Master's thesis

NTNU
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Effective ventilation solutions preventing sickbuilding syndrome in Norwegian schools

Master's thesis in Energy and Environmental Engineering
Supervisor: Guangyu Cao
June 2019

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Background and objective for Master thesis spring 2019

When a new school is put into use, this will be incorporated immediately into the municipality's overall maintenance plan and a separate operating and maintenance plan for the individual school facilities will be prepared. The Municipality of Trondheim has introduced a four-year maintenance cycle for its purpose buildings. With regard to schools that are to be demolished, rehabilitated or where the future is unresolved, only the most necessary maintenance is carried out, and this is primarily mitigating measures and organizational measures. Scheduled maintenance is thawed so that only emergency maintenance is carried out when necessary. When maintenance is reduced, it causes a backlog which means large costs when emergency measures must be implemented due to the fact that users in buildings have become ill. Furthermore, these buildings must have good cleaning and optimal building operation with satisfactory indoor climate, where no one gets sick even if the buildings are on hold. Schools where further operation is unresolved will still be in ordinary use, but unfortunately no funds will be set aside for upgrading and equipment as will be the case with newer schools that are under the municipality's maintenance and school budget. It is not uncommon for schools that are on hold to be in use for 10-15 years, some may be in use for almost 20 years. For the children, this constitutes their entire childhood. This will affect the children's everyday life and health in many ways. If many become ill, it will be associated with large social costs.

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

The following tasks are to be considered:

1. Literature review regarding the following issues:
    - What is the state of the art of indoor climate in these schools on hold in Trondheim?
    - How does the indoor climate affect the students' health and increase the incidence of asthma or allergy?
    - What simple measures can be used to improve indoor climate?
2. Conduct field measurements of indoor thermal environment and indoor air quality in selected schools.
3. Carry out survey in three schools regarding the effects of indoor environment on health.

4. Analysis of the effect of ventilation solutions on health comparing with earlier studies.
5. Make suggestions regarding new ventilation solutions to improve the indoor environment quality in Norwegian schools on hold.
6. Prepare a research article to disseminate the research results.

Abstract

Schoolchildren spend a significant amount of their time (20%) within the school building. Poor indoor climate in schools can affect the schoolchilds' development, health and academic performance. Today, there are many old school buildings in Norway that have come to their end of life and need major refurbishment or demolition, but have to keep operational while awaiting funding for new buildings. These schools are often struggling with a variety of problems connected to a bad indoor climate. This thesis tries to identify those problems in three schools in Trondheim, Norway. The three schools were Sunnland secondary school, Stabbursmoen primary and secondary school and Sørborgen primary school. A field study over three weeks measured the CO_2 concentration, relative humidity, room air, supply air and extract air temperature in four rooms in each school. Staff at each school were interviewed regarding the perceived indoor environment and any personal health or discomfort issues. Students from the fourth-grade level were invited to answer a questionnaire surrounding the indoor climate and experienced health problems. The results showed that in two of the schools, the CO_2 concentrations, temperatures and technical noise measurements exceeded the recommended limits. None of the rooms examined at Sunnland school or Stabbursmoen school had a satisfactory indoor environment. Three of the four rooms at Sørborgen primary school were assessed to have a satisfactory indoor environment. The reported health issues from two of the schools corresponded with the observed field data. The third school had decent results from the field study and few reported health issues. An association was registered between poor classroom indoor air quality and schoolchildren's risk of health problems, including asthma and allergy. Several possible measures to improve the indoor climate were identified, e.g. changes in the regulatory parameters and schedules, reducing the number of pupils in each class, spreading out the class schedule, airing out the classrooms by opening the windows during breaks and not using the supply air for heating purposes.

Sammendrag

Skolebarn bruker en betydelig del av sin tid (20%) i skolebygget. Dårlig inneklima i skolebygningene kan påvirke barns utvikling, helse og akademiske prestasjoner. Det er mange gamle skolebygninger i Norge i dag som er nedslitt og trenger totalrenovering eller riving og nybygg. Likevel må skolene fortsette å holde skolen åpen mens de venter på finansiering. Disse skolene sliter ofte med en rekke problemer knyttet til dårlig inneklima. Denne masteroppgaven forsøker å identifisere disse problemene i tre skoler i Trondheim, Norge. De tre skolene var Sunnlands ungdomsskole, Stabbursmoen barne- og ungdomsskole og Sørborgen barneskole. I en treukers feltstudie ble CO_2 konsentrasjonen, relativ luftfuktighet, romlufts-, tilførselsluft- og avtrekkstemperatur målt i fire rom ved hver skole. Personale på hver skole ble intervjuet om deres subjektive oppfattelse av innemiljøet og eventuelle personlige helse- eller ubehagsproblemer de kjenner i arbeidshverdagen. Studenter fra fjerde til tiende klasse ble invitert til å svare på et spørreskjema om inneklimaet ved skolen og potensielle helseproblemer de har opplevd i den siste tiden. Resultatene viste at i to av skolene var konsentrasjonene av CO_2, temperaturer og tekniske støy over de anbefalte grensene. Ingen av rommene som ble undersøkt på Sunnland skole eller Stabbursmoen skole hadde et tilfredsstillende innemiljø. Tre av de fire rommene på Sørborgen barneskole ble vurdert å ha et tilfredsstillende innemiljø. De rapporterte helseproblemene fra to av skolene samsvarte med de observerte feltdataene. Den tredje skolen hadde tilfredsstillende resultater fra feltstudiet og få rapporterte helseproblemer. En sammenheng ble derfor registrert mellom dårlig inneklima og skolebarns risiko for helseproblemer, inkludert astma og allergi. Flere mulige tiltak for å forbedre inneklimaet ble funnet, eksempelvis endringer i de regulatoriske parameterne og tidsplaner, redusere antall elever i hver klasse, større spredning i timeplan for et rom, utlufting av rommene ved å åpne vinduene under pauser og ved og ikke bruke tilførselsluften til oppvarming.

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1 Introduction

The way of life has changed for people in the last 50 years. More than ever before, people, and especially children and teens, are spending most of the day indoors. They are often sitting down in front of a desk with long periods without activity. Children spend 20-30% of their time at school. It is essentially the most significant indoor environment, second only to the bedroom at home during a persons development years.

§ 9-1A in the Norwegian Education Act states that all pupils in the Norwegian school system are entitled to a safe and satisfying school environment that promotes health and learning [58].

In 2013, the Norwegian Labour Inspection Authority published a comprehensive report after inspecting 301 schools in 280 different municipalities. Nine out of ten municipalities were forced to make improvements. They conclude that the municipalities do not use enough resources to ensure a safe and healthy learning environment in their schools [14]. Today's focus on saving energy and money can come into conflict with maintaining healthy classroom conditions. The tempting solution to turn down the heat or cooling or reduce ventilation could cost the society more in the long run [76]. With an environment empty of harmful and stressful contaminants, the absenteeism is expected to go down along with the number of sick days.

The children of today are the ones who will have to solve problems of tomorrow. A first-rate educational system and indoor environment are crucial to give the children the tools and knowledge they need to solve the global challenges ahead.

Three schools were chosen to participate in the project "Skoler på vent" (in English: Schools on hold) in the late Autumn of 2018. The project is commissioned by the Norwegian Asthma and Allergy Association (NAAF) in cooperation with Trondheim Municipality, SINTEF Community and the Norwegian University of Science and Technology. This master thesis was included in the project at the beginning of January 2019. The goal of the project is to test and document cheap and efficient measures that can help schools that are waiting for major refurbishments or new buildings. In other words, develop a "toolkit" that can be used to mitigate indoor climate problems at the end of a school buildings life. This thesis will be the foundation to establish and document the current conditions at the three different schools before any measures are tested. The results will be used in the future work of the project as the baseline to determine the effects of the different measures tested in the same schools during the first months of 2020.

The three schools who participated in the project were; Sunnland secondary school, Stabbursmoen primary and secondary school and Sørborgen primary school. Originally Saupstad, another school in Trondheim, was chosen to participate in the project instead of Sørborgen primary school. However, Saupstad was closed in November 2018, so Sørborgen primary school from the neighboring municipality of Klæbu was asked to participate instead. In the thesis, the three schools are henceforth referred to as Sunnland, Stabbursmoen and Sørborgen.

Sunnland secondary school, Stabbursmoen combined primary and secondary school and Sørborgen primary school have all had problems with their building structures over several years. The buildings are old and worn down, and their main buildings are all over 40 years old, the exception being the newly built structure at Sørborgen. The old section is still troublesome at Sørborgen.

In 2013, Trondheim municipality won a prize for having the best maintenance program in Norway for its school buildings [48]. Every fourth year they evaluate the conditions of all their schools and generate an investment plan for the next decade. Sunnland has since 2013 been marked in the worst category, while Stabbursmoen was placed in the worst category in 2017 [63][17]. Both schools have been approved by the city council to receive major funding towards new buildings or total refurbishment. They are the prioritized projects along with Nidarvoll school until 2022 [65] [62]. However, the schools have already been run under subpar conditions and have to continue operations with a declining situation in the forthcoming years.

Several schools in Bergen have had to close down in the last few years because of poor indoor climate that endangered the people using them. The users of the buildings, both students and teachers developed permanent health problems after working or attending the schools Varden or Landås [34][33][3]. In 2018, one in three people that worked or attended Varden school had been diagnosed with Asthma.

The goal of this thesis is to identify simple and effective measures that can improve the indoor climate in Norwegian schools. Especially schools that are awaiting major refurbishments or demolition. In these schools, only the absolute most necessary maintenance is done to preserve money. The teachers and pupils still have to work and attend these schools for sometimes up to ten years, while the conditions and indoor environment declines towards the intolerable.

Sick building syndrome is the definition of the unofficial medical condition manifesting itself in the symptoms and issues developed by the users of the building. The uses suffer from symptoms like headaches, fatigue, dizziness, nausea, dry skin, irritated eyes, throat or sinuses. The health issues develop for no apparent reason except that the inflicted spends time in the same building. One of the leading causes of sick building syndrome can often be pinned down to insufficient ventilation and heating systems.

A field study was conducted in each of the three schools; Sunnland, Stabbursmoen and Sørborgen. Four rooms in each school were installed with equipment that measured the temperature, relative humidity and CO_2 concentration. A hand full of employees at each school were interviewed regarding the indoor climate and potential health issues to map the perceived conditions among the daily users of the buildings. The pupils from the fourth-grade level and above were invited to participate in a web-based questionnaire that asked about the perceived indoor climate and if they had experienced any health problems in recent times that can be associated with subpar indoor environment conditions. The possible correlation between the perceived indoor environment and the measured parameters in the field study are studied, along with any health issues that stand out. Several specific, and some general, suggestions are put forth to improve the indoor environment at the three schools.

The thesis is divided into seven sections. The first is the introduction you are reading now, followed by a summery of the literature study performed as part of the project in Section 2. Section 3 introduces the three schools investigated in the Trondheim area; Sunnland, Stabbursmoen and Sørborgen. The methodology for the field study, interviews and web-based questionnaire is given in Section 4. Section 5.1 presents the results before they are discussed in Section 6.1. Lastly, the final conclusions are presented in Section 7.

2 Literature Study

In this section, a summary of the most important information from the literature study will be presented. Three main questions were to be answered:

1. What is the most current information available surrounding the indoor climate for the three schools in Trondheim that awaits major investments?
2. How does the indoor climate affect the students' health, more specifically, does the rate of asthma and allergy increase with poor indoor climate?
3. What simple measures can be used to improve the indoor climate?

The third question is answered partly in Section 3, two of three schools investigated in this thesis (Sunnland and Stabbursmoen) are awaiting major investments and are number two and three on the municipalities prioritized investment plan for the next three years [44][62].

2.1 Information available surrounding schools awaiting major investments in Trondheim

Previous master thesis about the indoor climate in schools in Trondheim
As a part of a master thesis from 2018, a field study was conducted in three schools in Trondheim; Hoeggen, Markaplassen and Rosenborg. In each school, five classrooms were equipped with instruments that recorded the temperature, relative humidity, CO_2 and $PM_2 \cdot 5$ for one week. These schools were concluded to have quite a good indoor climate based on the field study. The pupils of the school also answered the questionnaire "Mitt inneklima" (English: My indoor climate). Rosenborg secondary school, with its current buildings, opened in January 2010. The school uses a demand-controlled regulatory system where both temperature and CO_2 concentration are governing parameters. The school does not have any known indoor climate issues, but the pupils reported through the questionnaire a higher occurrence of health issues than the reference schools. The reference schools are data from schools without any known problems with their indoor climate. In Markaplassen, another school without any known indoor problems, the CO_2 levels exceed the given recommended limit of 1000 ppm repeatedly. One of the four classrooms had initially been part of a larger common area, but this area had been separated into two classrooms. One of the classrooms did not have any extract vents in the classroom after the remodeling. In the field study results, the CO_2 concentration exceeded the recommended value daily by several hundred ppm, while the remaining four rooms levels were mostly good. Both the field study results from Rosenborg an Hoeggen were good, with only a few rooms with a slightly high temperature [20]. Hoeggen school is an older school that does have some known indoor environmental problems. Therefore, it is in the high prioritized

category in the municipalities investment plan [62]. The main issue is still overcrowding, as a large portion of the pupils is located in temporary pavilions. However, the building is defined to be in good technical condition, something the results from the master thesis from 2018 support [20]. The school has had an internal upgrade over 2017 and 2018. The roof, outer walls and drainage remain to be renovated [65][17].

Remaining schools awaiting major investments
Nidarvoll school it the highest prioritized school in the investment plan for the municipality. The school is close to Sunnland secondary school, which is one of the schools investigated in detail in this thesis. One of the suggested solutions is to combine the schools in a significant rebuilding effort in the area. The technical equipment is almost at their end of life and the building envelope needs refurbishment.

The following schools are all categorized as schools that need more substantial investments before 2032; Nypvang, Rye, Breidablikk and Charlottenlund. The conditioning report from 2017 states that the situation will be critical for Nypvang in 2021, Rye in 2024 and first in 2029 for Breidablikk and Charlottenlund. In the last city council meeting in the middle of June 2019, only Nypvang and Hoeggen were placed on the new prioritized investment list of the schools in the worst technical condition. Nidarvoll, Sunnland and Stabbursmoen were already on the top of the investment list, these new schools were added behind them. An additional six schools were added to the list. Several of them were prioritized because of city planning purposes or expected capacity problems [62].

The investment strategy shown by Trondheim municipality is seemingly to push the buildings life expectancy as far as possible. Technical equipment like the ventilation system is used beyond what it is designed to do. Ventilation systems will typically lose capacity over time because of wear and tear in the system. At the end of life, the actual capacity delivered can be far below the modern requirements. The current air quality requirements call for a higher air flow then 30-40 years back when many of the ventilation systems were originally installed [42]. The lack of ventilation capacity results in CO_2 and other contaminants concentration levels to increase in the indoor air [1]. The heat loss increases in old buildings so it gets harder to keep a satisfactory temperature during the heating season [19]. By pushing the schools until things are critical one creates a period where the schools have to operate under critical conditions.

2.2 Indoor climates effect on students health

A literature study from 2004 concluded that ventilation rates of less than 10 liters of supply air per person in the building are associated with a statistically significant higher occurrence of health problems. Some studies showed that the occurrence of health problems decreased further by increasing the ventilation rates up until 20 liters per second. Several studies also suggest that the risk of sick building syndrome continues to decrease by lowering the CO_2 concentration to below 800 ppm. The literature study concluded that the relative risk of respiratory illnesses increase by 1.5-2 and increase by 1.1-6 for sick building syndrome for ventilation systems with low ventilation rates compared to high ventilation rates [61]. A Norwegian study from 1996 found a correlation between the CO_2 levels in the classroom and the health of the students [52]. It has also been found a relationship between academic performance and the ventilation airflow [73][35][15][76][78]. There is shown to be a connection between indoor air quality and respiratory symptoms [40][2], even at low pollutants level there was seen a relation [50].

Sick building syndrome (SBS) is the definition of the unofficial medical condition manifesting itself in the symptoms and issues developed by the user of a building. The symptoms cannot be linked directly towards airborne building contaminants. Diagnoses that can be linked are covered by the term building related illness. Symptoms that can go under sick building syndrome are numerous. Headaches, dizziness, nausea, coughing, concentration problems, fatigue, dry or itchy skin and irritation of the eyes, sinuses and throat are all possible indication towards sick building syndrome. One characteristic element of sick building syndrome is that the symptoms alleviate or disappear soon after leaving the building. The health issues develop for no apparent reason except that the inflicted spends time in the building [22][75].

The indoor air contains a various range of pollutants and contaminants, including: CO_2, volatile organic compounds, formaldehyde, mold, dust and fungi. Concentrations of these compounds, along with the ventilation rate, have been linked with health issues [57][18][30]. Mold exposure increases the risk of several respiratory issues [66][26]. Mould in a building is a clear sign of moisture problems. The chances of developing respiratory issues, including asthma, are between 1.4-2.2 higher in a building with moisture problems than buildings without [26]. Low levels of formaldehyde have been shown to increase the risk of allergy in children [31]. Irritation in the eyes, nose and throat is shown to be associated with the concentration of volatile organic compounds in the air [51]. At low relative humidity, people perceive the air as dry and experience issues like itching and burning in the eyes [49][60]. Allergic individuals are at a higher risk of health troubles in schools with poor air quality [9]. Temperatures above 22°C and CO_2 concentrations above 1000 ppm could result in increased mucosal membrane symptoms. The temperature is the most important parameter off the two [57].

2.3 Simple measures to improve the indoor climate

In daily life, there are many small things that people can do to improve the indoor climate without investing in new or improved technical equipment. As this thesis focuses on schools, only some of the most appropriate simple measures that can be implemented in schools are mentioned.

The Norwegian Asthma and Allergy Association have made a website with many minor measures that the students and school can implement to tackle different indoor climate problems. The measures are meant to be so simple that the students and teachers can implement them together, or talk with the building operator or principal if needed [13]. The Norwegian Health Institute also has an available checklist for the indoor climate that can be used to identify possible measures [25].

The ventilation airflow should be turned up if the contaminant concentrations are too high. This will most likely lower the concentrations. Norwegian schools do not use carpet flooring anymore, the exception being play mats that can be seen in kindergartens and in the lower grade levels. Carpets give an increase in particulate matter in the air. Mats on the inside of the entrances can stop soil and dirt from being brought into the building. These have to be regularly cleaned and should be made from a material that can easily be cleaned [74]. The students can clean horizontal surfaces themselves, and the classroom can be kept tidy without unnecessary clutter. The trash should be emptied every day or when an unpleasant odor is coming from the trash. Shoes should be left out in the wardrobe to minimize the amount of dirt dragged into the classroom after breaks. The classrooms should be emptied during breaks, which means that the pupils should be forced out in the fresh air.

The American National Heart, Lung and Blood Institute has developed a checklist to ensure that schools are asthma friendly. The schools must have implemented a string of eight measures to improve the daily conditions of the asthmatics pupils. They suggest that the schools implement a no idling policy in the car pick up zone, enforcing smoking bans and keeping the environment free clear from asthma-provoking substances [54][55].

To stop or lower the feeling of draft from the windows one can reseal the windows or the furniture can be moved away from the windows or cold wall to mention a few. These can also be combined for an even greater effect. If the temperature is too high, the ventilation supply air should be reduced to 20°C. The thermostats can be locked so that pupils cannot regulate the heaters. A more expensive solution is to install external solar shading. This will reduce solar heating massively. If the room is regulated by a thermostat, the sensor can be moved away from a local cold zone to measure the room conditions accurately. The windows should be opened up to increase the cooling of the room [13].

In a Dutch study published in 2008, three different strategies for improving the ventilation behavior of the students and teachers were tested. Ventilation behavior includes the opening and closing of windows. Their study concluded that an CO_2 warning device and a teaching package, also in combination with each other, were low-cost tools that improved the ventilation behavior [32]. A study concluded that potted plants in the classroom could improve the air quality by reducing the particle matter in the air [59].

Ventilation requirements

The Norwegian building regulations and standards give requirements for ventilation demands. The regulation (TEK-17) gives the minimum values allowed, while the standards give recommended values that should ensure good indoor air quality. In TEK-17 the lowest allowed ventilation airflow is 26 m^3/h per person and 2.5 m^3/h per square meter of floor area when the building is in use. 26 m^3/h is only valid for a person in light activity and 2.5 m^3/h per square meter is only valid for documented low-emitting materials. TEK-17 does not specify educational buildings in its requirements [28]. In the Norwegian standard NS3031, the lowest specific airflow is given as 10 m^3/h per square meter in educational buildings with constant air volume (CAV) ventilation. The recommended guideline value for specific airflow in schools is higher with 16 m^3/h per square meter [69]. The outside concentration of CO_2 in Norway is generally within 400-500 ppm. An older edition of the regulation (TEK-10) stipulated that the indoor CO_2 concentrations should not increase above 400-500 ppm of the the outside air concentration [29]. The regulation stipulates that the ventilation should give satisfactory indoor air quality without contaminants in concentrations that can give health issues or discomfort [28]. The noise equivalent levels limit for technical installations in rooms meant for education is 28 dB [68].

The Norwegian recommended norm for CO_2 concentration is 1000 ppm [24]. TEK-17 recommends that the indoor temperature is kept below 22°during the heating season. The recommended operative temperature for light work is between 19°C and 26°C. The lowest temperature is recommended when possible [28]. The relative humidity should be kept above 20%. This is because lower relative humidity can results in issues relating to static electricity, skin dryness and irritation of the eyes and mucous membranes [24].

3 Introducing the schools

Three schools in the Trondheim area were investigated in this project; Sunnland school, Stabbursmoen school and Sørborgen school. Sunnland secondary school and Stabbursmoen primary school are run by Trondheim municipality. Sørborgen is run and located in the neighboring municipality of Klæbu.

Figure 1: Map showing the location of Trondheim and the three schools within the Trondheim area (Illustration credit: Google maps).

In total, Trondheim municipality has 55 schools [47]. Klæbu municipality has three schools [43]. The schools were chosen on the background of the conditioning of the building structures or reported troublesome indoor climate. Common for the three chosen schools, is that their main building is at least 40 years old. Information presented in this section is a mixture of literature sources and information obtained during the preliminary meetings at the three schools. The preliminary meeting included a tour with representatives from the school. The three schools have had trouble over several years to keep a safe and satisfactory educational and working environment for its users.

Every fourth year Trondheim municipality considers the state of its schools. They are divided into three categories; red, yellow and green. Red means that the school needs massive investments, yellow needs some investments and green schools do not need any investments in the foreseeable future. In the latest inquiry from 2017, both Sunnland and Stabbursmoen were both marked as red [17]. In an earlier review from 2013

Sunnland was already marked as red, and Stabbursmoen was placed in the yellow category [63].

Trondheim municipality has suggested that they should spend 4 billion Norwegian kroner on school upgrades and refurbishments in the next sixteen years. Sunnland and Stabbursmoen are alongside Nidarvollen the highest prioritized projects [65][46]. Both schools are to be prioritized towards 2022, before a list of other larger projects will be initiated.

3.1 Sunnland school

Today, Sunnland secondary school has roughly 320 students and 35 employees. The main building at Sunnland has a net area of 4250 m^2.

The area surrounding Sunnland is a mixture of office buildings to the west, Nidarvoll school and child kindergarten in the south and residential area to the east and north. However, the main road into the city from the south is close to the school. The bypass road around the city center passes only 150 meters from the school. This means that some pollution from the roadway reaches the school grounds.

Sunnland school has two main buildings as well as a temporary pavilion. The largest building contains most of the classrooms. The administration, teacher offices, gymnasium and some other specialty rooms are located in the other building. This administration building is from roughly 1956. The main building has had several upgrades and modifications since it was raised in 1978. The school building was originally built as an open area school over two floors. Today, several drywalls divide the originally open areas into several individual classrooms. This has resulted in sound disturbance between the classrooms. The time of the different modifications is mostly unknown, as it has been a continuous process. There has been reported health problems among school staff that may come from the poor working conditions [45]. The pavilion that holds most of the specialized classrooms is within the requirements found in TEK-17 [44]. The school has been marked as red both in 2013 and 2017. In 2013 it was decided that the school could continue to operate for several years with some extended maintenance [63]. Four years later the report stated that the building is generally worn down. The technical installations and roof cover have reached their end of life. The floors are challenging to keep sufficiently clean, something that creates a poor indoor climate. The building envelope does not meet today's energy expectations. This increases the operating cost significantly [17].

The school is scheduled for demolition or a complete renovation process beginning in 2023. Until then, significant investments at the school are halted. The principal has expressed concern over the coming years. In the startup meeting, he said that the air quality was inconsistent. He also defined the conditions as challenging. In the last couple of years, there have been several inspections, including one from the labor inspection authority. In the autumn of 2018, the municipality performed week long temperature and CO_2 measurements in the classrooms of building C.

Figure 2: Picture of Sunnland school from the front. To the left is the main building, building C. The administration section is in the middle with the gymnasium to the left (Photo: Adresseavisen, Rune Petter Ness).

The temperature during the spring, summer and early autumn are especially challenging. Solar heating is a significant factor. There is not installed any air cooling capabilities in the ventilation handling unit. The temperature regulation is also slow, which is noticeable in the colder seasons. The school has taken several measures to combat some of these problems. During recess, all the pupils have to go outside. Also during breaks, the windows are supposed to be opened. This is protocol both during summer and winter. Finally, the principal stated that the airflow in the classrooms is to low per pupil.

The classrooms are small compared to the number of students. This results that the student desks are placed right next to the windows and ovens. In the classrooms with their own ventilation unit, the pupils sit right next to the fresh air outlets. This could result in a feeling of draft, as the students sit within the main throwing distance of the ventilation outlet. For the future, it is believed that the number of youths attending Sunnland secondary school will increase. The school is now within the recommended longtime usage capacity when including the pavilion. However, this theoretical boundary could be broken at Sunnland in the coming years [44]. The classrooms seem small and cramped.

There are closed shelves and cabinets at Sunnland. However, on top of the tallest cabinets, there was a thick layer of dust. The wardrobes also only consist of lockers. Every student has their own locker. The wardrobes look very tidy as everything is stored in lockers. The impression is that the school is cleaned sufficiently from day to day. However, on closer inspection, there was a thick layer of dust on top of the higher cabinets. In the classrooms, there are significant amounts of student work at display. Some of these are hanging on the walls and some are stored on top of the shelves and cabinets. The classrooms are equipped with thin curtains in a blueish color.

3.1.1 Ventilation system

The central ventilation unit for building C is from 1977. It is a high-velocity system. The air speed in the main ducts lies between 10-15 meters per second. The ventilation unit in building C is operated at maximum capacity. The ventilation is operated with a constant air volume.

The classrooms using the central ventilation system have had some modifications. Previously the fresh and extract air vents grills were placed on the same wall opposite the window wall. Now, a duct runs across the classroom which splits into two arms above the windows. Each arm has two grills so that the fresh air can flow into the classroom. This was an attempt to increase the distribution of fresh air in the classroom. However, the increase in the duct network would also increase the pressure drop in the ductwork, so that the total airflow would decrease somewhat without changing the output of the fan. The ventilation noise is a problem. In the classrooms it is noticeable, but not overwhelming. In the first floor corridor, where the main ventilation shafts come up, the noise from the ventilation is high. Recently the main ventilation fan for the supply air was replaced and some ventilation silencers were installed. This reduced the noise level, but it is still worrisome. During the tour of the school, there was a small air leak near the fan unit. Bravida measured the technical noise level in all the classrooms in building C on the 31. August 2018. The lowest value was 33 dB in Room 104 and the highest in Room 213, with 43.43 dB. Both the classrooms with central ventilation or classroom ventilation units struggle with background noise. The measured noise levels are given in Appendix H.

The original ventilation design used a recycled air unit. This unit is completely shut off. There is no recycling of air today.

Five classrooms have had the central ventilation ducts removed. The ducts have been sealed up. They have each been installed with a classroom ventilation handling unit from Swegon. The unit, a Swegon Compact Air, has a maximum capacity of 1300 m^3 per hour [72].

A window has been removed in these five classrooms to give the air handling units necessary access to the outside. The units are placed as close to the outside as advisable to minimize the pressure drop. These classroom units are run with a constant air volume. They are not connected to the central climate control system. The units are equipped with a rotating heat exchanger with an efficiency of maximum 85% [72]. They have both a supply and an exhaust fan. The manufacturer recommends that the ventilation units fresh air outlets are at least 400 mm from the nearest wall. This is to prevent potential noise problems. They also recommend that the closest workstation is at a minimum one meter away from the unit [72]. However, with a 2 °C lower temperature coming from the unit, the air velocity could be as much as 0.2 m/s at a distance of 3.5 meters from the unit. The preset diffuser setting throws the air at a 30-degree angle from the middle of the front of the unit. The diffuser position was assumed to be unchanged since the units were manufactured. This was later confirmed.

The custodian at Sunnland stated that the temperature of the ventilation unit in Room 203 was set to 20°C. The airflow was set at 900 m^3 per hour. It is operated from 07:30 AM to 15:30. The unit in Room 104 has a set temperature of 18.7 °C and an airflow of 850 m^3. It is operated continuously. The type of ventilation unit used in the classrooms at Sunnland does not have their own heating coil. The classroom ventilation units is in principle a displacement ventilation system when not equipped with the heating coil [71].

The auditorium room has had a damper installed that cuts off the airflow from the room. The damper is closed by default. The damper is controlled by a timer switch on the wall. It can be turned on by users when the room is in use. The airflow significantly reduces in the other rooms when the auditorium damper is open. The timer switch only has an open or shut setting.

The ventilation system operating hours for building C is Monday 04:00 to 16:00, Tuesday-Friday 06:00 to 16:00. The ventilation for the gymnasium and teachers offices are operated Monday-Thursday 06:00 to 18:30 and Friday 06:00 to 18:00. The rest of building B ventilation is operated from 06:00 to 19:00 Monday-Friday. The remaining time the ventilation is completely shut off. The ventilation can technically be turned on by a timer outside regular operating hours.

According to Seemi Lintorp, a HVAC engineer for Trondheim municipality, the ventilation airflow is maximized by today's ductwork. He has been responsible for the changes done on the ventilation system the last year.

3.1.2 Heating system

The school uses a variety of heating systems. In the old administration building, there is an old hydronic heating system with radiators. During the first meeting, held in a meeting room, there was disturbingly noise coming from the radiators in the room. This system is likely from the late 1950s and outdated. Today, this section, as well as the school nurse office, is heated up by hydronic radiators powered by district heating.

In large, the heating system for the main school building is done by the ventilation air and electrical heaters in the separate rooms. Earlier, the heating was done solely by the air. This was changed after complaints on the indoor climate. Electrical heaters were installed to cover the main heating load. The rooms are controlled by a climate control system. All the permanent electrical heaters are connected to the central control system. The electrical heaters are placed on the window walls. The climate controller system regulates the school only by temperature. Previously, the climate control system lowered the temperature at night. After complaints from the school that the temperature was to low in the morning, the temperature lowering at night was deactivated.

The custodian at Sunnland pointed that the largest challenges with the buildings are noise and temperature. In his opinion, the temperature problem can be primarily attributed to user error. He pointed out that the power supply of the electric convectors got pulled out or that windows were not closed. The central control system can not notice if a heater has power or not. In some classrooms, they have put in free-standing electrical convectors as an additional heat source. These convector heaters are not connected to the central control system.

The east-facing windows have been equipped with automatic solar shading on the outside. As a result, there is a limited possibility to open up the windows when the solar shading is deployed. The windows can just barely be opened without damaging the shading cloth. The west-facing facade does not have solar shading. Several classrooms only have a single window that can be opened by users.

The custodian has access to the central operating system. He can, therefore, control the operating hours and set temperatures. He is the only person at the school itself with this capability.

3.2 Stabbursmoen school

Stabbursmoen lies in the area of Heimdal. It is today both a primary and secondary school. Today, there are roughly 430 students in total across all grades and 50 employees. The net area is 5183 m^2. The main building was built in 1979. The school has a pavilion with several of the specialized classrooms. Residential area surrounds the school grounds. The school is divided over three floors. The main technical room solely occupies the third floor.

The school was categorized as yellow in 2013, but was demoted to the red category in 2017 by the municipality. In the report from 2017, it was stated that the building needed extensive rehabilitation both indoor and outdoor. The roof, windows, doors, elevator, ventilation, electrical and plumbing needed to be replaced. The foundation, exterior walls and the building's drainage also needed rehabilitation. The inside would need to be renovated afterward. Todays situation is worse than it was two years ago.

Stabbursmoen already exceeds its capacity within its school district. This problem is believed to continue [46]. Trondheim municipality council has considered moving the secondary school at Stabbursmoen to Åsveien School. If the secondary school is moved the school district zone will likely be changed so that Stabbursmoen takes over 40 primary school pupils from Åsheim school district [46]. The school's parents council has fought several times to keep offering the secondary levels at Stabbursmoen[21] [16]. In the future, it seems likely that Stabbursmoen will be a pure primary level school. In the budget proposal for 2019 and a three-year plan, it was stated that the refurbishment at Stabbursmoen should be done in 2021 [4]. However, later signals could indicate that the existing structures are demolished and a new school is built [65].

The school was initially built as an open area school. Eventually, the school transitioned into more traditional classrooms. Several drywalls have been set up to separate the different classes. The light fixtures have not been adjusted to the new classroom

Figure 3: Picture taken from the northwestern side of Stabbursmoen school.

setups. Neither has the ventilation setup been changed from the original open area design. The ventilation system has not been regulated in after the new walls have been put up. The classrooms do not have doors. The modifications done indoors have undoubtedly affected the temperature, airflow and lighting conditions at the school. The available space does not seem to be very well planned. There is a lack of daylight in some of the classrooms because of the absence of windows.

In the corners of the building, there are placed several larger classrooms. In these corner rooms, there are especially trouble with solar heating as the window area is doubled compared to other classrooms.

The school administration points out the after-school program rooms as the worst. The rooms are undersized according to the custodian, both in size and ventilation capabilities. In the student surveys, the students give a low score to the building structure itself. The survey is done on the last year students on both the primary and secondary level.

There is not enough wardrobe area today. The overcrowding of the existing wardrobes results that the clothes do not dry. There is a plann to build another wardrobe for one of the primary school levels. Indoor there is a no shoe policy. The children have to take off their boots in the wardrobe. In the ninth grade wardrobe, there are not any visible heating or ventilation systems. The walls in this wardrobe are covered by steel lockers used by the pupils. The door leading into the wardrobe has a stair right outside of it. This stair is salted when icy during the winter months. As a result of the salt and moisture in the room, the steel lockers have begun to decay. Clear white salt marks are visible on the lockers closest to the door.

The permanent installed convectors and ventilation system is connected and controlled by an indoor climate regulative system. The system is controlled from the main central in Trondheim Eiendom, a subsection of the municipality. However, since the raising of the drywalls, the sensors may not be within the classroom they are meant to regulate. Therefore, the real conditions within a classroom may not be observed through the climate system.

There are several open shelves and other surfaces above the floor were dust could gather. The school itself seems less maintained and not well cleaned. In the toilets, there is a smell of urine. Several rooms used by the after-school program is located in an old shelter section of the school. By the looks of it, the room was not designed for educational purposes. The height in the room is low and the lighting is terrible. There are not any windows in the room. The lighting conditions are worrisome. It is reported unsatisfactory in several of the regular classrooms as well.

3.2.1 Ventilation system

There are three separate ventilation systems for the main building at Stabbursmoen. The oldest system supplies the gymnasium and is worn out. The main system supplies the rest, excluding the teacher's office space. Both these units are from 1979 and are at their end of life. The main ventilation unit is operated at its maximum capacity. The teacher's workplace got connected to a new ventilation system in 2008.

The changing of filters is done by time or pressure drop across the filters. The pressure drop is read of analog manometers. When the pressure drop increases by 100 Pa the filters are changed. The custodian estimates that the filters are changed every 13-15 months. The last time the filters were changed was in December 2018. The changes are documented electronically. The filters are supposedly of good quality and result in a low-pressure drop according to the custodian.

The primary ventilation system has a rotating heat exchanger. The system was designed initially with the use of recirculating air as an energy-saving measure. This is not used today and the damper is completely closed. The central unit has a rotating heat exchanger. The ventilation is operated with a constant air volume.

In the the secondary school, they have organized the students to contribute to the improvement of the indoor climate. A few students are responsible to open the windows during recess.

Some of the rooms do not have an extract vent. In the AV-room, there are two vents above each door connecting the rooms. The extract grills are two meters in the adjacent room. On the entrance door, there is a sign that says that the maximum number of people allowed in the room is twenty. The ventilation system operating hours are Monday 04:00 to 16:00, Tuesday-Friday 06:00-16:00. The remaining time the ventilation is completely shut off. The ventilation can technically be turned on by a timer outside regular operating hours.

3.2.2 Heating system

The heating is done both by air and by convector heaters. Previously there had been complaining about cold temperatures in several classrooms. As a temporary measure, several fan coil units have been placed in some classrooms. The climate control system lowers the temperature at night to preserve energy. The heating system is turned on at 06:00 and turned off at 17:00 on weekdays[1]. It is believed to be completely turned off over the weekends.

Several windows on the south and eastern side have a solar filter on the outside. Previously there have been solar shading installed, but it was destroyed or broke down. The classrooms on the second floor are on the ground level on the eastern side of the school. Easy access by the children could be a reason that the previous outside solar shading was unsuccessful in the long term.

One of the main problems is the drafts from the windows. The cold air floating down from a window in cold weather can be unpleasant for the students sitting right next to the windows. There are only between one or three heating radiators in each classroom.

3.3 Sørborgen school

Sørborgen primary school is located in Klæbu municipality, a neighboring municipality of Trondheim. Today there are roughly 420 students and 70 staff in total. Of the 420 students, 140 uses the after school program. The adjacent building is occupied by the secondary school. Just beside the nearby building, there is a football field and a sports gym. To the south, there is a residential area. Besides that, the school is surrounded by a small forest and agricultural lands.

In early April 2013, the parent's committee at Sørborgen school sent an official letter of concern regarding the conditions at the school to the municipality. One of the concerns was that the lack of space resulted in, or at least enhanced, other problems such as bullying and violent behavior [64]. The Adolescence council responded after a meeting on the 13. April. The council responded:

> The lack of space is a known problem, but the available space would not change until the new school is finished. The principal will look at alternative utilization of the available space and report back. The pavilion will soon be rehabilitated and can safely be used again. This will improve the situation [41].

The school was built in 1967, but it was rehabilitated and expanded with a new section in 1996. Several smaller sections have been added to the old section from 1967. Between 2003 and the opening of the new school building in 2018 a temporary pavilion

[1] This was discovered to not be entirely true when analyzing the data from the field study.

Figure 4: Picture of the administration section, wing F, at Sørborgen school. The After school program uses the wing seen on the left.

was used. However, this pavilion was closed for a period by the health authorities in 2012 because of health hazards. Significant moisture and mold problems were reported. The pavilion was refurbished and put back to use the following year [56]. In late 2018 a new building was opened with a capacity of 225 students. This building houses the students from the fifth to seventh grade. It was built into the gymnasium from 1967. The new building stretches over two floors. The older sections are on the ground floor with a few exceptions. The Music room is located in the basement between the old and the new building. As part of the project with the new structure, the administration and teachers offices were refurbished. This section was also cut off from the old existing ventilation system and connected with the new buildings ventilation system instead.

Today, Sørborgen is not waiting for any major upgrades or refurbishments. The new structure has, after resolving some start-up problems, no known indoor climate problems. However, the older section still has some known problems. A noteworthy detail is that the number of students is lower today than earlier. Previous years over 500 students attended the school versus the 420 today.

Sørborgen has a semi-open classroom structure in the older sections. Each class has a home area, a small room without desks. The desks are placed in a larger area shared by several classes on the same grade level. The home areas are mostly used for shorter periods. The school uses the surrounding nature regularly during school hours [56]. The municipalities culture school uses the Music room after the regular school day. Sørborgen offers an after-school program to all pupils on the 1-4 grade-level.

The school has had trouble with noise and reverberation in the older sections. Previously, several sound absorbing plates have been mounted in several classrooms. This measure has had a perceived positive effect according to the administration, but any potential effects have not been documented. It is only confirmed that the plates installed are a Rockwool product of some sort.

An earlier inspection showed problems with the sound, light and floors at the school according to the administration. The staffs' safety representative pointed out that the air was troublesome. The regulating system is slow. It can not cope with rapid changes in the climate conditions. The school has a central control system that controls the ventilation and heating systems. The newly built section has both temperature and CO2-concentration sensors in each classroom connected to the central control system. The old section only has temperature sensors.

The older sections have several open lofts that are, for the most part, unused. Some of these loft areas are inaccessible without a ladder. This means that they are challenging to keep clean. There are several shelves in each classroom. Most of them are open and only waist high. Each classroom has a larger cabinet with doors. There was not any floor to roof cabinets or shelves observed. In the library, many large ventilation ducts are hanging from the roof; these are difficult to dust. However, the school looked to be well cleaned and maintained.

The wardrobe capacity is to low at the school. The wardrobe visited seemed damp, and the school representatives confirmed that nothing dries here. The wooden shelves had visible water damage on the lower parts by the floor.

3.3.1 Ventilation system

The old section has three different ventilation units. The old ventilation units are confirmed to be CAV systems. The new section also has three ventilation units.

The older section of the school uses a mix of displacement and mixing ventilation. The library has mixing ventilation, but most of the other rooms have displacement ventilation. In the older section, there is a manual controller for the air flow in some rooms. This requires a mechanical damper in the duct into the room. Before the preliminary meeting, the old ventilation system had not been adjusted after part of the F wing, the administration section, was moved over to the new buildings ventilation system. This was asked to be done before the official measurement period started some weeks later. The filters were changed at the start of May, so they were 10 months old during the measurement period. They are changed once every year by date, but can be replaced earlier if the pressure drop increases over a limit.

In the old section, there is a unit that covers the A and E wing. That is the green and yellow area. Three out of four classrooms that were instrumented in the field study are covered by this ventilation unit. Wing B, or the library section, has its own ventilation unit. Wing C, D and the old section of F, that is the after-school sections and the part of the administration wing, are covered by a separate ventilation unit. According to the custodian, the rooms facing east in the administration wing is still connected to the old section. The after school section is the two most southerner sections. In Figure 15, the wings are marked on the floor plan.

In the new section, there is a ventilation unit that covers all the classroom areas on both floors. One unit covers the gymnasium. The last ventilation unit covers the basement, wardrobes and showers. It is this last unit the Music room in the basement is connected to. It is operated from early in the morning until Monday 19:00, Tuesday 20:00, Wednesday 19:00, Thursday 21:00 and 17:00 on Friday. The main classroom unit in the new section follows almost the same schedule. The only difference being that it is run for 30 minutes longer on Mondays and Thursdays.

In the old section, there is a manual timer that can turn on the ventilation. Then, the ventilation can run for as long as five hours. The custodian can turn the ventilation on or off remotely. The school can also call operators of the central control system. They monitor it off-site. The ventilation unit for wing A and E start up at roughly 04:00 during the weekdays and is shut off roughly at 17:00. All the ventilation units are turned off outside their operating hours and during the weekends.

During the school tour, several of the displacement fresh air diffusers were seen partly covered up by shelves and other furniture. In a cultural activity room in the basement by the library, there was a noticeable low airflow into the room. The air quality degraded over only a few minutes while the group inspected the room. It was speculated if the motorized damper worked. By holding a paper sheet in front of the fresh air supply, it was evident that the air flow was feeble.

The ventilation units in the old section have been operated at a high capacity over an extended period. It is because of the addition of new sections throughout the years. Several parts have been replaced throughout the last ten years, among several fans and a heat exchanger.

3.3.2 Heating system

The heating to Sørborgen school is generated in a local district heating plant just a few hundred meters from the school. The plant uses biomaterials from local forestry as its sole fuel source. The plant was build in 2015 and uses a high yielding furnace with an efficiency rate of over 90% [12]. The plant is located behind, but as part of the sports gym.

In the older sections, the heating is done by hydronic radiators. However, some areas have electrical heaters instead. Wing A has a mixture of both radiators and electrical heaters. The radiators temperature is regulated by the outdoor temperature. If the outside temperature is 20 °C, the radiators are set to 20 °C. However, if the outside temp is minus 5 °C, the radiators are set to 55 °C. The heating starts at roughly 06:00 and shuts off at 12:30, but that is also dependent on the outside temperature. Not all the electrical heaters are connected to the central control system. The school lowers the set temperature outside of school hours.

The different wings are connected to several different heating loops. The E wing (yellow area) and the new administration wing has the same set temperature. Wing A, B, C, D, old F and G are operated with the same heating settings, but are divided into several sub-control loops.

Some parts of the building have internal solar shading; others have external solar shading installed. Several sections have neither. The external solar shading can be seen in Figure 4. The new section has automatic external solar shading installed. The administration wing also had it installed as part of the refurbishment.

There are several windows in each classroom that can be opened and closed by the users. The student desks are right next to the radiators. The radiators can be adjusted manually and are the only temperature control available in the rooms except opening the windows.

4 Methodology

The following chapter will give a description of the work undergone as part of this thesis. Both qualitative and quantitative methods have been used to evaluate the indoor climate at three schools in the Trondheim area. A combination of field measurements, field inspections, interviews and a questionnaire were used in the evaluation.

The schools were already picked as part of the project ”Skoler på vent” when the work with this thesis began. To include the schools in the project, a start up meeting was held at each school. A short presentation of the goal, timeline and necessary corroboration from the school was given. The goal of the meeting was to anchor the project within the school administration. This would hopefully give them an ownership feeling towards the project. The kick off meetings was completed in week four 2019.

4.1 Field study

In each of the three schools, four rooms were outfitted with measurement equipment. The room temperature, fresh air supply, extract air, relative humidity and carbon dioxide concentration were measured. Some spot measurements of the light conditions were performed at Stabbursmoen by the schools request. To measure the room operating temperature, relative humidity and carbon dioxid level an ELMA DT-802D [ELMA] was placed in each of the classrooms. To measure the outside temperature, supply air and extract air temperature in each room several iButton DS1922L [iButton] were used. The complete timeline for the field study is given in Table 7.

In total thirteen ELMA indoor monitors were tested. One was broken and was never used. They were named from 1 to 13. Hereafter the ELMA monitors are named as ELMA-X, were X is their number. Likewise the iButtons are named iButtons-X, ranging from 1 to 26. The iButtons are sometimes shortened to IB-X. This name system has been used consistent throughout the project. To program both the ELMA monitors and iButtons, software was downloaded from the their respective manufacturers. The ELMA monitors uses a program called ”Multiple Datalogger” and iButtons ”OneWire-Viewer (version 4.03)”. Both the ELMA and iButton devices were all synced and programmed by the same computer, an ASUS X556UQK. The measurement interval was set to 120 seconds on all devices. The same computer was used to analyze the results. The program used was Microsoft Excel. The complete overview over what instrument was used where, is given in Table 1.

The iButtons were programmed with the storage roll-over feature activated and stored the data as 8-bit. This meant that the measurement data was stored in a half degree increment. They were also programmed with a delayed start so they would first start logging on the morning of February 12. The ELMA monitors had to be started manually on-site.

During the tours of the school buildings, several rooms were discussed as possible

Table 1: Overview over the instruments, location and their identification. Outside means the iButton placed outside in the schoolyard.

Location	ELMA-X	iButton (fresh air)	iButton (extract air)
Sunnland			
Room 104	6	1	2
Room 108	5	3	4
Room 203	13	8	7
Room 207	1	5	6
Stabbursmoen			
Blåsal	12	10	11
Room 321A	4	9	16
Room SFO	9	13	12
Teacher's lounge	7	15	14
Outside		17	
Sørborgen			
Room 0217	11	18	19
Room 0222	2	22	23
Room 0273	10	20	21
Music room	3	24	25
Outside		26	

Table 2: Timeline with the important dates regarding the field measurements.

Timeline	What was accomplished
Jan. 21.	Kick-off meeting Sørborgen with school tour
Jan. 22.	Kick-off meeting Sunnland with school tour
Jan. 24.	Kick-off meeting Stabbursmoen with school tour
Feb. 12.	Installation of measurement equipment all three schools
Feb. 26.	Downloaded data and restarted two devices at Sunnland school as they had stopped recording
Mar. 5.	Retrieve all measurement equipment at Sunnland
Mar. 11.	Retrieve all measurement equipment at Sørborgen and Stabbursmoen
May 16.	Measurement of draft in Room 104 at Sunnland height

picks for the field measurements. Due to the lack of measuring equipment, only four rooms at each school could be instrumented. The research team and the school representatives agreed together on which room should be prioritized. The schools evaluation of the room was the most important factor when choosing the four rooms. Other criteria that was considered was the amount of usage, the ventilation system and the perceived indoor climate conditions during the tour. Measurement data from 2018 was used to find the worst rooms in building C at Sunnland. The type of ventilation system was also important when deciding rooms at Sunnland. To get some comparable data at Sunnland, two rooms with a classroom ventilation unit and two rooms connected to the central ventilation system were chosen.

In each classroom there was left a paper intended to be filled out by the teacher every period the room was in use. The papers returned after the measuring period can be seen in Appendix A. All floor areas given in this section are net area, i.e. the area floor space within the room walls.

Table 3: The defined time period the different rooms are in use.

School hours	Start	End
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
Stabbursmoen		
Room Blåsal	08:00	13:45
Room 321A	08:00	13:45
Room SFO	13:00	16:30
Teacher's lounge	08:00	16:00
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

In Table 3 the normal school hours are given for each room. The room is ordinary only used within this time span[2]. The periods were defined by the forms the schools returned after the field study. For Sunnland the principal sent the timetable for each room. These timetables were used instead of the forms. The forms are reproduced in Appendix A.

4.1.1 Experimental setup: Sunnland

The four rooms that were chosen at Sunnland are all located on the east side of building C. Room 104 and Room 108 are on the first floor. Room 203 and 207 are on the second floor. Room 203 is directly above Room 104 in the northern corner. Room 108 is below Room 207 in the southern corner on the eastern wall. In Figure 5 the four classrooms are marked by red squares. White arrows pinpoints the air intake for the classroom ventilation units in Room 104 and Room 203. As seen, the external solar shading is in use on roughly half the classrooms. It is installed on every window on the east side of building C. The picture to the left shows several larger trees that provided shade to several classrooms. This picture is taken is from earliest 2014 as the old pavilion

[2]The Music room is also regularly used after the normal school day has ended.

still stands in the top right corner. This structure burned to the ground in December 2014 [5]. It has later been rebuild to TEK-17 standard. Several of the trees seen in the leftmost picture are seen cut down in the picture to the right from 2019. Four tree stubs are clearly visible in the right picture in Figure 5. The basement level is not used by the school. A school nursing station is located there. The technical rooms for the building are also in the basement.

Figure 5: Picture of the east facing wall on building C on the left. On the right a air photo of Sunnland (Photo credit, right: gulesider.no)..

All four rooms were instrumented during the early morning on February 12. before the school day began. The classrooms on the ground floor is generally larger than the ones on the second floor. In Figure 6 one can see that there are five classrooms along the east side on the first floor. On the ground floor there are only four.

Room 104
There are 27 student desks in the classroom. However, the placement of the student desks seem to be changed semi-regularly. Three different setups were observed during the trips to the school. The total floor area is 69.9 m^2.

There is a ventilation unit located in the northeastern corner. The unit is placed 51 cm from the wall, but there is a heater that sticks out. The heater and ventilation unit are separated by 40 cm. There is one window that can be opened in the classroom. In Figure 5 it can be seen as the narrowest window in the bottom left red square. It used to be two, but one was removed because of the air ducts connected to the ventilation unit. The window is replaced by a thinner wall. The distance between the unit and the wall section that replaced the window is 55 cm. The solar shading on the largest window next to the ventilation unit is blocked by the external ventilation box. This classroom therefore has lost half of its solar shading. This can been seen in the left picture in Figure 5.

The blackboard is located on the southern wall. The classroom also has a smartboard. Three lockers are placed alongside the walls. These changed position throughout the visits at the school.

The ELMA-6 was placed on a small desk right in front of the smartboard. This desk is higher than the student desks which means it is placed perfect in the breathing zone

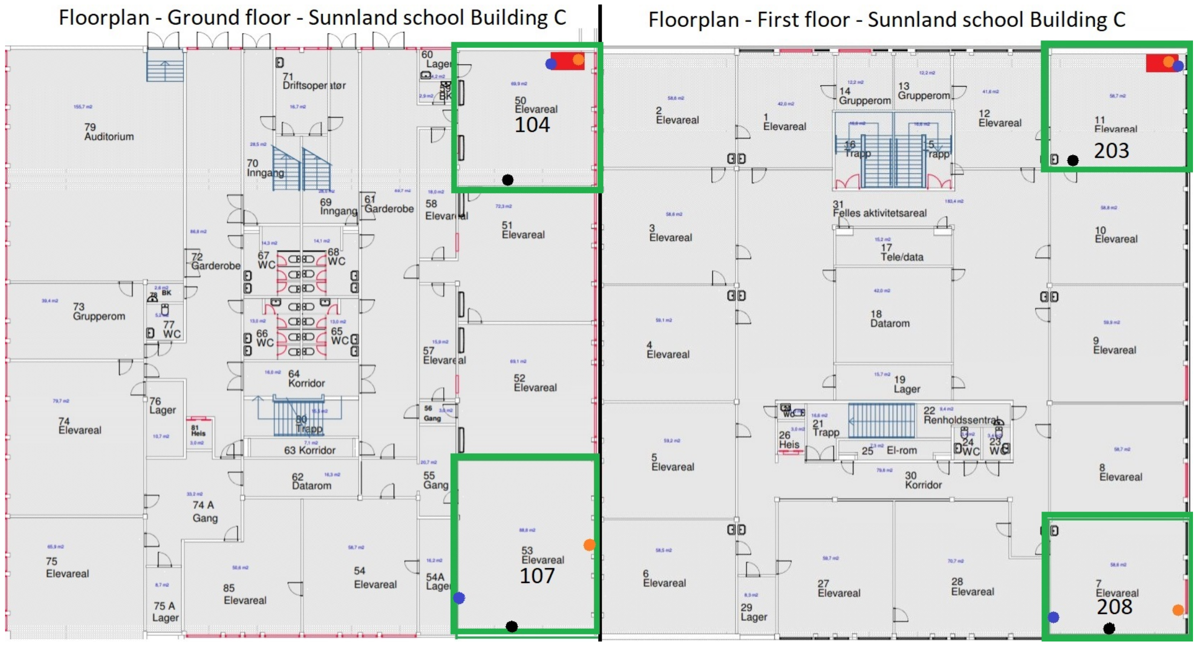

Figure 6: Floorplan over the ground and first floor of Building C at Sunnland. The black dot indicates the placement of the ELMA devices. The blue dots show the iButton measuring the supply air and the orange dots show the iButtons measuring the extract air. The red square shows the location of the classroom ventilation unit.

for a sitting student. The same type of desk was used in Room 108 and 203 for their ELMA monitor. The iButton measuring the supply air temperature was placed on the left side of the ventilation unit. The placement resulted in greater risk of losing the device as it was clearly visible and accessible. However, there was a heater placed on the wall right next to the ventilation unit on the other side. The heater could affect the measurements, so it was placed on the opposite side. It was taped right onto the protective grid for the supply vents. The iButton measuring was taped onto the grid at the air intake on top of the ventilation unit.

The measurement sequence of the ELMA-6 monitor was interrupted on the morning of February 18. The device only logs data and can not be accessed remotely. The ELMA monitor was controlled during the winter break in week 8 by personnel from SINTEF Community, but the person was unable to restart the measurement sequence. On February 26. the stored data was downloaded, reprogrammed and the measurement period continued without further problems.

Air velocity

During a two hour session on the May 16., there was done some measurements of air velocity. The measurements were concentrated around the ventilation handling unit in Room 104. The entire session was done without any occupants. The only person present was the person administrating the survey.

The instrument used was a TSI Velocicalc. It can measure several indoor climate parameters, but only air velocity was used. Each data point consists of the average value of between five to seven measurements taken with a ten second interval. A digital

Figure 7: Pictures from Room 104. The supply air iButton is marked by a blue circle in the top left picture, the extract air iButton is indicated by an orange arrow. The ELMA monitor is marked by a black circle in the bottom left picture.

clock was used to keep control over the time. The instruments own average and storage function was used. Each measurement had to be stored by pressing a button every ten seconds. The machine calculated the average value of the stored values. The memory had to be cleared before every new measurement series commenced.

These measurements were preliminary and not done under strict trial conditions. The goal of these measurements were to confirm or set aside the worries regarding the air velocity around the workstations closest to the ventilation unit. The results should therefore only be used as such.

Room 108

Room 108 is the largest ordinary classroom at Sunnland with 88.8 m^2. There are 28 student desks. The room uses the central ventilation system. In Figure 8 the modified duct system is clearly seen. The fresh air duct runs across the classroom before splitting into two arms running over the windows. The original fresh air outlet placement is almost seen in the bottom picture in the top right corner.

This room has three windows that can be opened. All the windows have external solar shading. However, in the pictures in Figure 8 one can see the lack of curtains. There is one curtain, that covers only one of the smaller windows.

Figure 8: Pictures from Room 108. The supply air iButton is marked by a blue circle on both pictures, the extract air iButton is indicated by an orange circle and the ELMA monitor by a black circle on the bottom picture.

The iButtons were placed within the grills of the fresh and extract air ducts. The ELMA monitor was placed in front of the classroom by the blackboard.

As in Room 104 there was a unplanned stop in the measurement series. As a result there is a loss of data between the late morning of February 14. to the afternoon on February 26. The reason for the stoppage is unknown, but it could be fiddling from the school pupils or that the power supply was unconnected. The data stored was downloaded on February 26. and the instrument was reprogrammed and the logging continued.

Room 203
There are 23 student desks. The room is in total 58.7 m^2.

The setup in Room 203 mirrored the setup in Room 104. The difference being that the fresh air iButton was placed on the other side of the classroom ventilation unit. There was no heater in the immediate vicinity that allowed for a more hidden placement. The room is smaller, but has fewer students compared to Room 104. The solar shading on the largest window next to the ventilation unit is blocked by the external ventilation box. Therefore, this classroom has lost half of its solar shading. This can been seen in the right picture in Figure 5. The room only has one window that can be opened. The smallest in the middle just like in Room 104. There is also no window curtains in the room.

There is a free standing electrical convection heater placed in this classroom. During the visits the heater was moved, and was observed in close proximity of the ELMA monitor.

Room 207
There are 24 student desks in Room 207. The total floor area is 58.6 m^2. In the room there are two windows that can be opened.

The ELMA monitor was placed on the cable tray running across the back wall. It was taped to the wall and cable tray to immobilize it. The height of the ELMA monitor is roughly the same as the student desks. This means that it is in the lower breathing zone of the students. The ventilation holes of the ELMA device was not covered in tape. The iButtons were placed in the extract and fresh air grills. They are marked with orange and blue circles in Figure 9. It is also seen a lack of curtains to completely cover all the windows.

Figure 9: Pictures from Room 207. The supply air iButton is marked by a blue circle, the extract air iButton is indicated by an orange circle and the ELMA monitor by a black circle. The ELMA monitor had been removed before the bottom picture was taken.

4.1.2 Experimental setup: Stabbursmoen

The rooms chosen at Stabbursmoen is spread around the main building. The rooms "Blåsal" and classroom 321A are located on the second floor, the SFO room is on the first floor and the Teacher's lounge is on the ground floor. The main building is roughly orientated north to south. That translates to north being to the left on the floor plans in Figure 10 and 11.

In the floor plans shown in Figure 10 and Figure 11 the position of the measuring

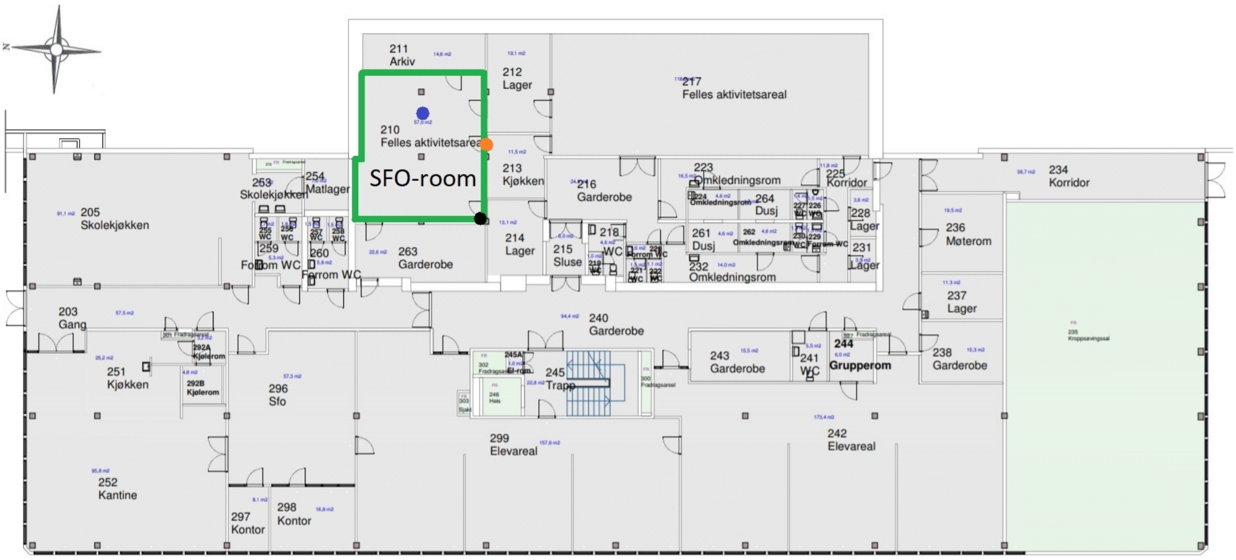

Figure 10: Floor plan over the first level at Stabbursmoen.

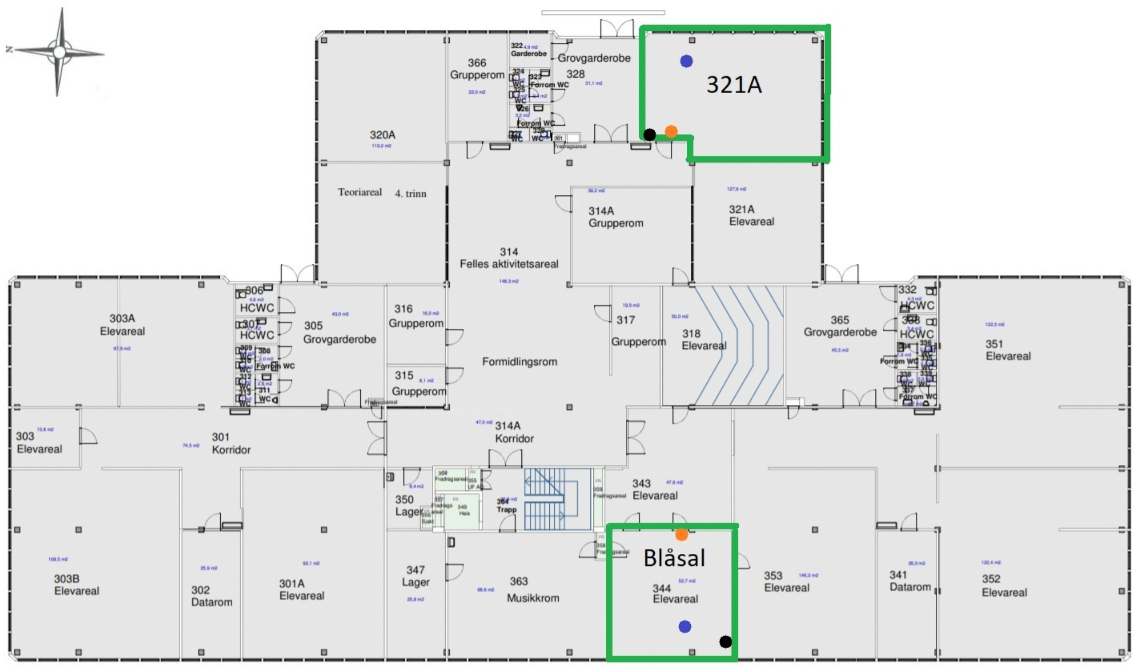

Figure 11: Floor plan over the second level at Stabbursmoen.

instruments are marked. The ELMA monitor is marked with a black dot, the iButton measuring the fresh air supply is marked with a blue dot and the extract air iButton is marked by an orange dot. The floor plans are not completely up to date. They are missing some new walls, but not in the areas where the measurements took place.

At Stabbursmoen a single iButton was placed outside to log the local temperature. This iButton was placed under the roofing structure infront of the entrance on the northern side of the building. It was placed as far from the doors as possible while still being shielded from the sun, rain and wind. In the bottom right picture in Figure 14 the exact placement is indicated by a white arrow.

Room Blåsal

The "Blåsal" room is actually a small auditorium with roughly 60 seats. The room is 52.7 m^2. There are no extract vents within the room. Two ventilation holes over the doors gives access to the extract vents in the neighboring room.

Figure 12: Pictures from the Room Blåsal. The top right picture is taken from outside the room towards the entrance door. The green screen was the poster pinned on the door. The blue circles shows the location of the supply air iButton and the orange circle show the exctract air iButton. The black arrows show the placement of the ELMA monitor at the start and end of the field study.

The school has put a restriction on the usage of the room. On the door there is a sign. The sign says "Maximum 20 pupils in the room. The room is to be vented after each class". Several windows in the room can be opened manually to vent the room. The two windows in the back can not be opened.

The ELMA monitor was placed under a seat on the back row. It was placed, as far as the power cord allowed, towards the center of the room. This ended up being roughly under the fourth chair from the right. The position is indicated by an black arrow in Figure 12. This was to move it away from the windows that were used to vent out the room. When the gear was collected the ELMA monitor had been moved right under the window as seen in the bottom right picture in Figure 12, indicated by a black arrow. The placement of the iButtons are indicated by a blue and an orange circle in the pictures to the left in Figure 12.

Room 321A

There are 28 student desks in the classroom. However, the administration informed that there are only 27 students in the class. The exact floor area in Room 321A is unknown. The Room has been separated by a drywall with several windows. The measurements were done in the corner room. The room is used by a fourth grade class.

The room is located on the second level. This means that it is on ground level with the east side of the school. The school is build into a hill.

Figure 13: Four pictures from Room 321A at Stabbursmoen. The fresh air iButton is marked with a blue circle and the extract air iButton by an orange circle. The black arrow point to the placement of the ELMA monitor.

The windows have a solar film attached on them as a solar shading measure. There are thin light blue curtains by each window. There are several electrical heaters mounted on the walls under the windows.

There is placed a free standing electrical convection fan heater on the floor near the emergency exit seen in the bottom picture in Figure 13. An interesting observation is that there is only one extract vent inside the room. There are several more right outside the entrance. The entrance do not have a door. The door marked on the floor plan (Figure 11) is not in use.

The ELMA device was placed in a corner on a desk in front of the classroom to the left of the television seen in Figure 13. The fresh air iButton was placed right onto the grill of the fresh air diffuser. The extract air iButton were placed right inside of the lip of the extract vent. Both iButtons was fastened by freezing tape. The taping can be seen in the two leftmost pictures in Figure 13.

Room SFO
The SFO-room is located on the first floor. It is not a classroom, but a playroom used by the after school program. It has no windows, so no natural light. The ceiling is lower than in other parts of the school. The room is 57 m^2.

The ELMA monitor was placed in an undesirable position due to lack of power outlets and security concern. As the children using this room are young, it was deemed likely that the instrument would not be safe unless placed well outside of their reach. It was therefore decided to place the ELMA monitor on top of a pipe in one of the corners. The pipe seemed inactive, so not in use, but this was never officially confirmed. The placement resulted that the ELMA device sat roughly 2.2 m above the floor. This was not within the breathing zone of its occupants.

The room did not have an extract vent, so the iButton was placed in the gap between the frame and the top of the door leading to the neighboring room. It was secured by tape. The neighboring room is 213 on the floor plan. The other iButton was taped in a similar way to the fresh air vent grill in room 321A. The ELMA monitor and iButtons placement can be seen in the bottom left picture in Figure 14.

Teacher's lounge
The Teacher's lounge is on the ground floor. It has a small kitchen corner in the back. The room is 73.8 m^2, but it is uncertain if this includes the 10.4 m^2 kitchen section.

The lounge has several windows that can be opened. The windows have a mixture of yellow and white curtains.

The ELMA was placed on a heightened table. This should ensure that it is within the breathing zone of a sitting adult. In the top left picture in Figure 14 the ELMA was put on the table the person is standing by. The fresh air iButton was taped to the ventilation grill closest to the ELMA monitor. It is marked by a blue circle in the same picture. Four extract vents were located in the back of the room. The extract air button was placed in one of them. Both iButtons were taped and placed similar to approach seen in Figure 13 for room 321A.

Figure 14: Four pictures from Stabbursmoen. The top left is from the Teacher's lounge, the black arrow shows the location of the ELMA monitor, beneath that is a picture from the SFO-room. The supply air iButtons are marked by the blue circles. The extract air iButton is marked by an orange circle. The top right show a light measurement done from the SFO room. The Bottom right picture shows where the iButton located outside was mounted, indicated by a white arrow.

4.1.3 Experimental setup: Sørborgen

Four rooms at Sørborgen were instrumented. They were all located in the old school structure. Three of the rooms are on the ground level. These rooms are marked in Figure 15. The Music room is located in the basement level just to the east of the F wing. In the floor plan (Figure 15), the placement of the ELMA monitors are illustrated by black dots, the fresh air iButtons by with blue dots and the extract air by orange dots.

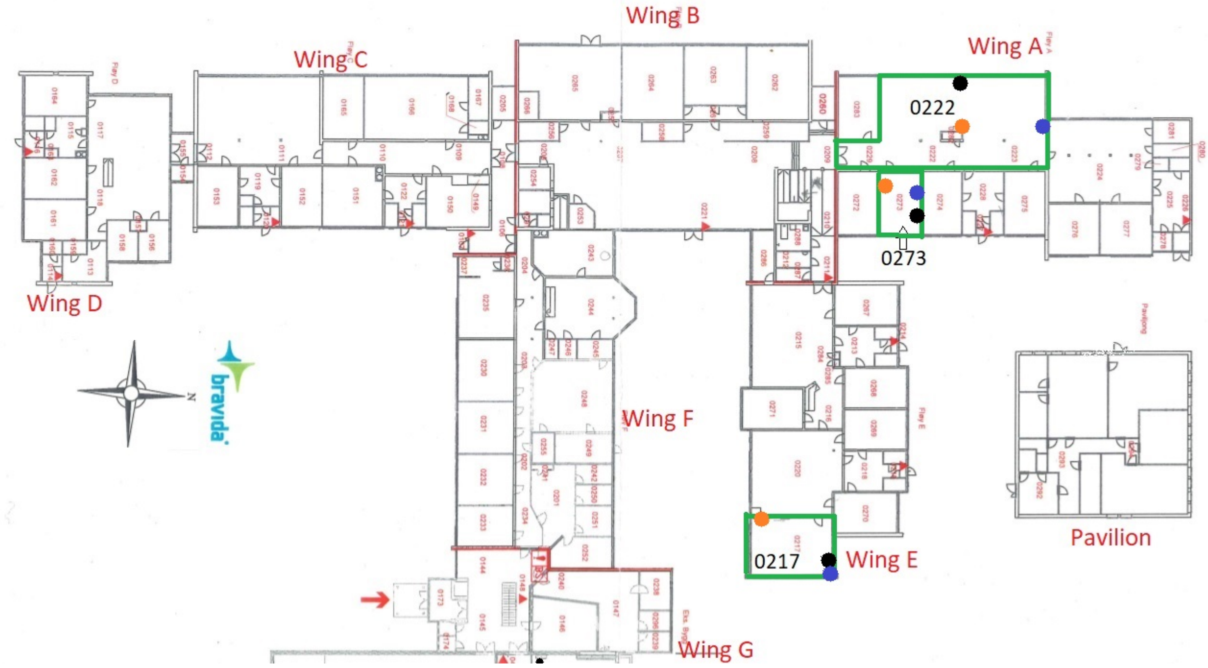

Figure 15: Floorplan of the ground level in the old section of the school. The Music room is therefore not included. Illustration credit: Sørborgen municipality.

Room 0217

Room 0217 is located in wing E, commonly called the yellow area by the school staff. The room uses displacement ventilation. The ELMA monitor was placed on top of a bookshelf right next too the fresh air vent. It was noted that the placement was to close to the fresh air outlet, but there was not any other viable options without an extensions power cord, except on a student desk or on the floor. The placement could affect the results and therefore not give an accurate representation of the real conditions. The fresh air iButton was placed on the backside of the displacement diffuser, but still over the air holes. In Figure 16 the ELMA monitors position is marked with a black circle, the extract air iButton is marked by an orange circle and the supply air iButtons placement is indicated by the blue arrow. The supply air iButton was taped to the backside of the displacement diffuser. The top right picture in Figure 16 is taken from the right corner seen in the bottom picture.

The extract inlet was located several meters high above floor height. The room has a sloping roof that ends in a two storey height. The extract vents were inaccessible without a ladder. The principle of thermal layers would ensure that the temperature closer to the roof would be higher than the occupant zone. Since the vents at that height would be far above the occupancy zone it was decided to place the ”extract” iButton lower. It was taped on the wall behind the desk furthest away from the fresh air outlet. It was taped roughly 1.8 m above the floor. In Figure 16, the extract air iButton was placed further back on the left wall in the bottom picture.

Room 0222

Room 0222 is in wing A, commonly called the green area at the school. It is a common work area shared by several classes in the same grade. The room uses displacement

Figure 16: The top left picture shows the "exctract" air iButton, marked with an orange circle, taped on wall in the back of the classroom. The top right picture shows the positioning of the ELMA monitor (black circle) and the displacement vent with the supply air iButton taped on the backside, indicated by a blue arrow. (Credit top pictures: "Skoler på vent")

ventilation. The room is equipped with radiators beneath each window.

The windows faces westward. There is not any solar shading visible. There is suspensions for curtains, but no curtains. The windows were changed sometime in the last 10 years. The markings on the window indicates that they were produced or mounted in 2008.

The ELMA monitor was placed in a open shelf separating the room into sections. The shelf is seen as the second row of shelves in the top picture in 17. The shelf walls would shield it from any direct sunlight. The iButtons were placed right onto the fresh air outlet and extract inlet. They were fastened by tape. The room has two fresh air diffusers on different sides of the classroom. It also has two extract vents close to each other in the center of the room. The iButtons were placed on the southern part of the classroom indicated by the blue arrow in Figure 17. It was taped on the backside of the displacement vent, but still over the ventilating holes. The top picture in Figure 17 shows most of Room 0222. The fresh air iButton was mounted on the backside of

Figure 17: The ELMA monitors posistion is indicated by the a black arrow. It was placed in the second row of open shelves seen in the top picture. The displacement diffuser with the supply air iButton is seen in the back of the top picture and in the bottom left picture. The supply air ibutton was hidden behind the diffuser indicated by the blue arrow. The orange circle marks the extract air iButton. (Credit bottom pictures: ”Skoler på vent”)

the diffuser seen in the far back of the room. The extract air iButton was fastened to a hidden, but identical vent to the one seen infront of the column, just on the opposite side. Is exact location can be seen in the bottom left picture in Figure 17.

Room 0273
Room 0273 is a home area for one of the classes that uses Room 0222 as a work area. It is a small room, but also uses displacement ventilation. The fresh air diffuser is partly covered up by furniture. The shelves are clearly seen in Figure 18. In the same figure one can see the thick white roll-up curtains deployed.

The ELMA monitor was placed on the teachers desk on the southern wall. The fresh air iButton was placed directly on the air outlet. The extract iButton was taped on the underside of the extract duct just on the inside of the air inlet. In Figure 18 the placement of the ELMA monitor is shown with a black and red circle. The supply iButton was mounted on the backside of the displacement vent shown in the bottom picture, indicated by a blue arrow. The extract vent is not visible in the pictures, but was located in the opposite corner on the same wall, indicated by an orange arrow. The intake reached roughly the same distance into the room as the fresh air duct.

Figure 18: Pictures from Room 0273. The extract vent is not visible, but is located to the right of the door close to the ceiling. The ELMA monitors placement is shown by the red and black circle. The supply and extract air arrows placement are indicated by a blue and an orange arrow respectively.

Music room

The Music room is located in the basement level, but has large windows on the southern wall. None of the windows can be opened.

The Music room uses dilution ventilation. It used to be connected to the old section,

Figure 19: Pictures from the Music room. The extract vent inlet is partly hidden behind the blackboard.

but is now connected to the new structure built in 2018. It has four fresh air diffusers, all located all on the eastern wall. One of the iButtons was taped directly onto the second from the right. The only extract vent is located on the northern wall, close to the northeastern corner. Both iButtons are marked by a blue and orange circle in the bottom picture in Figure 19. The ELMA monitor was placed on a table in the northwestern corner. It is shown with a black dot on the edge of the floor plan in Figure 15. However, it is placed a level below what is shown in the figure.

4.1.4 Measurement instruments

The three instruments used in the field study is presented in Tables 4, 5 and 6.

There were a total of thirteen ELMA DT-802D monitors at the beginning of the project.

Table 4: Technical specifications for the ELMA DT-802D [38].

ELMA DT-802D	Range	Accuracy	Resolution
Temperature	-5°C...50°C	±1°C	0.1°C
Relative humidity	≤ 90%	±5%	0.1%
CO_2	0...9999 ppm	± 100 ppm ±5% rdg @ 300...9000 ppm	1ppm

Four monitors was owned by NTNU, one by SINTEF Byggforsk and the last eight came from Trondheim Kommune Eiendom.

Table 5: Technical specifications for the iButtons DS1922L [39].

iButton - DS1922L	Range	Accuracy from -10 to 65°C	Resolution
Temperature	-40°C...85°C	±0.5°C	0.5°C

With the iButton DS1922L there are two different resolutions one can save the data. It can be stored as a 8-Bit or 11-Bit. The resolution differs from 0.5°with the 8-Bit to 0.0625°C with the 11-Bit. The 8-Bit option takes less data and results in a higher maximum sample amount.

A validation certificate was requested from the manufacturer for all the iButtons used in the project. In the validation document it became clear that they were last calibrated in October 24. or December 04. 2015. The company guarantee the accuracy for 12 month after the validation date. The iButtons are over two years past their certified period. The validation document, which includes the unique identification code for each iButton used is given in Appendix K.

Table 6: Technical specifications for the VelociCalc. Only the air velocity specifications are given [36].

VelociCalc - 8388-M-GB	Range	Accuracy
Air velocity	0.15 to 50 m/s	3 % of reading or 0.02 m/s, whichever is greater

The VelociCalc 8388 is an old instrument. It was discontinued by the manufacturer TSI at the end of 1998 [37]. The manufacturer recommended then a yearly re-calibration by TSI-staff [36].

4.1.5 Calibration of the measurement equipment

The ELMA monitors were tested in the accredited moisture lab before the field tests. The iButtons were tested in a refrigerated room in one of NTNUs labs after the field study. In both cases the devices were tested against more accurate instruments. The offset documented during these trials were used to adjust the field measurement results to achieve greater accuracy. The temperature and relative humidity seems to be fairly consistent, within their accuracy level, across all the instruments. The CO_2 measurements are less stable, especially ELMA-3. In the analyses of the data, a simple check was done. The CO_2 concentration should fall to right above 400 ppm during the night. 400 ppm is roughly the concentration of the outside air in Trondheim. As a result of this, several ELMA devices was also checked for their accuracy after the field study. All the iButtons were tested for accuracy after being collected from the field study. The calibration process is presented in detail in Appendix J. The calibration of the VelociCalc device was done by Helena Kuivjõgi.

4.2 Interviews

At the start-up meeting in January it was informed that the project wanted to interview some of the employees. At least the principle, custodian, school nurse, and the teachers that used the classrooms examined in the field study. Each school submitted a list with names and contact information for the people the project wanted to interview. The interview was planned to be short and informal so it could be done within a normal workday. The school would not have to shuffle its resources around to participate. SINTEF Community with Solvår Wågø designed an interview guide that was used in all the interviews. She also conducted roughly half of the interviews. The interviews were organized in week 7 and 9. The last interview was pushed to week 10.

All the interviews were done over the phone. They were not recorded or transcribed. They were held in Norwegian. Notes were taken directly during the interviews in a copy of the interview template. The interviewee was asked to rate, from a scale from 1 to 10, where 1 is good and 10 is bad, how they experience the indoor air quality. Similarly they were asked to rate the thermal conditions and acoustic conditions. Another question regarded any health problems or discomforts they may have experienced in the last two years. There were several other questions that went more in detail towards what they thought was the biggest indoor climate problems at the school. Also how that effected themselves, the rest of the staff and the students. The complete interview template is given in Appendix C. It was planned to interview two more teachers at Stabbursmoen and one more at Sunnland. However, they could not fit it within their schedule or were unavailable for other unknown reasons. One was on sick leave. They were contacted by phone, SMS and mail several times during week 7 and 9.

4.3 Questionnaire

The students at the schools were invited to answer a web based questionnaire. The survey was meant to give a basis for studying the students perceived opinion regarding the physical conditions at the school. It would also map any anomalies in the overall

Table 7: Overview over the interviewees. The staff safety representative and the teacher of room 203 at Sunnland is the same person. X indicates that the person was interviewed.

Position	Interviewed (Number)
Sunnland	Total: 9
Principal	X
Custodian	X
Staff safety representative	X
Teacher(s)	
Room 104	X (2)
Room 108	X
Room 203	X
Room 207	X (2)
School nurse	X
Stabbursmoen	Total: 5
Principal	X
Custodian	X
Staff safety representative	X
Teacher	
Room Blåsal	X
Room 321A	
Room 210	
Teacher's lounge	X
School nurse	X
Sørborgen	Total: 7
Principal	X
After school department head	X
Custodian	X
Teacher(s)	
Room 0217	X
Room 0222 and 0273	X
Room Music room	X
School nurse	X

students population health. Both could be important indications towards the indoor climate at the three schools.

Every pupil at the school from the fourth grade were invited to participate in the questionnaire. The youngest children from first to third grade were assessed to be to young to contribute.

The questionnaire was an updated version of The Norwegian Asthma and Allergy association existing survey; "Mitt Inneklima". The original survey and its questions were gone through during a meeting between SINTEF Community and NTNU. A few questions were suggested altered or added. Mainly the few original questions regarding noise and dry air were altered. Three questions regarding the lighting conditions were added. The questions asked if the light fixtures gave insufficient lighting, if the light fixtures gave an unpleasant light or if the sun light was unpleasant. These new questions does not have a reference value or uncertainty value.

The survey map the subjective experiences of the users. The results are compared with data from schools without any known indoor climate problems. The results are given with a dynamic uncertainty that depends on the number of respondents among other things. The backbone of the questionnaire is based on the Ørebro-method [8][6][7]. The model has been used in several studies earlier [23][70][67][20].

An application was sent and approved by the Norwegian Social Science Data Service before the survey was distributed to the schools. It was assumed that the application would be accepted as the questionnaire "Mitt Innklima" has been used numerous times before. The only difference was some minor changes to a few questions. The questionnaire is anonymous, although some personal health questions are asked, so the data security is important. The data was analyzed only by employees from NAAF. They delivered reports with the results that was used in this thesis. Before the questionnaire was introduced, two separate letters were sent to the parents of the pupils and the teachers. The letters shortly explained what the survey was, how it would be conducted, that it was anonymous and voluntary. The letters are given in their entirety in Norwegian in Appendix D and Appendix E.

The students would on the day be given an unique PIN code that they would use to log into "Mitt Inneklima". The teachers would be handing out the individual PIN codes. The PIN codes were not personal. The entire survey is roughly 40 questions. The first few questions are just background questions regarding gender, grade level and which school building they use the most. The next section consists of questions regarding the indoor climate. The third section concerns health related symptoms. The questionnaire is finished off with some more background information regarding health history and general well being of the person. The entire questionnaire should be completed within fifteen minutes. The entire questionnaire is given in Appendix F.

The questionnaire was planned to be completed in week 9 in all three schools. Wednesday was suggested as an ideal day after the aforementioned questionnaire meeting. It would ensure that the school would get time to get back into routines after the winter break. The two weeks between the installment of the instruments and the suggested date would hopefully mean that the students had accustomed themselves with the instruments. It would just be another normal day. The focus should not be on that some people are here to measure the presumed bad indoor climate. That could influence the results of the questionnaire. The teacher was not to focus much time on the questionnaire beforehand, it could quickly be a form of coaching.

Only Sørborgen completed the questionnaire in week 9 with some stragglers in week 10. Both Stabbursmoen and Sunnland experienced significant trouble with the web-based questionnaire. As a result both schools used significant resources over the coming weeks. NAAF and their partner gave technical support throughout the period. The schools put the questionnaire on hold until the problem was fixed. Stabbursmoen was finally able to complete the questionnaire in the middle of May.

The questionnaire data was processed and analyzed by NAAF. They delivered a report with the results from each school. The report gives the percentage of respondents on each question that has experienced the problem or symptom in the last three months. The results are also represented in a radar chart. In both cases the results are evaluated against the reference with a dynamic uncertainty. An example of the radar chart is given in Figure 20. The red line indicated the reference percentage from schools who do not have any known indoor climate problems. The blue line is the percentage answered from the given school. The circle furthest in in the diagram is zero percent. The percentage increases the further out from the inner circle you go. The new questions put discussed earlier are not included in the diagrams. The reports are generated by a script.

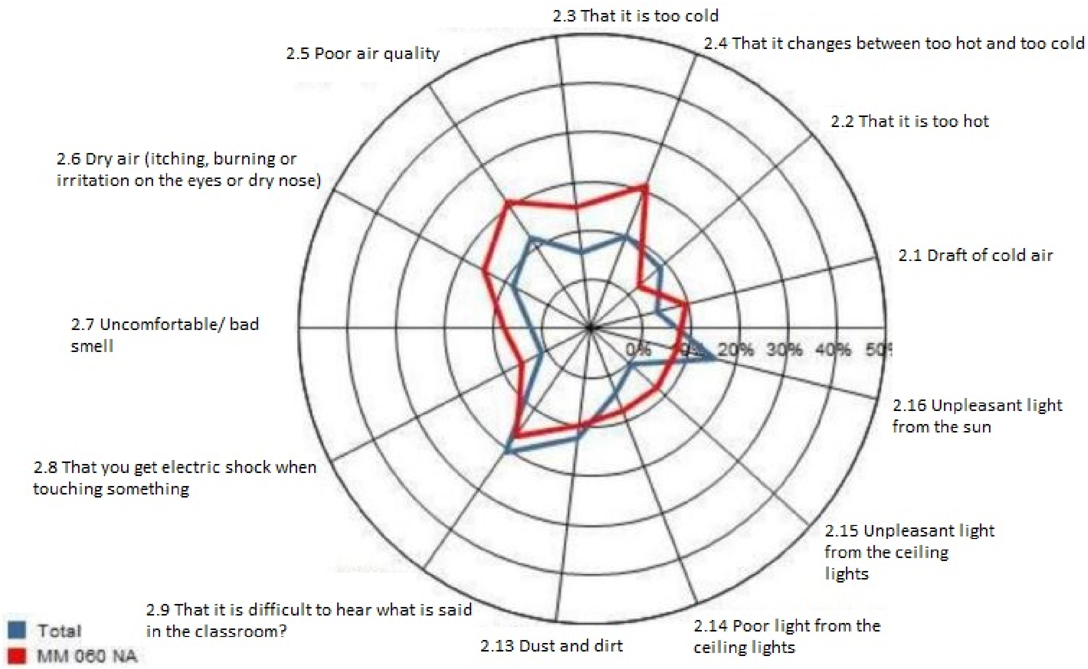

Figure 20: Example of the radar chart used to present the results from the questionnaire.

5 Results

5.1 Results from field study

In this Section, the results from the field study are presented. The grey area in the graphs presented in this section and Appendix B highlights the winter holiday in week 8. The grey area is given from 00:00 Monday to 23:59 Friday. The after-school program at Stabbursmoen and Sørborgen were open during the winter vacation.

The ELMA monitor has a warm-up time. The measurements from the first 30 minutes after being booted up, can be inaccurate. This explains several of the low and high values shown in the graphs in Section 5.1.1, 5.1.2 and 5.1.3.

Several different temperatures are used in the presentation of the results from the field study. The temperature measured by an ELMA monitor is always given as an orange line and defined as the room temperature. The supply air temperature, measured by one of the iButtons, is given as a light blue line. The extract air temperature, as measured by the other iButton, is given as a dark blue line. The outside temperature is given as a dark red dotted line. For Sunnland and Stabbursmoen, the outside temperature is measured by Voll weather station. In the results from Sørborgen, the outside temperature is the temperature recorded by the iButton placed outside in the schoolyard. The complete weather data from the field study is given in Appendix G. The CO_2 concentration is given by a black line. The recommended maximum CO_2 level is illustrated by a red dotted line, lighter in color than the outdoor temperature mentioned previously.

The relative humidity is hard to control indoors in the Norwegian climate during the colder seasons. With cold weather, the indoor humidity will drop. The only way to keep the relative humidity up with the current technical equipment is if the indoor temperature is kept much lower, which is an unwanted solution. An alternative solution is to install a humidifier in each room or in the air handling unit. However, humidifiers increases the maintenance and operative costs and the initial investment cost is also an issue. They can also be the reason for a bunch of other problems, as discussed in Section 2. The results of the relative humidity measurements from all three schools can be found in Appendix B. The relative humidity measurements are similar in all the classrooms. They fluctuate between 20% and 40% RH, but every room dips below 20% on the coldest days, which were Mar. 5. and Mar. 6. When the rooms went unused during the winter break week, the relative humidity varied less. Without humans to give off moisture through exhalation, the relative humidity fluctuates to a smaller extent.

5.1.1 Measurement results of indoor environment quality at Sunnland

In this section the results from Sunnland will be presented. Table 8 gives a quick overview of the results from the field study at Sunnland. Here, the percentages of measurements during the school day that exceeds the limits are given. The two different types of ventilation solutions at Sunnland seem to have different primary problems. The rooms with ventilation units in the classroom (Room 104 and Room 203), both struggle particularly with overheating. The rooms connected to the central ventilation system struggle with higher CO_2 levels and too low temperatures throughout the day. The relative humidity drops below the limit set at 20% in all four classrooms, but that is expected during the winter season. The relative humidity values across the four classrooms are similar, as expected. Room 207 has a slight decrease in the amount of time the relative humidity dropped below 20%. The difference compared to the other rooms investigated at Sunnland is unknown. It could be an inaccuracy in the ELMA monitor or just that the room was used more during the last day in the measurement period, Mar. 5. According to the room schedule at Sunnland, Room 207 is used an hour more on Tuesdays compared to the other classrooms. This partly explains why the relative humidity, with almost no exception, did not drop below 20%. Excluding Mar. 5. and 6., the relative humidity did not drop below 20% during the field study. Instead, it fluctuated roughly between 25% and 35% during the weather conditions in week 7-10.

The percentages presented in Table 8 were found with a series of nested if-statements in Microsoft Excel. For each measurement an if-statement checked the timestamp and measured value and returned a value of one if the timestamp was within the defined school hour and the measured value exceeded the recommended limit. If one or both statements were false, the return value was zero. Another if-statement returned a value of one if only the timestamp was within the defined school hours. The sum of the different returned values was added together. The sum from the if-statement which checked both the time stamp and measurement was divided by the sum of the if-statement that only checked the time stamp, and then multiplied with 100 to get the percentage. The weekends and the winter break were manually excluded from the functions in Excel. The same approach was used for all four parameters presented in Table 8 and in the identical tables (Table 10 and 11) in Section 5.1.2 and 5.1.3.

Table 8: Results exceeding the recommended limit within school hours at Sunnland school.

Results: **Sunnland** Field Study	CO_2 >1000 ppm	Temp. > 22°C	Temp. < 19°C	RH00 < 20%
Room 104	0.3%	11.3%	0.3%	10.7%
Room 108	11.0%	0%	8.3%	10.8%
Room 203	0.1%	65.3%	0.7%	10.4%
Room 207	11.1%	0%	45%	2.8%

As explained in Section 4, Room 104 and Room 108 have several days with data missing. The ELMA monitors went offline and had to be restarted again on-site. For Room 104 there is no data from Feb. 18 to Feb. 26., and Room 108 is missing data from Feb. 14. to Feb. 26.

Temperature

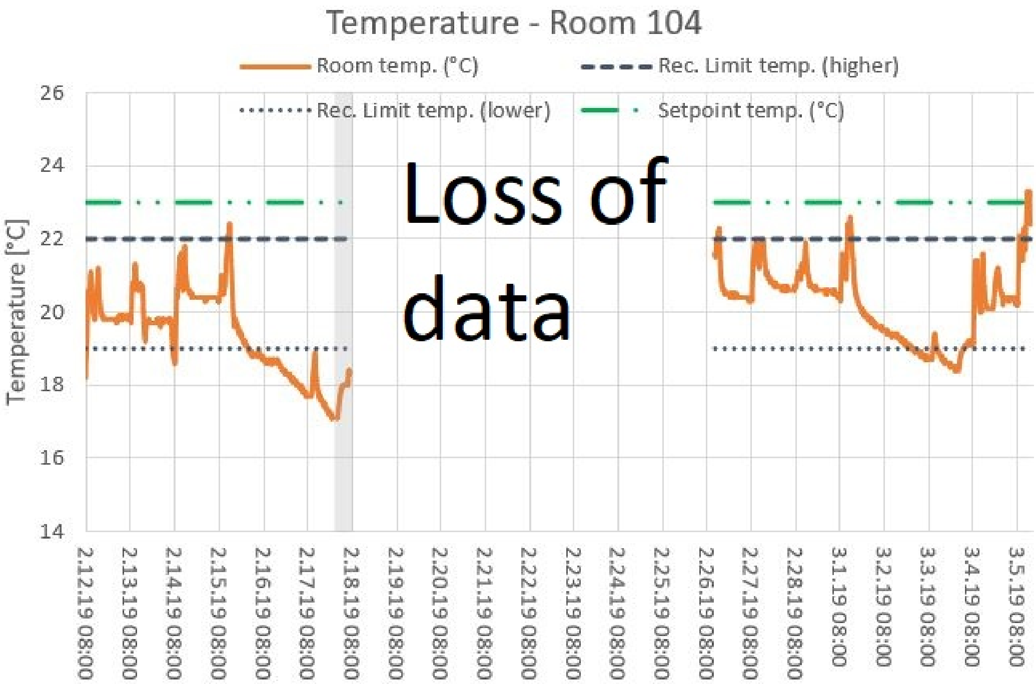

Figure 21: Air temperature measured in Room 104 from Feb. 12. to Mar. 05. The Grey area indicates the small part of the winter break measured before the ELMA monitor stopped recording.

By looking at Figure 21, 24, 26 and 28 it is clear that the control system still lowers the temperature during the weekends. The lowering of the temperature feature in the building control system was believed to be disabled. After analyzing the figures, it became clear that the feature is only disabled during the weekdays. Since the temperature is allowed to fall below 16°C during the weekends, the system has not enough time to increase the air temperature before school starts on Monday morning. The temperature of the building itself will take longer to return to the desired temperature than the room air. Surfaces can, therefore, still be cold throughout Mondays.

Figure 21 shows the room air temperature measured by the ELMA monitor placed in Room 104 at Sunnland with an orange line. The green semi-spotted line shows the setpoint temperature in the central control system. The dark grey line with longer dots show the maximum recommended temperature during the heating season, 22°C. The dark grey line made up by small dots shows the lower recommended temperature at low activity, 19°C. The graph shows that the temperature stabilizes just above 20°C in an empty classroom. During the school day, the temperature rises by 1-1.5°C from the baseline temperature. In the field measurement period, the room air temperature exceeded the recommended limit on several separate days.

Figure 22 gives a more detailed overview of the temperature conditions in Room 104 during the last five days of the field study. The light blue line is the supply air temperature measured, while the dark blue line is the extract air temperature measured. The outside temperature is included as a red dotted line with its y-axis to the right of the graph. During the weekend, Mar. 2. and 3., all the three indoor temperatures declines slowly similarly. The unit has a setpoint temperature of the supply air at 18.3°C, but the supply air temperature still decreases during the weekend. Remember, the ventilation unit in Room 104 is operated continuously. This is explained by the lack of a heating coil in the unit, so only the heat exchanger heats up the fresh could outside air. As the room temperature declines, the heat exchanger eventually does not have the required energy to maintain the desired temperature, so it slowly declines over the weekend.

Figure 23 shows the last two days in the field study in Room 104 in detail. The graph is the same as Figure 22, just zoomed in. The temperature difference between the supply and extract air is 2°C during the weekend, but increases to above 4°C for the last two days. The outdoor temperature dropped significantly during the night on Mar. 5. The indoor temperatures seem unaffected by the sudden change in the temperature outside. However, room and extract temperatures rise steadily after 08:00 when school starts. The occupants, lighting and technical equipment increase the temperature. The room temperature barely drops between classes, but the extract air temperature is reduced by roughly 1°C. It is not until the temperature in the room crosses 21°C that the ventilation unit manages to provide the supply air at the setpoint temperature. This seems to be the case as well on Mar. 1. in Figure 22.

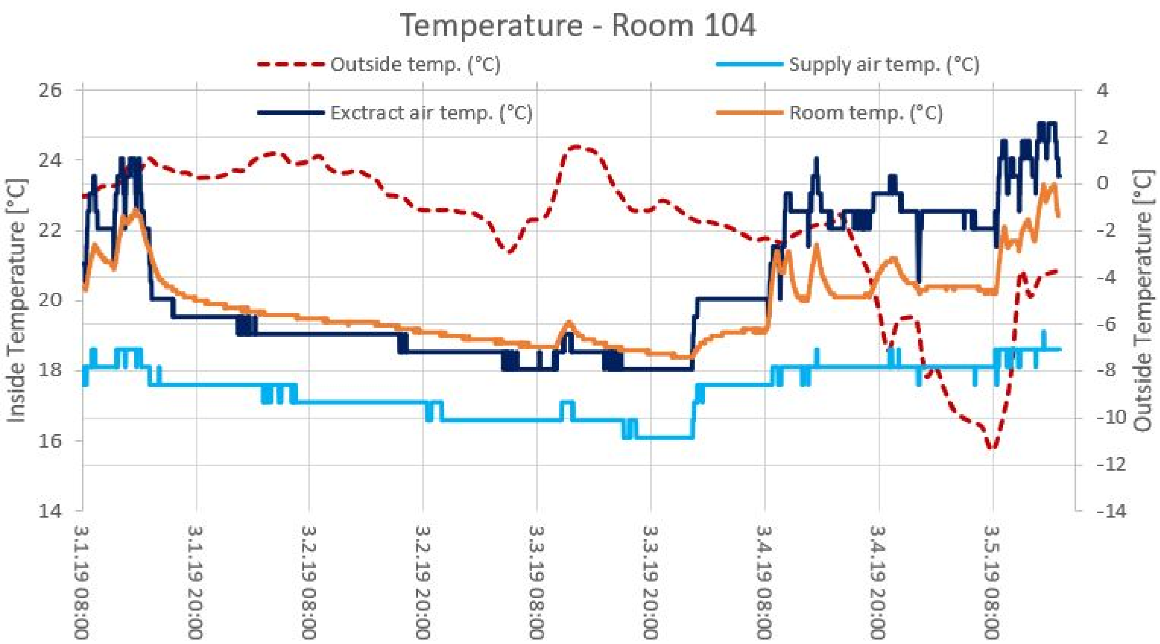

Figure 22: Air temperature measured in Room 104 from Mar. 01. to Mar. 05.

The room air temperature in Room 108 fluctuates with just over 1°C, between 19°C and 20.3°C. The regulatory system seems to work well as there are no larger peaks, so it manages to compensate for the occupants during use. If one compares the tem-

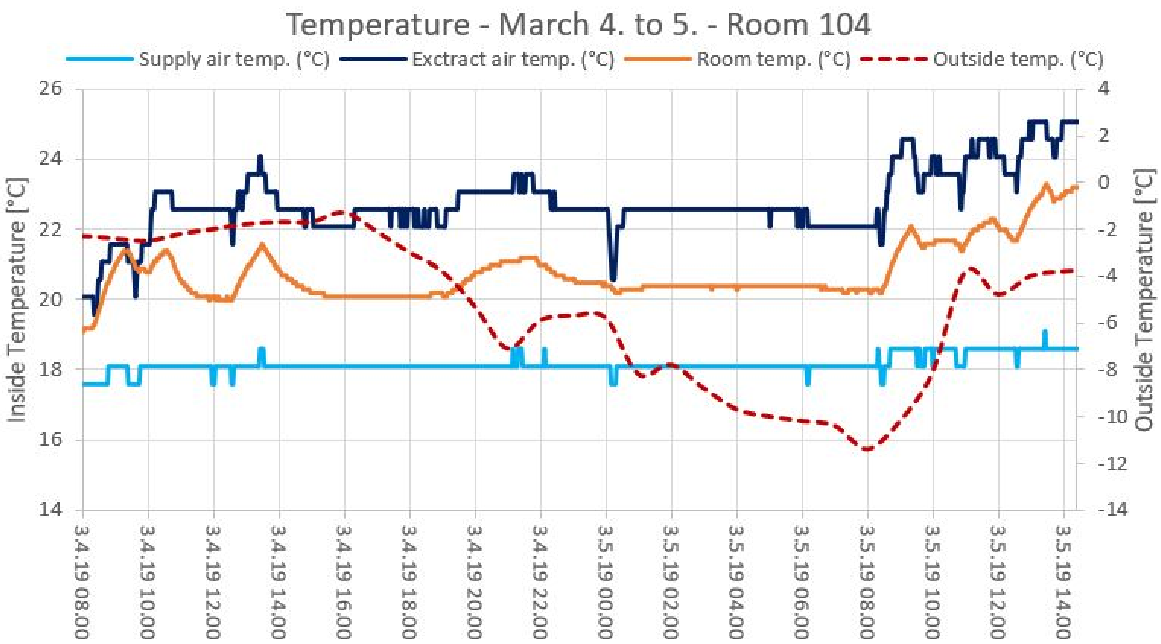

Figure 23: Air temperature measured in Room 104 from Mar. 04. to Mar. 05.

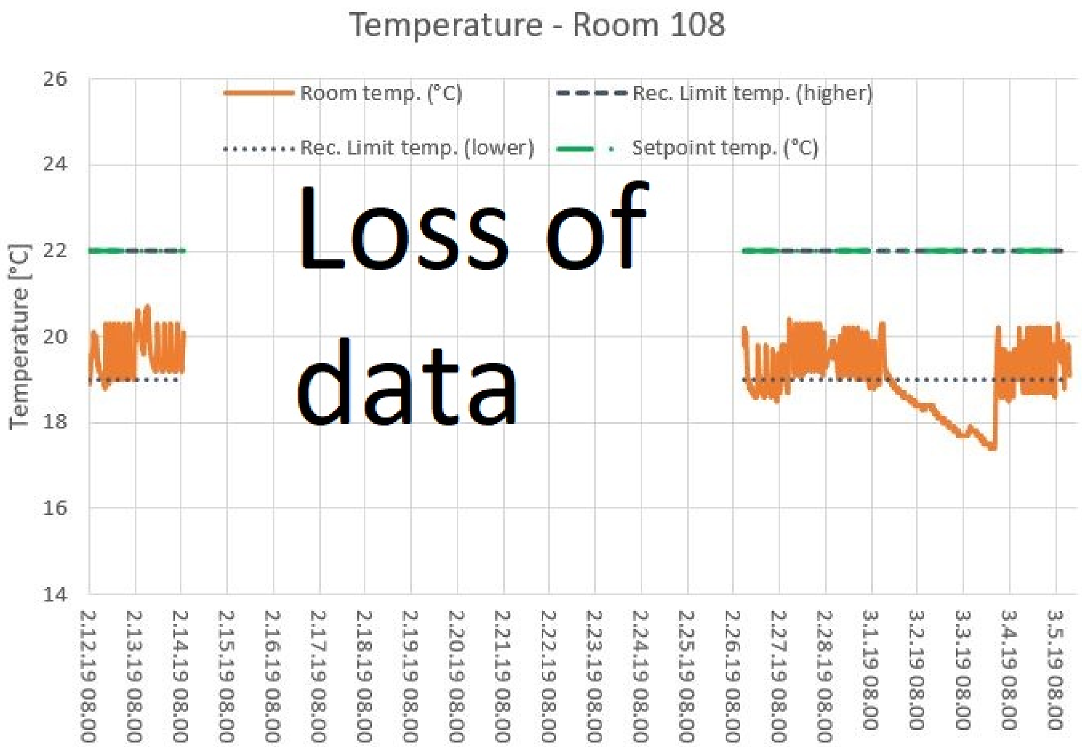

Figure 24: Air temperature measured in Room 108 from Feb. 12. to Mar. 05.

peratures from Room 104 in Figure 21 and Figure 24, one sees the difference and how well Room 108 is regulated. However, the room temperature is far below the setpoint temperature for the room (illustrated by green semi-spotted line in Figure 24). The setpoint temperature is 22°C for Room 108.

Figure 25 gives an even better overview of the temperature regulating for Room 108. During the hours the ventilation is on, the extract air temperature rises to several degrees above the supply air temperature. However, when the ventilation system turns off the supply air temperature increases above the extract air temperature. This is easily explained, as the heating system is continuously on during the school week. When the ventilation is turned off, the air in the room becomes stagnant, and the heaters heat the air. The warmer air rises up to where the supply air temperature is measured by the iButton. The supply air temperature is measured to 21-22°C when the ventilation is turned on. The room temperature is registered as 1°C lower.

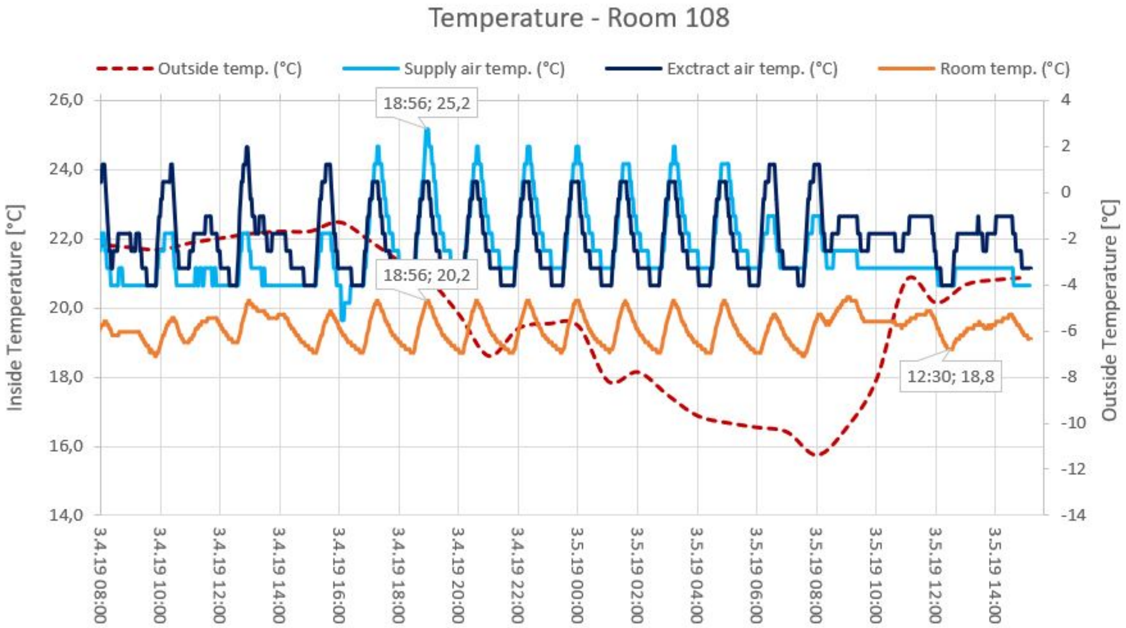

Figure 25: Air temperature measured in Room 108 from Mar. 04. to Mar. 05.

Figure 26 shows the temperature in Room 203. The graph looks similar to that of Room 104 in Figure 21, the only difference being Room 203 has a higher baseline temperature. During the winter break, the baseline temperature is visibly laying around 21°C. The temperature drops significantly during the weekends to 16°C and does not recover before school starts at 08:15 on Mondays. The temperature quickly rises on Mondays after school has begun. The room air temperature measured exceeds 22°C on a daily basis during the school weeks. Figure 27 shows a detailed overview of the temperatures in the classroom during the last five days of the field study. The supply air temperature again struggles to achieve the desired supply air temperature, which is 20°C in Room 203. The ventilation unit only seems to be able to provide the desired supply temperature when the extract air temperature is above 23°C.

The room air temperature increases rapidly during the school day. Room 203 uses an extra heater, which was observed right under the ELMA monitor. This means that the heater possibly can have affected the temperature measurements. The extra heater and the occupants together gives the rapid rise in temperature. It is nearly impossible to identify when the the extra heater affected the measurements by the ELMA monitor. The positioning of the heater changed and it is not certain it was always turned on.

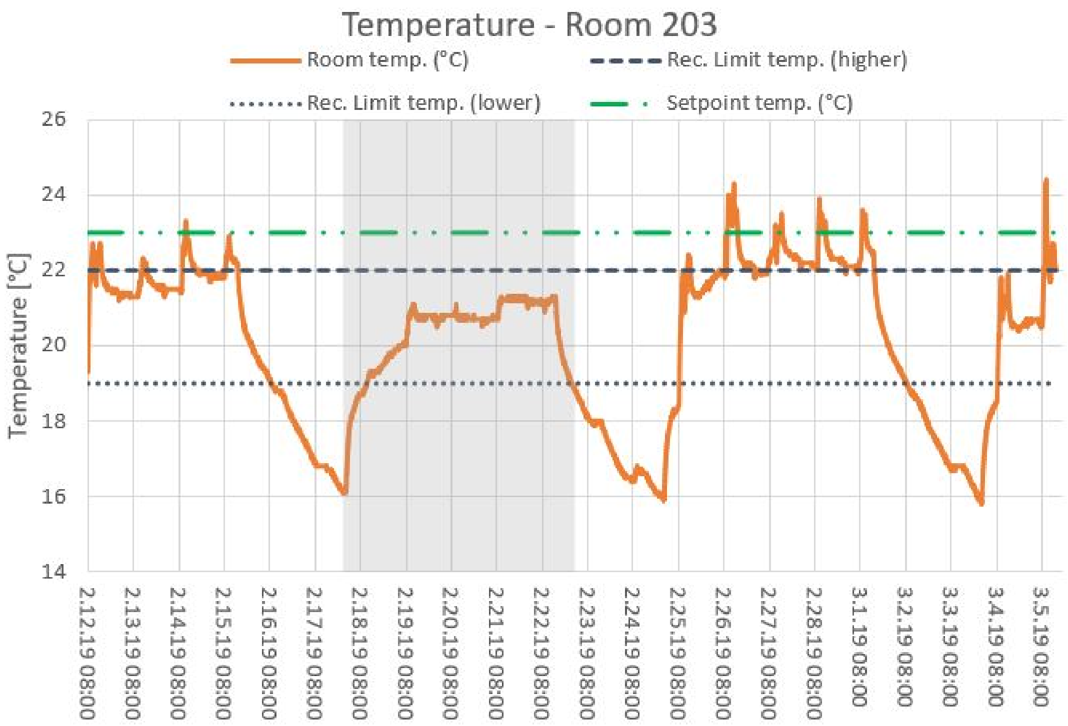

Figure 26: Air temperature measured in Room 203 from Feb. 12. to Mar. 05.

Solar heating could be another reason for the room temperature to suddenly rise.

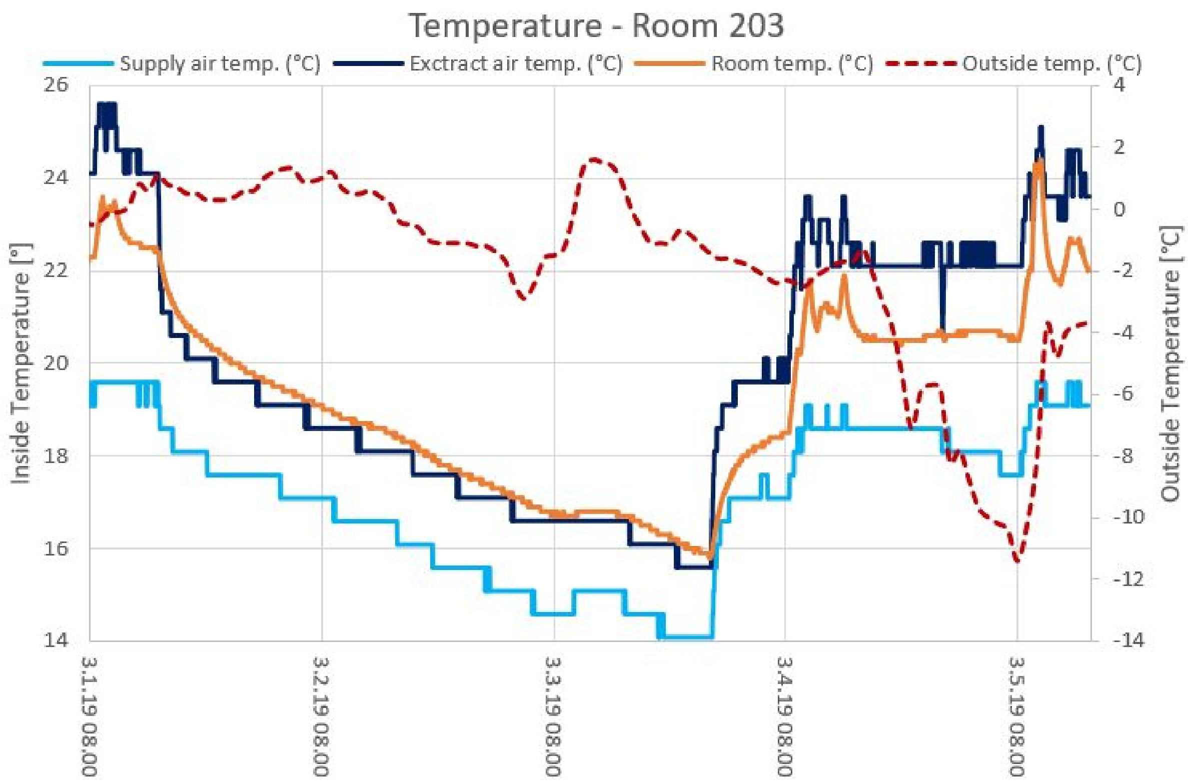

Figure 27: Air temperature measured in Room 203 from Mar. 01. to Mar. 05.

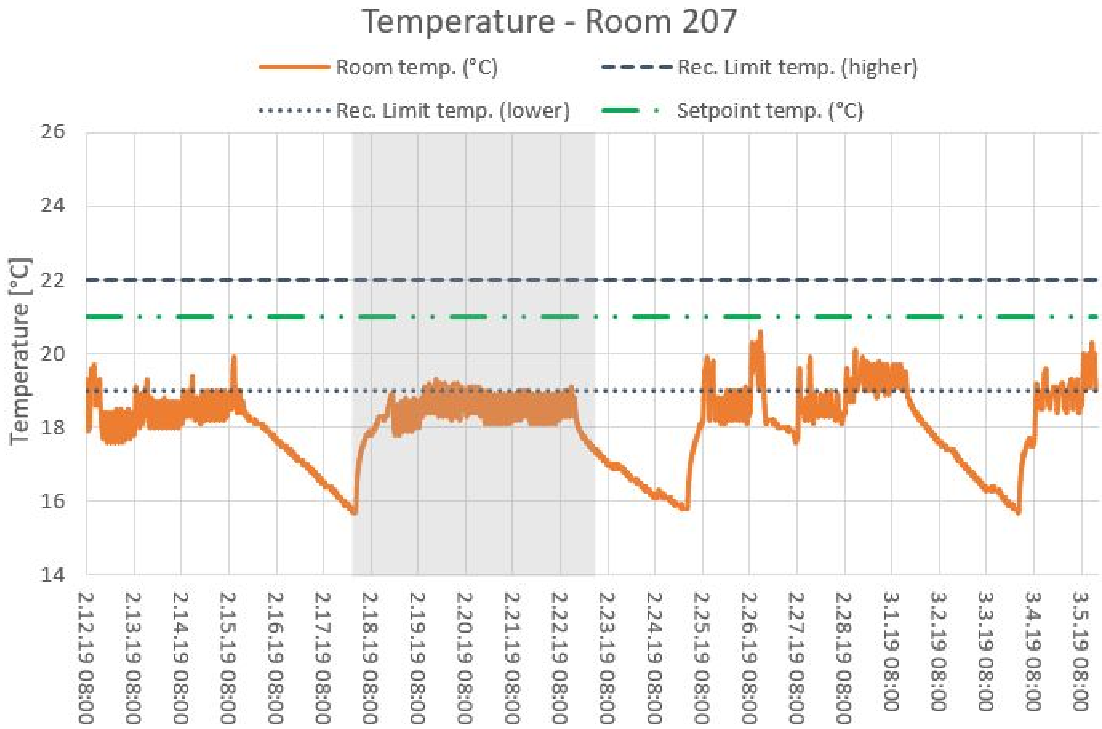

Figure 28: Air temperature measured in Room 207 from Mar. 01. to Mar. 05.

The temperature registered in Room 207 (Figure 28) mirrors the one observed in Room 108 (Figure 24) during the school week. The only difference is that in Room 207 the temperatures are 1°C lower across the entire week. During the winter break week one can see that the temperature is regulated between 18°C and 19°C. During the school week the temperature can reach upwards of 20°C. The setpoint temperature for Room 207 is 21°C. The registered room air temperature does not reach that temperature once during the field study period. In Figure 29, a detailed overview of the measured temperatures in Room 207 in the last five days of the field study is given. Once again, one can see that the extract air is higher than that of the supply air when the central ventilation is running. When the ventilation is turned off, the supply air measurements increases above the extract air on weekdays. In the weekend, when the heating is turned off, the extract air is highest, since the supply air is measured right by the windows where the heat loss is greater.

In all four classrooms investigated at Sunnland, the indoor temperature seem to be almost unaffected by changes in the outside temperature. However, during the field study, there were not any prolonged periods with freezing weather. The complete weather data from the entire field study period is given in Appendix G.

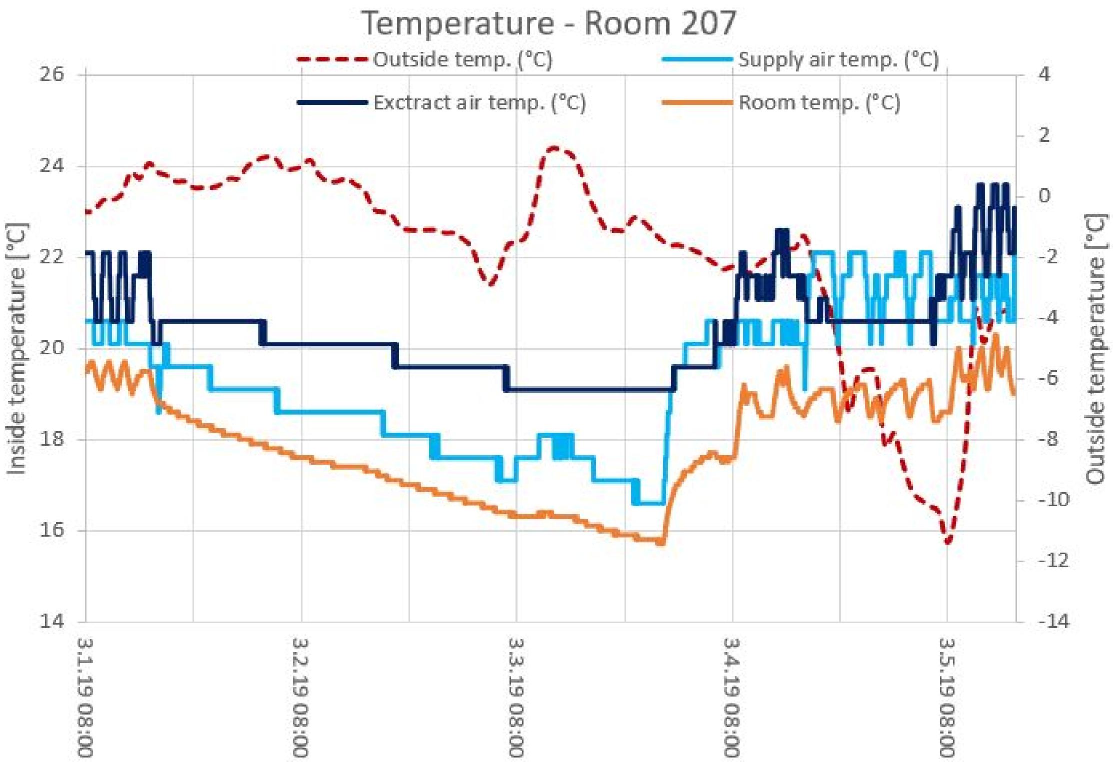

Figure 29: Air temperature measured in Room 207 from Mar. 01. to Mar. 05.

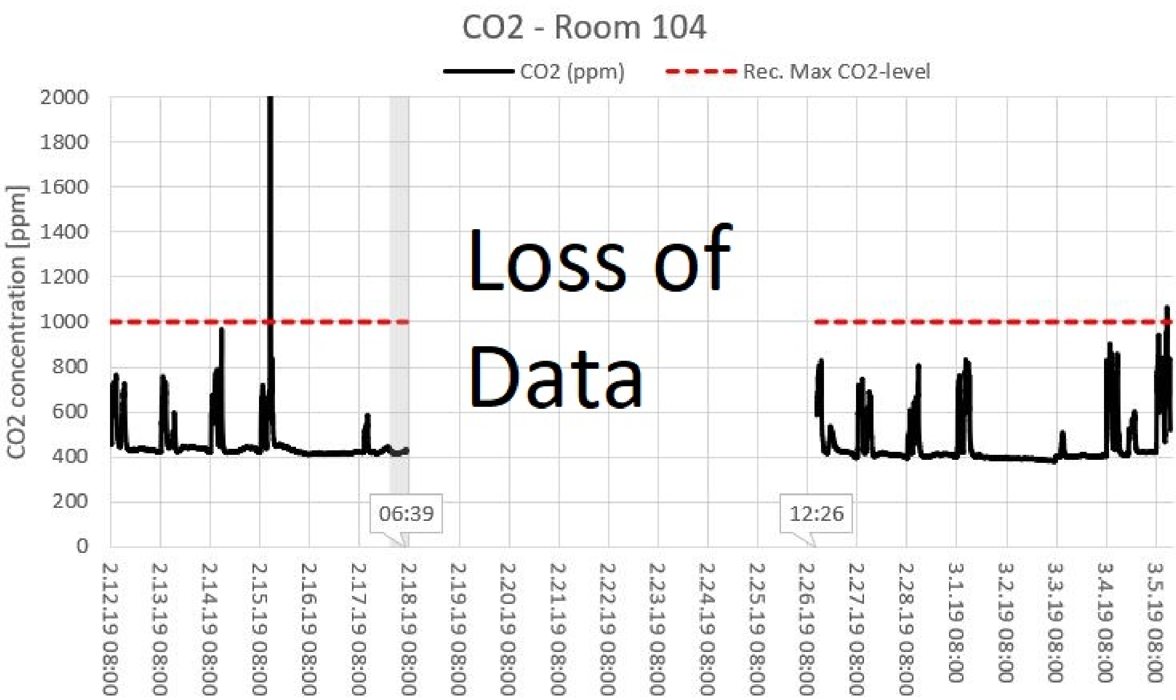

Figure 30: CO_2 concentration measured in Room 104 from Feb. 12. to Mar. 05.

Figure 30 shows all the CO_2 concentrations measured in Room 104. The CO_2 levels rise during the school day and peaks generally between 800 to 900 ppm. The values recorded are not great, but they are within the recommended values. The spike in con-

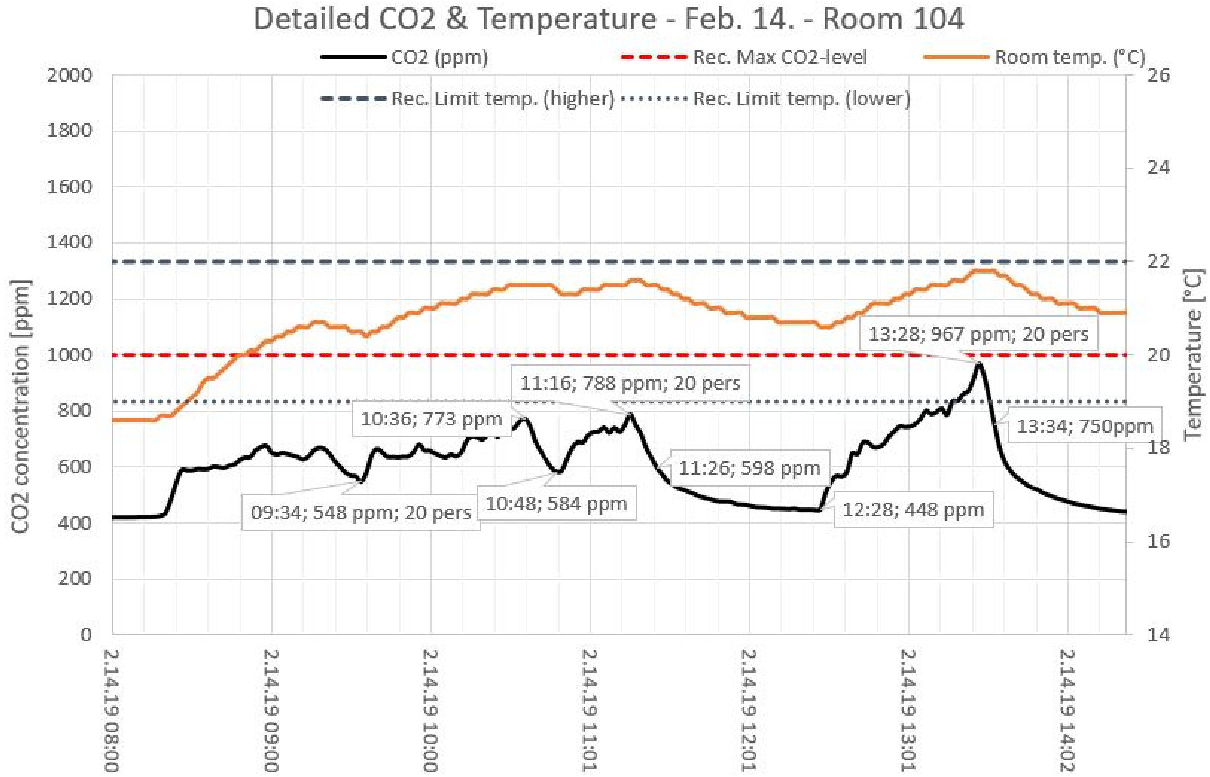

Figure 31: CO_2 concentration and temperature measured in Room 104 during the school hours on Feb. 14.

centration on Feb. 15. is by all accounts from a person breathing directly at the ELMA monitor. The measured value jumps from 760 ppm to 7530 ppm in the measurement. The next value drops down to 2000 ppm before it stabilized around 750 ppm again over a few measurements. It is assumed one or several persons breathed on the monitor. The monitor shows the concentrations live on the screen, so it could be interesting for the pupils. The screen could not be turned off without powering off the entire device. On the last day of measurements, March 5., the 1000 ppm barrier was exceeded by three consecutive measurements.

Figure 31 shows the CO_2 concentration and temperature for a single day in Room 104, Feb. 14. By looking at the labels on the graph, it is easy to see that the CO_2 concentration drops roughly 200 ppm during a 10 minute break. The concentration decreases faster the higher the concentration is and slows down as the concentration decreases, but that is a simple premise for dilution. In Figure 31, one can see that the temperature does not decrease substantially during short breaks, like with the CO_2 concentration. At 13:28, the highest CO_2 concentration and temperature were recorded, both just below their recommended maximum limits.

Figure 32 shows the complete series of CO_2 measurements done in Room 108. The first two peaks are lonely high values, most likely from a person breathing directly at the ELMA monitor invalidating those few measurements. The ELMA monitor was powered off by an unknown reason, so there lacks a significant amount of data from

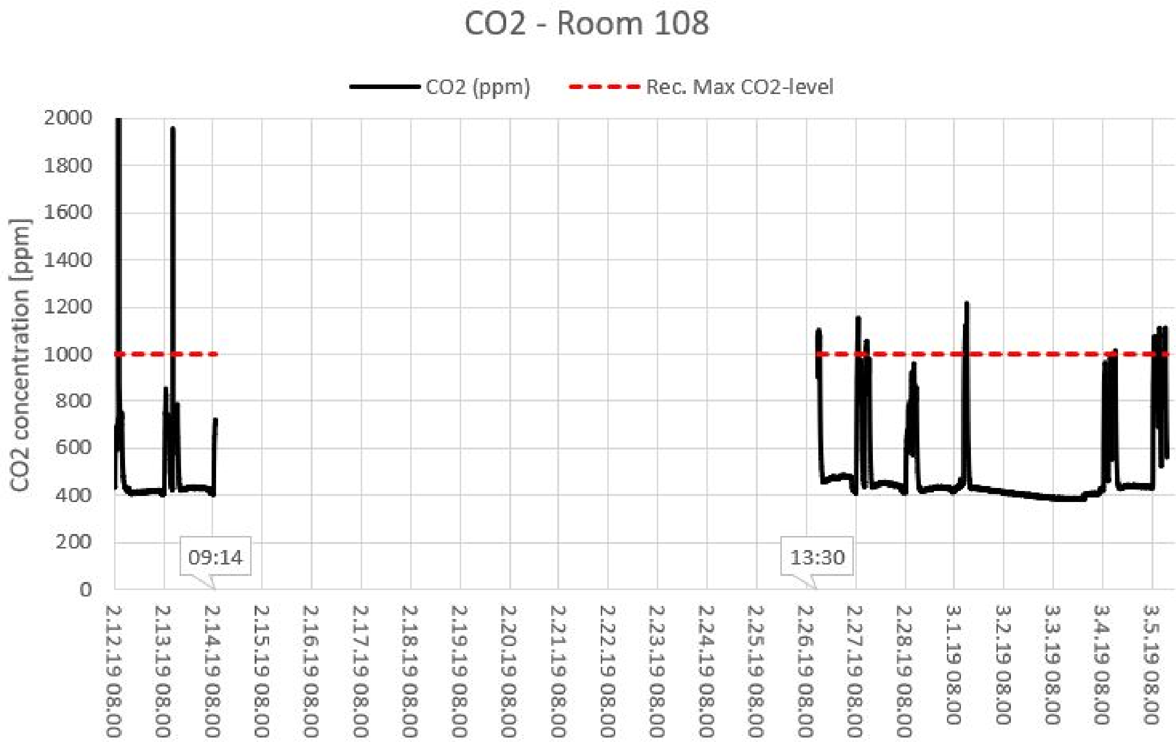

Figure 32: CO_2 concentration measured in Room 108 from the 12. Feb. to 05. March.

the field study period. The measurement series was continued on Feb. 26. at 13:30. The five school days worth of data collected after the winter break show that the CO_2 concentration peaks regularly above 1000 ppm. It only barely exceeded 1200 ppm on one occasion, Mar. 1.

Figure 33 show the CO_2 concentration and temperature in detail for March 5. By looking at the CO_2 curves, one sees that the CO_2 levels regularly drop in between classes, but that the room needs roughly 30 minutes to reach the baseline CO_2 concentration from a concentration of roughly 1000 ppm. The curve of the rising CO_2 concentration drops off right above 1000 ppm. This indicates that the room has a slightly too big occupancy load by today's ventilation solution. The measured room temperature does not rise much throughout the day.

Figure 34 shows the CO_2 concentration measured in Room 203. There are two peaks of singular measurements, on Feb. 27. and Mar. 5., that most likely comes from someone breathing directly or in close proximity of the ELMA monitor. The CO_2 levels in the classroom are reasonably good, excluding those two measurements. The concentration varies from day to day, probably in correlation with the number of occupants that changes some from day to day. The concentration rarely peaks over 900 ppm.

Figure 35 shows February 26. in detail. Unlike what was seen in Figure 33, both the temperature and CO_2 concentration changes significantly when the room is in use. The CO_2 levels drop quickly after a class, but the temperature decreases much more gradually. The exception being roughly at 09:30 when the temperature drops much quicker over a short period. This could be explained by the windows being opened during a

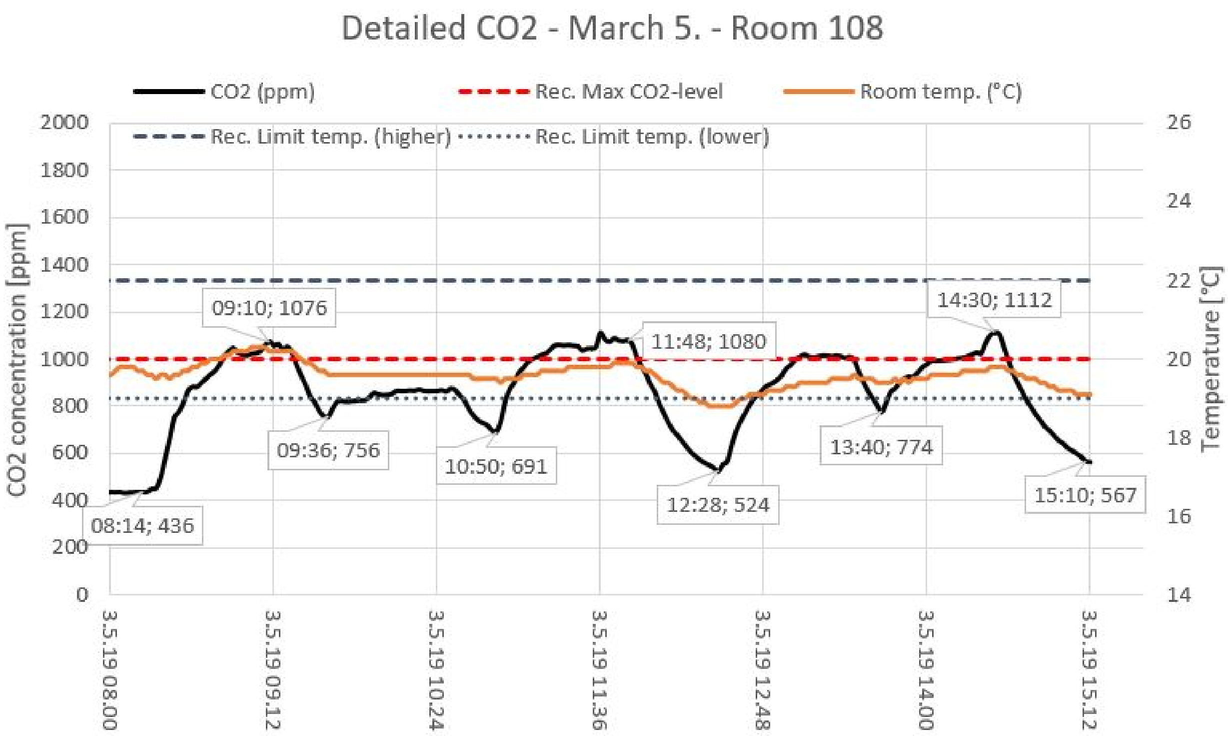

Figure 33: CO_2 concentration measured in Room 108 during the school hours on Mar. 03.

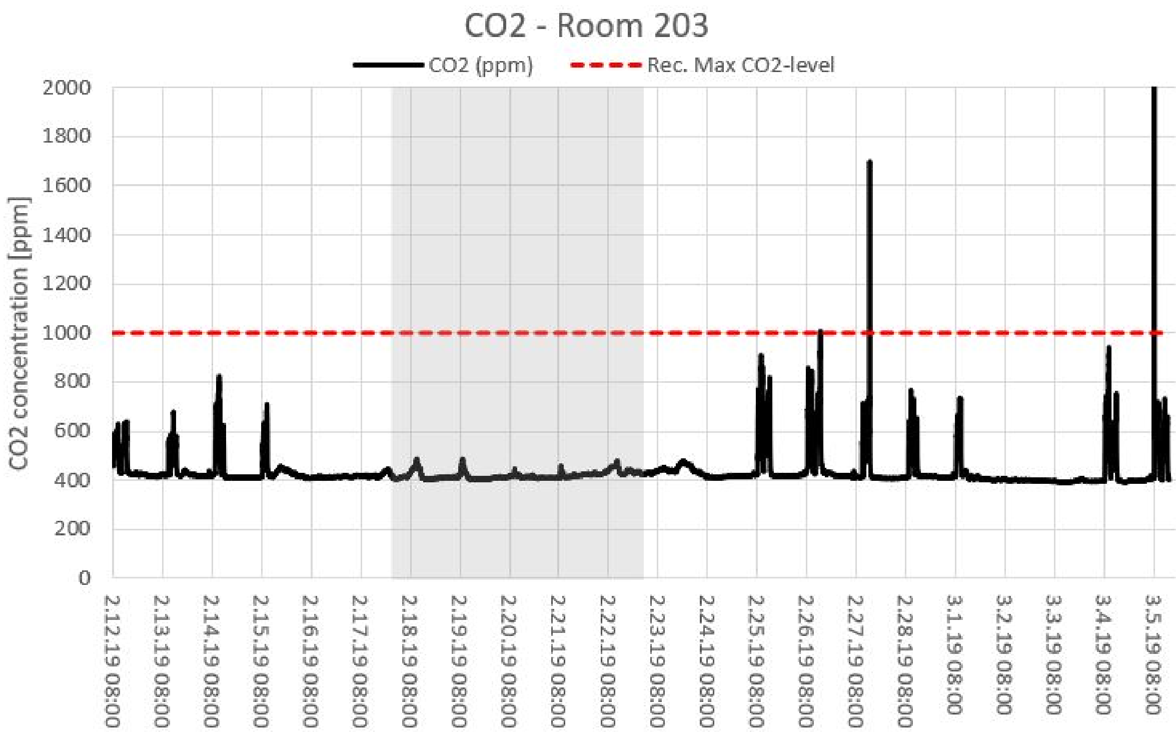

Figure 34: CO_2 concentration measured in Room 203 from Feb. 12. to Mar. 05.

shorter break. The rate of which the CO_2 concentrations rise varies throughout the day. One explanation is that some students work outside of the classroom, but they are all

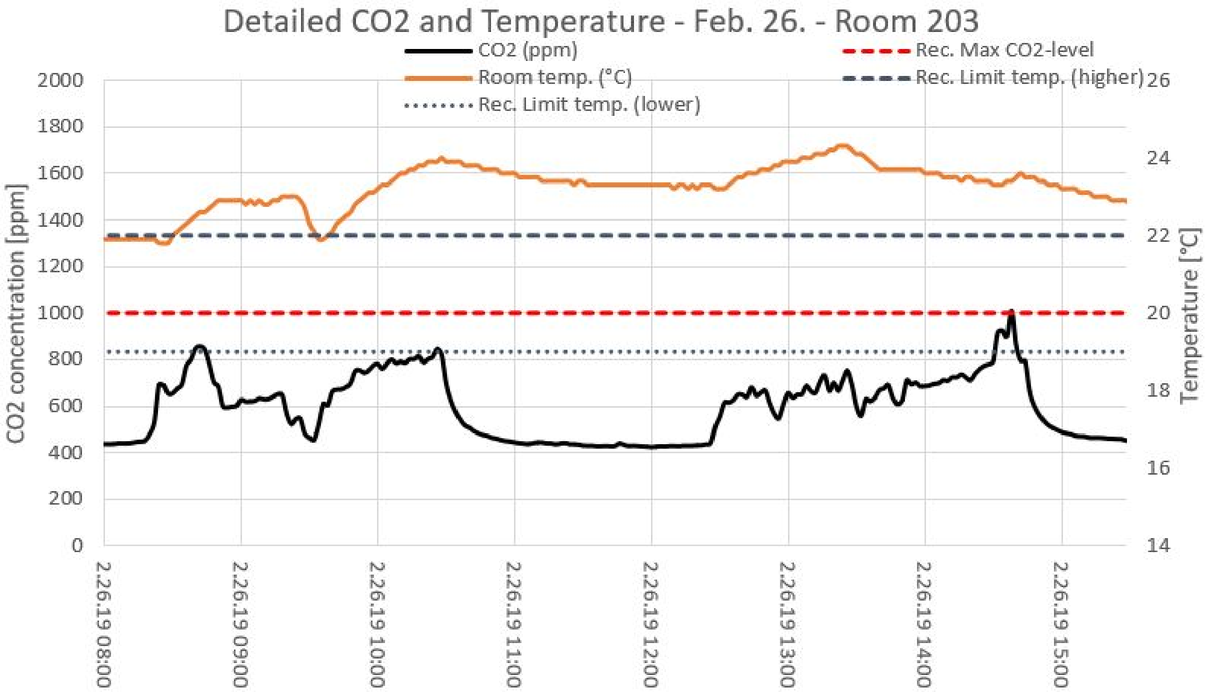

Figure 35: CO_2 concentration and temperature measured in Room 203 during the school hours on Feb. 26.

together at the start and end of sessions. That would explain the rapid growth seen in the beginning and end of several of the concentration peaks.

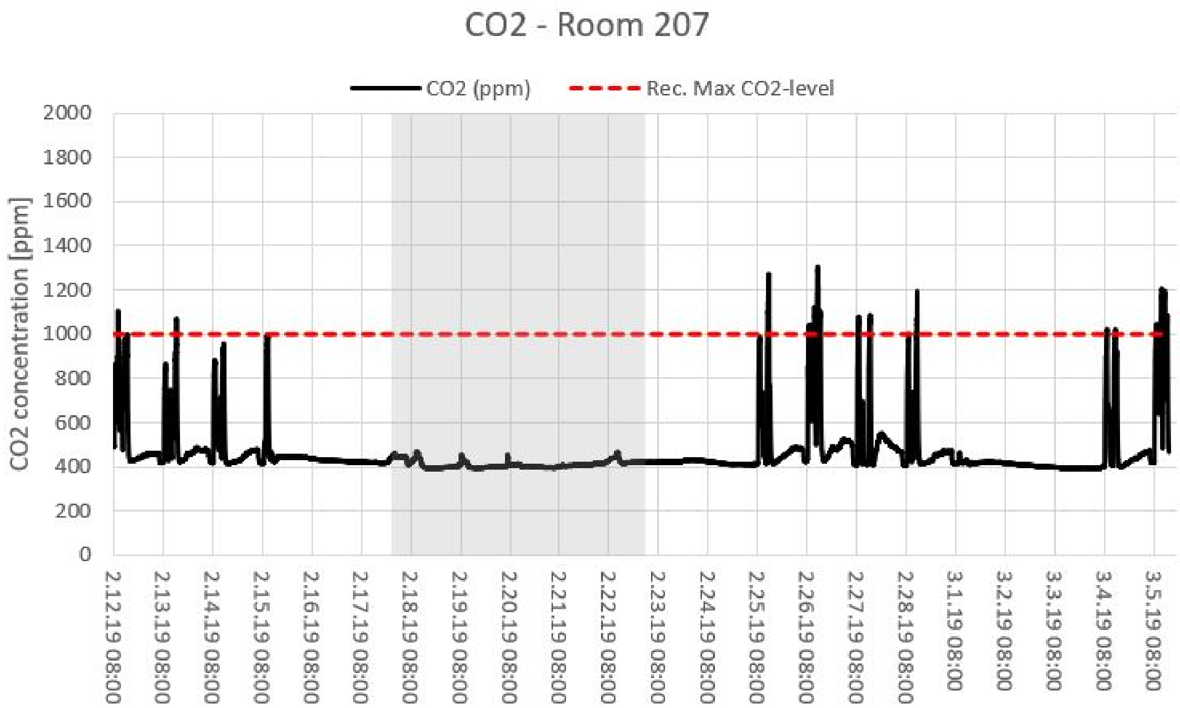

Figure 36: CO_2 concentration measured in Room 207 from Feb. 12. to Mar. 05.

Figure 36 gives the CO_2 concentration in Room 207 for the entire period. Room 207 has the highest CO_2 concentrations of the rooms investigated at Sunnland, but Room 108 is not far behind. Both rooms are still connected to the central building ventilation system. The 1000 ppm recommended limit is regularly broken, 11.1% of the time during the ordinary school week.

Figure 37 shows February 26. in detail. The room schedule is easily seen in the CO_2 concentrations. In just over one hour the CO_2 level rises from 400 to 1000 ppm. During the breaks between sessions, the CO_2 levels drop down to 600 ppm. During the next class, the CO_2 concentration rises again to roughly 1000 ppm, and the pattern repeats. During the fourth period, from 12:25 to 13:25, the CO_2 concentration increases to 1300 ppm. The last class follows the pattern of the first three classes. The reason for the increased CO_2 concentration is unknown. There could have been more people in the room or maybe the activity level was significantly higher during this class. The temperature fluctuated around 20°C throughout the day, dropping only to 19°C during the 30 minute lunch break. According to the room schedule, the room was used the entire day, with only 15 minutes break between the classes, excluding the longer lunch break. It was the same class that used Room 207 throughout the day.

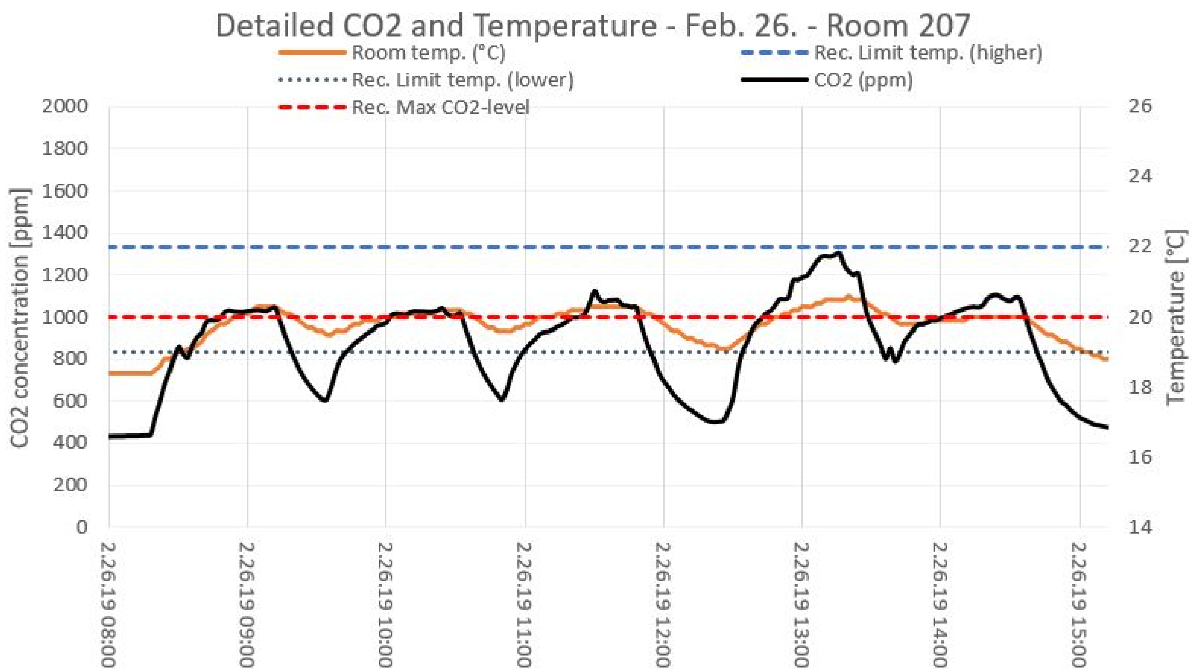

Figure 37: CO_2 concentration and temperature measured in Room 207 during school hours on Feb. 26.

Air velocity The air velocity was measured in Room 104. The measurements happened in an empty classroom after the school day was over. The classroom ventilation unit was running at standard capacity during the entire measurement series. Figure 38 illustrates the setup in the area closest to the ventilation unit on May 16. The red square marks the ventilation unit, the yellow squares the student desks, the orange circle with a black square illustrates the chairs. The black lines between the objects marks the original distances in the classroom. The grey rectangle in the top right corner is the electrical heater closest to the ventilation unit. The blue dots indicate the measuring spots and the bold number beside each blue dot is the identification number used in Table 9 to present the results.

There were 27 student desks, plus one desk for the teacher in the room. Three desks were placed together side by side. Between the ventilation unit and the blackboard there were four rows with three desks in each row by the window wall. The window wall is to the right in Figure 38, but only two of the closest rows to the ventilation unit is included in the figure. In the middle, there was a three desk placed back in the classroom; these three desks are visible to the left in Figure 38. Further to the left, there were four rows with three desks in each row. This room setup was from the day of the airspeed measurements, May 16. The setup had changed from what was seen in February during the field study and was shown earlier in Figure 7.

Each measurement presented in Table 9 consists of the average value from between five to seven measurements logged with a ten second interval. The instrument used (TSI VelociCalc 8388) stored and calculated the average values presented in Table 9. The measurements were done at different heights above the floor. Each measuring spot was not measured in all the different heights. Chair height means the height of the seat plate of the chair.

The results indicated that the airspeed by the student's workplace closest to the classroom ventilation unit is high enough that it can be experienced as uncomfortable. The equipment and the measurement procedure were not proper. As discussed in Section 4.1.1, the results should only be used to confirm or discredit the possibility of too high airspeeds by the student desks closest to the classroom ventilation unit.

Table 9: Results exceeding the recommended limit within school hours at Sunnland school.

Room 104 Air Velocity	2-4 cm above floor	20 cm above floor	Chair height	Desk height
1		0.62 m/s		
2		0.56 m/s		
3		1.09 m/s		
4		0.2 m/s		
5	0.22 m/s		0.04 m/s	0.02 m/s
6	0.15 m/s			0.01 m/s
7	0.08 m/s			0.01 m/s
8		0.02 m/s		0 m/s
9		0 m/s		0 m/s
10		0.22 m/s		0 m/s
11		0.2 m/s		
12		0.11 m/s		
13		0.18 m/s		

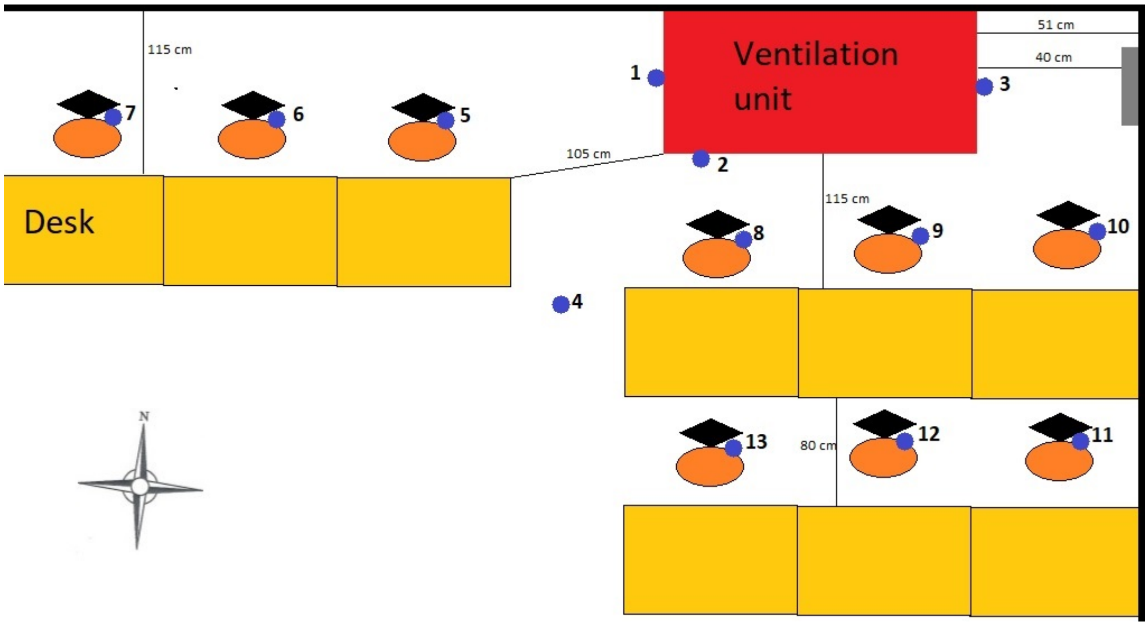

Figure 38: The setup in Room 104 close to the classroom ventilation on May 16. The red square marks the ventilation unit, the yellow squares the student desks, the orange circle with a black square illustrates the chairs. The black lines between the objects marks the original distances in the classroom. The grey rectangle is a electrical heater. The blue dots indicate the measuring spots and the bold number beside each blue dot is the identification number used in Table 9.

5.1.2 Measurement results of indoor environment quality at Stabbursmoen

Table 10: Results exceeding the recommended limit within school hours at Stabbursmoen school.

Results: **Stabbursmoen** Field Study	CO_2 >1000 ppm	Temp. > 22°C	Temp. < 19°C	RH < 20%
Room Blåsal	27.2%	0%	50.2%	3.1%
Room 321A	17.0%	15.0%	9.3%	11.7%
SFO room	16.5%	0%	0%	13.6%
Teacher's lounge	5.5%	51.2%	0%	25.7%

Table 10 gives an overview of the results from the field study at Stabbursmoen. The percentages given in Table 10 are the percentage of measurements that exceeded the recommended limits during hours the rooms are scheduled for usage. The weekends and the winter break is not included in the values in Table 10. The schedules are given in Table 3. In the four classrooms investigated, the CO_2 concentrations exceeded the recommended limit in all of them. Overheating is a problem in Room 321A, the measured temperature exceeds the recommended temperature 15% of the time during school hours. However, overheating is a significantly bigger problem in the Teacher'slounge with the temperature exceeded the set limit 51.2% of the time. This is exceptionally high since the Teacher'slounge is not in continuous use or under heavy loads. Room Blåsal struggles with too high CO_2 levels and too low temperatures. The low temperatures were expected as the room is regularly aired out by opening the windows. The relative humidity drops below 20% in all four classrooms. The relative humidity results were similar in all four rooms, but under occupancy load, the rooms responded with some difference. The SFO rooms relative humidity rose quickly to the high thirties when used; Room Blåsal followed the same pattern. The last two rooms followed a more gradual upsurge of the relative humidity during the school day. The results of the relative humidity measurements are presented in Appendix B.

Temperature

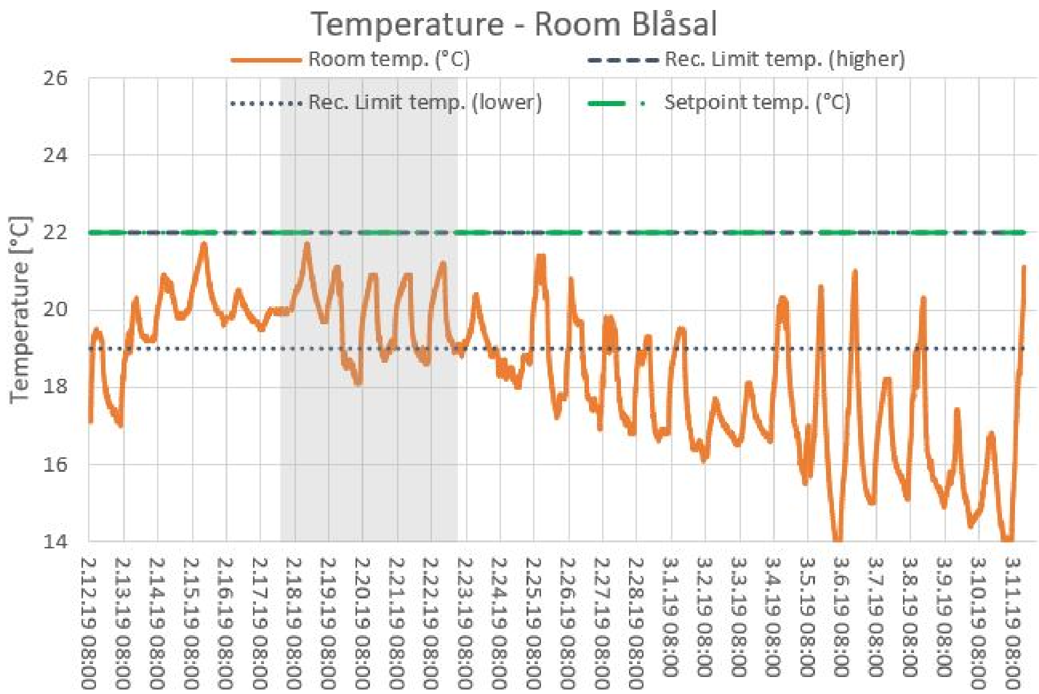

Figure 39: Air temperature measured in Room Blåsal from Feb. 12. to Mar. 11.

The entire room air temperature measurement series for Room Blåsal is presented in Figure 39. In the figure, the results show a room that struggles with regulating the temperature consistently. During the winter break, when the classroom was presumably mostly unused, the temperature fluctuates between 19°C and 21°C. The temperature does not reach the setpoint temperature or the maximum recommended temperature, both being 22°C. In the last ordinary school week, March 4. to March 8., the temperature regularly drops below 16°C during the night.

Figure 40 shows the temperature conditions in Room Blåsal from March 03. to March 07. in more detail. The temperatures measured from the iButtons are included, as well as the outside temperature. The temperature measured by the ELMA monitor is given by the orange curve. The orange line increases steadily every day until the last class of the day is over, it then decreases until the following morning until the heating and ventilation systems are powered back on again.

The extract air temperature, which is measured at the vent leading into the adjacent

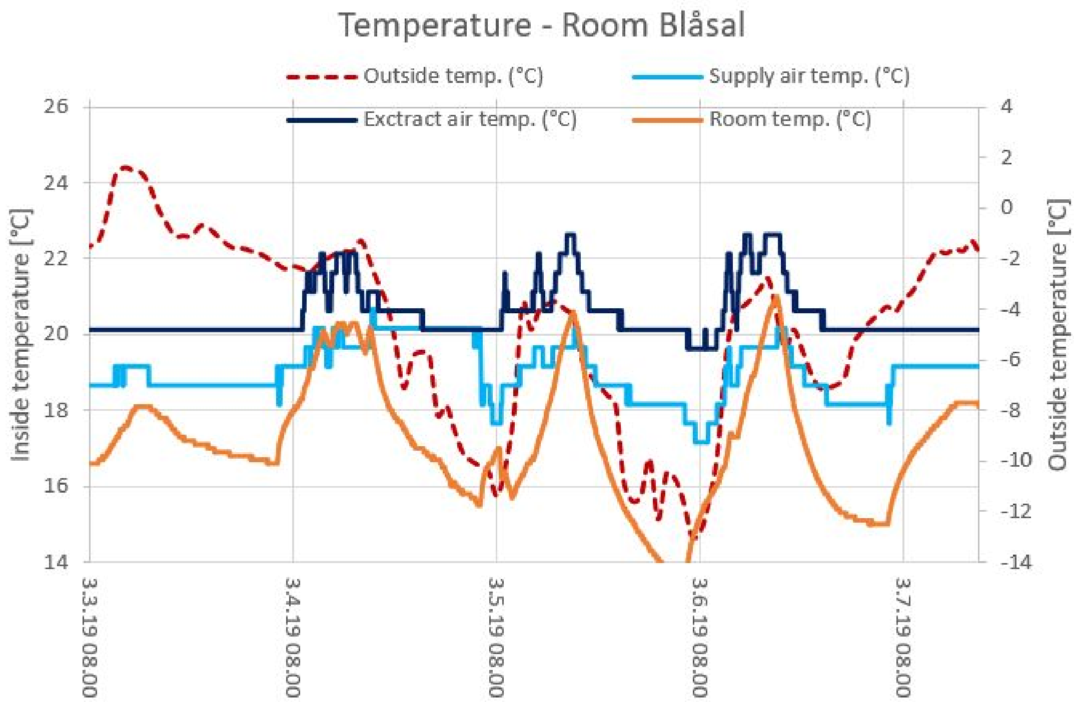

Figure 40: Air temperature measured in Room Blåsal from the Mar. 03. to Mar. 07.

room where the extract vents are, varies throughout the day. The temperature measured by the extract vent and the fluctuations seen coincides with classes using the room. The similar behavior is not seen in the data from the ELMA monitor. The supply air temperature measured seems to follow the rise of the room temperature. It does not seem to fall like the measured extract temperature between classes. The supply temperature should be held consistent by the fresh supply air and only increase incrementally, if at all. The temperature drop in the extract vent could be explained by windows being opened during breaks. The supply air has a setpoint temperature of 19.3 °C, but the measured supply air temperature increases beyond that after the room has been used for a while. This could indicate that the room is under-ventilated, since the supply air can not keep the temperature around the iButton taped directly on the supply air grill down.

The room temperature drops significantly during the colder nights on March. 5 and 6. The ELMA monitor measured temperatures below 14°C. However, the ELMA monitor was then most likely moved from the original placement further into the room, as explained below, and was now placed right next to the window. The measured temperature was most likely affected by the cooled down window. Figure 39 shows that the temperature started to drop on roughly February 25. As the weather data in Appendix G shows, there is no drastic drop in the outside temperature that explains why the measured nightly temperature suddenly fell. However, in the following days, the outside temperature falls more or less steadily until March 6. In the same time period, the night temperatures of the ELMA monitor also gradually decline. Therefore, it can be assumed that the ELMA monitor was moved to under the window on February 25. This move affected the remaining temperature measurements done by the ELMA monitor, as the cold window lowered the temperature of the air the ELMA monitor measured. The effect was biggest when the ventilation system was powered off, as the air became more stagnant.

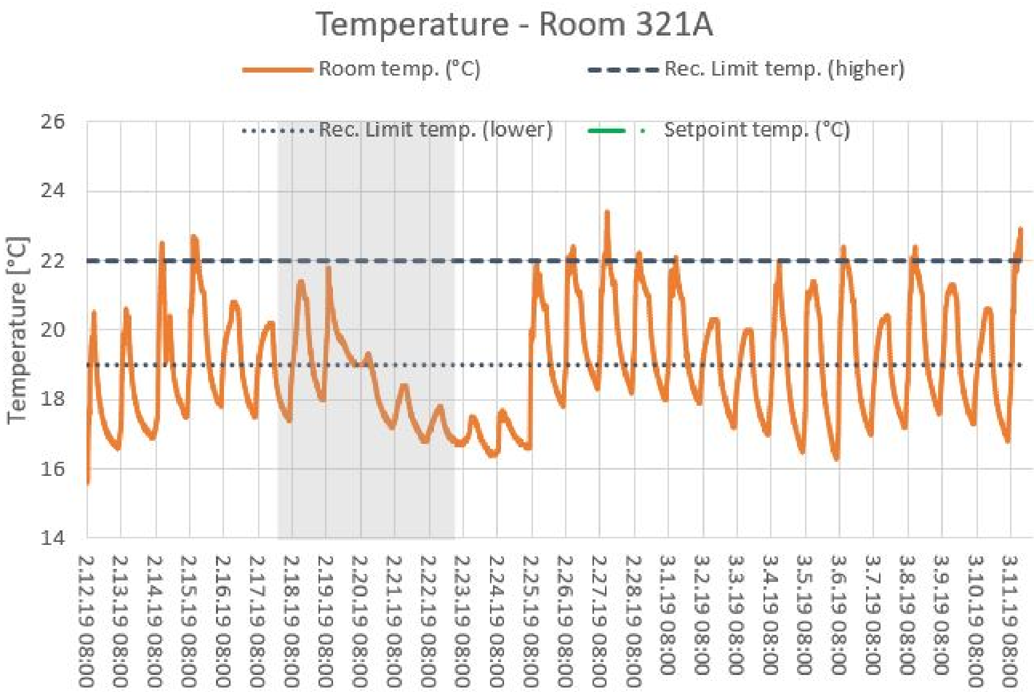

Figure 41: Air temperature measured in Room 321A from Feb. 12. to Mar. 11.

Figure 41 shows the entire temperature measurement series recorded by the ELMA monitor from Room 321A. The temperature drops heavily between the end of the school day and the next morning. The temperature falls and rises with an average of around 4°C every ordinary school day. The nightly temperature drops correlate well with the outside temperature.

The temperature exceeded the 22°C limit 15% of the time across all the school days during the field study. Figure 42 shows the measured temperatures from the last ten days of the field study in more detail. The supply and extract air temperature measurements are included along with the outside temperature. The extract air temperature increases between 3-4 °C from 08:00 and to later in the school day.

Figure 43 shows the period March 04. to March 07. In Room Blåsal, one could see that the measured supply temperature was above that measured by the ELMA monitor. This is also true in Room 321A. The supply air temperature is set on 19.3 °C, but it was measured upwards of 23°C on March 06. The high temperature measured from the supply air could indicate that the room is under-ventilated. The supply air temperature is measured to roughly 20°C at 08:00. The temperature measured by the ELMA monitor placed on a desk is measured at 18°C at 08:00. This tells us that the air mixture is not uniform in the classroom. The mixing ventilation does not function fully. The air is significantly hotter under the ceiling than down at desk height. At least, this is the case in the corner were the ELMA monitor was placed. The situation could be different in other parts of the room.

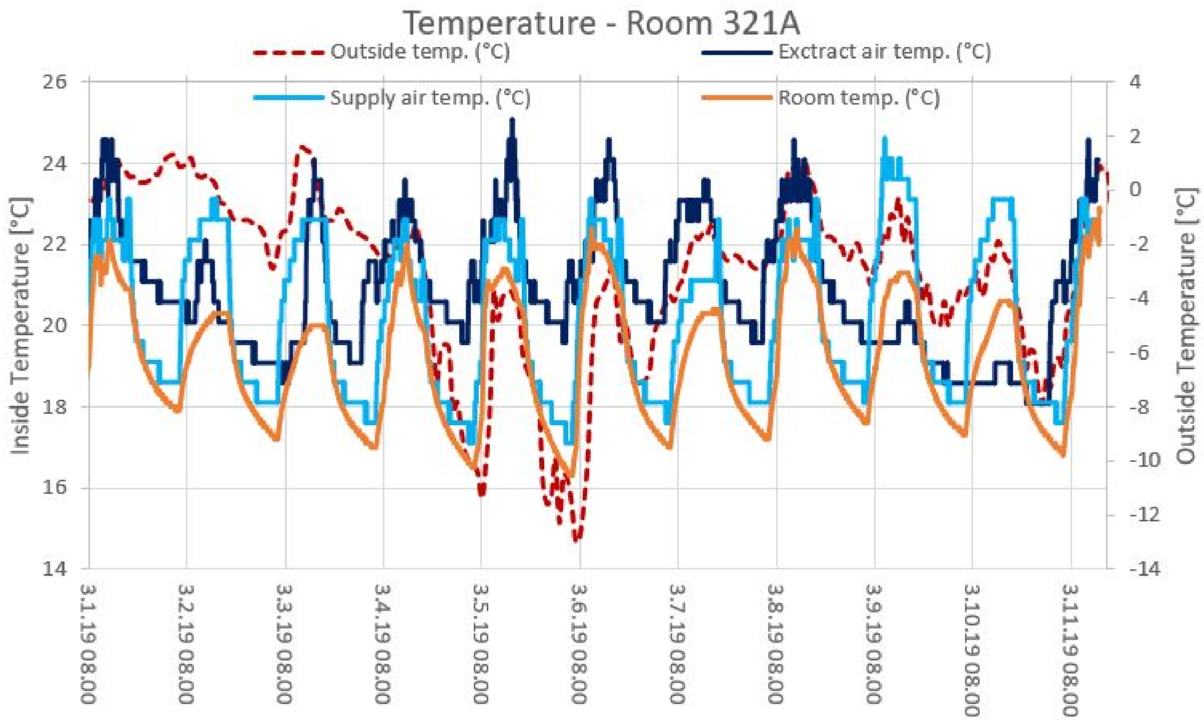

Figure 42: Air temperature measured in Room 321A from Mar. 01. to Mar. 11.

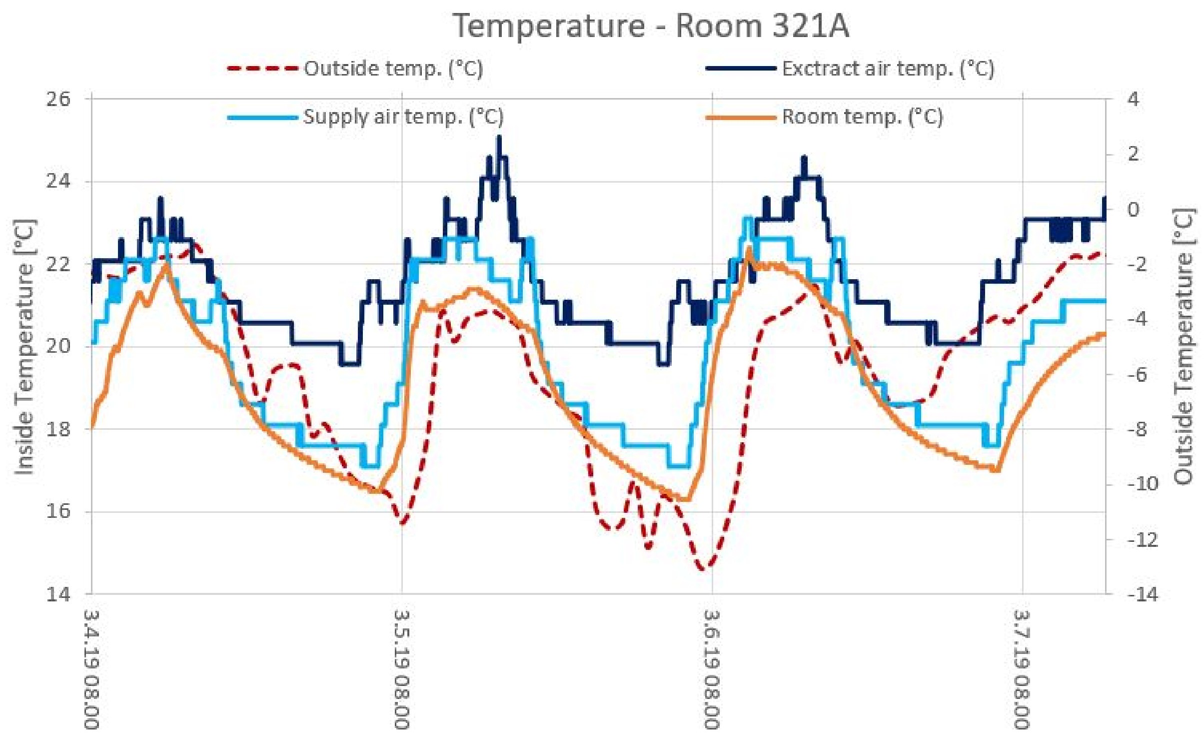

Figure 43: Air temperature measured in Room 321A from Mar. 04. to Mar. 07.

The temperature measured in the SFO room was stable during the entire measurement period. The temperature laid just above 20°. When the room was used, the temperature rose negligibly. The supply and extract measurements were also stable, with the

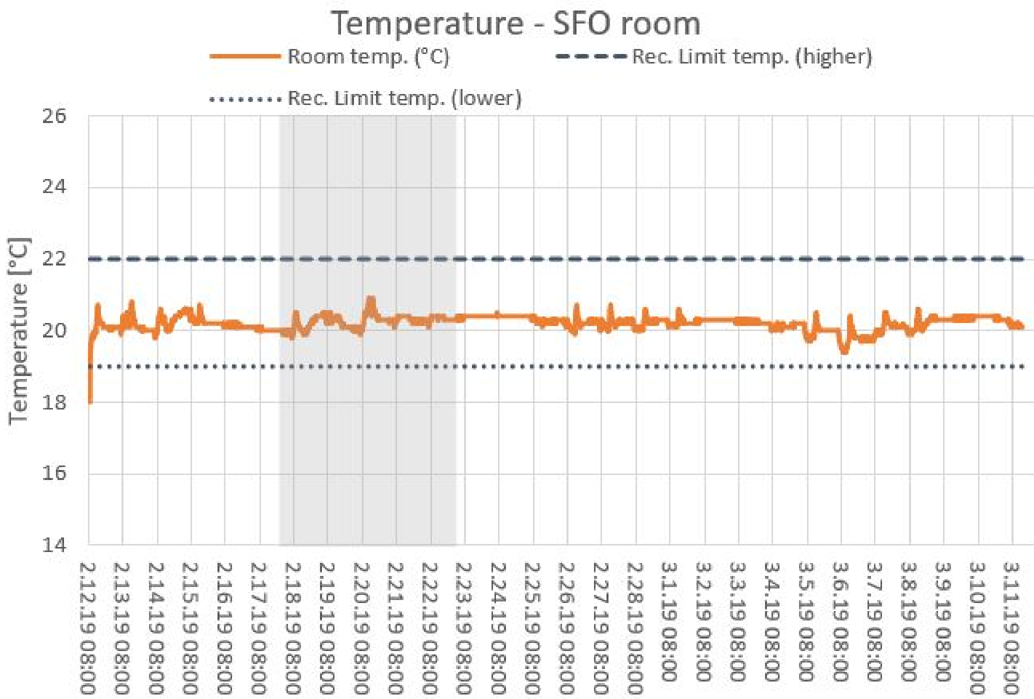

Figure 44: Air temperature measured in Room SFO from Feb. 12. to Mar. 11.

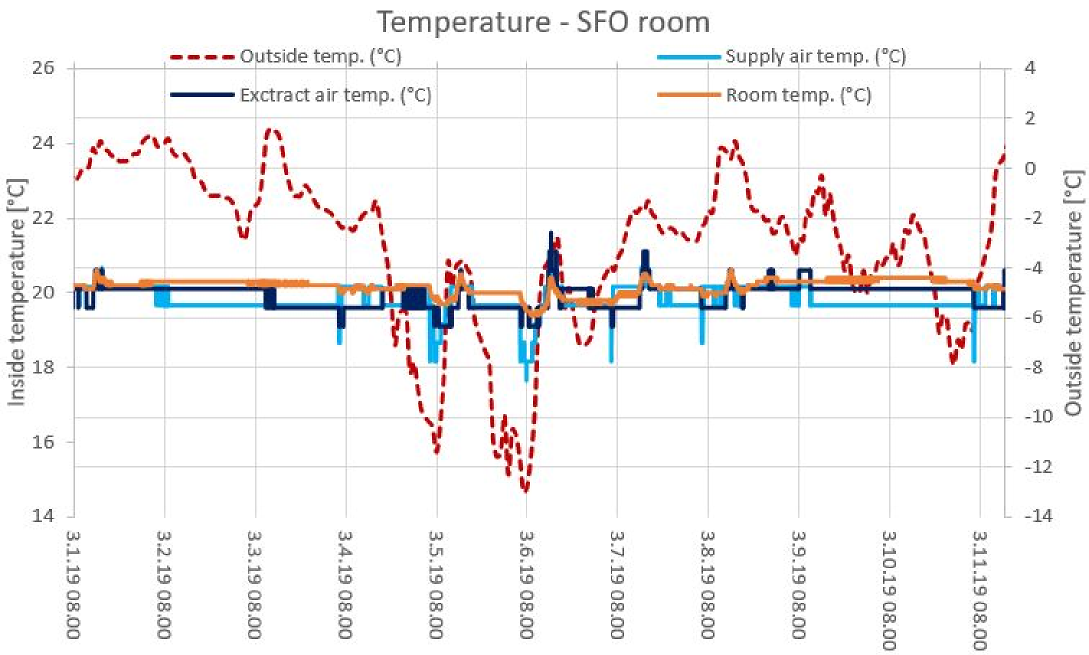

Figure 45: Air temperature measured in Room SFO from Mar. 01. to Mar. 11.

supply air temperature registering just below the extract air temperature. The extract air temperature was measured in a gap above in the doorway to the adjacent room. The results are presented graphically in Appendix B.

The entire measurement series from the ELMA monitor placed in the Teacher's lounge is presented in Figure 46. The large temperature fluctuations, as seen in Figure 46 for

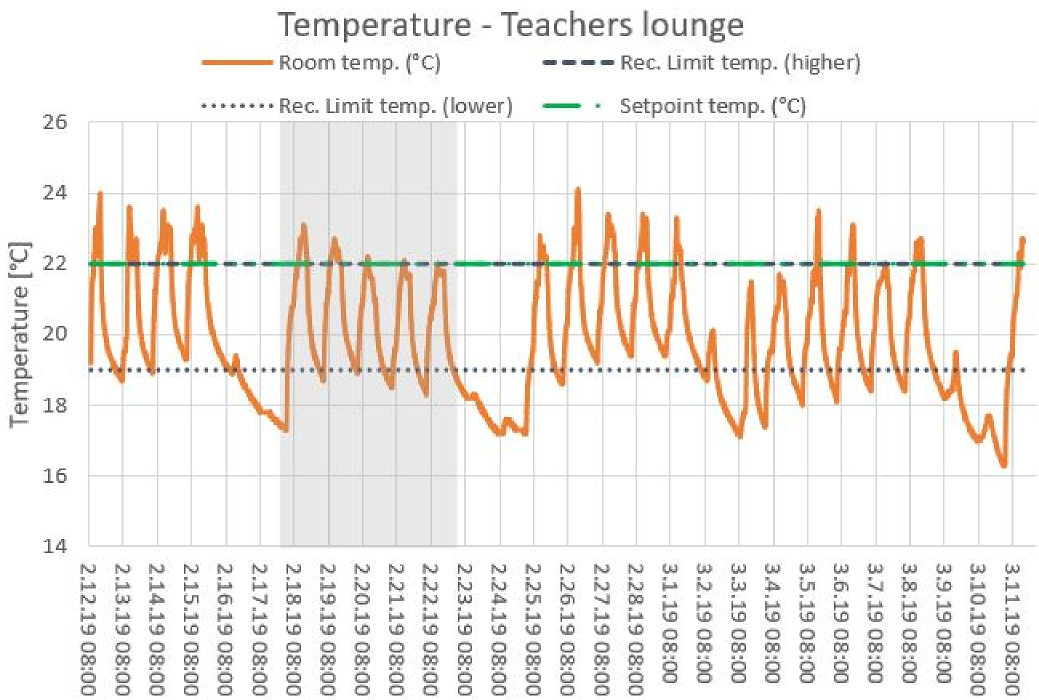

Figure 46: Air temperature measured in the Teacher's lounge from Feb. 12. to Mar. 11.

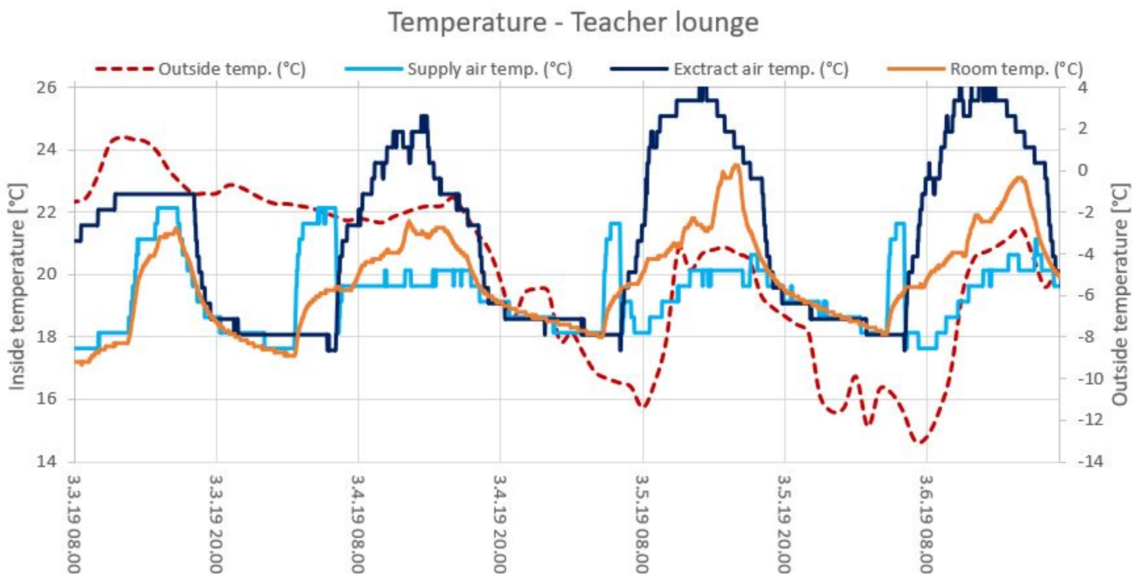

Figure 47: Air temperature measured in the Teacher's lounge from Mar. 03. to Mar. 06.

the Teacher's lounge, mirror that seen for Room 321A in Figure 41, but the fluctuations change less in the Teacher's lounge. The nightly temperature drops also seem to correlate less with the outdoor temperature than Room 321A.

By analyzing the data, it is believed that the heating of the room is turned on at 02:30 the night before Monday and at 04:30 the remaining weekdays. This is illustrated in Figure 47. It was deducted from the start time of the regular temperature increases. The ventilation is turned on at 06:00 every weekday. This is easy to identify as the fresh air temperature measurements plummet at precisely 06:00. This can best be seen in Figure 47. The fresh air temperature differs from the other rooms, since it does not exceed 20°C during the workday. The extract air temperature is significantly higher, but that does not seem to affect the fresh air temperature measured. The entire measurement series of the iButtons placed in the supply and extract vents in the Teacher's lounge is given in Figure80 in Appendix B.

The extract vents used to measure the extract vent temperature was located right above a coffee machine. The machine does give off some heat and moisture, but it is unknown how much it potentially could have affected the extract air temperature measurements. The measured extract air temperature is high. The extract air temperature rises consistently above 22°C, but the highest registered temperature was 26°C. The highest measured temperature in the Teacher's lounge was repeated on separate days. The temperature increases most during the staff meetings on Tuesdays. The room air temperature measured in the breathing zone reached 24°C, 24.1°C and 23.5°C during the Tuesdays meetings. It is assumed that there was not a meeting during winter break as the CO_2 measurements indicate a low occupancy load. The CO_2 concentrations also peaked highest during the Tuesday meetings. In the course of the meeting on February 12, the CO_2 levels almost reached 1600 ppm. The entire CO_2 measurement series from the Teacher'slounge can be seen in Figure 52. The CO_2 concentration peaks consistently above 1000 ppm during lunch hours and the Tuesdays meetings. The tall CO_2 peak on March 3. is a result of the room being used during the weekend. The ventilation system was not turned on, as illustrated by the slow decline of the CO_2 levels in Figure 52. A similar peak can be seen in the relative humidity measurements in Figure 81 in Appendix B.

Usually, the higher temperature in the extract air is not a problem, but the Teacher's lounge has a low ceiling height, resulting in a low air volume in the room even though the room is big. The high temperature in the extract air could indicate that the temperature is high in the upper portion of the occupancy zone as well. During the work day, defined from 08:00 to 16:00, the room air temperature was measured to be above 22°C in 54% of the time. The Teacher'slounge is sparsely used during long periods of the day, so 54% is exceptionally high. By looking at the winter break week, one sees that the assumed empty room reaches its setpoint temperature every day. It is a gradual temperature growth, but the setpoint temperature, 22°C, is reached before lunchtime. The CO_2 measurements indicate that there was some activity in the room, but far below the usual occupancy load. So the assumption that the room was empty is not entirely correct. Figure 47 shows that neither the room temperature or the extract air temperature drops down in periods with lighter loads. This is even more clear in Figure 53, where February 12. is shown in detail, in the figure one can see that the CO_2 level declines after the morning coffee meeting and lunchtime. The temperature remains almost constant in the same periods. Both the CO_2 level and temperature rises steadily during the staff meeting from 14:00 to 16:00. The CO_2 levels only exceed the 1000 ppm limit 5% of the time, this indicated that overheating is the main problem in the Teacher'slounge. The CO_2 mainly exceeds the 1000 ppm limit during the Tuesday meetings and sometime during the end of lunch. The room capacity is exceeded when the entire teaching staff is gathered there.

CO2

The CO_2 concentration measured in the Room Blåsal is given in Figure 48. The CO_2 measurements were 27.3% of the time, during school hours, above 1000 ppm. This is unusually high since the Room Blåsal is not continuously used like a regular classroom. By looking at the graph in Figure 48, it is believed that the CO_2 levels exceed the recommended limit of 1000 ppm in most sessions it is in use. Figure 49 shows both the CO_2 levels and temperature on February 25. The CO_2 levels rise to above 1000 ppm in only 15 minutes during the first class starting at 09:00. Similar rapid surges of the CO_2 concentration can be observed later in the day. The CO_2 concentration does decrease between classes, but it is unknown if this is the ventilation doing its job or the windows being opened as per the instructions on the entrance door seen in Figure 12 in Section 4.1.2. While the CO_2 concentration decreases, the temperature measured by the ELMA monitor remains relatively stable. The temperature is not affected by the occupant load like the CO_2 levels.

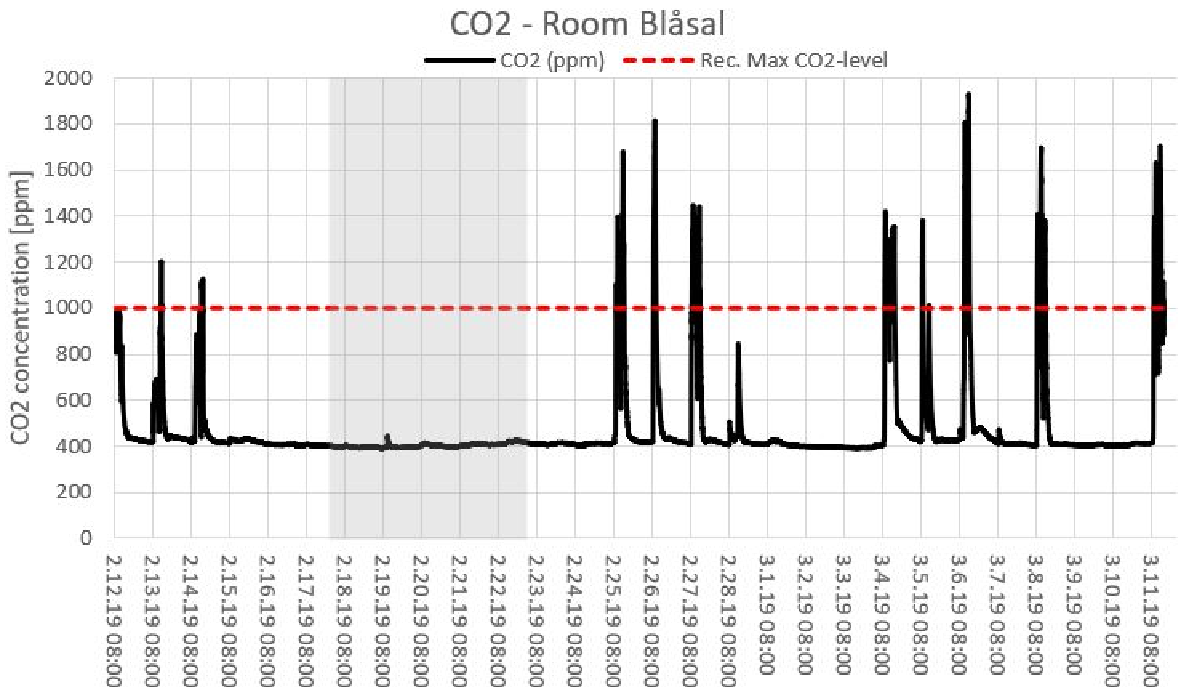

Figure 48: CO_2 concentration measured in Room Blåsal from Feb. 12. to Mar. 11.

The complete measurement series from Room 321A is given in Figure 50. It is evident that the CO_2 concentration exceeds the 1000 ppm limit regularly. During the regular school hours, the limit was exceeded 17% of the time, not including the weekends or the winter break. An important distinction is that the ELMA monitor was placed well away from the working desks of the pupils, so the measurements presented should be a decent representation of the conditions in the room. Figure 51 shows a detailed overview of the results from Room 321A on February 13. During the longer classes the CO_2 levels peaks above 1400 ppm. The CO_2 peaks change from day to day, but that could be explained by small differences in the occupant load. The classroom is definitively above its carrying capacity when the entire class is present. According

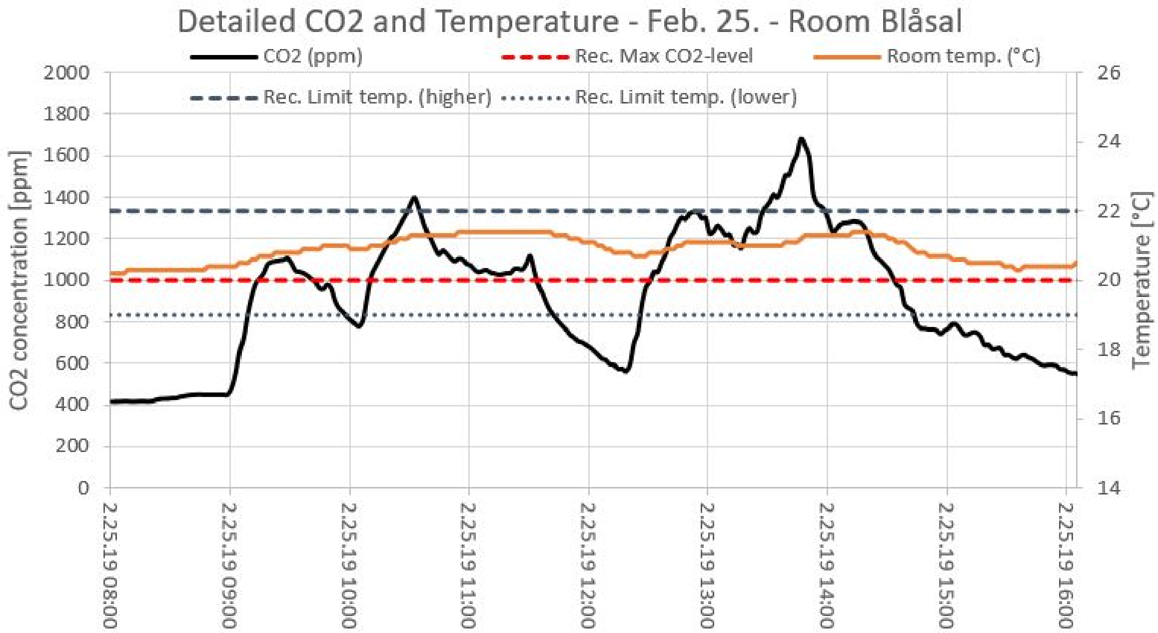

Figure 49: CO_2 concentration and temperature measured in Room Blåsal on Feb. 25.

to the occupancy form filled out by the school, there are 27 people in the room with perfect attendance.

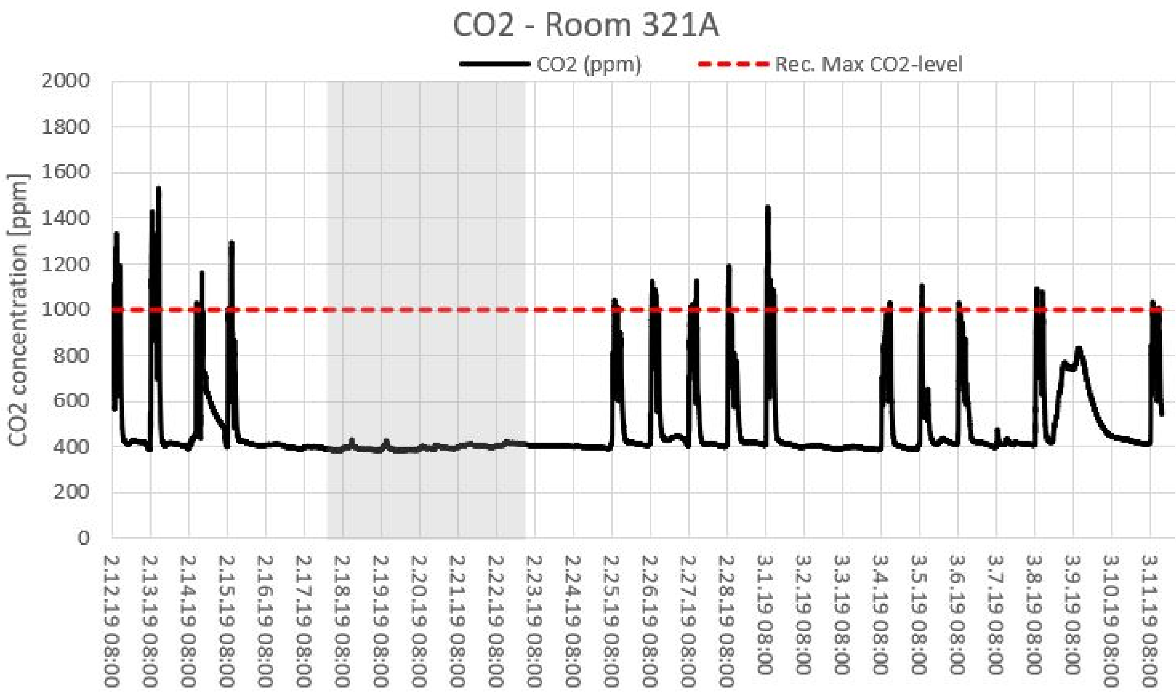

Figure 50: CO_2 concentration measured in Room 321A from Feb. 12. to Mar. 11.

As illustrated in Figure 51, the ventilation only manages to lower the CO_2 concentration from 1300 ppm to 700 ppm during a 30 minute break on February 13. The school did not fill out the occupancy form in detail. Therefore, it would be speculative to try

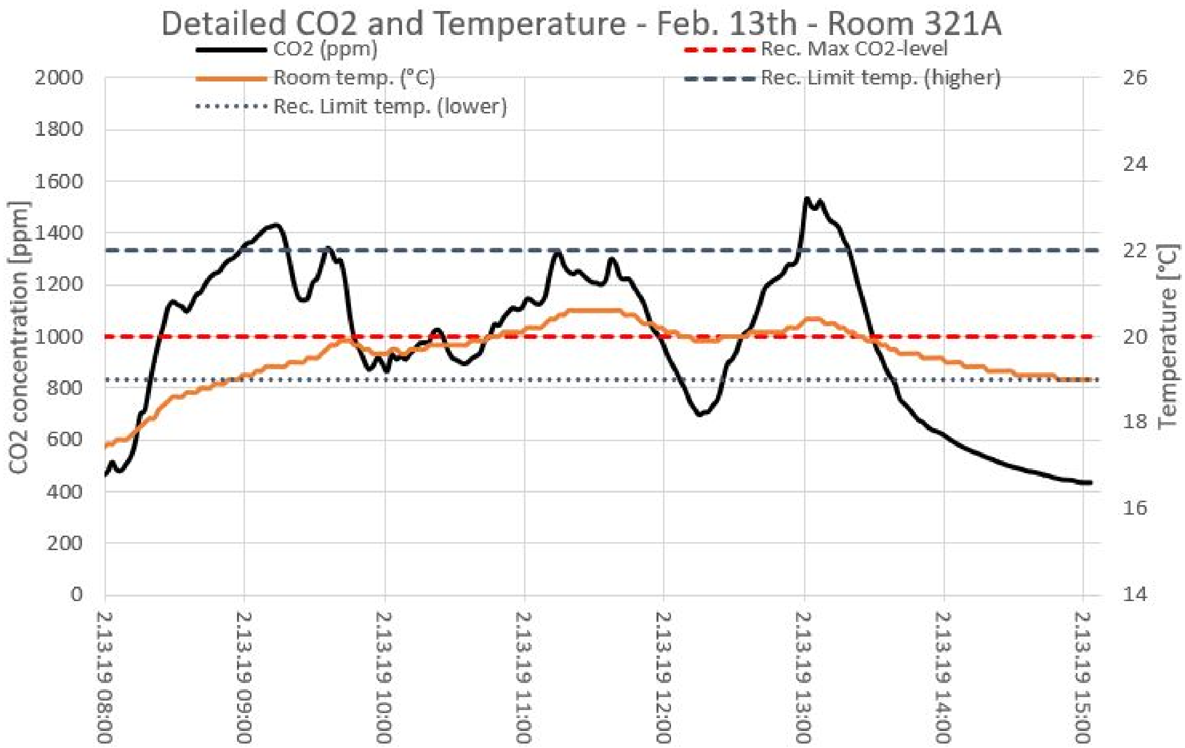

Figure 51: CO_2 concentration and temperature measured in Room 321A on February 13.

and determine the actual carrying capacity of the room and recommend a maximum limit of people using the room simultaneously.

The complete CO_2 measurement series for the SFO room is presented in Figure 54. All the tallest peaks in Figure 54 happens between 13:30 and 14:30. The 1000 ppm limit is broken daily, except on Mondays. It is unknown what happens on Mondays that result in the room being mostly unused. Figure 55 shows a detailed overview of the room on February 12. and 13. The CO_2 starts to rise roughly at 13:30 and reaches its peak within one hour. The CO_2 concentration decreases fast from 14:30. It does not seem like the room is used after roughly 14:30. It is not unlikely that the after school program has a predetermined activity every day at 14:30. The SFO room is sometimes used during the school day before the official after-school program starts.

Both the SFO room and Room Blåsal do not have their own extraction vents connected to the central ventilation system in the room. In both rooms, the CO_2 levels are a problem, especially with the rapid growth of the CO_2 concentration during occupant loads.

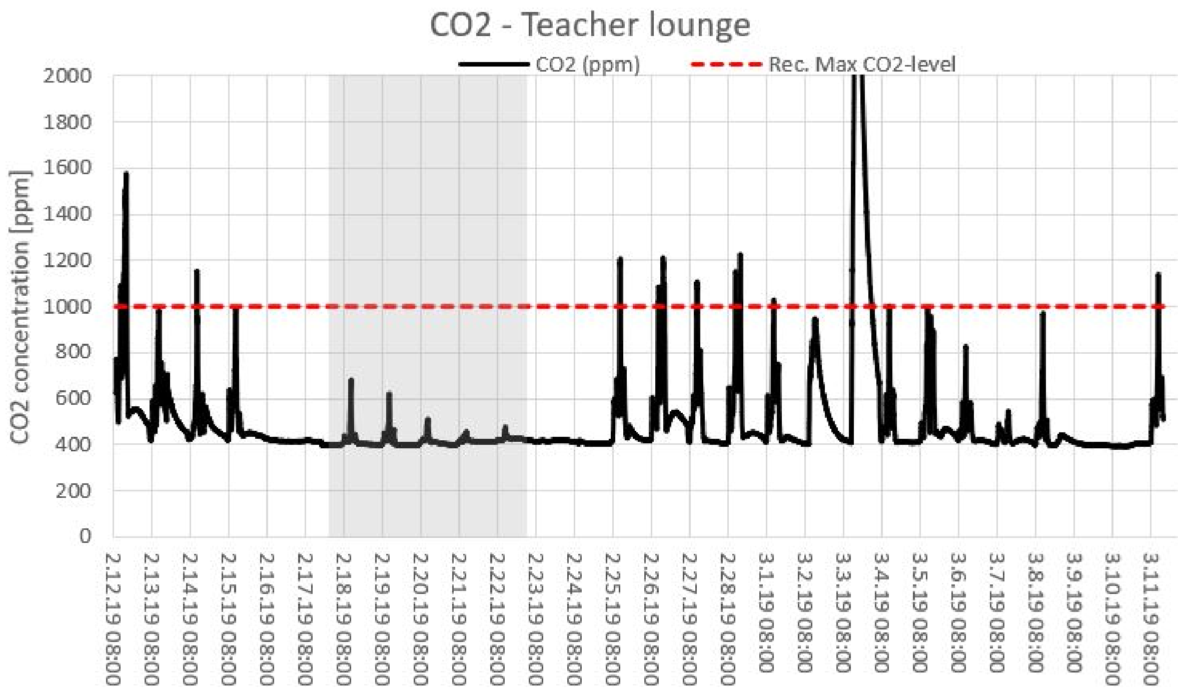

Figure 52: CO_2 concentration measured in the Teacher's lounge from Feb 12. to Mar. 11.

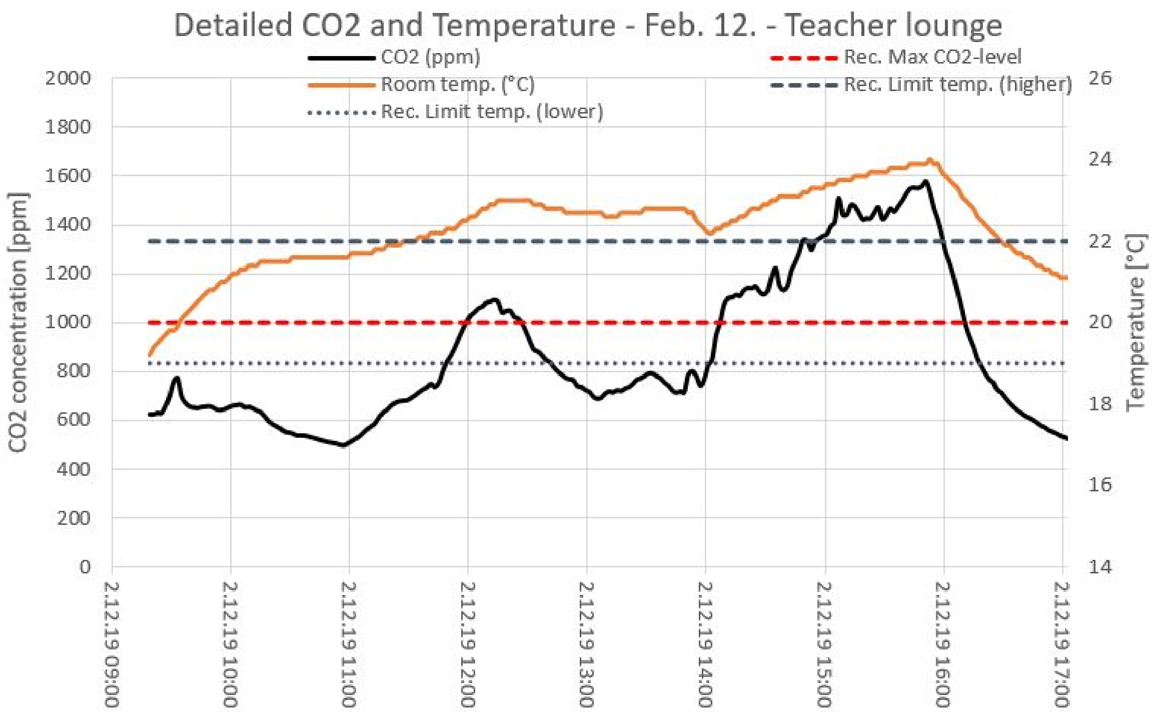

Figure 53: CO_2 concentration and temperature measured in the Teacher's lounge on Feb. 12.

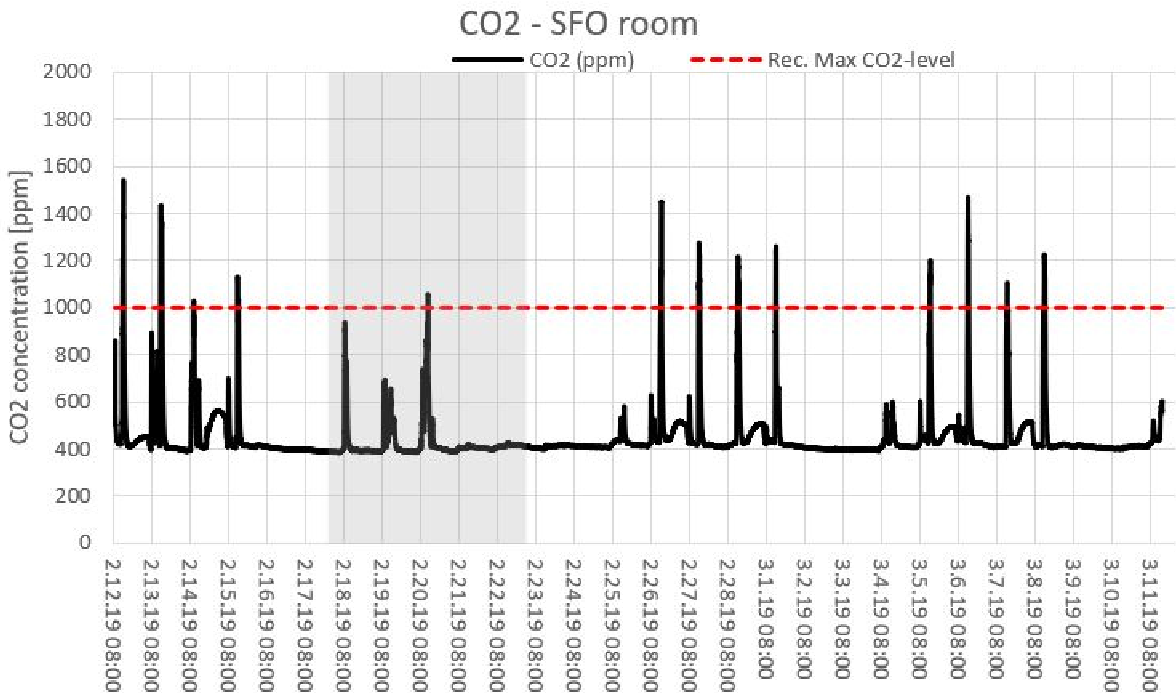

Figure 54: CO_2 concentration measured in the SFO room from Feb. 12 to Mar. 11.

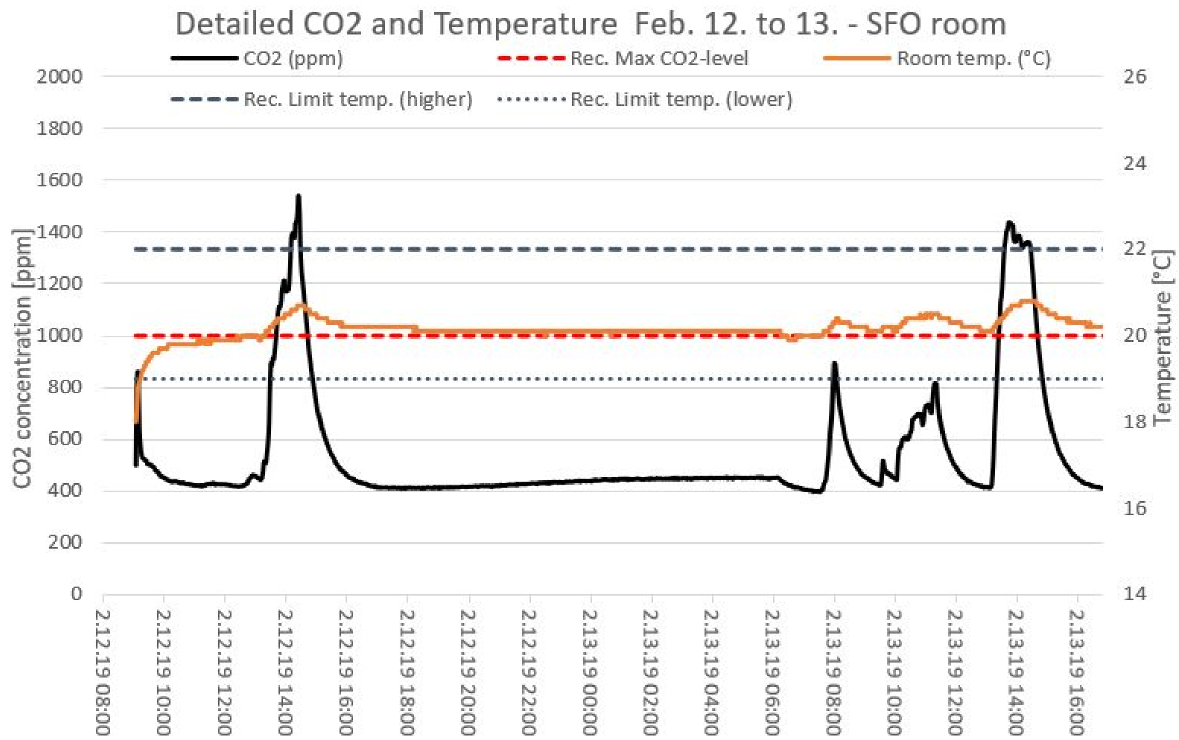

Figure 55: CO_2 concentration and temperature measured in the SFO room on Feb. 12.

5.1.3 Measurement results of indoor environment quality at Sørborgen

Table 11: Results exceeding the recommended limit within school hours at Sørborgen school. Music room* is the percentages after school hours from 13:15 PM to 21:30 PM. The Music room is regularly used by the culture after school program in the afternoon.

Results: **Sørborgen** Field Study	CO_2 >1000 ppm	Temp. > 22°C	Temp. < 19°C	RH < 20%
Room 0217	0%	0%	7.3%	30.8%
Room 0222	0%	58.5%	0.2%	17.4%
Room 0273	N/A	N/A	N/A	N/A
Music room	2.8%	11.2%	0%	33.1%
Music room*	4.0%	18.5%	0%	30.4%

Temperature

Table 11 shows the percentage of measurements that were above or below the recommended limits during school hours. The winter break and weekends are excluded from the results in Table 11. The measured CO_2 levels and temperature in Room 0217 never exceeded the maximum recommended values. The temperature was too low 7.3% of the time, and the relative humidity was below 20% in 30.8% of the regular school hours. The main problem that stands out from the four rooms investigated, seems to be a too high temperature in Room 0222. During school hours, the temperature exceeded 22°C in 58.5% of the time. The Music room also has a problem with overheating, but the percentages for the Music room can be misleading, as the room is not continuously used as the regular classrooms. This is further discussed on Section 6.1.

In Figure 83 (Appendix B) the room temperature lies within the recommended limits. The temperature stays round 20°C and rises 1-1.5°during the school day. The two sudden drops coincide with rapid temperatures drops after that the sun has gone down. In Figure 84 (Appendix B) the outside temperature starts to drop from 4°C to -9°C throughout the evening and night. The sudden drop in the room temperature, accompanied by the supply air temperature, starts at 04:00 on both days. In Section 3.3.1 the start up time for the ventilation unit that covers Room 0217 is given, it is 04:00. The heating is supposed to start up at 06:00, but the temperature decline does not stop until several hours later. On March 5. the temperature does not rise until 09:00, and on March 6. the temperature begins to rise at 08:30. As the field study initially was planned to end in week 9, the occupancy forms was not filled out for week 10. However, in week 7 and week 9, the form was filled out. In both weeks the room was occupied by 19-20 persons from 08:15.

The temperature drops steadily after the ventilation system is started up. Figure 56 shows a more detailed graph over the event. The supply air temperature drops simultaneously as the room temperature. The extract air temperature also drops, but not as much as the other two measured temperatures. March 5. and March 6. is a Wednesday and Thursday. These two days were the only ones where a significant temperature drop was observed in the classroom. The outside temperature was coldest on these nights, but the morning of March 11. was also a cold one. As illustrated in Figure 84 (Appendix B), there is a similar temperature drop, but it is smaller. There was not any other unusually cold night during the field study, see Appendix G.

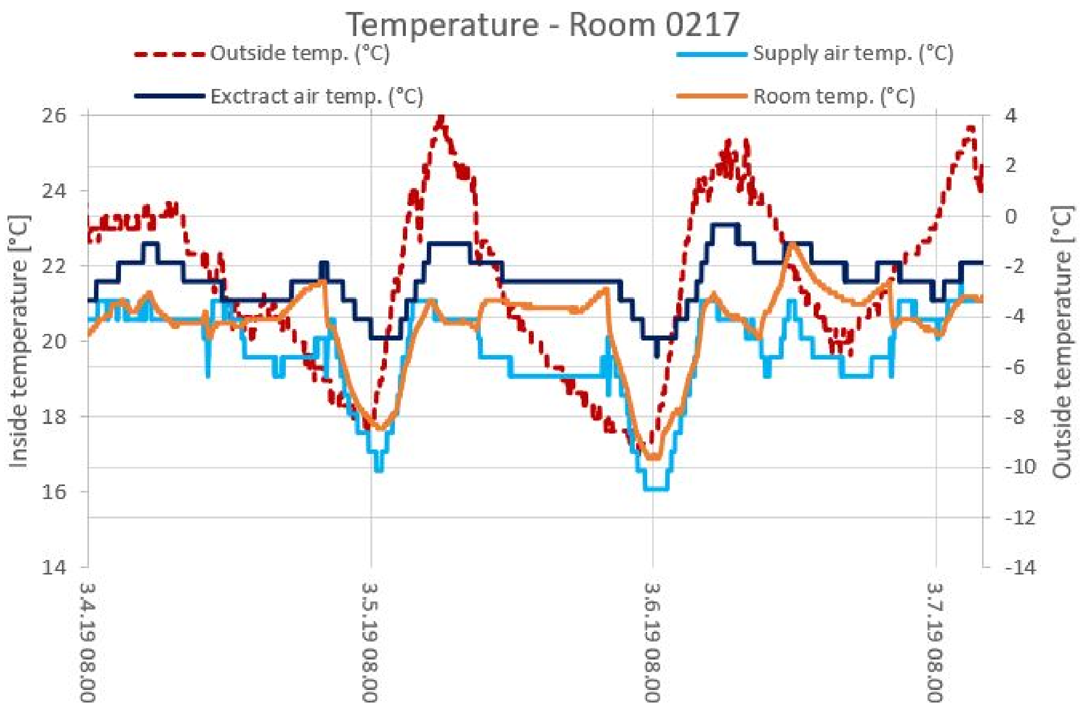

Figure 56: Air temperature measured in Room 0217 from Mar. 04 to Mar. 07.

As shown in Figure 56, the temperature rise in Room 0217 stopped when the school day was over on March 5. and 6., which points to the occupants as a substantial heat source during the day to regain the required temperature. After all the classes finishes for the day, the room manages to keep a stable temperature until the ventilation is turned on again the following night.

By analyzing the data, it seems that the system struggles to compensate for rapid temperature drops that fall below 0°C. In the interviews, the staff complained that the system struggled to cope with very cold weather. The field measurements confirm the staff's suspicion.

As illustrated in Figure 61, the CO_2 concentration was very low across the entire measurement period. The only exception is a short period in the evening. The CO_2 levels begin to rise just before 19:00 and peaks at 19:47 with a value of 1238 ppm. The time and length of the increased CO_2 concentration could be explained by a simple parent meeting. It is believed that the ventilation was not turned on. This is based on the rapid climb of the CO_2 levels and the slow but steady decline afterward. When the ventilation turns on at 04:00, the CO_2 levels quickly drop to the baseline concentration. The potential meeting explains the room temperature exceeding 22°C at the same time.

The room temperature measured by the ELMA monitor in Room 0217, as shown in Figure 83, could not be entirely representative of the actual room air temperature when the ventilation system was running. The ELMA monitor that measured the room temperature was placed close by the supply air displacement vent. The fresh air supplied could lower the measured temperature if the supply air was colder than the room temperature. The supply air could also increase the measured temperatures by the ELMA monitor if the room temperature was below that of the supply air. The first scenario, with the supply air lowering the measured temperature, is likely the case as the room temperature follows the supply temperature the first few hours after the school day has ended. But after the ventilation is powered off, the measured temperature by the ELMA monitor increases somewhat on Mar. 5. and Mar. 6. This is visible in Figure 56. The room temperature rises again at 17:00 when the ventilation is powered off.

What is marked as the extract air temperature in Room 0217 and in Figure 56, is not the temperature of the extract air. The extract vent was inaccessible, so the iButton was taped to an inner wall in the back of the classroom on the opposite side of the fresh air vent. The extract air temperature is, therefore, a better measurement towards the actual room temperature. As Figure 56 illustrates, the extract air temperature exceeds 22°C in the final period on both March 5. and 6. When the school day ended at 13:15, the temperature measured by the ELMA monitor is at its highest during the school hours, as is the extract air temperature. The temperature measured by the ELMA monitor then decreases until 17:00. This means that the supply air kept the temperature down while the ventilation system was powered on. When the ventilation is turned off at 17:00, the radiators increased the temperature in the room. After that the ventilation system has been turned off, the room temperature measured by the ELMA monitor show that it stabilizes at roughly 20.5°C. This is also visible for March 4. in Figure 56. Between 00:00 and 04:00 the temperature increase to roughly 21.5°C. At 04:00 the room and fresh air temperature plummets as the ventilation is turned on. The extract air temperature is not as affected by the ventilation being turned on as it is located on the opposite side of the room. A similar case with excessive heating in the afternoon and early evening was also observed in Room 0222.

As seen in Figure 57, Room 0222 has trouble with the room temperature. Every day the temperature increases to above 22°C. The grey area is Monday-Friday during winter break. The temperature increases from 20.5°C to just above 22°C the entire workweek in the winter break. The classroom was supposedly empty during the break. This point towards the pinpoint temperature being too high in the heating zone Room 0222 is a part of.

Similarly, like for Room 0217, one can see a definitive change in temperature on March 5. and March 6. in Figure 57 and 58. In Room 0222, there is a drop in temperature after the ventilation system is turned on at 04:00. The room temperature ends at a higher temperature the day before, so the temperature drop does not dip below 19°C. In Figure 59 the supply air, extract air, room temperature and outside temperature shown from the 08:00 on March 04. to the end of the workday on March 6. The Outside temperature drops below -8°C the night of March 5. and March 6. The ventilation is turned on at 04:00; this is visible in Figure 59 as the extract air temperature increase with 1.5-2°C. The dark blue line suddenly shifts vertically. The registered room and fresh air temperature start to decrease at the same time. After a little while, all three temperatures fall until the school day start. It is unclear if it is the heating system that at last manages to control the temperature or the occupants that makes the temperature rise. The answer is probably a mixture of both. The room temperatures peak just after 16:00 on both March 5. and 6.

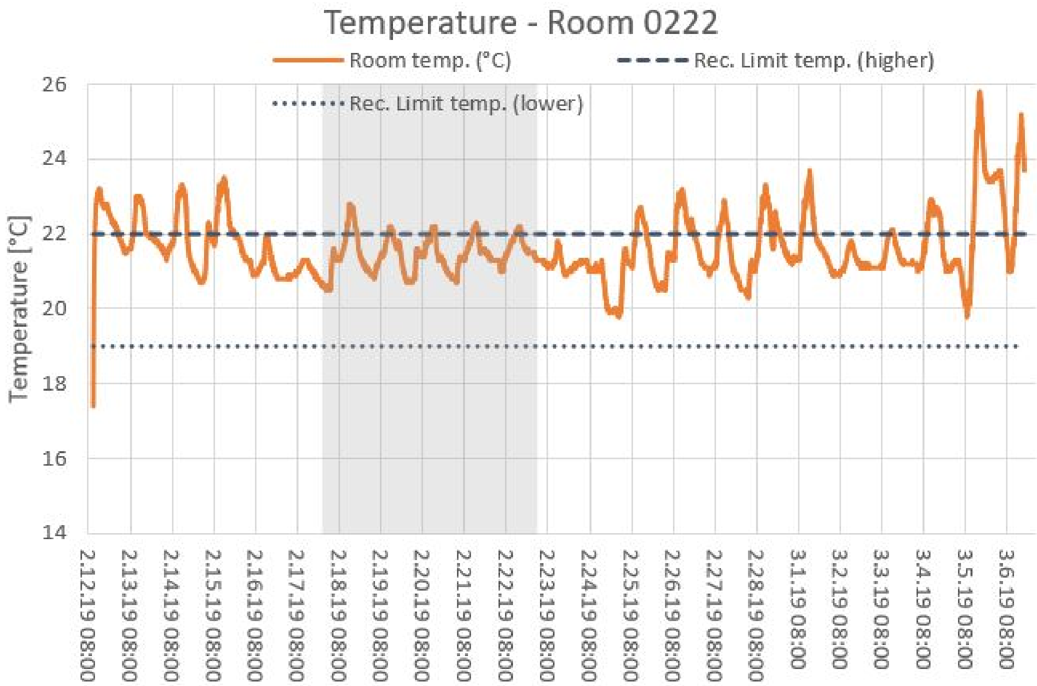

Figure 57: Air temperature measured in Room 0222 from Feb. 12. to March 06.

School is finished by 13:15, but the temperature increase for three hours after that in Room 0222. The radiators in Room 0222 are therefore responsible for the high temperatures. The system cannot regulate the system quick enough to stop the overheating. The heaters are probably turned up to maximum effect over the morning, but the residual heat, after the set point temperature is achieved, increases the temperature with several degrees. The control system sensor for the regulative program could be misplaced and not be representative of the actual conditions in the room. The placement of the temperature sensor was never inspected or registered. The setpoint temperature should, therefore, be lowered with at least 1-2°C. Lowering the setpoint temperature in Room 0222 will improve the thermal conditions on days without extreme cold weather as well. By the information available in Figure 56 it seems like the temperature in this heating zone, the on Room 0217 is a part of, lowers the room temperatures during the night. Further data confirms that the temperature is not lowered, not over the weekends either, at least not in the period March 01. to March 11. The temperature drop seen in the graph during the night is caused by the ventilation system being turned on. The drop is normally not as significant as during the two coldest days as seen in Figure 83.

Room 0222 has the same problem that Room 0217 have, that during very low outdoor temperatures, the heating system can not respond quickly enough. The difference between the two rooms is what happens when the desired temperature is reached.

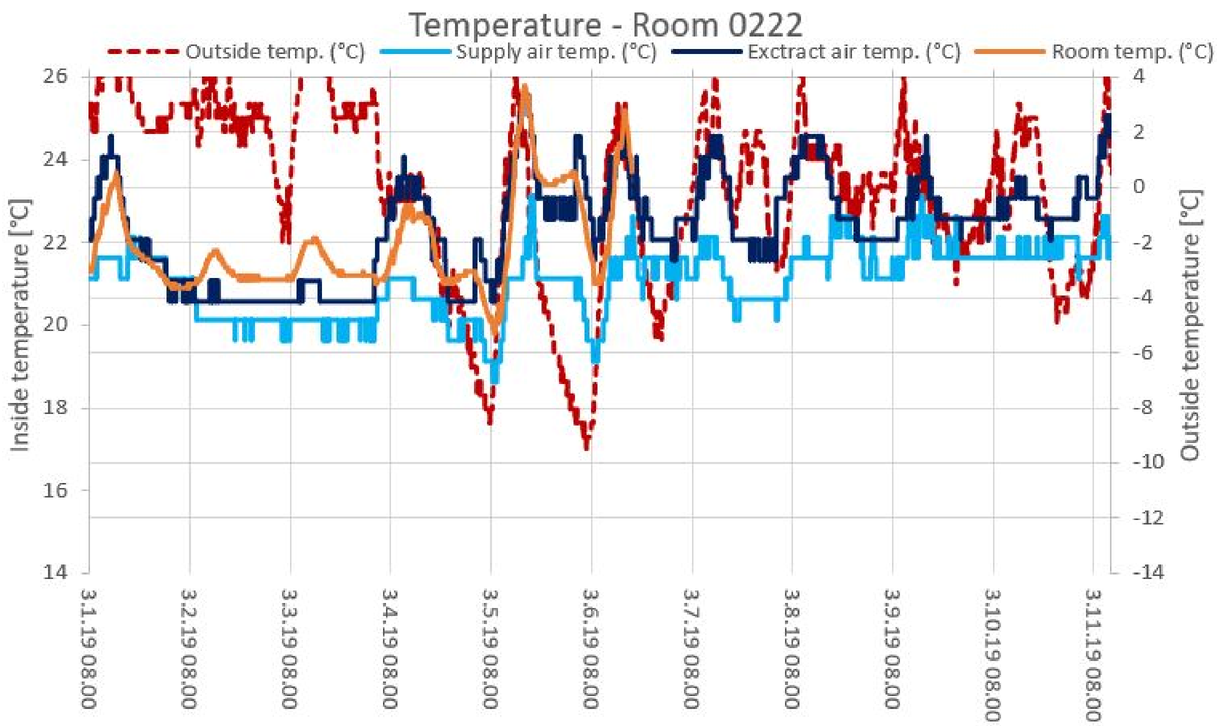

Figure 58: Air temperature measured in Room 0222 from March 01. to March 11.

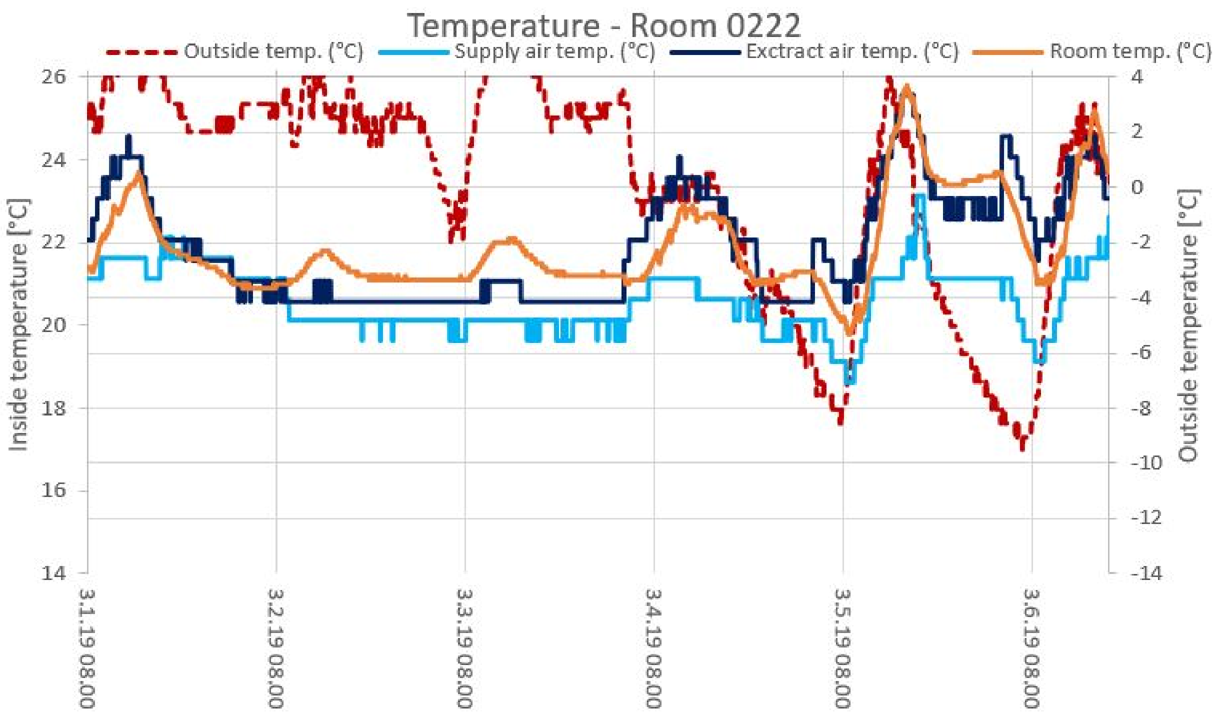

Figure 59: Air temperature measured in Room 0222 from March 01. to March 06.

In Room 0217 the temperature is kept within the recommended temperatures, but in Room 0222 the temperature exceeds the recommended temperature with several degrees for more extended periods of time. The overheating after school hours is misuse of energy and money. If one eliminates the problem, it could save the school money in the long term. Especially if it is a problem across several rooms. The regulative control program would have to impose several changes to put a lid on the overheating problems. Furthermore, the same suggestions put forth for Room 0217 regarding the heating and ventilation during cold spells, and how to mitigate the problem, is also true for Room 0222.

Room 0217 is a better room for displacement ventilation than Room 0222. The increased room height allows for the proper development of thermal layers in Room 0217. The height in Room 0222 is roughly 3-3.5 meters. The height is enough that displacement ventilation should work sufficiently. The placement of two supply vents at each side of the classroom and both extract vents in the middle is good. The likely choice of open shelves separating the different classes is both good and bad. These shelves can be seen in Figure 17. The openness of the shelves means that they will not act as a partition in the room, blocking the fresh air flow by the floor. The negative side is that the open solution gives a vastly increase in areas where dust can settle. However, as long the shelves and its content are regularly cleaned, it is a negligible factor.

The supply air temperature in Room 0222 is too high. Figure 58 illustrates this in the last 10 days of the field study. The supply temperature is roughly 21.5°C. The only exception is during weekends when the ventilation is shut off and during the colder mornings of March 5. and 6. The heating coil, heat exchanger or a combination of both can not sustain the wanted supply temperature during cold weather. The temperature of the extract air increases with several degrees above the supply temperature when the room is in use. This is a good sign of the displacement ventilation working as intended. However, the room temperature measured follows the extract air temperature very closely. This is not a good sign. When the temperature is almost the same 1 m above the floor and 2.5 m, it shows that the room does not have a fully developed higher temperature layer above the occupancy zone. The entire point of displacement ventilation is that the air is heated up by a source, a person for example, and the air rises, carrying contaminated air with it up and above the occupancy zone.

As shown in Figure 62, the CO_2 levels in Room 0222 are satisfactory. The peaks during the school day lay between 600 and 800 ppm according to the ELMA monitor placed roughly 1.2 m from the floor, right in the breathing zone of the pupils. The one occasion the CO_2 concentration exceeds 1000 ppm was outside school hours. It happened between 17:30 and 18:45 on February 28. It was probably a parent meeting or something similar. The rapid rise of the concentration and the slow descend afterward means the ventilation system was not turned on in this period.

When comparing the CO_2 levels in Room 0222 (Figure 86) and 0217 (Figure 85), it is evident that the CO_2 levels in Room 0222 increase more when the room is in use. This could, of course, be explained by the ventilation rates in the room and the occupancy load, but there is a possibility that the displacement ventilation is not as effective in Room 0222 because of the room geometry. The height is to low and the shelves separating the room hinders the air flows.

The users of the room should not be able to turn off the radiators. The regulatory valve should either be removed or changed so that only minimal regulation can be done on each radiator. Then, the pupils fiddling will have a minimal effect on the indoor thermal conditions, but the teacher still has some control over the temperature. Ideally, the possible regulating range should only be over 1-2°C. However, the heating system at Sørborgen is old, especially the radiators, so the heat adjusting valves are analog. These valves are not connected to the automated control system today. Therefore, the system will struggle to regulate a room if all the manual valves in the rooms are set in different positions. The original system was installed before automated climate control systems were standard. This is the main reason the automatic control system does not work properly. The entire heating system is not designed to be regulated automatically.

In the new building, the heating system will be designed to work with the automated control system, so the temperature regulating should be better there. The building envelope is also of a higher quality with modern technical equipment, so cold weather will not affect the indoor climate as quickly.

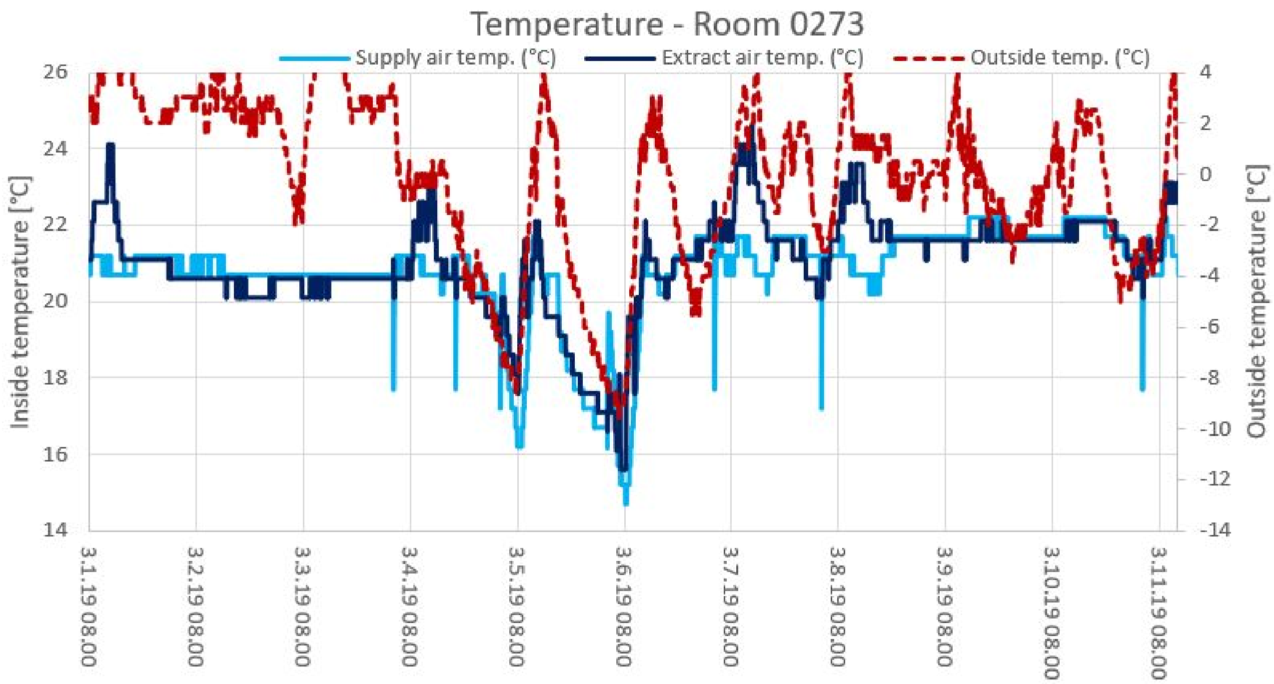

Figure 60: Air temperature measured in Room 0273 from March 01. to March 11.

The ELMA monitor placed in Room 0273 malfunctioned, see Section 6.5. All the data collected ended up being irretrievable. The only data collected from Room 0273 is from the iButton placed by the fresh air supply and extract air vent. The data is presented in Figure 60. The supply and extract air temperature is similar, but the extract air temperature increases when the room is in use. The results seem to mirror much of what was seen in the results from Room 0217 and Room 0222. During the cold spell from March 5. to March 6., the room became significant colder than usually.

Room 0273 is the smallest room investigated at Sørborgen. It is therefore not surprising that the temperature in the smallest room also dropped the lowest, below 15°C. The smaller room has less warm air and mass that can give its thermal energy to the cold air that is ventilated into the room. To use an analogy, the heat battery is smaller and runs out faster than the bigger batteries.

The light blue line in Figure 60 illustrates the supply air temperature measured in Room 0273 .The light blue line has a significant drop every weekday a few hours before 08:00. The drop is measured at 04:13, right after the ventilation system boots up for the day. The measured temperature quickly jumps back to where is was earlier. This behavior was not observed in the data from Room 0217 or Room 0222. In the other rooms the temperature stabilized during the afternoon, especially after the ventilation system was turned off at 17:00. However, in Room 0273 the temperature drops consistently after the school day is over. There is a possibility the radiator was turned off. The heating plan indicates that the system shuts down at 12:30. But this behavior was not seen in the results from the other two rooms presented earlier in this section. The temperature fall is not big enough that it is likely to assume an open window is the cause of the earlier temperature fall. During the weekends, the indoor temperature remains nearly constant. The last weekend on March 09. and 10., it was a few degrees below zero at night, but there are no visible change in the indoor temperatures recorded. Based on the data, the ventilation system seem to waste much heat during the colder days.

CO2

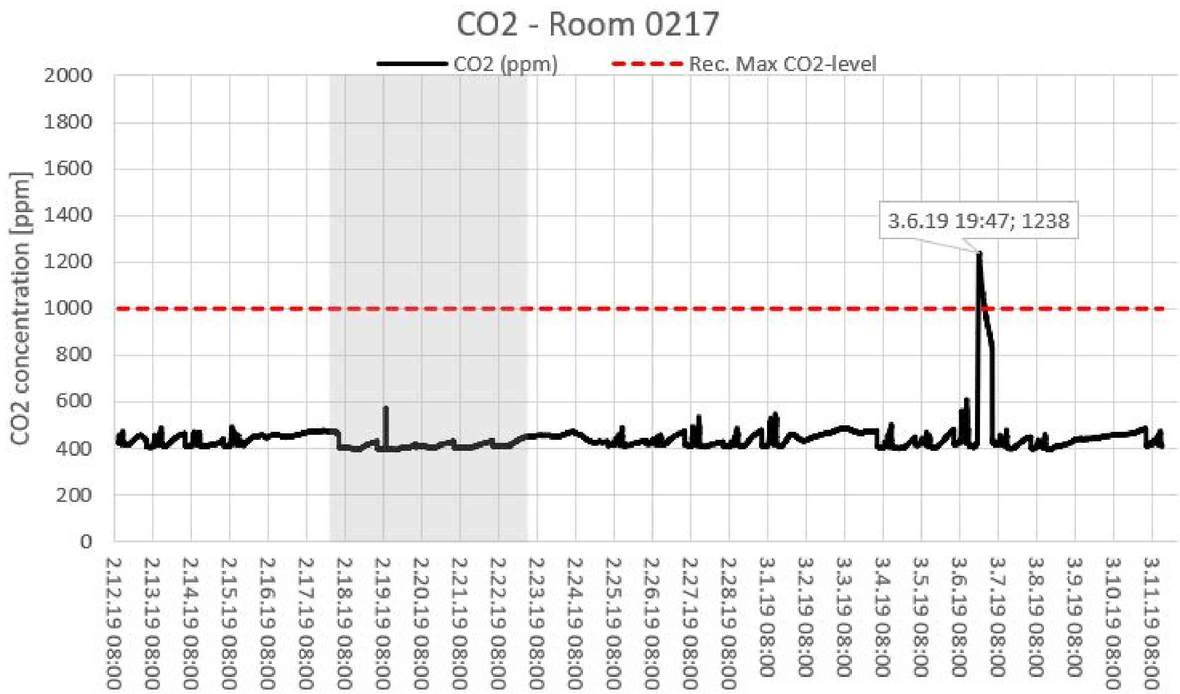

Figure 61: CO_2 concentration measured in Room 0217 from Feb. 12. to Mar. 11.

The temperature measured was consistent between 21°C and 22°C during the school hours. It was normal for the measured room temperature to reach just above 22°C during the day. The supply air temperature seems to be roughly 21°C with the extract air just above that. The measured extract air maxed out just below 24°C. The complete temperature measurement series can be seen in Appendix B. The CO_2 concentration

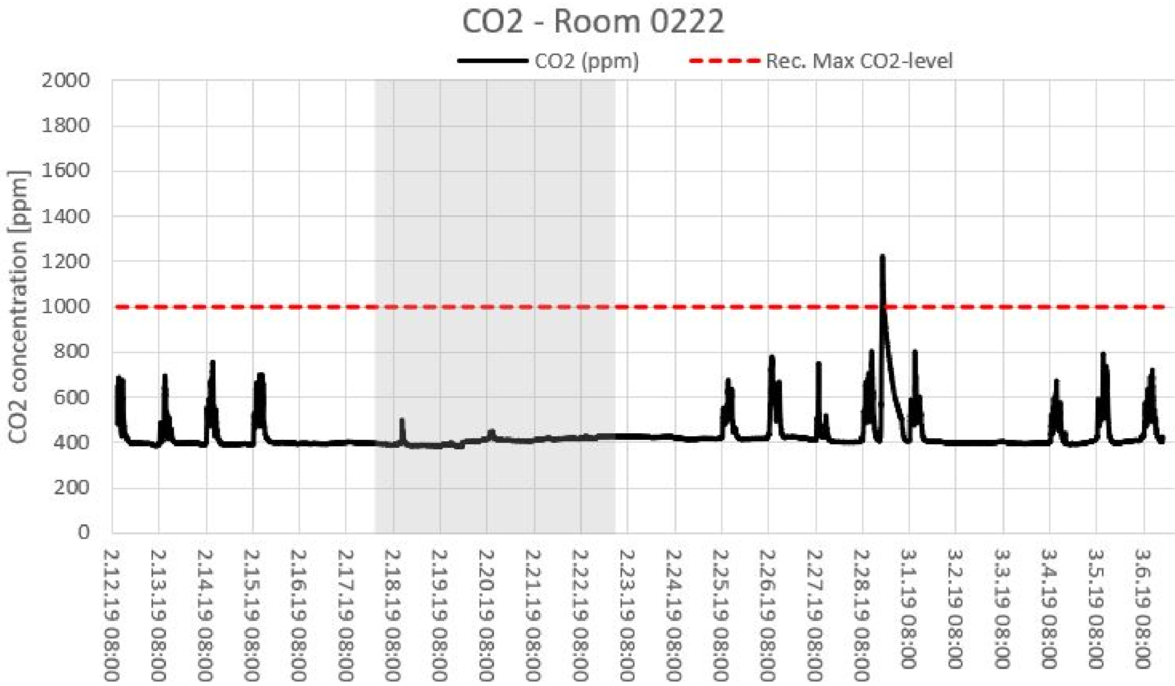

Figure 62: CO_2 concentration measured in Room 0222 from Feb. 12. to Mar. 11.

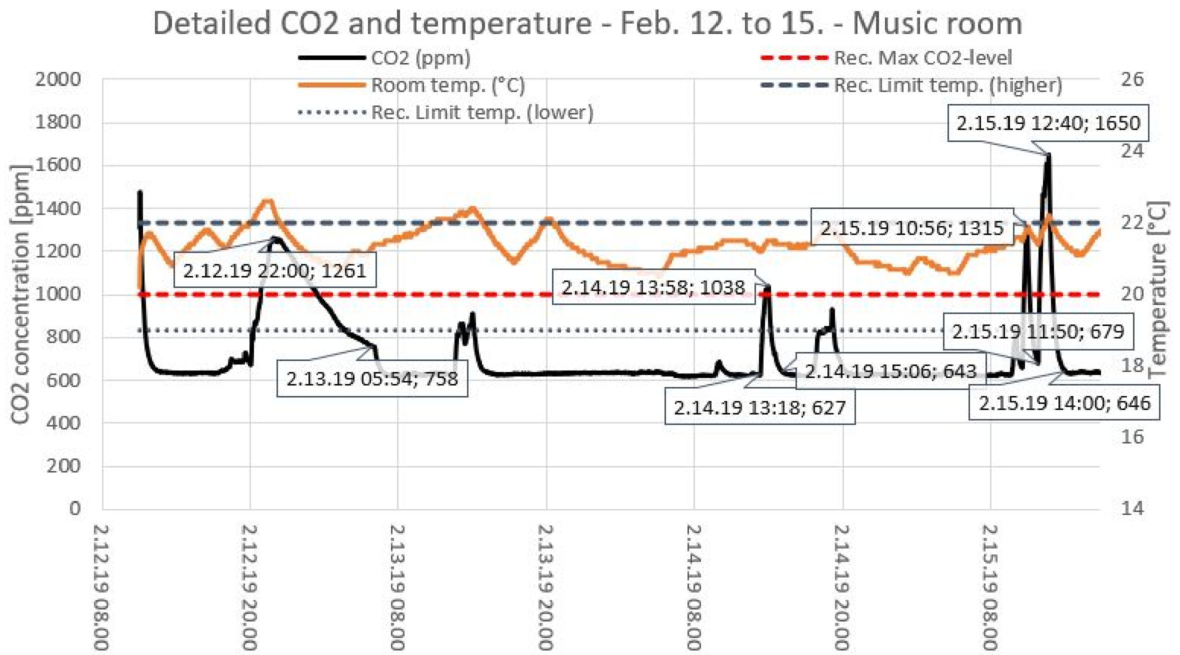

Figure 63: CO_2 concentration and temperature measured in the Music room from the Feb. 12. to Mar. 15.

measured in the Music room exceeded the 1000 ppm limit on several occasions. It happened several times during week 7 and once or twice each during week 9 and week 10. The complete measurement series can be seen in Appendix B.

In Figure 63, the first CO_2 top marked on the graph is peaking at 22:00, February 12.

This was a Tuesday. On Tuesdays, the ventilation system for the Music room shuts off at 20:00. The rapid growth starts just before 20:00. This means that the room was in use for two hours without the ventilation system running. The CO_2 concentration declines linearly until the ventilation system is started at 06:00. The peaks on both February 14. (13:58) and February 15. (10:56 and 12:40) are just as steep as the decline afterward. This indicates that a large group must have been using the room. The ventilation does manage to keep up with the rising CO_2 concentration. The concentration growth is still high at a CO_2 level of 1650 ppm. With the same occupancy and activity level, it is estimated that the CO_2 concentration would increase to around 1800 ppm before equilibrium is met with the ventilation system. The CO_2 concentration drops below 1000 ppm at 13:00 after the highest peak on February 15., twenty minutes after the 1650 measurement was done. According to the schedule at Sørborgen, a class begins at 11:45 and ends at 12:30. In this case, the class went ten minutes over the scheduled time. According to the schedule, there is not a recess before a new period starts at 12:30.

Figure 63 shows that the ventilation system in the Music room uses an hour to return the CO_2 concentrations roughly to the baseline level after the concentration has exceeded 1000 ppm. The temperature also decreases slowly after being raised. The teacher using the room claimed in the interview that the air quality was terrible during the evenings when groups of 25 people were using the room. It was still troublesome during the daytime, but noticeably better than later in the day.

According to the form filled out, three classes used the Music room during school hours on Thursday February 13. In order, the groups consisted of 21, 23 and 27 people. Between the groups, there was a 20 minute and a 45 minute break. However, the CO_2 concentration does not increase before 12:30 when the last period of the day begins. With groups of over 20 people, one would see some rise to the CO_2 concentration. This gives two options. Either the form is incorrectly filled out, or the ELMA monitor's CO_2 measurement feature is broken. The ELMA monitor has shown to be unreliable, so the instrument is likely broken. It is also likely that the form is filled out wrong; by experience, it is well known that the forms are ignored and then filled out later by memory. A third option is that the person or persons who filled out the form for the incorrect room. During the tour several activity rooms were shown, there is also supposedly something that can be interpreted as a music room in the newly built structure. The last claim is just speculation and can be wrong. However, the projects contact person was contacted and asked if the form could be from another room. Pictures of the Music room was enclosed in the mail. He was positive the form was filled out for the Music room. Still, he did not fill out the form, nor does he know if the form was filled out correctly. The possibility that the CO_2 measurements from the Music room are of poor quality increased after the exchange with the school representative.

Later in the week, the occupancy number does not match the measured data either. On Thursday February 15. the schools marching band had a two-hour practice from 17:30 to 19:30. There is no increase in CO_2 levels after the class ended their session at 12:40. It should be investigated if the form is filled out for the correct room. When the instruments were collected, a red rolled up mat was pushing the ELMA monitor against the wall. That could potentially have affected the measurements of the ELMA monitor.

5.2 Results from Interviews

In this Section, the results from the interviews are given. Nine people from the staff were interviewed at Sunnland, five were interviewed at Stabbursmoen and seven were interviewed from Sørborgen. They were asked questions from a preset interview guide (see Appendix C). The results are paraphrased from the answers in the interview notes. The answers presented in the text can be a mixture of several people. Only information obtained from the interview notes is presented in this chapter. The people interviewed were asked to rate the air quality, thermal conditions and sound conditions on a scale from 1 to 10, where 1 is good and 10 is bad. The average values from the answers at the different schools can be seen in Table 12.

Table 12: The average value from all the questions where the interviewee was asked to rate on a scale from 1 to 10, where 1 is good and 10 is bad.

	Air Quality [average]	Thermal Conditions [average]	Sound Conditions [average]
Sunnland	7.1	6.8	7.6
Stabbursmoen	5.8	7.0	7.0
Sørborgen	5.5	4.7	6.5

5.2.1 Sunnland

In total, nine people were interviewed over the phone. As mentioned above, they were asked to rate the air quality, thermal conditions and sound conditions on a scale from 1 to 10, where 1 is good and 10 is bad. Comparing the values from all three schools, Sunnland has the worst average values in two of the three rating questions (see Table 12). In the third question regarding thermal conditions, they are trailing Stabbursmoen with only 0.2.

The noise level is troublesome. The interviewees claim that the sound travels between the classrooms. They also say that the Smartboard makes some noise and that they notice that the walls vibrate. The vibration could be from the ventilation as well. According to the interviewees, both the rooms with and without the classroom ventilation units struggle with noise from the ventilation.

Several people report that they are troubled by headaches and that the headaches are more common at the end of the day. The staff talk among themselves about the poor indoor climate and potential health problems. It has had a significant focus during the work week over several years. The teachers claim that there is a significant difference between working in the classroom all day and back at the teachers' office. The concentration is better at the office. After spending three to four hours in a classroom, one has to recuperate after work. Dry eyes, skin and mucosal membranes are common, especially during the winter months. Dryness in the skin, face, eyes and hands improves during holidays. Several people complain about the cleaning, but not on the cleaners. The surfaces are very hard to keep clean.

One of the teachers explained that the classroom ventilation units were installed to lower the CO_2 concentration. The same person from Room 203 feels that the ventilation unit gives off cold air. The heaters in the room have to compensate, and they give off dry air according to the teacher. The blast from the ventilation unit can be felt far into the classroom one told. In Room 203, the teacher turns on an extra heater to get a reasonable operative temperature in the room. They also explained that it feels colder along the window row and by the ventilation unit. The temperature varies across the room (ref. Room 203).

In the interviews, the users of each classroom were asked to define the temperature in their classroom. The teachers were mostly correct in estimating the temperatures in their classrooms compared to the results from the field measurements given in Section 5.1. The interviews were done simultaneously, so the results are comparable. The teachers of Room 104 and 203 believed the temperature ranged from 16 degrees in the morning to upwards of 23-24 degrees later in the school day. The teachers of Room 108 believed it was around 20 degrees, while the teachers of Room 207 did not respond to this question.

One person pointed out that the teacher is more active in the classroom than the students. The students are sedentary during classes. When one teacher was sitting and only observing an entire class, he noticed that the room felt colder than usual. Another believed that the air quality was better on the ground floor than on the first floor. The students are not allowed to wear their outdoor jackets in the classroom as per the school rules. However, when they are visibly freezing, one has to overlook that rule. The students have to go outside during recess. It is sometimes a fight; they do not want to go out if it is cold or raining.

The worst season is the summer. It gets unbearably hot indoors; one person measured 32°C at their workstation. On the warmer days, classes have to be moved outside. On the coldest days, students bring their own blankets to keep warm. The school nurse said that the students complained about headaches, but without really knowing why. Teachers believe that it is harder to teach and communicate with the students at the end of the day. They are unresponsive or tired.

If they want to complain or change the temperature, they talk with the schools' custodian. The custodian believes the low-temperature problems can be attributed to user error. Windows are left open, or heaters are turned off. The teachers can regulate the temperature up and down by 1.5 °C according to the custodian. The switch mentioned by the custodian is too slow according to some of the interviewees. Some of the people asked did not mention it when asked about what options they had to regulate the temperature. The custodian believes the indoor climate is good. To summarize, it seems like there is not any systematic training towards what can, and what should be done to get the best possible indoor climate in the classrooms at Sunnland. Several teachers answered no when asked if they had gotten any information or training on how to regulate the classrooms. Different people mentioned how to operate the solar shading, regulate the temperature or turn on the ventilation in the auditorium.

5.2.2 Stabbursmoen

In total, six people were interviewed over the phone. As mentioned previously, they were to rate the air quality, thermal conditions and sound conditions on a scale from 1 to 10, where 1 is good and 10 is bad. In Table 12, the average values from the three questions are given. The values from Stabbursmoen are all above 5 (where 1 is good and 10 is bad). The staff experiences the thermal and acoustic conditions as more challenging than air quality. However, different rooms have vastly different problems. The smaller rooms, such as the meeting room for staff and the Room Blåsal, are highlighted as rooms with poor air quality. During the early spring and late autumn, the indoor environment is better than the winter and summer.

The interviewees stresses that solar heating is the most challenging problem. It can get unbearably hot. During the winter the corner classrooms can get especially cold. The coldest temperature the school themselves has measured in a classroom was 17 °C this winter according to the custodian. The principal believes it has been as low as 12-13°C. Extra fan heaters are placed inside the rooms on the coldest days. The interviewees also report that there is a distinct difference in the students' concentration level when it is too warm; they get less focused. The focus of the students shift from learning towards complaining when the conditions are adverse. After talks across the entire eighth-grade level, it became apparent that several students struggle with headaches during school hours, but this is likely from stress according to the school nurse.

The staff does not have any formal training in how to regulate the temperature or ventilation in the rooms. The lack of solar shading is believed to be the main contributor towards a poorer indoor climate in the hotter months.

The teacher offices on the ground level are cold. Both the teachers, administration and custodian, said so during the interviews. The principal told a story about a car that crashed into the wall by the teacher offices. In the hole made by the car, the insulation could supposedly be seen all compacted in the bottom, leaving much of the wall poorly insulated. Several people wish that the small things would be fixed, but only the most necessary maintenance is done, even on the smaller things. More than one expressed concern that things are not working, and they are not fixed. In one of the teacher offices, the users have "smuggled" in an extra heater themselves. Both students and staff sometimes have to use extra jackets and outside wear to keep warm inside.

There are too few sensors connected to the central climate control system. When the school calls in to complain about the temperature to the central operating desk at the municipality, the temperatures they read of their screens do not match the temperature they measure themselves with a hand-held instrument. The system regulates the temperature too slow. When the room gets too hot, several teachers experience that the system does not turn the heaters down or off. The heaters are turned off by students because they feel it is too warm. The plug is pulled out. The next day the classroom is too cold. Then the room heaters are turned on again, but sometimes with an extra heater. The extra heater is not turned off when the required temperature is achieved, so heaters close by some students are turned off, and the circle repeats.

The drywall that has been put up to make traditional classroom insulates sound poorly. The school nurse cannot perform a hearing test during recess. The noise is too loud. There is a real concern regarding the privacy during sensitive conversations. The entire building is not organized properly and feels messy. Many things sit and collect dust. The wardrobes are too small and become messy. This impacts the cleaning of the wardrobes. Several voiced their concern regarding the poor cleaning routines. One person said the following regarding the walls that were put up:

> ”Regarding the walls that have been put up to create classrooms, you have to choose between air quality or noise; it is like picking between the plague or cholera.”

The indoor climate gets a low score every year on the employee survey. The sickness absence is still low. It was higher before.

The secondary level has routines regarding airing out the classrooms during recess. On the lower grade-levels, there are poor routines. Some people complain about the noise from the ventilation, while some have grown accustomed to it. One notices when the ventilation turns itself off in the afternoon. It suddenly becomes quiet. Students with special hearing needs cannot be placed in some part of the school.

One person is unable to use contact lenses at work; the lenses dry out. The skin and lips also dry out. If one gets a cold, it sticks with you for longer than usual. Powerful headaches are a regular occurrence for one, but it completely disappears during holidays. The dryness of the skin and face improve noticeably during the summer holiday. One person points out that the health problems have increased after she started working five days, instead of two, each week. Feeling cold during the winter is standard among the staff. Some people have to drip their eyes sometimes. Several people report that these problems disappear during the long holidays.

In some of the rooms, there is very little natural daylight. The school has made the shift from fluorescent lights to LED. In some student areas, there is no daylight, low ceiling height and insufficient ventilation (ref. Room SFO). The Teacher’s lounge also has a lower ceiling height. The staff notices during the two-hour joint meeting on Tuesdays that the air quality degrades significantly. However, no one complained about the psychosocial work environment. Still, some believe that they have gotten sick because of the colder conditions during the winter.

5.2.3 Sørborgen

Seven employees were interviewed over the phone. In Table 12, one can see that, when asked about the air quality, thermal conditions and sound conditions, the average answered values are lower than for the other two schools investigated. The thermal conditions seem to be satisfactory, but not great, by the interviewee's answers, with an average value of 4.7 (where 1 is good and 10 is bad). The air quality was given a higher value. Especially one of the users of the Music room was unhappy with the air quality. That person defined it as a 10, the worst grade possible. Excluding the single answered value of 10, the average value of the thermal conditions at Sørborgen became 3.6, down from 4.7 with it included. Two people rated the thermal conditions with a value of 5 (where 1 is good and 10 is bad). A value of 3.6 is an acceptable value; it is not great, but adequate.

An important observation that came apparent during the interviews was that the air quality had improved significantly sometime during the last few months. It improved in the Music room, more during the day, but not much during the evenings. Some change was done to the ventilation operations after comments during the tour with the "Schools on hold" project group which was conducted on the 21. January. After this meeting, the ventilation systems were regulated. During the regulating work, it was noted that several of the motorized dampers were closed and broken. They were forced permanently open. The dampers for one of the rooms in the Green area (ref. Room 0273) and yellow area (ref. Room 0217) were closed. Users of these areas pointed out that the indoor air quality had been bad before, but it was satisfactory now. Headaches had been a regular occurrence for one person, but the teacher has not experienced it in the last month after the damper was fixed.

The staff has some possibility to regulate their classrooms. The radiators, in the rooms that have them, have a valve that can be regulated. Some of the staff were aware that the dial seen in some rooms could adjust the amount of ventilation air flow; others were not. Both the dial for the radiators and ventilation air flow are potentially accessible for the children. Sometimes the children turned the dial without the teacher noticing. If they turn down the radiators, it could be cold in the room the following day. The windows can be opened to regulate the temperature, but not in the Music room. The activity level in the Music room is higher than in a typical classroom. The teacher wishes one could regulate the temperature in the Music room so that it can be lowered.

Several people pointed out that they became extra tired after spending the school day in the common areas. The sound level is given as the main reason. Dryness of the eyes and mucosal membranes are a problem. One person needs eye drops at work. The same person does not use eye drops outside of work. In Table 12 the sound conditions was given an average value of 6.5. In the interviews, the human-made noise was believed to be responsible for the high sound level. The sound insulation between the common area and the group rooms are insufficient. One person said, "If there is singing in the neighboring room, we should just join in." The common work area for a grade level is sometimes a hallway for another. It is disruptive. The reverberation is troublesome. However, the consensus is that is has gotten better in several areas after several noise damping plates were installed. No one complained much about potential noise from the technical equipment, but the radiators give off more noise than the ventilation system. The ventilation system makes noise when the door to the teachers' offices are opened. The door has to be closed. In the teacher's lounge, the sound level can be high. Some people find it unpleasant and choose to eat lunch somewhere else. This is bad for the psychosocial work environment. Headaches, concentration problems, tiredness, exhaustion and dry eyes are problems that can be associated with poor indoor climate.

The general opinion is that the conditions are best in the spring and autumn. The cold days during winter and the hot sunny day in the summer are worst. The regulative system manages to keep the temperature more consistent during the spring and autumn. Rapid changes in outside temperatures result in unsatisfactory indoor temperatures. During the coldest days, several convector heaters with fans are set out in the classrooms. This increased the trouble with dry eyes. One person estimated that it was 10-15 days during the year where it is noticeably too cold in the area the person works now. Earlier, the same person worked in wing C and D, and there the number of colder days were higher. It is a bigger problem to keep the temperature up on cold days than down on warm days. Several people noted that before the new building was built, the temperature problem was more prominent. Previously the temperature in some classrooms was registered as 13°C on cold days. This has improved since then. The solar shading on the southern side of wing E is old and does not work.

The small wardrobes are highlighted by several as an essential problem. The children get wet on their feet, and it is impossible to dry anything there. However, the staff believes that the cleaning is good at the school.

5.3 Results from Questionnaire

In the following chapter the results from the questionnaire will be presented. Table 13 gives the total number of eligible student responses and the schools respond rate. Sørborgen school exceeded expectations with an 90% respond rate while Stabbursmoen school ended up with 61%. Sunnland school never partook successfully in the questionnaire, the details surrounding Sunnland is given in Chapter 5.3.1.

Table 13: Response rate of the questionnaire at Sunnland, Stabbursmoen and Sørborgen school.

Response rate	Eligible students	Responses	Respond rate [%]
Sunnland		0	0
Stabbursmoen	300	184	61
Sørborgen	244	219	90

5.3.1 Sunnland

Sunnland had trouble completing the questionnaire within the desired time period. Unforeseen technical difficulties arose when the students tried to log into the questionnaire simultaneously. People were kicked out, timed out or was refused to log on. The schools IT-system and internet setup is believed to be the culprit. As of 6. June, Sunnland has not completed the questionnaire. It is not believed that they will give it another try before the summer break. Their results are, therefore, not included.

5.3.2 Stabbursmoen

Figure 64 gives the total of students that answered, both boys and girls, that had experienced the given symptoms every week compared with the results from the reference schools that has no known indoor climate issues[3]. Figure 65 gives the reported indoor climate issues the students experiences on a weekly basis compared to reference schools without any known indoor climate problems[4][5]. The questions were the results exceeded the reference is given in Table 14. A complete detailed overview is given in Table 33 and Table 34 in Appendix I.

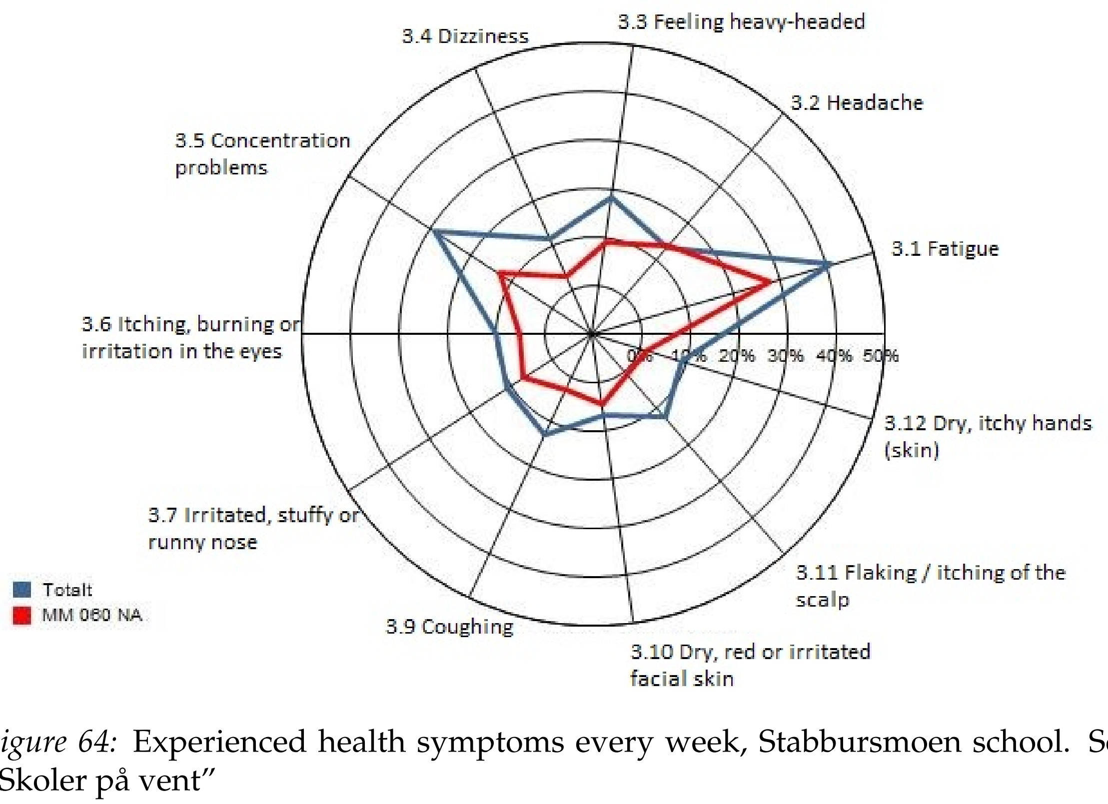

Figure 64: Experienced health symptoms every week, Stabbursmoen school. Source: "Skoler på vent"

[3]Question 3.8, 2.10, 2.11 and 2.12 does not appear on the radar charts in Figure 64 and 65.
[4]Question 3.8, 2.10, 2.11 and 2.12 does not appear on the radar charts in Figure 64 and 65.
[5]Question 2.14, 2.15 and 2.16 do not have a reference value.

Table 14: Results that exceeded the reference value including the given uncertainty at Stabbursmoen school.

Questionnaire Results **Stabbursmoen** Exceeded Reference data	Result	Reference	Uncertainty [+/-]
Health problems			
3.1 Fatigue	41%	28%	8%
3.3 Feeling heavy-headed	18%	9%	6%
3.4 Dizziness	11%	3%	4%
3.5 Concentration problems	29%	13%	6%
3.9 Coughing	13%	3%	4%
3.11 Flaking/itching of the scalp	13%	1%	4%
3.12 Dry, itchy hands(skin)	9%	2%	4%
Indoor Climate issues			
2.2 That it is too hot	23%	4%	3%
2.4 That it changes between being to hot and to cold	21%	15%	6%
2.5 Poor air quality	37%	21%	8%
2.10 Noise or disturbance from the students in the class	48%	10%	6%
2.11 Disturbing noise from outside (traffic/schoolyard/construction)?	20%	8%	6%
2.13 Dust and dirt	26%	8%	6%

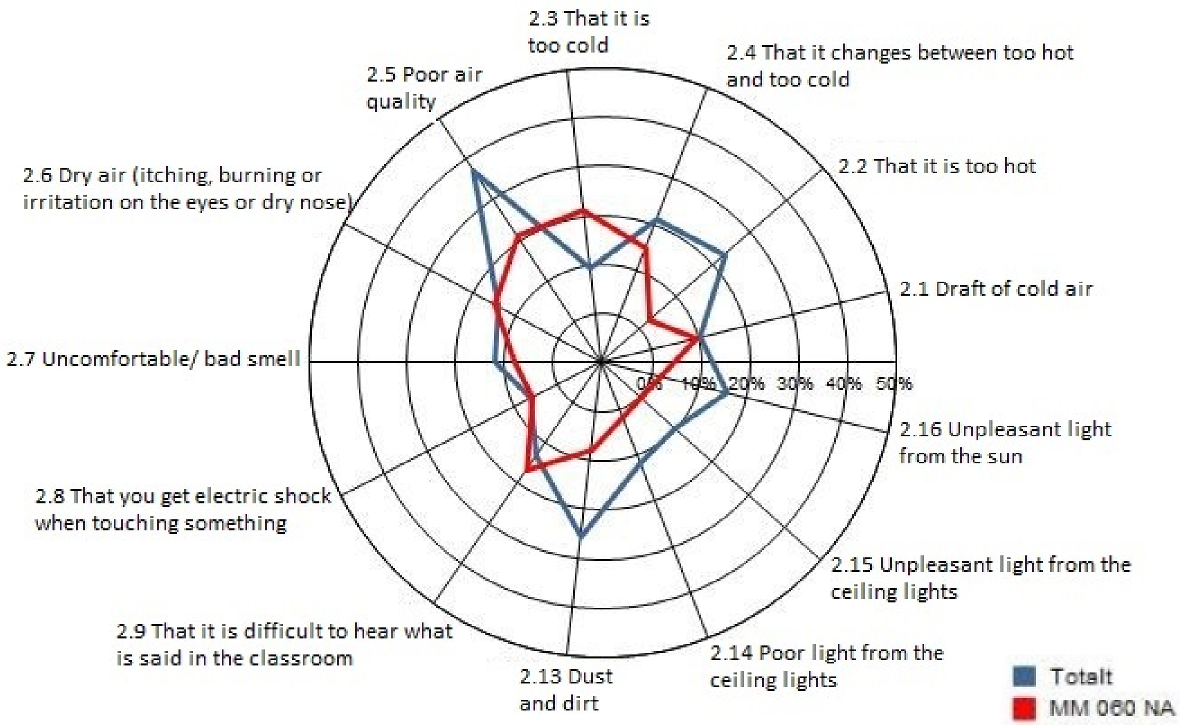

Figure 65: Reported weekly indoor climate problems, Stabbursmoen school. Source: "Skoler på vent"

5.3.3 Sørborgen

Figure 66 gives the total of students that answered, both boys and girls, that had experienced the given symptoms every week compared with the results from the reference schools that has no known indoor climate issues[6]. Figure 67 gives the reported indoor climate issues the students experiences on a weekly basis compared to reference schools without any known indoor climate problems[7][8]. The questions were the results exceeded the reference is given in Table 15. A complete detailed overview is given in Table 35 and Table 36 in Appendix I.

Table 15: Results that exceeded the reference value including the given uncertainty at Sørborgen school.

Questionnaire Results **Sørborgen** Exceeded Reference data	Result	Reference	Uncertainty [+/-]
Health problems			
3.6 Itching, burning or irritation in the eyes	11%	5%	5%
3.11 Flaking/itching of the scalp	5%	1%	4%
Indoor Climate issues			
2.10 Noise or disturbance from the students in the class	33%	10%	6%

[6]Question 3.8, 2.10, 2.11 and 2.12 does not appear on the radar charts in Figure 66 and 67

[7]Question 3.8, 2.10, 2.11 and 2.12 does not appear on the radar charts in Figure 66 and 67.

[8]Question 2.14, 2.15 and 2.16 do not have a reference value.

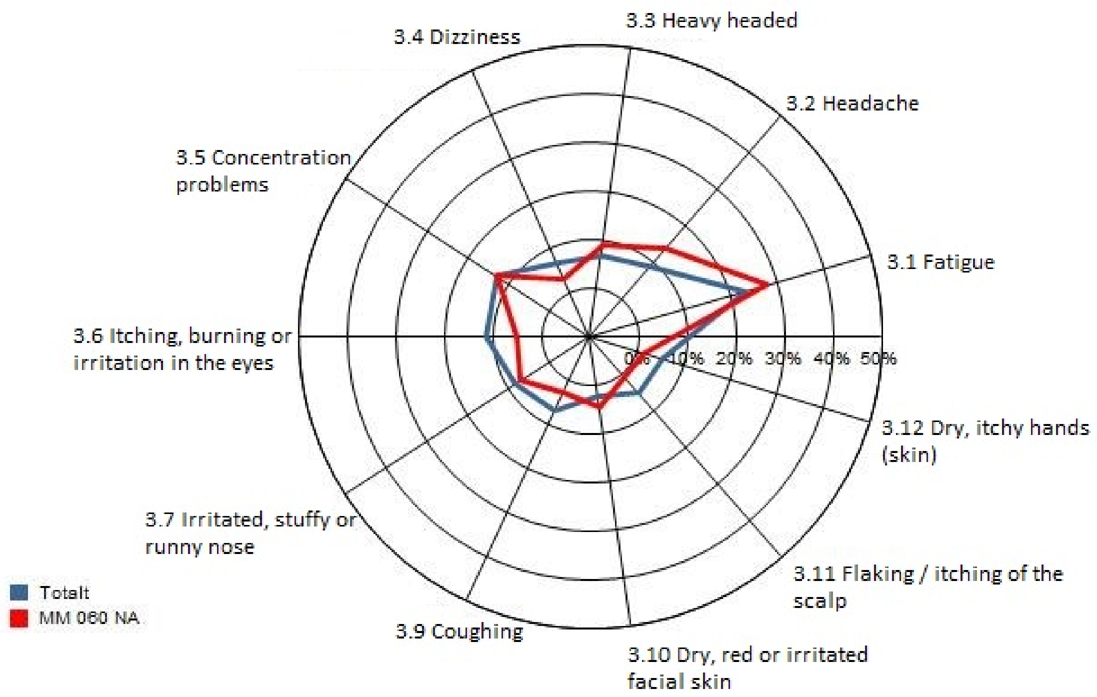

Figure 66: Experienced health symptoms every week, Sørborgen school. Source: "Skoler på vent"

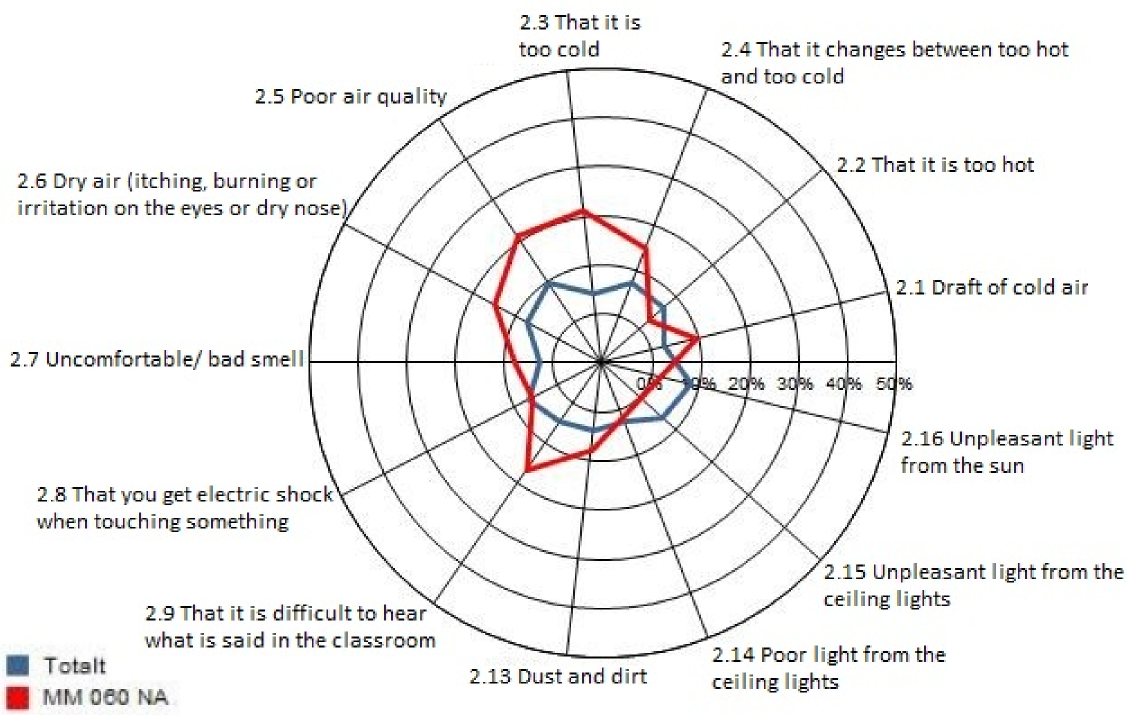

Figure 67: Reported weekly indoor climate problems, Sørborgen school. Source: "Skoler på vent"

6 Discussion

In the following section, several aspects surrounding the thesis will be discussed. The section is divided into four separate subsections. One general subsection where the more general aspects and issues the three schools have in common are discussed. There is also a subsection for each of the three schools were more specific issues for each school are discussed.

6.1 General discussion

During the field study, there were not any prolonged periods with constant cold weather. Therefore, the rooms performance were not tested under the most challenging days during the heating season. Only some of the indoor temperatures, mainly at Stabbursmoen, seemed to be affected by the few cold nights during the test period. The equipment was collected from Sunnland before the coldest night occurred on March 6.

Interpretation of presented data
The tables in Section 5.1.1, 5.1.2 and 5.1.3, which gives the percentages of measurements within the regular school hours that exceed the recommended limits, can easily be misunderstood. The values given in the tables are from the entire period specified in Table 3. None of the investigated rooms are used continuously; several classes during the day are held in other specialized classrooms. Some days the class starts early, other days they finish earlier than the last ordinary period. Depending on how much, or little, the room is actually used is an important factor to take into consideration when using the data from the tables. Between classes, there are also recesses and a longer lunch break every day. The classrooms are unoccupied during these times, but are included in the data given in the tables (Table 8, 10 and 11).

The occupancy forms filled out by the employees at Stabbursmoen and Sørborgen is the source for the number of hours their rooms are actively used. The data from these forms are given in Appendix A. There are presumably some minor discrepancies between the forms filled out and the actual schedule for each room at Stabbursmoen and Sørborgen. The official room schedule was used to define the number of hours with active use at Sunnland. The maximum hours for each room is the time period between the start and end times given in Table 3 multiplied by five to get the entire school week. Table 16 illustrate that the rooms are not constantly used within the time frame used to produce the results presented in Table 8, 10 and 11. However, the Teacher's lounge is almost certainly used by smaller groups throughout the day, but only lunchtime and the weekly meetings were filled out on the occupancy form.

When one or more of the measured values exceeds the recommended limit, it can take time before the measured values drop below the limit again. The limits are also most likely to be exceeded at the end of a session and, therefore, remaining above the limit into the break. Therefore, the entire period was chosen to represent the data, even though it can undersell the potential problems in a room that is rarely used.

Table 16: The numbers of hours are actually the time the different classrooms are used each week according to different given schedules. The last column is the total number of hours between the defined start and end time for each room each week.

School hours	Number of hours used each week, excluding breaks	Maximum hours within room hours, including breaks
Sunnland		
Room 104	15.5	31.67
Room 108	15.5	31.67
Room 203	14.5	31.67
Room 207	14.5	31.67
Stabbursmoen		
Room Blåsal	11.75	28.75
Room 321A	24	28.75
Room SFO	16.25	17.5
Teacher's lounge	10.25	40
Sørborgen		
Room 0217	20	25
Room 0222	16	25
Room 0273	Unknown	25
Music room	Unknown	25

In the teacher's lounge, the occupancy load can be high, but most of the time it is very low. The temperature exceeds the recommended limit of 22°C over 50% of the time in the Teacher's lounge during work hours. This illustrates that overheating is mainly a problem with the heating system and its regulation settings for the Teacher's lounge.

Insufficient regulation by the central climate control system
Inefficient or poor regulation settings were defined as a significant problem in all three schools. The regulation schedule should be revised at least once a year. The set point temperatures should be adjusted in several classrooms where the temperature was too high. At the same time, the lower regulatory temperature limit should be increased, especially at Stabbursmoen. Lowering the temperature in the classrooms will result in a slight upswing in relative humidity, but the difference will be small. The temperature should never be lowered below 19-20°C to increase the relative humidity. A lower temperature result in a thermal environment that most people find uncomfortable during light stationary work.

Training of the building operators
The technical solutions are worn down and are difficult to operate optimally. Therefore, it is crucial that the custodians get extensive training and instruction on how to maximize the performance of their building. This is probably best done by a third-party contractor with extensive experience with the technical solution and training custodians. In Trondheim, there is a company called Entro that facilitates the training of building operators. They focus on energy savings while maintaining a satisfactory indoor climate. A similar program like what they offer, as well as with a support pro-

gram, could be the best option to improve the conditions long term. The building operator can, with the right training and instruction, be the biggest asset to improving the indoor climate and maintaining in the final years of the buildings life. Especially since the buildings are old, and the buildings are not entirely digitized, so remote control is difficult to do efficiently. Stabbursmoen experienced this when the temperatures they measured and felt did not match that the central control operators read of their screen, several kilometers away.

Room distribution, scheduling and carrying capacity

An important factor for all three schools was that they want the classes to have their own classroom, a place where they can feel safe and at home. Therefore, they are reluctant to rotate classrooms. Using the specialized classrooms for standard classes could be an effective solution if they have free capacity. Just using an extra classroom for a period allows their own classroom to recuperate adequately before being put into use again the following period. One should avoid using the same classroom the entire day at Sunnland and Stabbursmoen. The pavilion at Sunnland is built to code and should be able to handle prolonged sessions much better than the classrooms in building C. The science room at Sunnland does not have any classes scheduled on Fridays and only one on Thursdays. The room schedule from Sunnland shows that there are days where the rooms are used almost the entire day, while other days they are not used. Room 104 only has one class scheduled on Mondays, but four on Tuesdays and Fridays. Room 108 only has two sessions on Mondays and Fridays, but five on Tuesdays with a 30 minute lunch break as the only longer break throughout the entire school day. Room 203 and Room 207 is mostly used Monday through Wednesday, and barely at all Thursday and Friday. This is not the best way to schedule the rooms to mitigate capacity problems. The usage should be spread throughout the week with as many breaks between classes as possible. On the other hand, this spread out room schedule would not be the most efficient use of human resources, neither for the teachers' nor the students' time. A compromise between the two, the indoor climate and the most efficient way of running the school, should be the goal. However, the optimal running of the school is likely to be prioritized by the administration if it ever came down to a choice.

The rooms with identified CO_2 concentration problems, were all above their carrying capacity with occupancy load when the limit was exceeded. With the help of the field results and the filled out occupancy forms, one should be able to estimate and recommend a maximum limit of users in a room. However, the forms were sadly not accurately filled out, so there are only a few rooms where it is possible to quantify the carrying capacity limit. More precisely, it is only sufficient information to accurately declare something about the carrying capacity in Room 0127 and Room 0222 at Sørborgen; namely that the today's occupancy load is below the carrying capacity of the rooms. Room 0222 struggles with overheating, but it is believed that the overheating problem can be resolved by lowering the set temperature and by installing some sort of solar shading; hopefully, an external shading as that has the best effect against overheating.

Furnishing of the classroom

In all the regular classrooms visited in all three schools, the student desk can be seen cramped up against the window walls. The desks against the window walls are visible in the pictures in Section 4. The window walls have the radiators or heaters mounted on them. They are mounted below the window to minimize the cold draft. During the tour at Sunnland and Stabbursmoen, the cold draft from the windows was pointed out as a problem. More staffers repeated the problem with drafts during the interviews. At Sunnland and Sørborgen there is mounted a heater or radiator under almost every window. At Stabbursmoen the majority of windows do not have a heater mounted beneath it. A difference between Stabbursmoen and Sunnland is the number of heaters in each room. The fewer heaters could result in higher thermal differences across the room. The people who sit by a heater could experience the thermal conditions as warm, while the people who sit by a window without a heater could experience it as cold. The fewer heaters have to produce more heat per unit, which gives local zones around the heater that feels even warmer. Rooms that struggle to maintain a high enough temperature during the colder seasons should get an additional new heater connected to the central control system. The heaters are a minor investment that can be reused in other buildings when the school is renovated or demolished.

The desks should be moved away from the windows and heaters. The Norwegian Institute of Public Health recommends that student desks are placed at least 80 cm from outer walls [27]. The windows are old, which means that they have a lousy U-value. The air on the inside of the window is cooled and falls towards the floor because of the buoyancy effect. This is what creates the feeling of draft below windows. Another factor contributor could be if the window frame is not sealed correctly. If the room is too small to move all desks 80 cm from the outer walls, the desks closest to the heaters and the largest windows should be prioritized. The chairs should not be placed within this 80 cm gap.

The desk should also be moved away from the classroom ventilation units in Room 104 and Room 203 at Sunnland. The ventilation units proximity to the window wall probably creates a draft going along the wall. In the interviews, a teacher pointed out that the students complained about the draft in Room 203. Room 104 is bigger than Room 203, so it should be possible to move the student desk away from both the window wall and the ventilation unit. Room 203 may be too small, but then the desk closest to the ventilation unit should be prioritized over the desks by the window in front of the classroom. The classroom ventilation units blow the air out in a 30-degree angle from the center of the unit. Therefore, it should not be placed any desks in 3.5 meter radius around the ventilation unit. The 3.5 meter radius is the maximum throwing distance of the air handling unit where the airspeed can be above 0.2 m/s. Since the ventilation unit is so close to the wall, it is reasonable to assume that the air is pushed along the wall creating some air movement in front of the ventilation unit as well. On the other hand, neither of the ventilation units are running on maximum capacity, so the throwing length is expected to be shorter, especially in front of the unit. The preliminary velocity measurements performed in Room 104 were not accurate enough to determine the exclusion zone around the classroom ventilation unit.

At Sørborgen several of the displacement diffusers were partially covered up by furniture. This is not ideal. The entire diffuser should not be covered. Even though it is not ideal, the CO_2 measurements indicate that today's ventilation capacity is sufficient in Room 0217 and 0222. Room 0273 also had a partially covered up fresh air displacement diffuser, but the CO_2 data was lost, so the situation in that room is unknown.

Unclear comparison
In the field study, the ambient air temperature was measured with the ELMA and iButton instruments. In the questionnaire, it was asked for operative temperature. In the phone interviews, it was asked about the temperature conditions, i.e., operative temperature. The two are not the same. Operative temperature includes the air temperature, mean radiant temperature and airspeed. The people interviewed, and the students that answered the questionnaire most likely did not think of what kind of temperature definition they should use when answering the question. The most natural way of answering is using oneself as the baseline.

The interviewees were asked to pinpoint their ideal temperature for maximal comfort, but most could not estimate the temperature precisely. All could answer if it were too warm, too cold or already ideal in their classroom. What most people think of is the comfort level they usually have. That thermal comfort level depends on more than just the air temperature, but also the airspeed, radiation, humidity, activity level and amount of clothing to name some. Every human is different, and so is also our needs. One of the teachers expressed this by mentioning that the temperature had to be higher in Room 203 because the ventilation unit created uncomfortable airspeeds.

Solar heating
For all three schools, but especially Sunnland and Stabbursmoen, the solar heating was a significant problem. The field study was conducted during the winter season, so the solar gain was close to negligible. The interviews and questionnaire focused both on the present conditions or the conditions over the last few months. However, since several people brought up solar heating as one of the main problems, measures to improve the situation are also discussed.

Sunnlands external shading seems to be of a shading cloth that activates and deploys when the sun is shining. It seems to be one of the cheapest choices, as the cloth seems to be susceptible to rifts. A similar solution is therefore not recommended at Stabbursmoen. Something more durable is needed.

Sørborgen had installed internal solar shading in several of the classrooms. Internal shading is not as effective as external shading. Internal shading is heated up and transfers that heat to the room air. External shading also gets warmed up, but the heat disperses in the outside air. Stabbursmoen experienced that the external solar shading quickly broke down when it was accessible from the ground. Internal shading can also gather up significant amounts of dust. A cheap setup with either rollers or retractable venetian blinds could be a solution if external shading is deemed too expensive.

Stabbursmoen only has a few more years left with the existing structures; therefore, more substantial investments towards external solar shading seem unlikely, especially since it has been tried before and failed. External shading is also a custom job, so its reuse potential is low. The internal shading solution is cheaper and can be mounted by the school custodian without hired help, reducing the cost further. The most exposed classrooms should have a new form of solar shading. If internal, the cleaning staff must dust or vacuum the shading regularly. Weekly cleaning increases the risk of health issues compared to cleaning with a frequency of two or more times a week [67]. More curtains are another option, but thick curtains can also collect dust and other contaminants, so a retractable solution is far better. The curtains cannot be retracted and collect dust even if it is bundled up beside the window. A more expensive and permanent solution would be to change the windows completely, but the investment would be much higher than the alternatives.

Smaller changes in the daily routines
All three schools send the pupils out during breaks. They are not allowed to remain in the classrooms. At Sunnland and Sørborgen, the classrooms are locked during breaks, the classrooms at Stabbursmoen are not locked as the classrooms do not have doors. Forcing the pupils out is an excellent measure to give the classrooms a break so they can recuperate before the next period. Outdoor shoes are not allowed inside, and this is a measure to decrease the amount of dust and dirt that is dragged into the classrooms. The schools do not use any carpets in the building except right inside of the entrances. The carpet or mat is supposed to gather up dirt, so it is not dragged further into the building under shoes. These carpets or mats should ideally be thoroughly cleaned several times a week.

Shelves and lockers should have doors that can be closed. This decreases the surfaces that dust can settle in. All horizontal surfaces should be dusted regularly; this includes the top of high shelves. Dust deposits will increase the amount of dust in the air, as dust is pulled up in by air movements. Furniture like shelves, should be placed along the inner walls when possible and not against a cold outer wall. The classroom, in general, should not be covered in art or project work made by the pupils. Paper, for example, can collect significant amounts of dust that is released to the room air. Paper collages and student art is also tricky to sufficiently clean. Any work should only be on display for a short time, if at all. Dust can irritate and inflame the mucosal membranes in the throat, nose, and airways. This again can result in a dryness feeling in the mucosal membranes, increase slime production, stuffy sinuses, and coughing. In the interviews, one teacher from Room 203 complained about dry air and claimed the heaters were to blame. This could be correct, but the extra heater used in Room 203 was an open high-temperature convection heater, so it definitively burned dust. Burned dust is like regular dust, just worse.

The classrooms should be distributed so that the largest classes get the bigger rooms with the highest ventilation air flow. This could come into conflict with the desire to keep the different grades together.

6.2 Discussion Sunnland

The air temperatures are repeatably observed, in three of the four classrooms, to be around 18°C when the schools start on Mondays at Sunnland. Even by the small number of classrooms investigated in the field study, the problem seems to be more prominent on the first floor than on the ground floor. This is illustrated in Figure 68. The heating should be considered to be started earlier in the morning on Mondays. By checking the measurement data in the four rooms, it seems like the heating is turned on around midnight. Still, eight hours is not reliably sufficient to heat the classrooms before the school begins on Monday morning. Room 203 struggles to increase the temperature compared to the larger room below, Room 104. Room 203 has more surface area towards the outside and more thermal bridges, as the ceiling of Room 203 also is the roof of the building. Therefore, the total heat loss will be greater in Room 203 than in Room 104. Room 203 is also the north-facing room, so the heat gain from the sun should be less than Room 207, resulting in a higher overall heat loss. Building C is an old structure with a high heat loss compared to modern standards. Figure 68 shows the temperature drop across a weekend, from March 01, 14:00 to March 04, 08:00 in the four classrooms investigated at Sunnland. The dark green line indicates the temperature drop in Room 203. The dark green line declines faster than the other three rooms. The yellow line, indicating Room 207, also falls faster than the classroom located on the ground floor, indicated by the light green and grey line as Room 104 and Room 108 respectively.

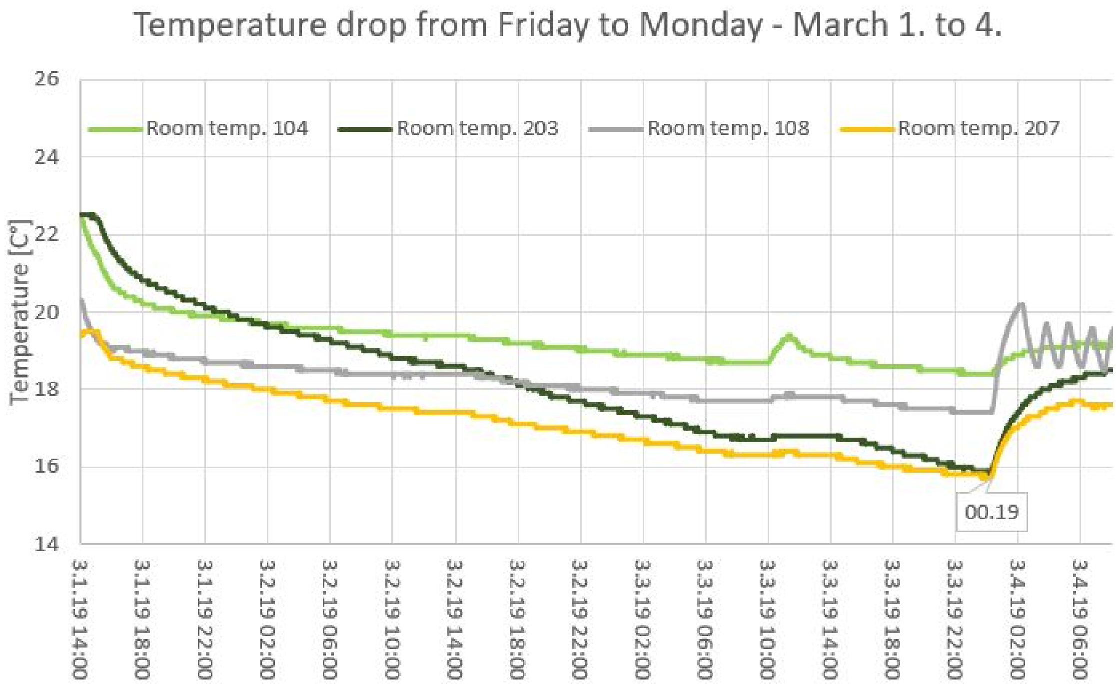

Figure 68: The temperature drop from Mar. 01, 14:00 to Mar. 04, 08:00 in the four classrooms investigated at Sunnland. The note indicates the time when the temperature start to increase on Mar. 04.

An interesting observation during the winter break week is that the stable temperature in an unused Room 203 is roughly 21°C. The setpoint temperature in the control system was 23°C when read off from the central control system in the middle of March. This gives a two-degree discrepancy between the setpoint temperature and the actual baseline temperature in the room. The same baseline temperature is only seen one day outside of the winter break week. Room 203 has an extra heater not connected to the central control system. As the room is empty outside of school hours, the extra heater must be the reason for the increased temperature outside of regular school hours in the other weeks. The extra heater is left on during the school week and only turned off at the end of Friday. In the interviews, it was confirmed that the extra heater was used every day during the winter season. As the temperature is already on the higher end before each class starts, the energy expelled from the people themselves results in temperatures above the recommended levels. The heat from the lighting and technical equipment in the classroom also contribute towards the additional temperature surge seen during school hours. Computers and smartboards go under technical equipment. Solar heating could theoretically account for the increased temperature during the day, or at least supplement the temperature upsurge. However, since the increased temperature stays up during the night, it is assumed that solar heating is not the main reason for the increased temperature.

Of the four rooms investigated at Sunnland, only Room 203 has a significant problem with high temperatures. During school hours Monday to Friday, the temperature was measured to be above 22°C in 65% of the time during school hours excluding the winter break. Similarly, Room 104 exceeded the temperature limit 11% of the time. It should be considered to install another heater connected to the central control system. The extra heater used today is an open convection heater. It is capable of burning dust, which leads to other indoor climate problems. A specific procedure is to remove the extra existing heater with a new lower temperature heater connected to the central control system. Table 8 tells us that the low temperature quickly rises when Room 104 and Room 203 is in use. The amount of time the temperature is below 19°C is low during school hours. However, surfaces can still be cold as they take longer to warm up than the air.

The classroom ventilation units do not have any heating capability, excluding the built-in heat exchanger. The supply fan will also negligibly increase the air temperature. The supply air of the classroom units regularly struggle to reach their desired temperature. This was seen in Figure 27. The setpoint temperature for the supply air in Room 104 is 18.3°C, but the setpoint temperature in Room 203 is 20°C. The supply air in Room 203 does not consistently reach 20°C.

Both the investigated rooms with classroom air handling units (Room 104 and Room 203) struggle with keeping the temperature constant. It is normal that the temperature increases with two degrees during the school day and with even more on Mondays. In comparison, in Room 108 and Room 207, the control system is capable of keeping a more even temperature. The difficulty with controlling the temperature is an obvious drawback of the classroom air handling unit. The temperature control gets much more complicated. At the same time, in the interviews, it was pointed out that the classroom ventilation units give off a noticeable draft. One person specified that their ideal comfort temperature was 21°C, but in a room with an air handling unit, the temperature needed to be a few degrees higher to be comfortable. The throwing distance where air speeds over 0.2 m/s could be as much as 3.5 m, at full capacity, from the ventilation unit according to the manufacturer [71]. However, the classroom units are not running at full capacity, so the throwing length where air speeds of 0.2 m/s can occur should be shorter than 3.5 m. The preliminary air velocity test confirmed that the airspeed was a problem at the workstations closest to the ventilation unit. Another solution to the low temperatures of the supply air is to install the heating coil feature in the air handling units. The heating coil could warm up the supply air with the help of the heat exchanger. The supply air could then be held at a constant temperature throughout the day, including the morning. However, the unit uses the displacement principle, so the supply air has to be of a lower temperature than the average room air temperature for it to function. Still, the supply air could be heated up extra by the heating coil to contribute to heating the room while it is unoccupied, before school starts, for example.

The classroom air handling units in Room 104 and Room 203 do not have the heating feature installed. The only heating of the supply air is done with the installed heat exchanger. When the classroom is cold and the ventilation unit is running, the supply air will not heat up the classroom, but actually cool it down even further as the heat exchanger can only recover roughly 80% of the energy from the extract air. The supply air temperature will always be lower than the room temperature during the heating season. The airflow from the ventilation unit on Monday mornings is, therefore, as low as 17°C, but with the noticeable airspeed, the temperature in the vicinity of the unit will feel even colder. To mitigate the problem, the room temperature cannot be allowed to fall as much during the weekends. Only lowering the temperature to 18-19°C during the weekends could be a compromise, or starting the heating system sometime during the early evening on Sunday. The tradeoff would be a higher energy usage. Regaining the desired room temperature earlier could also open up the possibility of starting the ventilation unit in Room 203 earlier so that the air in the room is completely fresh at the beginning of the school day. However, this is only advised if the room temperature has reached roughly 20°C at the time the ventilation unit is turned on.

It is also not understandable why the air handling unit in Room 104 is operated continuously, while the unit in Room 203 is operated from 07:30 to 15:30. Based on the interviews, the conditions are worse in Room 203 then in Room 104. Room 104 is not used outside of school hours or on the weekends. It does seem like there is potential to save some money in reducing the operating hours. Both the cost of running the unit and the potential reduction in heat loss will save money without compromising the indoor climate.

The ventilation units are also only programmed with a single routine. The units have several modes that should be used. The ventilation units could be powered down, but not off, outside of the regular school hours. This would allow the ventilation unit to still be able to control the contamination coming off from an empty room as stipulated in TEK17 [28]. The alternative is to turn off the ventilation units and maximize energy savings. It is important that the rooms are adequately ventilated before the room is used if the ventilation is turned off for a prolonged period. The units also have preset programs for use outside of the normal operating routines. One of them makes the unit run for 45 minutes (factory setting, the period can be changed) at the same effect as during normal mode. Furthermore, there is a setting that makes the unit perform at maximum output for a set time (factory setting is 15 minutes).

The standard operating routines should be modified to fit the schedule of the room. If the room goes unused in the last hours of the school day, it is unnecessary to keep the ventilation running with a high output. The unit should be set to the low output setting in the normal programming schedule. If the room is to be used suddenly, the teacher can turn on the overtime setting that makes the unit run at the standard output for some time. This requires that the teachers get training in how to operate the ventilation units. If the room is used heavily during the day, the maximum output feature can be used during recess, so the indoor climate is better for the next session. The maximum output period can be adjusted to fit the length of the standard recesses. The temporary increased draft and noise levels would go unnoticed as the classroom is empty during breaks. Today, no one except the custodian has any training in operating the classroom ventilation units. The ventilation schedule would need to be revised every semester or every time the room schedule changes.

An unlikely scenario, but still technical plausible is that the shut-off dampers in the classroom air handling units are not installed or are not functioning as designed. This would mean that the extra heat loss would be noticeable when the units are powered off. This could explain why the heat loss is greater in Room 203, but the scenario is unlikely. However, this is easily checked, and it is ,therefore, no harm in checking if they are installed and closed properly when the unit is powered down. The dampers should be checked regularly as a part of the maintenance plan for the units. If the shut-off dampers are not installed, or not functioning correctly, the units should probably be operated continuously until the dampers are installed or repaired. It will be a guess if the energy loss is higher when the unit is running or not. Figure 68 indicates that the heat loss would be largest if the unit was turned off if the no shut-off dampers scenario is true.

Sunnland has in total five classroom ventilation units. Based on the information gathered in Section 3.1.1 and the field results from Section 5.1 it is clear that the units are not operated in a way to maximize their potential. The operating schedules differ inexplicably and the teachers are not trained in how to operate the units at all. It is believed that the indoor climate can be improved while the energy costs are lowered. To improve the rooms to the highest possible standard with today's setup, one would need to increase the number of heating hours and, therefore, the energy cost. The increased energy cost from the heating is expected to exceed the potential savings from operating the classroom air handling units optimally, but the savings would decrease the extra heating cost. No calculations have been done to confirm or quantify the potential increased energy cost, or energy savings put forth in this Section.

The classroom ventilation units could be moved or rotated. Moving the unit to the middle of the back wall was considered, the back wall being the north facing wall, but it would increase the pressure drop in the system. This would again possibly increase the already elevated noise levels, as the fan would have to work harder to overcome the pressure drop in the longer air ducts. The main throwing zones, if the nozzles were kept in the sideways position would still increase the total area where it is recommended not to have any workstations. Alternatively, the nozzles could be set to push the air straight in front of the unit, splitting the classroom in two, creating a passageway in the middle of the room. Today's position could also be kept, but the air outlets are directed to send the air straight ahead. This would result in a free corridor clear from any desks by the windows. As previously mentioned, the desks should not be placed by the windows or heaters in the first place, so the best furniture plan could be this solution. The heaters could affect the displacement ventilation principle by increasing the fresh temperature before it reaches the pollution sources, i.e., the occupants, and creating the thermal plumes that are the backbone of the displacement ventilation theory. The ventilation system would still work as intended, but then, the total efficiency could decrease a little. An alternative solution that does not have the problem with the heaters is to rotate the air handling unit 90°. The nozzles should still be changed so that the air is blown straight ahead, but now along the north-facing wall, today's' back wall. The blackboard and smart board should then be moved from the south-facing wall to the north-facing wall. As the students have to sit some distance away from the blackboard to see comfortably, very little space is lost to the air column moving in front by the blackboard. The teacher would have to work predominantly in the air flow, but as the teacher has a higher activity level, they may feel less bothered by the colder air and draft. Furthermore, it is easier if only one person has to adjust their clothing, instead of an entire group. The downside to rotating the ventilation unit is that even more window area will be lost. The window will still be there, but the view and light will be blocked. The unit will have an even more dominating presence in the room if rotated 90°then it has in today's position.

In Figure 28, the temperature lies for the most part under 19°C. With such a low temperature; one would regularly expect complaints from the users of the room. However, the temperature seems to be well regulated between 18°C and 19°C. The temperature is two degrees below the set value temperature to the central control system. As illustrated in the results from the iButtons (supply and extract air temp.) in Figure 29, the temperature registered by the ELMA monitor is almost a degree lower than the fresh air supply temperature. The temperatures measured by the iButtons are still low. Both the iButtons were placed significantly higher than the ELMA monitor. The height difference is estimated to be 1.5 meters. The local buoyancy forces of the heaters directly underneath the fresh air vents could create a local vertical thermal gradient that increases the temperature measurements of the iButton. Especially when the ventilation system is turned off, but with the ventilation system on, the vertical thermal gradient should be negligible. This is the entire concept of mixing ventilation. The supply air should mix and dilute the room air, which results in similar thermal conditions across the designed ventilated space.

The mixing ventilation principle, but also the buoyancy effect can be seen in Figure 29. Figure 69 is a reproduction of Figure 29, just that it only presents the last two days and the outside temperature is removed. In Figure 69, one can see that the supply air temperature is relatively stable from 04:00 in the morning until 16:00. In the same period, the exhaust air follows the changes in the room temperature measured by the ELMA monitor. At 16:00, the supply air temperature starts to vary regularly with two degrees. The fluctuations seem to follow the temperature measured by the ELMA monitor while the exhaust air temperature is unaffected. The schedule for the ventilation is known from Section 3.1.1. It starts up at 04:00 on Mondays and shuts down at 16:00. The heating is not lowered during the night. The temperature fluctuations from 16:00 to 04:00 seem to match a system being regulated between 18.5°C and 19°C. When the temperature falls to 18.5°C the heaters turn on until the required temperature is reached, which in this case is 19°C. Since the ventilation system is turned off, the air around the fresh air vents where the iButton was placed was therefore stagnant. The warmer air from the heaters rises because of the buoyancy effect, and the temperature logged with the fresh air iButton can be higher than the rest of the room. The exhaust vent and the iButton that registered temperature there was far enough away from the heaters so that the temperature measurement remains close to constant in the same period.

While it can look suspect that the room temperature recorded by the ELMA monitor is so much lower than both the iButtons data, a similar situation was found in Room 108. Figure 25 shows a similar situation within the same period as in Figure 69. In Room 108, both the fresh air and extract iButtons follows the room temperature outside of the operation hours of the ventilation system. The fresh air iButton is still influenced the most. The likelihood that both the ELMA monitor in Room 108 and 207 are inaccurate is low, but still possible. Both ELMA monitors temperature measurements were adjusted as per the calibration data indicated. Mistakes in the calibration work could have led to a misinterpretation of the data. However, all the other ELMA monitors and their data were processed similarly, and the others did not show suspiciously low temperatures. The ELMA monitor has also shown not to be very reliable, but since the temperature measurements are similar in both Room 108 and 207, it reduces the suspicion that the data recorded is wrong. It is the CO_2 measurements that have been proven to be less reliable than advertised. Trondheim Eiendom performed their measurements with the same type of ELMA monitor for one week during the autumn of 2018. In their measurements, the temperature for Room 108 fluctuated between 18.8°C and 20°C and in Room 207 fluctuated between 20.5°and 22°C, as seen in Figure 24 and 28. These values from the Trondheim Eiendom are the raw values from the ELMA monitor; they have not been adjusted.

The setpoint temperatures in the classrooms rarely match the actual temperature the rooms are regulated to. The setpoint temperature is not reached. The sensor that registered the temperature in the different heating zones, defined as the rooms, could be inaccurate or their placement in the room, including their height on the wall, could not be representative of the conditions in the breathing zone of the students. The exact location of the regulatory sensor was not registered.

The Central ventilation system

Figure 69 shows the temperatures measured in Room 207, the results are similar to that seen for Room 108 in Figure 25, that the room temperature is below that measured for both the supply and extract temperature. This could be explained by a nonuniform air and temperature distribution in the room. The heating could be increased, and the

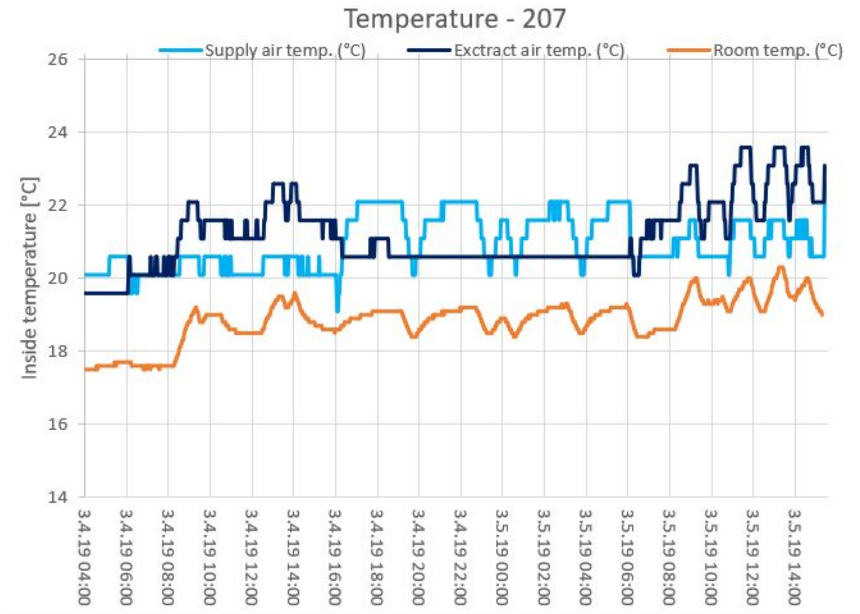

Figure 69: Air temperature measured in Room 207 from Mar. 04. to Mar. 05.

ventilation temperature decreased as a measure to achieve a more uniform distribution across the rooms connected to the central ventilation system.

The carrying capacity of two rooms investigated at Sunnland seems slightly exceeded. The CO_2 levels in the rooms connected to the central ventilation system, Room 108 and Room 207, were exceeded 11% of the time within the regular school hours. The CO_2 level cannot practically be adjusted any other way than by adjusting the ventilation or changing the CO_2 loads in the room. The only notable CO_2 source in the rooms is the occupants. 11% is not a terrible percentage, but it could be close to zero by having a slightly smaller class size, which will decrease the occupancy load. Room 108 has 28 student desks, while Room 207 has 24. By decreasing the class sizes by 2-3 students, the air quality should improve. The ventilation cannot be increased further without severely compromising other areas. The supply fan was switched out in August of 2018. Several classrooms have been disconnected from the central ventilation system. The auditorium is also usually cut off, but the dampers can be opened with a timer switch. Several measures have been made to increase the air flow into the remaining classrooms. Still, the airflow is too low, but there is not very much more to gain with toady's duct system. Changing the entire duct system is a large and expensive measure; it is unlikely that so much money would be approved for a school on hold. Another solution is to install another air handling unit that can cover part of today's load. Again, this would be an expensive upgrade with low chances of being approved unless it can be documented that the air quality far exceeds the recommended limits. However, the field measurements suggest that the indoor air quality is not terrible. In the field measurements, only the CO2, temperature and relative humidity were measured. Many other factors can create a bad indoor environment.

The auditorium is used from 08:15 to 11:45 on Fridays and in the first two hours on Monday and the last few hours on Wednesdays. When the auditorium is used and the ventilation timer is turned on, the supply air volume will drop in the other rooms. However, the auditorium is only booked on Monday and Friday for the music class that is mainly held in the music room next door. When the music room is used, the CO_2 concentration could suddenly rise in the other rooms connected to the central ventilation system. However, it has been difficult to identify such an increase without knowing exactly when the auditorium is used.

In the interviews, several people from the staff complained about health issues that likely can be attributed to poor indoor climate. The sick leave statistic among the staff is not unusually high, but smaller problems like dry skin and eyes and headaches are prevalent. These could be seen as symptoms of sick building syndrome. The students at Sunnland never partook in the questionnaire, which was unfortunate, as they could have given a good indicator towards the occurrence of sick building syndrome at the school.

The noise measurements completed at Sunnland in August 2018 and February 2019 (see Appendix H for details) show that the noise levels are already well above the current recommended limits. The lowest noise level registered with the ventilation on was measured in Room 104, with 33 dB and 34 dB in August and February respectively. Room 104 is the room furthers away from the central handling unit, so it is not surprising that the noise levels are lowest there. The room with the highest registered noise level in August was Room 128 with 42.5 dB. In February only the four rooms investigated in this study were measured, the highest registered noise level was then in Room 207 with 39 dB. Increasing the ventilation rates would also increase the noise, which is too high already, as shown in Appendix H. The limit for noise from the technical installations in building used for educational purposes is 28 dB according to NS 8175: 2012.

The airflow measured in August 2018 (shown Figure 97 in Appendix H) gives the air volume flow in Room 207 to be 751 cubic meters per hour. TEK 17 tells us that the minimum fresh air volume during light work should be at least 26 cubic meters per hour per person [28]. The minimum supply air volume per hour should also be minimum 2.5 cubic meters per hour per square meter of floor area. The two requirements are added together to find the minimum ventilation requirement by the current standard, TEK-17.

$$Minimum\ requirement = 26\ m^3/h \cdot number\ of\ occupants + 2.5\ m^3/h \cdot floor\ area \quad (1)$$

The number of student desks in Room 207 was 24, so assuming that there are 24 students and one teacher in the room, the minimum supply air volume per hour is, therefore, 797 cubic meters per hour by using Equation 1. The measured supply volume was 751 cubic meters per hour, so the ventilation airflow is below the modern minimum requirement, but not by much. The similar calculations can be done for Room 104 and Room 203, and both rooms ventilation rates exceeds the minimum requirement with 928 and 771 cubic meters per hour. There is not any data available from Room 108 regarding the supply air volume. The minimum requirement for Room 108 is 950 cubic meters per hour.

The ventilation capacity in Room 203 could theoretically be lowered while still being above the minimum air volume requirement set in TEK-17. By lowering the air flow, the airspeed and throwing distance will be reduced, and a smaller volume of colder air will be entering the rooms. The feeling of draft should, therefore, be reduced. The tradeoff is that the CO_2 levels will probably be increased. The CO_2 concentration measured in the field study in the room seem to be well balanced with today's capacity. If the number of people using the classrooms becomes less in the future, the ventilation unit output can be lowered without sacrificing increased CO_2 concentrations. This is also true for Room 104. The CO_2 concentration is an important indicator of how well other pollutants or contaminants are ventilated.

When the municipality calculates the available space in the school to determine if there is room for more students, they include the new pavilion and the really old pavilion. The old pavilion is used as a canteen, and the custodian's workshop is also located there. However, the school uses the classrooms in building C as base for all the grade-levels.

6.3 Discussion Stabbursmoen

Blåsal

The auditorium normally referred to as Blåsalen does not have any extract vents in the room. In Section 5.1.2 it was showed that the room most likely is under-ventilated. The airflow into the room should be increased. It should be considered to connect an extract vent to the extract duct passing by right outside of the Blåsal. An alternative solution is to install some small low powered and silent fans in the wall to the hallway where the extract vents are placed today. The passive vents seemingly do not cut the mustard. An extra fan would increase the sound traveling between the rooms, but as there are already two open vents above the doors, the increase in the sound transfer between the rooms should be negligible. A supply fan directly in the facade to keep the CO_2 levels down is not advised. The thermal condition will get unsatisfactory on cold days if the outside air is not heated [53].

It is unknown how many people use the Blåsal. The note on the door says a maximum of 20 people, but it is unknown if the rule is followed. If the rule is followed, the field results from Section 5.1.2 show that the number is too high. The maximum with today's conditions should be even lower, making the room even more ineffective. The typical class size is above 20 pupils, so classes would have to split into two groups to use the Blåsal.

The room instructions for the Blåsal also says that the room should be aired out between every break. It was no way to confirm if this is practiced in reality, or if windows are left partly open when the room is used. Therefore, the results from the Blåsal have several caveats surrounding them.

Adjustment of the ventilation system

The ventilation system has not been adjusted after the school built the walls to create more traditional classrooms. Therefore, it is possible that the ventilation system has not been adjusted since the original adjustments of the system in 1980. With the new walls, the airflow needs have changed. The teacher offices got their own ventilation handling unit, but the original ventilation system is believed not to be adjusted in afterward. The original design capacity has probably significantly decreased after almost 40 years in operation. It is unknown if the fans have been replaced, but by the noise level in the technical room alone, one can assume that the fans at the very least are old and worn out. The entire ventilation system should be adjusted after today's layout. This can, hopefully, increase the airflow into areas that need it the most. The ducts and dampers should also be checked for any trash or objects that are blocking the airflow.

As a case study, one can use Sørborgen to show off the benefits of adjusting the ventilation system. Sørborgen saw massive improvements after the old ventilation systems were adjusted succeeding the modifications to the system as part of the new building project. At Sørborgen, several dampers were found to be defective, therefore, restricting the airflow to several classrooms that were used daily. These were motorized dampers, but after they had been forced open or removed, the conditions improved considerably. Several of the interviewees said that their problems with headaches disappeared after the ventilation system was adjusted. The staff also noted that the indoor air quality had improved significantly.

In comparison, it is not believed that there are many, if any, motorized dampers outside of the air handling unit at Stabbursmoen. However, the space usage has significantly changed, so how the airflow was directed 40 years ago is almost guaranteed outdated. It is believed that Stabbursmoen would benefit from having its primary ventilation system adjusted, but it is difficult to estimate how big of an effect it would have.

Regulating of the room

The temperature regulation at Stabbursmoen is seemingly over a broader range compared to Sunnland. The nightly lowering of the temperature results in the temperature casually dropping 5°C from the end of the school day to the next morning. The temperature gradually increases throughout the day. With such a significant temperature increase, the occupants can experience it as uncomfortable. It is better to keep the temperature steady, so the occupants get adjusted to the temperature level. A theory is that the set point temperature in the classrooms are so high because the temperature is so much lower in the morning, so the setpoint temperature is increased so the temperature in the morning gets higher. This is a common misunderstanding of how heaters and rooms are regulated. The setpoint temperature could be set at 21°C and the room would have roughly the same temperature the next morning. The thermal mass in the room would be slightly warmer at the end of each day in a situation with a setpoint temperature of 22°compared with 21°C, but the difference should be almost negligible. It is important to mention that during the ordinary school days the temperature does not peak at 22°C, it continues to increase to as much as 24°C. The occupant or the fan heater could be responsible for the continued temperature climb, separately, or together. The school could save some energy by dropping the setpoint temperature. To avoid the cold mornings, the night lowering should be dropped, or just lowered less than it is today. Only allowing the temperature to only decrease to 19.5-20°C could have a positive effect on the occupant experience. Alternatively, the heating should be turned on a hour earlier Tuesday-Friday.

Cold air by the windows is a common complaint. It could be another solution to why the setpoint temperature is set so high, to compensate for the cold draft coming off the windows. As discussed in Section 6.1, moving the student's desk away from the cold windows, and potentially walls, should improve the comfort levels of the pupils considerably.

The heating should also be turned on earlier on Monday morning than at 06:00, just like they do at Sunnland. As the temperature decreases more over the weekend, the heating system needs more time to heat the school. The heating zone for the teacher's lounge start up at 02:30 on Mondays, so the settings in the control system varies across the school. In Room 321A, the heaters do not turn on before 06:00 on Monday mornings.

An alternative reason for the slow regulation of the temperature is that the measuring sensors are no longer placed within the rooms they are supposed to control. The walls put up to separate the open area into ordinary classrooms were put up without refitting the central control system outlay. The control sensors can probably be moved, but it will cost some money in materials, but mainly in human resources. A technician is likely needed to be to complete the work.

The sound measurements performed by SINTEF (see Appendix H) showed that the noise levels were above the recommended limits for an educational building. However, refitting the supply fan with a new one could decrease the sound levels, while still increasing the fresh air volume. The extract fan could of course also be changed, but the supply fan is usually the most significant noise generator of the two, as the air and sound both travel into the building. However, this is a bigger investment, so it is not likely to be feasible at Stabbursmoen.

The SFO room, or Room 210 in official room overviews, is not constructed for prolonged occupancy. The lighting conditions are poor, there are no windows or natural light, and the ceiling lights are insufficient. A handheld lux meter measured 77.5 lux after being placed on a chessboard that was located in the back of the room. On the floor directly under the ceiling lighting, it measured as 312 lux. The Norwegian Labour Inspection Authority recommends, for instance, that the lighting levels at a workstation are minimum 500 lux within the field of work [10]. As the room is mostly used as a playroom, the lighting standard is lower than the recommended 500 lux limit given above. However, 77.5 lux is too low in the play area and can result in extra strain on the eyes and even health problems [77].

Questionnaire
In the questionnaire results from Stabbursmoen, the students that participated reported about several health problems and indoor climate issues that were far above that of the reference schools. 48% of the respondents answered that they struggle with noise or disturbance from other students in the class. The open classrooms can possibly explain the question regarding noise or disturbance, as noise and other distractions travel between classrooms. A large portion of students (41%) reported problems with

fatigue, and poor air quality was close behind with a 37% respond rate. The field study data showed that several of the physical indoor climate conditions exceeded the recommended limits. 22% responded that it gets too hot, while 21% responded that it changes between being too hot and too cold. 26% experienced the school to be struggling with dust and dirt, which indicates insufficient cleaning. The cleanliness of the schools were also complained about in the interviews with the staff at Stabbursmoen.

Of the four rooms from Stabbursmoen that participated in the field study, only two of them are used by pupils who potentially participated in the questionnaire (Room 321A and Room Blåsal). In both these rooms, the measured physical conditions exceeded the recommended values. Too high temperatures were measured in Room 0321A, and the temperature was proven to change significantly during the school day in both rooms. The CO_2 values were measured repeatably to exceed the recommended value of 1000 ppm. The relative humidity was also measured to be low. The noise levels in an empty classroom were also measured to be too high. The measurement data stand by the problems and issues reported by the students through the questionnaire. Their reported health problems can come from the trying and difficult indoor environmental conditions. The main problems reported lay well above the reference schools used to compare the questionnaire results, including the uncertainty. The health problems that the staff reported in the interviews fit well with the answers given by the students in the questionnaire. As the field study results shows, the rooms are under-ventilated and have some problems with high and changing temperatures. The questionnaire results show a heightened occurrence of health problems, while the staff also complain about discomfort and health issues, therefore, it is believed that the building is responsible. The main building at Stabbursmoen is the likely explanation as to why its users struggle with health problems above normal.

6.4 Discussion Sørborgen

Music room

In the Music room, the CO_2 concentrations frequently exceeded the recommended 1000 ppm limit. As Figure 90 shows, there is not a clear recurring pattern that repeats every week. The larger tops seem to be random. The schedule for the Music room is unknown. The occupancy form was only partially filled out during the field study. The forms are available in Appendix A. The ventilation system in the Music room uses the mixing ventilation principle. All four fresh air diffusers are located on the same wall. The diffuser nozzles are set to divert the air mostly sideways. The throwing distance into the room can, therefore, be shorter than it should be. Fresh air vents usually are more spread out in a room, or the extract vent is located in such a place so that the airflow in the room covers much of the room. That is not the case in the Music room. The extract vent is very close to the back wall with all the fresh air vents. One could consider changing the diffuser cap of two of the fresh air vents to someone who sent the air more directly into the room.

There are five large windows in the Music room, but none of them opens. They are not emergency exits. The windows face a brick wall situated below ground level. It was never checked if it was a specific reason as to why this type of window was installed. The buildings at Sørborgen will continue to be used for many years to come, especially the section with the Music room. This increases the possibility that a more substantial investment can be approved. A more expensive measure could be to change out two of the windows. The windows are so high that they could be replaced by two smaller windows in which only the upper or lower part opens. This would allow the room to be aired during breaks, which could allow the room to be used by larger groups in succession. Opening of windows is an important way of lowering the temperature, as very few Norwegian schools have air conditioning.

The teacher was adamant that the temperature in the Music room is too high. Music is a form of activity, so the body creates more heat than during stationary school work. The problem is that the ventilation system covers two completely different areas. There is a conflict of interest. The ventilation unit that covers the Music room also covers the locker rooms and showers for the gymnasium. The high supply air temperature in Figure 89 (Appendix B) is explained by the need to keep the locker rooms a bit warmer than the other rooms in the school. One should investigate if the set temperature in the room can be lowered. It depends if one can change the temperatures locally in the system or just the entire heating. There are several possibilities, only limited by the possible configurations in the automatic control system. Without knowing the limitations of the system, it is difficult to suggest a specific solution without possibly negatively affecting other rooms. The custodian should investigate the possibility to lower the temperature to 19-20°C. The schedule of the room after regular school hours should be reviewed every six months. The custodian should change the ventilation schedule to fit the use of the room. The people responsible for the after-school activities should contact the custodian every time the start or end times changes. They have to remember that any activity outside of the agreed schedule requires the ventilation system to be turned on. Either they need training in how to manually turn on the timer, if there is a timer for this ventilation system, or inform the custodian in advance so he can turn it on within the relevant time.

The same system is also necessary for other schools: Updating the ventilation schedule regularly to fit the after-school activities. The gymnasium and a few other areas are frequently in use at Stabbursmoen outside of regular school hours, but according to the custodian, the ventilation is rarely on during the activities. This is not ideal. The ventilation should be on during the after school activities.

Regulation structure As seen in Section 5.1.3, the hydronic heating system at Sørborgen uses several hours to regain the necessary temperature to compensate for cold weather. Turning on it earlier should fix this, but that means the energy cost will increase the rest of the heating season to fix a problem that only occurs on the coldest days. An alternative is to change the regulatory approach. The regulative program could use the weather forecast to decide if the heating system should be turned on earlier or later. This is a more advanced form of regulation, but could save the school money in the long run.

The regulative problem during cold periods should be examined. Either the control parameters should be changed, or the regulative programming itself should be modified. Today's solution is too slow. The heating system should be turned on earlier in the morning if the outside temperature is low. If the ventilation system has a heating coil, the heating coil could be turned up in the hours before school starts to keep the temperature up while the building is uninhabited. The temperature did not drop in the room before the ventilation unit was turned on. In this paragraph, several theoretical solutions to mitigate the problem are suggested. They may not work. An alternative, but worse solution, is that the ventilation system is turned on later in the morning. However, this implies that other rooms will also be denied ventilation in the same period. The ventilation unit that covers Room 0217, for example, also covers the entire E and A wing. There could be rooms that benefit from the prolonged ventilation time before each school day. These rooms would suffer if the ventilation unit started up later in the morning. If the school is cleaned in the early hours of the morning, the ventilation has to be turned on before the cleaners start to work. The cleaners work with chemicals that can be harmful, so the ventilation system has to be on to ensure their safety and comfort.

Questionnaire
The questionnaire results were positive at Sørborgen. Only three questions exceeded the reference value, including the uncertainty, and two of them barely did. The health problems regarding itching or irritation in the eyes or flaking/itching of the scalps can both be attributed to the low relative humidity. However, in the Norwegian winter climate, it is expected that a portion will struggle with problems associated with dry air. The only indoor climate issue reported above reference value was that other pupils are noisy or disturb them in the classroom. As Sørborgen also is an open school, it will naturally increase the noise level compared to traditional classrooms. The good result in the questionnaire corresponds with the results from the field study, which also were good, especially in Room 0217 and Room 0222. However, most of the pupils that responded to the questionnaire are located in the new building, so one cannot compare the questionnaire and field study at face value. Twenty pupils responded that they mainly used the Wing A (Green area, Room 0222/0273), while fifteen pupils responded that they mainly used Wing E (Yellow area, Room 0217). However, the statistical uncertainty became so high that their answers became nearly useless when separated from the rest of the school. As only fourth graders and above were meant to participate in the questionnaire, it is unclear how so many can report that the Green or Yellow area is where they spend most of their time. Both the Green and Yellow areas have classes from the third grade or below. Therefore, only the answers from the entire school are presented.

6.5 Weaknesses with the work

Reference is not Norwegian
The reference values used in the questionnaire are not from Norwegian schools. The climate conditions define many of the challenges that old school buildings have today.

The results from the question regarding noise from classmates exceeded the reference values in both Stabbursmoen and Sørborgen. Both schools were built as an open area school, whereas today, Stabbursmoen is a semi-closed off, but the classrooms are still interconnected to each other without doors separating them. It is to expect that the noise level will increase in an open area school. It is not known if the reference schools were designed with conventional classrooms or as an open area school.

iButton misprogramming

The iButtons became only available the day before the field study began. Another student was in possession of all the iButtons, alongside the gadget used to program and read the data. 32 iButtons were programmed the evening before, but in the end, only 26 of them were used. The programming was rushed, and a critical mistake was made. The iButtons memory has a maximum capacity of 8192 samples with the 8-bit configuration. It is less with the 11-bit configuration. The iButtons were programmed with the same sample rate as the ELMA monitors, 120 seconds. This was done so the data from the iButton and ELMA devices could be easily compared against each other.

The field study was initially planned to go over three weeks. In the end, the equipment at Stabbursmoen and Sørborgen logged data for four weeks. The necessary personnel and transport were not available in week 9, which was the planned stop of the field study. The equipment at Sunnland was taken down on March 5. at Trondheim Eiendoms request. They had scheduled to use their ELMA monitors in other projects.

The 8192 maximum sampling memory with a sampling rate of 120 seconds does not cover the planned three weeks. It only allows room for 11.4 days, or 273 hours, worth of data. The rollover feature was also not deactivated. The iButton, therefore, stored new data over old data the data several times during the field study. Only ten days of data were recoverable from the iButtons, even less from the four at Sunnland.

Another problem was, that since the rollover feature was active, the iButton continued to store new data over the old until the mission was stopped. The equipment was brought in at the end of the workday on March 11., but the mission was first stopped on the following day. Another day worth of data was therefore lost. The gadget had to be collected from the same student mentioned earlier before the iButtons could be accessed. This student also used iButtons as part of her master thesis. In hindsight, the gadget should have been collected and ready for use before the iButtons were collected from the schools. As mentioned earlier, the equipment at Sunnland was collected a week earlier, but all the iButtons were stopped and the data downloaded during the same session. This resulted that six days worth of data disappeared from the iButtons that were at Sunnland. If the iButtons are to be used again in the next field study for ”Skoler på vent”, the sampling rate should be set to at least five minutes, and the rollover feature should be disabled. With that configuration, the memory will store data for 28 days. With a four-minute sampling rate, the memory will store data for 22 days.

When placing the instruments, the number and location of each ELMA and iButton were noted down on the floorplans. Later a field study journal was created, and all the information was gathered in one document. It became clear that a small mistake was made in the marking of the iButtons. In both Room 203 and Room 321A, an iButton was written down as number eight in the journal. All the iButtons had been marked before, either by a permanent marker directly or on a small bit of tape. An old number is a probable reason for the confusion. By looking at the data, it became apparent that the iButton with the number eight marking on it had to belong to Room 203. The fresh and extract air follows each other closely, which is to be expected when the air handling unit is shut off. This is illustrated well in Figure 27. As the rest of the iButtons were assumed to be correctly marked, iButton 16 was identified to belong to Room 321A by process of elimination. Figure 27 shows that iButton 16 correctly belongs to Room 321A. The temperature fluctuates perfectly in sync with the room temperature.

The resolution of the iButtons was only 0.5°C, so the resolution of the curves in graphs in Section 5.1 is low. Potential details in the data could have been lost that could have been useful in the evaluation of the indoor climate.

Placement of the iButtons
In several of the rooms that took part in the field study at Stabbursmoen, the iButtons were taped to the side of the supply air diffuser or grill. It is not certain that the iButton was placed in the actual supply airflow and, therefore, not measuring the supply air temperature accurately.

Preliminary air velocity experiment
The equipment was not meant to be used to measure such low airspeeds. The minimum value within the recommended range is 0.15 m/s as per Table 6. The instrument that was used is old; its reliability could be questioned. Another instrument designed to measure low airspeed should have been used instead. The experiment should have been completed more systematically and thoroughly. A stand should have been used during the measurements. The person holding the instrument resulted in some movement in the sensor tip. This movement could have resulted in some inaccuracies.

Unable to access measurement data
The ELMA 10 results from Room 0273 at Sørborgen ended up corrupted, or the device itself malfunctioned during the measuring period. When the data was recovered, the computer program crashed immediately after initiating the transfer sequence. The program gave a failure message. The message said the program had ended unusually and that the support team should be contacted for further information. After several retries another computer was used, but with the same result. After contacting the technical support for the ELMA monitor, the computer was restarted, hard rebooted and the unit driver was also checked. After several consultations with the technical support official, it was deemed that the data was irretrievable. At the same time, it was observed that the ELMA 10 unit displayed the incorrect date and time. The time and date were synchronized to the clock of a computer as part of the programming before the measuring period. On March 12. 2019 it showed instead 28-14-07. A clear sign that the unit itself had malfunctioned. The unit was still set to record when it was picked up on March 11. If someone tickled excessively with the device, the recording would be likely terminated. The measurement series could not have been restarted without the manufactures software, as the memory would need to be deleted to instigate a

new recording series. Since the recording session was still ongoing when collected, the cause seems to be instrument failure or data corruption. However, in later measurements in the walk-in refrigerator, as part of the post-calibration process for the iButtons, the device functioned without similar trouble. Still, since ELMA 10 has on multiple occasions malfunctioned, it should not be used in further studies without being returned to the manufacturer and checked for errors first.

Unreliable measurements
The ELMA monitors do not have an accuracy level high enough for detailed analysis. The accuracy level presented earlier in Table 4 in Section 4.1.4 is clear in that regard. However, during the calibration work and in the analyses of the field measurement results, it became obvious that the inaccuracies sometimes exceeded the values given in Table 4. In Figure 90, the default CO_2 concentration during the night is just above 600 ppm. From February 17. to March 11. one can almost draw a straight line between the gradual reduction of the nightly CO_2 concentrations. The CO_2 concentration ends up just below 400 ppm. Compared to the results from the other two working ELMA monitors deployed at Sørborgen in Figure 61 and 62, the nightly concentration lays roughly consistent around 400 ppm. In Room 0217, the CO_2 concentration increases slightly when the ventilation is turned off. The room or area around the air intake for that ventilation unit could have a small unknown CO_2 source. In the calibration work, the ELMA monitors registered a half degree difference in two separate tests compared to the same reference instrument over a three-degree temperature range. The ELMA monitors are not a reliable or accurate device.

Loss of data
The ELMA monitors placed in Room 104 and Room 108 had their original measurement series disrupted. The school was not informed to check if the monitors were recording, so it went unnoticed until the SINTEF noise measurements were completed during the winter break week. The person did not know how to initiate a new measurement series, so the master student visited the school and downloaded the stopped measurement series data and started a new one in both classrooms. There is missing data from the ELMA monitor placed in Room 104 from February 18. 06:39 to February 26. 12:36. From Room 108 there is missing data from February 14. 09:40 to February 26. 13:30. The gap between the start of the two series is because Room 108 was in use, so the monitor was not accessible until the next recess. A large part of the field period data is missing because the original measurement series was cut short. However, it is mainly the winter break, including the weekend before and after, that is missing. This period was undoubtedly the least important period of the field study. The results from Room 104 seem to be similar to that of Room 203, the same is true between Room 108 and Room 207, so it is possible to assume the missing data would look somewhat similar to what was recorded in the rooms above.

Amount of data Only a few rooms at each school were investigated thoroughly. The schools have other known indoor climate problems that were mostly ignored in this thesis. Several of the conclusions and suggestions put forth has a small amount of data to back it up. The schools had different technical solutions for most of the rooms. The results from one room can, therefore, not necessarily be used in the next room.

7 Conclusion

Schools that are on hold and awaiting funding for new structures or total renovation often have to continue operations for several years while funding for maintenance and minor upgrades dry up. The staff struggles to maintain a safe and healthy educational environment for themselves and their students. A literature study was completed that showed how poor indoor climate is associated with an increase in health problems like asthma and allergies. Simple measures can be implemented and possibly improve a poor indoor climate. The schools in Trondheim awaiting funding were accounted for, and two of them, Sunnland secondary school and Stabbursmoen primary and secondary school were chosen for further studies alongside Sørborgen primary school. A three week field study, which measured CO_2, relative humidity and temperature in four rooms at each of the three schools was completed. The field study was carried out during the heating season in February and March 2019. A handful of members of staff were interviewed while the students from the fourth-grade and upwards were invited to participate in a web-based questionnaire.

The central ventilation system at Sunnland and Stabbursmoen supplied too little fresh air into the rooms to cover the occupancy load. The CO_2 levels increase along with the room air temperature to above the recommended limits. In a room with over 60 seats at Stabbursmoen, only 20 people are allowed to use it simultaneously, but the CO_2 concentration still exceeded 1000 ppm. Several classrooms at Sunnland are equipped with their own air handling units in the classroom. These classrooms does not have problems with CO_2 levels, but struggles with draft, low operative temperatures and technical noise. The original ventilation systems in the buildings on the waiting list for major funding cannot maintain the airflows that give an indoor environment considered safe and healthy by today's standard. Specific suggestions on how to improve the indoor climate:

- The number of people in each class should be reduced so the carrying capacity of the classrooms is not exceeded.
- The classes should be spread throughout the day to let the classrooms recover properly between periods. The windows should be opened between periods to air the room quickly when the room is empty.
- Lower the temperature of the fresh air supply to 18-19°C, the supply air should not be used to heat the classrooms while they are occupied.
- The setpoint room temperature should be lowered to 20°C. The lower temperature will save energy, money and the environment. A lower temperature setpoint temperature will decrease the overheating issue during the heating season. Several of the rooms had setpoint temperatures of 22-23°C.
- The accuracy and placement of the regulatory sensor should be checked.
- The regulative parameters and schedules should be adjusted and revisited on a semi-regular basis. Custodians should be further trained in how to efficiently

operate their buildings to maximize their potential and create the best possible indoor climate within the restraints given. The energy savings potential is observed to be present; the schools can save energy and, therefore, money by optimizing their operations.

- External solar shading should be installed to avoid overheating.
- The ventilation system at Stabbursmoen should be adjusted as the floor plan has changed significantly after stepwise remodeling from an open area to traditional classrooms.

The conditions collected in the field corresponded well with the reported health issues among the students and employees in the three schools. The field data from Sørborgen complemented the perceived opinion of the interviewees and students. The rooms examined at Sunnland and Stabbursmoen struggled with minimum two of the following; air quality, thermal conditions or sound conditions. The reported health issues among the 61% eligible students at Stabbursmoen that participated in the questionnaire were over the results from the non-Norwegian reference schools. Sunnland ended up not partaking in the questionnaire. The two schools on the waiting list in Trondheim have an indoor environment that results in issues similar to that observed in buildings with defined sick building syndrome.

8 Further work

The measured suggested should be put to the test, with a similar field study, interviews and questionnaire afterward, and determine if measures had the desired effect and improved the indoor climate. The successful, documented actions can then be recommended to other schools with indoor climate problems, making the school day better both for the pupils and staff.

Only the primary heating season was investigated in this project, but problems with the indoor climate are also associated with other seasons. Similar work during another season, for example, to investigate and suggest measures associated with a hotter season would expand on the various efforts available in the school's arsenal for improving inadequate indoor climate environments. The results should not be valid just for buildings with educational purposes, but also for other building structures. Future work could prove that similar measures can be useful in different environments.

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Appendix A Person load

A.1 Sunnland

Table 17: Number of persons in the Room 108 at Sunnland school noted by school staff. Teacher noted that there was a significant number of absences this week.

Room 108 Week 7 Time	Monday	Tuesday	Wednesday	Thursday	Friday
0815-0915	12	11	11	15	0
0930-1030	0	?	12	15	0
1045-1145	12	25	0	15	0
1215-1315	0	0	12	13	18
1325-1425	?	0	12	17	?

Table 18: Number of persons in the Room 104 at Sunnland school noted by school staff.

Room 104 Week 7 Time	Monday	Tuesday	Wednesday	Thursday	Friday
0815-0915		11	20		
0930-1030	13		20	20	
1045-1115				20	
1225-1325				20	
1335-1435		18			

A.2 Stabbursmoen

Table 19: Number of persons in the Room 321A at Stabbursmoen as given by the timetable.

Room 321A Time	Monday	Tuesday	Wednesday	Thursday	Friday
0800-0900	27	27	27	27	27
0900-1000	27	27	27	27	27
1000-1100	27	27	27	27	27
1100-1145	27	27	27	27	27
1145-1215	0	0	0	0	0
1215-1300	27	27	27	27	27
1300-1345		27		27	

Table 20: Number of persons in the Room ”Blåsal” at Stabbursmoen as given by the timetable.

Room ”Blåsal” Time	Monday	Tuesday	Wednesday	Thursday	Friday
0800-0900		25		25	
0900-1000		25		25	
1000-1100	18				
1100-1145	18		24		
1145-1215					20
1215-1300	18	15	20		20
1300-1345	18	15			

Table 21: Number of persons in the staff break room at Stabbursmoen as given by the administration.

Teacher’s lounge Time	Monday	Tuesday	Wednesday	Thursday	Friday
0800-0900					
0900-1000					
1000-1100					
1100-1145	13	13	13	13	13
1145-1215	30	30	30	30	30
1215-1300					
1300-1345					
1400-1600		40		15	

Table 22: Number of persons in Room 210 at Stabbursmoen as given by the administration.

Room 210 (SFO) Time	Monday	Tuesday	Wednesday	Thursday	Friday
0800-0900					
0900-1000					
1000-1100					
1100-1145					
1145-1215					
1215-1300					
1300-1345	15	15	15	15	15
1400-1600	15	15	15	15	15
1600-1630	10	10	10	10	10

A.3 Sørborgen

Table 23: Number of persons in Room 0273 at Sørborgen as noted by the teacher during week 7.

Room 0273 Week 7 Time	Monday	Tuesday	Wednesday	Thursday	Friday
0815-0915		16 (0830-0850)		16	16
0915-1000					16 (0915-0930)
1020-1100					
1145-1230				18(1130-1145)	16
1230-1315			18 (1250-1315)		

Table 24: Number of persons in Room 0273 at Sørborgen as noted by the teacher during week 9. Teacher noted that it was hot during the first class on Monday.

Room 0273 Week 9 Time	Monday	Tuesday	Wednesday	Thursday	Friday
0815-0915	18	17 (0830-0845)	17 (0830-0850)	16 (0830-0850)	
0915-1000	0	6			
1020-1100	18	17			
1145-1230	18	18 (1145-1205)		17(1145-1200)	
1230-1315	in & out	17 (1255-1315)	17 (1240-1315)	17 (1300-1315)	

Table 25: Number of persons in Room 0217 at Sørborgen as noted by the teacher during week 7.

Room 0217 Week 7 Time	Monday	Tuesday	Wednesday	Thursday	Friday
0815-0915	19	0	19	19	19
0915-1000	19	0	19	19	14
1020-1100	19	19	19	19	14
1145-1230	19	0	14	19	8
1230-1315	19	19	14	19	8

Table 26: Number of persons in Room 0217 at Sørborgen as noted by the teacher during week 9.

Room 0217 Week 9 Time	Monday	Tuesday	Wednesday	Thursday	Friday
0815-0915	19	0	20	19	30
0915-1000	19	0	18	19	30
1020-1100	19	0	19	19	30
1145-1230	19	19	18	19	19
1230-1315	19	19	18	19	19

Table 27: Number of persons in Room 0222 at Sørborgen as noted by the teacher during week 7. *The numbers are approximations.

Room 0222 Week 7 Time	Monday	Tuesday	Wednesday	Thursday	Friday
0815-0915				52*	
0915-1000	28	19		52*	50* (0930-1000)
1020-1100			40*	52*	50* (1030-1045)
1100-1120	51	51	51	36	55
1145-1230	40*				
1230-1315	40*				40*

Table 28: Number of persons in Room 0222 at Sørborgen as noted by the teacher during week 9. Wednesday was a field day and therefore no classroom activity. *The numbers are approximations.

Room 0222 Week 9 Time	Monday	Tuesday	Wednesday	Thursday	Friday
0815-0915		40*		56	
0915-1000	40* (0900-0930)	40*		56	37
1020-1100	0				
1100-1120	54	54		54	54
1145-1230				56	
1230-1315	56*	36*		56	36

Table 29: Number of persons in the Music room at Sørborgen as noted by the teacher during week 7.

Music room Week 7 Time	Monday	Tuesday	Wednesday	Thursday	Friday
0915-1000			21		
1020-1100			23		
1145-1230			17	30	
Unknown			28 (1350)	School band (1730-1930)	

Table 30: Number of persons in the Music room at Sørborgen as noted by the teacher during week 9.

Music room Week 9 Time	Monday	Tuesday	Wednesday	Thursday	Friday
1315-1730	2			25 (1315-1400)	
1730-1900	6 (1800-1845)			14	

Appendix B Additional field study results

B.1 Sunnland exstra results

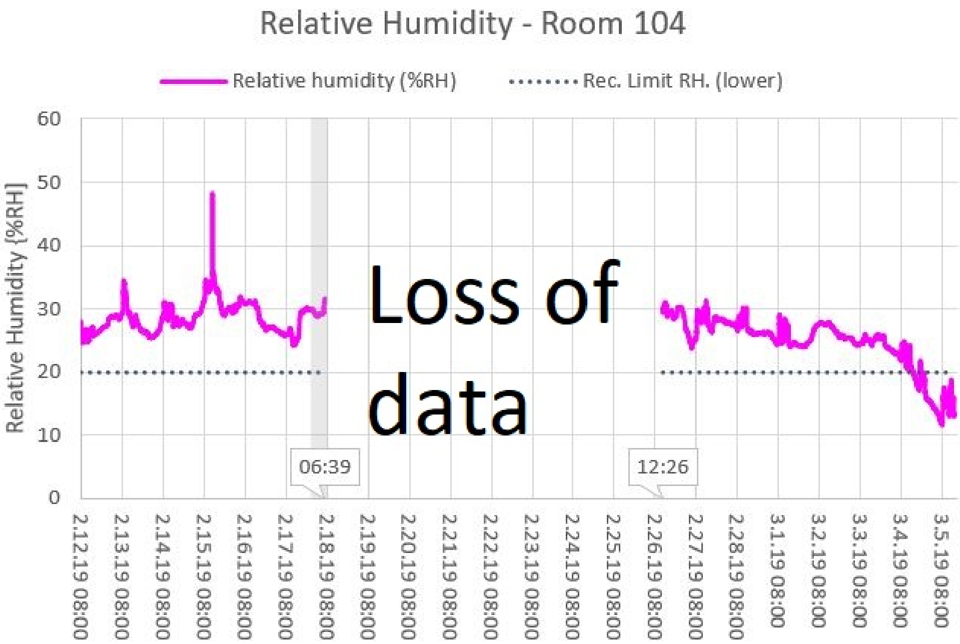

Figure 70: Relative humidity measured in Room 104 from the Feb. 12. to Mar. 05.

The relative humidity is difficult to control in the Norwegian climate without extra technical equipment in the ventilation handling unit. Some sort of humidifier in the ventilation handling unit or in the rooms are necessary to keep the relative humidity up. These humidifiers are not normal in Norway, as they need close and constant supervision. They can for example be with incorrect use be a source of Legionnaires' disease [11].

During cold temperatures outside, the relative humidity will drop in heated buildings. Relative humidity is the percentage of how close the air is to be saturated with water. When the air is fully saturated it can not hold any more water and the water begins to condense. Cold air can hold on less water than warm air, so it requires less water in cold air to achieve 100% relative humidity. When cold air is heated up, the air's capability to hold water increases, therefore, the amount of until the air now is saturated increases as well. The amount of water does not change in the air when it is heated from cold to hot, but the capability to hold water increases. Therefore, the relative humidity decreases in the rooms during colder weather. This principle is illustrated and seen in Figure 70, 71, 72, 73, 75, 76, 81, 79, 82,87 and 91. It is best observed during the morning of March 05. and 06. The cold air was heated up by the room, so the relative humidity dropped below 10% for a short while. When people started using the room the relative humidity increased again. Humans exhale some moisture with every breath. In the schools, the occupants are the most important source of humidity. During the winter break, one can see that the relative humidity fluctuates less than during the ordinary school weeks. The changes are slow and should be because of changes in the temperature or the relative humidity in the outside air. The outside relative humidity and temperature is given in Appendix G.

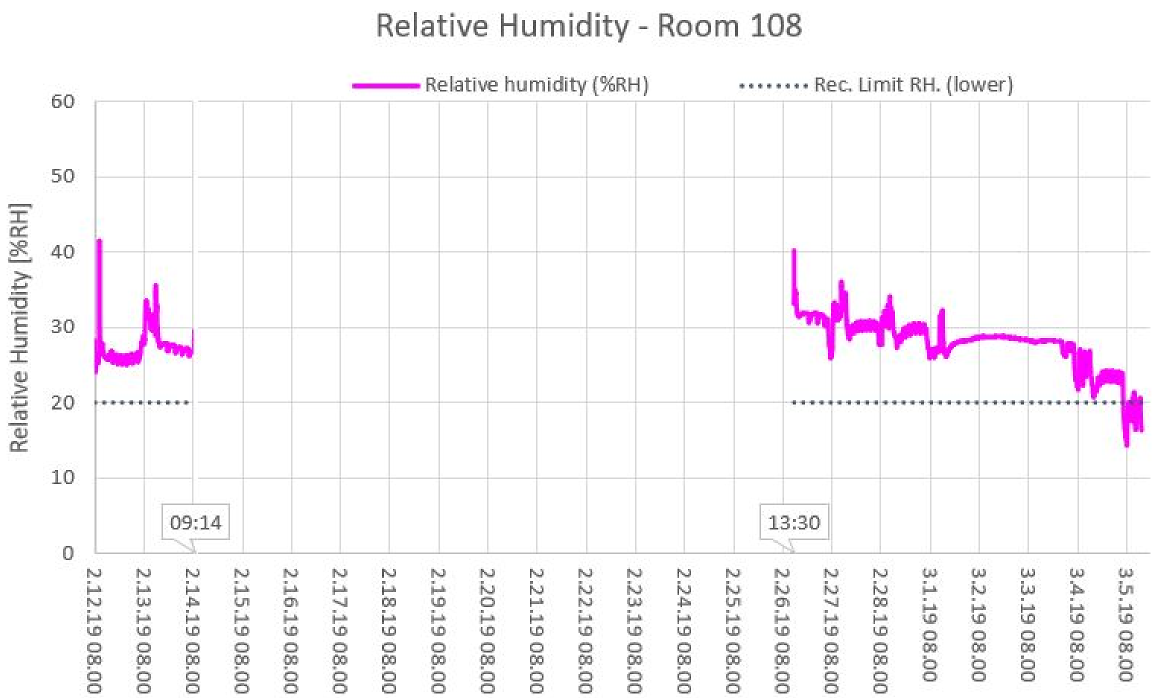

Figure 71: Relative humidity measured in Room 108 from the Feb. 12. to Mar. 05.

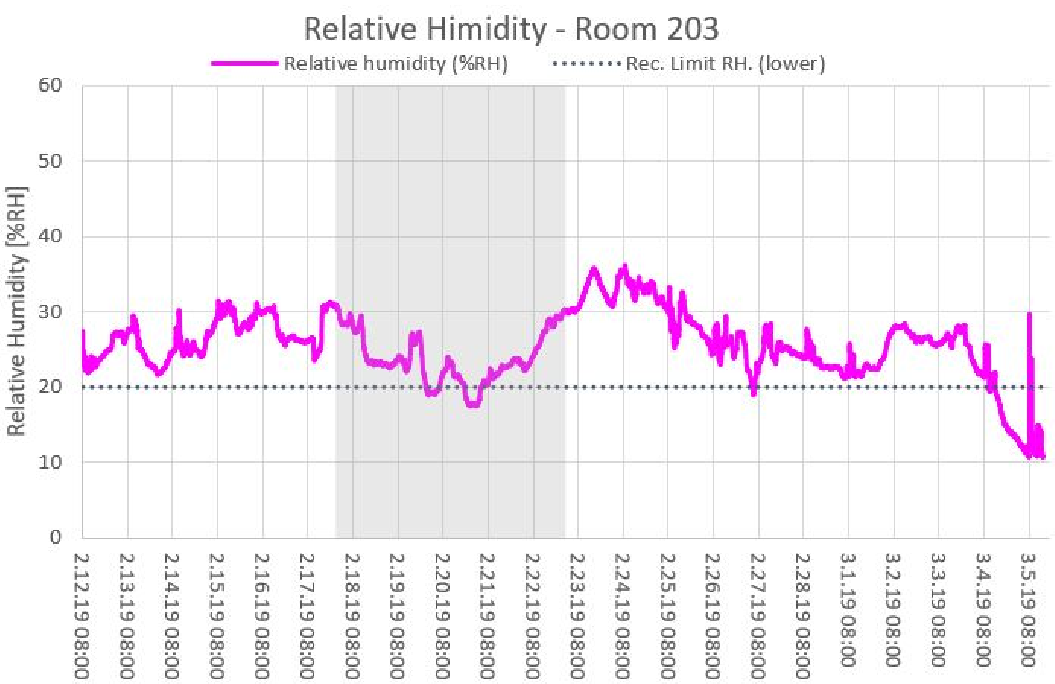

Figure 72: Relative humidity measured in Room 203 from the Feb. 12. to Mar. 05.

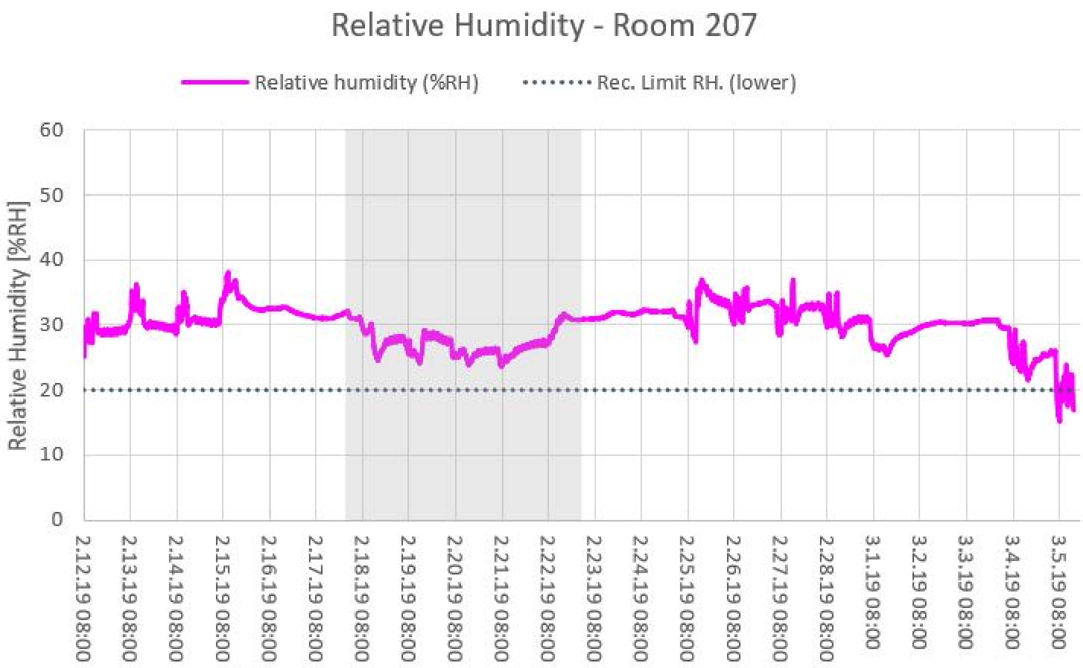

Figure 73: Relative humidity measured in Room 207 from the Feb. 12. to Mar. 05.

B.2 Stabbursmoen extra results

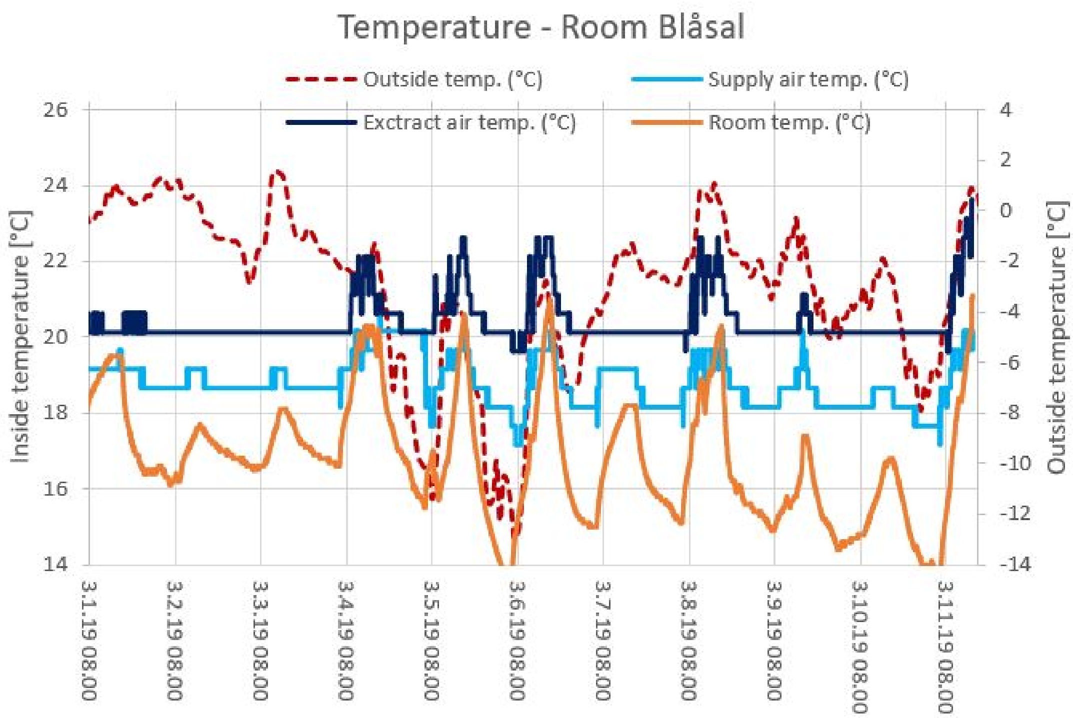

Figure 74: Air temperature measured in Room Blåsal from the 01. to 11. Mar..

Figure 74 shows the last ten days of the field study in more detail, including the supply and extract air temperatures. The extract air temperature is measured from the vents that leads out into the adjoining room where the extract vents are located.

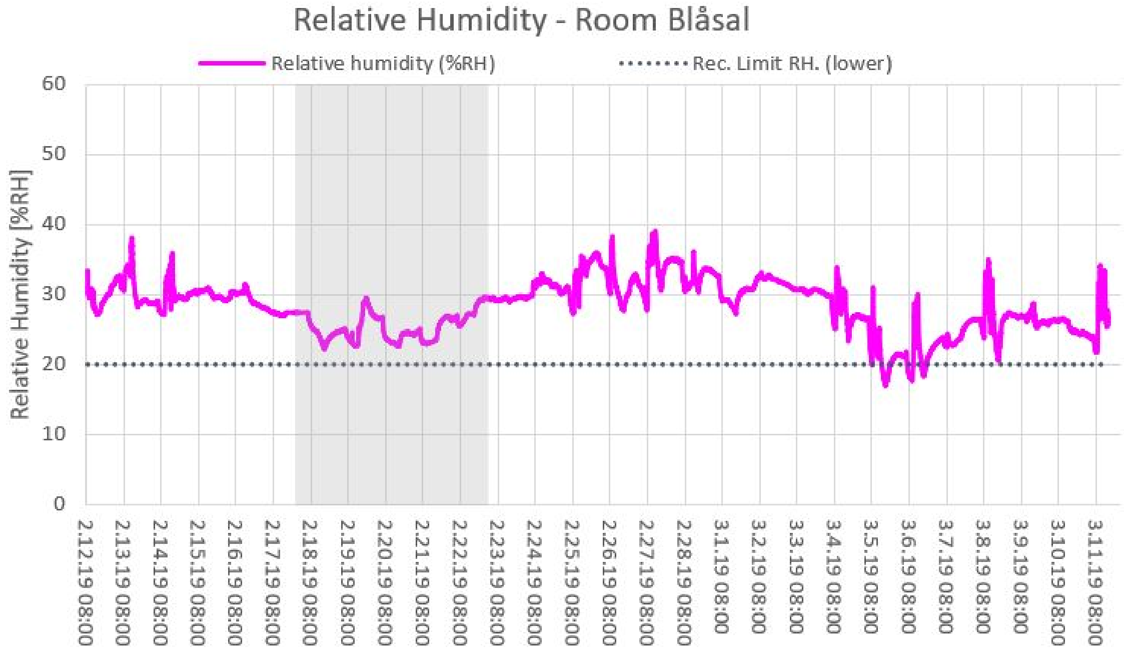

Figure 75: Relative humidity measured in Room Blåsal from the Feb. 12. to Mar. 11.

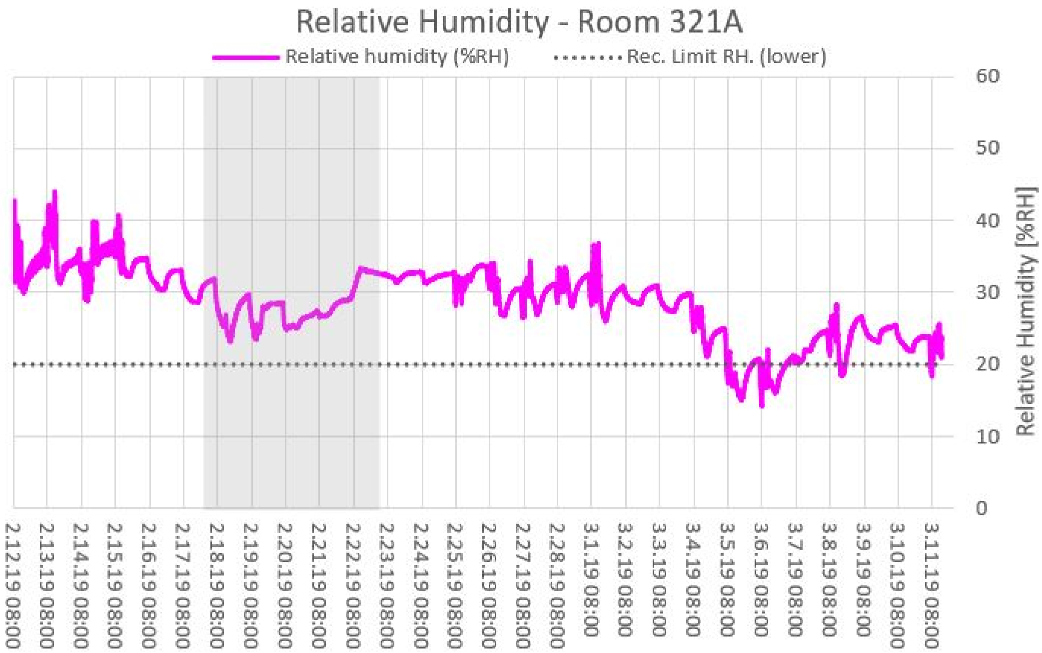

Figure 76: Relative humidity measured in Room 321A from the Feb. 12. to Mar. 11.

Figure 80 shows the all the temperature measurements done by the iButtons placed in the supply and extract vents.

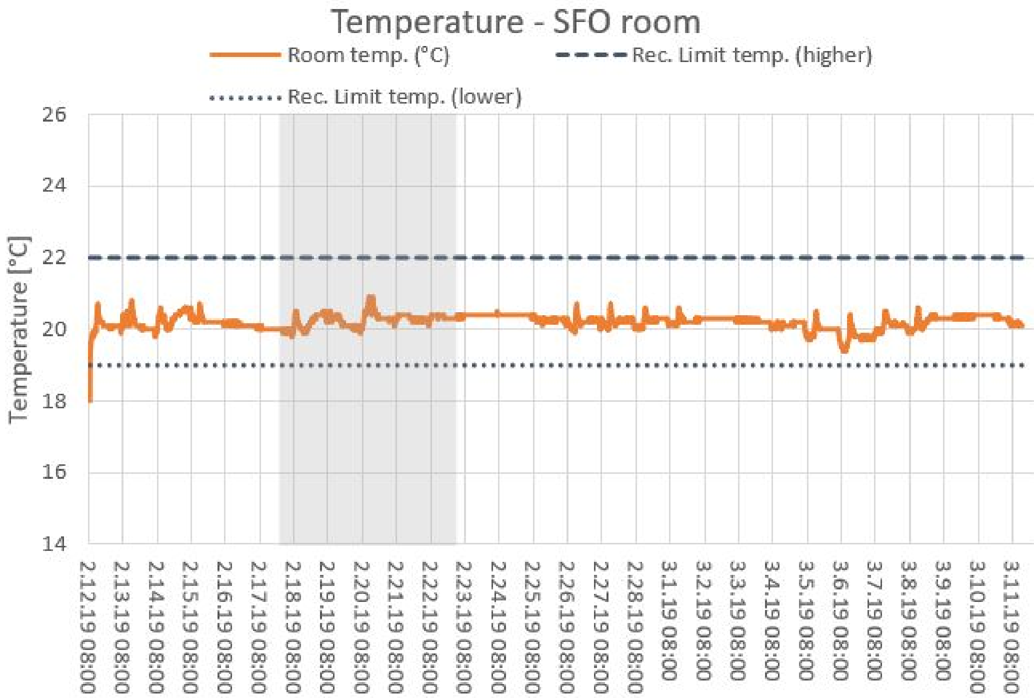

Figure 77: Air temperature measured in Room SFO from the 12. Feb. to 11. Mar..

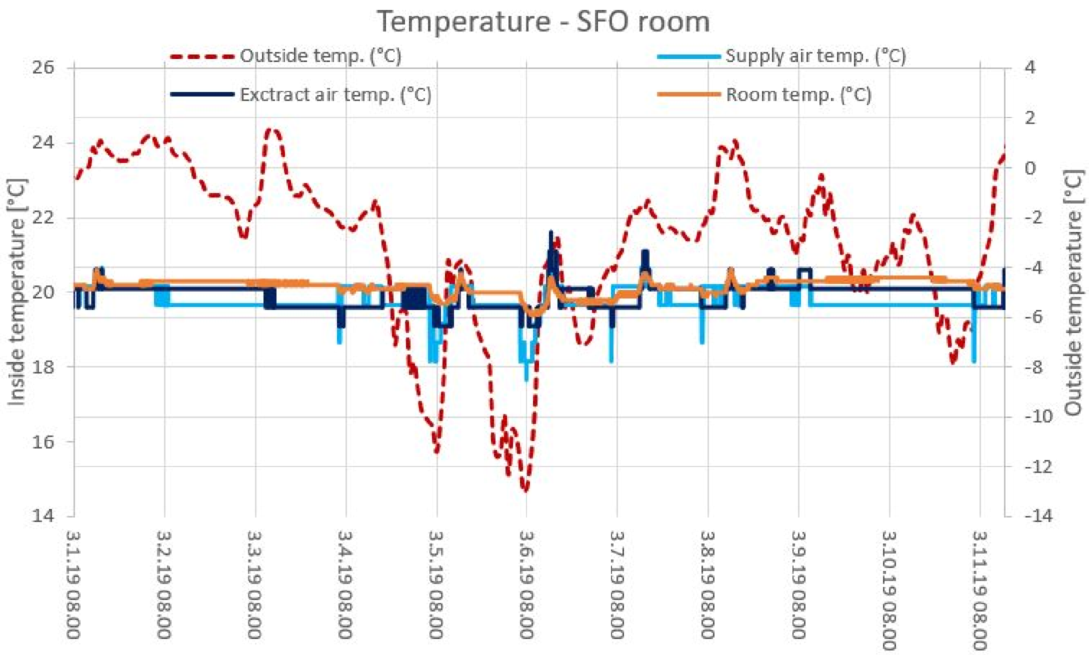

Figure 78: Air temperature measured in Room SFO from the 01. to 11. Mar..

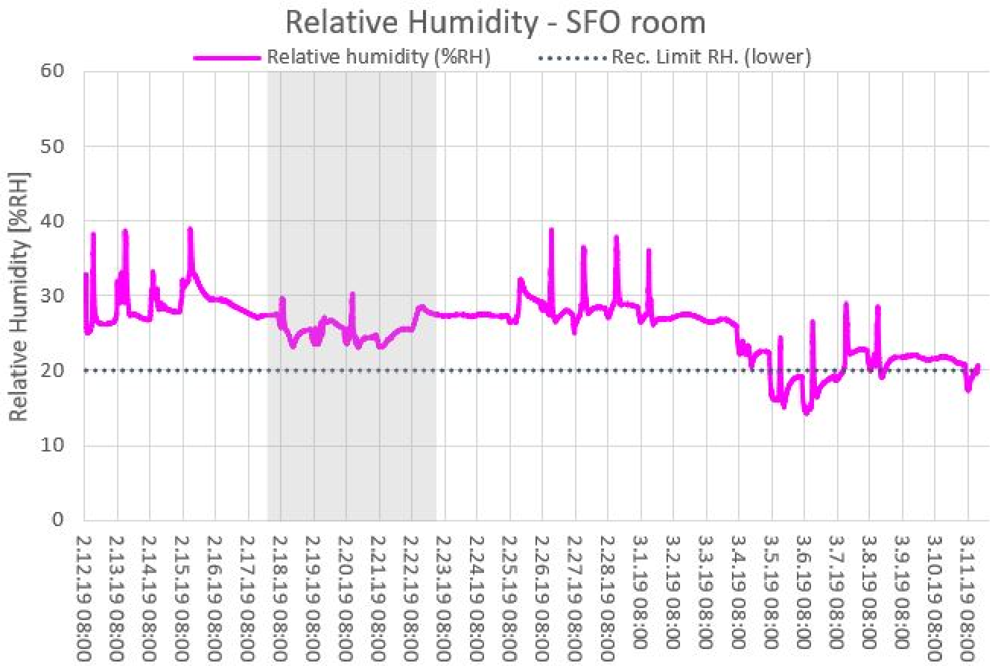

Figure 79: Relative humidity measured in Room SFO from the Feb. 12. to Mar. 11.

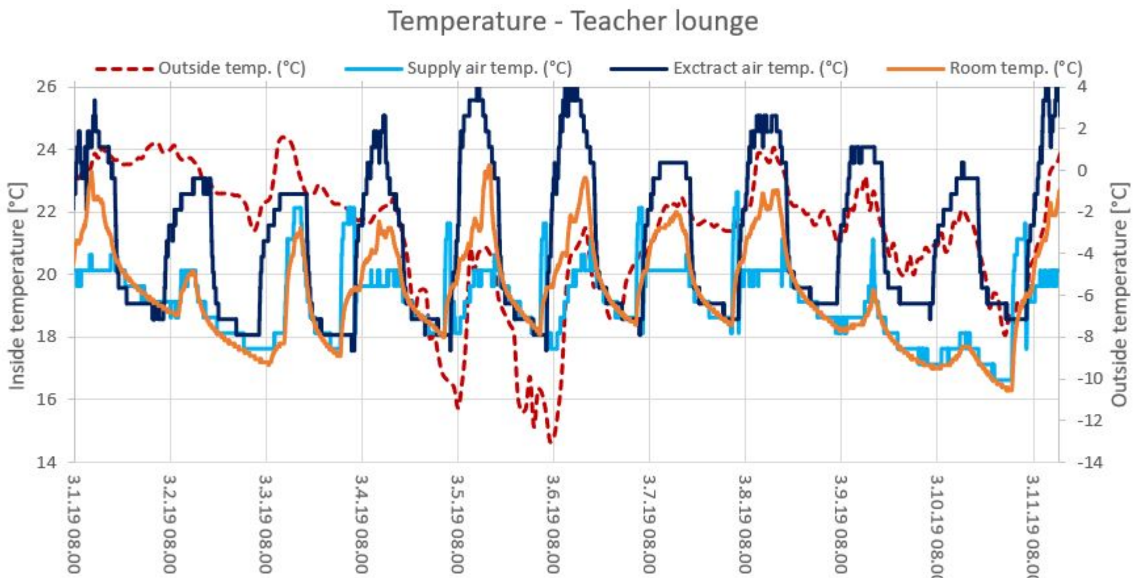

Figure 80: Air temperature measured in the Teacher's Lounge from the 01. to 11. Mar..

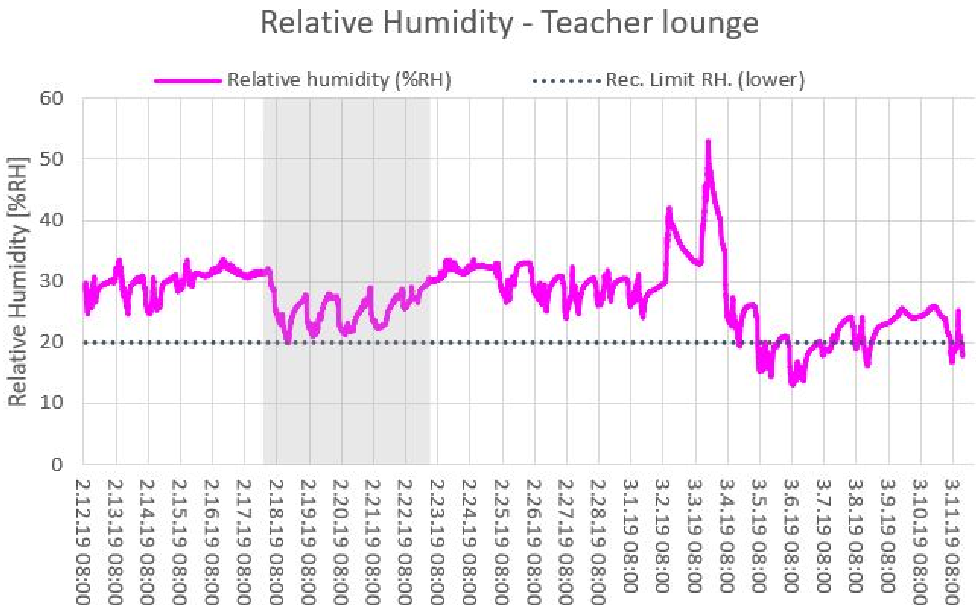

Figure 81: Relative humidity measured in the Teacher's lounge from the Feb. 12. to Mar. 11.

B.3 Sørborgen extra results

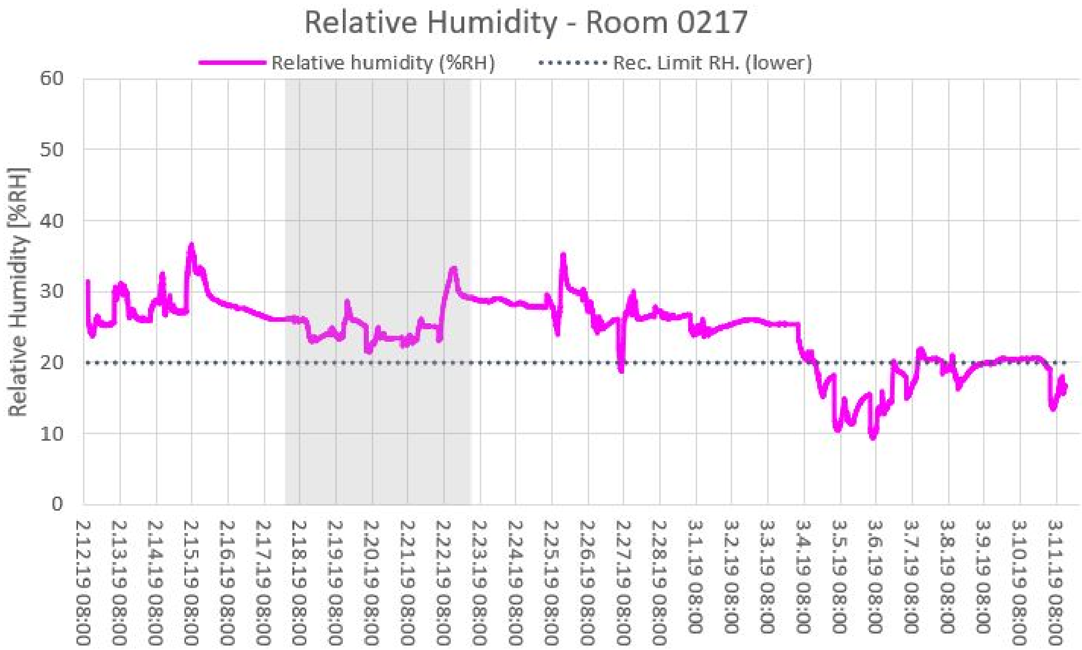

Figure 82: Relative humidity measured in Room 0217 from the Feb. 12. to Mar. 11.

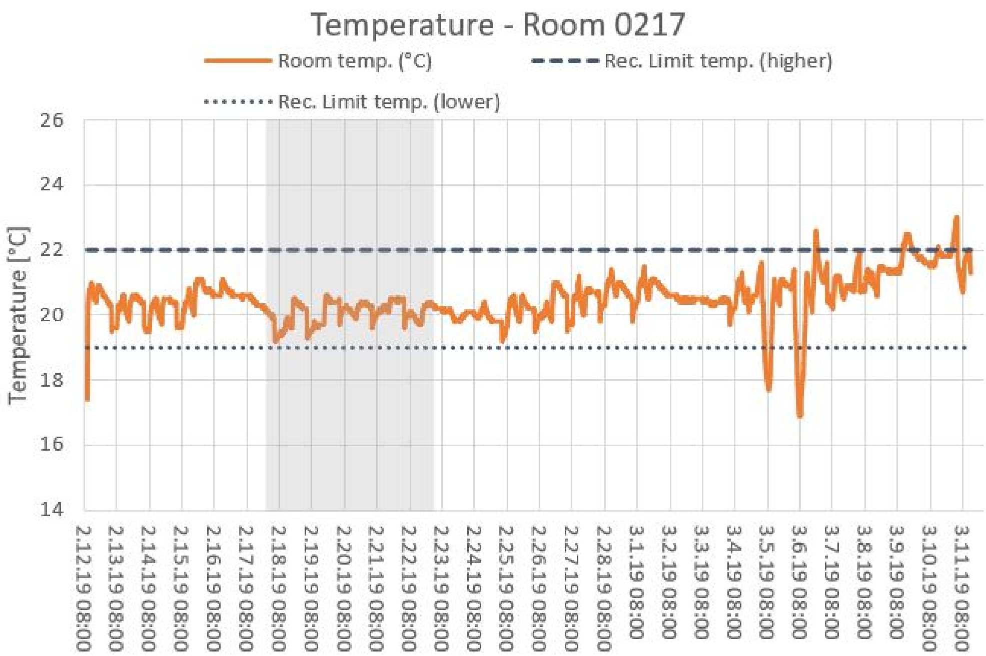

Figure 83: Room air temperature measured in Room 0217 from the Feb. 12. to Mar. 11.

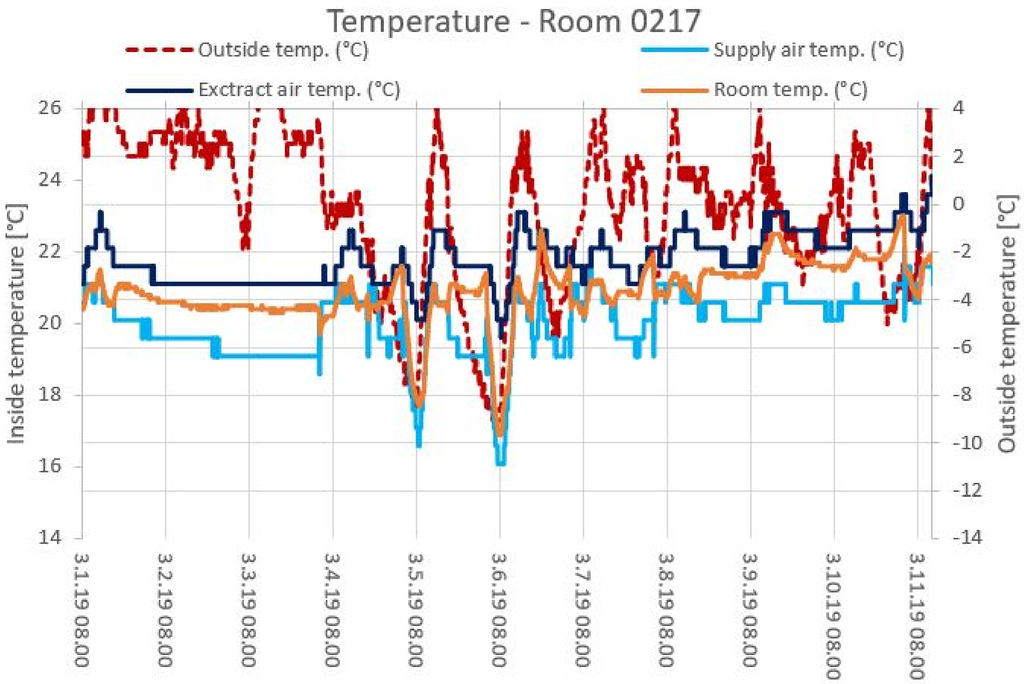

Figure 84: Room temperature measured in Room 0217 from the Mar. 01. to Mar. 11.

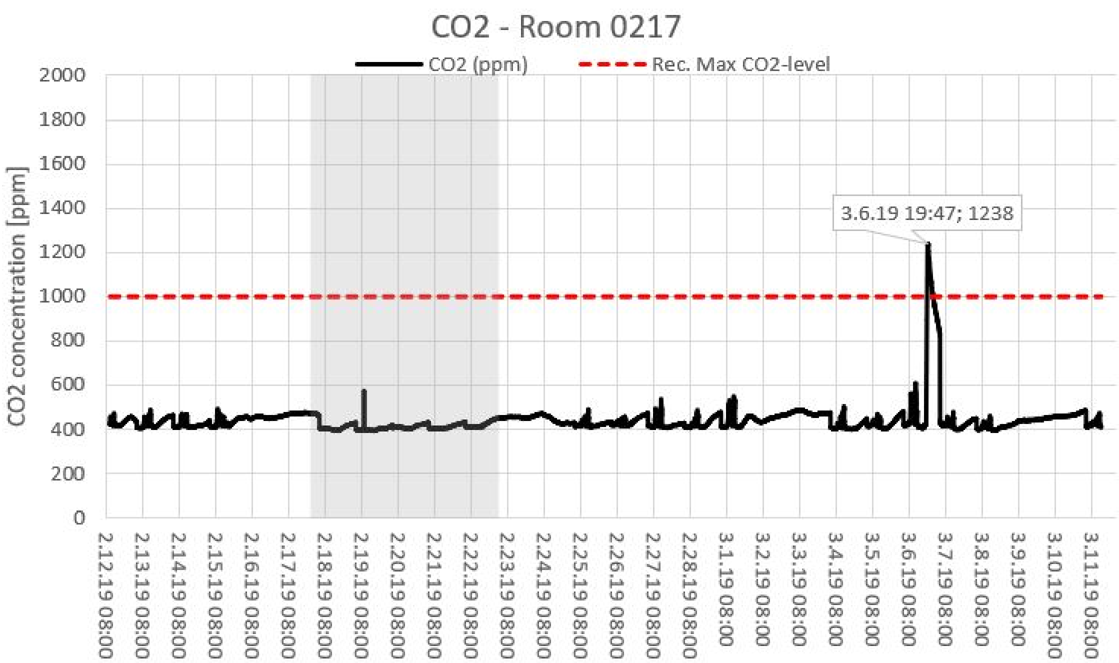

Figure 85: CO_2 concentration measured in Room 0217 from the Feb. 12. to Mar. 11.

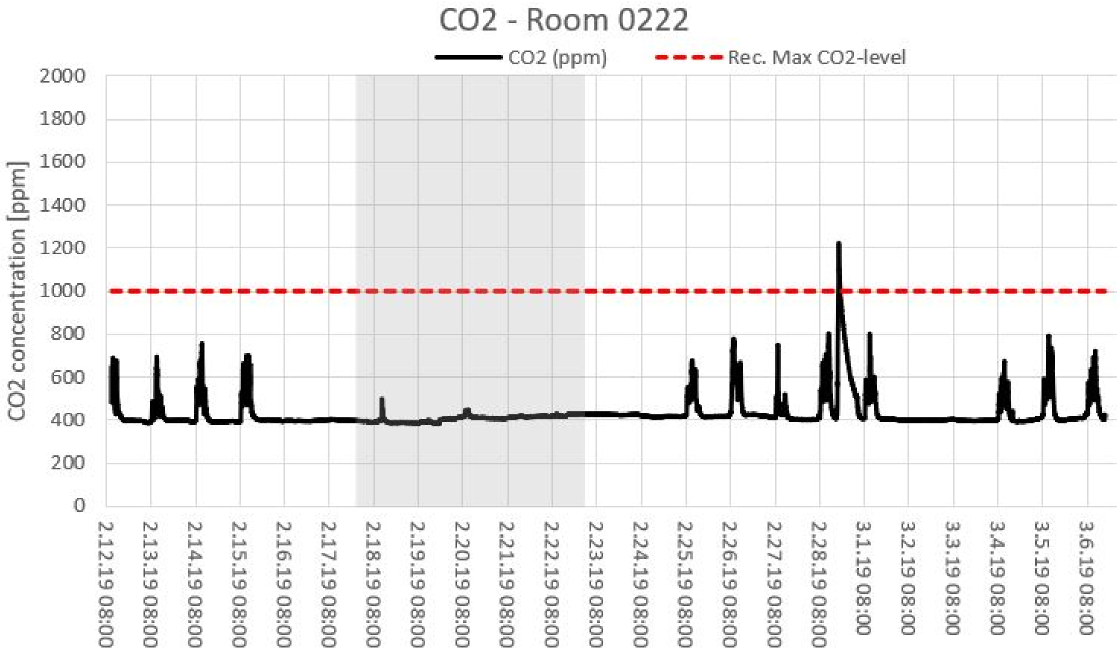

Figure 86: CO_2 concentration measured in Room 0222 from the Feb. 12. to Mar. 06.

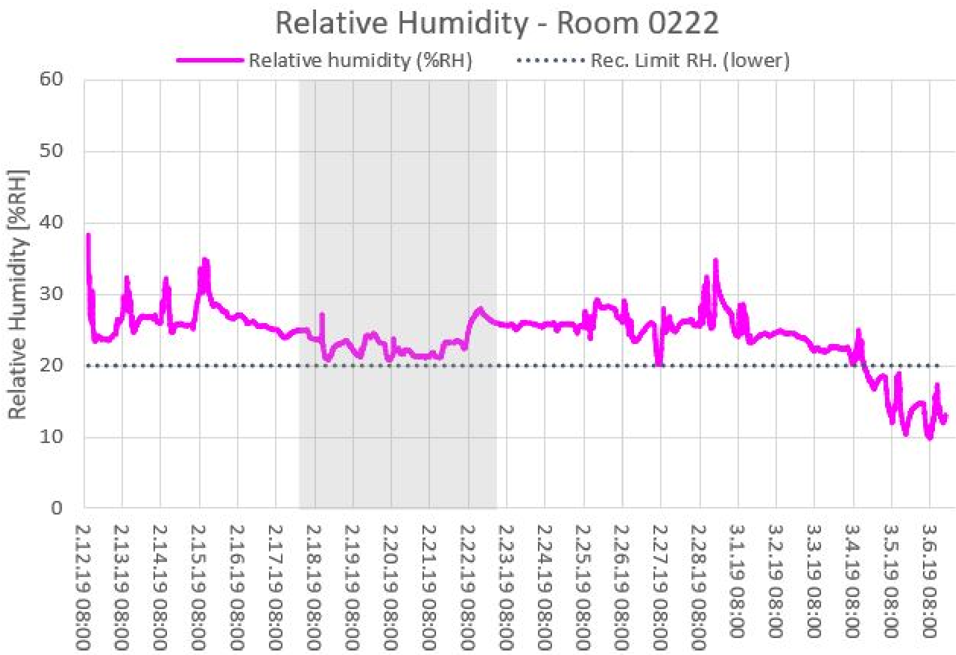

Figure 87: Relative humidity measured in Room 0222 from the Feb. 12. to Mar. 06.

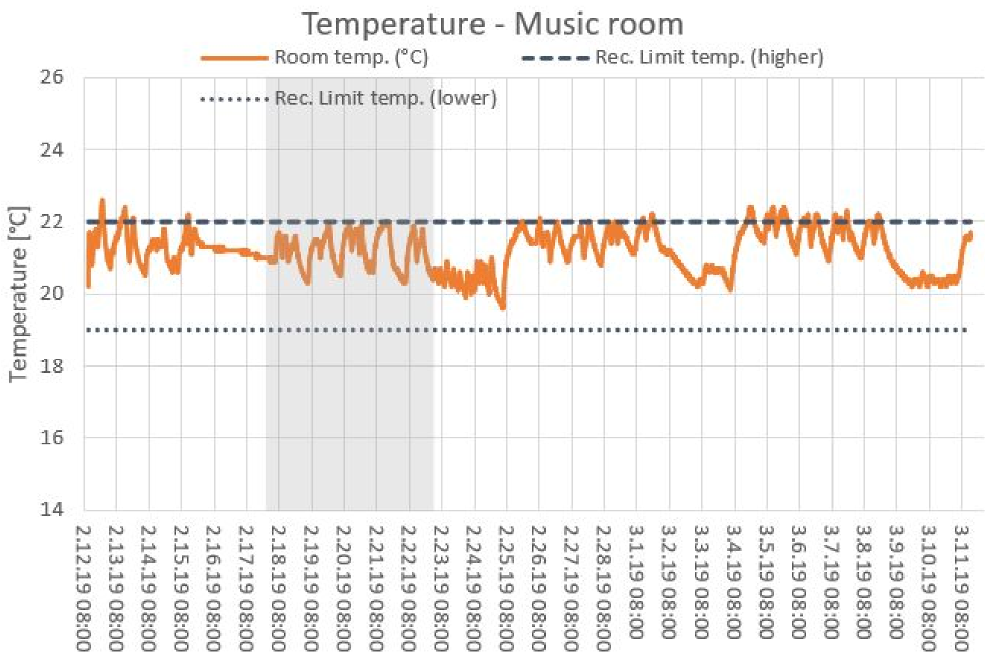

Figure 88: The room air temperature measured in the Music room from the Feb. 12. to Mar. 11.

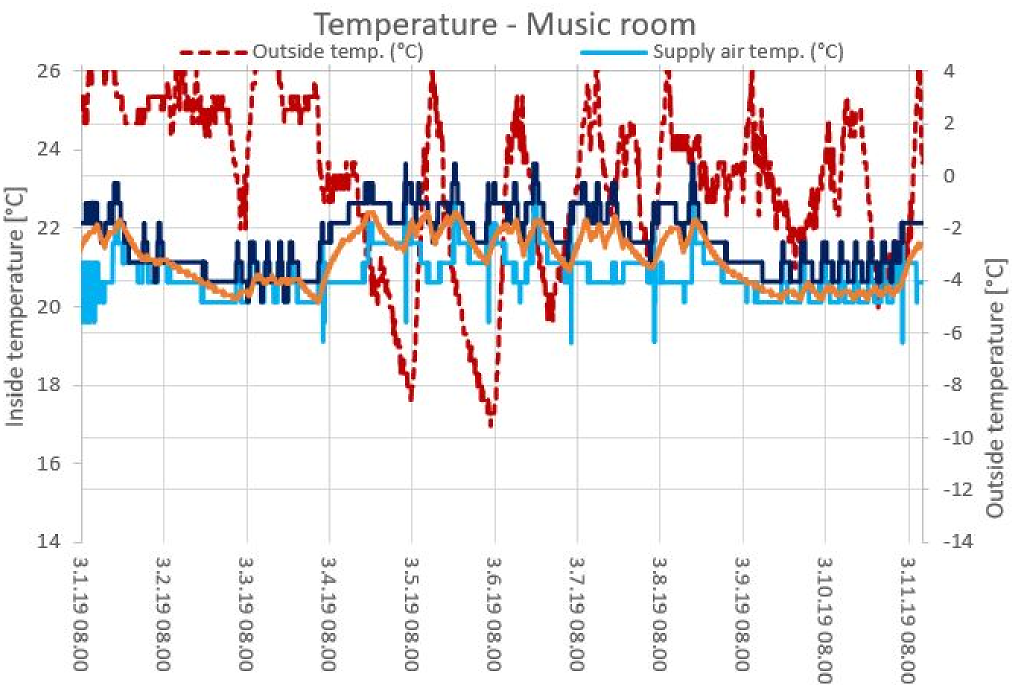

Figure 89: The room temperature measured in the Music room from the Mar. 01. to Mar. 11.

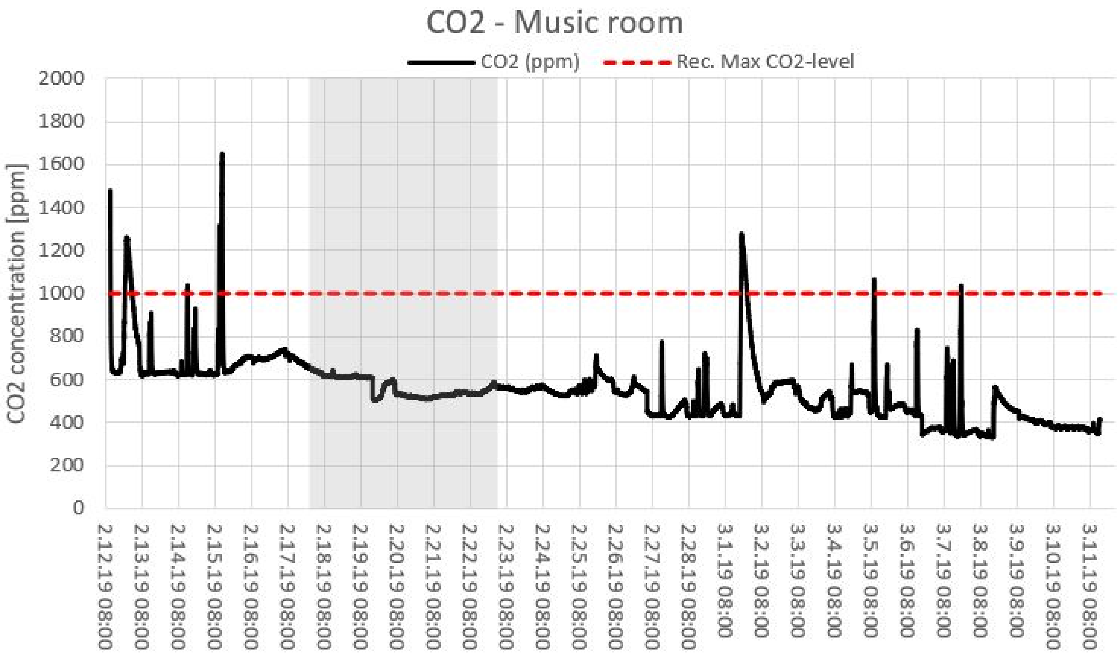

Figure 90: CO_2 concentration measured in the Music room from the Feb. 12. to Mar. 11.

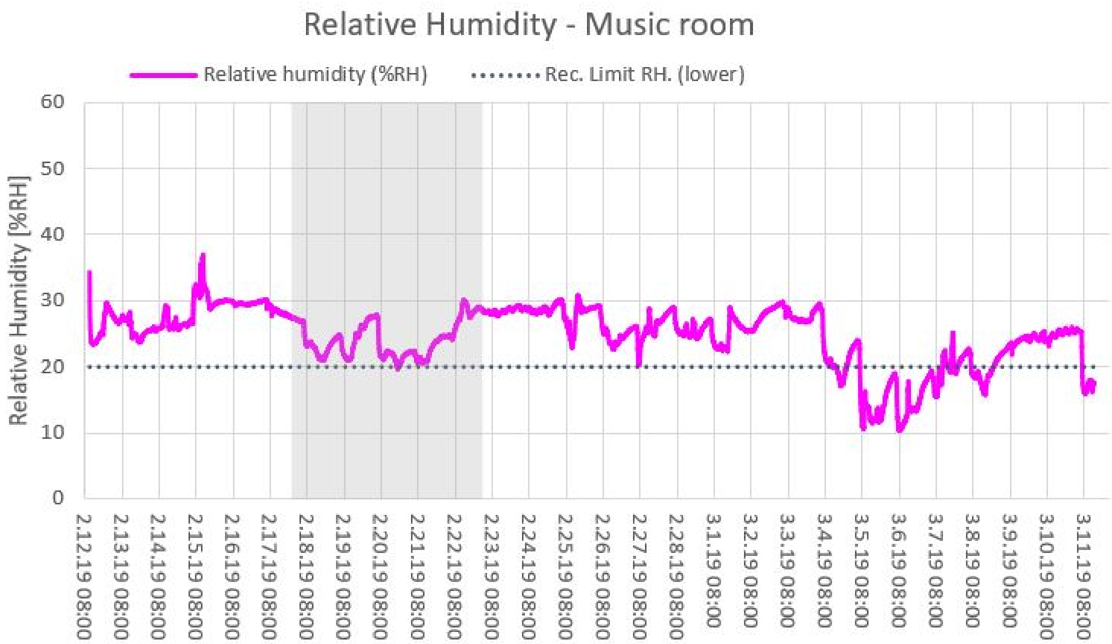

Figure 91: The relative humidity measured in the Music room from the Feb. 12. to Mar. 11.

Appendix C Interview guide

Intervjuguide rektor, lærere, driftspersonell og helsesøster

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?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

God Tilfredsstillende Dårlig

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

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

God Tilfredsstillende Dårlig

Hvilken temperatur er det i aktuelle rom?____

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

Har du som arbeider ved skolen fått opplæring og informasjon om hvordan du regulerer temperatur, ventilasjon og andre av klasserommenes tekniske installasjoner? ☐ Ja ☐ Nei

Hvilken informasjon og hvordan ble den formidlet?____________________________________

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

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

God Tilfredsstillende Dårlig

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

____
____

Intervjuguide rektor, lærere, driftspersonell og helsesøster

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 ....

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

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

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 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?____

Intervjuguide rektor, lærere, driftspersonell og helsesøster

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

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 Information letter to parents

The letter in Figure 92 is written by SINTEF Community w/Solvår Wågø, the project manager for ”Skoler på vent”.

Informasjonsbrev til foresatte

Foresatte til elev NN

Navn på skole

Sted, dato

Kjære foresatte!

Ditt barn går på en skole som venter på nybygg eller rehabilitering. Som et ledd i skolens arbeid for å oppnå et godt fysisk læringsmiljø i denne venteperioden ønsker vi å foreta en kartlegging av hvordan elever og ansatte opplever inneklimaet sitt, slik at det kan iverksettes tiltak som kan forbedre inneklima i denne vente-perioden. Effekten av tiltakene vil evalueres gjennom en ny spørreundersøkelse om ett års tid.

Om undersøkelsen

Kartleggingen foretas ved hjelp av en nettbasert spørreundersøkelse for elevene i fjerde til tiende klasse ved tre barne- og ungdomsskoler i Trondheim. Elevene vil bli bedt om å krysse av i et skjema. Videre vil de få et nytt skjema til utfylling om ett års tid. Spørsmålene vil omhandle hvordan eleven opplever inneklimaet på skolen. Spørreundersøkelsen gjennomføres i samarbeid med Norges Astma- og Allergiforbund, som foretar bearbeiding og analyse av resultatene. Analysene vil bli gjennomført på en sikker og forsvarlig måte av fagpersoner med god kompetanse og erfaring med slike undersøkelser. Skolen vil motta en oversiktsrapport med konkrete forslag til forbedringer. Undersøkelsen vil bli presentert for foreldrene ved starten på høstsemesteret 2019.

Trondheim kommune har tatt ut tre skoler som deltar i denne kartleggingen. Vår skole er så heldig å være en av de utvalgte. Spørreundersøkelsen er finansiert av Astma- og Allergiforbundet gjennom midler fra Extra-stiftelsen, og vil ikke belaste skolens budsjett. Prosjektet gjennomføres av forskere fra SINTEF Byggforsk og NTNU i samarbeid med Trondheim kommune og Norges Astma- og Allergiforbund (NAAF).

Informasjon om undersøkelsen vil dere finne på NAAFs nettsider:
https://www.naaf.no/fokusomrader/inneklima/inneklima-i-skoler/Skoler_paa_vent/

Ditt barns personvern

Det samles ikke inn navn og personalia. Alle svar er anonyme og den som har svart vil ikke kunne gjenkjennes. Norsk senter for forskningsdata (NSD), har vurdert at behandlingen av personopplysninger i dette prosjektet er i samsvar med personvernregelverket.

Det er frivillig å delta, men ditt svar er viktig for å få innsikt i problemstillinger som har betydning for barns helse og læringsmiljø. Foresatte som ikke ønsker at deres barn skal delta i undersøkelsen gir beskjed til kontaktlærer om dette.

Med hilsen

XXXXXX

Rektor

Figure 92: Letter sent to all the parents in the three schools.

Appendix E Information letter to school staff

The letter in Figure 93 is written by SINTEF Community w/Solvår Wågø, the project manager for "Skoler på vent".

SKOLER PÅ VENT_Informasjon til lærere, driftspersonell og helsesøstre som intervjues

Kjære ansatte ved Sørborgen, Sunnland og Stabbursmoen skoler

Din skole venter på nybygg eller rehabilitering. Som et ledd i skolens arbeid for å oppnå et godt fysisk læringsmiljø i denne venteperioden ønsker vi å foreta en kartlegging av hvordan elever og ansatte opplever inneklimaet sitt, slik at det kan iverksettes tiltak som kan forbedre inneklima i denne venteperioden. Effekten av tiltakene vil evalueres gjennom en ny spørreundersøkelse om ett års tid.

Om undersøkelsen

Kartleggingen foretas ved hjelp av en nettbasert spørreundersøkelse for elevene i fjerde til tiende klasse ved tre barne- og ungdomsskoler i Trondheim. Elevene vil bli bedt om å krysse av i et skjema. Videre vil de få et nytt skjema til utfylling om ett års tid. Spørsmålene vil omhandle hvordan eleven opplever inneklimaet på skolen. Spørreundersøkelsen gjennomføres i samarbeid med Norges Astma- og Allergiforbund, som foretar bearbeiding og analyse av resultatene. Analysene vil bli gjennomført på en sikker og forsvarlig måte av fagpersoner med god kompetanse og erfaring med slike undersøkelser. Skolen vil motta en oversiktsrapport med konkrete forslag til forbedringer. Undersøkelsen vil bli presentert for dere ansatte, elevrådet, foreldreråd/Brukerutvalg/FAU på skolene ved starten på høstsemesteret 2019 når tiltak skal iverksettes.

Trondheim kommune har tatt ut tre skoler som deltar i denne kartleggingen. Din skole er så heldig å være en av de utvalgte. Spørreundersøkelsen er finansiert av Astma- og Allergiforbundet gjennom midler fra Extra-stiftelsen, og vil ikke belaste skolens budsjett. Prosjektet gjennomføres av forskere fra SINTEF Byggforsk og NTNU i samarbeid med Trondheim kommune og Norges Astma- og Allergiforbund (NAAF).

Informasjon om undersøkelsen vil dere finne på NAAFs nettsider:
https://www.naaf.no/fokusomrader/inneklima/inneklima-i-skoler/Skoler_paa_vent/

Personvern

Alle svar er anonyme og den som har svart vil ikke kunne gjenkjennes. Norsk senter for forskningsdata (NSD), har vurdert at behandlingen av personopplysninger i dette prosjektet er i samsvar med personvernregelverket.

Det er frivillig å delta, men ditt svar er viktig for å få innsikt i problemstillinger som har betydning for barns helse og læringsmiljø, og de ansattes arbeidsmiljø. Foresatte som ikke ønsker at deres barn skal delta i undersøkelsen gir beskjed til kontaktlærer om dette, og det er frivillig å la seg intervjue.

Vi takker for at du vil delta. Dine svar er med på å fylle ut de resultater vi får fra målinger og spørreundersøkelse.

Med vennlig hilsen

Solvår Wågø

Prosjektleder

Figure 93: Letter sent to all the staff in the three schools

Appendix F Entire questionnaire

In this Appendix an example of the questionnaire is presented. Note, this is an old version. It is not updated with the latest changes to the questions.

Vedlegg 1 Spørreskjema

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

Takk for at du hjelper til!

Bakgrunnsspørsmål

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 b

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

Kjønn

- ☐ Jente
- ☐ Gutt

Hvordan synes du luften, støyen, temperaturen og lyset har vært på skolen di månedene?

Har du i skoletiden vært plaget av:

	Ja, ofte (hver uke)	Ja, iblant	Nei, aldri	V
Trekk av kald luft	☐	☐	☐	
For høy romtemperatur	☐	☐	☐	
Varierende romtemperatur	☐	☐	☐	
For lav romtemperatur	☐	☐	☐	
Innestengt (dårlig) luft	☐	☐	☐	
Tørr luft	☐	☐	☐	
Ubehagelig/vond lukt	☐	☐	☐	

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

	Ja, ofte (hver uke)	Ja, iblant	Nei, aldri
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
Har du hatt eller har du astma?	❑
Har du hatt eller har du allergi?	❑
Har du hatt eller har du eksem?	❑

Hvordan trives du på skolen?

Appendix G Weather data from field study

The weather data from two weather stations in Trondheim is presented in this appendix. The stations are Voll and Skjetlein weather station. Both stations were chosen as they are the closest to at least one of the schools geographically. In Table 31 the distance between the three schools and the weather stations are given. The altitude difference is also given in the same table. A negative altitude difference means that the school is lower situated than the weather station. Voll and Skjetlein stations both record temperature and relative humidity. However, only Voll records precipitation and wind data. The data available is recorded hourly. The precipitation data given in Figure 96 is the total rainfall per hour.

The weather data given in Figures 94, 95 and 96 are gathered from the Norwegian Meteorological Institute (NMI) database. There will be some differences between the actual outdoor parameters at the school and what is recorded at the weather stations. The data from NMI still provides an acceptable accuracy for its application in this thesis.

Table 31: The distance and altitude difference between Voll and Skjetlein weather stations and the three schools; Sunnland, Stabbursmoen and Sørborgen.

	Voll Distance [km]	**Voll** Altitude[m] Difference	**Skjetlein** Distance [km]	**Skjetlein** Altitude[m] Difference
Sunnland	2.4	-60	8.8	-5
Stabbursmoen	8.2	27	3.0	93
Sørborgen	11.8	36	9.8	102

In Figure 95 the recorded temperatures at the weather stations are compared to the recorded temperatures by the iButtons placed outside at Stabbursmoen and Sørborgen. The temperature recorded by the iButtons are higher than the weather stations measured. This is especially true during the morning and early afternoon. There is a chance that the sun has warmed up the structures enough to influence the iButton measurements. The iButtons were shielded from direct sunlight.

As mentioned in Sectin 6.5, the iButtons only held data from the March 1. Therefore, the graph in Figure 95 only shows the temperature from the last 10 days of the main field study.

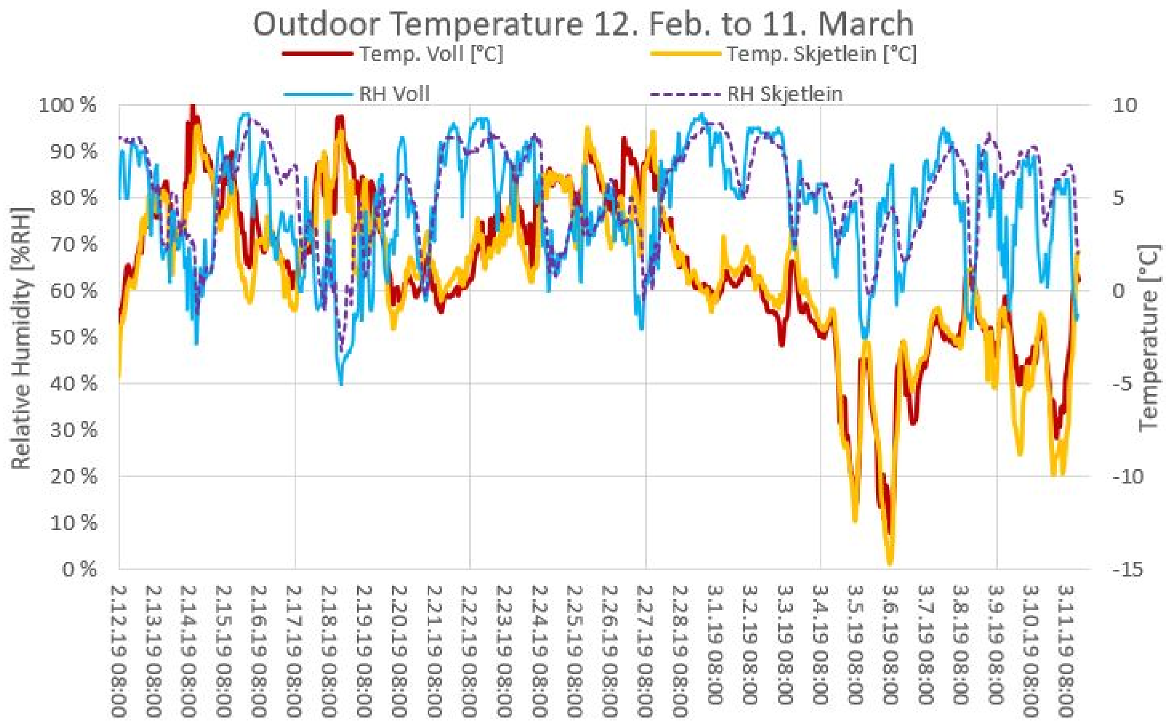

Figure 94: Outside temperature and humidity at Voll and Skjetlein measuring station between 02.12.2019 08:00 - 03.11.2019 18:00.

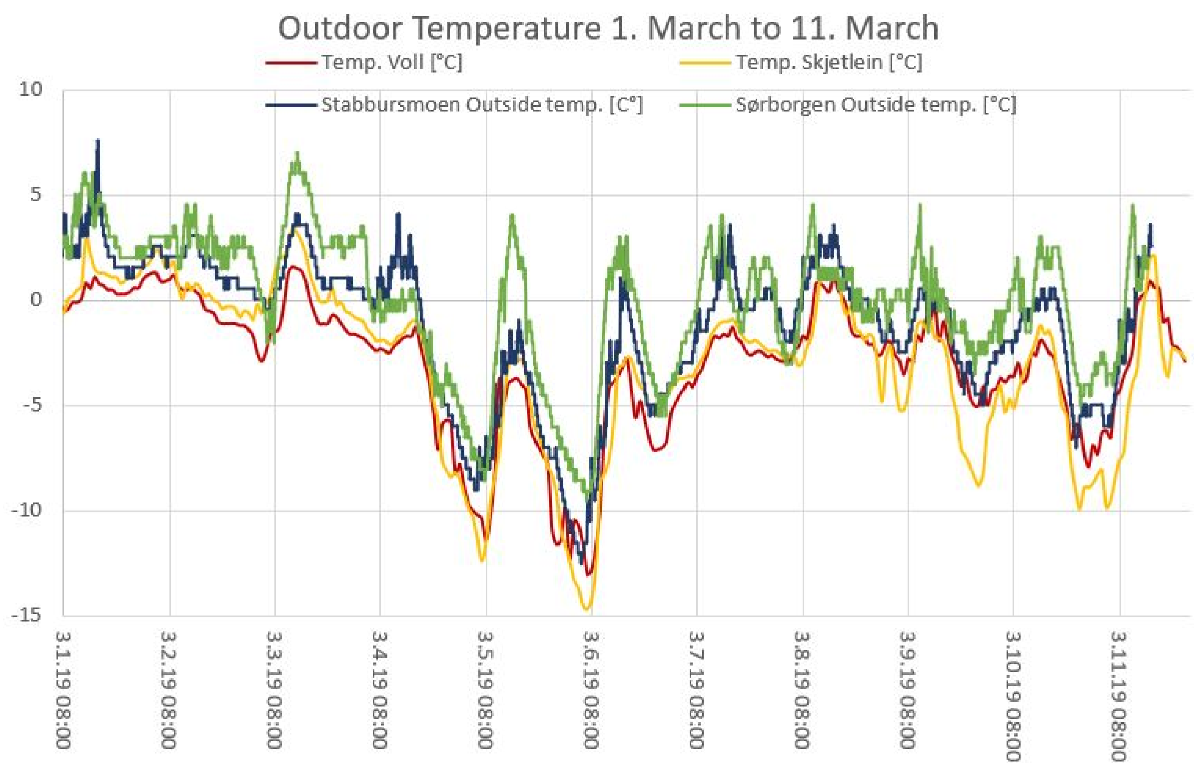

Figure 95: Outside temperature at Voll and Skjetlein measuring station and the logged iButton temperature from Stabbursmoen and Sørborgen between 03.01.2019 08:00 - 03.11.2019 14:00.

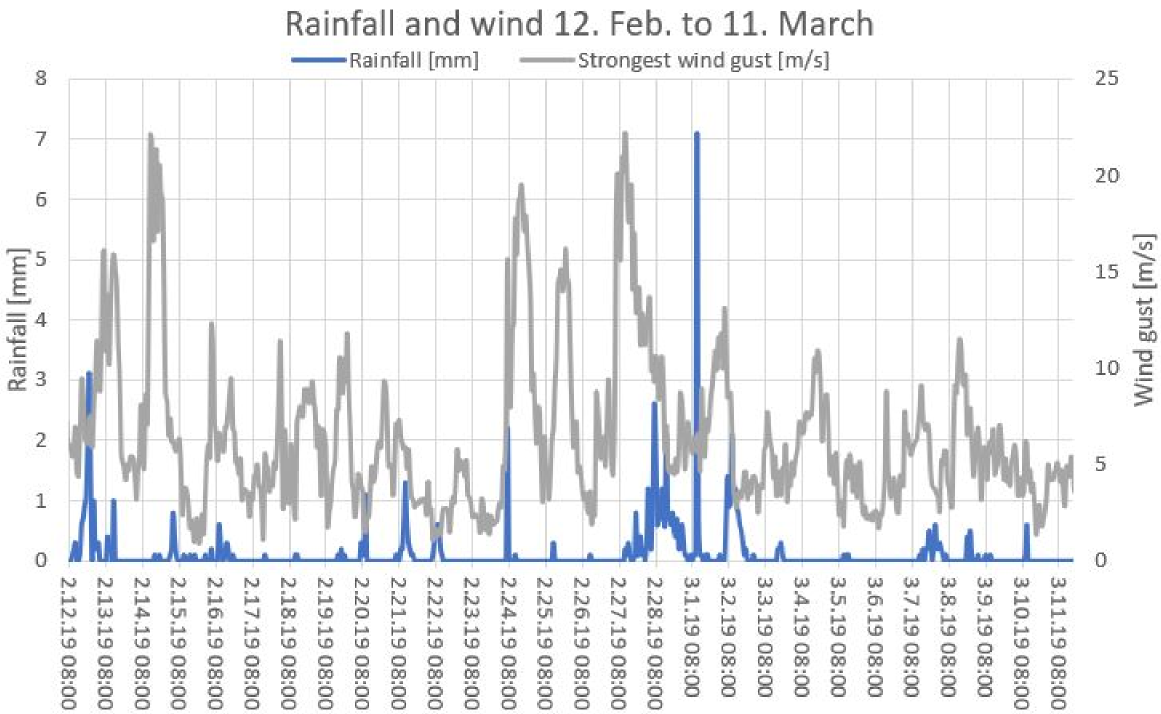

Figure 96: Hourly rainfall and the highest registered wind gust at Voll measuring station between 12.02.2019 08:00 - 11.03.2019 18:00.

Appendix H Technical noise and ventilation rates

Bravida measured the fresh air supply in most of the classrooms on two occasions; the 24. and 31.of August 2018. They also measured the technical noise on the 31. of August. The results is given in Figure 97. Airflow was not measured in the classroom with their own ventilation units. However, the noise measurements were performed also in these rooms. The noise measurements are consistent with the measurements done by SINTEF Community six months later.

KOMETVEIEN 8

bravida

Måleprotokoll Luftmengder. Sunnland skole. 1 og 2 etg. Målt 31.08.2018.

ROM	Tilluft Målt 24.08	Tilluft Målt 31.08	Støymåling 31.08	Kommentar
R104			33 db	Klasseromsaggregat
R106	670	732	35,5 db	
R107	730	756	36 db	
R127				Ikke målt
R128	680	816	42,7 db	
R129	165	208	33,4 db	Lite grupperom
R120	662	714	35,5 db	
R119	650	755	35,5 db	
R203			38 db	Klasseromsaggregat
R204	678	724	36 db	
R205	665	699	40 db	
R206	667	738	39,7 db	
R207	692	751	39 db	
R208			36 db	Klasseromsaggregat
R210			36,5 db	Klasseromsaggregat
R213	682	722	43,3 db	
R214	700	717	37,4 db	
R215	215	285	33,5 db	Lite rom
R216	637	680	36 db	
R217			38 db	Klasseromsaggregat
Sum	8493	9297	0	0

Figure 97: Measured ventilation air rates at Sunnland school, building C, August 2018. (Photo: Trondheim Kommune)

The fresh air supply was measured before and after the fresh air supply fan was replaced. The replacement was meant to lower the noise from the ventilation system and increase the air capacity closer to the original capacity.

Anders Homb at SINTEF Community measured the sound level from the technical in-

Table 32: Equivalent levels measured by SINTEF Community in February at Sunnland School, Stabbursmoen School and Sørborgen School.

	$L_{pA,eq}$ [dB]
Sunnland	
Room 104	34
Room 107	36
Room 203	38
Room 207	39
Stabbursmoen	
Room 0321A	36
Room "Blåsal"	32
Room SFO	34
Teachers lounge	31
Sørborgen	
SFO 117/118	32
Room 0215	30
Room 0222	30
Room 0224	24

stallations at the three schools. The measurements were done during the winter break at the schools. The measurements were performed according to NS-EN ISO 16032. The ventilation system was operating at normal capacity during the measurement period. The ventilation system was not turned off, so the measurements include background noise. The results from the measurements are given in Figure 32. The sound levels given in Table 32 is the measured equivalent levels, as they are considered the most important for stationary noise from ventilation.

Appendix I Questionnaire results

I.1 Sunnland

Sunnland did not take part in the questionnaire. See Chapter 5.3.1 for more details.

I.2 Stabbursmoen

Table 33: Result from the indoor climate problem section of the questionnaire by Stabbursmoen School. Red marks questions were the responses are higher than the reference + uncertainty. (Source: "Skoler på vent")

Questionnaire Results **Stabbursmoen** Indoor Climate	Result	Reference	Uncertainty [+/-]
2.1 Draft of cold air	11%	10%	6%
2.2 That it is too hot	23%	4%	3%
2.3 That it is too cold	9%	21%	8%
2.4 That it changes between too hot and too cold	21%	15%	6%
2.5 Poor air quality	37%	21%	8%
2.6 Dry air (itching, burning or irritation on the eyes or dry nose)	14%	15%	6%
2.7 Uncomfortable/ bad smell	12%	8%	5%
2.8 That you get electric shock when touching something	7%	6%	5%
2.9 That it is difficult to hear what is said in the classroom?	14%	17%	8%
2.10 Noise or disturbance from the students in the class	48%	10%	6%
2.11 Disturbing noise from outside (traffic / schoolyard / construction)?	20%	8%	6%
2.12 Noise from the ventilation or other things in the building?	14%	8%	6%
2.13 Dust and dirt	26%	8%	6%
2.14 Poor light from the ceiling lights	12%		
2.15 Unpleasant light from the ceiling lights	10%		
2.16 Unpleasant light from the sun	16%		

Table 34: Result from the section reported health problems of the questionnaire completed by Stabbursmoen School. Red marks questions were the responses are higher than the reference + uncertainty. (Source: "Skoler på vent")

Questionnaire Results **Stabbursmoen** Health problems	Result	Reference	Uncertainty[+/-]
3.1 Fatigue	41 %	28 %	8 %
3.2 Headache	14 %	14 %	6 %
3.3 Feeling heavy-headed	18 %	9 %	6 %
3.4 Dizziness	11 %	3 %	4 %
3.5 Concentration problems	29 %	13 %	6 %
3.6 Itching, burning or irritation in the eyes	10 %	5 %	5 %
3.7 Irritated, stuffy or runny nose	11 %	7 %	5 %
3.8 Hoarseness / dryness in the throat	7%	5 %	5 %
3.9 Coughing	13 %	3 %	4 %
3.10 Dry, red or irritated facial skin	7 %	5 %	5 %
3.11 Flaking / itching of the scalp	13 %	1 %	4 %
3.12 Dry, itchy hands (skin)	9 %	2 %	4 %

I.3 Sørborgen

The results presented in Table 35 and Table 36 are from the entire school. Of the 219 students that answered the questionnaire, the most part of them are situated in the new building that opened in 2018. The fifth, sixth and seventh grade are all located there. Only the fourth grade participated in the questionnaire and are located in the older section.

Table 35: Result from the indoor climate problem section of the questionnaire completed by Sørborgen School. Red marks questions were the responses are higher than the reference + uncertainty. (Source: "Skoler på vent")

Questionnaire Results **Sørborgen** Indoor Climate	Result	Reference	Uncertainty[+/-]
2.1 Draft of cold air	3%	10%	6%
2.2 That it is too hot	7%	3%	4%
2.3 That it is too cold	4%	21%	8%
2.4 That it changes between too hot and too cold	7%	15%	6%
2.5 Poor air quality	10%	21%	8%
2.6 Dry air (itching, burning or irritation on the eyes or dry nose)	7%	15%	6%
2.7 Uncomfortable/ bad smell	3%	8%	5%
2.8 That you get electric shock when touching something	7%	6%	5%
2.9 That it is difficult to hear what is said in the classroom?	5%	17%	8%
2.10 Noise or disturbance from the students in the class	33%	10%	6%
2.11 Disturbing noise from outside (traffic / schoolyard / construction)?	7%	8%	6%
2.12 Noise from the ventilation or other things in the building?	3%	8%	6%
2.13 Dust and dirt	4%	8%	6%
2.14 Poor light from the ceiling lights	3%		
2.15 Unpleasant light from the ceiling lights	7%		
2.16 Unpleasant light from the sun	9%		

Table 36: Result from the section reported health problems of the questionnaire completed by Sørborgen School. Red marks questions were the responses are higher than the reference + uncertainty. (Source: "Skoler på vent")

Questionnaire Results **Sørborgen** Health problems	Result	Reference	Uncertainty[+/-]
3.1 Fatigue	23 %	28 %	8 %
3.2 Headache	9 %	14 %	6 %
3.3 Feeling heavy-headed	7 %	9 %	6 %
3.4 Dizziness	6 %	3 %	4 %
3.5 Concentration problems	13 %	13 %	6 %
3.6 Itching, burning or irritation in the eyes	11 %	5 %	5 %
3.7 Irritated, stuffy or runny nose	8 %	7 %	5 %
3.8 Hoarseness / dryness in the throat	6%	5 %	5 %
3.9 Coughing	7 %	3 %	4 %
3.10 Dry, red or irritated facial skin	3 %	5 %	5 %
3.11 Flaking / itching of the scalp	5 %	1 %	4 %
3.12 Dry, itchy hands (skin)	6 %	2 %	4 %

Appendix J Calibration

Calibration of the measurement instruments used in the project ”Skoler på vent” Spring 2019

Sigbjørn Voktor Svinvik

June 2019

Table of Contents

1 Methodology

The different ELMA monitors was bought by different owners at different times. The calibration and accuracy of the devices were not adequately documented. Therefore two test measurements were performed in the Moisture Laboratory at SINTEF Byggforsk in Trondheim. All the ELMA instruments were placed in the same room with a Rotronic CP11 Handheld instrument. Both the ELMA monitors and CP11 measures carbon dioxide (CO2), temperature and relative humidity (RH). In total, thirteen ELMA indoor monitors were tested. They were named from 1 to 13. So hereafter the ELMA monitors are named as ELMA X, where x is their number. The tests were carried out from February 5. to February 8.

A second set of tests were performed in the coldroom in the basement of one of the laboratories run by the department of Energy and Process engineering at NTNU Gløshaugen. The test room is built as a fully functional walk inn refrigerator. The room is only regulated by temperature and the temperature was set to 16 °C. Three ELMA monitors and 26 iButtons were tested against each other and a more accurate Pegasor climate monitor.

1.1 Setup

1.1.1 Moisture Laboratory

The Moisture Laboratory contains two separate rooms which are accredited for measuring water vapor permeability. Both rooms are roughly 8 m^2. The two rooms have separate climate control units that keep a constant temperature and relative humidity when in use. During this test only one of the rooms was in active use with ongoing measurements. This room is designated Room 1. The other room with the turned off climate control is hereafter called Room 2.

Both the ventilation systems for Room 1 and Room 2 extracted air from the same anteroom. The exhaust air from the rooms were dumped in the same room as the air intake was located. The exhaust air vent and fresh air intake was right next to each other. The Anteroom is ventilated by the central ventilation system in the building. The doors from the lobby into Room 1 and Room 2 were not air tight. There were some air exchange even with closed doors.

In both rooms all the measuring instruments were placed over two shelves. The two highest shelves were used in both Room 1 and Room 2. The shelves were metal and allowed continuously air flow in between the shelves themselves. The instruments were placed closely towards the sensors that the climate control system used to regulate the room. These sensors registered the temperature and relative humidity and could be read off outside the doors of both Room 1 and Room 2. There were two sensors that registered both temperature and relative humidity for each room. These four permanent sensors were last calibrated in June 2018.

All the ELMA monitors and the CP11 were programmed using the same computer. Their clock was synchronized with the computer. All the devices were programmed to log with a measuring period of 120 seconds. The measurement series were started manually when placed inside the test room. The assigned measuring period can result in 60 seconds difference between the recorded values. An assumption that the near stable conditions within the test rooms kept the resulting inaccuracies from the different sampling times negligible.

The Rotronic CP11 handheld instrument has a higher accuracy level than the ELMA DT-802D. The technical specifications for the CP11 and ELMA DT-802D is given in Table 1 and 2 respectively. To control the ELMA instruments, the measurements from Room 1 and Room 2 were compared to the measured data from the CP11 during the same time. The reference was the CP11 in Room 1 and Room 2.

$\text{Difference}_t = Referance_t - Measured\ value_t (1)$

Room 1 was set to 23°C and 50% relative humidity. During the first 90 minutes of the test series in Room 1 values from the fixed sensors were registered by hand. Readings between 22.9-23.3°C and 47.2-50.5% RH were observed. The readings were done roughly every fifth minute while a person remained in the anteroom. The test in Room 1 started roughly 12:00 PM on the 5. February and ended at 10:30 AM the day after. Figure 1 shows the setup of all the instruments in both Room 1 and Room 2.

In Room 2 the relative humidity was registered at 24.2 and 22.5 % RH at the beginning of the measurement period by the fixed sensors. The temperature was read of as 23.6°C on both instruments. These readings were after a grown man had been in Room 2 with a closed door for around 20 minutes. During this period the instruments were rigged up with power supplies and prepared to begin a new measurement series. The door was closed to increase the CO_2 levels in the room. This would increase the CO_2 range tested in the laboratory. Since the room was not air tight the CO_2 levels could not increase to harmful concentrations within the short time period. There were no other direct CO_2 sources in the rooms besides the occasional laboratory personnel. When taking down the instruments after the second test period, the fixed sensors registered 22.5% RH and 21% RH and 20.1°and 20.0°C. The second test period started at 01:00 PM on February 6. and ended at 00:40 AM on February 8. The CP11 was battery powered and ran out of power during the morning of 8. February. To ensure that no measurements were compromised by an ill-powered device, the defined test period was defined to end at 00:40 AM. The measurement session was originally not stopped until the following morning. The decision to exclude the last eight hours was done in the analyses of the data. The CP11 showed a clear constant negative trend in accuracy for the CO_2 measurements in the final hours. No similar result was observed in the data from the ELMA monitors.

Figure 1: The picture to the left shows the setup for Room 2. The two black rods are the permanent room sensors. The top right picture shows the setup in Room 1. The bottom right picture illustrates the two permanent sensors in Room 1.

1.2 Coldroom

The ELMA 10 and all the iButtons used were placed inside a small cardboard box and left in a coldroom at the laboratory at EPT from Friday afternoon on the 15. March and over the weekend to Monday morning. The test room was to well insulated so the temperature did not reach upwards of 16 degrees during the weekend. The experiment was therefore repeated in the following week under more constant conditions. During the second experiment a Pegasor indoor climate monitor was also placed inside the coldroom. It was placed side-by-side of the other instruments. Figure 2 shows the setup for both the first and second test series.

Figure 2: The leftmost picture shows the setup during the first session in the coldroom. The rightmost picture shows the cardbox seen in the leftmost picture. In the middle picture the setup for the second test session in the coldroom is shown. The large device seen is the Pegasor monitor.

Lastly all the iButtons were placed inside a students locker in a study room with the ELMA 10 monitor. The goal of this test was to find any significant changes in the iButtons at a higher temperature. Figure 3 shows the setup in the study room. The second locker from the floor furthers to the right was the one used. The ELMA 10 monitor is clearly visible in the picture to the left in Figure 3. The iButtons are more hidden, but are seen in the plastic bag just behind the ELMA 10.

Figure 3: The picture to the left shows the iButtons and ELMA 10 inside the locker. As seen they were placed on top of a thick book that insulated them from the metal. The locker was closed and locked as seen in the picture to the right.

1.3 Instruments

In the following subsection the instrument used will be presented. The technical data for the ELMA DT-802D, Rotronic CP11, iButtons and Pegasor indoor monitor are given in respective Table 1, 2, 3 and 4. The ELMA monitors have a a significantly lower CO_2 concentration accuracy compared to the CP11 and Pegasor.

There was a total of thirteen ELMA DT-802D monitors at the beginning of the project. Four monitors was owned by NTNU, one by SINTEF Byggforsk and the last eight came from Trondheim Kommune Eiendom.

With the CP11 CO_2 measurements it is given from the manufacturer that the device has a null drift of less than 10 ppm per year. The Rotronic instrument

ELMA DT-802D	Range	Accuracy	Resolution
Temperature	-5°C...50°C	$\pm 1°C$	0.1°C
Relative humidity	$\leq$ 90%	±5%	0.1%
CO_2	0...9999 ppm	± 100 ppm ±5% rdg @ 300...9000 ppm	1 ppm

Table 1: Technical specifications for the ELMA DT-802D [2].

Rotronic CP11 - Handheld	Range	Accuracy at 23±5°C	Resolution
Temperature	-20°C...60°C	$\pm 0.3°C@5 \sim 40°C$	0.1°C
Relative humidity	0.1% ... 99.95% RH	$\pm 3\% RH(10 \sim 95\%$ RH)	0.1%
CO_2	0...5000 ppm	± 30 ppm +5% rdg	1 ppm

Table 2: Technical specifications for the CP11 Handheld instrument [1].

used in this project was not calibrated. It was reasonable recently acquired by SINTEF Byggforsk and therefore assumed to be within the given technical properties given in Table 2.

iButton - DS1922L	Range	Accuracy from -10 to 65°C	Resolution
Temperature	-40°C...85°C	$\pm 0.5°C$	0.5°C

Table 3: Technical specifications for the iButtons DS1922L [3].

The iButton DS1922L has two different resolutions one can log data with. It can be stored as a 8-Bit or 11-Bit. The resolution differs from 0.5°with the 8-Bit to 0.0625°C with the 11-Bit. The 8-Bit option takes less data and results in a higher maximum sample amount. It is the 8-Bit conflagration that is given in Table 3.

Pegasor AQ Monitor	Range	Accuracy	Resolution
Temperature	-40°C...+80°C	$\pm 0.2°C$	0.1°C
Relative humidity	0... 90% RH	±3% RH	0.1% RH
	90... 100% RH	±4% RH	0.1% RH
CO_2	0...5000 ppm	± 30 ppm + 2% of reading between +20°C and 30°C	1 ppm

Table 4: Technical specifications for the Pegasor [4].

The Pegasor monitor can also measure particle matter, but this function was not needed.

2 Calibration results

2.1 ELMA 1

2.1.1 CO_2

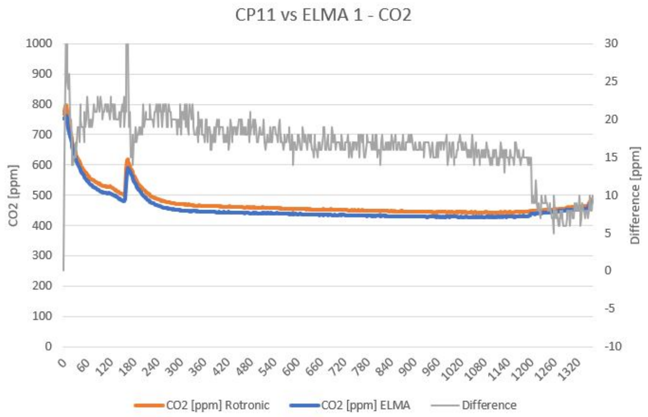

Figure 4: Comparing ELMA 1 vs. the CP11 Handheld device in the moisture laboratory Room 1.

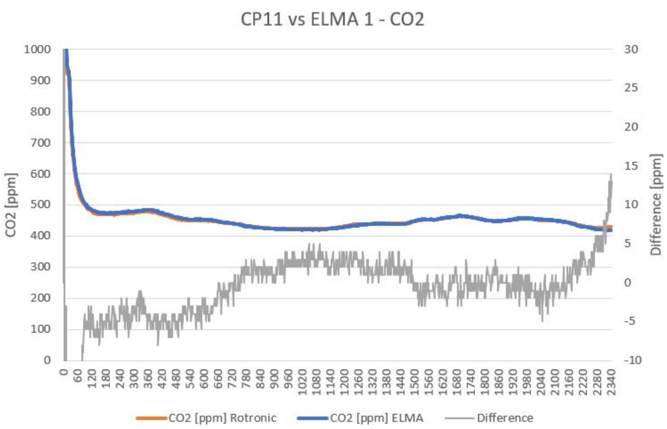

Figure 5: Comparing ELMA 1 vs. the CP11 Handheld device in the moisture laboratory Room 2.

2.1.2 Temperature

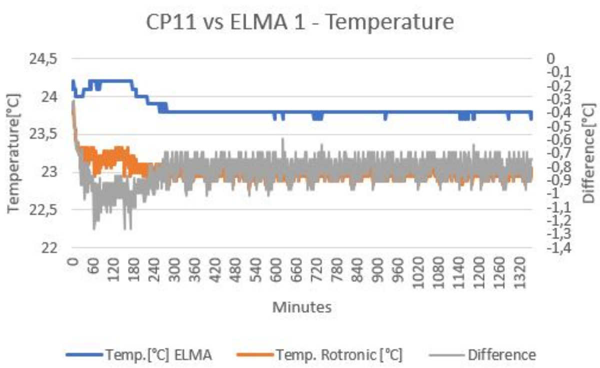

Figure 6: Comparing ELMA 1 vs. the CP11 Handheld device in the moisture laboratory Room 1.

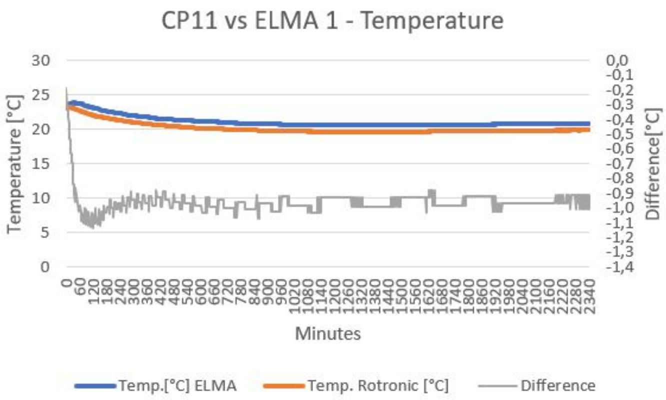

Figure 7: Comparing ELMA 1 vs. the CP11 Handheld device in the moisture laboratory Room 2.

2.1.3 Relative humidity

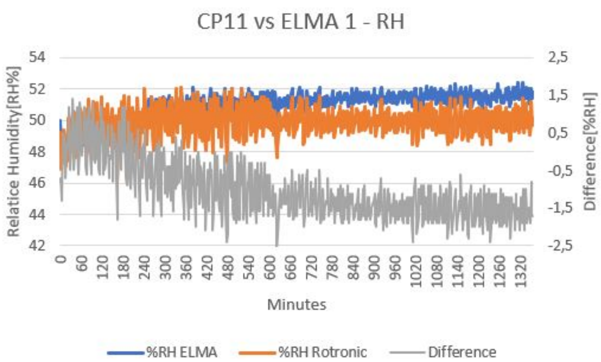

Figure 8: Comparing ELMA 1 vs. the CP11 Handheld device in the moisture laboratory Room 1.

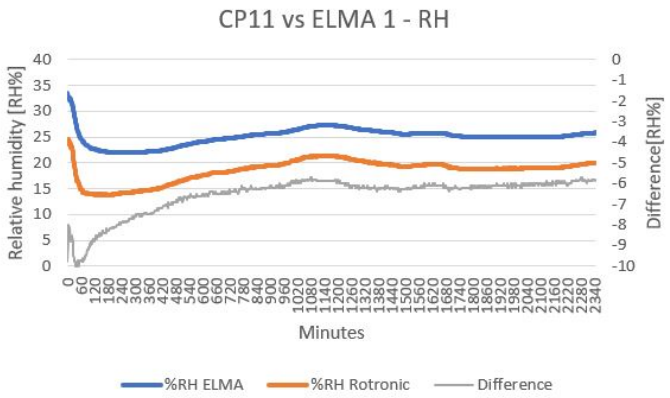

Figure 9: Comparing ELMA 1 vs. the CP11 Handheld device in the moisture laboratory Room 2.

2.2 ELMA 2

2.2.1 CO_2

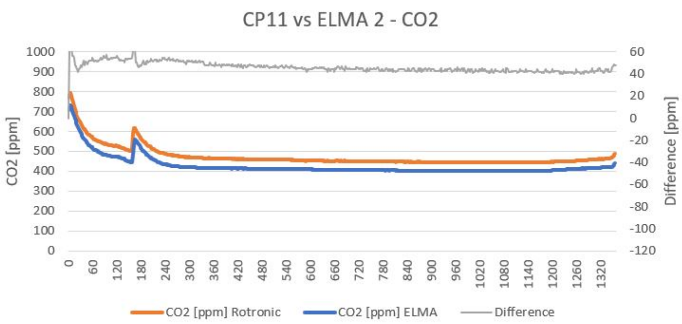

Figure 10: Comparing ELMA 2 vs. the CP11 Handheld device in the moisture laboratory Room 1.

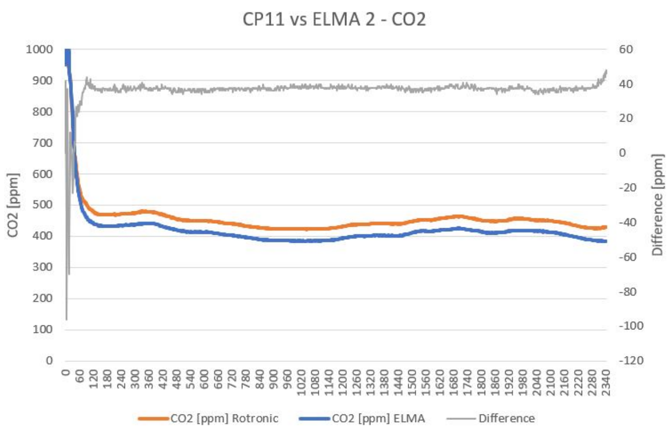

Figure 11: Comparing ELMA 2 vs. the CP11 Handheld device in the moisture laboratory Room 2.

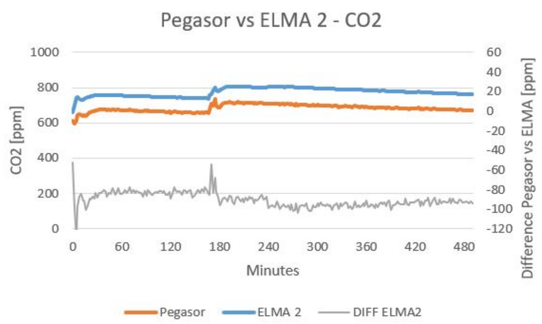

Figure 12: Comparing ELMA 2 vs. the Pegasor device in the coldroom.

2.2.2 Temperature

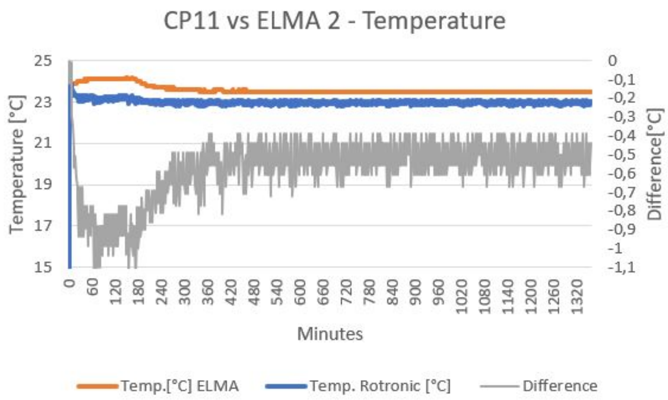

Figure 13: Comparing ELMA 2 vs. the CP11 Handheld device in the moisture laboratory Room 1.

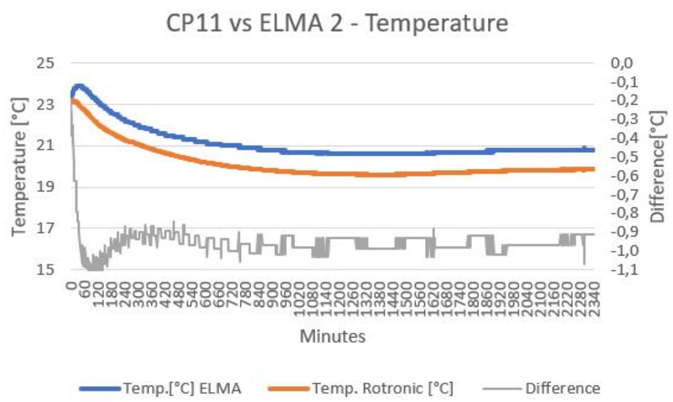

Figure 14: Comparing ELMA 2 vs. the CP11 Handheld device in the moisture laboratory Room 2.

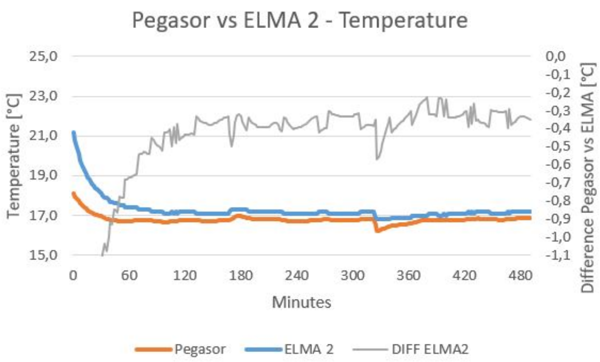

Figure 15: Comparing ELMA 2 vs. the Pegasor device in the Coldroom.

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2.2.3 Relative humidity

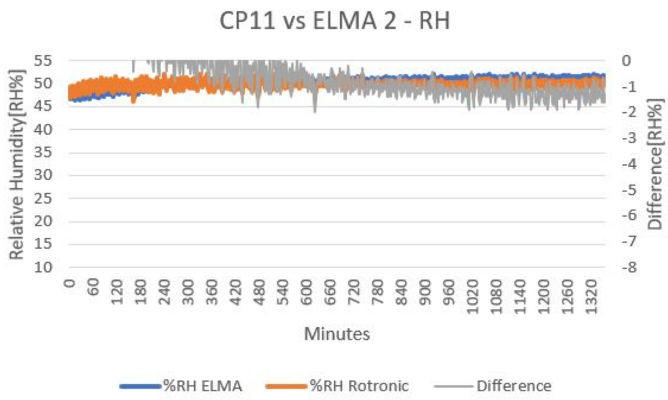

Figure 16: Comparing ELMA 2 vs. the CP11 Handheld device in the moisture laboratory Room 1.

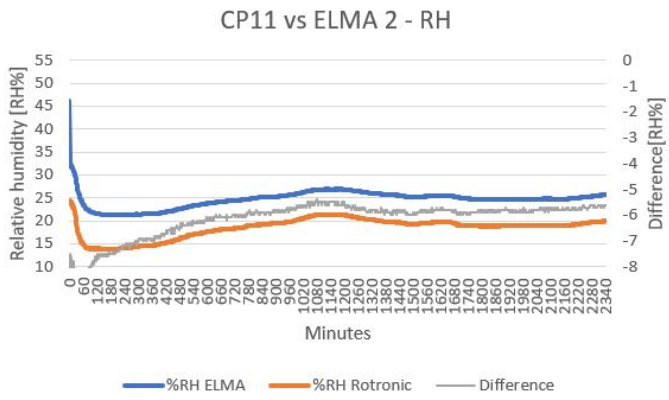

Figure 17: Comparing ELMA 2 vs. the CP11 Handheld device in the moisture laboratory Room 2.

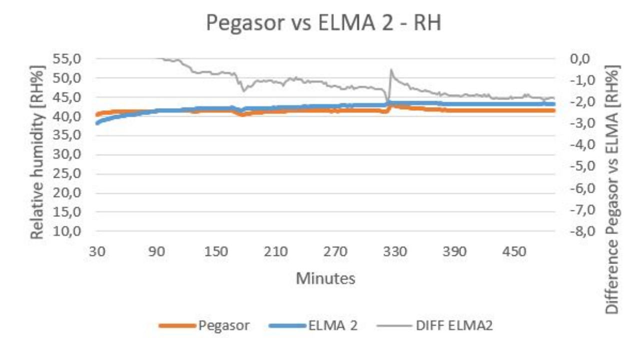

Figure 18: Comparing ELMA 2 vs. the Pegasor device in the Coldroom.

2.3 ELMA 3

2.3.1 CO_2

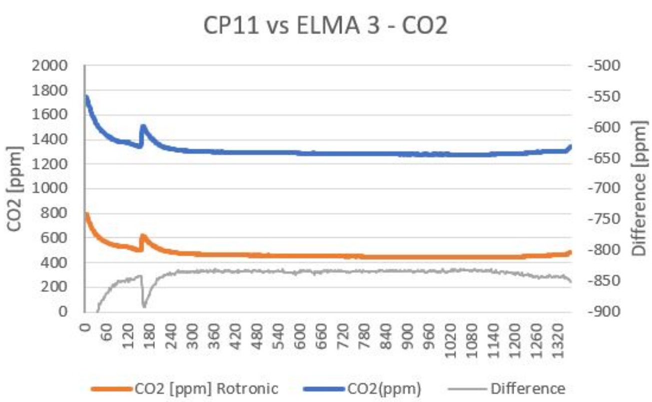

Figure 19: Comparing ELMA 3 vs. the CP11 Handheld device in the moisture laboratory Room 1.

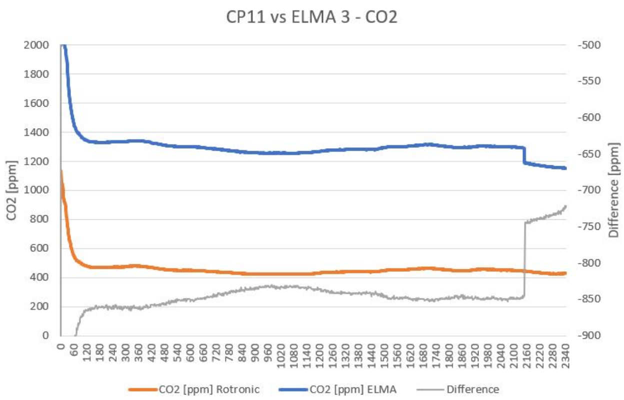

Figure 20: Comparing ELMA 3 vs. the CP11 Handheld device in the moisture laboratory Room 2.

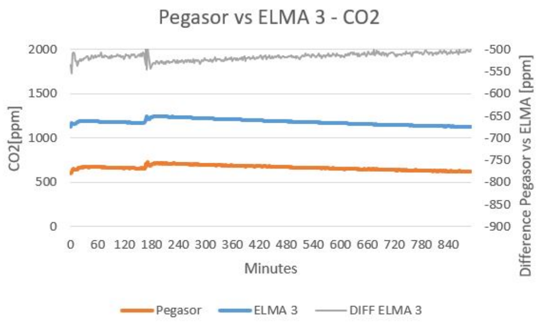

Figure 21: Comparing ELMA 3 vs. the Pegasor device in the moisture laboratory Room 2.

2.3.2 Temperature

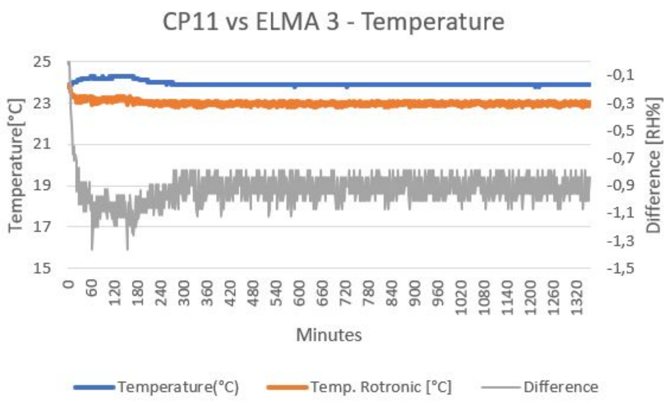

Figure 22: Comparing ELMA 3 vs. the CP11 Handheld device in the moisture laboratory Room 1.

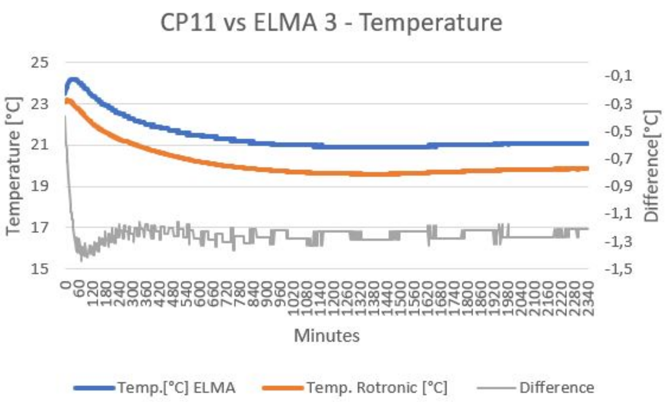

Figure 23: Comparing ELMA 3 vs. the CP11 Handheld device in the moisture laboratory Room 2.

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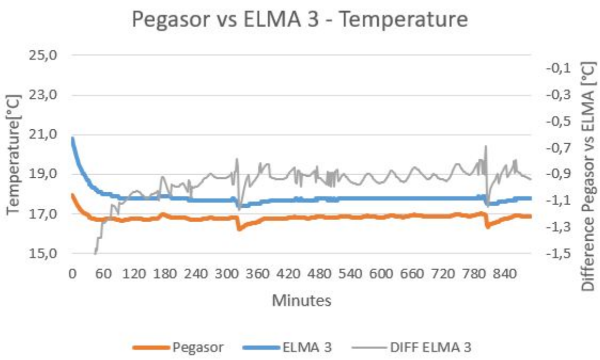

Figure 24: Comparing ELMA 3 vs. the Pegasor device in the moisture laboratory Room 2.

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2.3.3 Relative humidity

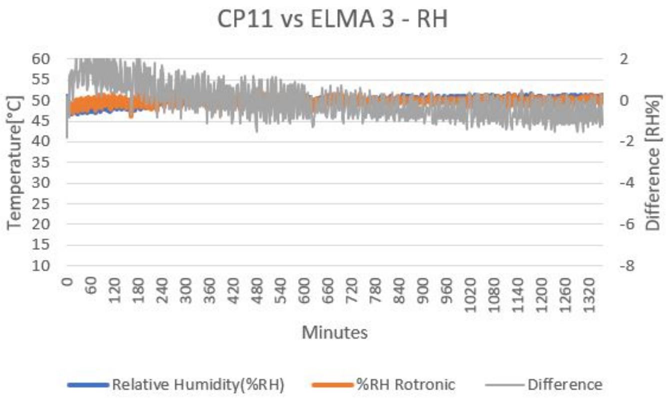

Figure 25: Comparing ELMA 3 vs. the CP11 Handheld device in the moisture laboratory Room 1.

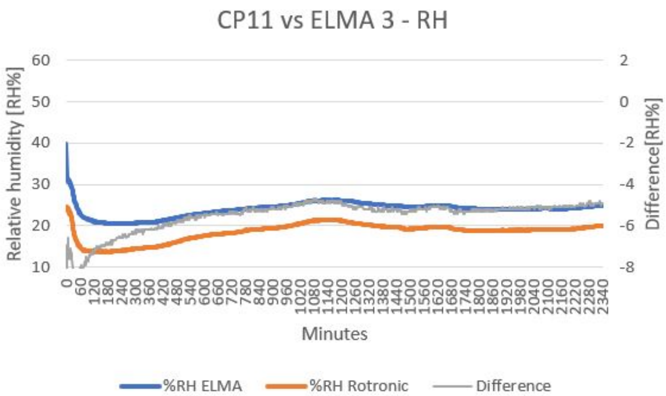

Figure 26: Comparing ELMA 3 vs. the CP11 Handheld device in the moisture laboratory Room 2.

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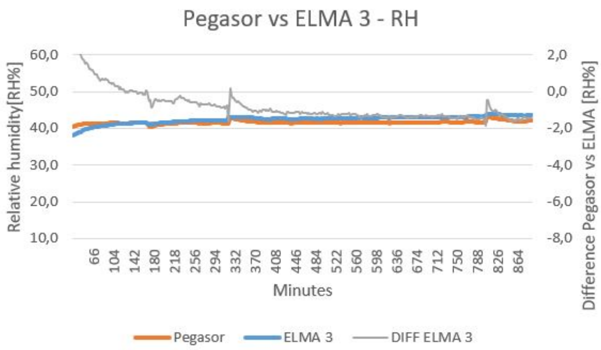

Figure 27: Comparing ELMA 3 vs. the Pegasor device in the moisture laboratory Room 2.

2.4 ELMA 4

2.4.1 CO_2

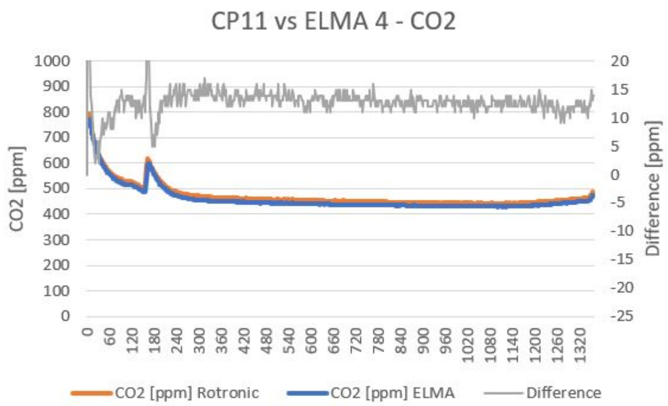

Figure 28: Comparing ELMA 4 vs. the CP11 Handheld device in the moisture laboratory Room 1.

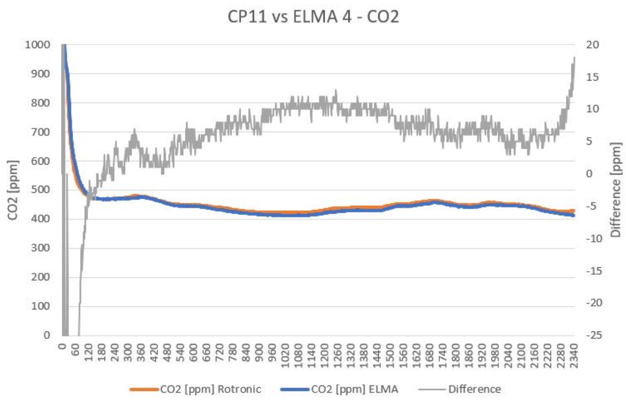

Figure 29: Comparing ELMA 4 vs. the CP11 Handheld device in the moisture laboratory Room 2.

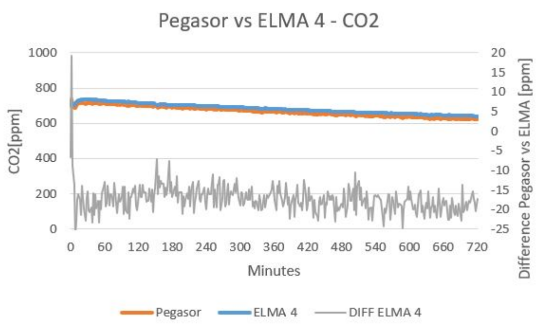

Figure 30: Comparing ELMA 4 vs. the Pegasor device in the moisture laboratory Room 2.

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2.4.2 Temperature

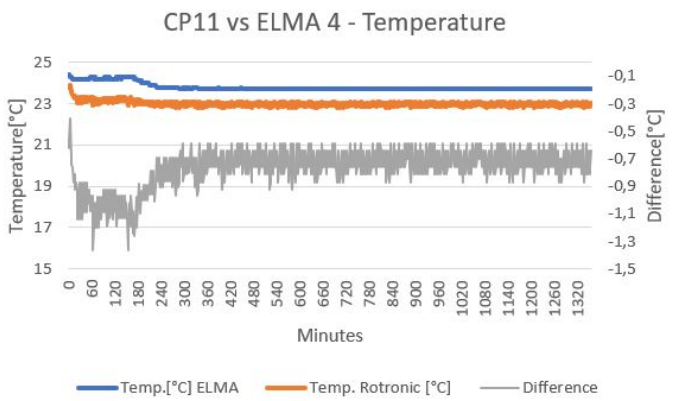

Figure 31: Comparing ELMA 4 vs. the CP11 Handheld device in the moisture laboratory Room 1.

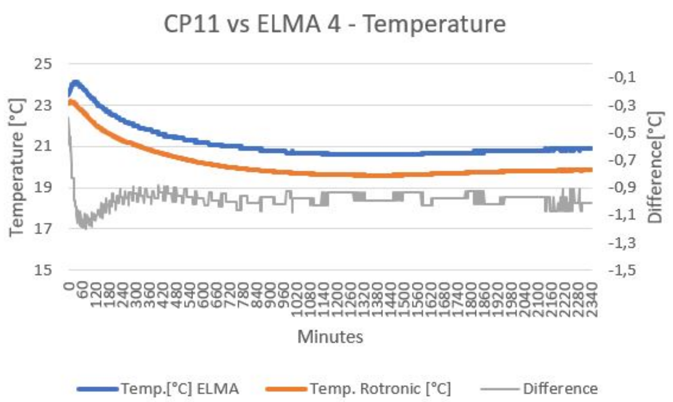

Figure 32: Comparing ELMA 4 vs. the CP11 Handheld device in the moisture laboratory Room 2.

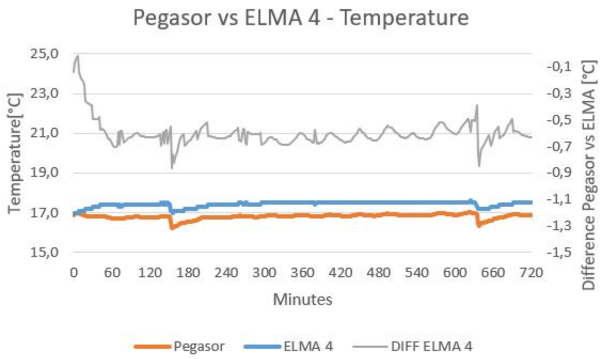

Figure 33: Comparing ELMA 4 vs. the Pegasor device in the moisture laboratory Room 2.

2.4.3 Relative humidity

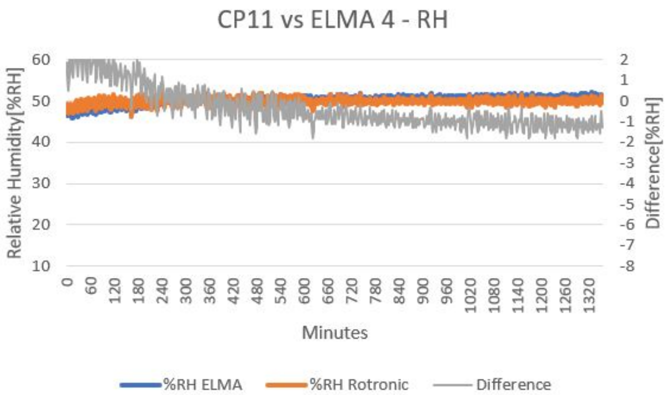

Figure 34: Comparing ELMA 4 vs. the CP11 Handheld device in the moisture laboratory Room 1.

25

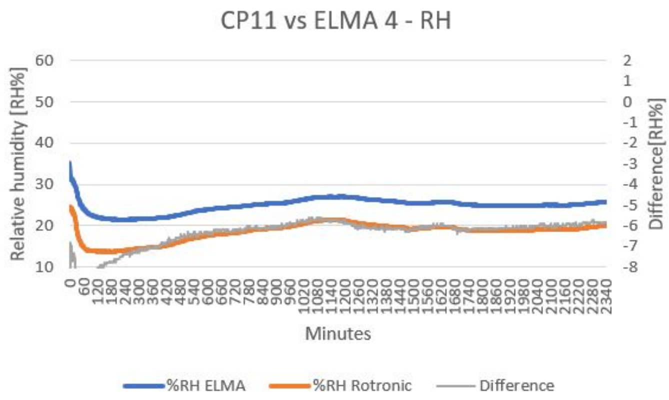

Figure 35: Comparing ELMA 4 vs. the CP11 Handheld device in the moisture laboratory Room 2.

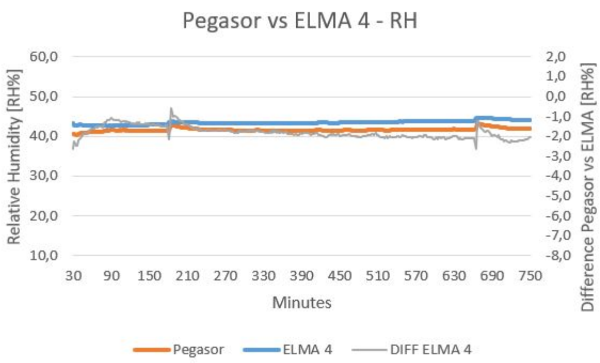

Figure 36: Comparing ELMA 4 vs. the Pegasor device in the moisture laboratory Room 2.

2.5 ELMA 5

2.5.1 CO_2

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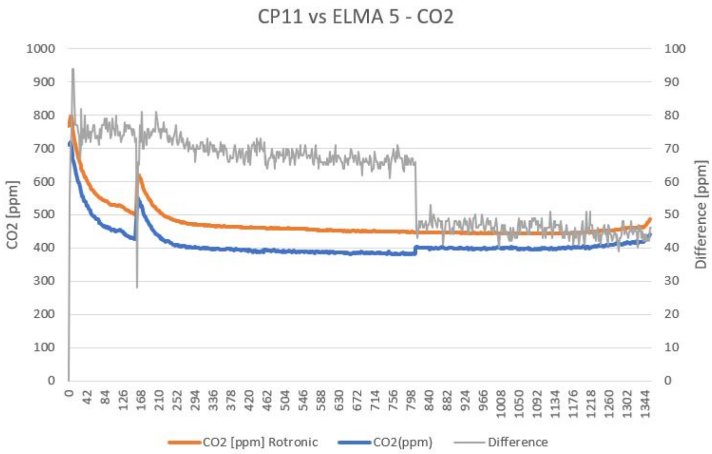

Figure 37: Comparing ELMA 5 vs. the CP11 Handheld device in the moisture laboratory Room 1.

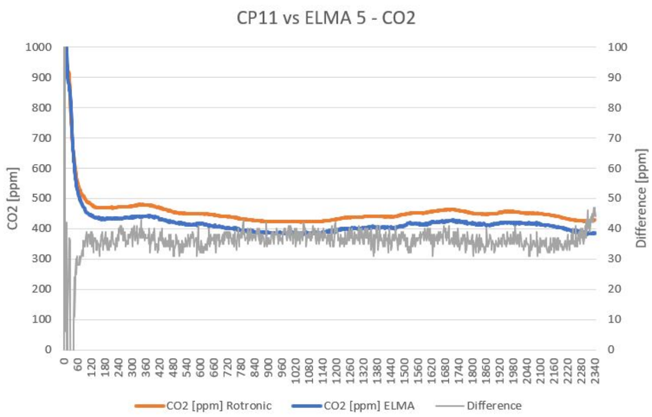

Figure 38: Comparing ELMA 5 vs. the CP11 Handheld device in the moisture laboratory Room 2.

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2.5.2 Temperature

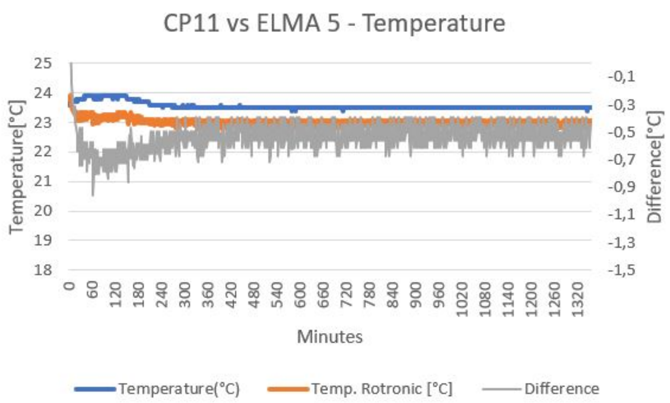

Figure 39: Comparing ELMA 5 vs. the CP11 Handheld device in the moisture laboratory Room 1.

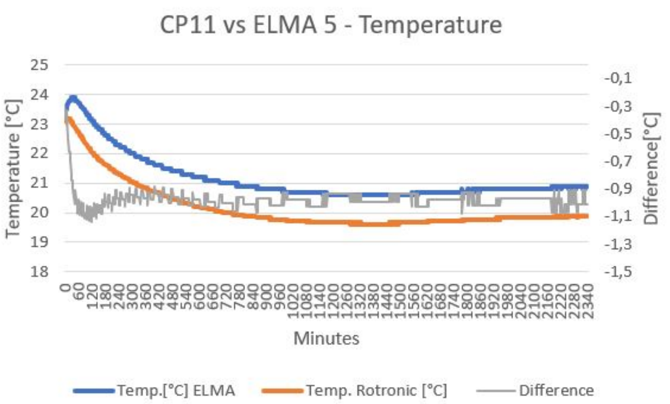

Figure 40: Comparing ELMA 5 vs. the CP11 Handheld device in the moisture laboratory Room 2.

2.5.3 Relative humidity

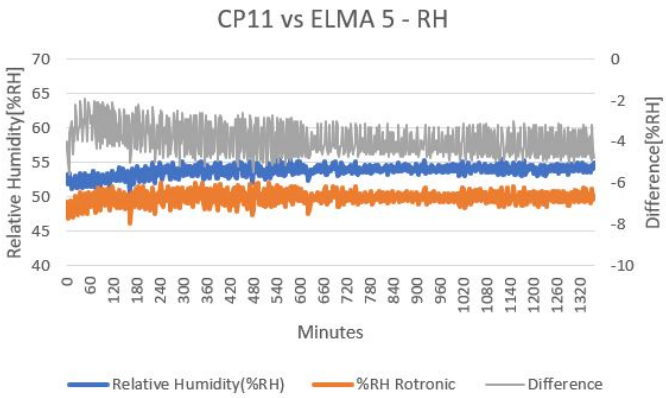

Figure 41: Comparing ELMA 5 vs. the CP11 Handheld device in the moisture laboratory Room 1.

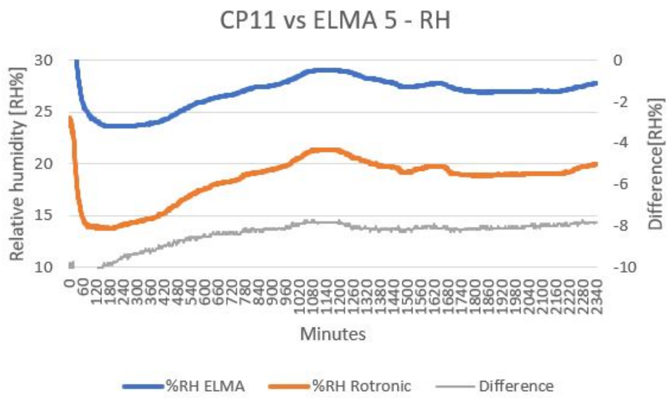

Figure 42: Comparing ELMA 5 vs. the CP11 Handheld device in the moisture laboratory Room 2.

29

2.6 ELMA 6

2.6.1 CO_2

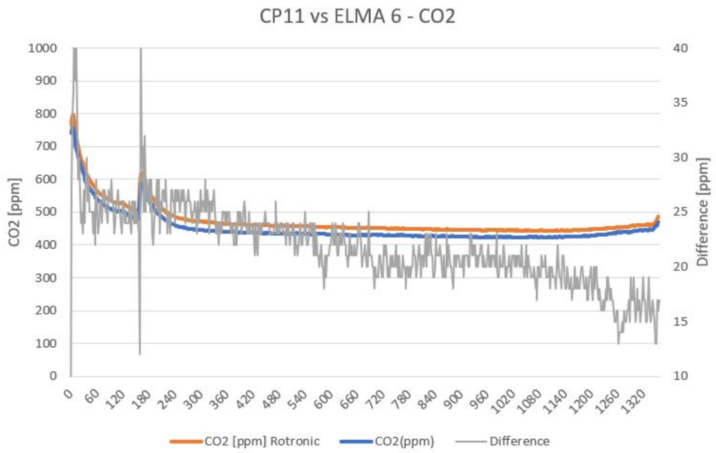

Figure 43: Comparing ELMA 6 vs. the CP11 Handheld device in the moisture laboratory Room 1.

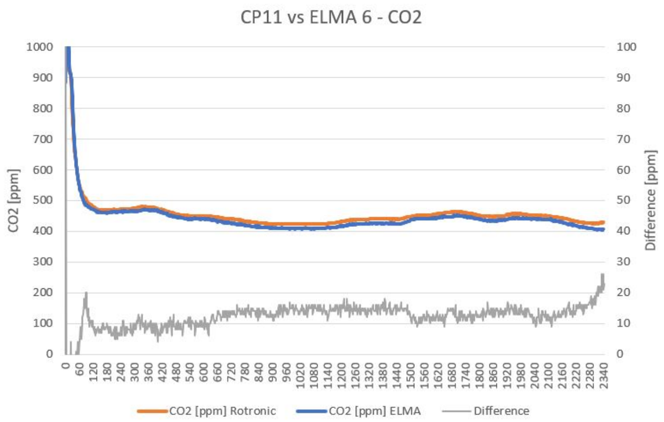

Figure 44: Comparing ELMA 6 vs. the CP11 Handheld device in the moisture laboratory Room 2.

2.6.2 Temperature

31

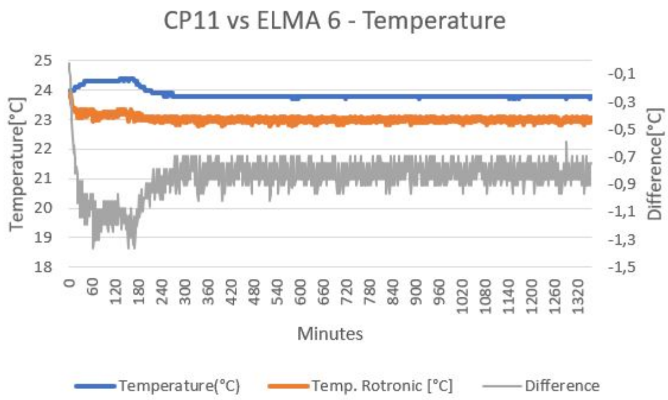

Figure 45: Comparing ELMA 6 vs. the CP11 Handheld device in the moisture laboratory Room 1.

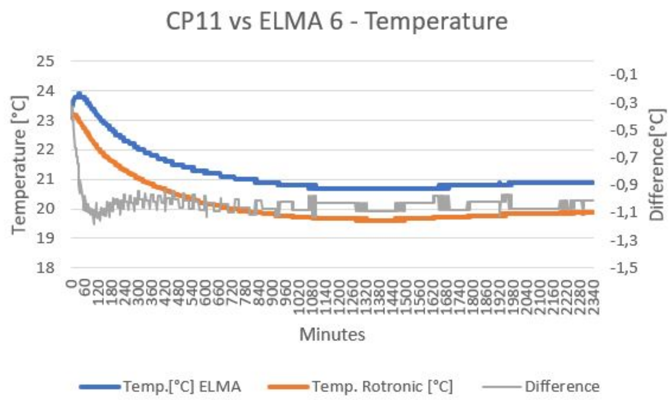

Figure 46: Comparing ELMA 6 vs. the CP11 Handheld device in the moisture laboratory Room 2.

2.6.3 Relative humidity

32

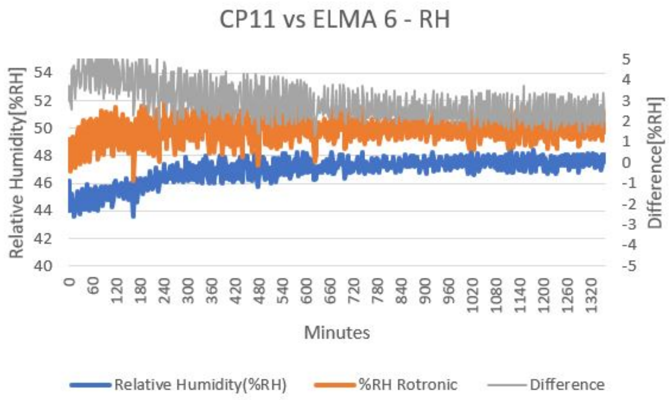

Figure 47: Comparing ELMA 6 vs. the CP11 Handheld device in the moisture laboratory Room 1.

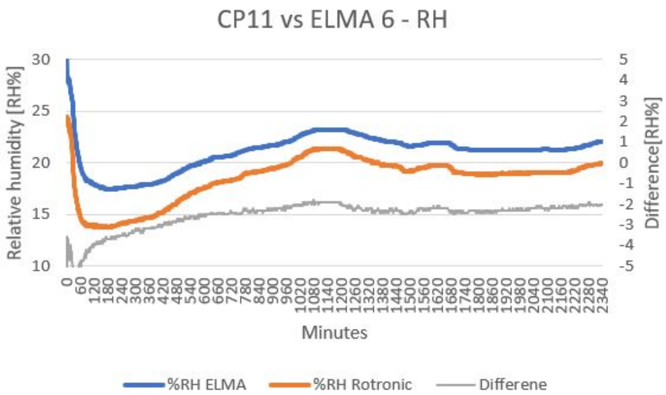

Figure 48: Comparing ELMA 6 vs. the CP11 Handheld device in the moisture laboratory Room 2.

2.7 ELMA 7

2.7.1 CO_2

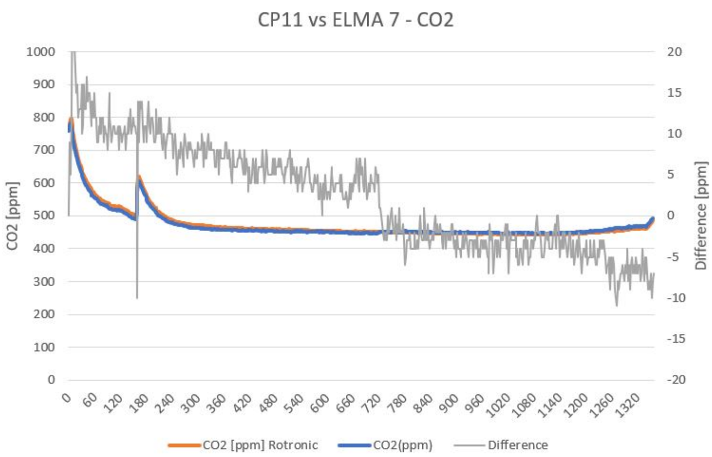

Figure 49: Comparing ELMA 7 vs. the CP11 Handheld device in the moisture laboratory Room 1.

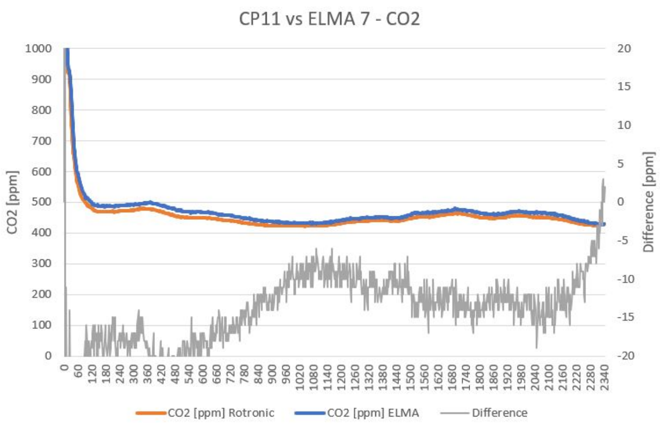

Figure 50: Comparing ELMA 7 vs. the CP11 Handheld device in the moisture laboratory Room 2.

34

2.7.2 Temperature

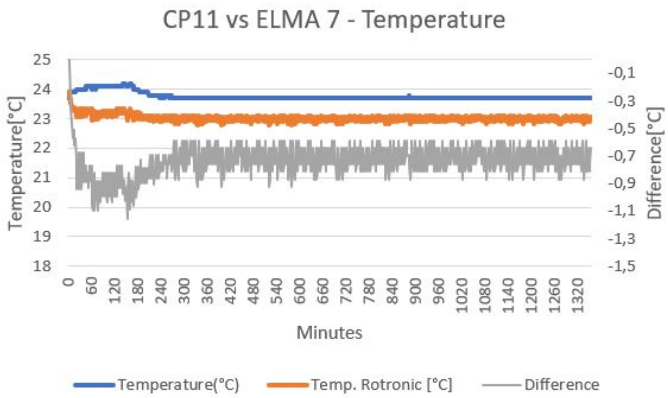

Figure 51: Comparing ELMA 7 vs. the CP11 Handheld device in the moisture laboratory Room 1.

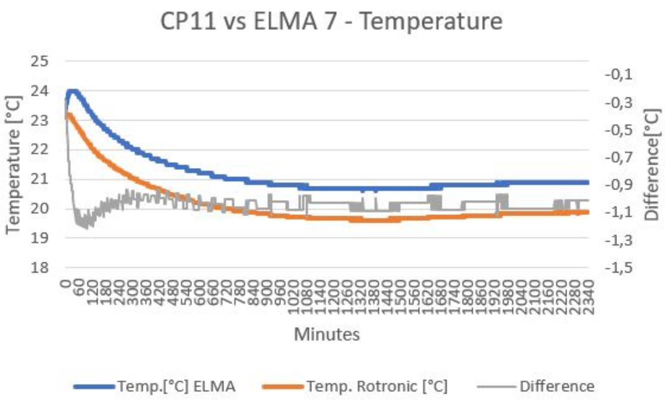

Figure 52: Comparing ELMA 7 vs. the CP11 Handheld device in the moisture laboratory Room 2.

2.7.3 Relative humidity

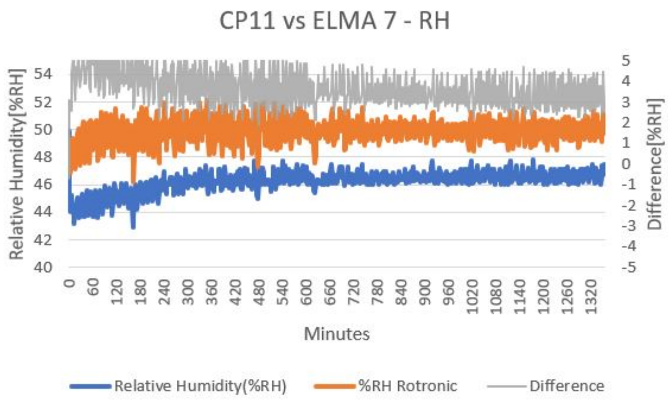

Figure 53: Comparing ELMA 7 vs. the CP11 Handheld device in the moisture laboratory Room 1.

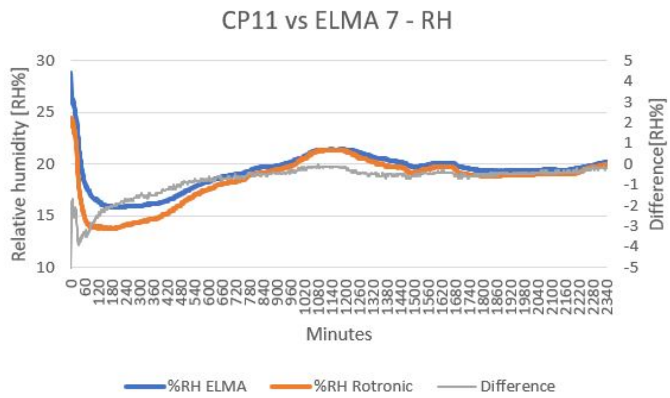

Figure 54: Comparing ELMA 7 vs. the CP11 Handheld device in the moisture laboratory Room 2.

36

2.8 ELMA 8

The ELMA 8 indoor climate monitor did not work, therefore no data is included. See subsection 3.1.2 for further explanation.

2.9 ELMA 9

2.9.1 CO_2

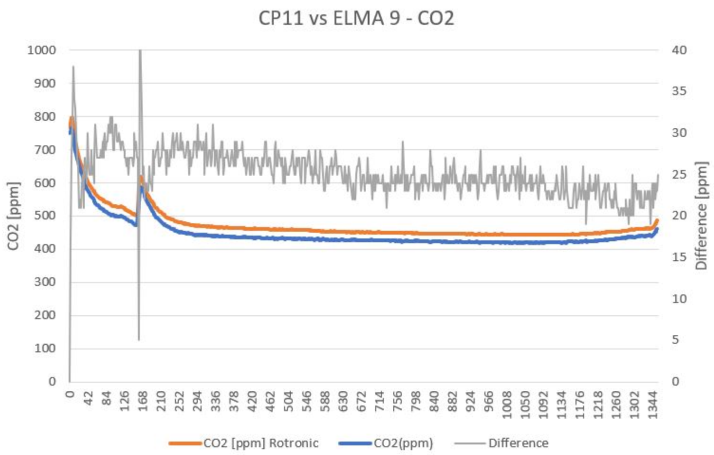

Figure 55: Comparing ELMA 9 vs. the CP11 Handheld device in the moisture laboratory Room 1.

37

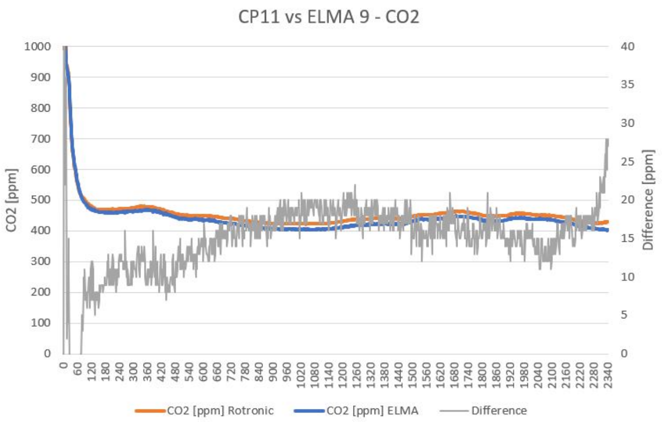

Figure 56: Comparing ELMA 9 vs. the CP11 Handheld device in the moisture laboratory Room 2.

2.9.2 Temperature

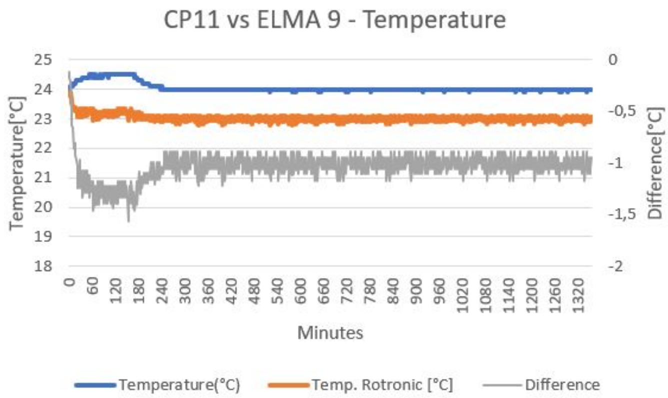

Figure 57: Comparing ELMA 9 vs. the CP11 Handheld device in the moisture laboratory Room 1.

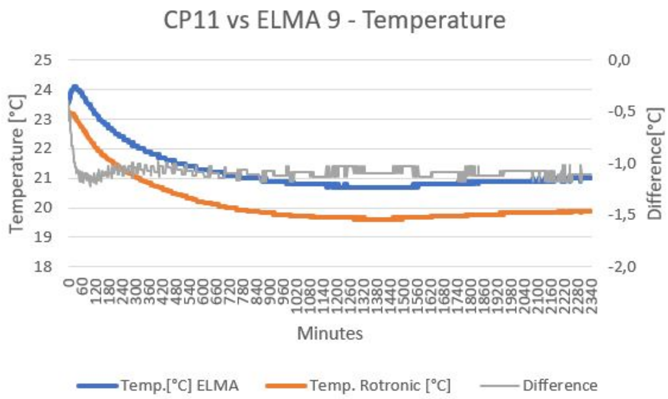

Figure 58: Comparing ELMA 9 vs. the CP11 Handheld device in the moisture laboratory Room 2.

2.9.3 Relative humidity

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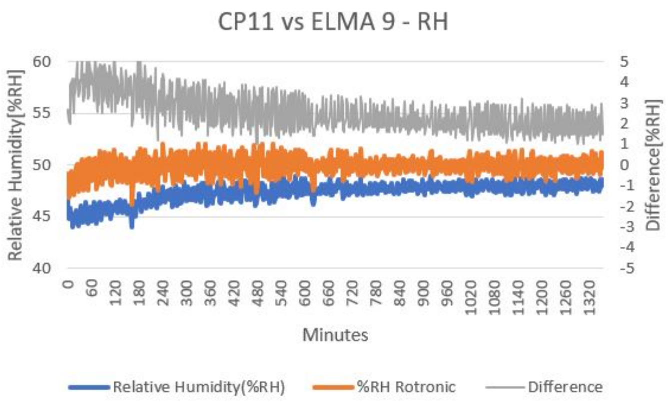

Figure 59: Comparing ELMA 9 vs. the CP11 Handheld device in the moisture laboratory Room 1.

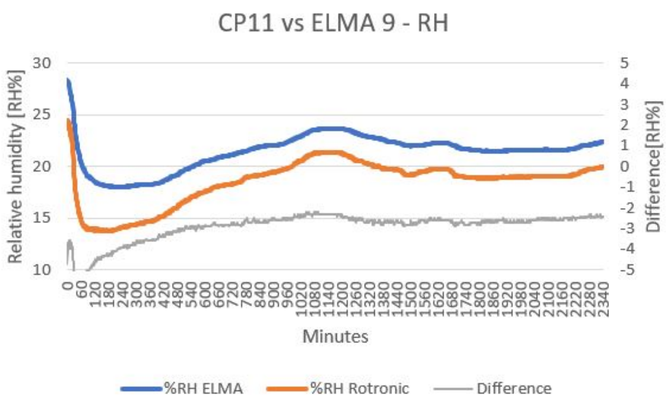

Figure 60: Comparing ELMA 9 vs. the CP11 Handheld device in the moisture laboratory Room 2.

2.10 ELMA 10

2.10.1 CO_2

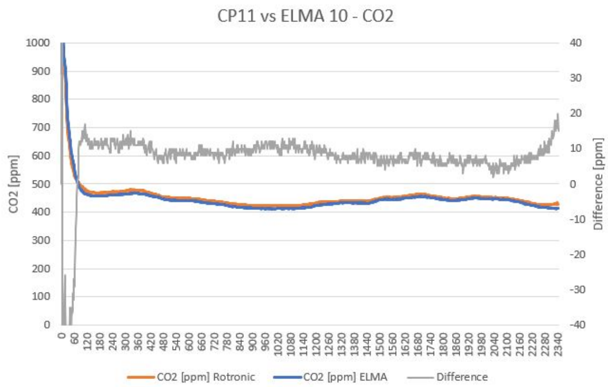

Figure 61: Comparing ELMA 10 vs. the CP11 Handheld device in the moisture laboratory Room 2.

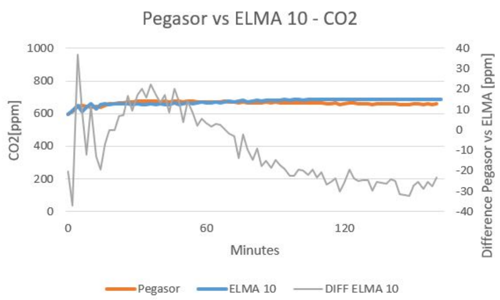

Figure 62: Comparing ELMA 10 vs. the Pegasor device in the moisture laboratory Room 2.

2.10.2 Temperature

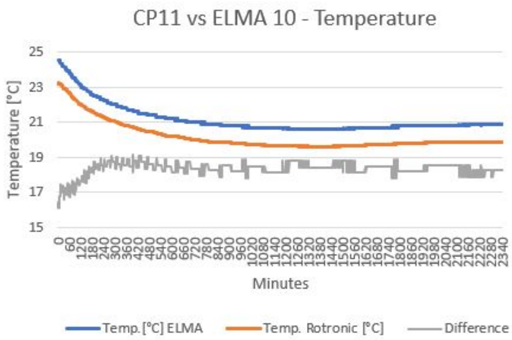

Figure 63: Comparing ELMA 10 vs. the CP11 Handheld device in the moisture laboratory Room 2.

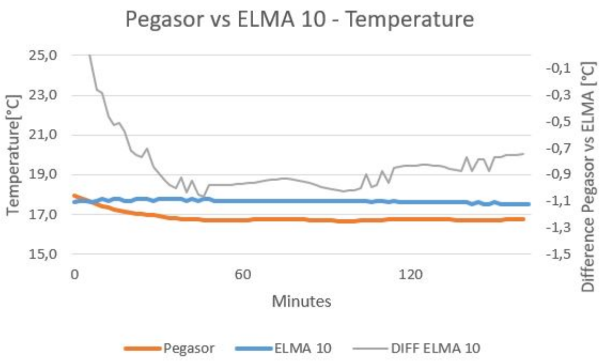

Figure 64: Comparing ELMA 10 vs. the Pegasor device in the moisture laboratory Room 2.

2.10.3 Relative humidity

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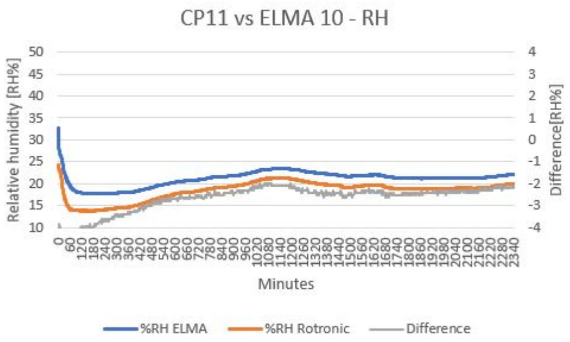

Figure 65: Comparing ELMA 10 vs. the CP11 Handheld device in the moisture laboratory Room 2.

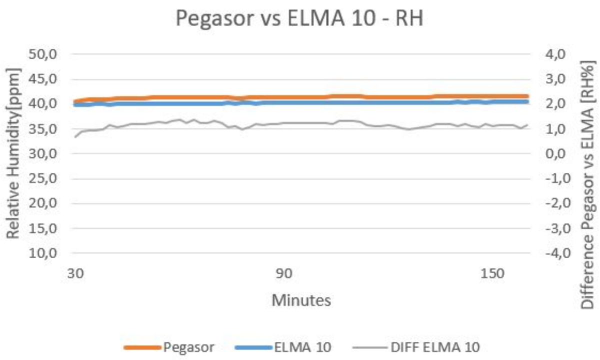

Figure 66: Comparing ELMA 10 vs. the Pegasor device in the moisture laboratory Room 2.

2.11 ELMA 11

2.11.1 CO_2

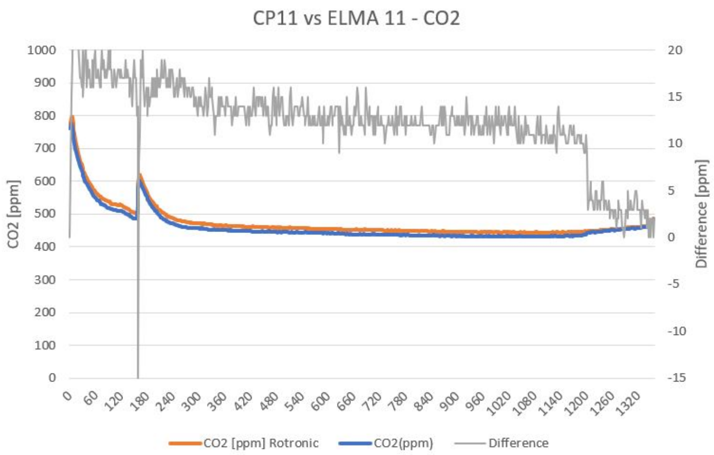

Figure 67: Comparing ELMA 11 vs. the CP11 Handheld device in the moisture laboratory Room 1.

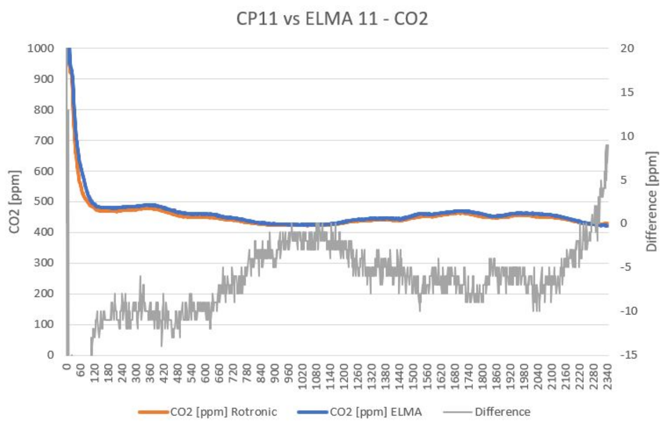

Figure 68: Comparing ELMA 11 vs. the CP11 Handheld device in the moisture laboratory Room 2.

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2.11.2 Temperature

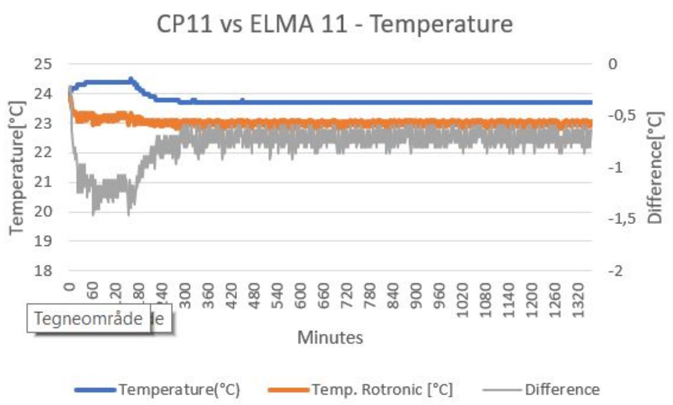

Figure 69: Comparing ELMA 11 vs. the CP11 Handheld device in the moisture laboratory Room 1.

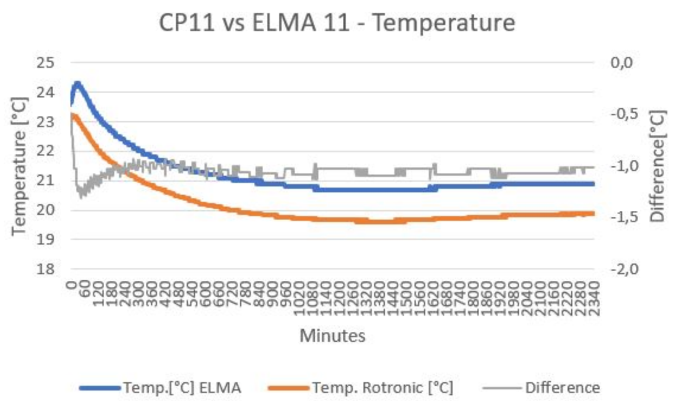

Figure 70: Comparing ELMA 11 vs. the CP11 Handheld device in the moisture laboratory Room 2.

2.11.3 Relative humidity

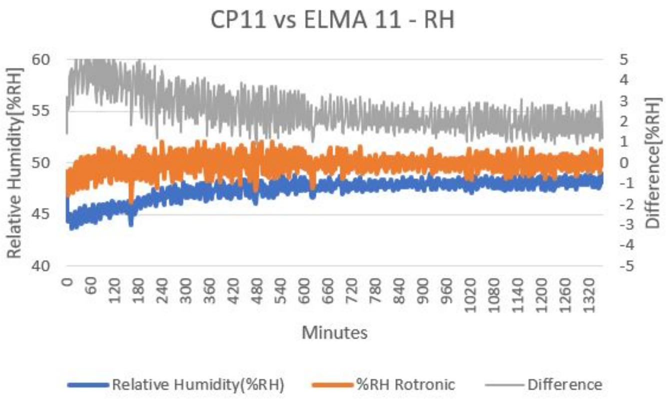

Figure 71: Comparing ELMA 11 vs. the CP11 Handheld device in the moisture laboratory Room 1.

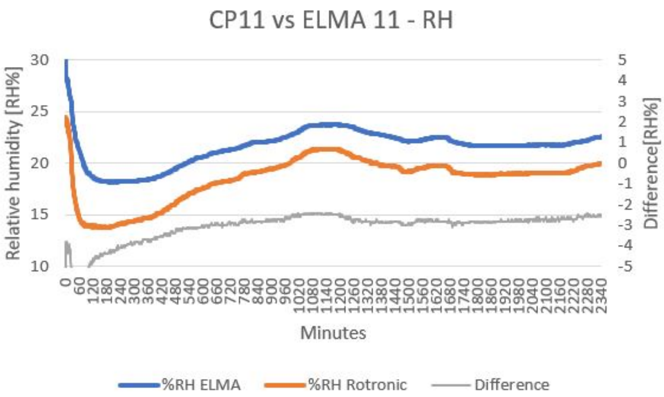

Figure 72: Comparing ELMA 11 vs. the CP11 Handheld device in the moisture laboratory Room 2.

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2.12 ELMA 12

2.12.1 CO_2

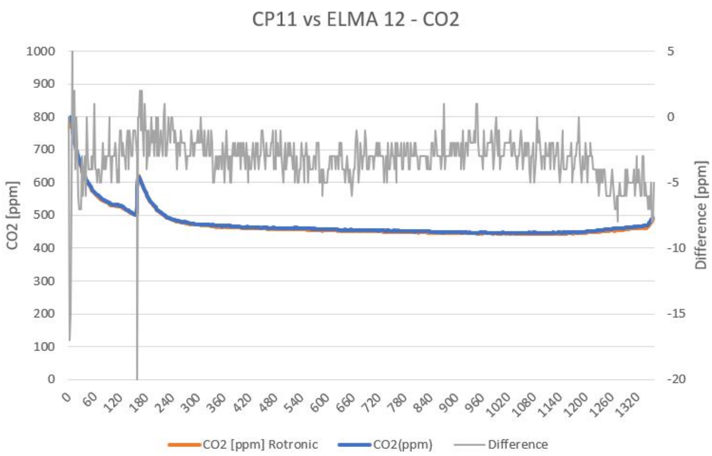

Figure 73: Comparing ELMA 12 vs. the CP11 Handheld device in the moisture laboratory Room 1.

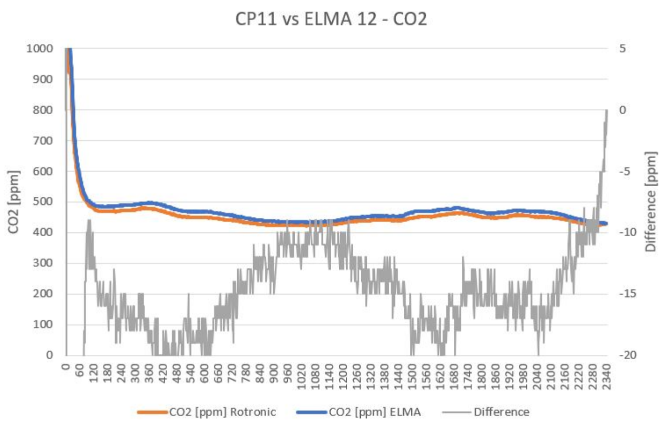

Figure 74: Comparing ELMA 12 vs. the CP11 Handheld device in the moisture laboratory Room 2.

2.12.2 Temperature

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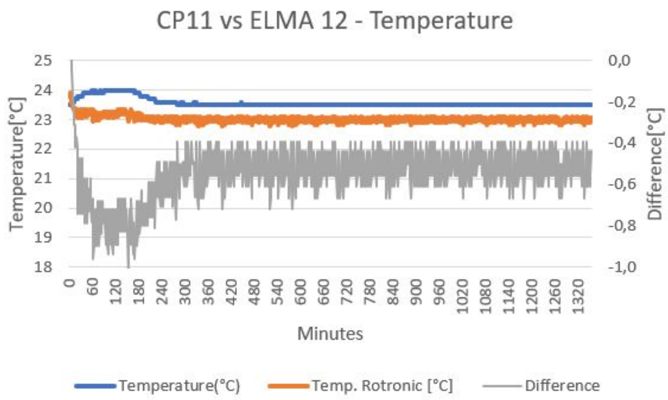

Figure 75: Comparing ELMA 12 vs. the CP11 Handheld device in the moisture laboratory Room 1.

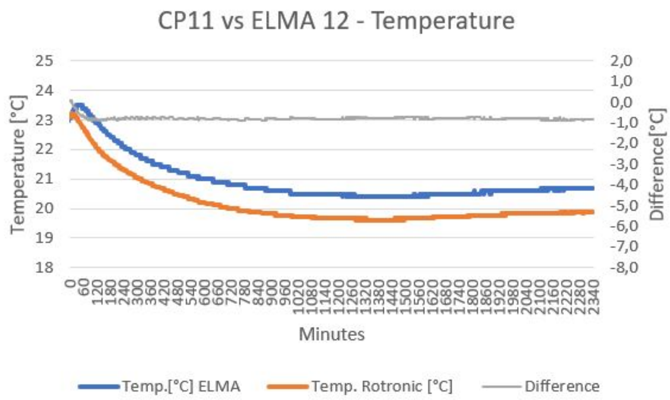

Figure 76: Comparing ELMA 12 vs. the CP11 Handheld device in the moisture laboratory Room 2.

2.12.3 Relative humidity

49

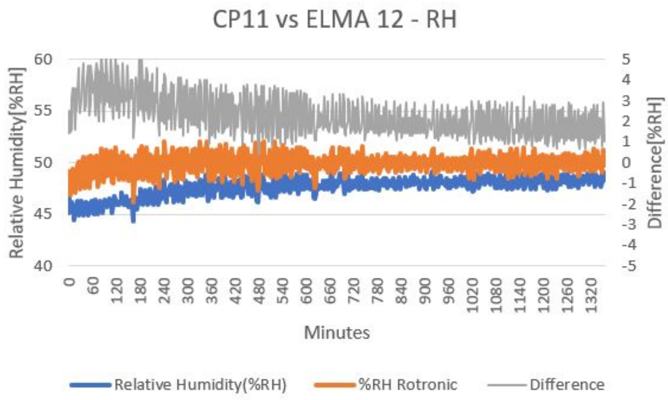

Figure 77: Comparing ELMA 12 vs. the CP11 Handheld device in the moisture laboratory Room 1.

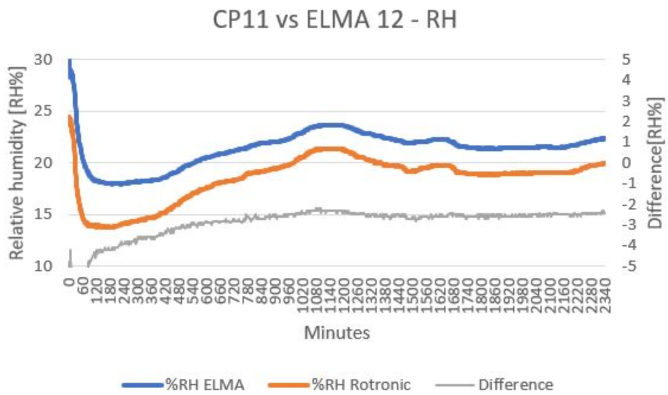

Figure 78: Comparing ELMA 12 vs. the CP11 Handheld device in the moisture laboratory Room 2.

2.13 ELMA 13

2.13.1 CO_2

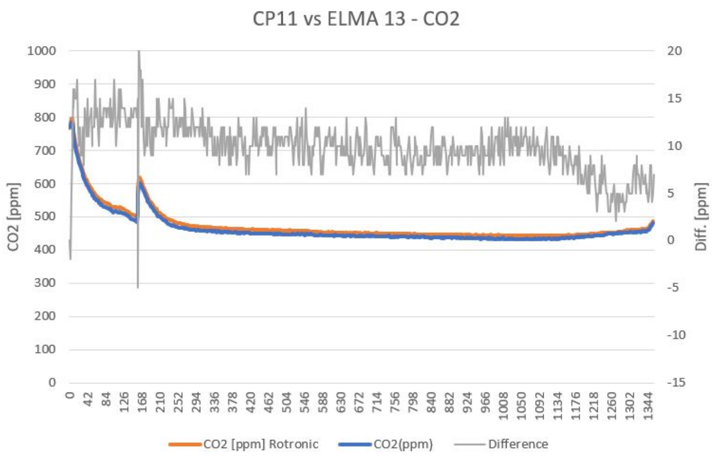

Figure 79: Comparing ELMA 13 vs. the CP11 Handheld device in the moisture laboratory Room 1.

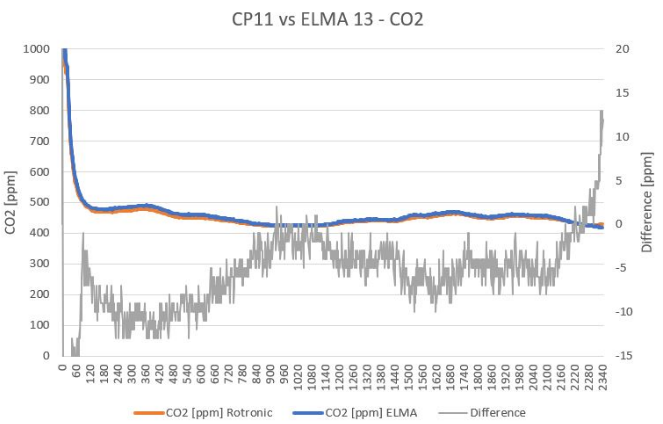

Figure 80: Comparing ELMA 13 vs. the CP11 Handheld device in the moisture laboratory Room 2.

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2.13.2 Temperature

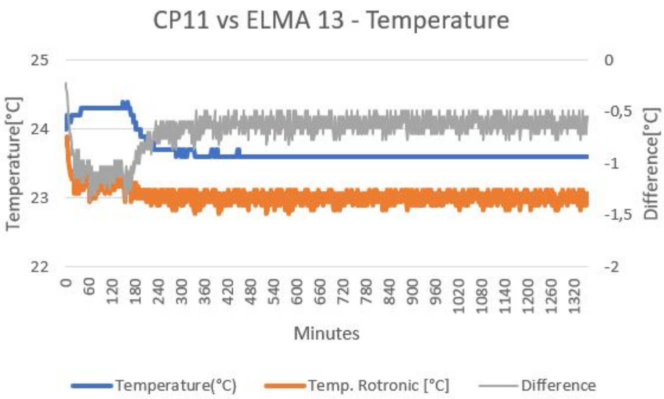

Figure 81: Comparing ELMA 13 vs. the CP11 Handheld device in the moisture laboratory Room 1.

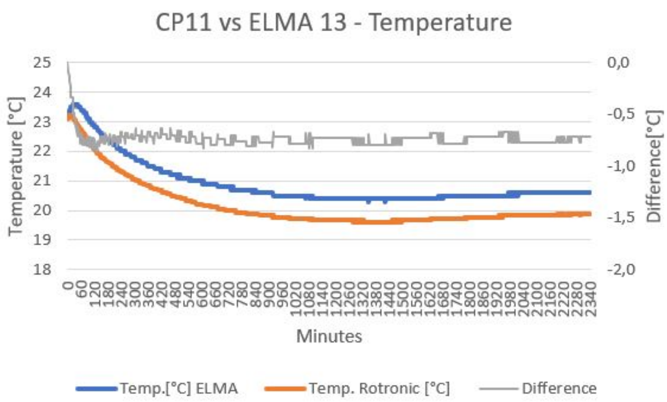

Figure 82: Comparing ELMA 13 vs. the CP11 Handheld device in the moisture laboratory Room 2.

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2.13.3 Relative humidity

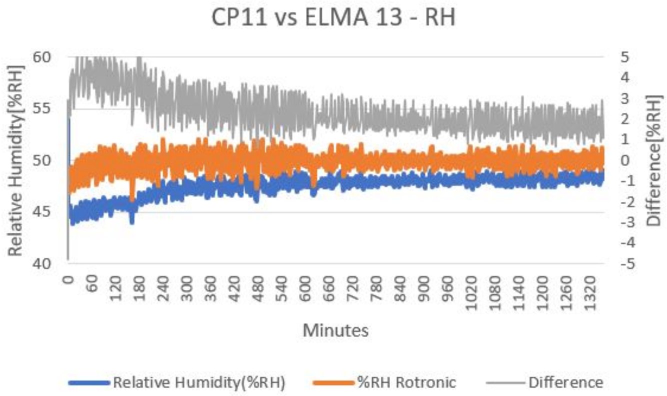

Figure 83: Comparing ELMA 13 vs. the CP11 Handheld device in the moisture laboratory Room 1.

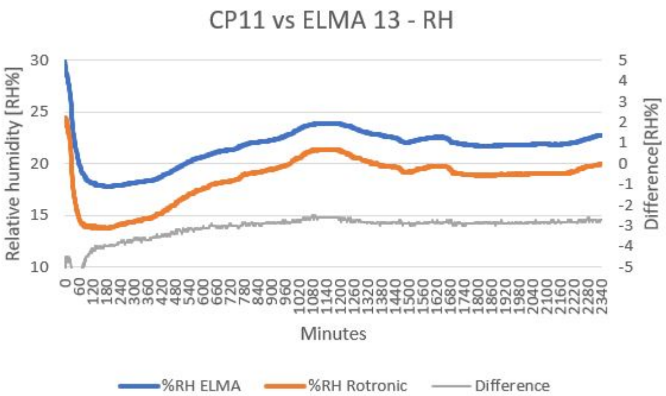

Figure 84: Comparing ELMA 13 vs. the CP11 Handheld device in the moisture laboratory Room 2.

2.14 iButtons

Figure 85: All 26 iButtons measurements from the first session in the coldroom.

Figure 86: All 26 iButtons measurements from the second time in the coldroom and from the study hall. The shift in location is visible with the drastic change in temperature. This happened roughly at 13:00.

The iButtons were tested against each other and the ELMA 10 device over a range of temperatures. As illustrated in Figure 85, the temperature increase slowly from 10.5°C to 13 °C. The iButtons gave similar results with a average difference from the lowest to highest recorded temperature at any given time to be only 0.3°C. The ELMA 10 with adjusted values laid within the iButtons range.

In the second test session, the temperature in the coldroom had reached stable conditions. The difference between the highest and lowest recorded value was also here below 0.5°C. The second session was divided into two separate locations. The first half of the test was performed in the coldroom. In the second part the iButtons was put into a student locker in a study hall at NTNU. The change in location is easily visible because of the rapid change in temperature seen in Figure 86. The average difference across the entirety of the second session was 0.36°C.

3 The offset

The ELMA monitors recorded values should be adjusted with the values given in Table 5, 6 and 7. The values given in the tables are read off the graphs given in Figures 10 to 84.

3.0.1 Temperature - ELMA indoor monitors

3.0.2 Relative Humidity - ELMA indoor monitors

To find the recommended correction for the relative humidity measurements, the difference from Room 1, Room 2 and the coldroom was averaged. Data only exist for three of the monitors from the coldroom. There appear to be a linear correlation between the rooms, but insufficient climate conditions were examined to say for certain. Taking the average of 50% RH and 19% RH should

	23°C	19.8°C	16.8°C	Recommended correction
ELMA 1	-0.8°C	-1°C		-0.9°C
ELMA 2	-0.5°C	-0.9°C	-0.3°C	-0.7°C
ELMA 3	-0.9°C	-1.2°C	-0.9°C	-1.1°C
ELMA 4	-0.7°C	-1°C	-0.6 °C	-0.9°C
ELMA 5	-0.5°C	-1°C		-0.8°C
ELMA 6	-0.8°C	-1°C		-0.9°C
ELMA 7	-0.7°C	-1°C		-0.9°C
ELMA 8				N/A
ELMA 9	-1°C	-1.1°C		-1.1°C
ELMA 10		-1°C	-0.9°C	-1.0°C
ELMA 11	-0.7°C	-1°C		-0.9°C
ELMA 12	-0.5°C	-0.8°C		-0.7°C
ELMA 13	-0.6°C	-0.7°C		-0.7°C

Table 5: The offset from the laboratory test and the final correction recommended to the ELMA monitors for the ”Schools on hold” project.

give an reasonably accurate correction value. In the field measurements the relative humidity hovered around 30%.

	50%RH	40% RH	19% RH	Recommended correction
ELMA 1	-1.5		-6	-3.8
ELMA 2	-1.5	-1.8	-6	-3.1
ELMA 3	-0.5	-1.7	-5	-2.4
ELMA 4	-1	-2	-6	-3
ELMA 5	-4		-8	-6
ELMA 6	2.5		-2	0.3
ELMA 7	3.5		0	1.8
ELMA 8				N/A
ELMA 9	2		-2	0
ELMA 10		-1	-2	-0.5
ELMA 11	2		-2	0
ELMA 12	2		-2	0
ELMA 13	2		-3	-0.5

Table 6: The offset from the laboratory test and the final correction recommended to the ELMA monitors for the ”Schools on hold” project.

	450ppm (Room 1)	450ppm (Room 2)	660ppm (coldroom)	Recommended correction
ELMA 1	16	0		0
ELMA 2	43	37	-85	0
ELMA 3	-835	-835	-528	-510
ELMA 4	13	10	-18	0
ELMA 5	44	36		0
ELMA 6	20	15		0
ELMA 7	0	0		0
ELMA 8				0
ELMA 9	24	18		0
ELMA 10		10	-25	0
ELMA 11	13	2		0
ELMA 12	-3	-16		0
ELMA 13	10	-3		0

Table 7: The offset from the laboratory test and the final correction recommended to the ELMA monitors for the "Schools on hold" project.

3.0.3 CO_2 - ELMA indoor monitors

The CO_2 measurements gathered during the calibration experiments show that some of the monitors can suddenly change its accuracy. This is clearly visible in Figure 22 and 20 compared to Figure 21. The difference observed in both Room 1 and Room 2 is roughly 350 ppm higher than that observed later in the coldroom. In Figure 20 we see a rapid change of 100 ppm in the difference. A change that is unique to the ELMA 3 monitor. The test performed before the field study shows a difference of 850 ppm, but the post experiment show a difference of only 510 ppm. The reliability of the ELMA 3 monitor is uncertain. It has not been observed a similar behavior from the other ELMA monitors. The difference between the ELMA monitors and the control device is with only a few exceptions within the given error range of the control instrument. Without further tests it was decided that the accuracy level would not increase by correcting the field data based on the experiments performed. The exception being ELMA 3, which is recommended to be corrected by 510 ppm. This value should be subtracted on all the CO_2 measurements done by ELMA 3 in the field study. Higher concentrations of CO_2 should have been checked as part of the calibration process. As this work can not conclude on the accuracy of the ELMA devices, the accuracy level given by the manufacture should be used in future works.

3.0.4 iButtons

In these trials, the iButtons were programmed to save the measurements in the 11-bit format. This gives a higher accuracy reading. From the analysis of the tests it became clear that all the iButtons gave similar results. The average difference between the lowest and highest measuring point throughout the first series was only 0.3 °C, and 0.4 °C for the second series. The iButtons were programmed to save the data in 8-bit during the measuring period at the schools. The iButtons therefore only recorded values with a resolution of 0.5°C. Since the recorded difference were lower than the accuracy level given, no corrections were done on the iButtons. The average measurement of all the iButtons where 0.9°C lower than that of the ELMA 10 device. Previously test have shown that the ELMA 10 gives values of 0.9°C to 1°C higher than both the CP11 and Pegasor monitors. It is therefore assumed that the iButtons give accurate temperature readings with the 0.5°C resolution. The comparison test performed on the iButtons show that they give accurate measurements within the range of 11°C to 23°C. The given accuracy level given by the manufacture seems to hold. The data collected with the 26 iButton instruments should not be adjusted.

3.1 Weaknesses with the calibration

3.1.1 Short measurement range

The testing range of the experiments performed in this paper does not cover the entirety of the recorded field measurement range. Only some specific conditions were tested. The recommended corrections recommended earlier in this paper is a constant value. It does not vary even though the experiment showed that the difference was not constant. The necessary accuracy level in the field measurements was concluded to not need a higher precision than that given in section 3. Several of the tested conditions falls within the expected parameters at the schools.

The values given in Table 5, 6 and 7 were read off the graphs. This results in some inaccurate read-offs. Some of the graphs varied noticeably during mostly stable conditions. This shows that the ELMA instruments are potentially not very accurate even during stable conditions. The CO_2 measurements are less accurate than for the temperature and relative humidity. However, the experiments performed as part of the calibration were not performed under perfect stable conditions. This reduces the validity of the trials, but since the goal was not to perfectly calibrate the instruments, the conditions were deemed acceptable.

3.1.2 Problems with the ELMA devices

ELMA 8
The ELMA 8 monitor did not function when inspected before the test in the first moisture room at the laboratory at SINTEF Byggforsk. The screen locked immediately after being powered on. The device did not respond to any input. The battery was removed and the power supply was changed out. The monitor was restarted several times, but the locked situation continued. The procedure was repeated before the test in the second room in the moisture laboratory. There was no change. ELMA 8 was finally found to be defective. Therefore it was marked and set aside. It was not used any further in the project.

ELMA 10
ELMA 10 measurement data could not be recovered after the session in Room 1. The data was lost when the device was programmed for the session in Room 2. Before initiating the session in Room 2, a short test series was completed. This test series results could be downloaded without trouble. The main session in Room 2 was than complected without any trouble.

iButtons resolution The iButtons were only tested with the 11-bit configuration, but the 8-bit configuration was used in the field study. The assumption that the offset is the same in the different storage configuration could be wrong.

4 VelociCalc

The student Helena Kuivjõgi tested the VelociCalc as part of her thesis at NTNU. Her results is presented in Figure 87.

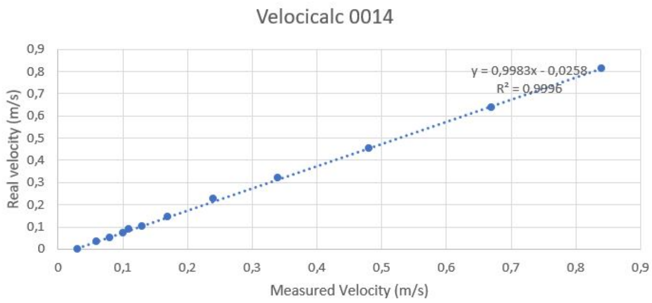

Figure 87: Graph showing the measured vs. real air velocity. Credit: Helena Kuivjõgi

References

[1] Rotronic AG. Cp11 short instruction manual. https://www.rotronic.com/en/productattachments/index/download?id=738, 2019. Accessed: 18-03-2019.

[2] Elma instruments. Manual elma dt-802d. https://elma-instruments.no/Admin/Public/DWSDownload.aspx?File=2018. Accessed: 21-12-2018.

[3] Maxim Integrated. ibutton temperature loggers with 8kb data-log memory. https://www.maximintegrated.com/en/products/ibutton/data-loggers/DS1922L.html/tb$_{t}ab0, 2019. Accessed : 18 - 03 - 2019$.

[4] Alphasense Ltd. Pegasor aqtm indoor air quality monitor operating manual. https://www.bsria.co.uk/download/product/?file=o2016. Accessed: 21-12-2018.

Appendix K iButton validation certificate

International Certificate of Validation

Revision: 1

Maxim Integrated
4401 S. Beltwood Pkwy
Dallas, TX 75244-3292

Certificate Request Date: 2019-03-12

Maxim Integrated certifies that the iButton data logger(s) identified below have been thoroughly tested per Maxim's Quality Assurance procedures. For the iButtons listed below, performance accuracy specifications* are certified to have been met over the stated range and have been validated on the date(s) given. Validations are performed with reference instrumentation that is certified traceable in accordance with the National Institute of Standards and Technology (NIST). Validation equipment certifications are on file at Maxim Integrated, Dallas, Texas, USA.

* For complete accuracy specifications, refer to the Special Features section and the Temperature Accuracy graphs located in the part's data sheet.

Reference Instrumentation

Temperature: Minco Thermometer, Model S9689PA5X12, Serial Number ranges: 10-1, 1758-12, 1758-1761, 1763-1766, 1769, 1788-1790, 1792, 1794-1808, 1810-1829, 1838-1847, 1849-1867, 1885-1893, 1897-1962, 1964, 1969, 1971-1991, 1993, 2582, 2582-2596, 2604-2625, 2658-2667, 2677-2709, 2714-2738, 2743-2781, 2823-2879, 2882-2999, 3000, 3000-3089, 3091-3092, 3095-3214, 3218-3310, 3313-3362, 3370-3390, 3395, 3399-3400, 3402, 3405-3414, 3445-3454, 3456-3467, 3469-3474, 3505-3509, 3520-3531, 3535-3537, 3539-3544, 3546, 3548-3553, 3555-3557, 3559, 3562, 5001-5, 5001-5003, 5005, 5024-5052, 5054-5084, 5088, 5401-5410, 8000-8, 8000-8150, 8152-8181, 9

Accuracy of Reference Instrumentation: ±0.035°C over a range of -100°C to +200°C

The temperature accuracy of the devices listed below are certified for 12 months after date of receipt by customer.

1

Part Number	Serial Number	Final Test Date
90-1922L#F52	0100000047962041	2015-12-04 14:46:14
90-1922L#F52	1800000045D5FC41	2015-10-24 15:06:06
90-1922L#F52	19000000478C8741	2015-12-04 13:34:39
90-1922L#F52	2D00000045D85B41	2015-10-24 15:29:02
90-1922L#F52	3200000047868E41	2015-12-04 14:20:36
90-1922L#F52	3400000047859041	2015-12-04 12:49:23
90-1922L#F52	4100000047976B41	2015-12-04 14:36:56
90-1922L#F52	4400000045DEBF41	2015-10-24 16:24:56
90-1922L#F52	5400000045DC1541	2015-10-24 16:27:58
90-1922L#F52	7600000045E57C41	2015-10-24 17:01:31
90-1922L#F52	7700000045E84C41	2015-10-24 17:46:29
90-1922L#F52	7C00000045E71141	2015-10-24 15:02:24
90-1922L#F52	870000004797A841	2015-12-04 12:34:03
90-1922L#F52	8E00000047886F41	2015-12-04 14:00:16
90-1922L#F52	B900000045E11241	2015-10-24 17:56:39
90-1922L#F52	BF00000045D4D841	2015-10-24 16:46:56
90-1922L#F52	BF00000045D87441	2015-10-24 15:36:42
90-1922L#F52	C000000047923741	2015-12-04 14:33:15
90-1922L#F52	C0000000479AFF41	2015-12-04 14:44:01
90-1922L#F52	C300000045D31E41	2015-10-24 16:14:58
90-1922L#F52	C9000000478DF041	2015-12-04 13:00:39
90-1922L#F52	CE00000045DF5D41	2015-10-24 18:01:20
90-1922L#F52	D300000045D7E241	2015-10-24 15:06:06
90-1922L#F52	D400000045DF9A41	2015-10-24 15:30:08
90-1922L#F52	E4000000478A7941	2015-12-04 14:44:23
90-1922L#F52	FE00000045E59441	2015-10-24 17:01:54

Authorized by:

Job Title: QA DIRECTOR

Authentication Code: 0b37aa5ed85e1510abeb7ed37a4b44d3d6d04111 Owner: Automatic Information BU

Sigbjørn Voktor Svinvik

Effective ventilation solutions preventing sickbuilding syndrome in Norwegian schools

NTNU
Norwegian University of
Science and Technology