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Evaluation of Indoor Environment in Norwegian Schools

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1 Abstract

The purpose of this study is to examine the indoor environment for Brannfjell School in Oslo municipality and is connected with the ongoing DIGG-MIN-SKOLE project. It is reported as a school with known indoor environmental problems. The study is evaluating simple measures to improve the environment.

The study have been conducted through field measurements. Brannfjell school had two different sensors installed in the school, Airthings wave plus sensors and SLA by Schneider Electrics. These two were compared and evaluated in the context of each other. The sensors measured CO2 and Temperature levels in three different classrooms in the school.

A compared analysis of the result indicates that Brannfjell school may not have a satisfactory indoor environment. The sensors are not correctly placed and the CO2 values are already close to 1000 ppm and above 1000 ppm in some cases if readings are to be trusted. However the temperature levels seems to be in the satisfactory range. The sensors needs to be placed correctly in order to continue the study in the master thesis where field measurements, interviews, questionnaires, and computation will be conducted.

2 Sammendrag

Formålet med denne prosjektoppgaven er å undersøke innemiljøet for Brannfjell skole i Oslo kommune og er knyttet til det pågående DIGG-MIN-SKOLE-prosjektet. Det er en skole rapportert med kjente innemiljøproblemer. Studien evaluerer enkle tiltak for å forbedre miljøet.

Studiet er utført gjennom feltmålinger. Brannfjell skole hadde to forskjellige sensorer installert på skolen, Airthings wave plus-sensorer og SLA av Schneider Electrics. Sensorene ble sammenlignet og evaluert i sammenheng med hverandre. Sensorene målte CO2 og temperaturnivåer i tre ulike klasserom på skolen.

En sammenlignet analyse av resultatet indikerer at Brannfjell skole ikke har et tilfredsstillende innemiljø. Sensorene er ikke riktig plassert og viser allerede CO2-verdier nær 1000 ppm og over 1000 ppm i noen tilfeller. Disse må plasseres riktig for å fortsette masteroppgaven hvor feltmålinger, intervjuer, spørreskjemaer, og beregning vil bli utført.

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3 Introduction

In this chapter, the background and motivation for this project thesis will be introduced. It is assumed that the reader has knowledge of basic fundamentals regarding indoor environment in buildings.

This project thesis is connected with the ongoing project DIGG-MIN-SKOLE, which is funded by the Research Council of Norway. Oslobygg KF and NILU (Norwegian Institute for Air Researchi) are the project owner and project manager respectively of the DIGG-MIN-SKOLE project. In addition, NTNU, the Norwegian Asthma and Allergy Association, KLP, Airthings, Schneider Electric, GK Norge AS and Johnson Control are also participants. Several schools in the Volda and Oslo municipalities are participating in the DIGG-MIN-SKOLE project, but the scope for this project thesis will only encompass Brannfjell secondary school. It is located in Ekeberg, Oslo municipality and was built in 1972. Brannfjell is one of Oslo's biggest middle schools and has around 600 pupils distributed in 21 classes. Brannfjellskole (n.d.).

Data will be collected from staff and pupils about how they experience the indoor climate in their school. The data will be combined with air quality data from sensors in the schools' technical facilities and other indoor climate sensors. Based on this, the planned machine learning model will estimate the probability of students and staff experiencing health problems or a reduction in their well-being. It will also calculate which indoor climate factors are most likely to be responsible for any issues being faced by the staff and students, alongside identifying which measures should be implemented in order to attain the best possible effect on the indoor climate and help improve the situation at the school in a positive way.

Figure 1: Brannfjell Skole Brannfjellskole (n.d.)

3.1 Background and Motivation

Heating, Ventilating and Air Conditioning (HVAC) systems account for a substantial proportion of energy consumption in non-residential buildings and have been identified as a vital target area where significant reductions in energy use can be achieved. One report shows the loads from HVAC to comprise approximately 39 percent of commercial electricity use, of which 17 percent of the load was contributed to ventilation. Poor indoor air quality and the main pollution sources may cause adverse health effects on human health. Consequences of poor indoor air quality can be respiratory tract infections, asthma exacerbation, headache, abnormal tiredness, dry skin, dry and irritated mucous membranes of the eyes nose and throat. In the last two decades, attempts have been made to investigate the controversial relationship between indoor air quality, thermal comfort, health effect and student learning performance.

In Norway, a large number of existing buildings are still using conventional or local exhaust ventilation, which may result in an indoor climate undesirable for good health. Several studies have shown that the mean indoor CO2 concentration in many existing buildings was higher than 1000 ppm, which is the advised maximum CO2 concentration indoors. A recent study conducted in a high school in Vestfold county in Norway showed that over 30 percent of students have experienced health problems, such as headaches or concentration issues every week for the last 3 months. Over 40 percent have experienced feeling heavy-headed and over 60 percent have experienced fatigue.

3.2 Objective

The aim of the project is to investigate and evaluate the effect of indoor environment on human health in school buildings in Norway.

The following tasks are performed:

- Literature review regarding typical ventilation solutions in school buildings in Norway and how the indoor environment affect human health
- Select case buildings and rooms for data collection of indoor environment quality
- Analysis of ventilation systems in selected school buildings and preparation of measurement and user survey for school buildings
- Data collection from case buildings regarding indoor environment quality, thermal comfort and health symptoms (this task will be continued in the master thesis)
- Evaluate the indoor environment and health effect (this task will be continued in the master thesis)
- Make conclusions and suggestions for schools (this task will be continued in the master thesis)
- Prepare a short article to disseminate the research results and propose a research topic for master project (this task will be continued in the master thesis)

4 Literature review

This chapter will present the relevant theory and and literature study to this project thesis.

4.1 Indoor environment in Norwegian schools

Given the growing awareness of the adverse impacts of poor air quality there is an increasing interest in improving the indoor environment in school buildings. Indoor climate is of great importance for well-being, health and productivity. The need for better indoor climate is further heightened in Norway, as we spend on average 90 percent of our time indoors due to our climatic conditions. Vaage (2012). Children under 15 years constitute approximately 18 percent of Norway's population. SSB (2022). Students in Norway receive around 8000 hours of compulsory instruction during their primary and lower secondary education. OECD (2022). Poor IAQ can cause acute and chronic health effects, especially in the case of children as they are particularly susceptible to adverse respiratory effects. According to the Norwegian Institute of Public Health, approximately 25 percent of school-age children have asthma. NAAF (2022) It is important that the school environment does not lead to or worsen asthma or allergic diseases.

Poor IAQ also impacts the cognitive performance of students. 30 percent of teaching staff report being exposed to poor indoor climate most of the time, compared to an average of 21 percent for all other professions. SSB (n.d.) In a survey of more than 4,000 students, 38 percent said they often experienced dense and trapped air. Other environmental conditions reported were that it was either too hot or cold and the air was dry. Holøs (2015). A good indoor climate can contribute to a better learning and teaching environment and reduce absence or sick leave. Studies have been done where relationships were developed between the classroom air quality and learning outcomes, which is illustrated in figure 2. It is anticipated that reducing the negative effects of poor classroom air quality would also lead to considerable socio-economic benefits. Wargocki et al. (2020).

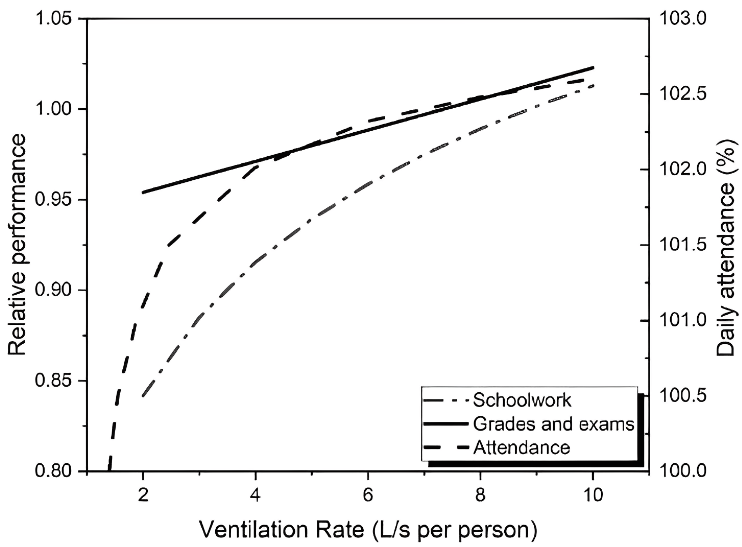


Figure 2: Performance of schoolwork, national and aptitude tests and exams, and students daily attendance as a function of classroom ventilation rates. Sadrizadeh et al. (2022)

4.1.1 Ventilation System

Mixed ventilation is the most common ventilation system in Norwegian schools and is the traditional method to supply air into ventilated areas. It is also referred to as dilution - or momentum ventilation. The air is supplied to the room with high velocity so that the room air becomes homogenous. It is possible to supply air with relatively low temperatures without causing drafts. The supply air terminal is often located on the ceiling or high on the walls, outside the zone of occupancy to avoid draught. The high velocity of the supply air will generate a re-circulation of the air in the room. Pollutants such as body odor and exhaust gases from materials will be mixed with the room air with stirring ventilation. We strive to use so much air that the pollutants are diluted to a level where they do not cause us discomfort or harm to our health. Brannfjell skole has this type of ventilation. Lin et al. (2005), Tekna (2021).

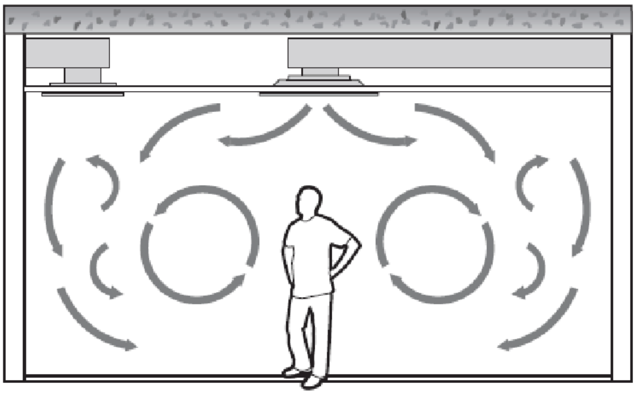


Figure 3: Mixing ventilation. Price (2016).

4.1.2 Requirements for ventilation in schools

Indoor environment in schools is regulated by a variety of laws and regulations. The Education Act states that all pupils in schools have the right to a good physical environment. Schools shall be planned, built, adapted and operated in such a way that they consider the safety, health, well-being and learning of the pupils. The school's environment shall be in accordance with the academic norms recommended by the academic authorities. Folkehelseinstituttet (2015). If certain environmental conditions deviate from these norms, schools must document that the environment has a satisfactory effect on the students.

The Buildings Regulation (TEK17) set requirements for indoor climate and health and the guidelines to TEK17 include pre-accepted standards for the supply of fresh air. Humans are usually the biggest source of pollution in buildings. In addition, there is a need to ventilate away contaminants from materials, installations and objects or user equipment. TEK17 states that the fresh air requirement can be calculated at the largest value of A + B and C, where A is person load, B is material load and C is polluting activities and processes. DIBK (2017).

In ordinary classrooms, only A and B are relevant and TEK 17 § 13-3 specifies the following requirements are applied:

1. *Fresh air supply due to pollution from people with light activity must be a minimum of 26 m3 per hour per person. At activity levels other than light activity, the fresh air supply must be adjusted so that the air quality is satisfactory.*

2. *Fresh air supply due to pollution from materials, products and installations must be kept to a minimum of:*

(a) *2.5 m3 per hour per m2 floor area when the rooms are in use*

(b) *0.7 m3 per hour per m2 floor area when the rooms are not in use.*

4.1.3 Thermal climate requirements

The guidelines for TEK17 and regulations on the environmental health protection in schools state that operating temperature must be kept between 19-26 °C, except in the case of particularly high outdoor temperatures. The temperature in classrooms should be kept under 22 °C in the heating season. Higher air temperature will result in a drier air which leads to lower air quality and therefore an increase in ventilation demand. DIBK (2017).

4.2 Thermal comfort

Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment, and it is assessed by subjective evaluation. ASHRAE (2017). Thermal comfort is important in schools, since it affects human productivity and their well-being. Thermal discomfort can substantially reduce the key aspects of individual human efficiency, such as reading and thinking logically. Different studies have shown that productivity of many routine tasks has been reduced as much as 15 percent under thermal stress. Wyon (1996). Thermal comfort depends on six different parameters, which can be divided into two groups, environmental and personal parameters. The environmental parameters consist of air temperature, mean radiant temperature, relative air velocity and relative humidity. The personal parameters are metabolic rate and clothing insulation. According to studies done by ASHRAE, an environment where 80 percent of the occupants are satisfied the thermal environment is acceptable. Due to the existence of biological differences between every single person, it is difficult to satisfy all occupants at the same time.

4.2.1 Thermal Comfort standards:

Most used standards regarding thermal comfort are ASHRAE 55 and ISO 7730. Both formed their standards for comfortable thermal environments from P.O. Fanger's comfort equations, which is the combined quantitative combination of the environmental and individual variables. Fanger et al. (1985). The environmental variables are dry-bulb air temperature, mean radiant temperature, relative air velocity and relative humidity. Individual variables are affected by the activity level (metabolism rate) and the clothing level (degree of insulation). ASHRAE 55 specifies boundaries and implies that 90 percent of the occupants should find the thermal environment acceptable, if the environment is thermally uniform. The framework defined in ASHRAE 55 is only concerned with steady state cases where ISO 7730 is evaluating changes over time. The general output of data for each standard is the Predicted Mean Vote (PMV) and Percentage of people dissatisfied (PPD). Ekici (2013).

4.2.2 Predicted Mean Vote

The PMV is an index that predicts the mean value of occupants on the seven-point thermal sensation scale, seen in table 1, based on the heat balance of the human body. Thermal balance is obtained when the internal heat production is equal to the loss of heat to the environment. Markov (2002).

Scale	Thermal Sensation	Description
3	Very Hot	Intolerably warm
2	Hot	Too warm
1	Slightly warm	Tolerably uncomfortable, warm
0	Neutral	Comfortable
- 1	Slightly cold	Tolerably uncomfortable, cool
- 2	Cold	Too cold
- 3	Very Cold	Intolerably Cold

Table 1: Thermal sensation scale

4.2.3 Percentage of People Dissatisfied

Through PMV, the prediction of the thermal sensation of the occupants can be predicted. The PPD is an index that establishes a quantitative prediction of the percentage of thermally dissatisfied, people who feel too warm or too cool. It is characteristic of the PPD index that its value does not fall below 5 percent of any value of PMV. The reason for this occurrence is because of the difference in thermal sensation between individuals is not identical. PPD essentially gives the percentage of people predicted to experience local discomfort. Markov (2002).

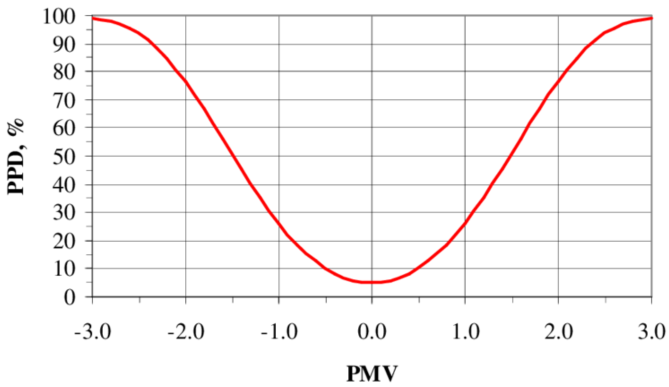


Figure 4: Relationship between PPD and PMV. Markov (2002)

4.2.4 Local Thermal Discomfort

The comfort equation predicts the dissatisfaction with the environment due to discomfort of the body as a whole, but thermal dissatisfaction can also be caused due to unwanted heating or cooling of one specific part of the body. This phenomenon is called local thermal discomfort and is grouped under four categories.

Firstly, draught is the most common complaint for indoor climate. Draughts is caused due to heat loss from the skin and depends on the air velocity, the turbulence and the air temperature. A highly turbulent airflow causes more discomfort compared to a low-turbulent flow and is dependent on the fluctuation of the skin temperature. To predict the PPD due to draught, the index draught rating (DR) can be used.

Secondly, you have radiant temperature asymmetry. This is a term introduced by Fanger to describe the asymmetry of a radiant field. The amount of people dissatisfied due to hot or cold windows, walls, ceilings and heated panels. Limits specified by ISO 7730 is that the radiant temperature asymmetry from windows or other cold vertical surfaces should be less than 10° C, and from a warm ceiling should be less than 5° C. Fanger et al. (1985).

Thirdly, vertical air temperature differences can cause local thermal discomfort. This is caused by large differences in temperatures between the head and the ankles. According to studies, optimal results can be obtained if the upper limit of 3° C is maintained.

Finally, hot or cold feet caused by the floor temperature are another reason for local thermal discomfort. The heat loss is influenced by the conductivity, the heat capacity of the material of the floor and the footwear. In order to avoid heat loss in the feet an optimal level of floor temperature should be maintained, which has been suggested by studies to be 24° C. Markov (2002).

4.3 Indoor Climate Parameters

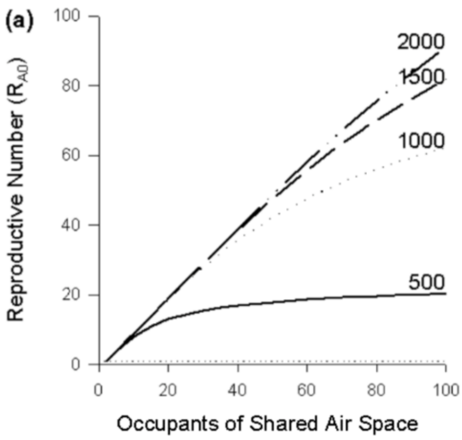
A few parameters were examined to analyze the indoor climate conditions in the Brannfjell school building, including Carbon Dioxide concentration, Relative Humidity and Volatile Organic Compounds. These parameters are common variables examined in studies on IAQ.

4.3.1 Carbon Dioxide

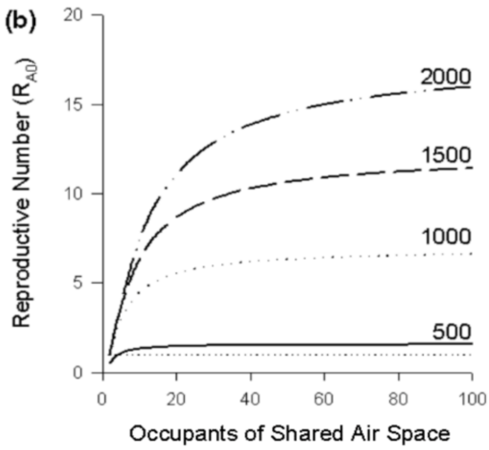
Carbon dioxide (CO2) is a gas that is present in the atmosphere and is exhaled by humans. In indoor spaces, the concentration of CO2 can build up as a result of the respiration of people and pets, as well as from other sources such as combustion appliances, tobacco smoke, and the use of certain products like paints and solvents. CO2 is an important indoor climate parameter because it can affect the air quality and the comfort of the people occupying the space. High levels of CO2 can lead to increased fatigue, headaches, and difficulty concentrating, which can affect productivity and overall well-being. Federspiel et al. (2004).

The concentration of CO2 in indoor air is typically measured in parts per million (ppm). The maximum concentration of CO2 that is considered safe in indoor spaces is a topic of debate, and there are no strict standards that apply in all cases. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) recommends that the concentration of CO2 in indoor air should be kept below 1,000 ppm. But other studies imply it should be below 800 ppm. Satish et al. (2012).

Risk of airborne transmission is also higher with the concentration of CO2. A study done by using the Wells-Riley equation gives a model for the reproduction number for how contagious a disease can be inside a building, assuming there exist at least one carrier inside the the room. Rudnick and Milton (2003).



(a) Measles, q = 570 quanta/h, t = 10 h



(b) Influenza, q=100 quanta/h, t=4 h

Figure 5: R_{A0} for airborne disease as a function of number of occupants in a room and concentration of CO_2 (ppm). $C_0 = 350$ ppm, $C_a = 37\ 500$ ppm, same in both models. Rudnick and Milton (2003).

The study shows that the reproductive number of a disease is lower for lower CO2 concentrations. To maintain good indoor air quality and comfortable conditions, it is important to ensure that there is sufficient ventilation to allow for the exchange of indoor and outdoor air. This can help to lower the concentration of CO2 and other contaminants in the air.

4.3.2 Relative Humidity

Relative humidity (RH) is the measure of the amount of moisture in the air relative to the maximum amount of moisture the air can hold at a given temperature. It is expressed as a percentage, with 100 percent relative humidity indicating that the air is fully saturated with moisture and cannot hold any more.

In an indoor space, relative humidity can affect the comfort and well-being of the people occupying the space, as well as the condition of the building and its contents. As illustrated in the figure below, high relative humidity can lead to increased levels of mold and dust mites, which can trigger allergies and other respiratory issues. On the other hand, low relative humidity can cause dryness in the air, which can lead to dry skin, throat and eyes, in addition to creating static electricity. Arundel et al. (1986).

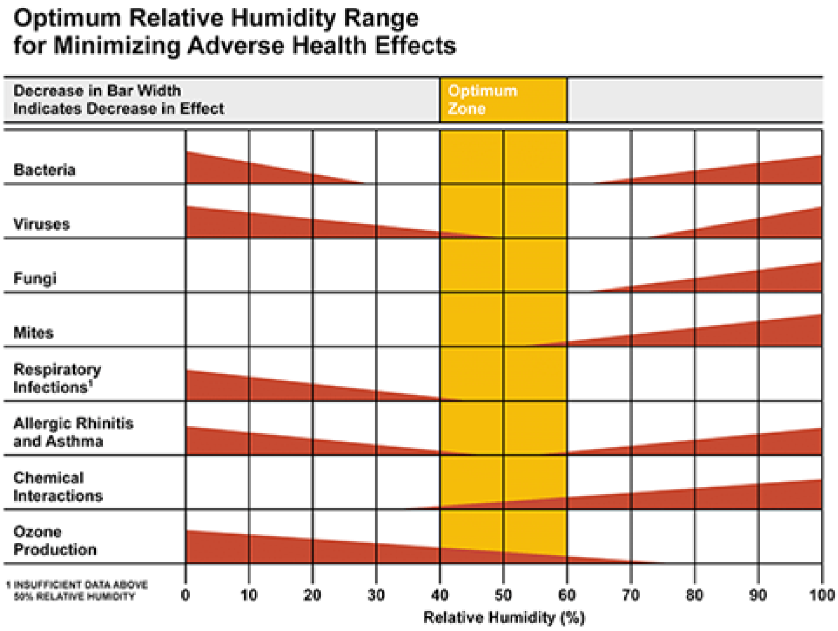


Figure 6: Optimum Relative Humidity Range. Arundel et al. (1986).

ASHRAE recommends maintaining relative humidity levels between 30 percent and 60 percent in indoor spaces to promote comfort, minimize the risk of adverse health effects and damage to building materials. The ideal relative humidity level may vary depending on the climate, season and activities taking place in the space.

In Norway the most common problem during heating season is dry air. This occurs because the air supply is being extracted from a cold outside temperature and results in a loss of water vapour when it is heated up. This can be reduced with the use of a humidifier for indoor air, however this should be avoided due to the risks of moisture damage to materials. Bjørheim (2019).

4.3.3 Volatile Organic Compunds

Volatile organic compounds (VOCs) are gases that are emitted by certain materials, products and activities. They are found in a wide range of products, including paints, cleaning supplies, building materials and personal care products. VOCs can also be released from combustion sources such as tobacco smoke and vehicles. EPA (2022).

VOCs can have a negative impact on indoor air quality and the health of the people occupying the space. Some VOCs can cause irritation to the eyes, nose and throat, as well as headaches, dizziness and other symptoms. Long-term exposure to high levels of VOCs may also have more serious health effects, such as damage to the liver, kidney and central nervous system. EPA (2022).

To improve indoor air quality, it is important to reduce the use of products that contain VOCs, and to ensure that there is sufficient ventilation in the space to allow for the exchange of indoor and outdoor air. It is also recommended to use low-VOC or VOC-free products whenever possible.

5 Methodology

5.1 Questionnaire

A questionnaire has been prepared to distribute to occupants in the school building in the next semester. It was developed to achieve an accurate representation of both the health symptoms experienced by staff and students and the perceived IAQ in the school. Since the same questionnaire will be used in other schools in the future, in addition to the fact that occupants range from 4th year in elementary school up to 13th grade in high school, it was important that it was user friendly and easy to understand. Another factor that was kept in mind while designing the questionnaire was regarding the number of questions to include, as it should be done in a short amount of time so it does not disturb the learning of the children and interrupt the classes.

It is designed by NILU and will be a web based questionnaire where occupants can easily access it through a tablet, phone or computer. The first page will be divided into four to five different categories consisting of air quality, temperature, sound, light and health. Next to the questions an icon will also be placed to ensure an easier understanding for all participants. The options on the questionnaire will be scaled with smiley faces which are equivalent to Very satisfied - Satisfied - Not so Satisfied - Not satisfied at all. The design will be similar to the figure illustrated below.

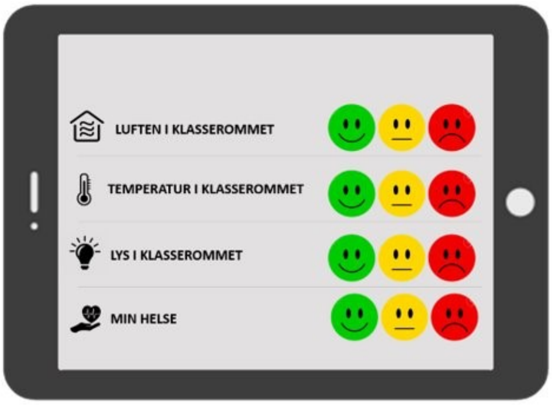


Figure 7: First page of the questionnaire

If the user chooses an option other than Very satisfied, a new page will open up where there will be a seven-point Likert scale on most of the new questions. This range was chosen to give detailed answers for the machine learning model which will be implemented later. This makes it easier to estimate the PPD and PMV and also gives the opportunity to register a neutral alternative.

Since some questions will reflect long term effect of IEQ on health, and some questions evaluate short-term effect, some of the question will occur more frequent than others and can be managed by a time interval. In this way the most important data can be gathered efficiently. The questionnaire is anonymous, so no personal data is obtained in the survey. The questions are based on previous "Mitt inneklima" (My indoor Climate) surveys. NAAF (2016).

5.2 Field Measurements

5.2.1 Equipment

The equipment used for the purpose of data gathering of field measurements was Airthings Wave Plus sensors and The SpaceLogic SLA Series sensors by Schneider Electrics.

The parameters measured by Airthings Wave Plus are radon, VOCs, CO2, relative humidity, temperature, and air pressure. The logging interval for this sensor is five minutes and the sensor specifications are shown in table 2. The sensors use advanced technology to continuously monitor and measure the levels of various indoor air parameters, and the data can be displayed on an accompanying app or dashboard. A detailed sensor specification is given in the appendix. Airthings (n.d.).

For The SpaceLogic SLA Series by Schneider Electrics, the parameters measured are only CO2 and temperature as this is an old management system. The logging interval for this sensor is event based. Everytime the measuring value changes by a certain value it will be logged. For this thesis the configuration settings were set to default, where the logging delta was 10 ppm for CO2 and 0.2 °C for temperature. The sensor specifications are shown in table 2. A detailed sensor specification can be found in the appendix. Schneider (n.d.).

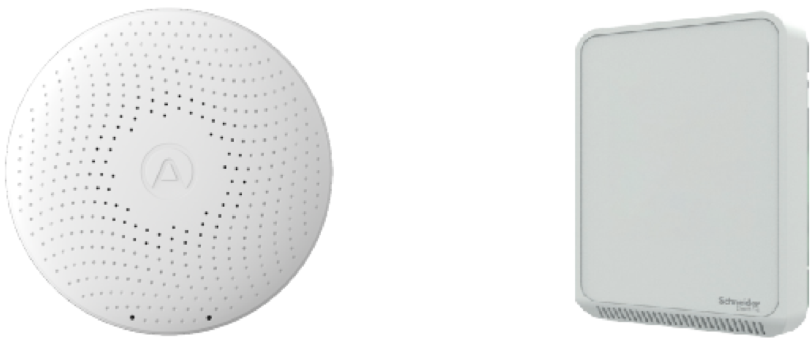


Figure 8: Airthings Wave Plus Sensor (left) and SLA sensor (right). Airthings (n.d.), Schneider (n.d.).

Sensor specifications	**Airthings Wave Plus**	**SLA sensor**
CO2 Accuracy:	± 30 ppm or ± 3 percent	± 30 ppm or ± 3 percent
Resolution:	1 ppm	-
Range:	400-5000 ppm	0-5000 ppm
Temperature		
Accuracy:	± 0.1 °C	± 0.2 °C
Resolution:	0.1 °C	0.1 °C
Range:	4 °C - 40 °C	0 °C - 50 °C

Table 2: Sensor specifications for both sensors. Airthings (n.d.), Schneider (n.d.).

5.2.2 Measurement locations

The data obtained from the sensors was conducted in the period between 01.11.22 to 30.11.22 during opening hours of 06:00 - 17:00. All the classrooms that had the Airthings sensor were compared for the amount of time the CO2 ppm was over unacceptable values. They were compared for CO2 over 800 and 1000 ppm, Temperature over 22 °C and under 19 °C. They were also compared for relative humidity under 30 percent and VOCs over 250 ppm. In the appendix all the values can be seen. After the data had been collected and analyzed three classroom were chosen for the purpose of this project thesis in order to present the varying range of results:

- Classroom 23 - With the average amount of time with CO2 over unacceptable values.
- Classroom 26 - with the highest amount of time with CO2 over unacceptable values and allegedly the one with the worst IAQ.
- Classroom 34 - With the least amount of time with CO2 over unacceptable values and allegedly the one with the best IAQ.

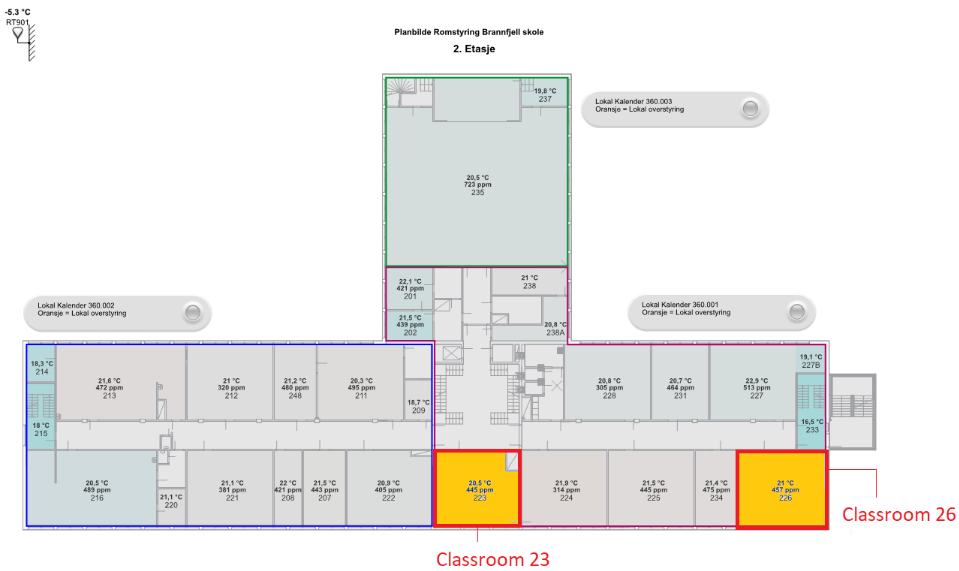


Figure 9: 2. floor with measured classrooms

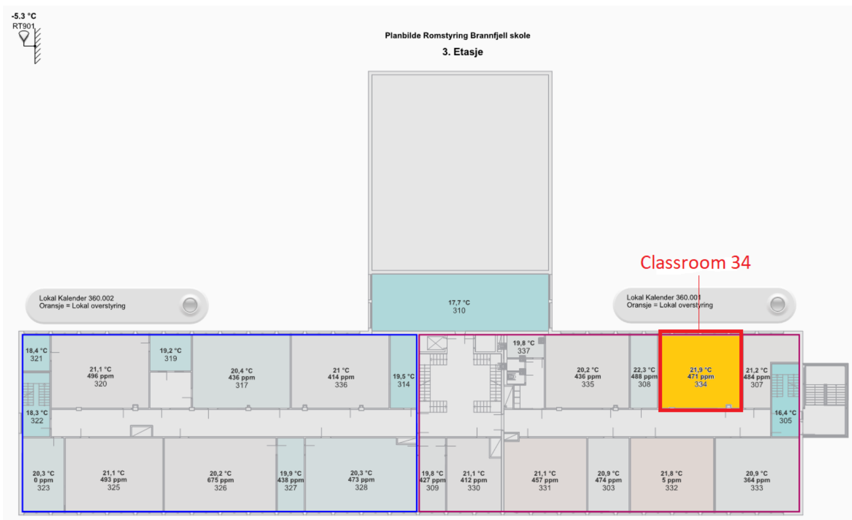


Figure 10: 3. floor with measured classroom

5.2.3 Sensor locations

The sensors are placed differently in each room which may affect the right measuring value. Both sensors are supposed to be located inside the occupancy zone, which is defined as a cube with vertical surfaces usually 0.6 m from the outer walls and 0.2 m from the inner walls. The horizontal surface range is between 0.05 m to 1.8 m above the floor. Nemitek (2019).

Classroom 23

Both sensors are located 2.2 m above the floor and against the wall as can be seen in the figure below. Red rings are for the SLA sensor and the blue rings are for the Airthings sensor.

Figure 11: Classroom 23 with sensor location

Classroom 26

For classroom 26 the sensors are placed on each side of the blackboard as can be seen in the figures below.

Figure 12: Classroom 26

Figure 13: Sensor location in Classroom 26

Classroom 34

For classroom 34 both sensors are placed on the wall next to a pupils desk as can be seen in the figure below:

Figure 14: Sensor location in Classroom 34

5.2.4 Collection of Data

In the case of the Airthings Wave Plus sensors the data was gathered with the help of John Charles Almén, who provided access to the live dashboard data being collected by the sensors in Brannfjell School.

In the case of the SLA Schneider Electrics sensors the data was gathered with the help of Erik Gustafsson, who provided all the data collected by these sensors in Brannfjell School.

6 Results and Discussion

6.1 Field measurements

The results from the field measurements in the classrooms at the school are illustrated in the figures below. Both the SLA Schneider sensors and the Airthings Wave Plus sensors are compared for CO2 and Temperature. Since the measurements of the SLA sensors were event-based the readings shown in the charts are more compact compared to the Airthings sensors, which are more spread out since it has a 5 min interval. All measurements are obtained from opening hours 06:00-17:00 everyday.

CO2 in Classroom 23

For classroom 23 both values are under 1000 ppm, but the SLA sensors seem to measure a slightly higher CO2 value.

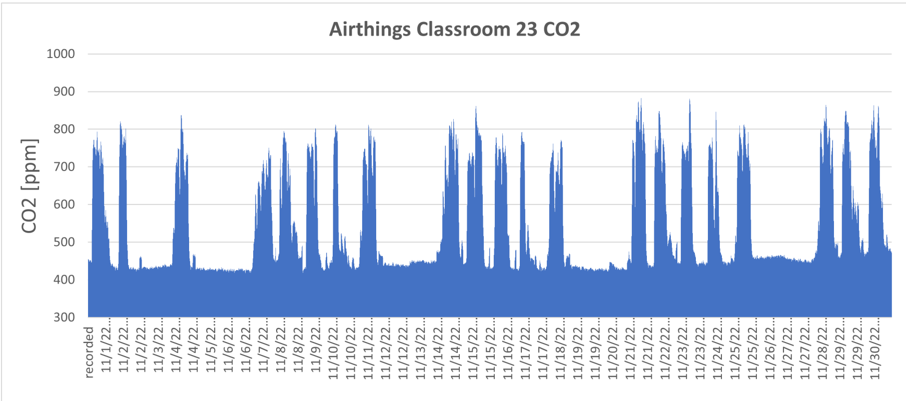


Figure 15: CO2 ppm from Airthings sensor in Classroom 23

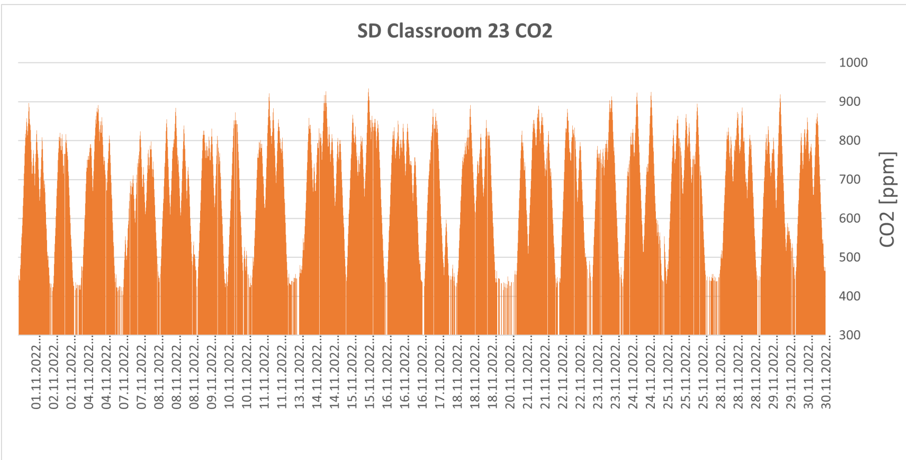


Figure 16: CO2 ppm from SLA sensor in Classroom 23

Temperature in Classroom 23

Both sensors are relatively similar and are inside the recommended values 19-22 °C. The SLA sensor measures a slightly higher temperature than the Airthings sensor.

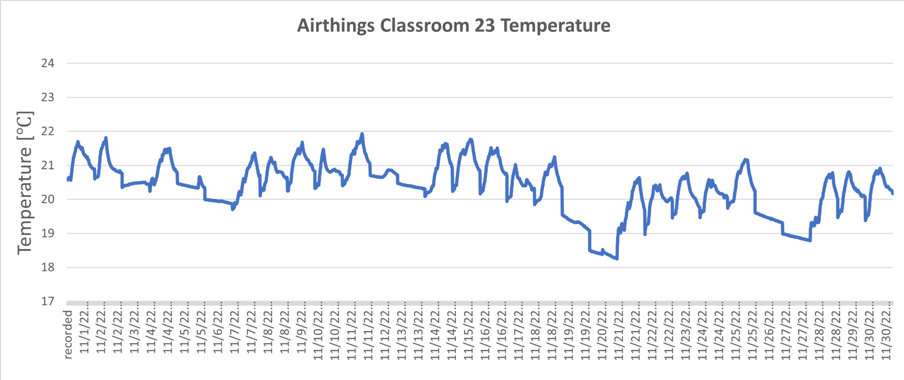


Figure 17: Temperature from Airthings sensor in Classroom 23

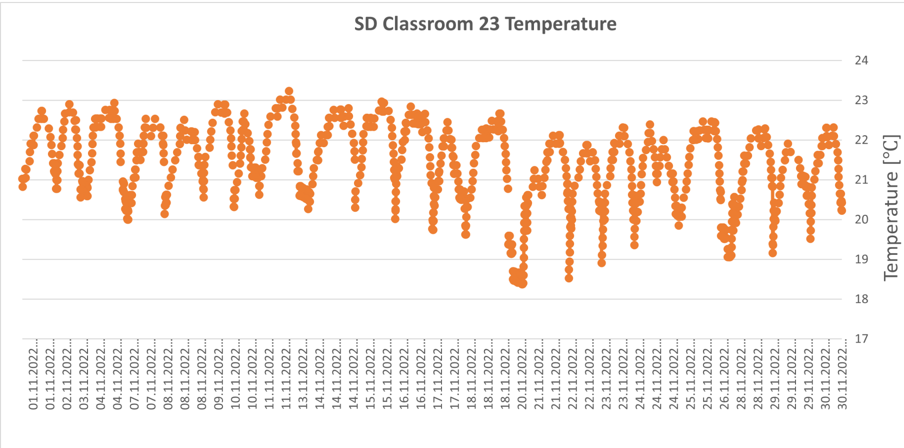


Figure 18: Temperature from SLA sensor in Classroom 23

CO2 in Classroom 26

For classroom 26 the sensors have a large difference. The Airthings sensor measures a CO2 over 1000 ppm and even up to 1200 ppm, while the SLA sensor has the highest value at 800 ppm.

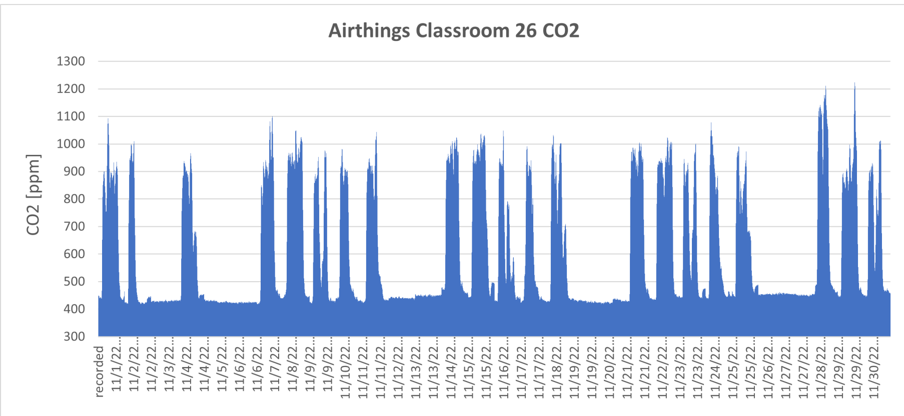


Figure 19: CO2 ppm from Airthings sensor in Classroom 26

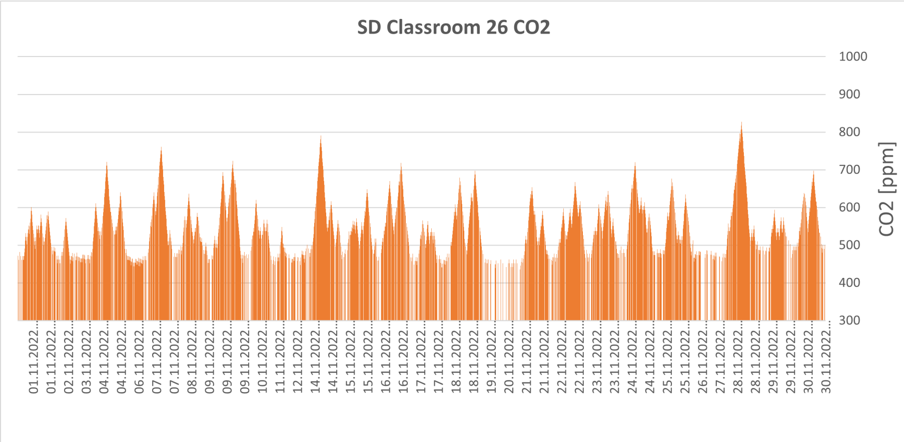


Figure 20: CO2 ppm from SLA sensor in Classroom 23

Temperature in Classroom 26

Both sensors are quite similar for the temperature values.

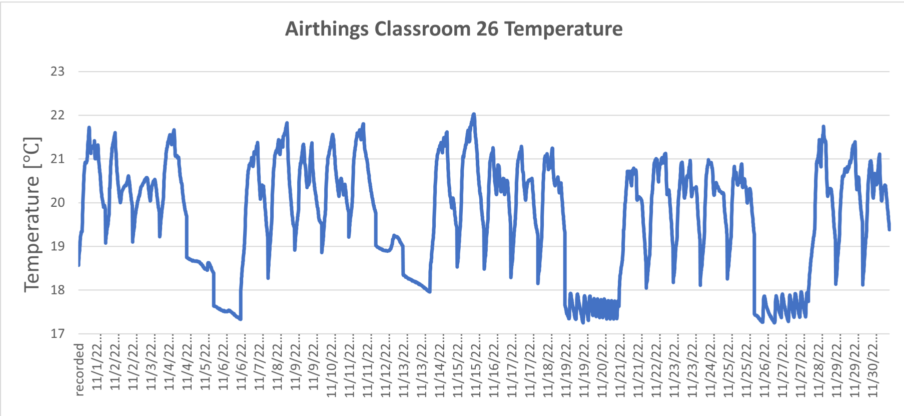


Figure 21: Temperature from Airthings sensor in Classroom 26

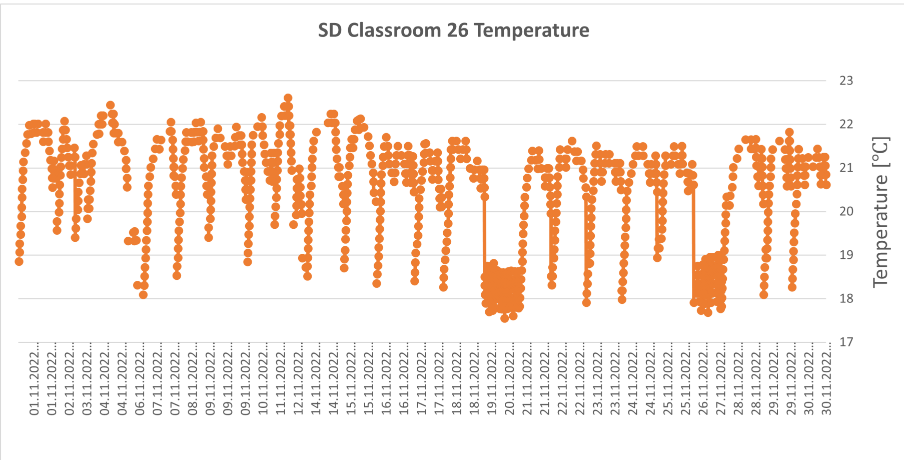


Figure 22: Temperature from SLA sensor in Classroom 26

CO2 in Classroom 34

Both sensors also have a quite different CO2 value here. But now the Airthings sensor is measuring a lower value with an average between 600-700 ppm. Where the SLA sensor is indicating a value around 900-1000 ppm.

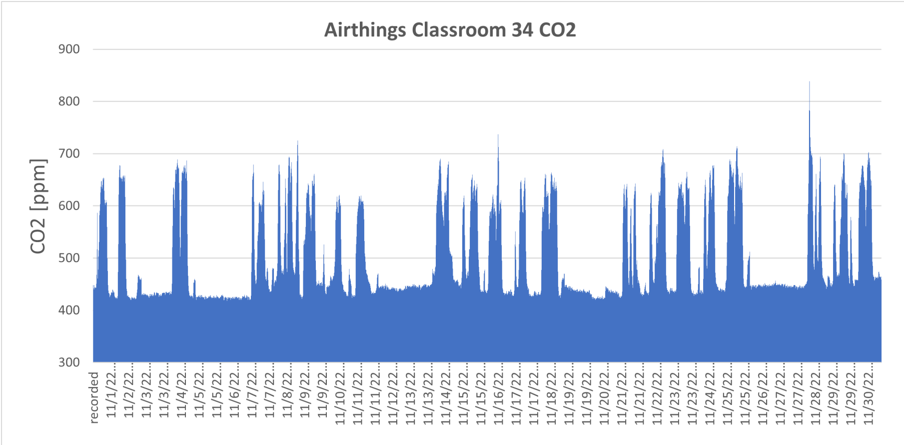


Figure 23: CO2 ppm from Airthings sensor in Classroom 34

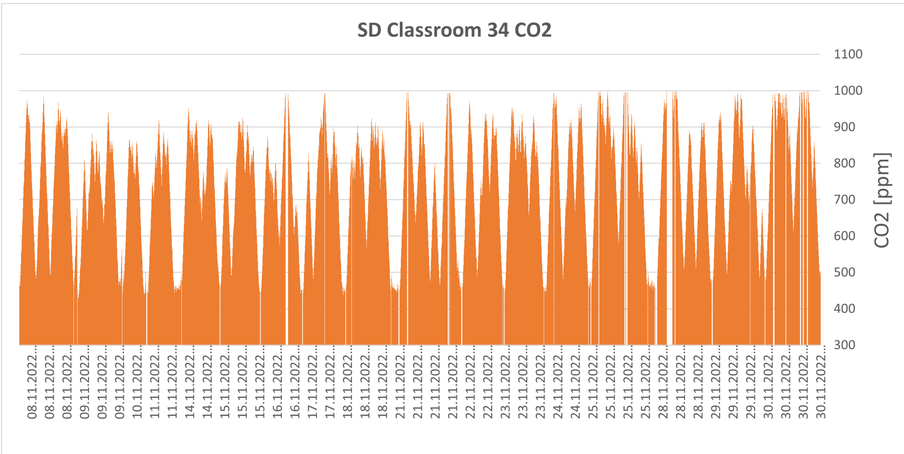


Figure 24: CO2 ppm from SLA sensor in Classroom 34

Temperature in Classroom 34

The temperature measured is sightly different as the SLA sensor is almost one degree higher for all measured values.

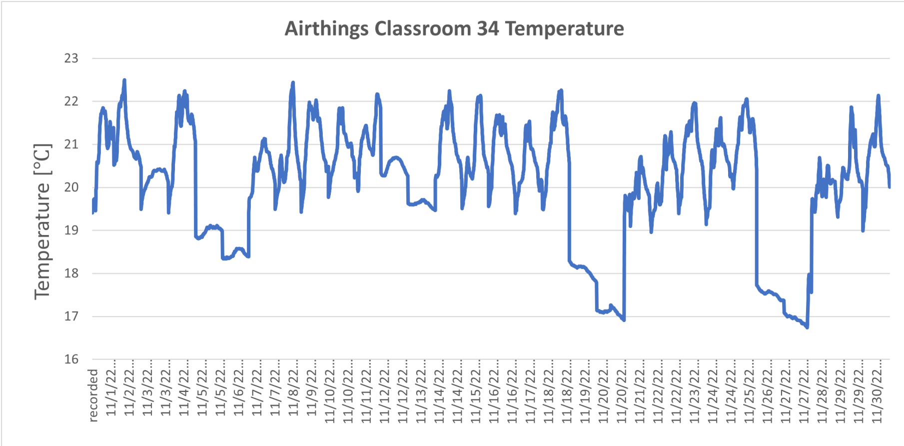


Figure 25: Temperature from Airthings sensor in Classroom 34

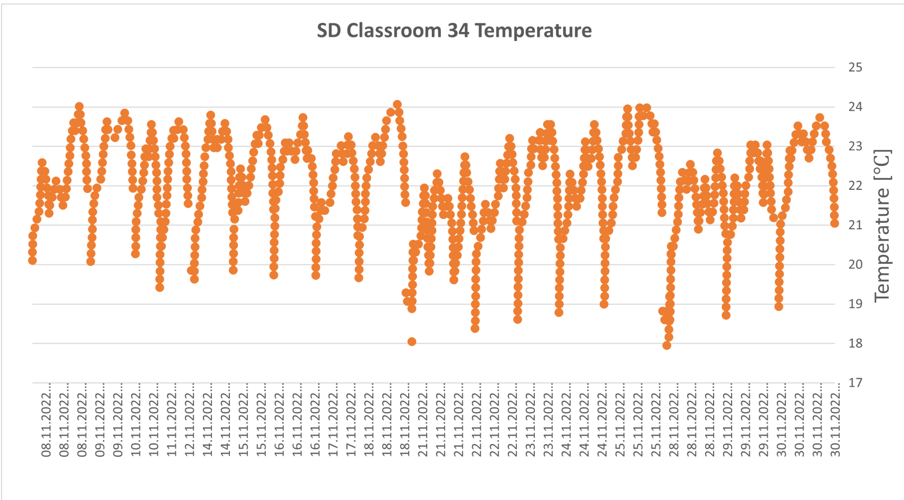


Figure 26: Temperature from SLA sensor in Classroom 23

6.2 Discussion

From the field measurements classroom 23 seems to have good CO2 values because its under 1000 ppm, but as mentioned earlier the sensors are placed outside the occupancy zone and does not give a realistic impression of what the real value actually is. Results from the field measurements show that the temperature in the classrooms is within the recommended range of 19 - 26 °C. But the readings acquired from the SLA sensors show temperature over 22 °C which is slightly too hot in the heating season and can lead to dry air.

For Classroom 26 the Airthings sensor is showing CO2 values over 1000 ppm, while the SLA sensor is showing very low and satisfactory results. This needs to be further investigated, as the SLA sensor may need to be changed or something is blocking it due to its placement. In case of temperature readings both sensors have provided quite similar and satisfactory data.

For Classroom 34 the Airthings sensor is showing satisfactory and low CO2 values while the SLA is showing values close to 1000 ppm. This also needs to be further investigated, but may be due to the placement of the SLA sensor being next to a pupils desk. The temperature readings of the SLA sensor is consistently 1 degree higher compared to the Airthings sensor.

All sensors needs to be placed correctly and it needs to be made sure that it is not being blocked by another heat or pollution source. Furthermore all sensors providing varying results in the same classroom must be checked for the need of calibration. In addition the designed set point for ventilation rate should be considered according to the placement of the sensors.

If there is not an opportunity to change the location of the sensors permanently into the occupancy zone, a temporary test should be conducted in order to determine the correct set point for the ventilation system. In order to do this, a sensor should be temporary placed within the occupancy zone and it should be compared with the existing sensors to determine what the reading on the existing sensors are when the new sensor hits the set point. Once this is determined the new set-point on the existing sensors should be adjusted accordingly.

7 Limitations of the study

To get a full understanding of the indoor air quality in the building, more information about the ventilation system needs to obtained. However, the equipment and time limitations made this impossible. Since the ventilation system is old, it is difficult to obtain the technical data and ventilation rate. OslobyggKF are still working on gathering information about the system for the master thesis. Due to time limitations and clash of schedules, even though a survey had been prepared for the staff and students it could not be completed in time.

8 Conclusion

In this project thesis, the results from investigations at Brannfjell skole were presented. The field measurements revealed that the temperature levels were relatively satisfactory but the CO2 concentration reaching over 1000 ppm in two rooms implies an insufficient ventilation rate.

One conclusion which can be drawn with certainty is that the placement of the IAQ sensors in all classrooms need to be as per the guidelines provided. Consistency of placement is key to all classrooms in order to obtain useful data. The placement of the sensors should be reevaluated and investigated. All sensors for measuring indoor climate should be placed so that they are as representative as possible of the IAQ in the room. Placement at head height on an interior wall with a good distance from doors, windows and heat sources is recommended. Sensors being placed in the exhaust valve is a possibility, mainly because they are less prone to vandalism, but such placement requires a good mixture of the air in the room to be able to show correct values and may give misleading values if the ventilation not sufficient.

In order to obtain results with absolute certainty the above mentioned recommendations need to be followed, otherwise due to the negligent placement of the sensors it deems them obsolete as their readings cannot be trusted. Therefore, the true CO2 levels must be determined in order to get clarity on whether the ventilation rate is insufficient or not. For further evaluation of the schools' environment the surveys need to be conducted and the staff members interviewed.

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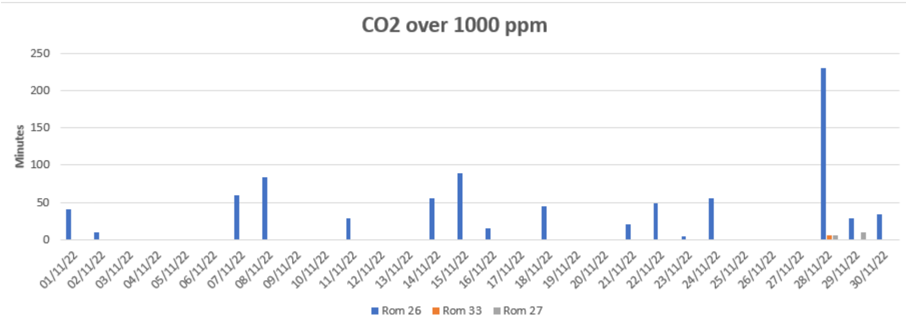
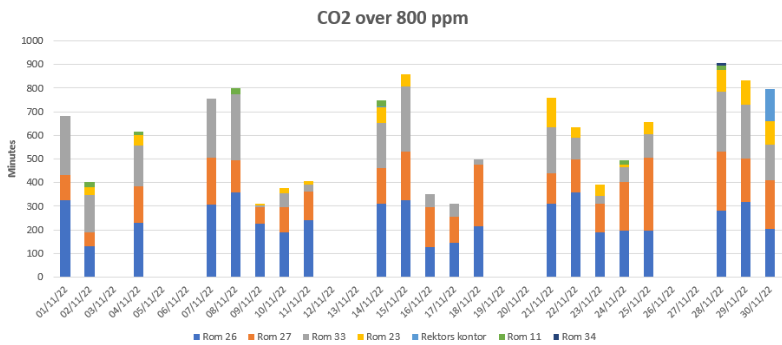
Appendix

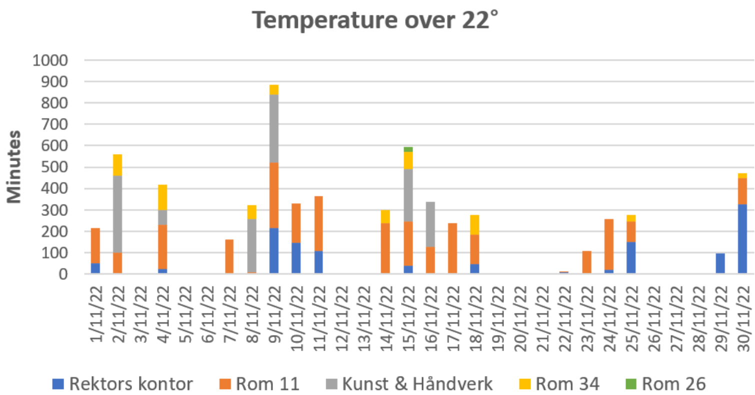
A Results from comparing different rooms



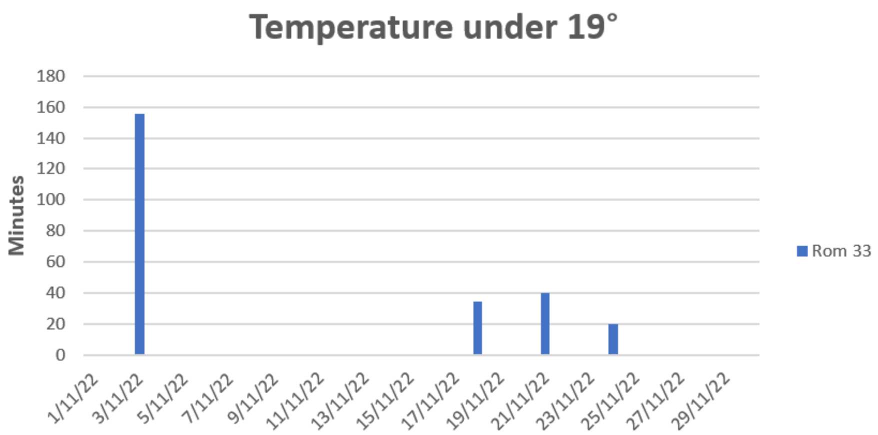
Amount of minutes with CO2 over 1000 ppm during opening hours from 1.11 to 30.11



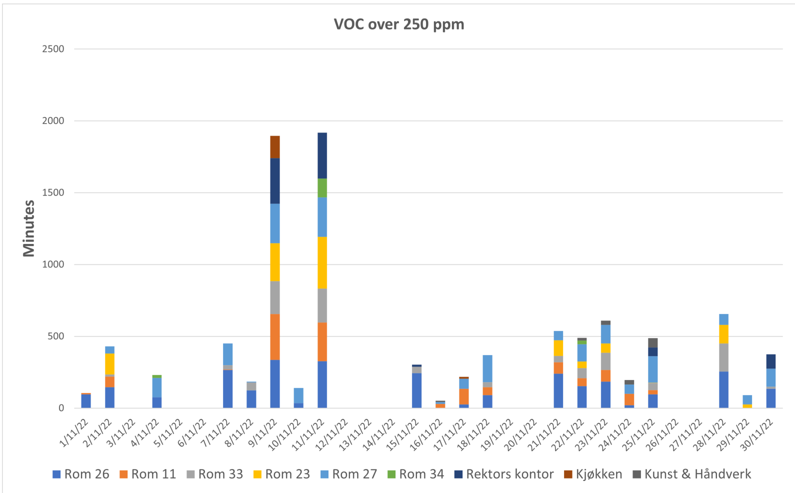
Amount of minutes with CO2 over 800 ppm during opening hours from 1.11 to 30.11



Amount of minutes with temperatures over 22° or under 19° during opening hours from 1.11 to 30.11



Amount of minutes with temperatures under 19° during opening hours from 1.11 to 30.11



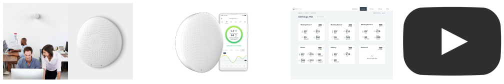
Amount of minutes with VOCs over 250 ppm during opening hours from 1.11 to 30.11

AIRTHINGS

Wave Plus

Radon and Indoor Air Quality Monitor

DOWNLOADS



We spend 90% of our time indoors where the air is often 2 to 5 times worse than the air outside. Continuous monitoring of indoor air quality is key for minimizing negative health effects, preventing illness and increasing productivity, energy and good health. Airthings, air quality specialists and experts in radon, created the Airthings Wave Plus as the first smart air quality monitor with radon detection. Wave Plus has since won multiple awards for consumer electronics, innovation and was among the 2019 TIME Magazine inventions of the year. It is the perfect solution for homeowners to gain full visibility into six indoor air factors; radon, carbon dioxide (CO_2), airborne chemicals (TVOCs), humidity, temperature and air pressure. Airthings Wave Plus includes a free app (iOS/Android) and an online dashboard with advanced analytics.

AIRTHINGS DASHBOARD

The Airthings Wave App and online dashboard provide a quick and easy solution to view, compare and export data for your particular needs. Users have complete access to interpretations of IAQ data and tips to reduce indoor air hazards, optimize ventilation and save energy.

PRODUCT FEATURES

Sensors: Radon, CO_2, TVOC, Temp, Humidity & Air Pressure
Visual indicator: Red/Yellow/Green glow ring
Long battery life:
  Bluetooth: 16 months
  SmartLink (Hub): 18 months
Supports wall or ceiling mount
Free mobile app for iOS and Android
Web dashboard
Mobile notifications
Wireless connection (Bluetooth or Airthings SmartLink)

ADDITIONAL SPECIFICATIONS

Operational Environment: 4°C to 40°C
Weight: 219g (with batteries)
Dimensions: 12 cm (diameter) x 3.6 cm (height)
Power: 2 AA batteries
Connectivity: Bluetooth & Airthings SmartLink

EASY INSTALLATION WITH APP

To install the Wave Plus simply download the Airthings Wave App, pull the battery tab, mount it to the wall or ceiling, and follow the easy instructions in the app to register your device. In addition, simply wave in front of the device to receive a color-coded visual indicator of the overall air quality.

IAQ SENSOR SPECIFICATIONS INTEGRATIONS

Sensor sampling interval: 5 minutes
Sensor Resolution:
  Temperature ∓ 0.1°C / F
  Humidity ∓1%
  Pressure ∓0.15hPa
Settling time:
  TVOC ~7 days
  CO_2 ~7 days
CO_2 details:
  NDIR Sensor (Non-Dispersive Infra-Red):
  Measurement range 400–5000 ppm
  Non condensing 0 – 85%RH
  Optimum Accuracy ±30ppm ±3% within 15 – 35°C / 60 - 95°F
  and 0 – 80%RH can be reached after multiple settling
  cycles on locations with natural indoor CO_2 fluctuations

Works with IFTTT
amazon alexa
works with the Google Assistant

RADON SPECIFICATIONS

Radon sampling: Passive diffusion chamber
Detection method: Alpha spectrometry
Measurement range: 0 – 500 pCi/L / 0 – 20,000 Bq/m^3
Accuracy/precision at 5.4 pCi/L / 200 Bq/m^3:
After 7 days ~ 10 %   After 2 months ~ 5 %

ADDITIONAL INFORMATION

PACKAGE CONTENT

Air Quality Detector
2 AA batteries
Instruction Manual

PRODUCT CODES

EAN: 7090031109301
UPC: 854232008033
SKU: 2910

REQUIREMENTS

One of the 3 latest major versions of iOS or Android, supporting

PACKAGE

Weight: 346g / 12.2 oz
Dimension: 153x153x46mm / 6x6x1.8

RADON TVOC CO_2 HUMIDITY TEMP PRESSURE

SpaceLogic Sensors
Air Quality Sensors – Analog

Note: A subset of models shown.

Product Description

The SpaceLogic SLA Series of air quality sensors for living space is a flexible multisensor platform for use with BAS controllers designed to accept 4 to 20mA, 0 to 5Vdc or 0 to 10Vdc outputs. Housings are available in Medium matte white and Optimum faces available in black and white. All housing types are available with three user interface options: touchscreen, LCD with three buttons and blank. CO_2 and temperature sensors are included with all SLA Series air quality sensors. Models with VOC sensors and relative humidity sensors are also available.

Features

- Medium matte white housing or optimum glass panel housing available in white or black
- Field calibratable non-dispersive infrared CO_2 sensor
- Replaceable RH element available in 1% & 2% with NIST certificate
- VOC sensor available
- Temperature output on all models
- 61 mm (2.4”) backlit color touchscreen and LCD, three button display options available
  - Digital temperature indication (0.1° display resolution of °F or °C
  - Digital humidity indication (0.1% RH display resolution)
  - Digital CO_2 indication (0 to 2000 ppm display resolution)
  - Stoplight feature for visual indication at user-configurable CO_2 threshold levels (touchscreen models only)
  - Selectable temp, RH and fan speed setpoint (0-10V)
  - Configurable screen/button lock and display timeout
  - Override
- Selectable 4 to 20mA, 0 to 5V and 0 to 10V analog outputs
- 18-24 AWG screw terminals

Available Products Matrix

	Housing	User Interface	CO_2 Sensor	RH Sensor*
SLA	☐	☐	☐	☐
	S = Medium white matte housing	T = Color touchscreen	C = NDIR CO_2	2 = 2%
	W = Optimum white housing	L = 3-button LCD display	CV = NDIR CO_2 / VOC	X = None
	B = Optimum black housing	X = None		

Example: SLA S T C 2

*Replaceable RH module available to be ordered separately per table below.

Replaceable RH Elements

Model	RH Accuracy	Calibration Certificate	Description
SLXRHS1N	±1%	X	Replaceable RH Sensor, 1% w/NIST Cert
SLXRHS2N	±2%	X	Replaceable RH Sensor, 2% w/NIST Cert
SLXRHS2X	±2%		Replaceable RH Sensor, 2%

USA: +1 888-444-1311
Europe: +46 10 478 2000
Asia: +65 6484 7877
www.schneider-electric.com

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April 2022
Z207900-0H nk

Specifications

Operating Environment	
Input power	Class 2; 20 to 30 Vdc, 24 Vac, 50 to 60 Hz
Analog output	Selectable 4 to 20 mA, 0 to 5 V, 0 to 10 V
Operating temp. range	0 to 50 °C (32 to 122 °F)
Operating humidity range	0 to 95% RH non-condensing
Housing material	High impact ABS plastic
IP rating	IP 30
Mounting location	For indoor use only. Not suitable for wet locations.
Surface mount	The device can be surface mounted on Single Gang J-Box, British Standard and CE60 wall boxes
CO_2 Sensor	
Sensor type	Non-dispersive infrared (NDIR), diffusion sampling
Output range	0 to 2000/5000 ppm (selectable)
Accuracy	±30 ppm ±3% of measured value
Repeatability	±20 ppm ±1% of measured value
Response time	<60 seconds for 90% step change
VOC Sensor	
Sensor type	Solid state
Output range	0 to 100% AQI for VOC
Accuracy	±15% of measured value
Output scale	0 to 1,000 ppb of total VOC (TVOC)

	Level	Ventilation Recommendation	TVOC (ppb)
AQI table*	>61%	Greatly increased	>610
	20 to 61%	Significantly increased	200 to 610
	10 to 20%	Slightly increased	100 to 200
	5 to 10%	Average	50 to 100
	0 to 5%	Target value	0 to 50

RH Sensor	
HS sensor	Thin-film capacitive, replaceable
Accuracy	±2% from 10 to 80% RH @ 25°C (77 °F)
Hysteresis	1.5% typical
Linearity	Included in accuracy specification
Stability	±1% @ 20°C (68 °F) annually for 2 years
Output range	0 to 100% RH
Temperature coefficient	±0.1% RH/°C above or below 25 °C (77 °F) typical

Temperature Sensor	
Sensor type	Solid state, integrated circuit
Accuracy	±0.2 °C (±0.4 °F) typical
Resolution	0.1 °C (0.1 °F)
Range	0 to 50 °C (32 to 122 °F)
Display Models	
Touchscreen	61 mm (2.4 in), color, backlit, capacitive, 240x300px Setpoint: 0-10Vdc. Temperature, humidity or fan speed selectable Timeout override: Display timeout** Lockout override: Touchscreen/button lockout**
LCD	52mm (2.05 in), segmented with 3 buttons Setpoint: 0-10Vdc. Temperature, humidity or fan speed selectable Timeout override: Display timeout** Lockout override: Touchscreen/button lockout**
Setpoints* **	
Temperature setpoint	0 to 10V output Scale: 10 to 35 °C (50 to 95 °F) / 0 to 50 °C (32 to 122 °F)
Humidity setpoint	0 to 10V output Scale: 0 to 100% RH
Fan speed setpoint	0 to 10V output Off 0V, Auto 1.5V, Low 3.3V, Med. 6.7V, High 10.0V
Override	
Override button	Display models feature a momentary-to-ground override button
Wiring Terminals	
Terminal blocks	Screw terminals, 18-24 AWG
Screw terminal torque	0.2 N-m (2.0 in-lbF) max.
Regulatory Information	
Agency approvals	UL 916, European conformance CE: EN61000-6-2 EN61000-6-3 EN61000 Series - industrial immunity EN 61326-1 FCC Part 15 Class B, REACH, RoHS, Green Premium, RCM (Australia), ICES-003 (Canada), EAC (Russia)

* Air Quality Index for VOC aligns with TVOC levels for IAQ as specified by the WHO (World Health Organization).
** DIP switch selectable.
*** One setpoint type is selectable via DIP switch on display models only.

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