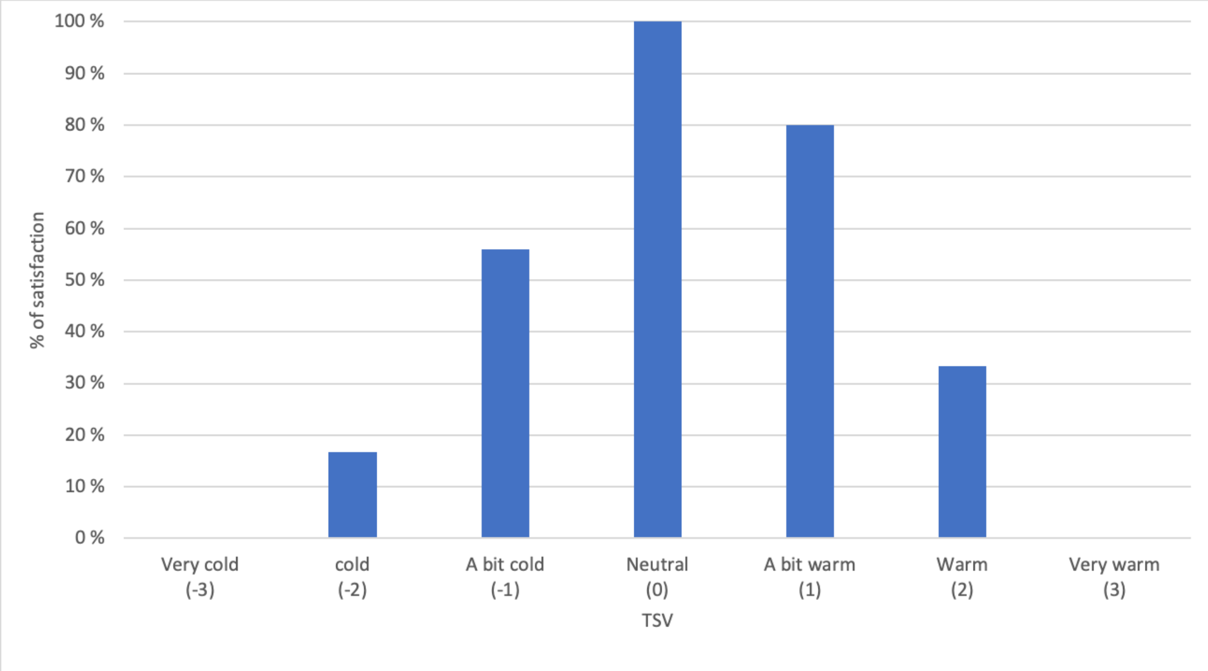


Figure 5.21: Percentage of pupils feeling satisfied with the thermal sensation

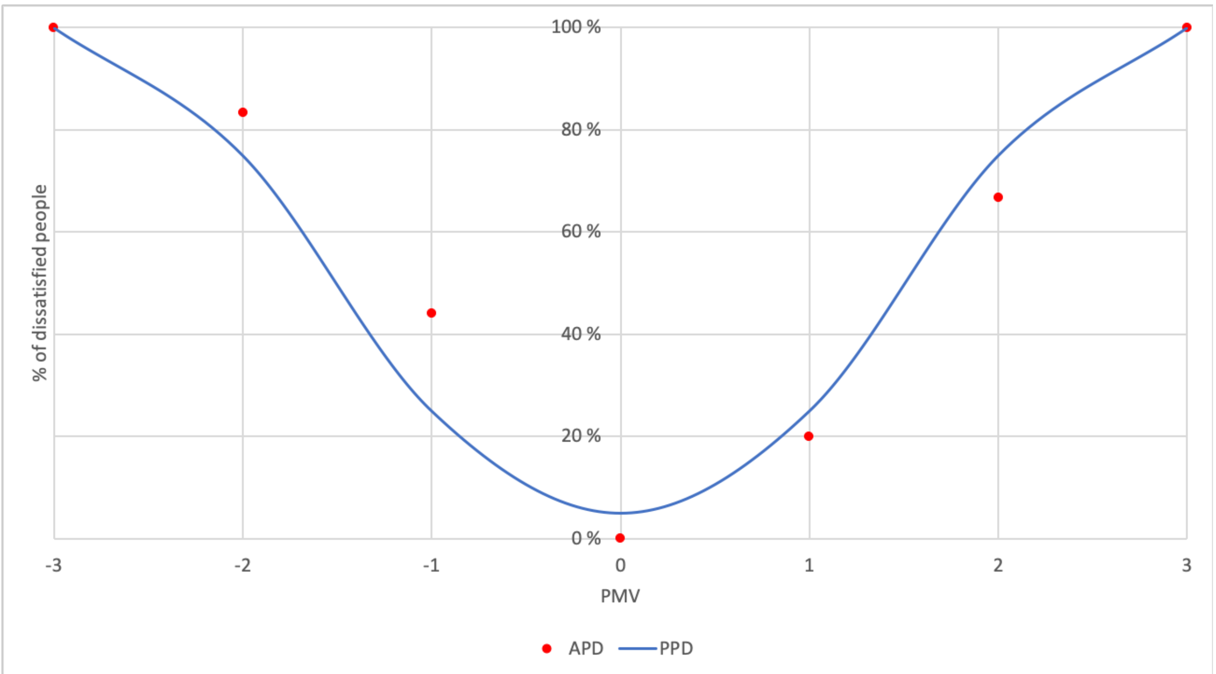


Figure 5.22: Predicted Percentage of Dissatisfaction and Actual Percentage of Dissatisfaction

The investigation of the thermal environment reveals a wide variety of how the pupils perceive the thermal conditions. Nevertheless, the centralization around "neutral," seen in figure 5.19, indicates that the temperature is set on a temperature the majority find comfortable (PMV [-1, 1]), which is the main finding from this investigation.

## 5.5 $CO_2$ prediction by use of machine learning

In this section, predicting carbon dioxide in a classroom using machine learning will be presented and discussed. The prediction will be visualized together with the real(measured) output values of carbon dioxide. By this, the correlation is obvious.

### 5.5.1 Uncertainties

The data collected to use in the model is limited, reasoning COVID-19 and lock down of schools in Norway. It has influenced the ability to further develop the model and its accuracy. The data set used in the prediction only consists of 52 data points, which is not enough data to train the model to make a good prediction. Therefore, the results from this section can not be used to conclude, but it gives an indication for if ML can be further used in predicting indoor air quality based on carbon dioxide.

### 5.5.2 The prediction by use of Random Forest and AdaBoost

In figure 5.23 and 5.24, the result of the prediction is presented. The vertical axis is the carbon dioxide level measured in ppm, and the horizontal axis is time, measured in minutes. The blue line represents the real measured level of carbon dioxide, and the red dots represent the 25 % of test data, which are predicted by the algorithms. The remaining 75 % of data is utilized for training the model. The data set used in the model consisted of 52 data points. It resulted in 13 points, which was predicted by the model.

To evaluate the accuracy of the two algorithms, the errors of how much the model is making mistakes in the prediction. The original target will be compared to the predicted values by evaluation MSE (Mean Squared Error), MAE (Mean Absolute Error), and $R^2$ (Coefficient of determination). The three model evaluation metrics are listed in table 5.15. The accuracy of the prediction based on the metrics is both evaluated as good, but not perfect. The limited amount of data impacts the models' sensitivity to make better predictions. Based on the evaluation of the metrics, Random Forest makes a better prediction of the two algorithms.

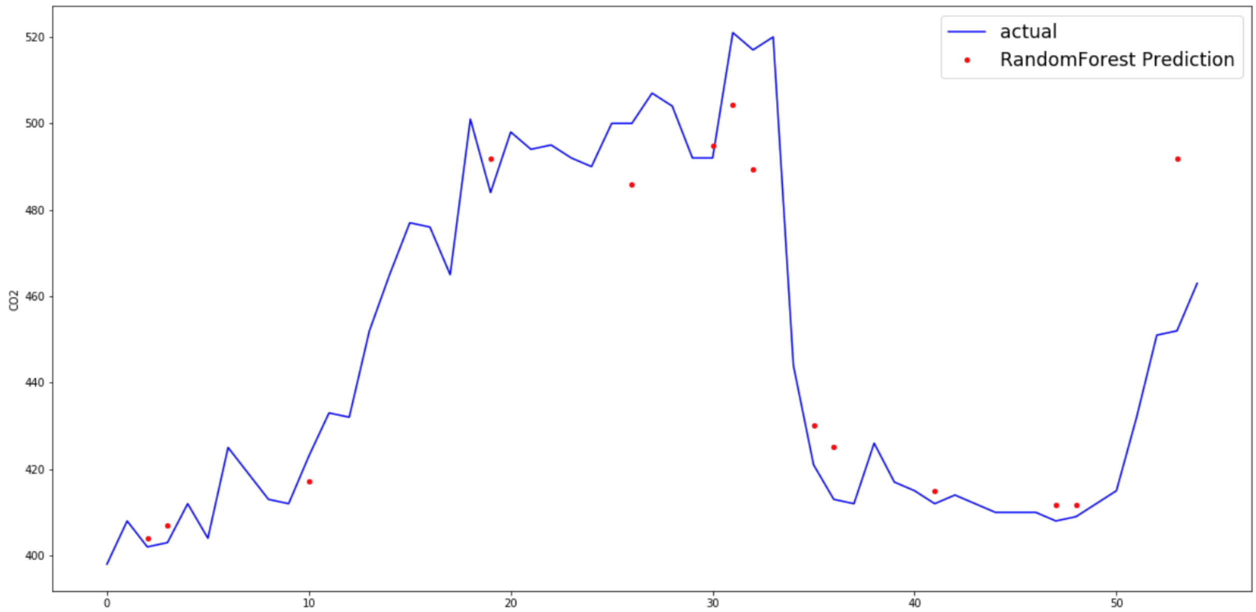


Figure 5.23: Result of prediction by use of Random Forest prediction

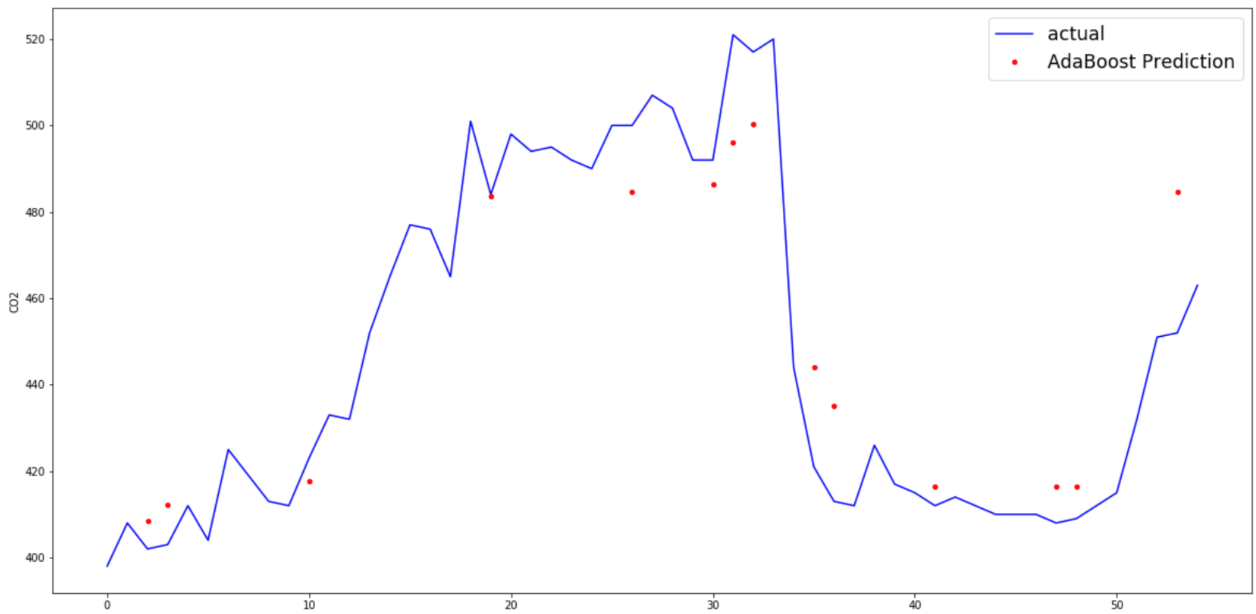


Figure 5.24: Result of prediction by use of Random Forest prediction

Table 5.15: Evaluation metrics for the two different prediction algorithms, Random Forest and AdaBoost

| | **Random Forest** | **AdaBoost** |
|---|---|---|
| MSE | 229.9 | 253.4 |
| MAE | 10.8 | 13 |
| $R^2$ | 0.85 | 0.80 |

The result based on the limited amount of data, it is not statistically possible to conclude if the model can make a satisfactory prediction. However, the result gives a good indication for if it is a method that should be tested and worked with further, to predict the level of carbon dioxide in a room. The correlation between the actual value and the predicted value indicates that the model, with better data, can be utilized to predict the carbon dioxide level inside a classroom.

The importance of each feature included in the model is seen in table 5.16 and 5.17. The relative humidity is the feature that has the greatest influence on the prediction. For Random Forest, temperature and occupants have approximately equal importance. With AdaBoost, the temperature is of higher importance than occupants. With more data and a longer time frame than two hours, it could have been functional to implement more inputs. For instance, the model could make a better prediction if it was provided with outdoor conditions, like relative humidity, temperature, and carbon dioxide. It could easily be done by implementing extra columns and expand the code which reads the imported file, to read the additional data. It was not done because the outdoor conditions were quite steady, and therefore, more features would not impact the prediction.

Table 5.16: The importance of features included in the model, Random Forest

| **Features** | **Feature importance** |
|---|---|
| RH% | 0.880770 |
| Temperature | 0.064045 |
| Occupants | 0.055185 |

Table 5.17: The importance of features included in the model, AdaBoost

| **Features** | **Feature importance** |
|---|---|
| RH% | 0.763644 |
| Temperature | 0.162800 |
| Occupants | 0.073555 |

## 5.6 Evaluation of measures implemented in January 2020, based on the result from field measurements, Interviews, and questionnaires

Based on the results presented, the measures taken to improve the indoor environment will be discussed. There is both quantitative and qualitative analysis used in the evaluation. Additionally, the subjective input from the interviews must be taken into account as well. Each school will be evaluated by itself, before a total evaluation of the project will be presented. In table 5.18, the measures which could be evaluated during the heating season are summarized, with the location, affected parameter, and a short comment regarding if the measure was successful or other comments. Measures implemented to improve the cooling season is not commented because it has not been investigated in this study.

### 5.6.1 Stabbursmoen School

Stabbursmoen school was the school that had most measures implemented in January 2020. The biggest measure taken regarding cost was replacing old incandescent fixtures with new led fixtures. By the feedback among the employees, it is also the most noteworthy measure taken. There has been said that this measure alone improves the experience of staying inside the school. There are no links from the questionnaire among the pupils that can be drawn directly to indicate if the measure has improved the indoor environment. Headache and dizziness are health-related problems that can occur with poor lighting, but they were quite similar for 2019 and 2020 and not deviating from the reference value. By the interviews, 50 % of the respondents said they were troubled with headache, compared to 0 % in 2020. This can be an indication that the measure has been improved.

The second extensive upgrade for Stabbursmoen was to implement a Swegon compact classroom aggregate in the room with the poorest air quality, Blåsal. This measure has had mixed feedback among the employees. The main opinion is that the aggregate improves the overall air quality in the room, but at the expense of thermal comfort. It is said that the aggregate generates local draught, so the pupils place as far away from the aggregate as possible. Also,

Table 5.18: Summery of the implemented measure, location, affected parameter and evaluation

| Measure | Location of measure | Affected parameter | Comment |
|---|---|---|---|
| Cut of setback for set point temperature of the ventilation system during nights and weekends | Stabbursmoen and Sunnland | Thermal conditions | Successful measure |
| Replace of incandescent fixtures to new led fixtures | Stabbursmoen | Lightning | Successful measure |
| Implementation of external Swegon compact classroom aggregate | Stabbursmoen, and<br>Sunnland (2018) | Air quality<br>Thermal conditions | Successful measure for air quality<br>Can influence the thermal conditions negatively |
| Establish the possibility to open all windows associated with a utilized area | Stabbursmoen | Air quality<br>Thermal conditions | Successful measure for air quality<br>Can influence the thermal conditions negatively |
| Rearrange the placements of pupils' desks to avoid local thermal discomfort | Sunnland | Thermal conditions | Not efficient |
| During all types of breaks, all pupils should leave critical rooms, so full venting if rooms can be made possible | All | Air quality<br>Thermal conditions | The results indicates positive impact |
| In the end of a school day, teachers should look over that radiators are not manually turned off | All | Thermal conditions | The results indicates positive impact |
| During the day, radiators with thermostat should be controlled if they are set to the right | All | Thermal conditions | The results indicates positive impact |

it is said that the room is too cold. During the field measurements, this matter was frequently discussed with the operator at the school, and it was communicated that the commissioning of the aggregate was high prioritized. It is believed that the thermal discomfort experienced in the room improved after the implementation, especially considering the thermal comfort study conducted in this room. There was not an astonishing result of discomfort among the pupils. Also, the velocity meter did not measure unusual high draught (>0.5 m/s), which indicates that the situation has improved since implementation. Both the carbon dioxide level and low temperatures have decreased from the measurements, and it is an improvement. This measure has improved indoor air quality.

The cut of a setback for set-point temperature during nighttime and weekends seems to have diminished temperature fluctuations. It is mentioned in the interviewees by some that temperatures in the morning are more comfortable now than before. The operator has said that the cut of setback has not impacted the use of energy for the school. The questionnaire shows fewer students who find the temperature too cold, but a higher number of pupils find the school's temperature too hot. It can be an effect of the cut of the setback for the set-point temperature. Hence the temperature is higher in the morning when the pupils arrive at school. The measurements may indicate that the temperature is set to high after the change has been made, and this should be regulated. Too high temperatures affect productivity and tiredness for the occupants. It is two health-related problems that have a negative development, based on the questionnaire, which may indicate that the temperature is set too high.

### 5.6.2 Sunnland School

Sunnland school was already implemented with four Swegon compact classrooms aggregates, before the start of this project. It is believed that this measure improved the indoor air quality already before the first measurements of 2019. The overall results from the field measurements at Sunnland school indicate that the indoor air quality in the case rooms is mostly fine. There are exceptions, for example, room 207 has had an increase of 23 % for values 1000 ppm of carbon dioxide, and relative humidity below 20 % has had a significant increase for room 108 and room 207. However, the result from the interviews and the questionnaire is not comprehensive with this result. The cause of this will be discussed later on in the section.

The measure, cut off the setback for set-point temperature during night and weekend, has had good feedback from the teachers. From the interviews, it has been noticed an improvement. It is not as cold as it used to be in the morning hours. However, the general opinion seems to be that it is still too cold. The average score for the thermal conditions has deteriorated from 6.8 to 8.4 (scale from 1-10, where 1 = perfect conditions). From the questionnaire, the ratings from the students do not deviate from the reference value, and there are no comparable values from 2019, making it difficult to evaluate whether the pupils find the thermal conditions better.

Reasoning local thermal discomfort from radiators and classroom aggregates, it was suggested by the project group that to rearrange the desks in the classrooms in such a matter that the influence from these sources would be minimized. The teachers attempted it, but the result ended with pupils moving the desks back to the discomfort sources. This measure was not successful for Sunnland school, but it could work for other schools with the same problem if the classroom area is large enough.

The measure of actively using blinds during the cooling season has not been tested because the field measurements were executed during the heating season, and overheating by radiation from the sun is not a problem for a typical winter in Norway.

Although the result from the field measurements can indicate that the air quality and thermal conditions are moderately satisfactory, especially compared to Stabbursmoen, the result interviews and questionnaires are not coherent. The result from the questionnaire concerning health symptoms, seen in figure 5.3, clearly states that the pupils are affected. There has not been discovered a scientifically proven reason for the conflicting results. Therefore the discussion will be based on assumptions and the overall impression. One reason could be that the test rooms included in the study were chosen wrongly. It is based on a discussion from an information meeting with the project group and employees from Sunnland. During the meeting, it was asked why the rooms were included in the study when other rooms were experienced as more problematic. The teachers who were interviewed were teaching in other rooms than the test rooms, which implies that their answers can not be representative of the test rooms. It is, therefore, reasonable to believe that there might have been chosen the wrong rooms to include in the study, and the results do not describe the overall indoor environment condition for the school.

Also, Sunnland school is the oldest school in Trondheim and has been waiting for a new school building since 2013. It is reasonable to think that the school's employees are quite tired of waiting for improvements and have to work in unfavorable conditions for a severe matter of time. It might influence the subjective meaning of the school and their attitude towards indoor environmental problems. It is believed that implementing the classroom aggregates in 2018 has led to a significant improvement for indoor air quality and that it would have been beneficial for the result of this project if the first field measurements were conducted before the implementation.

### 5.6.3 Sørborgen School

From the findings in the study in 2019 [35], the conclusion was that Sørborgen school had a satisfactory indoor environment. Therefore, there were not implemented any measures to improve indoor air quality. From the new result, the level of carbon dioxide is very much satisfying. The mean concentration of carbon dioxide was measured to be around 450 ppm for all the included test rooms. It is well within the recommended value of a maximum of 1000 ppm. From the interviews, the average score for both air quality and thermal conditions has improved and is by far the school with the best perceived indoor environment. The answers from the questionnaire are as well superior. The response in 2020 is related to health problems within the reference values, except "itching, burning or irritation in the eyes." The responses related to the experienced indoor environment are also within (or better than) the reference-value, except for "noise or unease from co-pupils. The fact that the pupils find co-pupils disturbing can not directly be directed to the indoor environment but is more a pedagogical or behavioral problem.

According to the field measurements, it is likely to believe that too high temperature and low relative humidity are the main indoor environment problems for the school. Those two parameters are often related to each other. By decreasing the set point temperature, this problem would be resolved. The questionnaire regarding health symptoms has an excellent correlation with the reference. The one health problem which has a slightly higher occurrence than the reference value is "itching, burning or irritation in the eyes," which can be caused by the low humidity. Health symptoms (itchy eyes, dry mucous, eczema) related to low relative humidity did also occur among the employees in the new interviews. It is highly reasonable to think that there is a correlation between these findings.

Based on the findings from this study and last year's study, it is reasonable to say that the school does not suffer from a poor indoor environment. However, the operator should control and manage the temperature more frequently to improve and maintain good results.

### 5.6.4 General for all schools

The personal measures to be implemented by the school's perspective has had different outputs for the different case schools. The implementation success of these measures is strictly dependent on the management, employees, and the information communicated to the pupils. From the interviews, it appears that the deployment of efficient but straightforward measures, such as venting the room in breaks and not interfering with the radiators' thermostat, differs for the schools. More than one object from Sunnland had a negative attitude towards believing that these measures would have a real impact. For Sørborgen and Stabbursmoen, the frame of mind was more open to implementing the measures. It is believed that the positive attitude has improved the air quality and thermal conditions towards a better state. In addition, it was noticeable that Sørborgen and Stabbursmoen had more insight into which measures were implemented and discussed to improve the indoor environment.

Ideal, the measures should have been implemented autumn 2019, which was the initial plan, but due to a shortage in the budget, it had to be moved to January 2020. The field measurements, interviews, and questionnaires were executed in February and Mars the same year. It is a short amount of time to adjust to the changes, and it would have been beneficial to redo the interviews and questionnaire in Mai as well if the schools had not closed because of COVID-19. Also, because the study was executed during the heating season, there are no results that can indicate whether or not the measure of actively using blinds to avoid overheating during the cooling season has had an impact.

# Chapter 6

# Conclusion

In Norway, multiple schools with inferior indoor environment still operates even though rehabilitation or reconstruction is planned for. Some schools have even operated for more than a decade after the schools were listed as candidates for rehabilitation or reconstruction. The reason for this is budget constraints within the municipalities. Therefore, schools are put on hold. The literature states that an inferior indoor environment has a negative impact on children's health and may lead to health issues such as asthma and allergens. The situation where multiple schools have inferior indoor environment will therefore be associated with high social costs if the situation does not improve. This study shows that there are relatively simple measures that can be implemented to improve the indoor air quality and optimize the indoor environment. Further, the study shows that attention about these issues from the schools' top-level management and a staff that is engaged are essential factors of a successful implementation.

The evaluation of the results from the field measurements from 2020 and 2019 has proven that installing a Swegon compact classroom aggregate is an efficient measure to improve the air quality for rooms with low air supply. The cut of setback set-point temperature during night and weekends improves the thermal condition without compromising energy consumption.

The analysis of the interviews indicates that behavioral measures are dependent on the attitude and willingness to make improvements. Rearrangement of seating at Sunnland School was not a success. However, the outcome may have been different if a stricter discipline was enacted. Based on the interviews, the replacement of old incandescent fixtures with new led fixtures was a success at Stabbursmoen school. Further, the study shows a significant positive psychological impact of allowing all windows to be manually opened. The reason is believed to be that the occupants are then more in control of temperature regulations.

Random Forest prediction gave a moderately good prediction of carbon dioxide indoors. With further work on the Machine Learning model and a proper amount of training data, the conclusion is that it can be a beneficial tool to predict the air quality in a room, based on carbon dioxide.

This study has also shown the significance of using both quantitative and qualitative methodologies to evaluate indoor air quality, because the study only included a couple of rooms in each school for the field measurements. By interviewing the employees, it was possible to gain an overall impression of the indoor environment status for the whole school, and has been essential to evaluate the implemented measures.

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# Appendix A

# Fanger's PMV-PPD Equations

$$PMV = (0.352 * e^{0.042\frac{M}{A_{Du}}} + 0.032) * [\frac{M}{A_{Du}} * (1-\eta) - 0.35 * [43 - 0.061 * \frac{M}{A_{Du}} * (1-\eta) - p_a]$$

$$-0.42 * [\frac{M}{A_{Du}} * (1-\eta) - 50] - 0.023 * \frac{M}{A_{Du}}(44 - p_a) - 0.0014 * \frac{M}{A_{Du}}$$

$$*(34 - T_a) - 3.4 * 10^{-8} * f_{cl} * [(T_{cl} + 273)^4 - (T_{mrt} + 273)4] - f_{cl} * h_c * (T_{cl} - T_a)]$$

Where

$$T_{cl} = 35.7 - 0.032 * \frac{M}{A_{Du}} * (1-\eta) - 0.18 * l_{cl} * [3.4 * 10^{-8} * f_{cl} *$$

$$[(T_{cl} + 273)^4 - (T_{mrt} + 273)^4] + f_{cl} * h_c(T_{cl} - T_a]$$

Where

$$h_c = \begin{cases} 2.05 * (T_{cl} - T_a)^{0.25} > 10.4\sqrt{v} \rightarrow h_= 2.05(T_{cl} - T_a)^{0.25} \text{ (Free convection)} \\ 2.05 * (T_{cl} - T_a)^0.25 < 10.4\sqrt{v} \rightarrow h_c = 10.4\sqrt{v} \text{ (Forced convection)} \end{cases}$$

Where

$$f_{cl} = \begin{cases} I_{cl} < 0.5clo \rightarrow 1.0 + 0.2I_{cl} \\ I_{cl} > 0.5clo \rightarrow 1.05 + 0.1I_{cl} \end{cases}$$

The PPD equation is as follows:

$$PPD = 100 - 95 * e^{0.03353*PMV^4 + 0.2179*PMV^2}$$

**Abbreviations**

**PMV** = Predicted Mean Vote

**M** = Meatabolic rate production []kcal/h]

$\mathbf{A}_{Du}$ = Sirface area of human body [$m^2$]

**H** =Height of the occupant [m]

**W** = Weight of the occupant [kg]

$\eta$ = Mechanic efficiency

$\mathbf{P}_a$ = Water vapour pressure [mmHg]

$\mathbf{P}_g$ = Saturated vapour pressure [mmHg]

**W** = Relative air humidity [%]

$\mathbf{T}_a$ = Air temperature [°C]

$\mathbf{f}_c l$ = Clothing area factor; The ratio of the surface area of the clothed body to the surface area of the naked body

$\mathbf{T}_{cl}$ = Surface temperature of clothing [°C]

$\mathbf{T}_{mrt}$ = The mean radiant temperature [°C]

$\mathbf{h}_c$ = Convective heat transfer coefficient [kcal/$m^2$h°C]

$\mathbf{I}_c l$ =Thermal resistance of of clothing [1 clo = 0.155 $m^2$K/W]

$v$ = Relative air velocity [m/s]

**PPD** = Predicted Percentage of Dissatisfaction [%]

# Appendix B

# Test of sensors

The result from the test of sensors.

Date: 04.02.2020

Location: SINTEF Community, Høgskoleringen 7B, 7034 Trondheim

Attendee: Maren Pedersen and Solveig Askevold Ulsund, NTNU Supervisor: John Clauss, SINTEF

## B.1 Test of indoor air quality sensors

Figure B.1 (carbon dioxide), B.2 (temperature), and B.3 (relative humidity) presents the result from the test conducted in the climate chamber. The graphs are presented for each parameter, with each significant name. The sensors stabilizes around 12.10. The reference used is the values measured by the sensors in the room, seen in figure B.4. The standard deviation is calculated by subtracting the value of stable measurements from the the reference value and is found in table B.1. The following is to be considered for the test:

- ELMA-6 did not measure carbon dioxide
- ELMA-8 failed to start under the test
- CA-3 was setup with wrong start. Therefore, the sensor is running for a shorter amount of time than the rest and uses longer time to stabilize
- There was an shortage of sensor when the test was conducted. Hence, all of the sensors used in for the field measurements are not tested

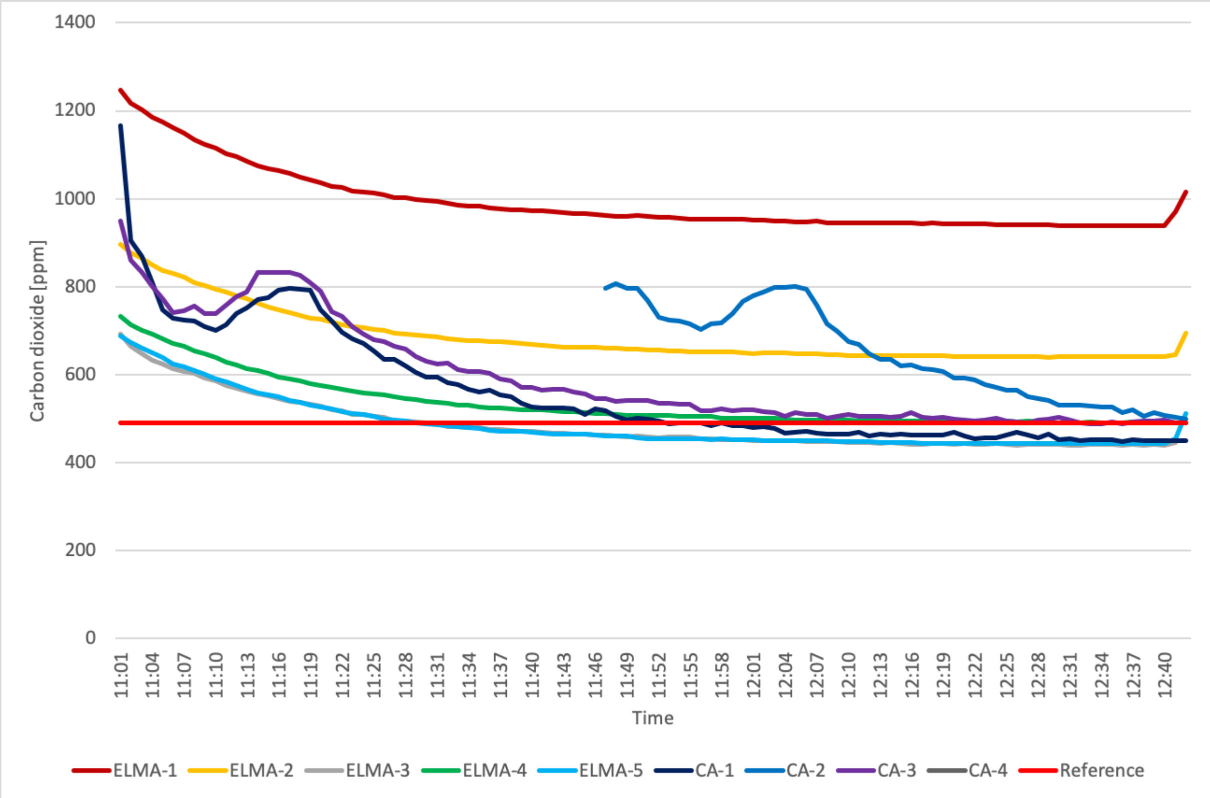


Figure B.1: Measured values for test of carbon dioxide

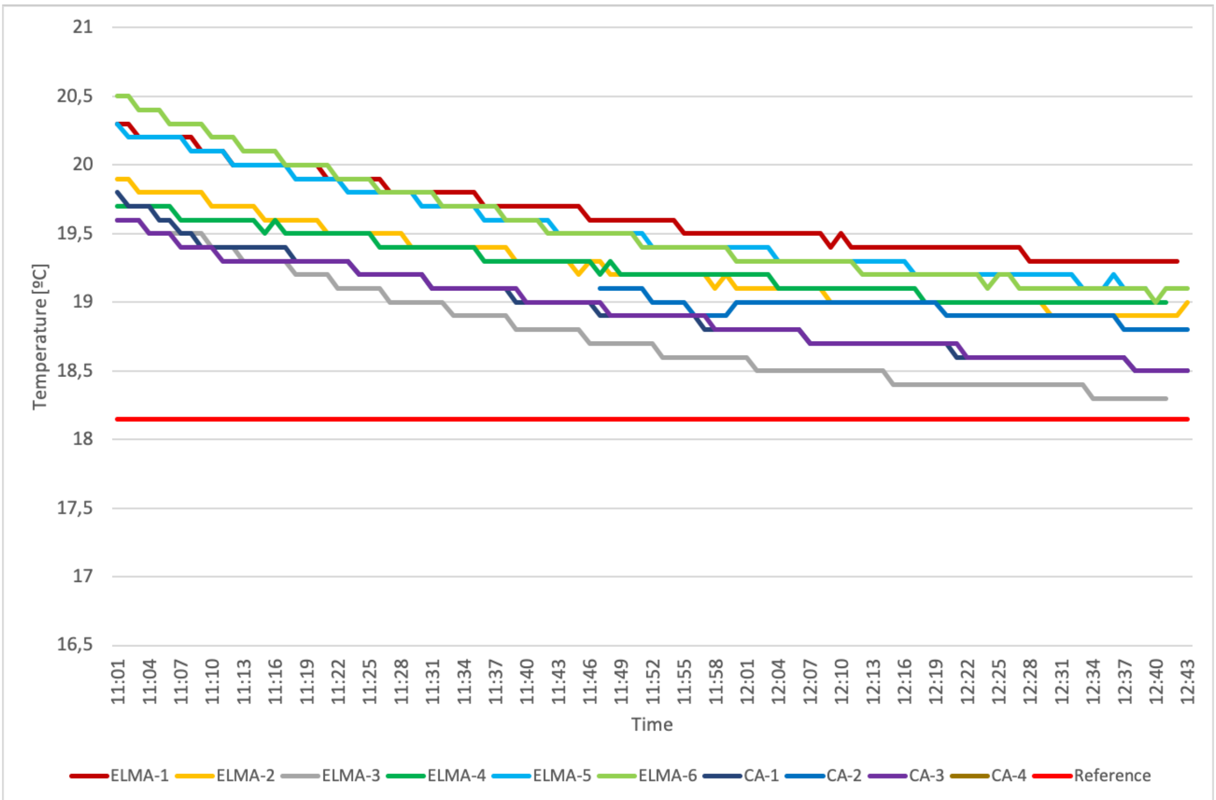


Figure B.2: Measured values for test of temperature

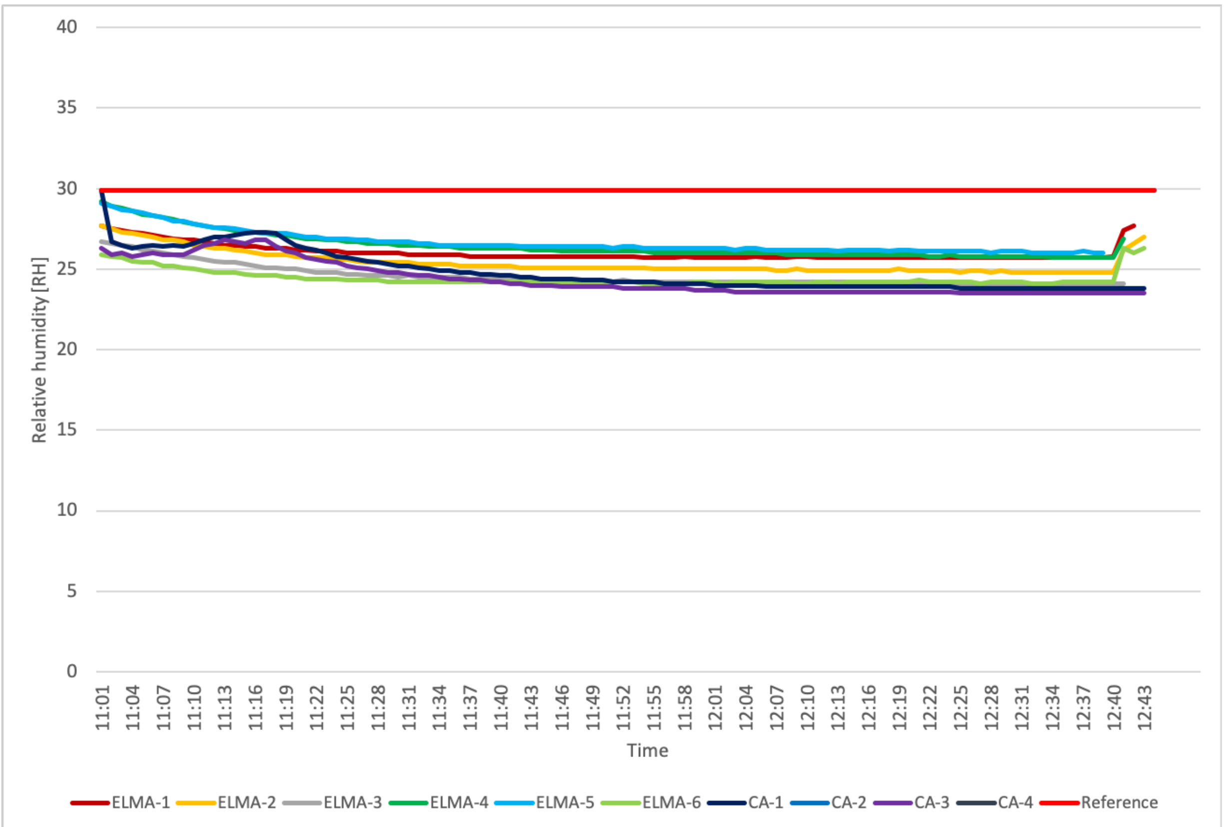


Figure B.3: Measured values for test of relative humidity


Figure B.4: Temperature for climate chamber

## B.2 Test of iButtons

Figure B.5 presents the measured values for the iButtons utilized in the study. The corrolation between the sensors is evaluated as satisfying and is not in need of adjustments.

Table B.1: Calculated standard deviation from the sensor-test

| **Sensor** | **Standard Deviation Carbon dioxide** *[ppm]* | **Standard Deviation Temperature** *[° C]* | **Standard Deviation Relative humidity** *[%]* |
|---|---|---|---|
| ELMA-1 | 449 | 1.15 | -4.2 |
| ELMA-2 | 152 | 0.75 | -5.1 |
| ELMA-3 | -50 | 0.25 | -5.8 |
| ELMA-4 | 2 | 0.85 | -4.2 |
| ELMA-5 | -47 | 1.05 | -3.9 |
| ELMA-6 | | 0.95 | -5.8 |
| CA-1 | -37 | 0.45 | -6.1 |
| CA-2 | 40 | 0.75 | 0 |
| CA-3 | 6 | 0.45 | -6.4 |
| CA-4 | -10 | 0.15 | -6.1 |

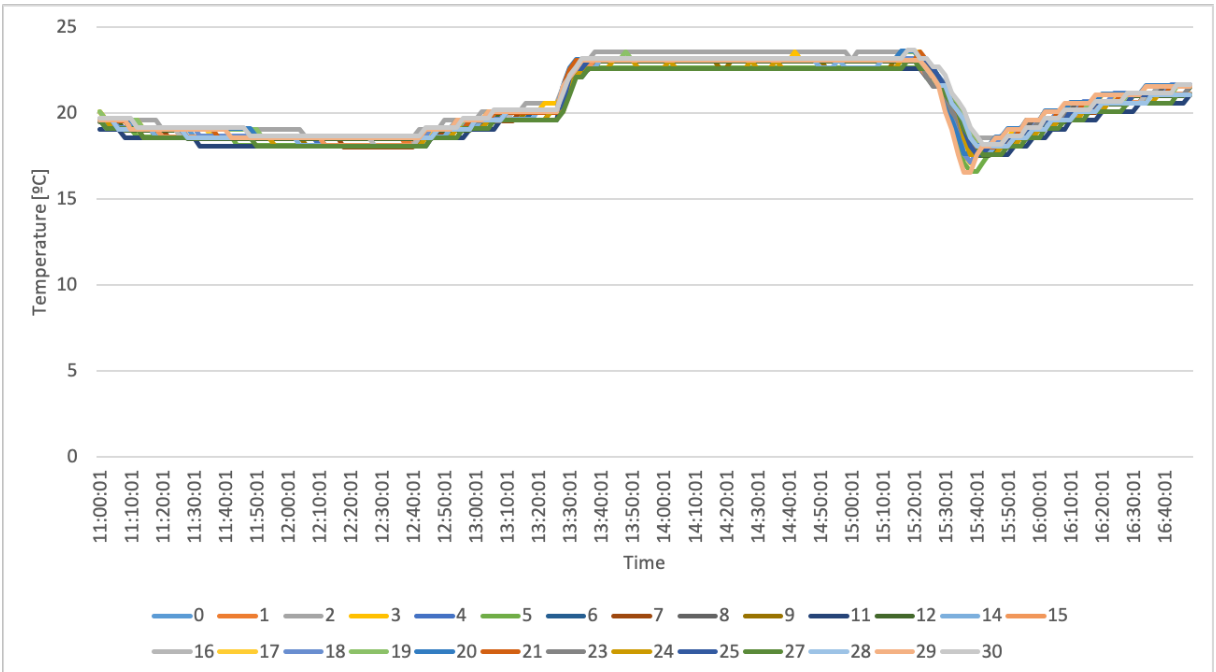


Figure B.5: Measured values for iButtions

# Appendix C

# Ineterview Guide of 2020

The interview guide from 2020, developed by SINTEF. The interview guide only exists in a Norwegian version.

# Skoler på vent – hvordan står det til med inneklima?

Skole:

- ☐ Sunnland
- ☐ Stabbursmoen
- ☐ Sørborgen

Ansatt som:

- ☐ Rektor
- ☐ Fagleder/avdelingsleder
- ☐ Verneombud
- ☐ Lærer
- ☐ Driftspersonell
- ☐ Helsesøster

På en skala fra 1-10, hvordan opplever du luftkvaliteten på din skole nå?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

God Tilfredsstillende Dårlig

På en skala fra 1-10, hvordan opplever du temperaturforholdene på din skole nå?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

God Tilfredsstillende Dårlig

Hvilken temperatur er det i aktuelle rom nå?___________________________________________

Hvilken temperatur burde det være?/ Hva er din komfort-temperatur?_________________

Vet dere hvilke tiltak som har blitt gjennomført på skolen?_____________________________

________________________________________________________________________________

Har tiltakene gjennomført nå høsten/vinteren 2019 påvirket inneklima?__________________

På hvilken måte?_________________________________________________________________

________________________________________________________________________________

Har det siden sist vi snakket sammen (i fjor på denne tiden) vært fokus på opplæring og informasjon, hvordan ansatte og elever skal forholde seg til regulering av temperatur og ventilasjon i klasserommene? _________________________________________________

Hvilken informasjon og hvordan ble den formidlet?____________________________________

Har det vært fokus på hva dere; ansatte og elever, selv kan gjøre for å oppnå bedre inneklima?
________________________________________________________________________________

Hvordan har det (eks. inneklimatips på poster) blitt tatt i mot av elever, lærere og ansatte?___________________________________________________________________________

På en skala fra 1-10, hvordan opplever du lydforholdene på din skole nå?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

God Tilfredsstillende Dårlig

Hvis ubehag; hva forårsaker ubehag og støy nå? (ventilasjon, ytre forhold, elever, etterklangstid)

________________________________________________________________________________

______________________________________________________________________________

Har du opplevd noen av følgende helseproblemer eller ubehag siste 2 år:

- ☐ Astma
- ☐ Allergi
- ☐ Hyppige forkjølelser
- ☐ Vondt i hodet over lengre tid
- ☐ Kløende øyne
- ☐ Tørre slimhinner
- ☐ Eksem
- ☐ Konsentrasjonsproblemer
- ☐ Trøtthet og utmattelse
- ☐ Annet som du tror kan ha sammenheng med dårlig inneklima ………………………………

Har dette endret seg nå etter gjennomføring av tiltak?_________________________________

Hvilken årstid er det best inneklima på din skole? ☐ Vinter ☐ Vår ☐ Høst

Hvilken årstid er det verst inneklima på din skole? ☐ Vinter ☐ Vår ☐ Høst

Har dette endret seg nå etter gjennomføring av tiltak?_________________________________

Hvorfor tror du at det er slik?………………………………………………………………………………

Hva mener du påvirker inneklimaet mest på din skole?

- ☐ Ventilasjonsløsning
- ☐ Oppvarmingsløsning
- ☐ Belysningsløsning
- ☐ Romvolum og takhøyde
- ☐ Avstand til dagslysflate og vinduer
- ☐ Renhold
- ☐ Bruk av innesko
- ☐ Annet:……………………………………………………………………………… ………………………………

Har dette endret seg nå etter gjennomføring av tiltak?_________________________________

Har du inntrykk av at inneklima på din skole påvirker de ansatte og deres:

- ☐ Termisk komfort
- ☐ Helse
- ☐ Psykososialt arbeidsmiljø
- ☐ Annet

  På hvilken måte?_______________________________________________________

- ☐ Konsentrasjonsevne og produktivitet

  Hvordan og i hvilken grad?

  Årsak? (støy, luftkvalitet, annet..?)

- ☐ Trøtthet og utmattelse

  Hvordan og i hvilken grad?____________________________________________

Har du inntrykk av at inneklima på din skole påvirker elevenes

- ☐ Helse
- ☐ Læring

  På hvilken måte?______________________________________________________

- ☐ Konsentrasjonsevne og læringsresultater

  Hvordan og i hvilken grad?

  Årsak? (støy, temperatur, luftkvalitet, annet..?)______________________________

- ☐ Trøtthet og utmattelse

  Hvordan og i hvilken grad?

  Når på dagen?

  - før eller etter lunch ☐ Før ☐ Etter
  - før eller etter utetid ☐ Før ☐ Etter

Har dette endret seg nå etter gjennomføring av tiltak?______________________________

På hvilken måte?____________________________________________________________

Er det annet du ønsker å tilføye som påvirker inneklima, helse og læringsmiljø på din skole som kan ha sammenheng med inneklima og vedlikehold av skolen?

___________________________________________________________________________

___________________________________________________________________________

*Takk for at du tok deg tid til å svare på spørsmålene.*

# Appendix D

# Questionnaire

The questionnaire

Mitt inneklima

English; My indoor environment), developed by NAAF (in Norwegiean).

**Hvordan opplever du inneklimaet på skolen din?**
Vi ønsker å ha et godt inneklima på skolen vår. Inneklimaet er viktig for helse, trivsel og læring.Vi vil gjerne vite hva du synes, og håper du vil svare på noen spørsmål. Du skal ikke oppgi navn, og ingen får vite hva du har svart. Når elevene har svart på undersøkelsen, lages det en rapport som skolen kan bruke for å opprettholde et godt inneklima eller forbedre inneklimaet ved skolen din.

Takk for at du hjelper til!

**<u>Bakgrunnsspørsmål</u>**

**Klassetrinn**

Drop down liste – klassetrinn: 4, 5, 6, 7,8,9,10,VDG1, VDG2, VDG3

**I hvilken skolebygning er du mest?**

Listen er basert på de navnene på bygningene som rektor har satt opp. Du kan bare velge ett bygg

- ☐ Bygning 1
- ☐ Bygning 2
- ☐ Bygning 3

**Kjønn**

- ☐ Jente
- ☐ Gutt

**Hvordan synes du luften, støyen, temperaturen og lyset har vært på skolen din de siste 3 månedene?**

**Har du i skoletiden vært plaget av:**

| | Ja, ofte (hver uke) | Ja, iblant | Nei, aldri | Vet ikke |
|---|---|---|---|---|
| Trekk av kald luft | ☐ | ☐ | ☐ | ☐ |
| For høy romtemperatur | ☐ | ☐ | ☐ | ☐ |
| Varierende romtemperatur | ☐ | ☐ | ☐ | ☐ |
| For lav romtemperatur | ☐ | ☐ | ☐ | ☐ |
| Innestengt (dårlig) luft | ☐ | ☐ | ☐ | ☐ |
| Tørr luft | ☐ | ☐ | ☐ | ☐ |
| Ubehagelig/vond lukt | ☐ | ☐ | ☐ | ☐ |
| Statisk elektrisitet som gjør at du får støt | ☐ | ☐ | ☐ | ☐ |
| Støy | ☐ | ☐ | ☐ | ☐ |
| Støv og skitt | ☐ | ☐ | ☐ | ☐ |
| For svak belysning fra taklampene | ☐ | ☐ | ☐ | ☐ |
| For skarp belysning fra taklampene | ☐ | ☐ | ☐ | ☐ |
| Skarpt lys fra solen | ☐ | ☐ | ☐ | ☐ |

| | | | | |
|---|---|---|---|---|
| Plagsom varme fra solskinn gjennom vinduene | ❑ | ❑ | ❑ | ❑ |
| Plagsom varme fra ovner i nærheten | ❑ | ❑ | ❑ | ❑ |
| Kaldt på gulvet | ❑ | ❑ | ❑ | ❑ |
| Påvirker noen av disse faktorene dine skoleprestasjoner negativt? | ❑ | ❑ | ❑ | ❑ |

**Noen spørsmål om helseplager**

**Har du i løpet av de siste 3 månedene merket noen av de følgende plagene når du er på skolen?**

| | Ja, ofte (hver uke) | Ja, iblant | Nei, aldri | Vet ikke |
|---|---|---|---|---|
| Trøtthet | ❑ | ❑ | ❑ | ❑ |
| Hodepine | ❑ | ❑ | ❑ | ❑ |
| Tung i hodet | ❑ | ❑ | ❑ | ❑ |
| Svimmelhet/ørhet | ❑ | ❑ | ❑ | ❑ |
| Konsentrasjonsproblemer | ❑ | ❑ | ❑ | ❑ |
| Kløe, svie, irritasjon i øynene | ❑ | ❑ | ❑ | ❑ |
| Irritert, tett eller rennende nese | ❑ | ❑ | ❑ | ❑ |
| Heshet/tørrhet i hals | ❑ | ❑ | ❑ | ❑ |
| Hoste | ❑ | ❑ | ❑ | ❑ |
| Tørr, rød eller irritert hud i ansiktet | ❑ | ❑ | ❑ | ❑ |
| Flassing/kløe i hodebunnen | ❑ | ❑ | ❑ | ❑ |
| Tørr, kløende hud på hendene | ❑ | ❑ | ❑ | ❑ |

**Noen spørsmål om allergiske sykdommer**

| | Ja/Nei/Vet ikke | Nei |
|---|---|---|
| Har du hatt eller har du astma? | ❑ | ❑ |
| Har du hatt eller har du allergi? | ❑ | ❑ |
| Har du hatt eller har du eksem? | ❑ | ❑ |

**<u>Hvordan trives du på skolen?</u>**

| | Ja, oftest | Ja, iblant | Nei, sjeldent | Nei, aldri | Vet ikke |
|---|---|---|---|---|---|
| I timene? | ❑ | ❑ | ❑ | ❑ | ❑ |
| I friminuttene? | ❑ | ❑ | ❑ | ❑ | ❑ |
| Har du noen å være sammen med på skolen? | ❑ | ❑ | ❑ | ❑ | ❑ |

# Appendix E

# Survey: Thermal Comfort

Survey for thermal comfort envestiogation

## Trivsel i klasserom - elevundersøkelse

Jeg er en: Jente ☐ Gutt ☐

### 1) Hvordan føler jeg meg akkurat nå?

| Veldig kald | Kald | Litt kald | OK | Litt varm | Varm | Veldig varm |
|---|---|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

### 2) Kryss av i boksen du er enig med

AKKURAT NÅ, I KLASSEROMMET

Jeg ønsker det mye kaldere ☐ ❄❄❄

Jeg ønsker det kaldere ☐ ❄❄

Jeg ønsker det litt kaldere ☐ ❄

Jeg synes det er akkurat passe varmt ☐

Jeg ønsker det litt varmere ☐ ☀

Jeg ønsker det varmere ☐ ☀☀

Jeg ønsker det mye varmere ☐ ☀☀☀

### 3) Føler du deg komfortabel med temperaturen akkurat nå?

Ja ☐ Nei ☐

### 4) Har du på deg en genser

Ja ☐ Nei ☐

## Appendix F

# Machine Learning code for prediction of air quality, based on $CO_2$

The following code is used when predicting air quality, based on carbon dioxide. The software used is Jupyter and the language is Phyton.

Type *Markdown* and LaTeX: $\alpha^2$

In [1]:
```
import pandas as pd
```

# Title

In [2]:
```
# "#"legger til tittel - insert - markdown "##" legger til liten tekst
```

## 1. import data and data exploration

Take a look about data. The data has separator '\t', so 'read_table' should be used to import.

In [1]:
```
= pd.read_table('') #importerer fil. Bytter ut filnavn for å hente ny fil.
```

In [2]:
```
df.head()
```

Write a code to describe data, find the missing value,data type,unique data et al.

In [3]:
```
def description(df):
    summary = pd.DataFrame(df.dtypes,columns=['dtypes']) #get the type
    summary['Missing'] = df.isnull().sum().values #the count of missing va
    summary['Uniques'] = df.nunique().values #the count of non-unique valu
    summary['First Value'] = df.iloc[0].values
    summary['Second Value'] = df.iloc[1].values
    summary['Third Value'] = df.iloc[2].values
    return summary

description(df)
```

In [4]:
```
    #df['Occupants']
    #summary = pd.DataFrame(df.dtypes,columns=['dtypes']) #get the type
    #df.dtypes forteller hvilket type tall kolonnen inneholder
```

In [5]:
```
import matplotlib.pyplot as plt
```

In [6]:
```
df['Occupants'].plot(kind = 'hist')
```

In [ ]:
```
df['SootM'].plot(kind = 'line')
```

In [ ]:
```
df['Temperature'].plot(kind = 'line')
```

In [7]:
```
df['RH%'].plot(kind = 'line')
```

In [8]:
```
df['CO2'].plot(kind = 'line')
```

### 2. Encoding the 'Occupants' data to: 0-1

In [9]:
```
from sklearn.preprocessing import MinMaxScaler
```

Convert the 'Occupants' data to 0 - 1

In [10]:
```
df['Occupants'] = MinMaxScaler().fit_transform(df['Occupants'].values.resha
```

In [ ]:
```
df.sample(10)
```

### 3. Split the dataset

In [ ]:
```
from sklearn import model_selection
```

Train data: 75%; Test data: 25%; Split data with shuffling and according to the index

In [ ]:
```
train_idx,test_idx = model_selection.train_test_split(df.index,
                                                      test_size = 0.25,
                                                      shuffle = True,
                                                      random_state = 1
                                                     )
```

In [11]:
```
x_train = df[df.columns[0:4]].iloc[train_idx]
y_train = df['CO2'].iloc[train_idx]

x_test = df[df.columns[0:4]].iloc[test_idx]
y_test = df['CO2'].iloc[test_idx]

print('rate of train:',len(x_train)/(df.shape[0]),'\n'
      'rate of test :',len(x_test)/(df.shape[0]))
```

## 4. Build predition model

In [12]:
```
import numpy as np
from sklearn.metrics import mean_squared_error,mean_absolute_error,r2_scor
from sklearn.ensemble import RandomForestRegressor
from sklearn.ensemble import AdaBoostRegressor
#from sklearn.gaussian_process import GaussianProcessRegressor
from sklearn.externals import joblib
```

```
/opt/anaconda3/lib/python3.7/site-packages/sklearn/externals/joblib/__ini
t__.py:15: DeprecationWarning: sklearn.externals.joblib is deprecated in
0.21 and will be removed in 0.23. Please import this functionality direct
ly from joblib, which can be installed with: pip install joblib. If this
warning is raised when loading pickled models, you may need to re-seriali
ze those models with scikit-learn 0.21+.
  warnings.warn(msg, category=DeprecationWarning)
```

### 4.1 RandomForestRegressor

In [13]:
```
RFR = RandomForestRegressor(n_estimators = 100,random_state = 1)
```

Fit model and get the importance of each feature

In [14]:
```
RFR.fit(x_train,y_train)
f_importance_RF = pd.DataFrame({'features':x_train.columns,
                                'feature_importances':RFR.feature_importan
```

In [15]:
```
f_importance_RF
```

Evaluate the predict results

In [16]:
```
Y_pred_RF = RFR.predict(x_test)
print('MSE:',mean_squared_error(Y_pred_RF,y_test))
print('MAE:',mean_absolute_error(Y_pred_RF,y_test))
print('R2:',r2_score(Y_pred_RF,y_test))
```

Visualize the results

In [17]:
```
import matplotlib.pyplot as plt
```

In [18]:
```
plt.figure(figsize = (20,10))
plt.plot(df.index, df['CO2'], 'b-', label = 'actual')
#plt.plot(x_test.index, y_test, 'g^', label = 'test data',markersize = 4)
plt.plot(x_test.index, Y_pred_RF, 'ro', label = 'RandomForest Prediction',r
plt.legend(fontsize = 'xx-large')
plt.ylabel('CO2')
plt.show()
```

### 4.2 AdaBoostRegressor

In [19]:
```
ABR = AdaBoostRegressor(n_estimators = 300,random_state = 2)
ABR.fit(x_train,y_train)
f_importance_AB = pd.DataFrame({'features':x_train.columns,
                                'feature_importances':ABR.feature_importan
```

In [20]:
```
f_importance_AB
```

Evaluate the predict results

In [21]:
```
Y_pred_AB = ABR.predict(x_test)
print('MSE:',mean_squared_error(Y_pred_AB,y_test))
print('MAE:',mean_absolute_error(Y_pred_AB,y_test))
print('R2:',r2_score(Y_pred_AB,y_test))
```

Visualize the results

In [22]:
```
plt.figure(figsize = (20,10))
plt.plot(df.index, df['CO2'], 'b-', label = 'actual')
#plt.plot(x_test.index, y_test, 'g^', label = 'test data',markersize = 4)
plt.plot(x_test.index, Y_pred_AB, 'ro', label = 'AdaBoost Prediction',mark
plt.legend(fontsize = 'xx-large')
plt.ylabel('CO2')
plt.show()
```

# Appendix G

# Measures: Stabbursmoen

A presentation (Norwegian) of known the indoor environment problems for each room, suggested measures and implemented measured in January 2020 for Stabbursmoen school. The list of measures is developed by all collaborative partners in the project.

# Stabbursmoen skole

| Rom | Problemer | Forslag løsninger |
|---|---|---|
| SFO | • Ventilasjon, høyfrekvent støy dominerer. Verdier over anbefalinger gitt i NS 8175:2012. Elever og lærere klager også over støy, både fra tekniske anlegg, men også annen intern støy.<br>• Dårlig belysning, ingen dagslys. | • Innregulering av ventilasjonsanlegget kan både forbedre luftkvalitet og redusere støy.<br>• Skifte til bedre kunstig belysning. |
| 321A | • For høy temperatur i perioder.<br>• Manglende rutiner for lufting i pauser?<br>• For dårlig ventilasjonskapasitet når alle elever er tilstede. Bekreftes av spørreundersøkelse. Det er 27 elever når alle er tilstede.<br>• Ventilasjonsstøy, midlere frekvenser dominerer. Verdier over anbefalinger gitt i NS 8175:2012. | • Redusere settpunkt for romoppvarming.<br>• Lufte i pauser ved behov.<br>• Angi maksimalt antall elever per rom basert på målinger.<br>• Innregulering av ventilasjonsanlegget kan både forbedre luftkvalitet og redusere støy. |
| Blåsal | • For dårlig ventilert sett i sammenheng med personbelastning. Bekreftes av spørreundersøkelse.<br>• Problemer med for lav temperatur på grunn av lufting i pauser.<br>• Ventilasjon, lavfrekvent støy dominerer. Verdier over anbefalinger gitt i NS 8175:2012. | • Angi maksimalt antall elever per rom basert på målinger.<br>• Gjøre innledende prøving for å måle hvor mye luft som kommer ut av tilluftsventiler<br>• Innregulering av ventilasjonsanlegget kan både forbedre luftkvalitet og redusere støy.<br>• Lufterutiner i pauser – "stormlufting" (stor vindusåpning, kort tidsperiode) gir effektivt luftutskifting uten å senke temperaturen vesentlig. |
| Lærerrom | • For høy temperatur.<br>• Litt for lite kapasitet på ventilasjonsanlegg når rommet brukes til fellesmøter.<br>• Ventilasjon, lavfrekvent støy dominerer. Verdier over anbefalinger gitt i NS 8175:2012. | • Redusere settpunkt for innetemperatur.<br>• Gjøre innledende prøving for å måle hvor mye luft som kommer ut av tilluftsventil.<br>• Innregulering av ventilasjonsanlegget kan både forbedre luftkvalitet og redusere støy. |

## Valgte tiltak

- Natt- og helgesenkning av romtemperatur er fjernet.
- Tilbud på ny belysning mottas i nær framtid. Montasje påstartes straks vi mottar nye armatur. Gjennomføres i klasseromsareal samt areal for SFO. Montasje gjennomføres med egne ressurser og utføres etter en prioriteringsliste når det er ledig tid.
- Det monteres klasseromsaggregat i blårommet. Finansiering av tiltaket er ikke avklart, men gjennomføres senest i januar.
- Vi vil gjennomføres kontrollmåling av luftmengder på deler av ventilasjonsanlegget for å avdekke om brannspjeld er lukket eller om det er direkte feil på innreguleringen av dette. Anleggets kanaldimensjoner gjør det vanskelig å omfordele luft mellom arealer. Gjennomføres i januar pga manglende budsjett 2019.
- Det er solavskjerming på byggets sydside. Dette har ikke vært i bruk de siste årene. Det vil gjennomføres en tilstandsvurdering av dette for å avdekke muligheten for å ta dette i bruk igjen.
- Det vil etableres mulighet for å åpne vinduer i alle klasserom og grupperom. Gjennomføres november 2019.

***Følgende tiltak gjennomføres fra skolens side:***

- Elever går ut i pauser samt gjennomføring av lufterutiner i kritiske rom
- Lærere følger opp at ovner ikke er avskrudd etter endt skoledag.
- Ovner med termostat sjekkes med tanke på rett setpunkt.

***Tiltak som avventes og har mulighet for gjennomføring etter forespørsel fra skolen:***

- Montasje av panelovner i rom som oppleves for kalde.

# Appendix H

# Measures: Sunnland

A presentation (Norwegian) of known the indoor environment problems for each room, suggested measures and implemented measured in January 2020 for Sunnland school. The list of measures is developed by all collaborative partners in the project.

# Sunnland skole

<table>
<tr><th>Rom</th><th>Problemer</th><th>Forslag løsninger</th><th>Valgte tiltak</th></tr>
<tr><td>104<br>(kompaktaggregat)</td><td>▪ Kompaktaggregatene går hele tiden. Også når skolen ikke er i drift.<br>▪ Trekk fra kompaktaggregat kommenteres I intervju<br>▪ For høy innetemperatur<br>▪ Lydmålinger viser nivå over anbefalingene satt i NS 8175:2012. Intervjuene viser også at ventilasjonstøy er kommentert av brukerne.</td><td>▪ Plassering av pulter i klasserom. Unngå kastesone fra kompaktaggregat og områder for nærme oppvarmingskilder.<br>▪ Systematisk opplæring av lærere slik at de er trygge på innregulering av temperatur på "sine" klasserom.<br>▪ Ventilasjonsanlegg programmeres slik at kapasitet tilpasses timeplan.</td><td rowspan="4">▪ Natt- og helgesenkning av romtemperatur er fjernet i C-bygget<br>▪ Plassering av pulter i klasserom i forhold til klasseromsaggregat<br>▪ Elever går ut i pauser samt gjennomføring av lufterutiner i kritiske rom<br>▪ Lærere følger opp at termostat på ovner ikke er avskrudd etter endt skoledag<br>▪ Aktiv bruk av solavskjerming på sommerstid for å hindre overtemperatur.<br>Tiltak som avventes og har mulighet for gjennomføring etter forespørsel fra skolen:<br>▪ Montasje av klasseromsaggregat på klasserom.<br>▪ Montasje av panelovner i rom som oppleves for kalde.<br>Følgende tiltak gjennomføres fra skolens side:<br>• Elever går ut i pauser samt gjennomføring av lufterutiner i kritiske rom<br>• Lærere følger opp at ovner ikke er avskrudd etter endt skoledag.<br>• Ovner med termostat sjekkes med tanke på rett setpunkt.</td></tr>
<tr><td>107</td><td>▪ Høyere CO2-nivå og lengre perioder med for lave temperaturer<br>▪ For lav temperatur i helger gjør at varmesystemet ikke rekker å øke temperaturen for skolen starter på mandag. Innetemperaturen kan synkte til under 16°C.<br>▪ Lydmålinger viser nivå over anbefalingene satt i NS 8175:2012.</td><td>▪ Plassering av pulter i klasserom<br>▪ Systematisk opplæring av lærere slik at de er trygge på innregulering av temperatur på "sine" klasserom.</td></tr>
<tr><td>203<br>(kompaktaggregat)</td><td>▪ For høy innetemperatur<br>▪ Kompaktaggregatene går hele tiden. Også når skolen ikke er i drift<br>▪ Trekk fra kompaktaggregat kommenteres I intervju<br>▪ For lav temperatur i helger gjør at varmesystemet ikke rekker å øke temperaturen for skolen starter på mandag. Innetemperaturen kan synkte til under 16°C.<br>▪ Lydmålinger viser nivå over anbefalingene satt i NS 8175:2012.</td><td>▪ Plassering av pulter i klasserom. Unngå kastesone fra kompaktaggregat og områder for nærme oppvarmingskilder.<br>▪ Ventilasjonsanlegg programmeres slik at kapasitet tilpasses timeplan.<br>▪ Systematisk opplæring av lærere slik at de er trygge på innregulering av temperatur på "sine" klasserom.</td></tr>
<tr><td>207</td><td>▪ Har de lengste periodene med for høy CO2-konsentrasjon.<br>▪ Lydmålinger viser nivå over anbefalingene satt i NS 8175:2012.</td><td>▪ Plassering av pulter i klasserom<br>▪ Systematisk opplæring av lærere slik at de er trygge på innregulering av temperatur på "sine" klasserom.</td></tr>
</table>

## Appendix I

# Poster of simple measures to improve indoor environment

Presentation (in Norwegian) of poster with five simple measures to improve indoor environment, developed by SINTEF, NTNU, NAAF and Trondheim Kommune

# Sørborgen skole

## 5 enkle inneklimatips for bedre læringsmiljø på din skole

Bedre inneklima kan oppnås dersom elever, lærere og ansatte samarbeider om dette.

De som har ansvar for skolebygningen påser at ventilasjonsanlegg og varmeanlegg fungerer slik det skal. Renholder rengjør gulv og områder som er avtalt.

**For å oppnå best mulig inneklima må den enkelte passe på:**

1. **Å lufte rommene regelmessig!**
   Bruk vindu og dør aktivt gjennom skoledagen for å få frisk luft i klasserommet.

2. **At varmekilder ikke blir blokkert eller skrudd av/på!**
   Er det er for varmt eller kaldt, så gi lærer beskjed slik at varmen reguleres.

3. **At minst mulig sand med sko og klær trekkes inn utenfra!**
   Børst av skoene ute på avskrapningsrista og bruk innesko.

4. **Å bruke gardiner og utvendig solavskjerming på solfylte dager!**
   Trekk for gardiner og forsøk reduser solinnstrålingen og rommet.

5. **Å rydde klasserommet slik at renholder kommer til!**
   Hold orden, og sørg for at renholder kommer til på alle flater.

***Hilsen skolens rektor og inneklimaprosjektet «Skoler på vent».***

SINTEF | ASTMA- OG ALLERGIFORBUNDET – gjør Norge friskere | NTNU Kunnskap for en bedre verden | TRONDHEIM KOMMUNE

# Appendix J

# Article

Article written (in Norwegian) in April 2020 in conjunction with the results from the field measurements and concerns regarding reopening of schools with poor ventilation, due to COVID-19. The article was not published due to weak statistical foundation.

# Norske skoler med dårlig inneklimakvalitet bør ikke åpnes i korona pandemi

Av Solveig Askevold Ulsund, Guangyu Cao,

**Sammendrag**. Luftbåren transport er en av de viktigste mekanismene for overføring av smittsomme sykdommer som kopper, tuberkulose, alvorlig akutt luftveissyndrom (SARS), H1N1 og Corona virus (SARS-CoV-2). En luftbåren smittsom infeksjon kan kun overføres ved innånding av luft som tidligere har blitt pustet ut av en smittebærende person [1]. $CO_2$-konsentrasjon er en målbar indikator på utåndet pust inne i et rom, og kan dermed brukes til å kartlegge smittefare. Ved en konsentrasjon av $CO_2$ som overskrider 1000-1500 ppm kan smitterisikoen øke 5-10 ganger, sett i forhold til utendørs konsentrasjon av $CO_2$. Derfor bør ikke norske skoler med dårlig inneklimakvalitet åpnes under corona pandemi.

Høye konsentrasjonsmengder av $CO_2$ innendørs kommer av ineffektiv ventilasjon. Dårlig ventilasjon er et kjent problem blant norske skoler. Dette er et problem fordi barn og unge er mer sensitive til luftforurensning, sammenlignet med voksne, på grunn av at de fortsatt har organer som er under utvikling. Dette vil bli et økt problem når verden står ovenfor en pandemi med det smittsomme viruset COVID-19.

I løpet av dette studiet har det blitt utført målinger på skoler som venter på rehabilitering eller nytt bygg, hvor $CO_2$-nivået kartlegges i utvalgte rom. Analysen av resultatene har vist at $CO_2$-nivået overstiger 1000 ppm i løpet av tiden hvor det befinner seg elever og lærere inne i rommene.

## Bakgrunn

COVID-19 har nå smittet over 2 300 000 mennesker (over 7000 i Norge) i over 190 land [1-2]. Ventilasjonssystem i bygg kan spille en viktig rolle for å forebygge og kontrollere eksponering av mennesker for smittestoffer og påvirker inneklimaet i stor grad. Norske myndigheter har bestemt at barnehager og barneskoler skal h.h.v åpne 20. April og 27. April.

I Norge, finnes flere skoler som venter på en avklaring om bygningens eller virksomhetens framtid. Skoler der videre drift er uavklart, vil fortsatt være i ordinær bruk, men det blir dessverre ikke satt av midler til oppgradering og utstyr slik det blir med nyere skoler som er under kommunens vedlikehold og skolebudsjett. Det er ikke uvanlig at skoler som står på vent er i bruk i 10-15 år, noen kan være i bruk i nærmere 20 år.

Norske myndigheter har satt en maksgrense på 1000 ppm CO2 innendørs på skoler og barnehager [3]. Et norskt studie som ble gjennomført I 2003 viste at: [4]

- 400-800 ppm = god luftkvalitet
- 800-1000 ppm = mulig kritisk luftkvalitet
- 1000-2000 ppm = kritisk luftkvalitet

I August 2018 ble prosjekt «Skoler på vent» startet opp av SINTEF, i samarbeid med NTNU, NAAF og Trondheim kommune. Målet for prosjektet er å sette fokus på inneklima i gamle skoler som er satt på vent grunnet påvente av midler til rehabilitering, eller oppsett av nytt bygg. I prosjektet er det valgt ut tre case-skoler som tilhører Trondheim kommune. [5-6]

Bakgrunnen til prosjektet er nyere forskning som har vist at inneklima og luftkvalitet kan være helseskadelig for unger som er i utvikling. Skolene er valgt på grunnlag av en evaluering fra Trondheim kommune, hvor statusen til skoler i Trondheim blir evaluert hvert fjerde år. Skolene blir rangert i tre kategorier; rød, gul og grønn, hvor rød er den verste kategorien og betyr at skolens status er kritisk, som vil si at skolen har behov for en betydelig oppgradering eller å bli erstattet av et nytt bygg. 2. [6]

Målet med denne artikkelen er å synliggjøre at det er en betydelig høyere smitterisiko ved åpning av skoler på vent med ineffektive ventilasjonssystem som ikke klarer å opprettholde et $CO_2$-nivå under 1000 ppm.

## Beskrivelse av caseskole

Caseskolen er en kombinert barne- og ungdomsskole og er en av tre skoler på vent som har blitt undersøkt i forbindelse med samarbeidsprosjektet, "Skoler på vent". Skolen ligger i Trøndelag fylke og huser omtrent 430 elever og 50 ansatte. Skolen består et bygg som ble satt opp i 1979. Originalt var skolen bygget som en åpen skole-løsning. Dette har blitt endret i senere tid, hvor det har blitt satt opp skillevegger som har delt arealet opp i rom. Det antas at dette har blitt gjort uten særlige hensyn til tekniske systemer, noe som har ført til problemer i ettertid. [7]

*Tekniske systemer*

I hovedbygget er det tre separate ventilasjonssystem. Hovedsystemet forsyner hele bygningen bortsett fra gymsalen og lærerarealet. Disse har hvert sitt eget ventilasjonssystem. Hovedsystemet ble installert i 1979 og det har ikke vært noen oppgraderinger på systemet annet enn vanlig vedlikehold. Ventilasjonssystemet tilknyttet lærerarealet er relativt nytt og ble installert i 2008. [7]

## Konsekvenser av dårlig ventilasjon og risiko for luftbåren smitte estimert fra karbondioksid konsentrasjon

Dårlig inneklima er et kjent problem i norske skoler. Barn er mer sensitive for eksponering mot luftforurensing sammenlignet med voksne. Hos barn og unge er ikke luftveiene, immunforsvaret, fordøyelsessystemet og nervesystemet fult utviklet, som fører til lettere inngang for giftige stoffer som kan påvirke organene. Konsekvenser av dårlig inneklima er mange og kan bidra til sykdom og helseplager hos elever og ansatte som blant annet; luftveisinfeksjoner. [9-10]

Utåndet pust er hovedkilden til utslipp av smittsomme luftbårne partikler. Utåndet pust inneholder nesten 40 000 ppm av $CO_2$, hvor utendørs luft inneholder omtrent 400 ppm. I et klasserom vil hovedkilden av $CO_2$ konsentrasjon komme direkte fra brukerne, da det sjeldent finnes andre store kilder til $CO_2$. Derfor kan den målte konsentrasjon av $CO_2$ brukes til å estimere risikoen for smitte av luftbårne infeksjoner på en skole basert på Wells-Riley ligning, total mengde $CO_2$ inne i et rom og en karbondioksidbasert risikoligning. Dette gir følgende modell for reproduksjonsnummeret for hvor smittsom en sykdom er i en bygning, forutsatt at det er minst en smittebærer i rommet. [11]:

$$R_{A0} = (n-1) * [1 - \exp\left(-\frac{\bar{f}qt}{n}\right)]$$

Hvor:

$R_{A0}$ = Reproduksjonsnummer for en smittsom sykdom i en bygning
$n$ = Antall personer i det ventilerte rommet
$\bar{f}$ = Andel inneluft som er utåndet luft
q = kvantegenereringshastigheten av en infisert person [quanta/s]
t = Total eksponeringstid [s]

Følgende modell kan videre brukes for risikoevaluering for forskjellige scenarioer av ulike typer luftbårne virus med forskjellige verdier for *q*. Jo høyre *q*-verdien er desto mer smittsom er en sykdom. Meslinger har høy *q*-verdi, influensa har middels *q*-verdi og Rhinoviruset har veldig lav *q*-verdi. Reproduksjonsnummeret til en luftveisinfeksjon kan kalkuleres ut ifra å anta at det finnes en smittet person blant en gruppe mennesker inne i et rom, antall personer i rommet, ventilasjonsraten og gjennomsnittlig konsentrasjon av $CO_2$ i rommet. [11]

Figur 2 viser reproduksjonsnummeret for meslinger som en funksjon av antall personer i et rom. Kalkulert $R_{A0}$ for meslinger, med en kvantegenereringshastighetsrate på 570/h hvor eksponeringstiden er 10 timer (to skoledager), vil $R_{A0}$ øke omtrent lineært med antall personer i rommet ved høye konsentrasjoner av $CO_2$. Detter er ikke tilfellet ved lave konsentrasjoner av $CO_2$, men $R_{A0}$ er fortsatt mye større enn 1 og det kan derfor antas at spredning av sykdommen vil forekomme selv i et veldig godt ventilert rom. [11]

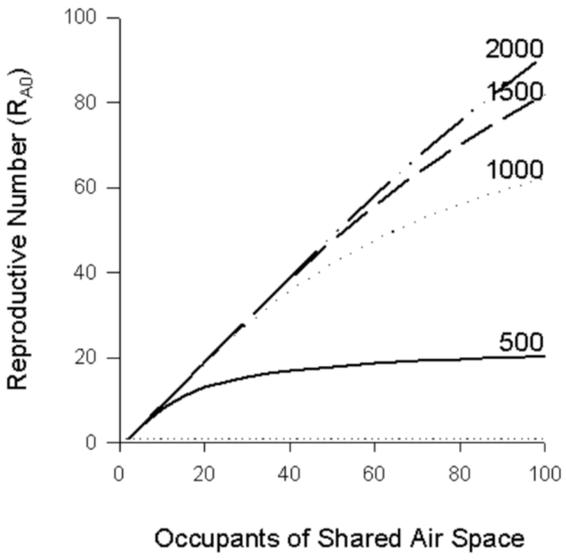


*Figure 1 $R_{A0}$ for meslinger som en fuksjon av antall personer i et rom og konsentrasjon av $CO_2$ (ppm) (q=570 quanta/h, t=10 h, $C_0$=350 ppm, $C_a$ =37 500 ppm [11]*

Figur 2 viser reproduksjonsnummeret for influensa som en funksjon av antall personer i et rom. Kalkulert $R_{A0}$ for influensa, med en kvantegenereringshastighetsrate på 100/h hvor eksponeringstid er 4 timer, vil smitterisikoen kun være stor ved høye konsentrasjoner av $CO_2$. Sammenlignet med smitterisiko utendørs, vil $R_{A0}$ nesten 5-dobles ved $CO_2$ konsentrasjoner over 1000 ppm og nesten 10-dobles ved $CO_2$-konsentrasjoner over 1500 ppm. I bygninger med godt ventilerte rom og lave konsentrasjoner av $CO_2$ vil $R_{A0}$ være lavere enn 1, og dermed redusere risikoen for smitte. [11]

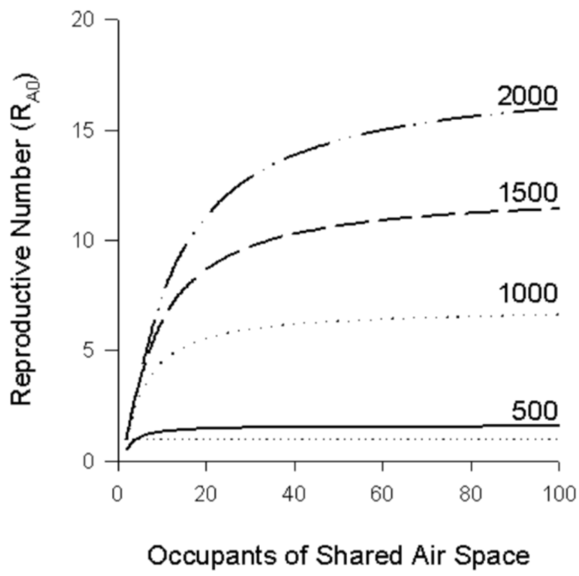


*Figure 2 $R_{A0}$ for influensa som en fuksjon av antall personer i et rom og konsentrasjon av $CO_2$ (ppm) (q=100 quanta/h, t=4 h, $C_0$=350 ppm, $C_a$ =37 500 ppm [11]*

## Målinger

Målingene ble utført vinteren 2020. Det ble plassert ut inneklimasensorer i to rom, med kjente inneklimaproblemer. Inneklimasensoren brukt er av typen C.A 1510 og måler karbondioksidnivå, temperatur og relativ fuktighet. Høsten 2019 ble det også gjennomført luftmengdemålinger for alle testrommene på casekolen for å kunne beregne maksimal personlast til rommene.

Inneklimasensorene logget data 24 timer i døgnet i to uker med normal elevaktivitet i rommene. I dataanalysen er det kun brukt målepunkter tatt under ordinær drift av rommene, for å kunne måle prosentavvik fra terskelverdier over 1000 ppm og 1500 ppm

For å måle luftmengder på caseskolen skole ble det brukt et luftmengdemåler-instrument, Accubalance TSI, som måler momentane verdier. Det ble målt tre verdier for hver ventil som tilfører luft til rommet, hvor gjennomsnittet ble brukt i beregningene. . Summen av gjennomsnittsverdien fra hver ventil angir den totale mengden av frisk luft som blir tilført rommet.

For å beregne maksimal personlast er det antatt at ventilasjonsraten er konstant, basert på typen ventilasjon, CAV. Beregningene er også basert på krav til ventilasjon i undervisningsbygg, §13-3 [8]:

1. *Frisklufttilførsel på grunn av forurensninger fra personer med lett aktivitet skal være minimum 26 m3 per time per person. Ved annet aktivitetsnivå enn lett aktivitet, skal frisklufttilførselen tilpasses slik at luftkvaliteten blir tilfredsstillende.*
2. *Frisklufttilførsel på grunn av forurensning fra materialer, produkter og installasjoner skal være minimum:*
    a. *2,5 m³ per time per m2 gulvareal når bruksenheten eller rommene er i bruk*
    b. *0,7 m³ per time per m2 gulvareal når bruksenheten eller rommene ikke er i bruk [4].*

Videre kan maksimal personlast for et rom bergenes, basert på antakelse om konstant luftmengde (CAV). Personlasten, $n$, er gitt ved :

$$n = \frac{\dot{V}_{tot} - A * \dot{V}_{areal}}{\dot{V}_{person}}.$$

Hvor:

$\dot{V}_{tot}$ = Total luftmengdevolum [m³/h]
$A$ = Areal [m²]
$\dot{V}_{area}$ = Luftmengdevolum per gulvareal [m³/h*m²]

# Resultat og diskusjon

## Luftmengdemålinger

I tabell 2 vises resultatet fra målinger gjort av luftmengder tilført fra ventilasjonsanlegget, arealet til de respektive rommene, og beregnet personlast. Målingene er gjennomført når anlegget kjøres på full kapasitet.

*Tabell 1 Målte luftmengder for tilførsel av luft, areal av rom og beregnet personlast, Stabbursmoen skole*

| | LUFTMENGDE TILFØRSEL [M³/H] | AREAL [M²] | BEREGNET PERSONLAST |
|---|---|---|---|
| ROM 1 | 123,0 | 52,7 | 0 |
| ROM 2 | 175,0 | 120 | -5 |

Resultatet fra luftmengdemålingene viser at ventilasjonssystemet ikke tilfører tilfredsstillende mengde luft til Rom 1 og Rom 2. Hovedgrunnene til at ventilasjonssystemet er ineffektivt er antatt å være forårsaket både av utformingen og alderen til ventilasjonssystemet. Kanalene som fører inn til ventilene er for de fleste rommene målt til en indre diameter på 200 mm. Dette setter store begrensinger til hvor store luftmengder som kan tilføres uten at det går på bekostning av lydkvaliteten. Dette ser ut til å være et gjentakende problem og kan antas å gjelde for de fleste elevarealene, i og med at kanaldiameteren er den samme for alle tilførselskanalene.

## Analyse av luftkvalitet i Rom 1 og Rom 2

Grafene i figur 4 og 5 presenterer $CO_2$-nivået inne i Rom 1 og Rom 2 i peridoen 25. februar til 6. mars. Figurene viser alle målte verdier gjennom hele døgn, inkludert helger. Den blå linjen viser $CO_2$-nivået variasjon i løpet av måleperioden. De to røde linjene markerer terskelverdiene på h.h.v. 1000 ppm og 1500 ppm. I figurene går det tydelig frem hvordan parameterne endres når rommet er i bruk, i forhold til tiden utenfor drift. Topp-punktene gjenspeiler tidspunkt der rommene er i bruk til undervisning. Når rommet ikke er i bruk ligger $CO_2$-nivået stabilt like under 500 ppm, som tilsvarer utendørskonsentrasjon av $CO_2$  Med en gang rommet fylles opp av elever, stiger karbondioksidnivået raskt og man kan se fra at konsentrasjonen overstiger 1000 ppm store deler av brukstiden for begge rom.

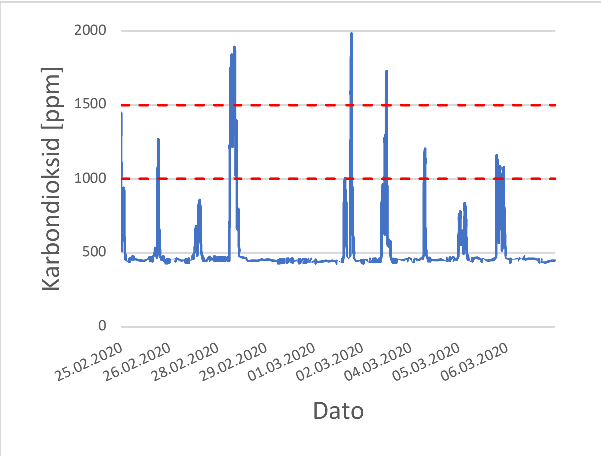


*Figure 3 Bildetekst*

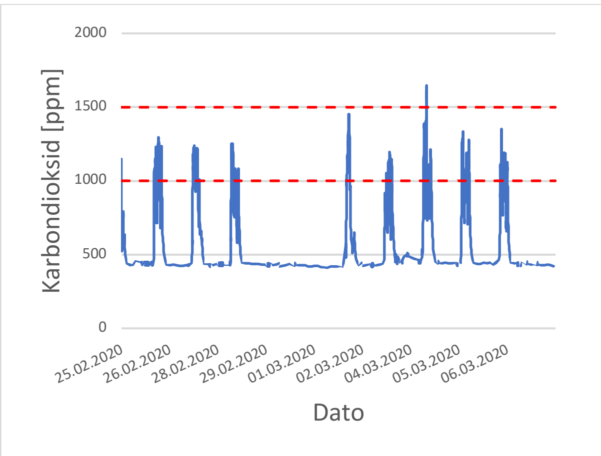


*Figure 4 Bildetekst*

I tabell 3 vises andelen av tiden hvor $CO_2$-nivået overstiger terskelverdiene, gitt i prosent. Utregningen inneholder kun brukstiden til klasserommene. Den viser at konsentrasjonen av $CO_2$ overstiger 1000 ppm for 21 % og 43 % av tiden for henholdsvis Rom 1 og Rom 2

*Tabell 2 Utregnet avvik over terskel for Rom 1 og Rom 2 i løpet av måleperioden 25.02.2020 – 06.03.2020*

| ROM | >1000 PPM | >1500 PPM |
|---|---|---|
| ROM 1 | 21 % | 7 % |
| ROM 2 | 43 % | 0 % |

## Konklusjon

Skoler som er satt på vent er ofte utstyrt med gamle og utslitte ventilasjonssystemer som ikke kan tilfredsstille luftmengdetilførsler tilsvarende dagens standarder. Dette kan ha fatale konsekvenser for elever og ansatte på skolen i perioder med høy spredning av luftbårne sykdommer. Ifølge litteraturen vil smitterisikoen økes opp mot 5 ganger for brukere av en skole hvor konsentrasjonen av $CO_2$ overstiger 1000 ppm, hvis brukerne befinner seg inne i rommet i mist 4 timer.

Fra resultatene er det tydelig at kritiske konsentrasjoner av $CO_2$ oppstår og vedvarer store deler av dagen på caseskolen. Siden det samme ventilasjonssystemet står for tilførsel av luft til alle undervisningsareal er betimelig å anta at de resterende rommene, som det ikke har blitt gjennomført målinger for, også har for lave luftmengder til å holde konsentrasjonen av $CO_2$ på et lavt nok nivå til at det ikke medfører en økt risiko for smitte av luftveisinfeksjoner for elever som oppholder seg på skolen en hel skoledag.

Med dette som bakgrunn, bør det diskuteres om caseskole og andre skoler som inngår i kategorien av skolene som er satt på vent, bør åpnes igjen 27. april, som følge av endrede smittevernstiltak mot COVID-19 spredning.

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# Appendix K

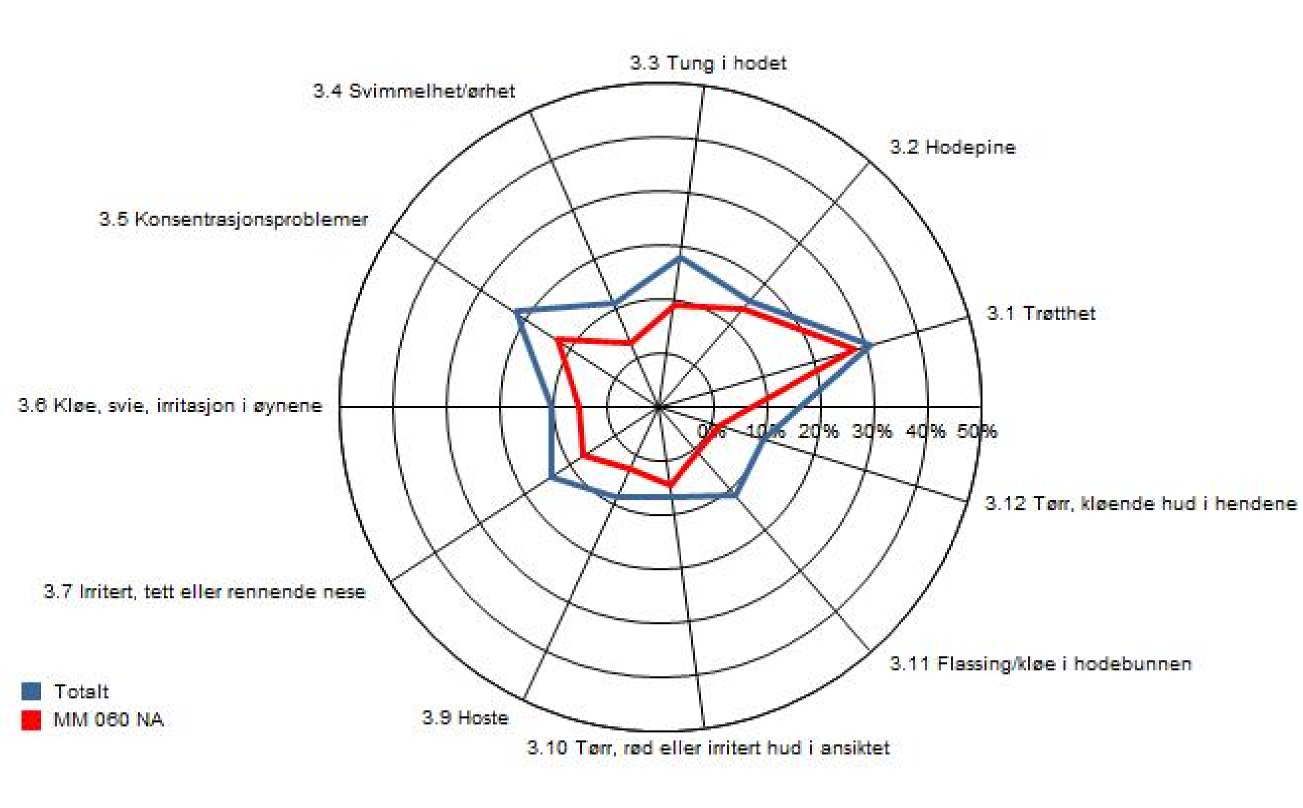
# Result from Questionnaire: Stabbursmoen

Result from the questionnaire "Mitt inneklima" (English; My indoor environment) from Stabbursmoen school, 2020, delivered by NAAF. The results are presented in a spider chart and table format. The tables are presented with the calculated uncertainties for the reference values. If the response percentage deviates from the reference w/uncertainty, it is marked the color red.

# 4. Samlet resultat for hele skolen

## Rapporterte helseplager

Antall respondenter: 248




*Total prosent av elevene (både jenter og gutter) som har symptomer hver uke, sammenlignet med referanseverdier for skoler som* ***ikke*** *har noen kjente inneklimaproblemer.*

Tabellen nedenfor viser andel (%) elever som oppgir at de har opplevd helseplager hver uke de siste 3 måneder når de er på skolen (faktorer som er uthevet og markert med rødt ligger signifikant over referanseverdien).

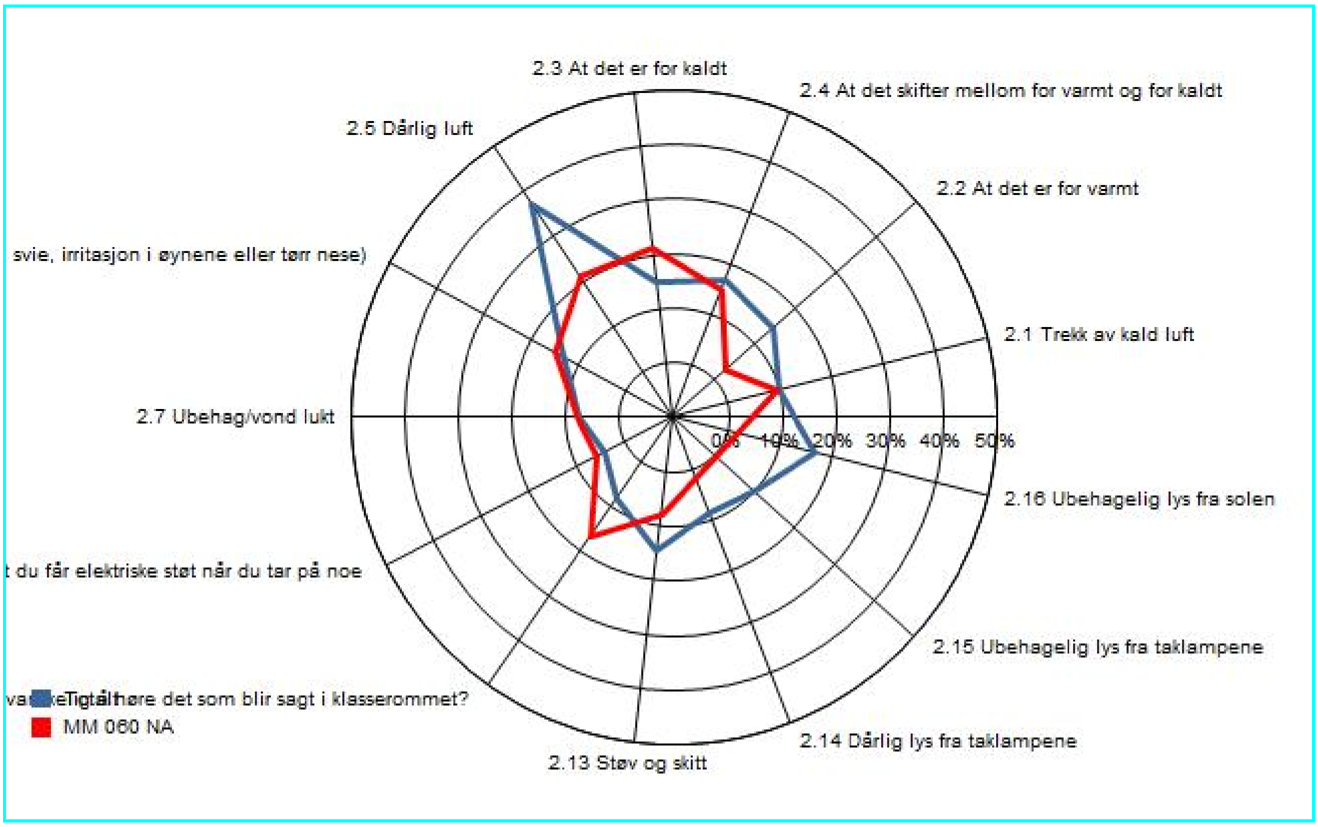
| Faktor | Resultat | Referanse m/usikkerhet* | | |
|---|---|---|---|---|
| 3.1 Trøtthet | 31% | 28% | +/- | 8% |
| 3.2 Hodepine | 16% | 14% | +/- | 6% |
| **3.3 Tung i hodet** | **18%** | **9%** | +/- | **6%** |
| **3.4 Svimmelhet/ørhet** | **11%** | **3%** | +/- | **4%** |
| **3.5 Konsentrasjonsproblemer** | **22%** | **13%** | +/- | **6%** |
| **3.6 Kløe, svie, irritasjon i øynene** | **10%** | **5%** | +/- | **5%** |
| **3.7 Irritert, tett eller rennende nese** | **14%** | **7%** | +/- | **5%** |
| 3.8 Heshet/tørrhet i hals | 6% | 5% | +/- | 5% |
| **3.9 Hoste** | **8%** | **3%** | +/- | **4%** |
| 3.10 Tørr, rød eller irritert hud i ansiktet | 7% | 5% | +/- | 5% |
| **3.11 Flassing/kløe i hodebunnen** | **12%** | **1%** | +/- | **4%** |
| **3.12 Tørr, kløende hud i hendene** | **10%** | **2%** | +/- | **4%** |

**Referansematerialet er basert på resultater fra tilsvarende undersøkelser på skoler som* ***ikke*** *har noen kjente inneklimaproblemer. Usikkerheten i referanseverdien vil avhenge av antall elever.*

# 4. Samlet resultat for hele skolen

## Opplevd inneklima

Antall respondenter: 248




*Rapporterte inneklimafaktorer som har gitt elevene ukentlige plager (angitt i prosent), sammenlignet med referanseverdier for skoler som ikke har noen kjente inneklimaproblemer. Fire av parametrene finnes det ikke referanseverdier for.*

Tabellen nedenfor viser andel (%) elever som oppgir at de er plaget av forhold ved skolens inneklima hver uke de siste 3 måneder når de er på skolen (faktorer som er uthevet og i rødt ligger signifikant over referanseverdien).

| Faktor | Resultat | Referanse m/usikkerhet* | | |
|---|---|---|---|---|
| 2.1 Trekk av kald luft | 10% | 10% | +/- | 6% |
| **2.2 At det er for varmt** | **15%** | **3%** | +/- | **4%** |
| 2.3 At det er for kaldt | 15% | 21% | +/- | 8% |
| 2.4 At det skifter mellom for varmt og for kaldt | 17% | 15% | +/- | 6% |
| **2.5 Dårlig luft** | **37%** | **21%** | +/- | **8%** |
| 2.6 Tørr luft (kløe, svie, irritasjon i øynene eller tørr nese) | 13% | 15% | +/- | 6% |
| 2.7 Ubehag/vond lukt | 8% | 8% | +/- | 5% |
| 2.8 At du får elektriske støt når du tar på noe | 4% | 6% | +/- | 5% |
| 2.9 At det er vanskelig å høre det som blir sagt i klasserommet? | 8% | 17% | +/- | 8% |
| **2.10 Støy eller uro fra elevene i klassen** | **40%** | **10%** | +/- | **6%** |
| 2.11 Forstyrrende bråk utenfra (trafikk/skolegård/byggevirksomhet)? | 9% | 8% | +/- | 6% |
| 2.12 Susing eller du fra ventilasjon eller andre ting i bygningen? | 9% | 8% | +/- | 6% |
| **2.13 Støv og skitt** | **15%** | **8%** | +/- | **6%** |
| 2.14 Dårlig lys fra taklampene | 9% | | | |
| 2.15 Ubehagelig lys fra taklampene | 10% | | | |
| 2.16 Ubehagelig lys fra solen | 17% | | | |

**Referansematerialet er basert på resultater fra tilsvarende undersøkelser på skoler som ikke har noen kjente inneklimaproblemer. Usikkerheten i referanseverdien vil avhenge av antall elever. Fire av parametrene finnes det ikke referanseverdier for.*

*Spørsmål 1.14, 1.15 og 1.16 har vi per i dag ikke referanseverdier for. Derfor er spørsmålene ikke med i plottet.*

# Appendix L

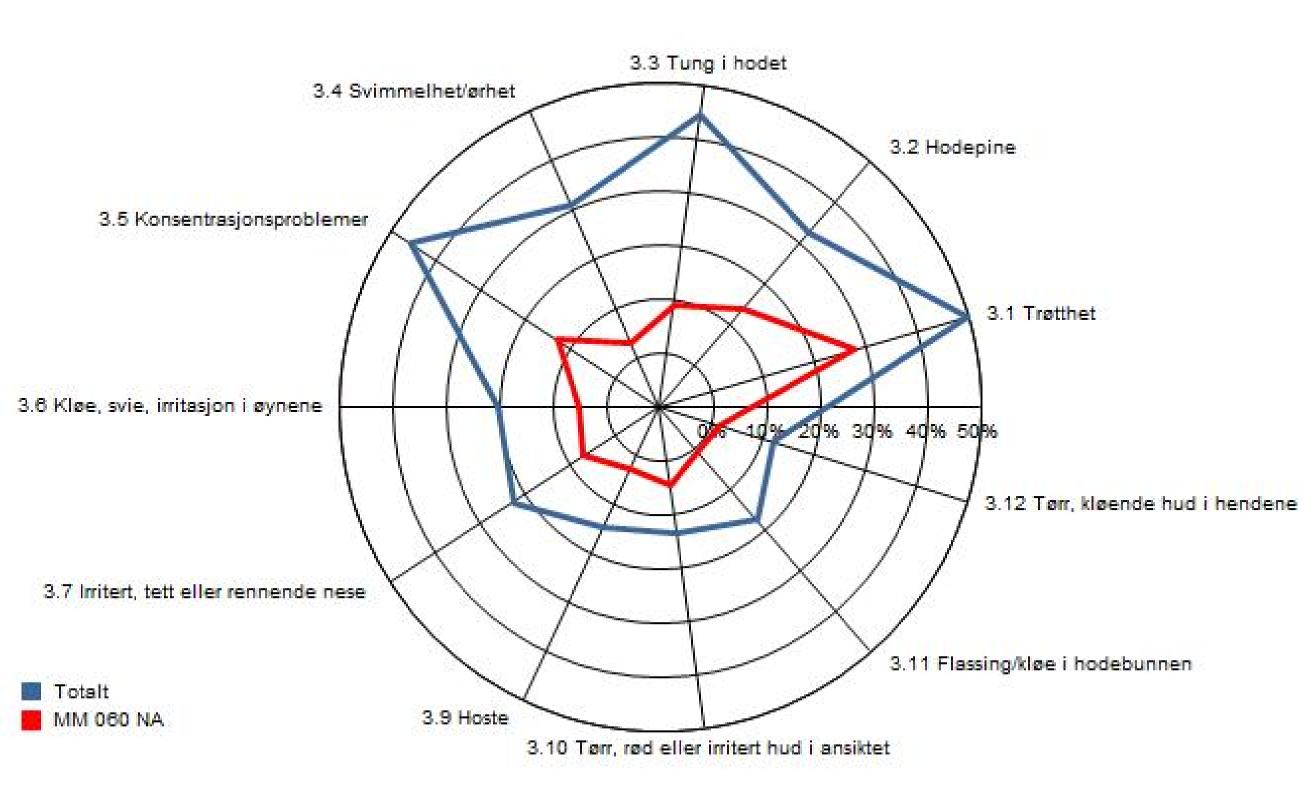
# Result from Questionnaire: Sunnland

Result from the questionnaire "Mitt inneklima" (English; My indoor environment) from Sunnland school, 2020, delivered by NAAF. The results are presented in a spider chart and table format. The tables are presented with the calculated uncertainties for the reference values. If the response percentage deviates from the reference w/uncertainty, it is marked the color red.

# 4. Samlet resultat for hele skolen

## Rapporterte helseplager

Antall respondenter: 123




*Total prosent av elevene (både jenter og gutter) som har symptomer hver uke, sammenlignet med referanseverdier for skoler som **ikke** har noen kjente inneklimaproblemer.*

Tabellen nedenfor viser andel (%) elever som oppgir at de har opplevd helseplager hver uke de siste 3 måneder når de er på skolen (faktorer som er uthevet og markert med rødt ligger signifikant over referanseverdien).

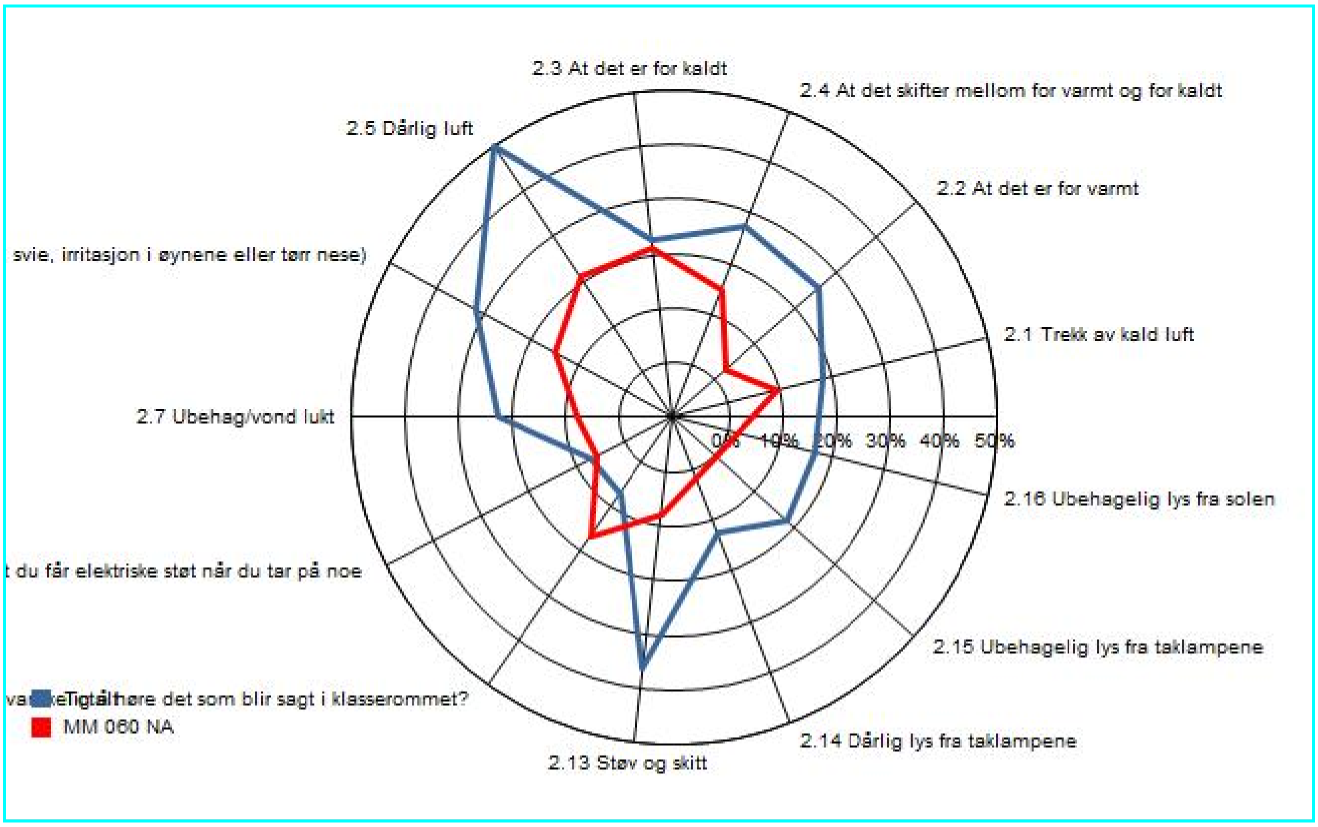
| Faktor | Resultat | Referanse m/usikkerhet* | | |
|---|---|---|---|---|
| **3.1 Trøtthet** | **53%** | **28%** | +/- | **10%** |
| **3.2 Hodepine** | **33%** | **14%** | +/- | **9%** |
| **3.3 Tung i hodet** | **45%** | **9%** | +/- | **9%** |
| **3.4 Svimmelhet/ørhet** | **31%** | **3%** | +/- | **6%** |
| **3.5 Konsentrasjonsproblemer** | **46%** | **13%** | +/- | **9%** |
| **3.6 Kløe, svie, irritasjon i øynene** | **20%** | **5%** | +/- | **7%** |
| **3.7 Irritert, tett eller rennende nese** | **23%** | **7%** | +/- | **7%** |
| **3.8 Heshet/tørrhet i hals** | **14%** | **5%** | +/- | **7%** |
| **3.9 Hoste** | **15%** | **3%** | +/- | **6%** |
| **3.10 Tørr, rød eller irritert hud i ansiktet** | **14%** | **5%** | +/- | **7%** |
| **3.11 Flassing/kløe i hodebunnen** | **18%** | **1%** | +/- | **6%** |
| **3.12 Tørr, kløende hud i hendene** | **12%** | **2%** | +/- | **6%** |

**Referansematerialet er basert på resultater fra tilsvarende undersøkelser på skoler som **ikke** har noen kjente inneklimaproblemer. Usikkerheten i referanseverdien vil avhenge av antall elever.*

# 4. Samlet resultat for hele skolen

## Opplevd inneklima

Antall respondenter: 123




*Rapporterte inneklimafaktorer som har gitt elevene ukentlige plager (angitt i prosent), sammenlignet med referanseverdier for skoler som ikke har noen kjente inneklimaproblemer. Fire av parametrene finnes det ikke referanseverdier for.*

Tabellen nedenfor viser andel (%) elever som oppgir at de er plaget av forhold ved skolens inneklima hver uke de siste 3 måneder når de er på skolen (faktorer som er uthevet og i rødt ligger signifikant over referanseverdien).

| Faktor | Resultat | Referanse m/usikkerhet* | | |
|---|---|---|---|---|
| 2.1 Trekk av kald luft | 19% | 10% | +/- | 9% |
| **2.2 At det er for varmt** | **26%** | **3%** | +/- | **6%** |
| 2.3 At det er for kaldt | 23% | 21% | +/- | 10% |
| **2.4 At det skifter mellom for varmt og for kaldt** | **28%** | **15%** | +/- | **9%** |
| **2.5 Dårlig luft** | **81%** | **21%** | +/- | **10%** |
| **2.6 Tørr luft (kløe, svie, irritasjon i øynene eller tørr nese)** | **32%** | **15%** | +/- | **9%** |
| **2.7 Ubehag/vond lukt** | **23%** | **8%** | +/- | **7%** |
| 2.8 At du får elektriske støt når du tar på noe | 7% | 6% | +/- | 7% |
| 2.9 At det er vanskelig å høre det som blir sagt i klasserommet? | 7% | 17% | +/- | 10% |
| **2.10 Støy eller uro fra elevene i klassen** | **40%** | **10%** | +/- | **9%** |
| 2.11 Forstyrrende bråk utenfra (trafikk/skolegård/byggevirksomhet)? | 15% | 8% | +/- | 9% |
| 2.12 Susing eller du fra ventilasjon eller andre ting i bygningen? | 16% | 8% | +/- | 9% |
| **2.13 Støv og skitt** | **37%** | **8%** | +/- | **9%** |
| 2.14 Dårlig lys fra taklampene | 13% | | | |
| 2.15 Ubehagelig lys fra taklampene | 19% | | | |
| 2.16 Ubehagelig lys fra solen | 17% | | | |

**Referansematerialet er basert på resultater fra tilsvarende undersøkelser på skoler som ikke har noen kjente inneklimaproblemer. Usikkerheten i referanseverdien vil avhenge av antall elever. Fire av parametrene finnes det ikke referanseverdier for.*

*Spørsmål 1.14, 1.15 og 1.16 har vi per i dag ikke referanseverdier for. Derfor er spørsmålene ikke med i plottet.*

## Appendix M

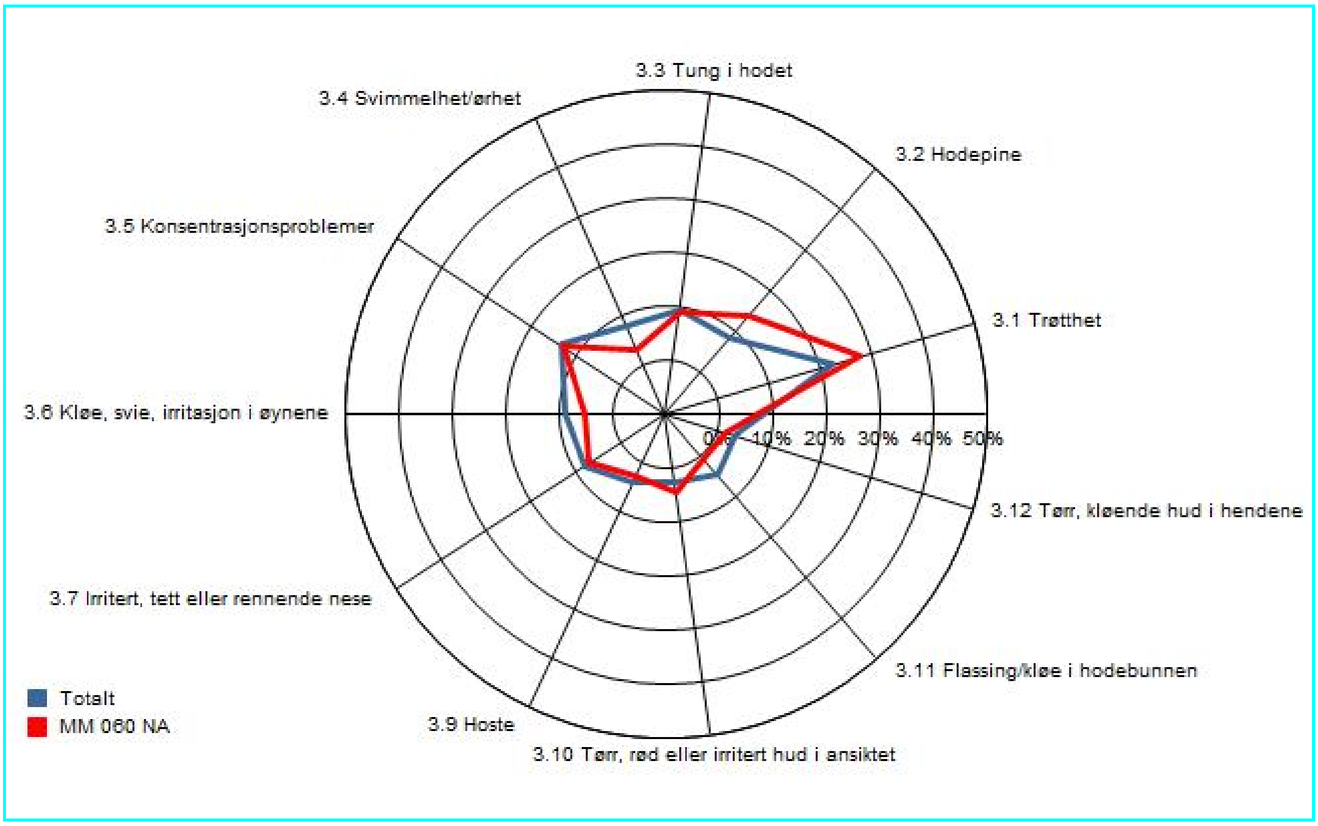
# Result from Questionnaire: Sørborgen

Result from the questionnaire "Mitt inneklima" (English; My indoor environment) from Sørborgen school, 2020, delivered by NAAF. The results are presented in a spider chart and table format. The tables are presented with the calculated uncertainties for the reference values. If the response percentage deviates from the reference w/uncertainty, it is marked the color red.

# 4. Samlet resultat for hele skolen

## Rapporterte helseplager

Antall respondenter: 193




*Total prosent av elevene (både jenter og gutter) som har symptomer hver uke, sammenlignet med referanseverdier for skoler som **ikke** har noen kjente inneklimaproblemer.*

Tabellen nedenfor viser andel (%) elever som oppgir at de har opplevd helseplager hver uke de siste 3 måneder når de er på skolen (faktorer som er uthevet og markert med rødt ligger signifikant over referanseverdien).

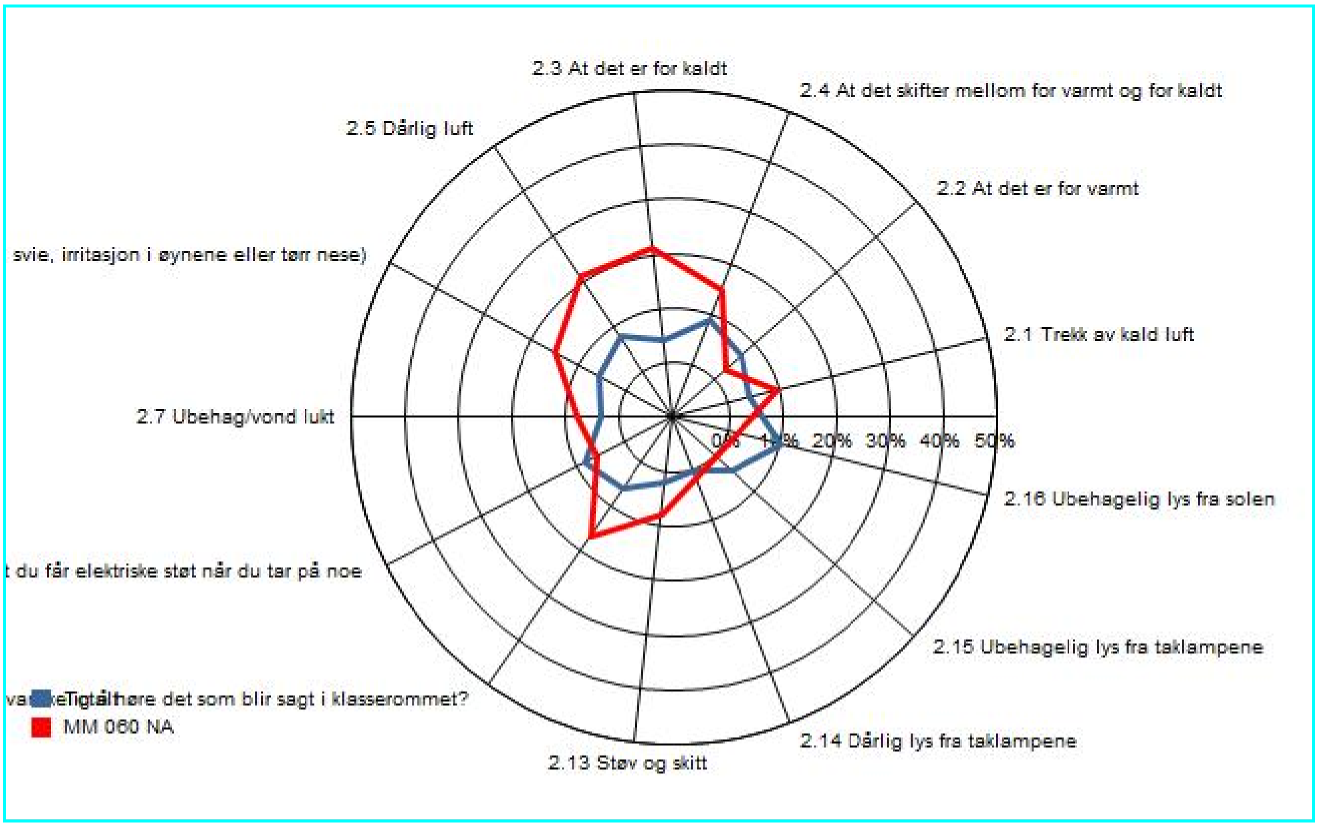
| Faktor | Resultat | Referanse m/usikkerhet* | | |
|---|---|---|---|---|
| 3.1 Trøtthet | 23% | 28% | +/- | 8% |
| 3.2 Hodepine | 8% | 14% | +/- | 6% |
| 3.3 Tung i hodet | 9% | 9% | +/- | 6% |
| **3.4 Svimmelhet/ørhet** | **8%** | **3%** | +/- | **4%** |
| 3.5 Konsentrasjonsproblemer | 13% | 13% | +/- | 6% |
| 3.6 Kløe, svie, irritasjon i øynene | 9% | 5% | +/- | 5% |
| 3.7 Irritert, tett eller rennende nese | 8% | 7% | +/- | 5% |
| 3.8 Heshet/tørrhet i hals | 3% | 5% | +/- | 5% |
| 3.9 Hoste | 4% | 3% | +/- | 4% |
| 3.10 Tørr, rød eller irritert hud i ansiktet | 3% | 5% | +/- | 5% |
| **3.11 Flassing/kløe i hodebunnen** | **5%** | **1%** | +/- | **4%** |
| 3.12 Tørr, kløende hud i hendene | 4% | 2% | +/- | 4% |

**Referansematerialet er basert på resultater fra tilsvarende undersøkelser på skoler som **ikke** har noen kjente inneklimaproblemer. Usikkerheten i referanseverdien vil avhenge av antall elever.*

# 4. Samlet resultat for hele skolen

## Opplevd inneklima

Antall respondenter: 193




*Rapporterte inneklimafaktorer som har gitt elevene ukentlige plager (angitt i prosent), sammenlignet med referanseverdier for skoler som ikke har noen kjente inneklimaproblemer. Fire av parametrene finnes det ikke referanseverdier for.*

Tabellen nedenfor viser andel (%) elever som oppgir at de er plaget av forhold ved skolens inneklima hver uke de siste 3 måneder når de er på skolen (faktorer som er uthevet og i rødt ligger signifikant over referanseverdien).

| Faktor | Resultat | Referanse m/usikkerhet* | | |
|---|---|---|---|---|
| 2.1 Trekk av kald luft | 5% | 10% | +/- | 6% |
| 2.2 At det er for varmt | 7% | 3% | +/- | 4% |
| 2.3 At det er for kaldt | 4% | 21% | +/- | 8% |
| 2.4 At det skifter mellom for varmt og for kaldt | 9% | 15% | +/- | 6% |
| 2.5 Dårlig luft | 8% | 21% | +/- | 8% |
| 2.6 Tørr luft (kløe, svie, irritasjon i øynene eller tørr nese) | 6% | 15% | +/- | 6% |
| 2.7 Ubehag/vond lukt | 4% | 8% | +/- | 5% |
| 2.8 At du får elektriske støt når du tar på noe | 8% | 6% | +/- | 5% |
| 2.9 At det er vanskelig å høre det som blir sagt i klasserommet? | 6% | 17% | +/- | 8% |
| **2.10 Støy eller uro fra elevene i klassen** | **27%** | **10%** | +/- | **6%** |
| 2.11 Forstyrrende bråk utenfra (trafikk/skolegård/byggevirksomhet)? | 5% | 8% | +/- | 6% |
| 2.12 Susing eller du fra ventilasjon eller andre ting i bygningen? | 2% | 8% | +/- | 6% |
| 2.13 Støv og skitt | 2% | 8% | +/- | 6% |
| 2.14 Dårlig lys fra taklampene | 1% | | | |
| 2.15 Ubehagelig lys fra taklampene | 5% | | | |
| 2.16 Ubehagelig lys fra solen | 11% | | | |

**Referansematerialet er basert på resultater fra tilsvarende undersøkelser på skoler som ikke har noen kjente inneklimaproblemer. Usikkerheten i referanseverdien vil avhenge av antall elever. Fire av parametrene finnes det ikke referanseverdier for.*

*Spørsmål 1.14, 1.15 og 1.16 har vi per i dag ikke referanseverdier for. Derfor er spørsmålene ikke med i plottet.*

Solveig Askevold Ulsund

Evaluation of Measures to Improve Indoor Environment Norwegian Schools

NTNU

Kunnskap for en bedre verden