Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Civil and Environmental Engineering

Nardeep Singh

Numerical and experimental study of the effect of sensor location on evaluation of indoor environment quality in a Norwegian school

Master's thesis in Sustainable Energy Use in Buildings
Supervisor: Guangyu Cao
Co-supervisor: Hans Martin Mathisen
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ABSTRACT

The purpose of this study is to examine the indoor environment for Kuben High School in Oslo municipality and is connected with the ongoing DIGG-MIN-SKOLE project. It is reported as a school with known indoor environmental problems. The study is evaluating simple measures to improve the environment with understanding how the placement of sensors affect the CO2 readings.

Carbon dioxide sensors are used as the control input in the high energy efficiency ventilation technique known as demand control ventilation (DCV). In order to accurately determine the indoor air quality and real ventilation rate while implementing the DCV, the measurement data quality of CO2 sensors is crucial. In this research, computational fluid dynamics analysis was used to model and simulate the airflow field and CO2 spatial distribution in an indoor environment of a classroom with seated CO2 generating occupants. The classroom's airflow streamlines, velocity, turbulence, and spatial distribution of CO2 were examined. In order to ensure an accurate measurement data collection and achieve a high energy efficiency in the DCV system, we need to properly arrange the CO2 sensors.

The study have been conducted through field measurements and simulations. Kuben High School had two different sensors installed in the school, Airthings View Plus sensors and ELMA Chauvin Arnoux. These two were compared and evaluated in context of each other. The sensors measured CO2, relative humidity and temperature levels in the classroom. The simulation was then compared to these results.

SAMMENDRAG

Formålet med denne studien er å undersøke innemiljøet for Kuben videregående skole i Oslo kommune og er knyttet til det pågående DIGG-MIN-SKOLE prosjektet. Det er rapportert som en skole med kjente innemiljøproblemer. Denne studien evaluerer enkle tiltak for å forbedre miljøet med å forstå hvordan plassering av sensorer påvirker CO2-avlesningene.

Karbondioksidsensorer brukes som kontroll i høy energieffektiv ventilasjonsteknikk kjent som behovskontrollventilasjon. For å nøyaktig bestemme inneluftkvaliteten og reell tilluftsmengde mens du implementerer DCV, er måledatakvaliteten til CO2-sensorer avgjørende. I denne forskningen, blir numerisk fluiddynamikk brukt til å modellere og simulere luftstrømfeltet og CO2-rom distribusjon i et innendørs miljø i et klasserom med sittende CO2-genererende brukere. I denne oppgaven ble strømmninglinjene til klasserommets luftstrøm, vindhastighet, turbulens og fordeling av CO2 undersøkt. Å sikre nøyaktigheten av målingene og plassere CO2-sensorene i klasserommet riktig, er viktig for å sikre nøyaktige innsamling av måledata og for å få et effektiv DCV for å oppnå høy energieffektivitet.

Studien er utført gjennom feltmålinger og simuleringer. Kuben Videregående Skole hadde to forskjellige sensorer installert på skolen, Airthings View Plus-sensorer og ELMA Chauvin Arnoux. Disse to ble sammenlignet og evaluert i sammenheng med hverandre. Sensorene målte CO2, relativ fuktighet og temperaturnivåer i klasserom. Simuleringen ble deretter sammenlignet med disse resultatene.

PREFACE

This master's thesis was completed in the spring semester of 2023 at the Department of Energy and Process Engineering of the Norwegian University of Science and Technology in Trondheim. The DIGG-MIN-SKOLE project and NILU, was involved in the thesis' writing. I would like to express my deepest appreciation to Professor Guangyu for his advice and insightful comments. Additionally, I would want to express my gratitude to the research advisors at NTNU, especially towards Azimil Gani Alam for his support and encouragement throughout the whole process. I also want to express my gratitude to everyone who helped with the experiments in Trondheim at NTNU and for the measurement in Kuben high school. I want to close by thanking my family and friends for their encouragement and support during the process.

Nardeep Singh.
Trondheim, June 2023

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ABBREVIATIONS

- **DCV** Demand Controlled Ventilation
- **IAQ** Indoor Air Quality
- **NTNU** Norwegian University of Science and Technology
- **CFD** Computational Fluid Dynamics
- **CAD** Computer aided design
- **HVAC** Heating, Ventilating and Air Conditioning
- **PMV** Predicted Mean Vote
- **PPD** Percentage of people dissatisfied
- **DR** Draught Rating
- **BMR** Basal Metabolic Rate
- **MET** Metabolic Equivalent of a Task
- **RF** Relative Humidity
- **FEA** Finite Element Analysis
- **OPC** Optical Partical Counter
- **PS** Portable Sensor

CHAPTER

ONE

INTRODUCTION

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

This project thesis is connected with the ongoing project DIGG-MIN-SKOLE, which is funded by the Research Council of Norway. Oslobygg KF and NILU (Norwegian Institute for Air Research) are the project owner and project manager respectively of the DIGG-MIN-SKOLE project. In addition, NTNU, the Norwegian Asthma and Allergy Association, KLP, Airthings, Schneider Electric, GK Norge AS and Johnson Control are also participants. Several schools in the Volda and Oslo municipalities are participating in the DIGG-MIN-SKOLE project, but the scope for this project thesis will only encompass Kuben high school. It is located in Økern, Oslo municipality and is one of Oslo's biggest high schools with over 1800 pupils. Kuben (n.d.)

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

1.1 Motivation

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

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

1.2 Project description

The aim of the project is to investigate and evaluate the effect of indoor environment on human health in school buildings in Norway. To find an optimal sensor location and see how different locations for the sensors can affect the CO2 readings. This master thesis is a continuation of the project thesis done in the fall semester of 2022. Since this is a continuation, some parts of the theory are reused from the project assignment. Singh (2022).

The following tasks were performed:

- Literature review regarding typical ventilation solutions in school buildings in Norway and how the indoor environment affects human health (this task was done previously in the project thesis).
- Selection of case buildings and rooms for data collection of indoor environment quality.
- Analysis of ventilation systems in selected school building and preparation for measurement of the chosen classroom.
- Simulation of the selected classroom and a comparison of field measurements versus simulation.
- Make conclusions and suggestions for optimal sensor placement in schools.

CHAPTER
TWO

THEORY

2.1 Indoor environment in Norwegian Schools

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

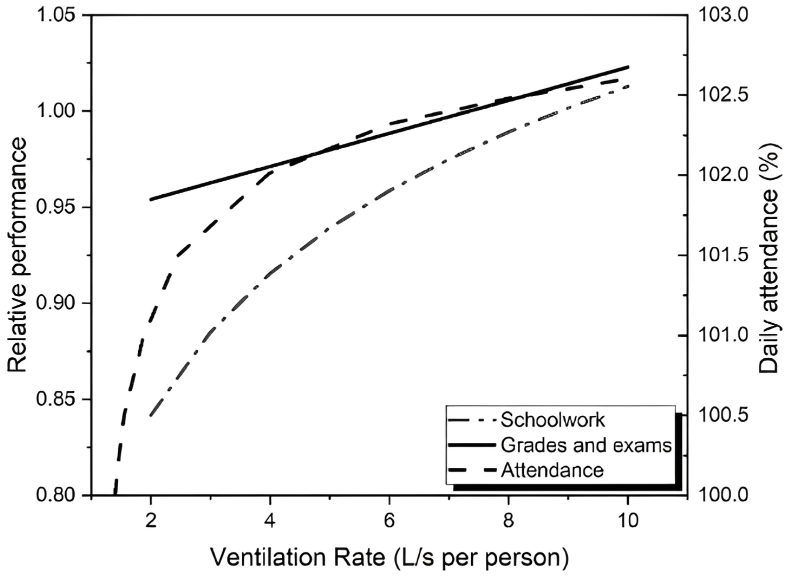


Figure 2.1.1: Performance of schoolwork, national and aptitude tests and exams, and students daily attendance as a function of classroom ventilation rates. Sadrizadeh et al. (2022)

Poor IAQ also impacts the cognitive performance of students. 30 percent of teaching staff report being exposed to poor indoor climate most of the time, compared to an average of 21 percent for all other professions. SSB (n.d.). In a survey of more than 4,000 students, 38 percent said they often experienced dense and trapped air. Other environmental conditions reported were that it was either too hot or cold and the air was dry. Holøs (2015). A good indoor climate can contribute to a better learning and teaching environment and reduce absence or sick leave. Studies have been done where relationships were developed between the classroom air quality and learning outcomes, which is illustrated in figure 2. It is anticipated that reducing the negative effects of poor classroom air quality would also lead to considerable socioeconomic benefits. Wargocki et al. (2020). Singh (2022).

2.1.1 Ventilation system

Mixed ventilation is the most common ventilation system in Norwegian schools and is the traditional method to supply air into ventilated areas. It is also referred to as dilution - or momentum ventilation. The air is supplied to the room with high velocity so that the room air becomes homogenous. It is possible to supply air with relatively low temperatures without causing drafts. The supply air terminal is often located on the ceiling or high on the walls, outside the zone of occupancy to avoid draught. The high velocity of the supply air will generate a re-circulation of the air in the room. Pollutants such as body odor and exhaust gases from materials will be mixed with the room air with stirring ventilation. We strive to use so much air that the pollutants are diluted to a level where they do not cause us discomfort or harm to our health. Kuben high school has this type of ventilation. Lin et al. (2005), Tekna (2021). Singh (2022).

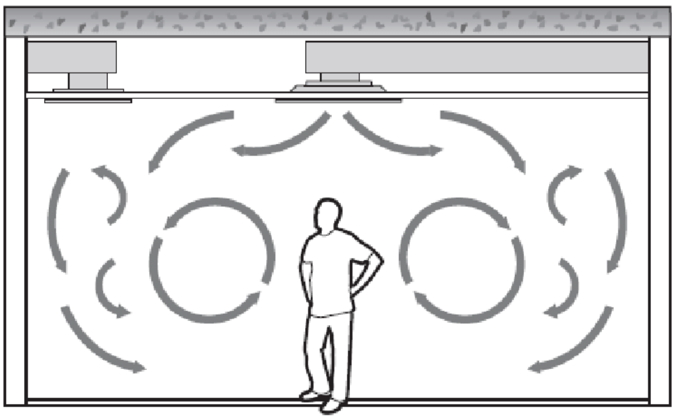


Figure 2.1.2: Mixing ventilation. Price (2016).

2.1.2 Requirements for ventilation in schools

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

The Buildings Regulation (TEK17) set requirements for indoor climate and health and the guidelines to TEK17 include preaccepted standards for the supply of fresh air. Humans are usually the biggest source of pollution in buildings. In addition, there is a need to ventilate away contaminants from materials, installations and objects or user equipment. TEK17 states that the fresh air requirement can be calculated at the largest value of A + B and C, where A is person load, B is material load and C is polluting activities and processes. DIBK (2017). Singh (2022).

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

1. *Fresh air supply due to pollution from people with light activity must be a minimum of 26 m3 per hour per person. At activity levels other than light activity, the fresh air supply must be adjusted so that the air quality is satisfactory.*
2. *Fresh air supply due to pollution from materials, products and installations must be kept to a minimum of:*
   (a) *2.5 m3 per hour per m2 floor area when the rooms are in use*
   (b) *0.7 m3 per hour per m2 floor area when the rooms are not in use.*

2.1.3 Thermal climate requirements

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

2.2 Thermal comfort

Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment, and it is assessed by subjective evaluation. ASHRAE (2017). Thermal comfort is important in schools, since it affects human productivity and their well-being. Thermal discomfort can substantially reduce the key aspects of individual human efficiency, such as reading and thinking logically. Different studies have shown that productivity of many routine tasks has been reduced as much as 15 percent under thermal stress. Wyon (1996). Thermal comfort depends on six different parameters, which can be divided into two groups, environmental and personal parameters. The environmental parameters consist of air temperature, mean radiant temperature, relative air velocity and relative humidity. The personal parameters are metabolic rate and clothing insulation. According to studies done by ASHRAE, an environment where 80 percent of the occupants are satisfied the thermal environment is acceptable. Due to the existence of biological differences between every single person, it is difficult to satisfy all occupants at the same time. Singh (2022).

2.2.1 Thermal Comfort standards

Most used standards regarding thermal comfort are ASHRAE 55 and ISO 7730. Both formed their standards for comfortable thermal environments from P.O. Fanger's comfort equations, which is the combined quantitative combination of the environmental and individual variables. Fanger et al. (1985). The environmental variables are dry-bulb air temperature, mean radiant temperature, relative air velocity and relative humidity. Individual variables are affected by the activity level (metabolism rate) and the clothing level (degree of insulation). ASHRAE 55 specifies boundaries and implies that 90 percent of the occupants should find the thermal environment acceptable, if the environment is thermally uniform. The framework defined in ASHRAE 55 is only concerned with steady state cases where ISO 7730 is evaluating changes over time. The general output of data for each standard is the Predicted Mean Vote (PMV) and Percentage of people dissatisfied (PPD). Ekici (2013). Singh (2022).

2.2.2 Local Thermal Discomfort

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

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

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

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

Finally, hot or cold feet caused by the floor temperature are another reason for local thermal discomfort. The heat loss is influenced by the conductivity, the heat capacity of the material of the floor and the footwear. In order to avoid heat loss in the feet an optimal level of floor temperature should be maintained, which has been suggested by studies to be 24° C. Markov (2002). Singh (2022).

2.3 Indoor Climate Parameters

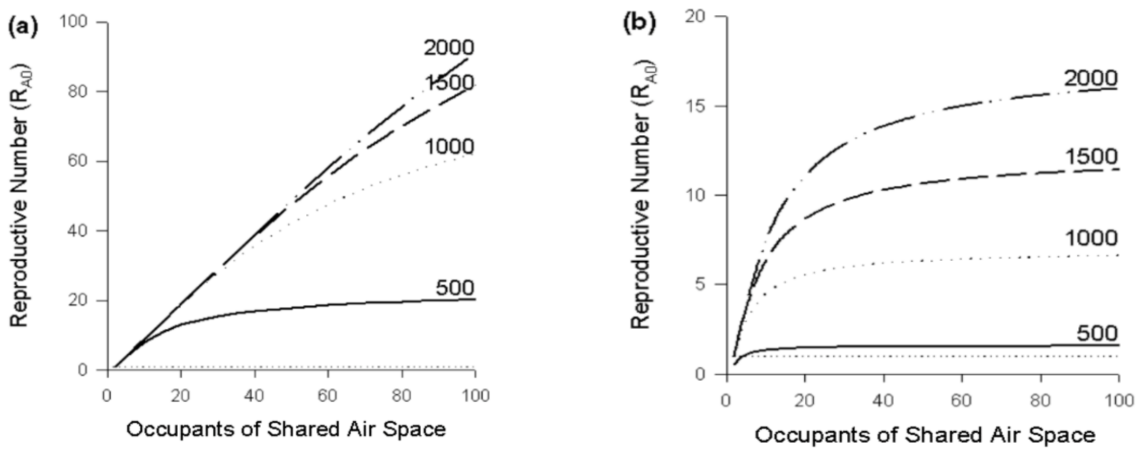
A few parameters were examined to analyze the indoor climate conditions in the Kuben high school building, including Carbon Dioxide concentration, Relative Humidity. These parameters are common variables examined in studies on IAQ.

2.3.1 Carbon Dioxide

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

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

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



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

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

Figure 2.3.1: R_{A0} for airborne disease as a function of number of occupants in a room and concentration of CO_2 (ppm). $C_0 = 350$ ppm, $C_a = 37\ 500$ ppm, same in both models. Rudnick and Milton (2003).

The study shows that the reproductive number of a disease is lower for lower CO2 concentrations. To maintain good indoor air quality and comfortable conditions, it is important to ensure that there is sufficient ventilation to allow for the exchange of indoor and outdoor air. This can help to lower the concentration of CO2 and other contaminants in the air. Singh (2022).

2.3.1.1 CO2 generation rate of occupants

CO2 generation rate refers to the amount of carbon dioxide produced by a certain process or activity over a given period of time.

The first step in estimating the CO2 generation rate is to determine the BMR of the individuals of interest. A key component of the energy requirements for the human body is the energy essential for life, for example, cell function, maintenance of body temperature, brain function, and cardiac and respiratory function, and is referred to as basal metabolism with an energy requirement called the basal metabolic rate (BMR). BMR is dependent on sex, age and body mass (m). Yang et al. (2020)

In addition to the BMR value, the level of physical activity must be considered in establishing human energy requirements also known as Metabolic Equivalent of Task (MET). The concept of MET is based on the idea that a person's energy expenditure increases proportionally with the intensity of physical activity. The resting metabolic rate (RMR) is defined as 1 MET, which represents the energy expenditure of a person at rest. Persily and Jonge (2017).

The ordinary age of the occupant in the 11th year is between 16 and 17 years. The average CO2 generation rates for the age group 16 to $<$ 21 while sitting quietly and during writing when sitting are shown in table 2.3.1 below.

Sex	1.2 Met	1.4 Met
Male	0.0045 l/s	0.0053 l/s
Female	0.0035 l/s	0.0042 l/s

Table 2.3.1: CO2 Generation Rate. Persily and Jonge (2017)

2.3.2 Relative Humidity

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

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

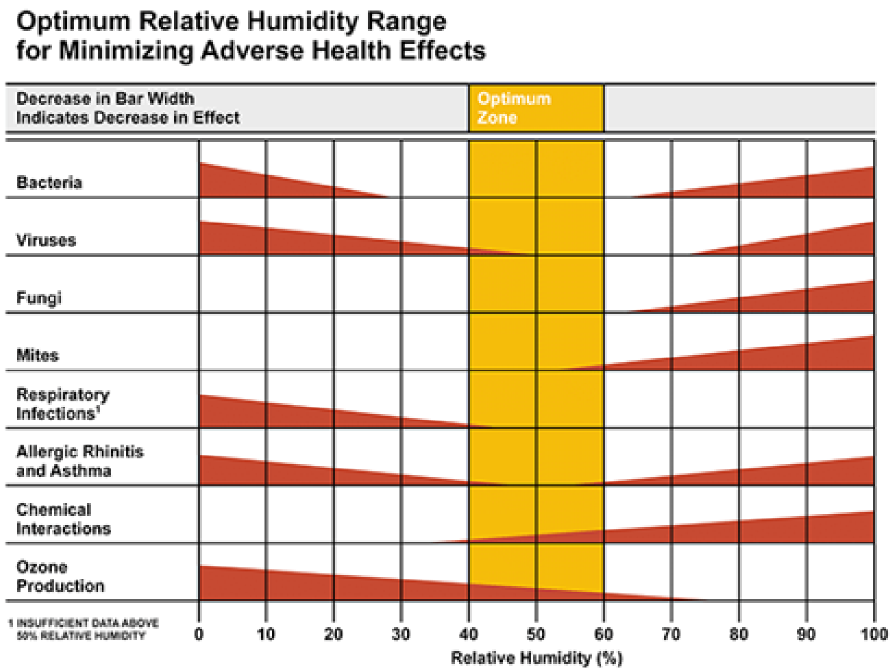


Figure 2.3.2: Optimum Relative Humidity Range. Arundel et al. (1986).

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

In Norway the most common problem during heating season is dry air. This occurs because the air supply is being extracted from a cold outside temperature and results in a loss of water vapour when it is heated up. This can be reduced with the use of a humidifier for indoor air, however this should be avoided due to the risks of moisture damage to materials. Bjørheim (2019). Singh (2022).

2.4 Simulation Softwares

Two different simulation softwares were used in this thesis. One for imitating the real-life classroom and one for calculating the air supply rate.

2.4.1 Solidworks SP4.1 2021

One of the simulations used in this project was Solidworks SP4.1 2021. It has several additions for different types of simulations. The Solidworks Flow Simulation is a Computational Fluid Design (CFD) software that allows one to analyze and optimize the performance of fluid flow and heat transfer. The software enables users to simulate and analyze the behavior of fluids and gases within a Computer Aided Design (CAD) model of a product, providing detailed information of the flow patterns, velocity, temperature, and pressure distribution.

With SolidWorks Flow Simulation, users can model and analyze a wide range of fluid flow scenarios, including laminar and turbulent flows, steady-state and transient flows, compressible and incompressible flows. The software provides a range of powerful tools for setting up simulations, such as defining the boundary conditions, selecting the fluid properties, and specifying the flow rate and pressure. SolidWorks Flow Simulation also includes advanced post-processing capabilities that allow users to visualize and analyze simulation results in detail. The software provides a range of tools for generating 2D and 3D visualizations of flow patterns, temperature, pressure distributions and other key parameters. Solidworks (n.d.)

2.4.1.1 The Navier-Stokes equations

The Navier-Stokes equations, the mathematical formulations of the laws of conservation of mass, momentum, and energy, are solved in fluid regions by Solidworks Flow Simulation. Hosch (2023).

Continuity Equation. The mass of the flow remains constant throughout time in a controlled volume. The law of conservation of mass is represented by the following:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho v) = 0 \tag{2.1}$$

Momentum Equation. The conservation of momentum states that momentum is neither created nor destroyed since it is constant in a control volume. It can only change as a result of forces acting in accordance with Newton's rules. Defined as:

$$\frac{\partial \rho u}{\partial t} + \nabla \cdot (\rho v \otimes v) = -\nabla P + \rho g + \nabla \cdot \tau \tag{2.2}$$

Energy Equation. The first law of thermodynamics, conservation of energy, stipulates that the total amount of energy in a system will increase as a result of the work and heat given to it.

$$\frac{\partial \rho E}{\partial t} + \nabla \cdot (\rho E + P)v = \nabla \cdot (k\nabla T) + \nabla \cdot (\tau v) + \rho v g + Q \tag{2.3}$$

2.4.1.2 Turbulence Intensity

Turbulence intensity refers to the relative strength or magnitude of the turbulence within a fluid flow. It provides an indication of how turbulent or chaotic the flow is compared to its average velocity. Molland and Turnock (2007). Turbulence intensity is typically expressed as shown in the equation below, where u' is the root-mean-square of the turbulent velocity fluctuations and U is the mean velocity :

$$I = \frac{u'}{U} \tag{2.4}$$

The average turbulence intensity in a non complex device like large pipes or ventilation flows is between 1 and 5 percent. The diffuser or the supply air valve often causes the turbulence to increase when it spreads the airflow throughout the room. A study done with a human manikin to find out the turbulence intensity of a exhalation was done. The mean turbulence intensity was about 0.055 at the center of the exit in the first half of the exhalation process, while it was about 0.092 in the second half of the exhalation process. Average turbulence intensity of the whole exhalation process is 0.0735 or 7.4 percent. Feng et al. (2015).

2.4.2 Contam Software

Contam is a computer simulation software that is designed to model the movement of air and pollutants through indoor environments. The software was developed by the National Institute of Standards and Technology (NIST) in the United States and is widely used in building science, environmental health, and industrial hygiene fields. NIST (2023).

The software models the movement of air and pollutants through the zones, accounting for factors such as air temperature, humidity, pressure, and airflow patterns. It can also be used to model the dispersion of airborne contaminants such as pollutants, allergens, and infectious agents. Contam can be used to simulate the effects of different ventilation strategies and pollutant control measures, helping to optimize building design and operation for improved indoor air quality. NIST (ibid.).

To find the supply airflow through contaminant concentration these mass balance equation formulas are used in the software:

$$C_{(t=2)} = C_\infty + \frac{n \cdot \dot{m}}{V} - (C_\infty - C_{(t=1)} + \frac{n \cdot \dot{m}}{V}) \cdot e^{\frac{-Q}{V} \cdot \Delta t} \tag{2.5}$$

$$Q = \frac{-V}{t} \cdot \ln\left(\frac{X - C_{(t=2)}}{X - C_{(t=1)}}\right) \tag{2.6}$$

$$X = C_\infty + \frac{n \cdot \dot{m}}{V} \tag{2.7}$$

CHAPTER
THREE

METHODS

3.1 Field measurements

3.1.1 Equipment

The equipment used for the purpose of data gathering of field measurements was Airthings View Plus sensors and the Elma Series sensors by Chauvin Arnoux.

The parameters measured by Airthings View Plus are radon, VOCs, CO2, relative humidity, temperature, and air pressure. The logging interval for this sensor is five minutes and the sensor specifications are shown in table 3.1.4. The sensors use advanced technology to continuously monitor and measure the levels of various indoor air parameters, and the data can be displayed on an accompanying app or dashboard. A detailed sensor specification is given in the appendix. Airthings (n.d.). Singh (2022).

For Elma Series by Chauvin Arnoux, the parameters measured are only CO2, temperature and relative humidity as this is an older measurement equipment. The logging interval for this sensor is 15 seconds and the sensor specifications are shown in table 3.1.4. A detailed sensor specification can be found in the appendix. ELMA (2023).

Figure 3.1.1: Airthings View Plus

Figure 3.1.2: ELMA CA 1510

Sensor specifications	**Airthings View Plus**	**ELMA Chauvin Arnoux sensor**
CO2		
Accuracy:	± 30 ppm or ± 3 percent	± 50 ppm or ± 3 percent
Resolution:	1 ppm	1 ppm
Range:	400-5000 ppm	0-5000 ppm
Temperature		
Accuracy:	± 0.1 °C	± 0.5 °C
Resolution:	0.1 °C	0.1 °C
Range:	4 °C - 40 °C	-10 °C - 60 °C

Table 3.1.1: Sensor specifications for both sensors. Airthings (n.d.), ELMA (2023).

For measuring the classroom parameters a Bosch PLR 50C was used. The Bosch PLR 50C is a laser distance meter that offers an easy solution for measuring distances, calculating areas and volumes with high accuracy up to 50 meters. The Bosch PLR 50C includes automatic switch-off for energy efficiency, ability to calculate areas and volumes, and an easy-to-use interface. Specifications are mentioned in the table below. Bosch (2023).

Figure 3.1.3: The Bosch PLR 50C

Sensor specifications	**Bosch PLR 50C**
Laserdiode:	635 nm
Laser class:	2
Measuring range:	0.05 - 50.00 m
Accuracy:	± 2.0 mm

Table 3.1.2: Sensor specifications for Bosch PLR 50 C

3.1.2 Calibration of Elma sensors

To calibrate the Elma sensors, a Pegasor Air Quality Indoor was used as a standard reference. It is a compact and easy-to-use device that measures a range of pollutants in indoor air such as particulate matter (PM2.5, PM10), volatile organic compounds (VOCs), and carbon dioxide (CO_2). The Pegasor AQ utilizes the diffusion charging operation principle to detect small particles that Optical Particle Counters (OPCs) cannot detect nor measure. The monitors are also designed to be low maintenance, with long-lasting sensors and automated calibration features that help to ensure accurate and reliable measurements. The Pegasor has high resolution with sampling time that can be performed up to every second with a 0.1 percent accuracy of the measured concentration. Pegasor (2023).

Figure 3.1.4: Pegasor AQ Indoor.
Pegasor (2023)

In the following illustrations the different sensors are marked accordingly with their own color and number to make it easier to differentiate between them. The sensor's serial numbers have been codified as Portable Sensors (PS).

Sensor Serial Number	**Color**	**Portable Sensor Number**
164706 RJH	Yellow	PS-1
142938 RFH	Blue	PS-2
142937 RFH	Orange	PS-3
164707 RJH	Grey	Ps-4

Table 3.1.3: Codification of sensors

All the equipment was then put in the workstation which is a gas tight chamber. By using a gas tight chamber to calibrate instruments, the environment can be carefully controlled and monitored to ensure that the instrument is operating under consistent conditions. This makes it possible to accurately determine the instrument's response to specific gas concentrations, allowing for precise calibration of the instrument's sensitivity and accuracy. The Pegasor AQ was placed in the middle and the Elma sensors were placed around it. A few candles were lit to generate CO2 for the measurement. The values obtained from the calibration are added in the appendix and the trendlines are shown below.

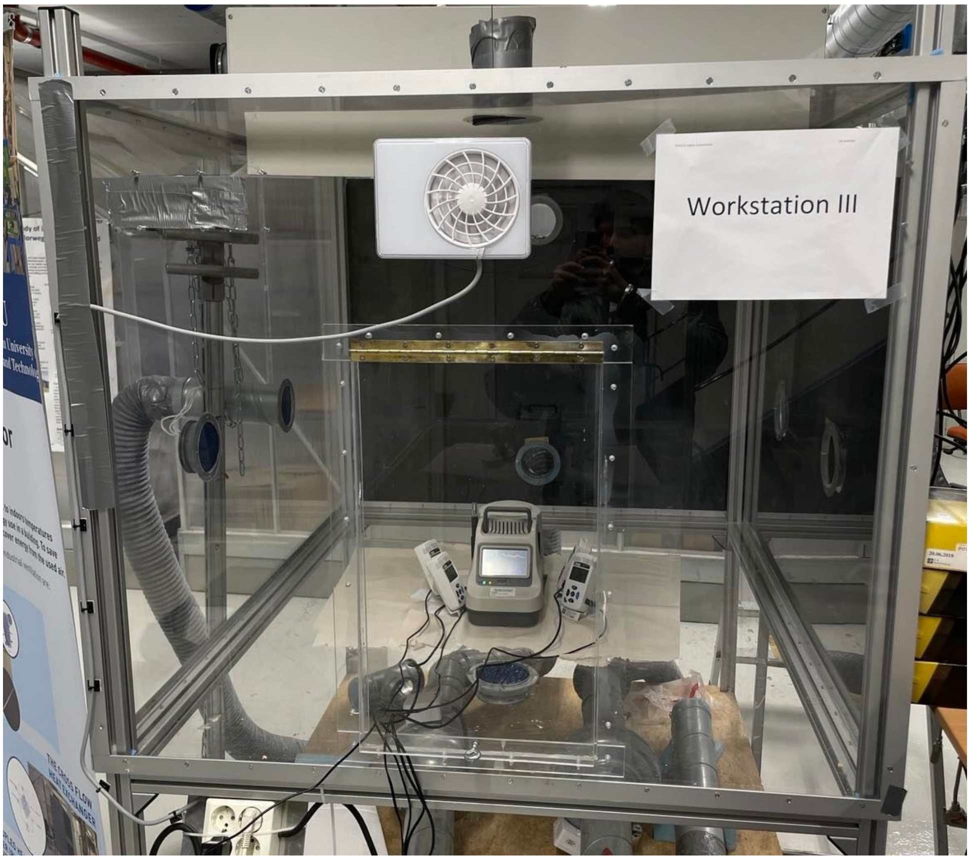


Figure 3.1.5: Gas tight Workstation

Time	**Action**
10:40	candle on, recording on, fan off
11:22	candle off, recording on, fan off
11:30	candle off, recording on, fan on
11:42	candle off, recording off, fan off

Table 3.1.4: Calibration process on 10.03.23

After the measurement was done the values were put in a scatter graph to compare and to determine the level of agreement or disagreement between them. A scatter graph can help to identify any patterns or trends in the data, as well as any outliers or discrepancies.

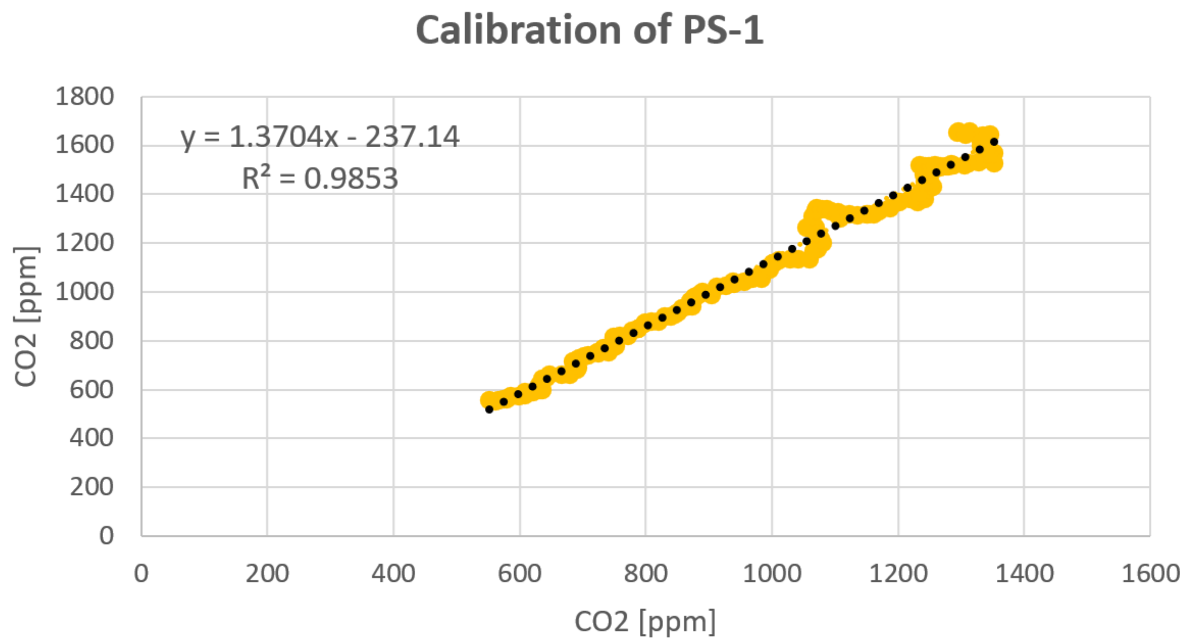


Figure 3.1.6: Calibrated PS-1 (164706 RJH)

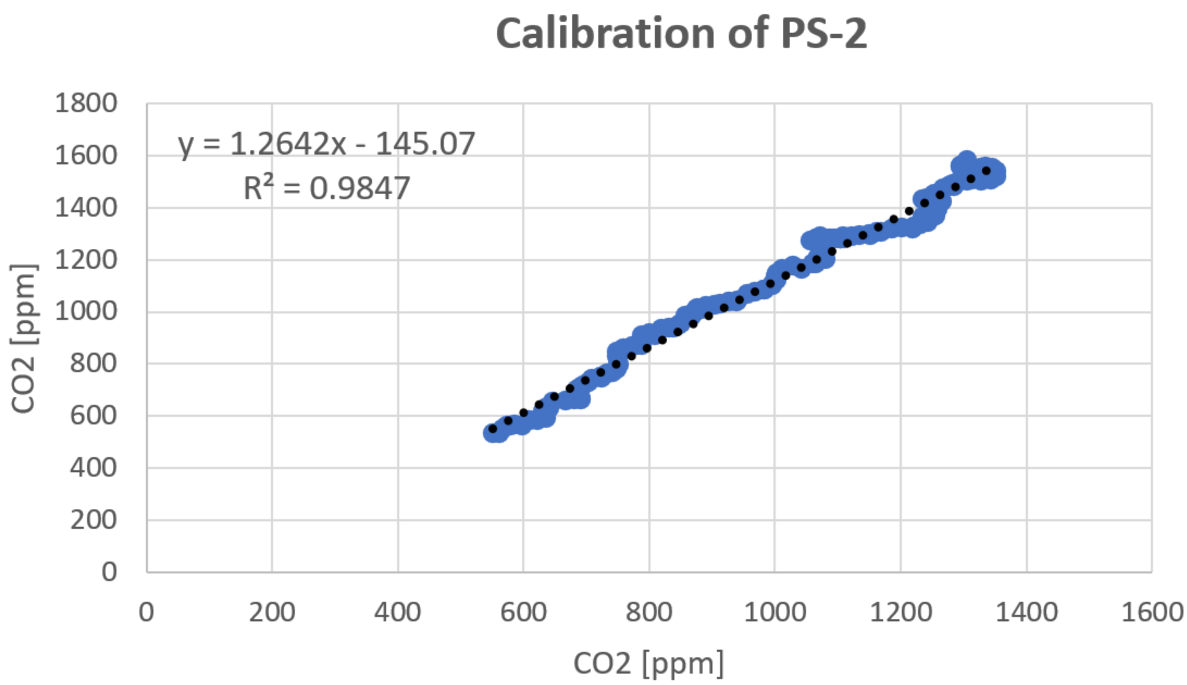


Figure 3.1.7: Calibrated PS-2 (142938 RFH)

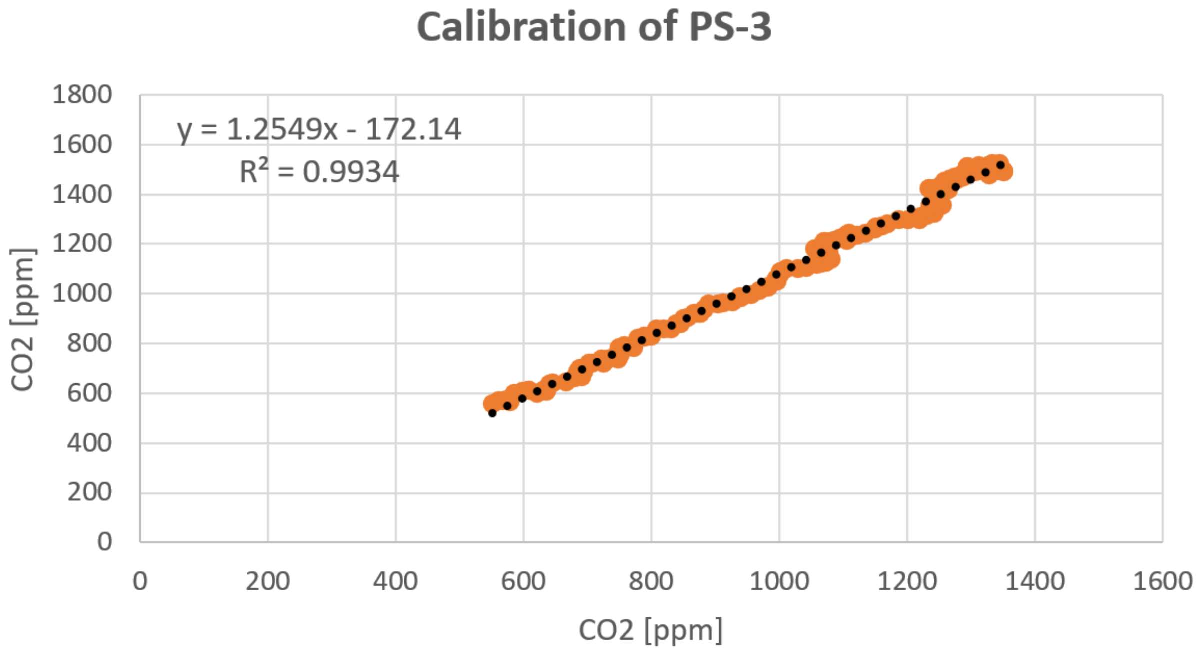


Figure 3.1.8: Calibrated PS-3 (142937 RFH)

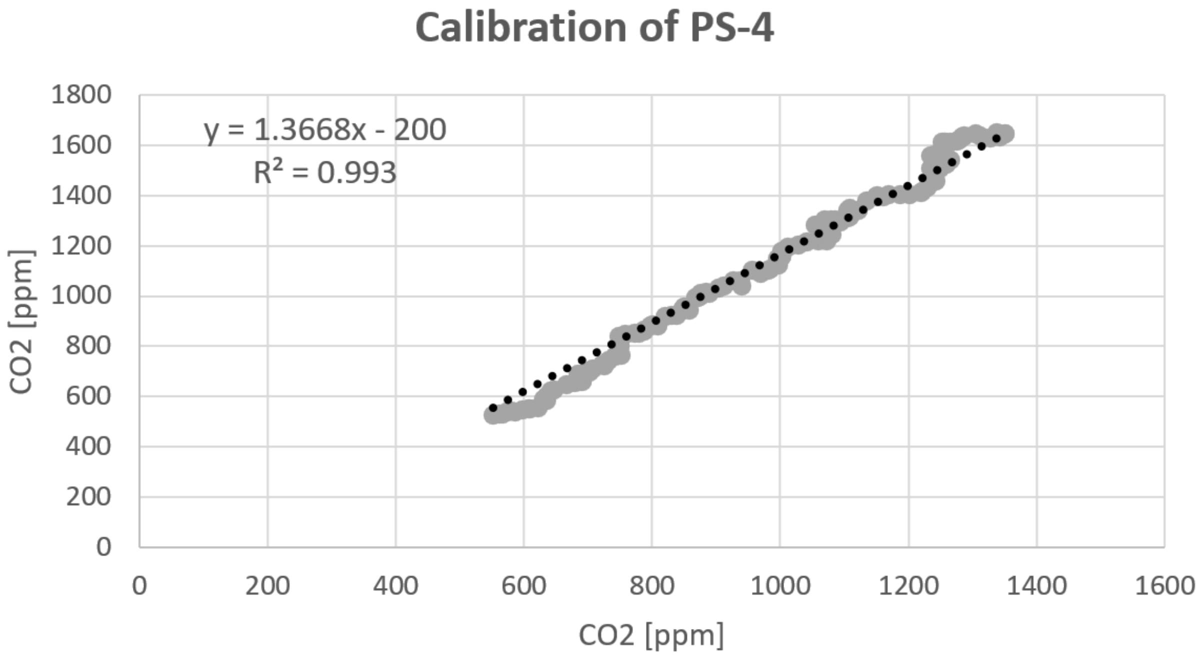


Figure 3.1.9: Calibrated PS-4 (164707 RJH)

The values inserted in the scatter graph for all instruments were from 10:40 AM when the recording and candle was started, to 11:22 AM when the candle was turned off. All results had a coefficient of determination R^2 above at least 0.98 which shows a very high correlation. The trendlines were later used for each sensor when calibrating the correct value.

3.1.3 Placement of sensors

After the sensors were calibrated, they were ready to be placed in the classroom at Kuben High school. All sensors were placed at sitting head height level of 1.2 m. The reason for placing sensors at this height is that it is the most relevant height for detecting the air quality that people are actually breathing. They were installed at 12:00 AM 30.03.23 to 12:30 AM 31.03.23.

Figure 3.1.10: Floorplan with sensor locations made in Smartdraw (2023).

Figure 3.1.11: 3707 1

Figure 3.1.12: 3707 2

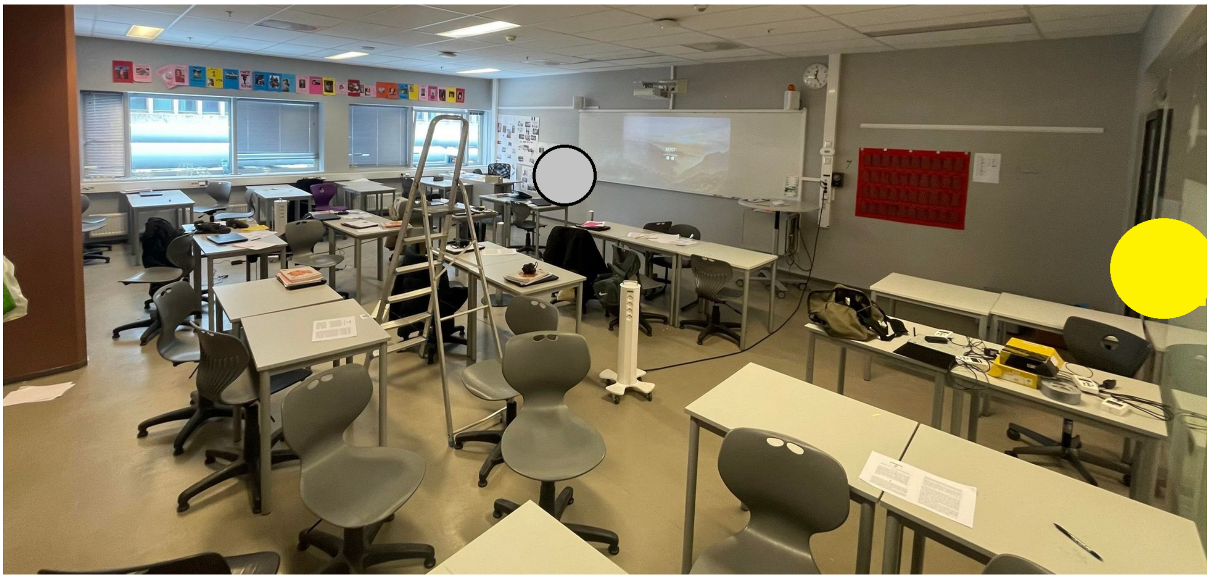


Figure 3.1.13: 3707 3

Figure 3.1.14: 3707 4

3.2 Simulation

3.2.1 Construction of classroom in Solidworks

After the dimension, layout, and design of the classroom was measured it was ready to be constructed in Solidworks. The classroom was measured with the Bosch PLR 50C to be 7.05 m x 9.70 m x 2.80 m (W x L x H) and constructed accordingly. There were four inlets placed symmetrically in the middle of the classroom and one outlet exhaust was placed closer to the door. All inlets and the outlet was measured to have a diameter of 0.6 m. The classroom also had four windows on the east side and a door on the west side, and all were assumed as closed with no leakage.

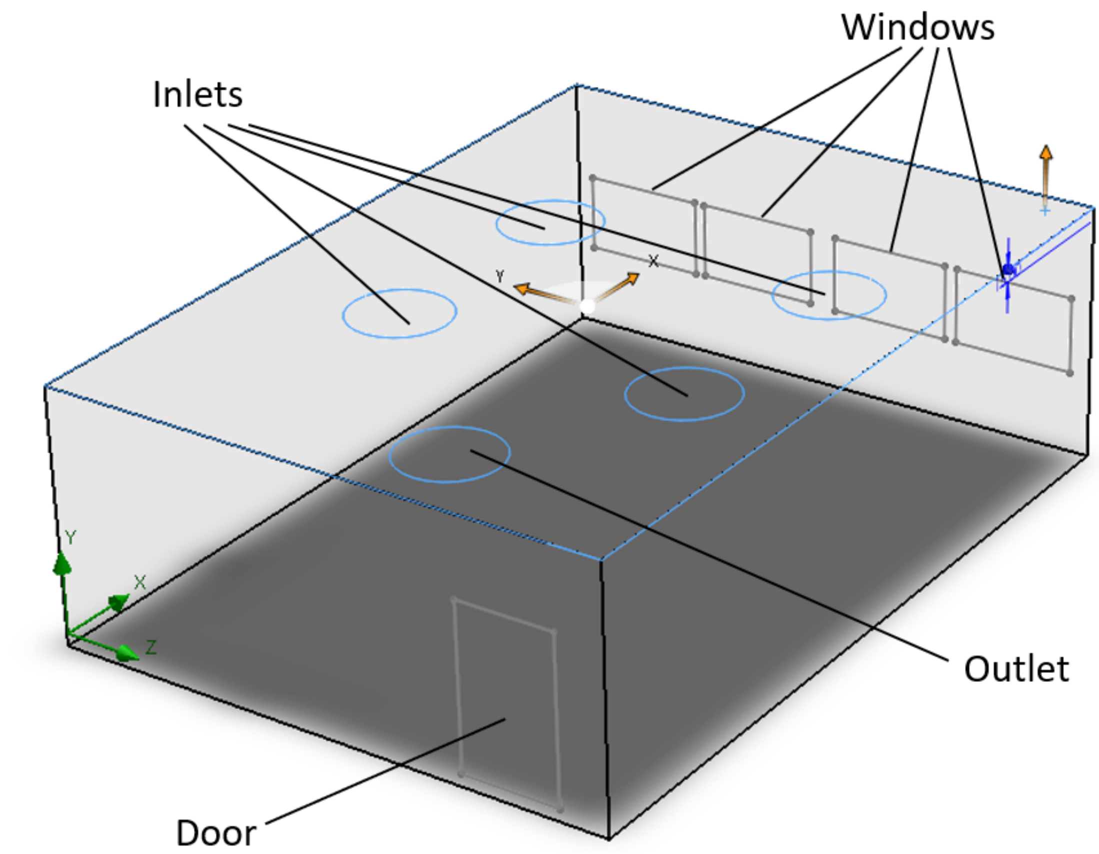


Figure 3.2.1: Clasroom 3707 in Solidworks.

After the classroom was constructed the occupants were ready to be added. A Computer Aided Model (CAD) of a human body was downloaded from Grabcad (2023) Community, which serves as a hub for engineers and designers. Here one can access a vast collection of CAD models and assemblies. It serves as a valuable resource for inspiration and knowledge sharing between people.

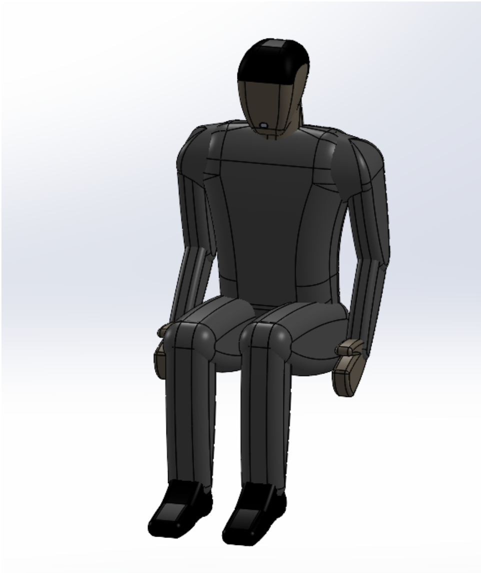


Figure 3.2.2: Human Body Model

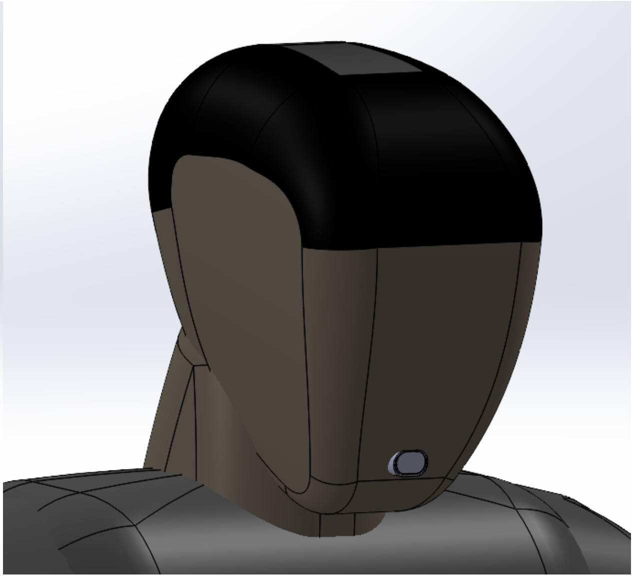


Figure 3.2.3: Constructed Mouth Piece

The only adjustment made to the human model was a change from standing to sitting body position and a self constructed mouthpiece to serve as the inlet of CO2. The mouth piece constructed had a size of 1.2 cm x 2.3 cm. The occupants were then added in the classroom and placed according to the real life scenario. In this simulation, all occupants are assumed to be sitting down and not exerting any energy at all.

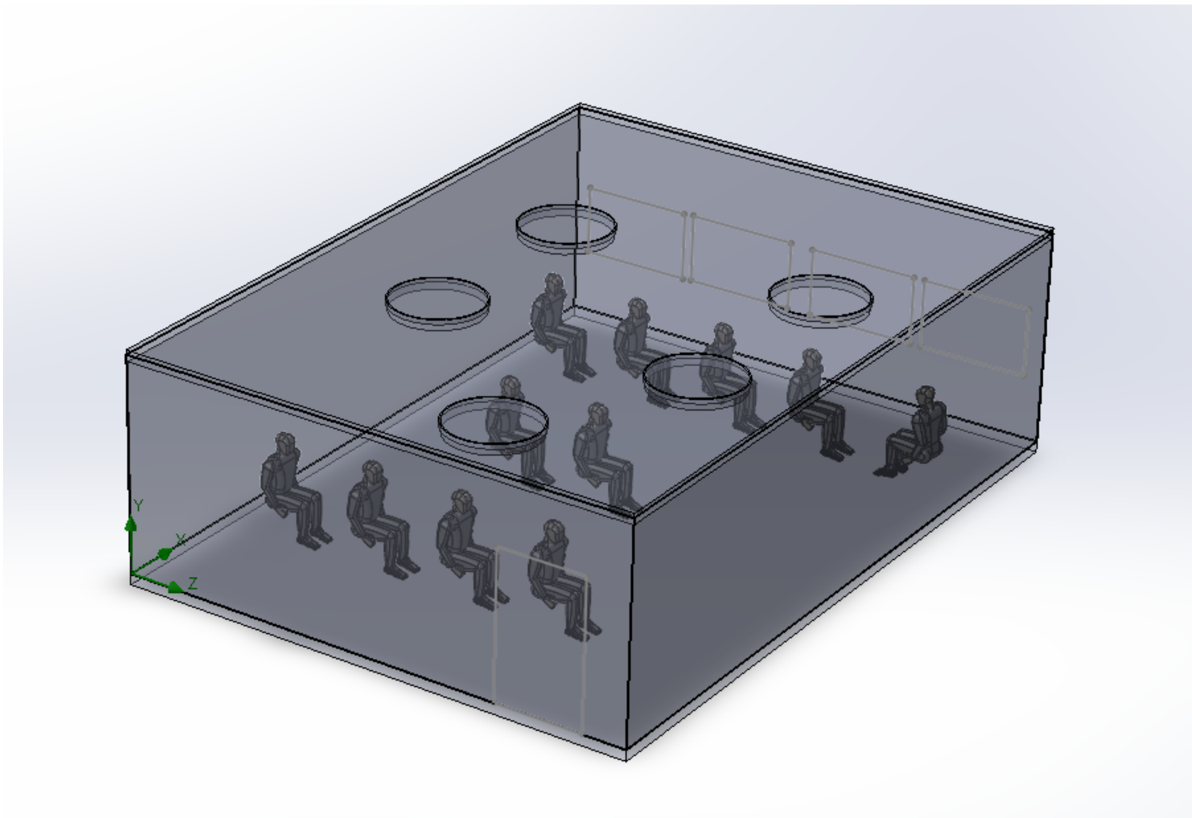


Figure 3.2.4: Classroom with occupants in Solidworks

3.2.2 Calculation of air supply rate in Contam

Since the air supply rate was not possible to gather through the building automation system it had to be calculated. The supply air rate was calculated through the help of the CONTAM Software which uses the mass balance equations 2.5. The airflow in the classroom was modulated by a duct damper centrally controlled by the CO2 level and is a varying number, but is assumed as constant in this simulation.

First, the room was constructed in the CONTAM software, where the dimensions and room volume was selected. The room had a floor area of 68.4 m^2 and a volume of 191 m^3. Contaminant data was also added with initial CO_2 concentration as 420 ppm.

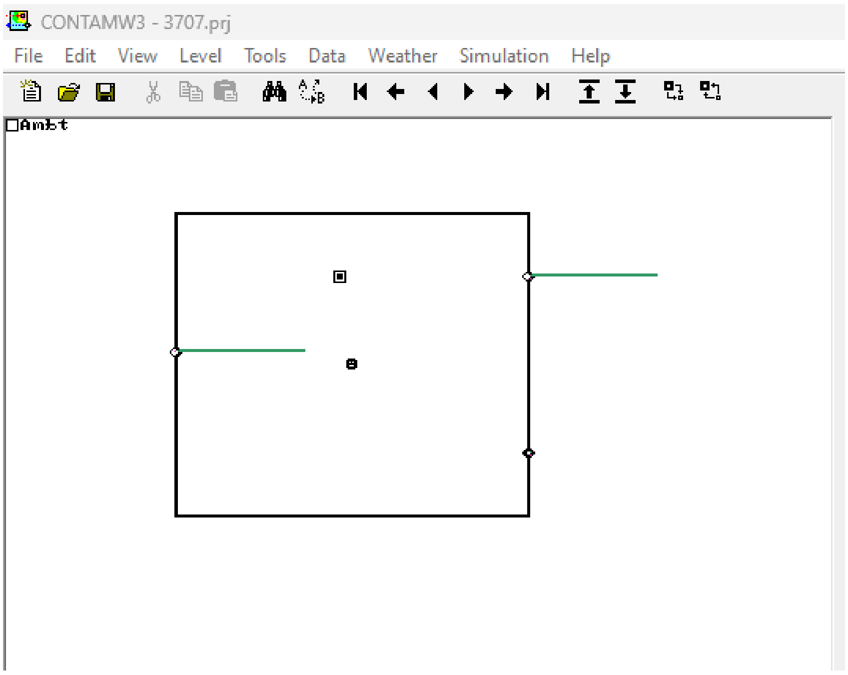


Figure 3.2.5: Contam setup

The occupant schedule was created according to the real life scenario. Generation rate of CO2 for the occupants was set to 15.84 l/h which is the average number from table 2.3.1. Number of occupants was set to 11 and a multiplier was applied according to when they left the classroom. A trial and error method with changing the air supply rate was used to obtain the most similar results to the average CO_2 concentration readings from the ELMA sensors.

Start time	**End time**	**Percentage of occupants in room**
00:00:00	08:45:00	0
08:45:00	09:52:00	100
09:52:00	10:04:00	20
10:04:00	10:20:00	100
10:20:00	11:15:00	0
11:15:00	12:00:00	0

Table 3.2.1: Occupancy schedule

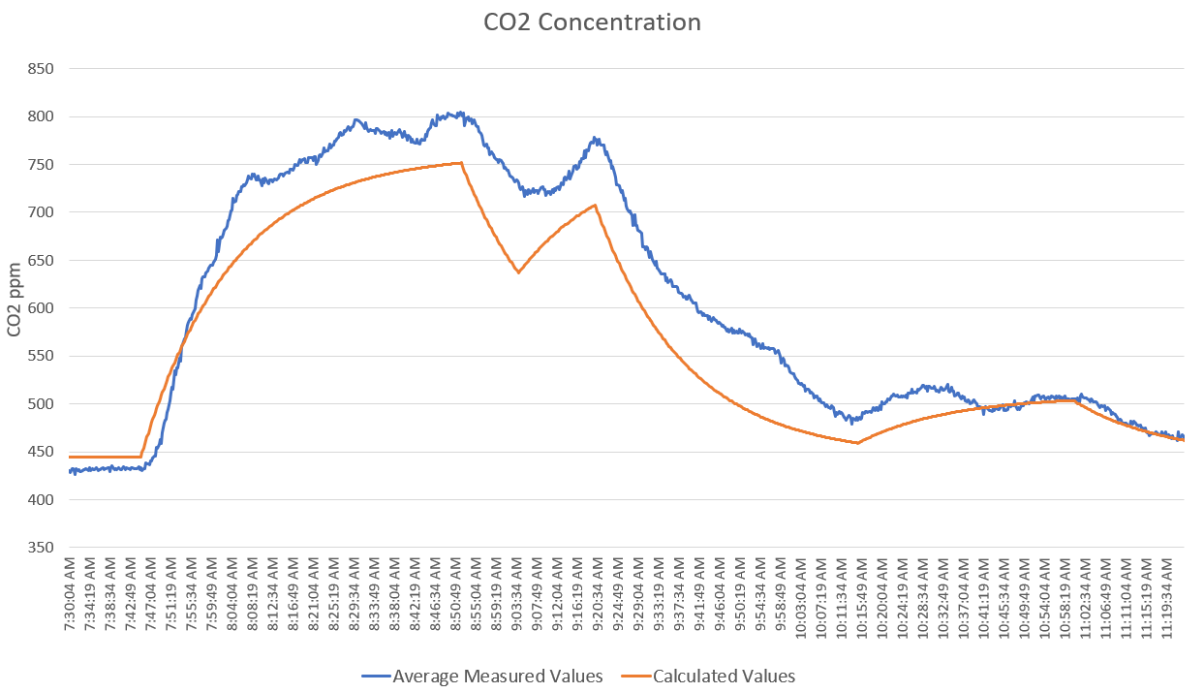


Figure 3.2.6: Calculated CO2 values

The trial and error method, resulted in an airflow of 600 m^3/h giving a quite similar graph to the average measured CO_2 values in the classroom as you can see in figure 3.2.6.

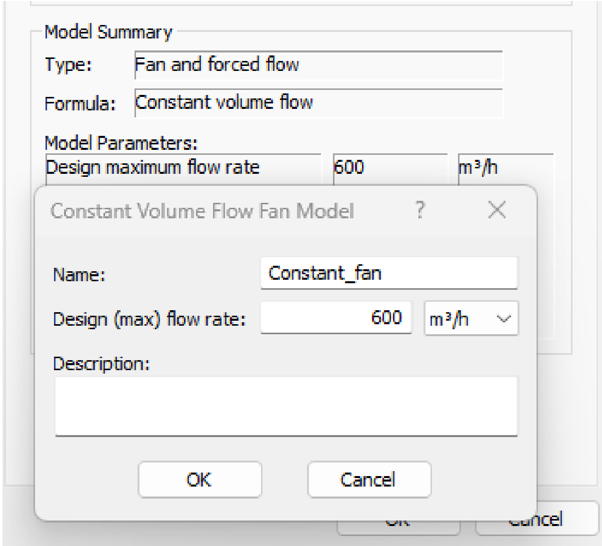


Figure 3.2.7: Calculated Airflow Rate

3.2.3 Minimum airflow

According to the TEK17 law, since the classroom is designed for having 31 occupants and with 26 m^3/h air supply per person and 2.5 m^3/h air supply per floor area should give a minimum airflow of 977 m^3/h. However, this classroom had 11 occupants which equals to a minimum airflow of 457 m^3/h. The current air supply rate of around 600 m^3/h is more than satisfactory. The design rate is set to 1320 m^3/h as can be seen in figure 3.2.8.

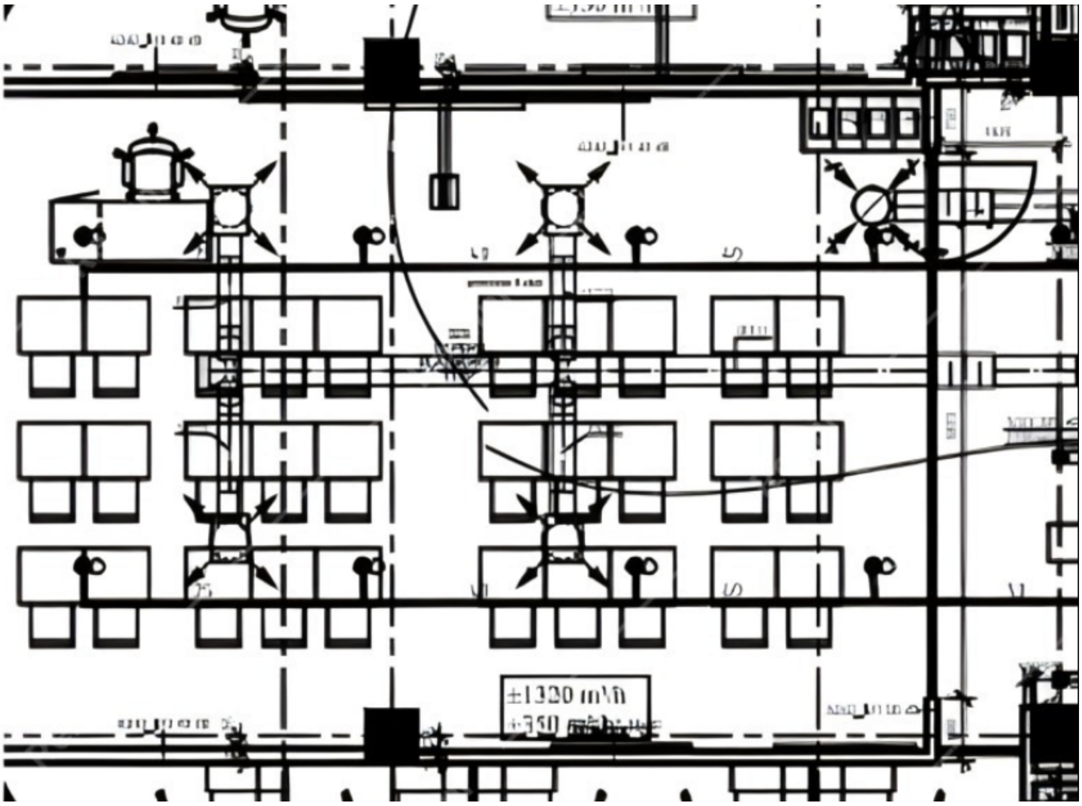


Figure 3.2.8: Floor Plan

3.2.4 Setting initial conditions

Before running the simulation the wizard settings were adjusted, which is a tool that guides users through the process to set up and run a simulation.

The analysis type was set to internal for studying and understanding the behavior of fluid flow within an enclosed or confined space. Physical features were set to time-dependent in order to study transient events, unsteady flow patterns and the evolution of the flow within this model. The total simulation time was set to 60 min and the time step size to 5 min. The gravity in the Y component was set to -9.81 m/s^2 for a more accurate representation of real-world scenarios and to help evaluate the structural integrity and motion behavior of particles in the design.

SolidWorks Flow Simulation provides a wide range of predefined gases that can be used in simulations to analyze fluid flow and heat transfer. These predefined gases have preconfigured properties, such as density, viscosity, specific heat, and thermal conductivity. One predefined gas that was chosen was air. It has a molar weight of 0.02896 kg/mol. However, a user-defined gas was constructed for CO2, with a molar weight equal to the air (gas).

Initial conditions were set to a pressure of 100058 Pa, due to the height of the school being at 106 meters above sea level. It was calculated by using formula 3.1 from EngineeringToolbox (2023).

$$p = 101325 * (1 - 2.225577 * 10^{-5}h)^{5.25588} \tag{3.1}$$

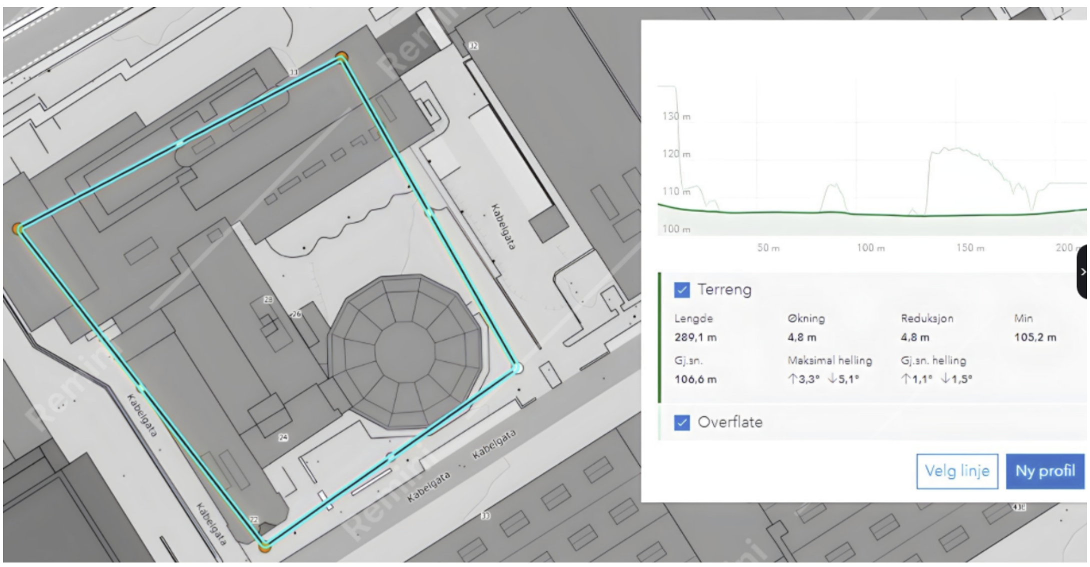


Figure 3.2.9: Height above sea level. Høydedata (2023)

The walls were set to adiabatic so no heat is transferred into or out of the system, and the change in internal energy is only done by work. Temperature was set to 23 degrees Celsius which was the average temperature in the room. Concentration was set to a volume fraction of 0.99958 for Air, and 0.00042 for Carbon Dioxide, since the atmospheric CO2 concentration is 420 ppm. DailyCO2 (2023).

3.2.5 Setting boundary conditions

After the air flow supply rate was calculated from CONTAM it was added as the inlet volume flow in the room. The inlet was set to 600 m^3/h which equals to 166.67 l/s. The flow was set to uniform and substance concentration was set to a volume fraction of 0.00042 for CO2. Since the ventilation system was balanced it can be assumed the outlet is exhausting a equal volume of air.

To approximate reality, a plate was added a few centimeters below the inlet to act as the diffuser in the classroom. The diffusers in the classroom have bladed holes to swirl the supply air which throws air both vertically and horizontally to mix the air. The plate was used to replicate this phenomena.

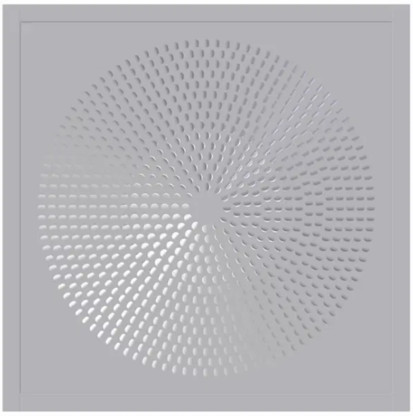


Figure 3.2.10: Diffuser from below Figure 3.2.11: Diffuser Trox (n.d.).

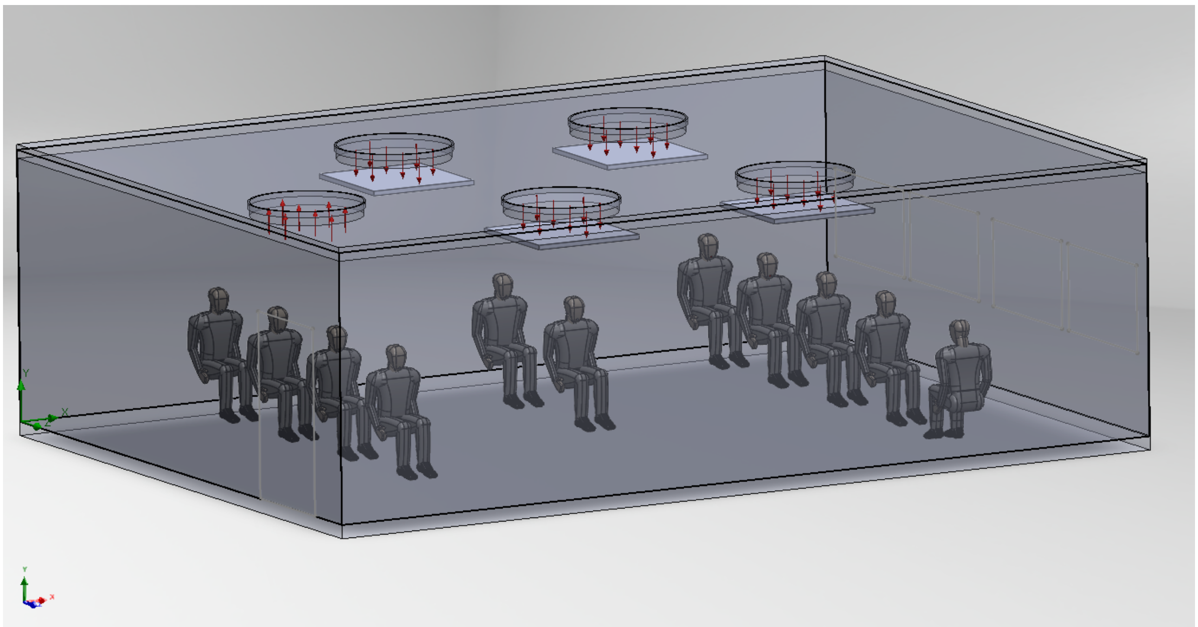


Figure 3.2.12: Plates added in Solidworks

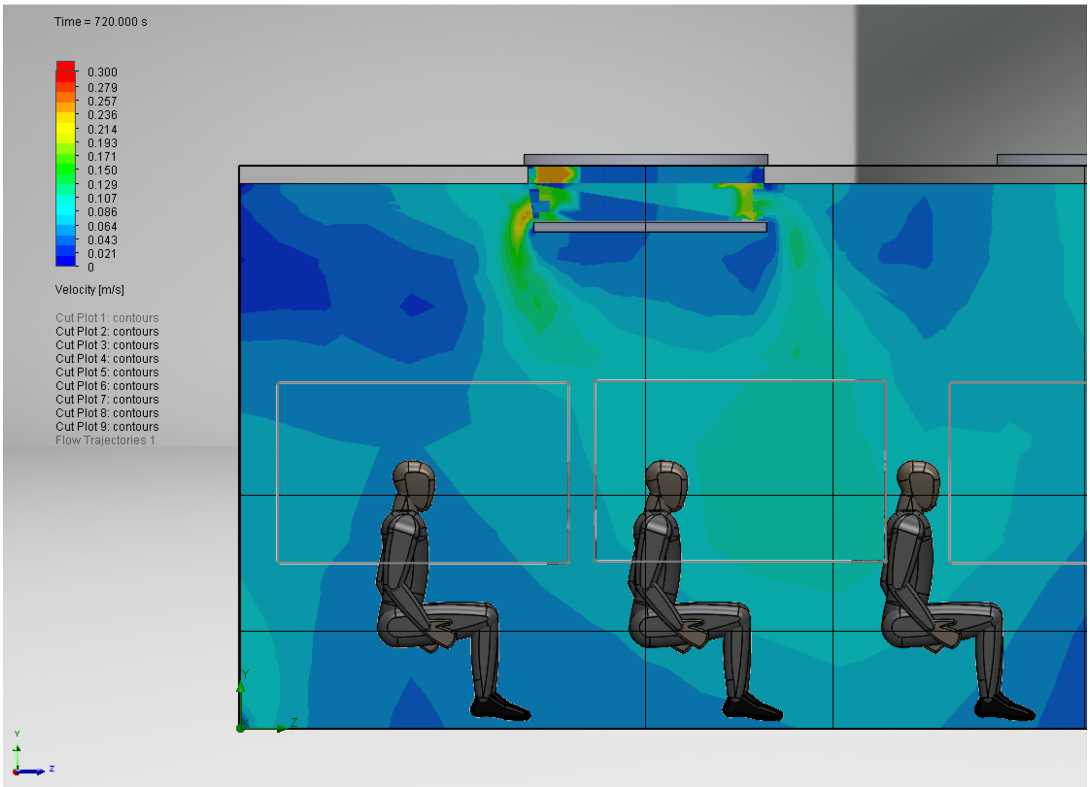


Figure 3.2.13: Velocity profile with the plates

The inlet volume flow for the mouth pieces was set to 0.0044 l/s which is the average from table 2.3.1. Volume fraction was set to 1, which is complete CO2 generation from the occupants. Below in figure 3.2.14 all boundary conditions can be seen.

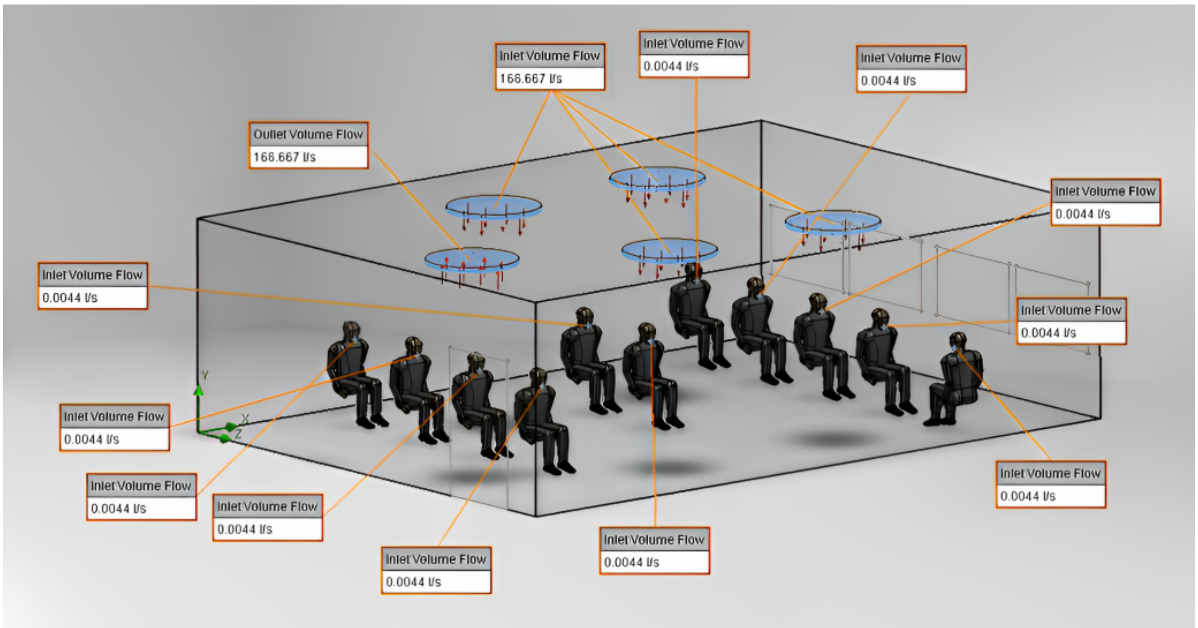


Figure 3.2.14: Boundary conditions

The turbulence parameters for the inlets was defined by turbulence intensity and turbulence length. For the inlet volume flow from the ventilation, the turbulence intensity was set to 5 percent and a turbulence length to 0.0311 m, which is the diameter of the inlet. The inlet volume flow from the occupants was set to 7 percent accompanied with a turbulence length as the diameter for the mouthpiece.

3.2.6 Mesh settings

The mathematical representation of a physical system that includes a part or assembly and boundary conditions is called Finite Element Analysis (FEA). It is not always possible to estimate behavior in the real world using straightforward calculations. By effectively describing physical processes using partial differential equations, a general technique like FEA offers an easy way to express complicated behaviors. One of these methods is meshing. Ansys (n.d.)

Meshing is the most crucial processes in carrying out an accurate simulation using FEA. A mesh is composed of elements having nodes that symbolize the geometry's shape. Uneven forms are difficult for a FEA solver to work with, but typical shapes like cubes make it much easier. The process of meshing is the transformation of amorphous shapes into more discernible volumes, or "elements." Ansys (ibid.)

The meshing settings for this simulation was set to the lowest refinement to have a faster simulation. This is at the cost of accuracy but was needed because of the long simulation time.

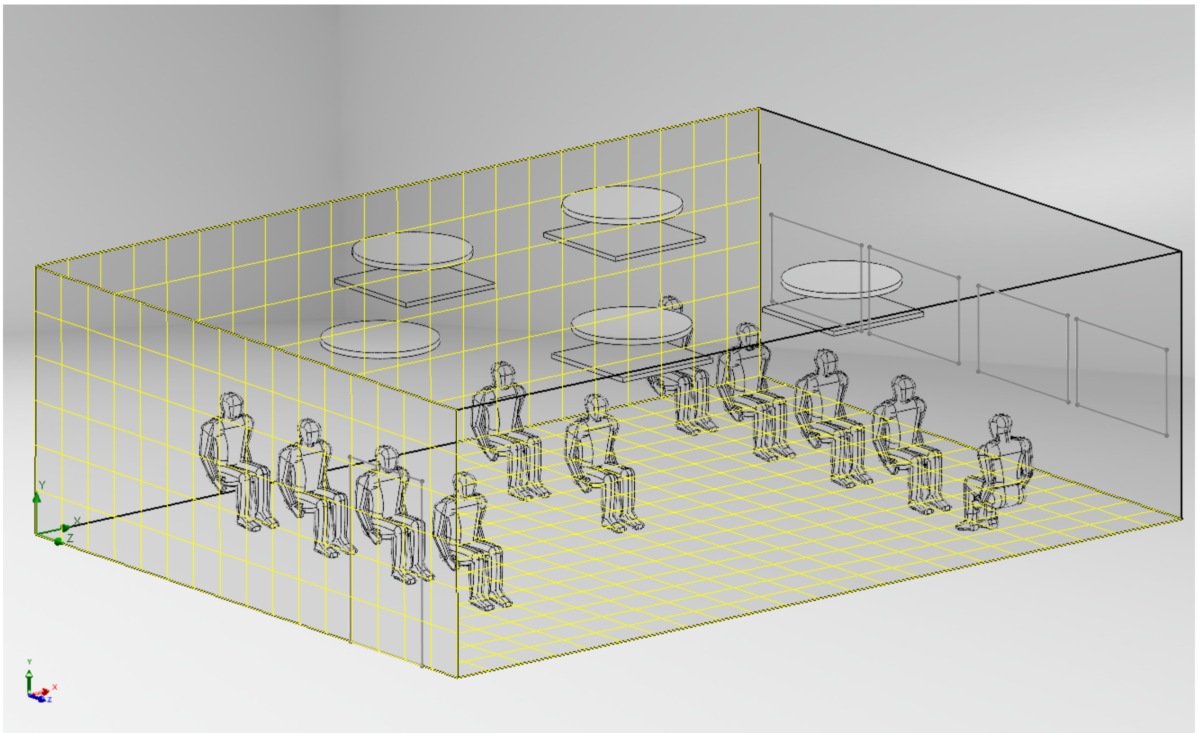


Figure 3.2.15: Global Mesh

CHAPTER

FOUR

RESULTS

The results from the simulation and the field measurements done in Kuben High School in March 2023 will be presented in the following sections.

4.1 Field Measurement Results

The results and analysis from the field measurements done in Kuben High School in March 2023 will be presented in this chapter. The classroom was used from 08:45 AM until 12:15 AM during which measurements were taken. The class had a break at 10:15 AM and after this the number of occupants changed to unknown.

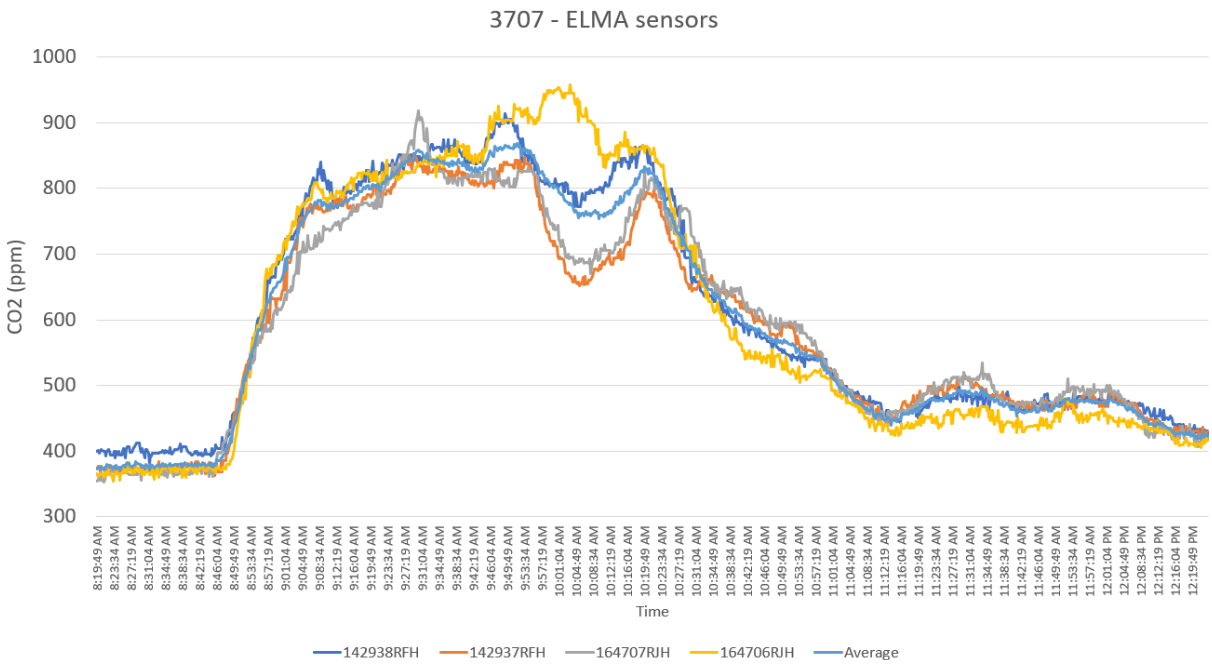


Figure 4.1.1: ELMA results from 3707

From figure 4.1.1 it can be seen that the CO_2 level inside the classroom is between 900-800 ppm when it is in use. However during a period of 45 minutes between 9:45 AM to 10:30 AM, the sensors showed different values. PS-1 (yellow) located closest to the door and the exhaust outlet has the highest readings around 900 to 950 ppm. PS-2 (dark blue), placed on the north facing wall, is close to the average reading (light blue) with a steady level around 750-800 ppm. PS-3 (orange), by the window, and PS-4 (grey), by the teacher, has the lowest values around 700 ppm in that time slot. There is a significant difference of 300 ppm between the most extreme locations.

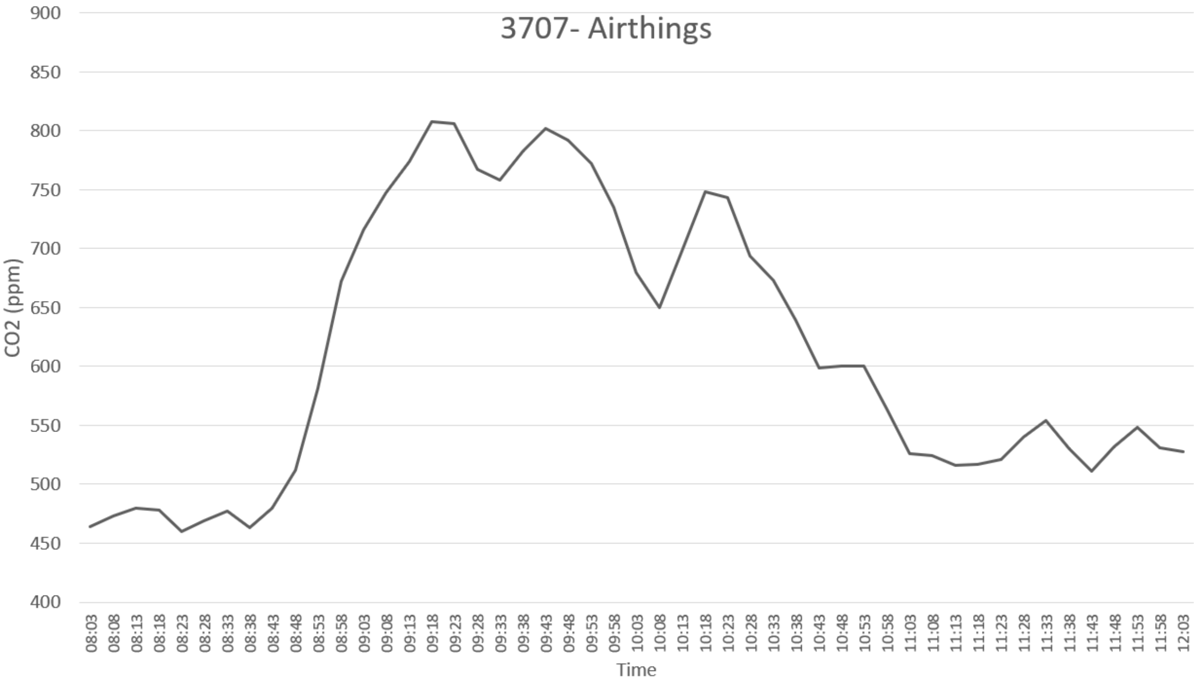


Figure 4.1.2: Airthings results from 3707

For the Airthings sensor, the levels are a bit lower between 800-750 ppm when in use. In the time step between 9:45 AM to 10:30 AM it drops down to 650 ppm. Rest of the graph is quite similar to ELMA.

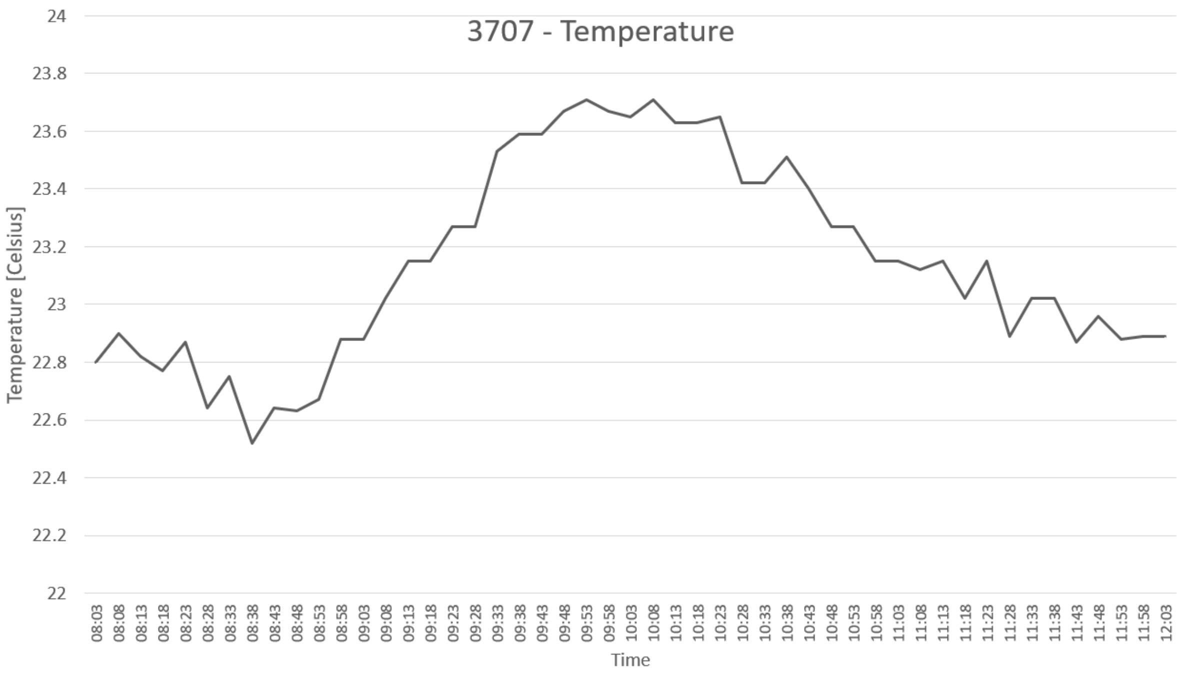


Figure 4.1.3: Temperature Airthings results from 3707

The temperature in the classroom was around 23 degrees all the time. It follows the CO2 graph slightly.

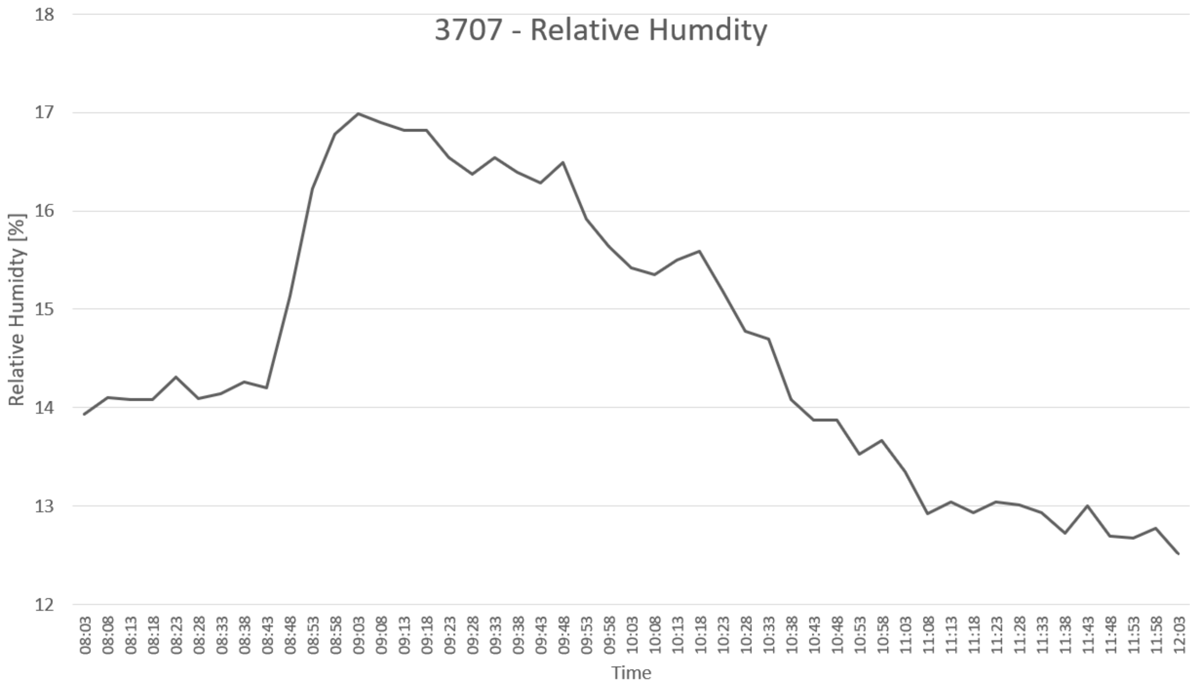


Figure 4.1.4: Humidity Airthings results from 3707

The relative humidity in the classroom is quite low. It starts at 14 percent and increases to 17 percent at the start of the class, and later falls down all the way to under 13 percent.

4.2 Simulation Results

The predicted airflow streamlines by Solidworks simulation can be seen in figure 4.2.1. The injected air from the inlet hits the plate and deflects to the sides and then downwards and mixes with the air from the breathing occupants which then gets circulated within the classroom. Large circulating airflows can be seen in the corners, especially by the teacher's desk.

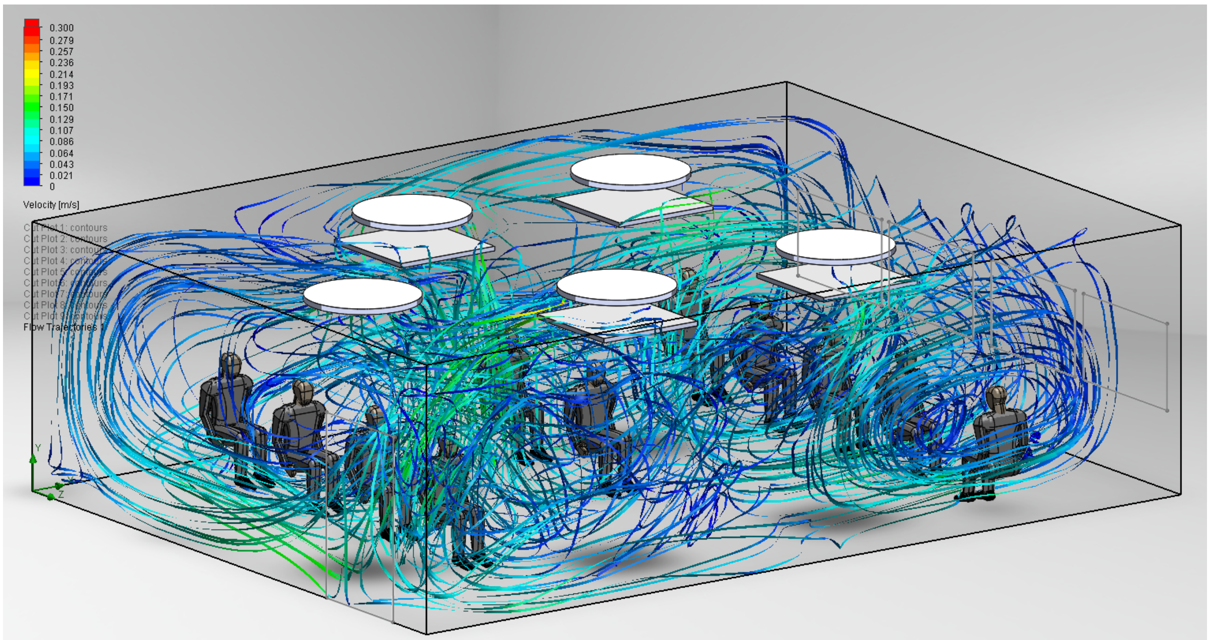


Figure 4.2.1: Airflow Streamlines results from Solidworks

The airflow velocity contour at a cut plane at the height of 1.2 m is shown in figure 4.2.2. The airflow velocity is observed larger by the breathing occupants on the left side compared to the right side of the classroom.

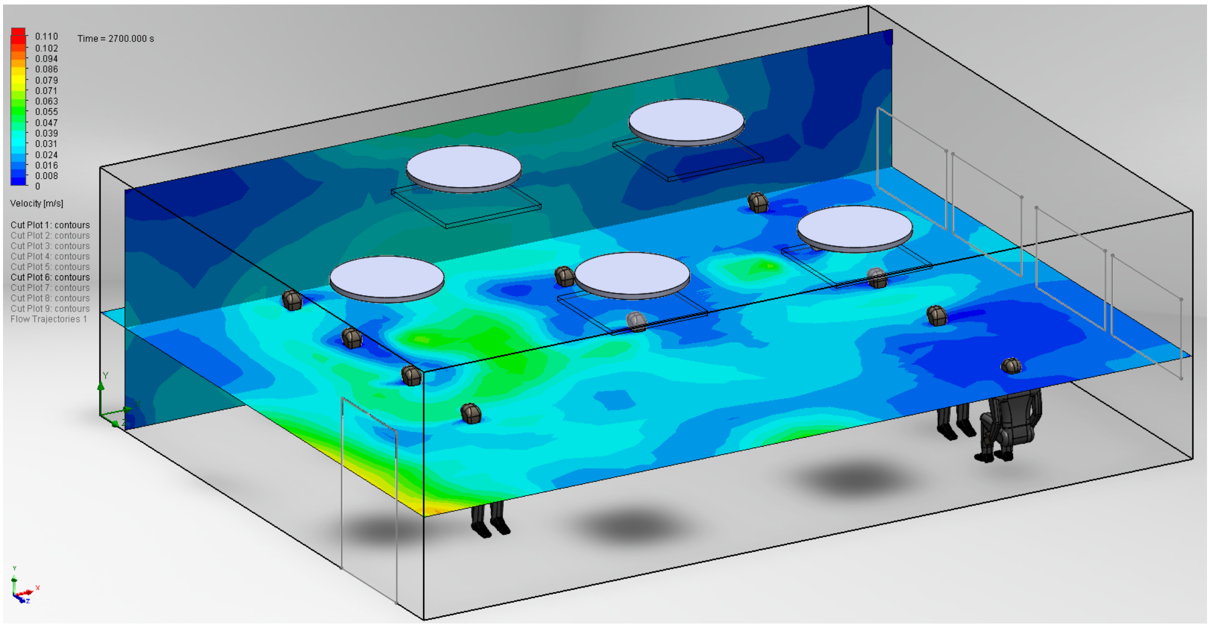


Figure 4.2.2: Airflow velocity contour at cut plane on breathing zone

The airflow velocity contour at cutplanes for the inlet are shown in figure 4.2.3. The airflow velocity is observed larger by supply valve closes to the exhaust and the door, compared to the rest of the inlets.

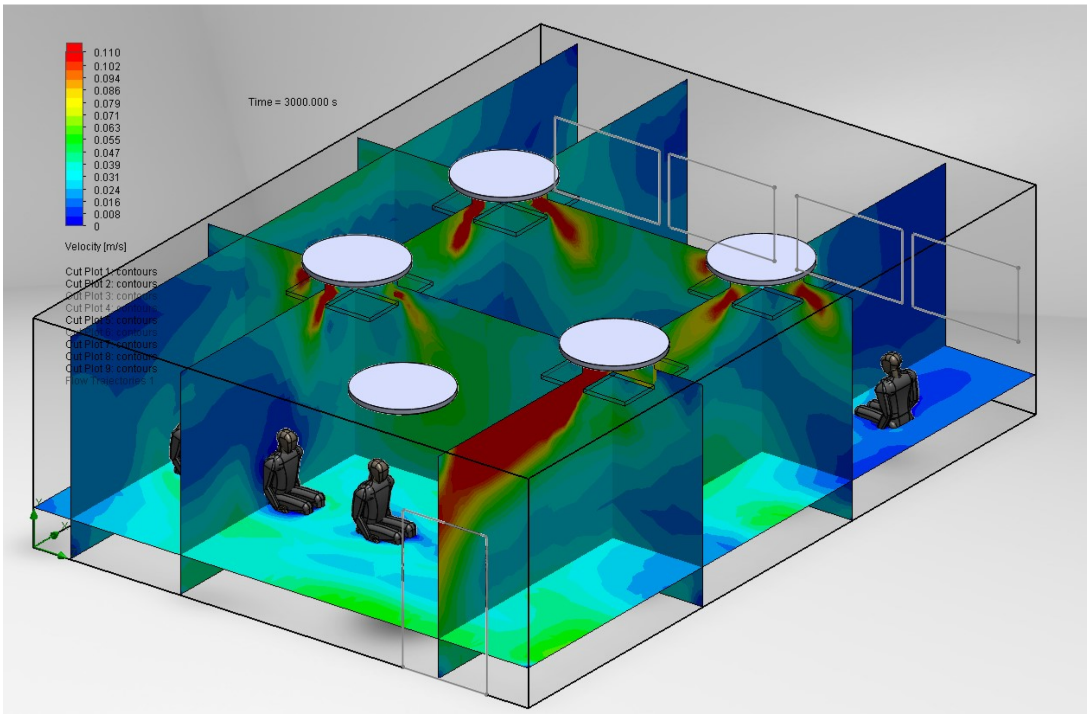


Figure 4.2.3: Airflow velocity contour from inlets

Figure 4.2.4 displays the spatial distribution of volume fraction of CO2 in the classroom at the height of 1.2 m after 50 minutes or 3000 seconds. It can be observed that there is a higher fraction of CO2 on the right hand side and a lower fraction of CO2 close to the extract valve.

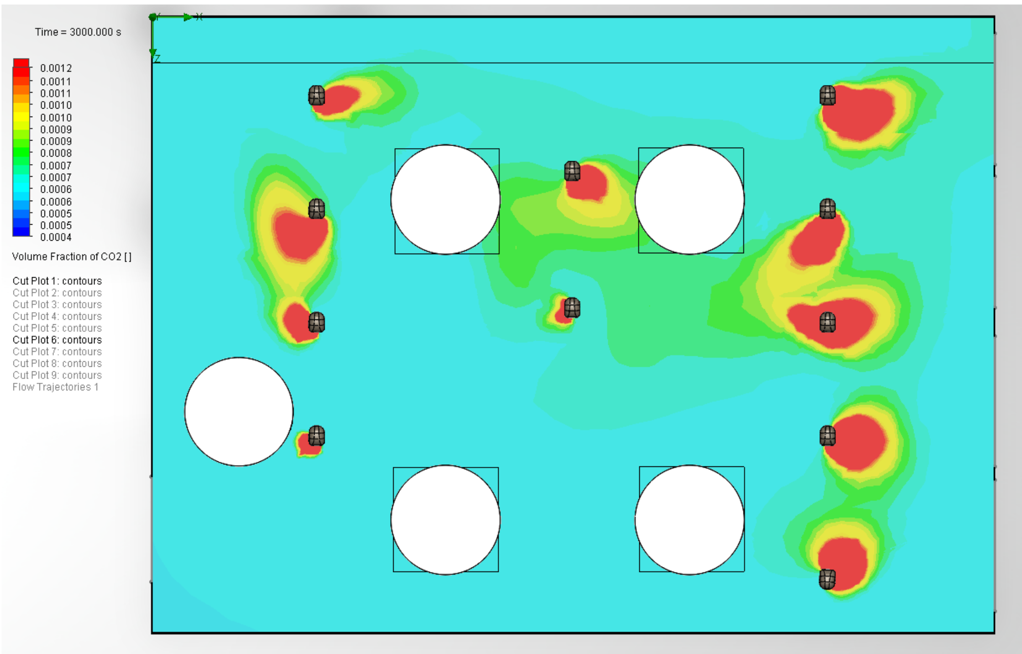


Figure 4.2.4: CO2 contour at cut plane on breathing zone

At a height of 2 m above the ceiling the CO2 fraction is also lower on the left side. There is more CO2 mixing at this level.

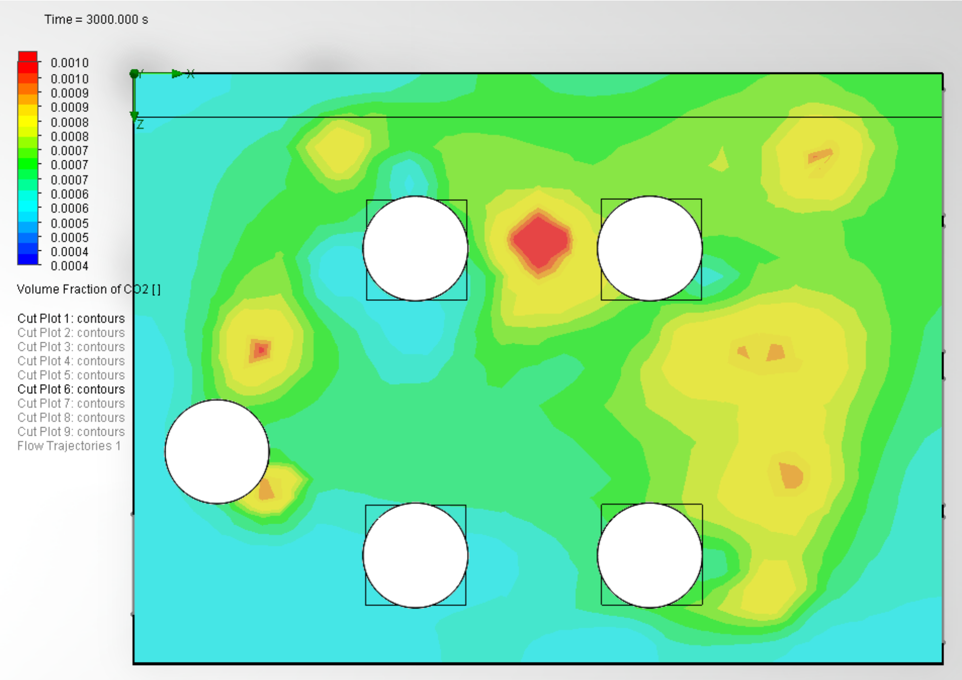


Figure 4.2.5: CO2 contour at cut plane 2 m above floor

The CO2 distribution between the occupants can be seen from the sides in figure 4.2.6 and 4.2.7. The distribution shows a lower CO2 concentration by the door and a higher in the rest of the classroom.

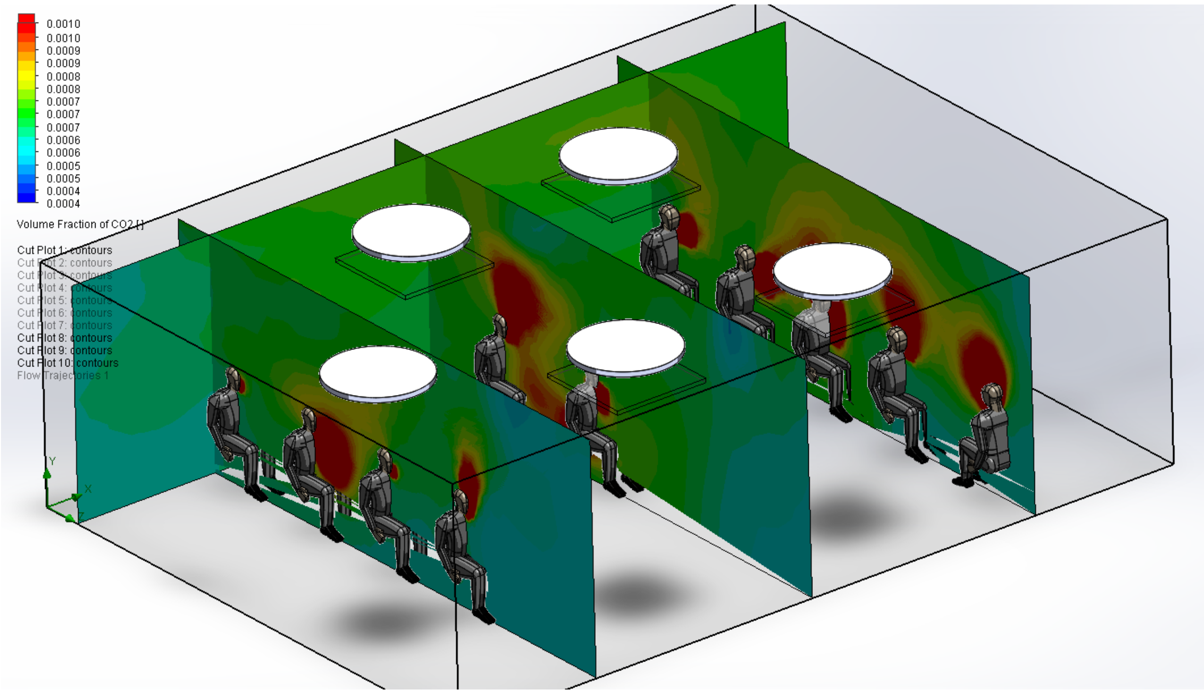


Figure 4.2.6: CO2 contour cut plane from the side

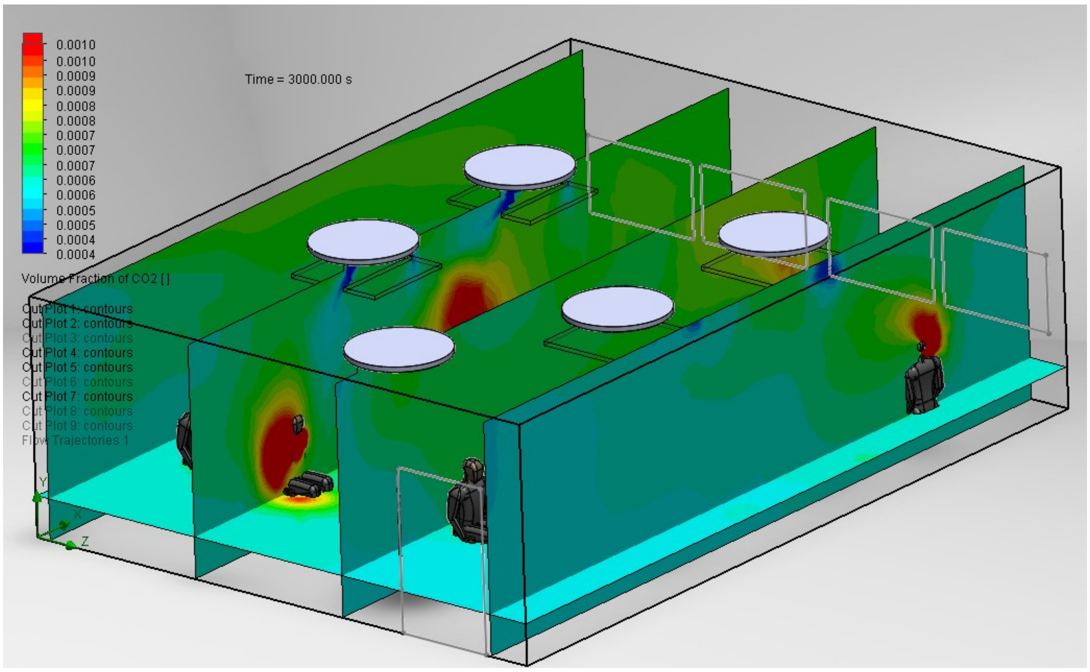


Figure 4.2.7: CO2 contour cut plane from the other side

The temperature distribution can be seen in figure 4.2.8. Indicates higher temperatures by the windows and lower close to the extract. It has a correlation with the air velocity because of higher velocity leads to a lower temperature.

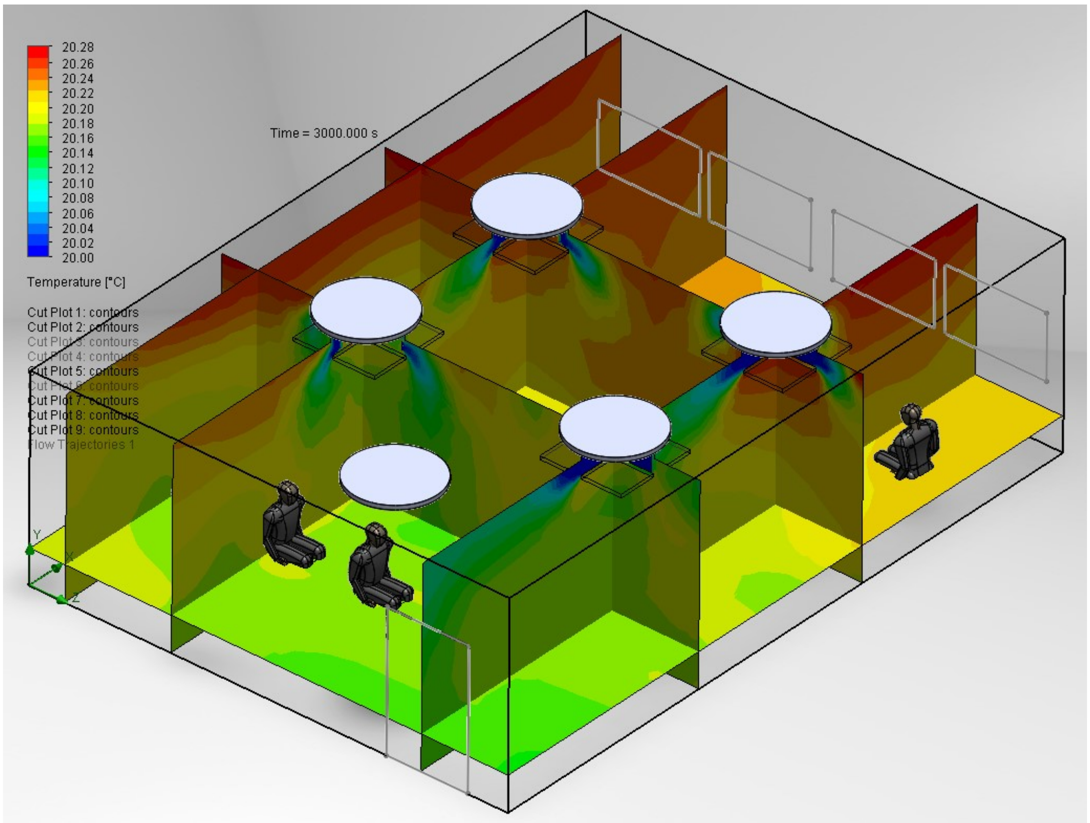


Figure 4.2.8: Temperature contour cut plane from the side

In Solidworks the exact location of the real-life placed sensors were pinpointed and the CO2 readings from those locations were tracked. After 15 minutes or 900 seconds the concentration in the room became steady and was around 600 to 700 ppm. While in the real life scenario it was around 800 at a steady level. All the sensors have relatively the same value except for PS-3 (orange), which has almost 100 ppm higher for about 40 minutes. In the last 30 minutes of the simulation, PS-4 (grey) oscillates drastically while increasing and reaches values over 1000 ppm.

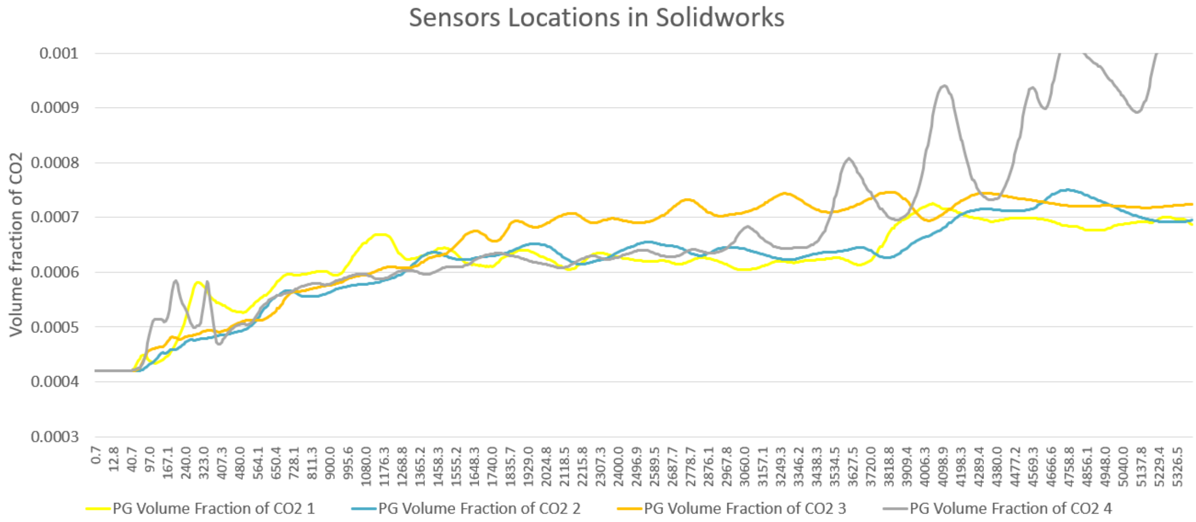


Figure 4.2.9: Same sensor location in Solidworks

4.3 Uncertainties

The accuracy and uncertainty of the Pegasor AQ Indoor used during calibration plays a significant role in calibration uncertainty. This reference standard should have a lower uncertainty when measuring the concentration of CO2 than the sensor being calibrated. Also, environmental factors such as temperature, humidity, and pressure, can affect the readings of a CO2 sensor and therefore it was put in the gas-tight workstation.

Random errors, which are inherent fluctuations in measurement readings, and systematic errors, which cause consistent biases in the measurements, can also contribute to uncertainties. These errors can arise from instrument imperfections, sensor drift, or external factors.

In the CONTAM simulation the airflow rate was roughly estimated through trial and error method and did not give the exact correct airflow. The air supply rate in the room was varying and made it difficult to calculate and therefore there is a big uncertainty that the chosen airflow can be far off the real value. In the Solidworks simulation the mesh generation was also set to the lowest refinement which decreases accuracy and increases uncertainty in the results.

CHAPTER

FIVE

DISCUSSION

From the field measurements classroom 3707 seems to have good CO2 values because its under 1000 ppm, however the CO2 readings of different sensors are not consistently the same. In the time interval between 9:45 AM to 10:30 AM the readings have a difference up to 300 ppm which is significant. The reason for this is unknown, as we cannot definitely conclude which parameters can be affecting the readings and only assumptions can be made. It may be due to windows being opened which can explain why both the sensors which were closest to the windows had the lowest readings. Alternately, it may be that the students except for the row sitting closest to sensor number 1 left the classroom. It may also be a combination of both circumstances. The activity in the classroom should have been monitored closer.

The ELMA sensors compared to the Airthings are overall similar with exception of a short interval. The ELMA sensors monitored every 15 seconds, while the Airthings records only every 5 minutes. During the mentioned interval, the Airthings dropped down to 650 ppm while sensor 1 increased to 950 ppm. Consideration must be given to the fact that the Airthings sensor was closer to the door. It is hard to compare because they are two different sensors, with different calibrations and have slightly different accuracies.

The SolidWorks simulation results were a bit lower compared to the field measurements. The simulation had a steady value around 650 to 700 ppm while the field measurement was around 850 ppm. This can be due to the fact that interior pollution has not been taken into account and only contaminant pollution from the occupants has been considered. The last 30 minutes of the simulation PS-4 increases while oscilliating and reaches very high levels of CO2. This may occur due to the airflow patterns in the simulation circulating in the same place. With a higher mesh density, the convergence and stability of the numerical solver can be improved and will reduce the chances of numerical instabilities.

The air is also not mixing as well due to low refinement on the mesh settings and not adding the right diffuser in the simulation. The turbulence intensity generated from the airflow hitting the plates are also unknown. With a higher mesh, smaller cells will capture a more detailed flow which can be important in accurately predicting the behavior of the fluid.

The temperature in the room is satisfactory and stable around 23 degrees Celsius. Temperature level follows the CO2 graph similarly and has a total change of 1 degree from the bottom of the graph to the top. The humidity on the other hand is extremely low. It starts at 14 percent, increases to 17 percent then drops down to below 13 percent. The recommended level is between 30 and 60 percent for indoor spaces to promote comfort, and minimize the risk of adverse health effects. It is the most common problem during heating season and occurs due to the fresh air supply entering the classroom containing low moisture. A humidifier can help to improve the indoor health for the occupants.

5.1 Limitations

To get a full understanding of the indoor air quality in the classroom, more information needs to obtained. However, the equipment and time limitations made this impossible. Since the building automation system is old, it was difficult to obtain the technical data and ventilation rate, and was therefore calculated manually. Due to time limitations and clash of schedules only two days were utilized for the field measurements. Because of privacy and security reasons, the occupant behaviour could not be recorded and only information provided by the teacher was relied upon. The computer for the simulation was also not strong enough for doing the calculations. Neither was the furniture in the classroom added which also affects the airflow patterns and CO2 distribution. Lower simulation time was given more emphasis compared to accuracy and detail.

CHAPTER
SIX

CONCLUSIONS

The airflow field and CO2 spatial distribution in a classroom seated with CO2 generating occupants has been modelled and simulated utilizing a CFD analysis. The airflow streamlines, velocity and CO2 spatial distribution in the indoor space of the classroom have been investigated. The results demonstrated that the CO2 spatial distribution within the classroom was not homogeneous and not mixed well in the simulation due to low meshing. For an efficient DCV, deployment of the CO2 sensors should be avoided in the vicinity close to the occupants, because high CO2 concentration was observed. Different locations close to the extract valve, walls and windows were examined. Sensor placement close to extract valves will have a higher concentration compared to the average concentration and should therefore be taken into account. This also applies to sensors close to open windows which have a lower CO2 concentration compared to the average concentration of the room. Location of the sensors can affect the average readings up to $\pm$ 150 ppm in some cases. In case a sensor is placed closer to the extract a lower setpoint must be set for calculating the average CO2 value in the classroom. Similarly, if a sensor is placed closer to the windows a higher setpoint must be set for calculating the average CO2 concentration. This will increase the DCV efficiency and provide a more comfortable environment for the occupants.

The simulation was not able to reflect the true CO2 concentration within the indoor space as was accomplished by the field measurements, but did illustrate airflow patterns which indicates how the air moves within the space. The airflow patterns demonstrated in the simulation shows high movement and velocity of air towards the extract valve. It also shows a lot of circulating air in the corners of the room.

The CFD modelling could not provide useful enough information on proper placement of CO2 sensors for assuring the measurement data quality and achieving a higher effective DCV. Further work most be done with more accurate simulation parameters and with a better monitoring of the activity in the classroom and the airflow supply rates in order to definitively ascertain the optimal location for placement of the sensor.

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APPENDICES

.1 Sensor Specifications

Specifications

- Extracted sample temperature can be from -20 °C to room temperature (non-condensing)
- 0-100% RH
- No sample conditioning needed
- Time response 1 s – 60 min
- Max data storage time 1 year
- Measured ultrafine particle size range from 10 nm and up
- Modulating trap voltage to provide mean particle size information for data calculation
- Total ultrafine particle mass, total ultrafine particle number and LDS measurement simultaneously from 10 nm and up.
- modulating trap voltage providing size information to the sensor for data calculation.
- No sample conditioning needed
- Low maintenance need
- Concentration range for particle number 300 $1/cm^3$ up to $6*10^8$ $1/cm^3$
- Concentration range for particle mass 1 $\mu g/m^3$ up to 200 mg/m^3
- Dimensions 165 x 200 x 340 mm, weight 7 kg
- Clean air flow generated and monitored with internal pump and flowmeter
- Sample flow generated and monitored with internal pump and flowmeter. Measurement result is flowrate corrected (sensor loading, and altitude effects eliminated)
- Built in data storage 1 GB, flash memory
- Connections USB to Stick, analog V (0-10 V) or mA (4-20 mA). Range adjustable by the user. Modbus over Ethernet, wireless 3G/4G modem, radio modem, cloud service
- Operating voltage AC 100-240 V or DC 24 V, 2,7 A (power supply included in the shipment)
- Continuously self-diagnosed for trap voltage, corona voltage, corona current, and sensor impedance, both trap insulator and main insulator. Impedance indicates sensor loading and possible cleaning need/water condensation.

Pegasor AQ Indoor Technical Data

AIRTHINGS

View Plus

Complete indoor **air quality monitor**

DOWNLOADS

DIGITAL USER MANUAL

The most advanced air quality tech. 9 out of 10 people in the world breathe unsafe air according to WHO guidelines. With View Plus, you can keep your family safe from air pollutants: radon, particulate matter (PM), carbon dioxide (CO_2), humidity, temperature, airborne chemicals (VOCs) and air pressure. When there is so much that is out of your control–pollution, asthma, allergies, wildfire, virus–you have more control than you think when it comes to indoor air quality with View Plus. Airthings View Plus is battery operated (or powered by USB), wireless and WiFi connected, includes a customizable display, app (iOS/Android) and online dashboard with full data and reporting. When you know what's in the air you breathe, small changes make a big difference.

HIGHLIGHTS

CALM TECH DISPLAY

Customizable display and wave function to view pollutants with simple color coding

WIRELESS

WiFi connected and battery operated (battery lifetime up to 2 years) or plug in with USB

BUILD YOUR AIR QUALITY SYSTEM

Use as a Hub to bring other Airthings monitors online for access to data anytime, anywhere

APP / DASHBOARD

App and online dashboard with graphs, notifications and insights

SMART HOME INTEGRATIONS

Integrate with your smart home using IFTTT, Google Assistant and Amazon Alexa

EASY TO USE

Intuitive design with batteries included for quick and simple setup

PRODUCT FEATURES

SENSORS

Particulate matter (PM_1* & $PM_{2.5}$), radon, CO_2, VOC, temperature, humidity, air pressure

DISPLAY

2.9 " 296128 pixels ePaper

Visual indicator: Color coded red/yellow/green glow indicator

LONG BATTERY LIFE

WiFi: up to 2 years (depends on sensor interval and WiFi router)

Optional operation on USB (runs from batteries if removed)

MOUNTING

Supports wall mounting or placement on flat surface

Optimum product placement is breathing height of (110-170cm / 40-70in above floor). Only suitable for mounting at heights below 200 cm / 6.5 ft

Double-sided tape for wall mount included in package

Alternatively use 3 screws of type countersunk M4 (not included)

APP, DASHBOARD AND CONNECTIVITY

Free mobile app for iOS and Android with notifications

Web dashboard with sensor data

802.11 b/g/n (2.4 GHz) WiFi, Airthings SmartLink & Bluetooth Low Energy

Wireless connection over WiFi

SmartLink when used as a Hub for other Airthings devices

Bluetooth for onboarding and daily use configuration only

Hub functionality is enabled when connected with WiFi and USB cable is plugged into device

ADDITIONAL SPECIFICATIONS

RECOMMENDED OPERATING CONDITIONS

Temperature 4 to 40 °C / 39 to 104 °F, Humidity 0 % to 85 % (non condensing). Prolonged exposure to very dry or humid conditions may affect the visual appearance of the display. Exposure to very humid conditions can degrade the radon sensor.

PHYSICAL SPECIFICATIONS

Weight: 360 g / 12.7 oz (with batteries, without cable)

Dimensions: 17 x 9 x 3.3 cm / 6.7 x 3.5 x 1.3 in

Power: 6 AA batteries or USB

PRIVACY: Noise Indicator used for measuring sound pressure level only, no privacy concerns (Noise is only enabled for Airthings for Business)

* Only visible in the Airthings Dashboard

AIRTHINGS

PACKAGE CONTENT

Air Quality Monitor
6 AA batteries
USB cable
Quick Start and Regulatory Booklet
Double-sided tape

REQUIREMENTS

One of the 3 latest major versions of iOS or Android, supporting Bluetooth 4.2 or later

PACKAGE

WEIGHT: 511 g / 18 oz

DIMENSION: 200 x 115 x 60 mm / 7.9 x 4.5 x 2.4 in

PRODUCT CODES

EAN: 7090031109608
UPC: 854232008224
SKU: 960
MODEL: 2960
Device serial number: 2960xxxxxx

INTEGRATIONS

Works with IFTTT
amazon alexa
works with the Google Assistant

SENSOR SPECIFICATIONS

TEMPERATURE / HUMIDITY / PRESSURE

Technology: solid state sensor

Sensor interval 5 min (2.5 min with USB cable connected)

Temperature Accuracy: ±0.5 °C / ±1 °F

Humidity Accuracy: ±3 %RH

Pressure Accuracy: ±0.6 mBar/hPa

RADON

Radon sampling: Passive diffusion chamber

Detection method: Alpha spectrometry

Sensor interval 60 min (fixed)

Measurement range: 0 – 20,000 Bq/m^3 / 0 – 500 pCi/L

Typical accuracy after more than 30 days of continuous measuring at 200 Bq/m^3 / 5.4 pCi/L:
7 day average: ±10 %,
2 month average: ±5 %

PARTICULATE MATTER

Technology: laser scattering based optical particle counter

Measurement interval is configurable to 10 min or 60 min (2.5 min with USB cable connected)
Particle size detection range: 300 nm to 10 µm

Measurement Range ($PM_{2.5}$): 0 ~ 500 µg/m³

Measurement Accuracy ($PM_{2.5}$): below 150 µg/m³: ± (5 µg/m³ + 15%), above 150 µg/m³: ± (5 µg/m³ + 20%)

Calibrated with a GRIMM reference instrument using cigarette smoke source

Classified as Class 1 Laser per IEC60825-1 Ed. 3. This device complies with 21 CFR 1040.10 and 1040.11, except for conformance with IEC 60825-1 Ed. 3., as described in Laser Notice No. 56, dated May 8, 2019. Caution: These devices contain one or more lasers. Usage other than as described in the user guide, repair, or disassembly may cause damage, which could result in hazardous exposure to infrared laser emissions that are not visible. This device should be serviced by Airthings or an authorized service provider.

VOC

Technology: Metal-oxide based gas sensor

Measurement interval 5 min (fixed)

Settling Time: ~7 days

Measurement range: 0 - 10,000 ppb

Self-calibrated using an automatic baseline algorithm that updates continuously based on the cleanest air the sensor is exposed to.

The VOC and CO_2 sensors continuously calibrate by using the cleanest level of air as a baseline to distinguish from polluted air. For this reason, it is important that the sensor is exposed to clean air on a weekly basis.

More info

CO_2

NDIR Sensor (Non-Dispersive Infra-Red):

Measurement interval 5 min (2.5 min with USB cable connected)

Measurement range 400 – 5000 ppm

Accuracy ±50 ppm ±3 %RH within 10 – 35 °C / 50 - 95 °F and 0 – 80%RH, after initial calibration time of 7 days
Self-calibrated using an automatic baseline algorithm that updates once a week

SENSOR DATA UPDATE INTERVAL

Sensor data in app (iOS/Android) and online dashboard update interval depends on configuration:

WiFi: same as PM measurement interval (10 min or 60 min when battery operated, 2.5 min with USB cable connected)

RADIO SPECIFICATIONS

BLUETOOTH LOW ENERGY

Output power: <5 mW

Frequency Range (MHz): 2400.0 - 2483.5

AIRTHINGS SMARTLINK

Output power: <25 mW

Frequency range (MHz):
in Europe 868 - 870
in North America 902-928
in Singapore 920-923
in Hong Kong 920-923
in Australia 923-928
in India 865-870

802.11 b/g/n (2.4 GHz) WiFi

Output power: <50 mW

Frequency Range (MHz): 2400.0 - 2483.5

WANT TO KNOW MORE?

Detailed information and FAQs on our sensors can be found here.

RADON PM CO_2 HUMIDITY TEMP VOC PRESSURE

V1-12-2021

4. SPECIFICATIONS

4.1 REFERENCE CONDITIONS

Influence quantities	Reference conditions
Supply voltage	3 ± 0.5V
Air pollution	no pollution (CO, solvents, etc.)

4.2 MEASUREMENT CHARACTERISTICS

4.2.1 CO_2 measurements

Type of sensor	Dual-beam infrared cell
Measuring principle	Non-dispersive infrared (NDIR) technology
Measurement range	0 to 5.000ppm
Intrinsic uncertainty	±3% ±50 ppm at 25°C and 1013 mbar; in ECO mode, ±3% ±80 ppm at 25°C and 1013 mbar
Response time at 63%	195 seconds
Resolution (R)	1ppm

4.2.2 Influences on the measurements of CO_2.

The influence of the temperature is 1 ppm/°C from -10 to +45°C.
The influence of the atmospheric pressure is:

$CO_{2\,real} = CO_{2\,measured}\ x(1 + (1013\text{-}P)x0{,}0014)$ avec P= pressure in mbar.

4.2.3 Temperature measurements

Type of sensor	CMOS
Measurement range	-10 to +60°C
Intrinsic uncertainty	±0.5°C at 50% RH
Influence of relative humidity	±0.5°C ±R from 10 to 40% RH Outside of the range stated above, ±0,032 x (T-25°C) ± R
Resolution (R)	0.1°C or 0.1°F

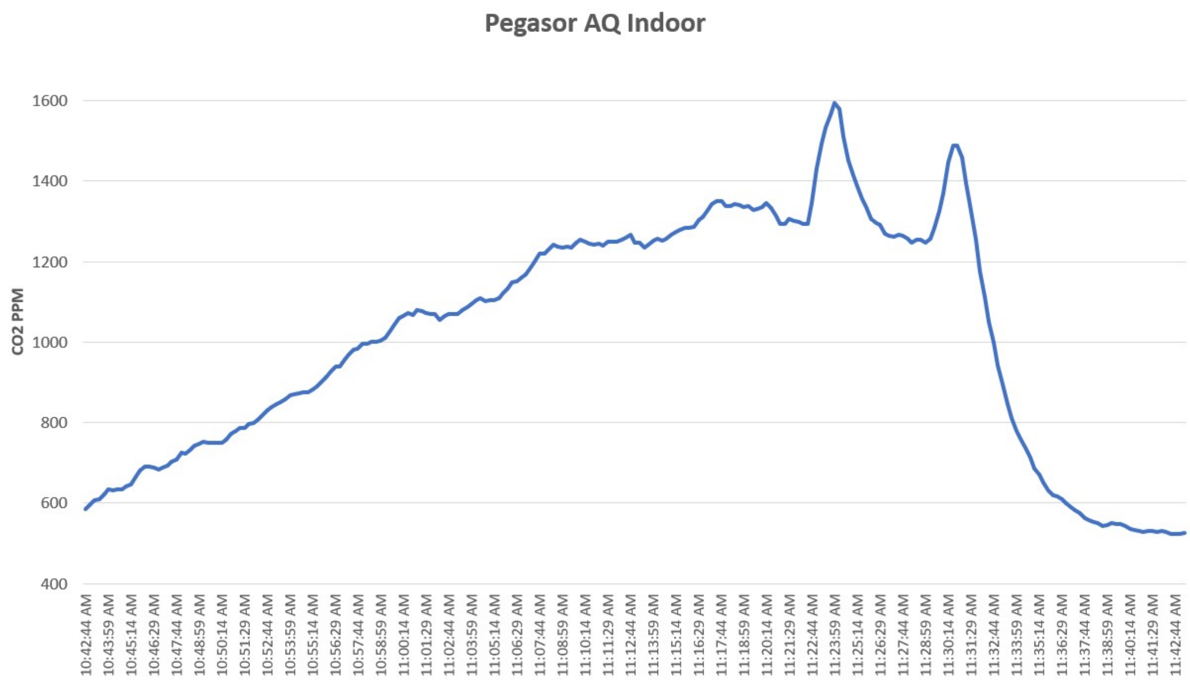
4.2.4 Humidity measurement

Type of sensor	Capacitive
Measurement range	5 to 95 %RH
Intrinsic uncertainty	± 2 %RH ± R from 10 to 90 % RH ± 3 %RH ± R outside of the range stated above.
Resolution (R)	0.1 %RH
Measurement hysteresis	± 1 %RH **Note:** Prolonged exposure to values outside the 10% to 80% range may lead to a measurement bias of as much as ± 3 %RH. This bias disappears after 5 days at between 20 and 30°C and 40 and 75% RH.
Rate of increase of intrinsic uncertainty	< 0.5 %RH/year.

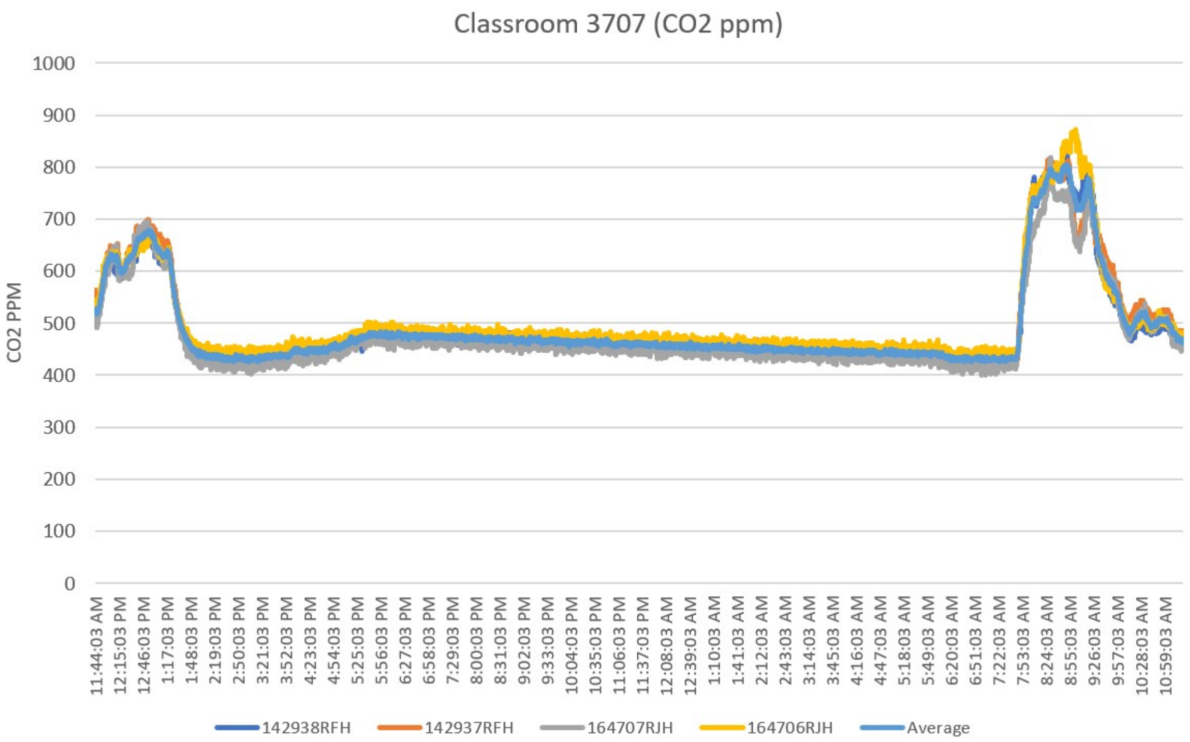
Tekniske data

Digital laserafstandsmåler	PLR 50 C
Varenummer	**3 603 F72 2..**
Afstandsmåling	
Måleområde[A)]	0,05–50 m
Målenøjagtighed[B)]	±2,0 mm
Generelt	
Driftstemperatur[C)]	−10 °C ... +50 °C
Opbevaringstemperatur	−20 °C ... +70 °C
Relativ luftfugtighed maks.	90 %
Maks. anvendelseshøjde over referencehøjde	2000 m
Tilsmudsningsgrad iht. IEC 61010-1	2[D)]
Laserklasse	2
Lasertype	635 nm, < 1 mW
Laserstrålens divergens	< 1,5 mrad (360°-vinkel)
Automatisk frakobling efter ca.	
– Laser	20 s
– Måleværktøj (uden måling)[E)]	5 min
– *Bluetooth*® (hvis inaktiv)	3 min
Batterier	3 × 1,5 V LR03 (AAA)
Dataoverførsel	
Bluetooth®	*Bluetooth*® 4.2 (Low Energy)[F)]
Driftsfrekvensområde	2402–2480 MHz

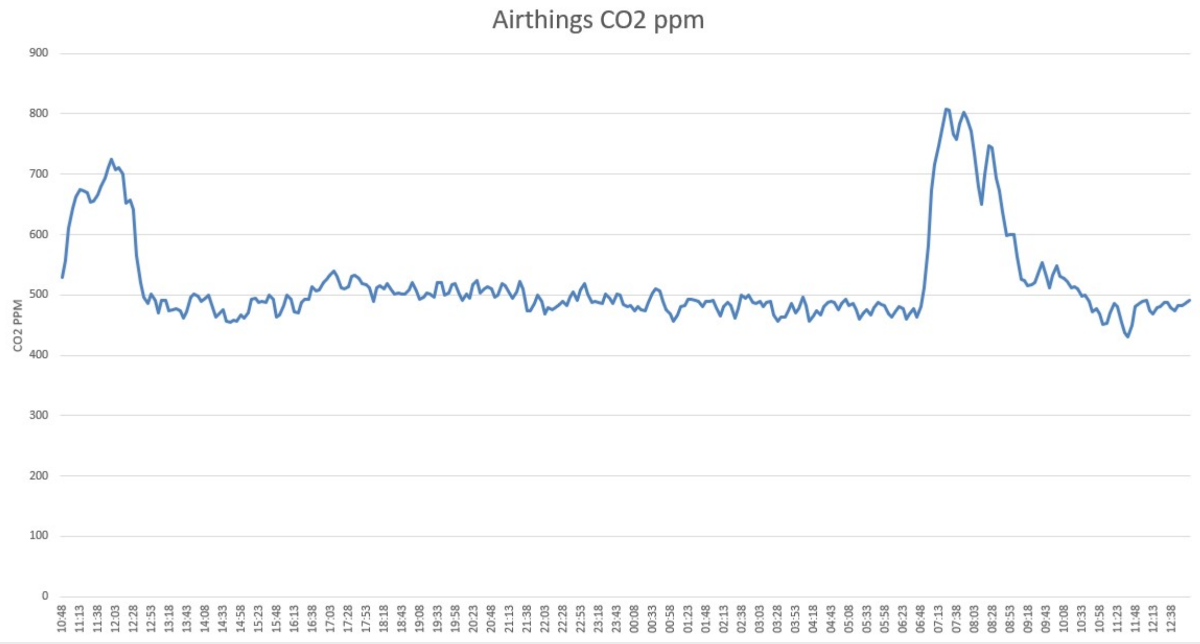
.2 Measured Data



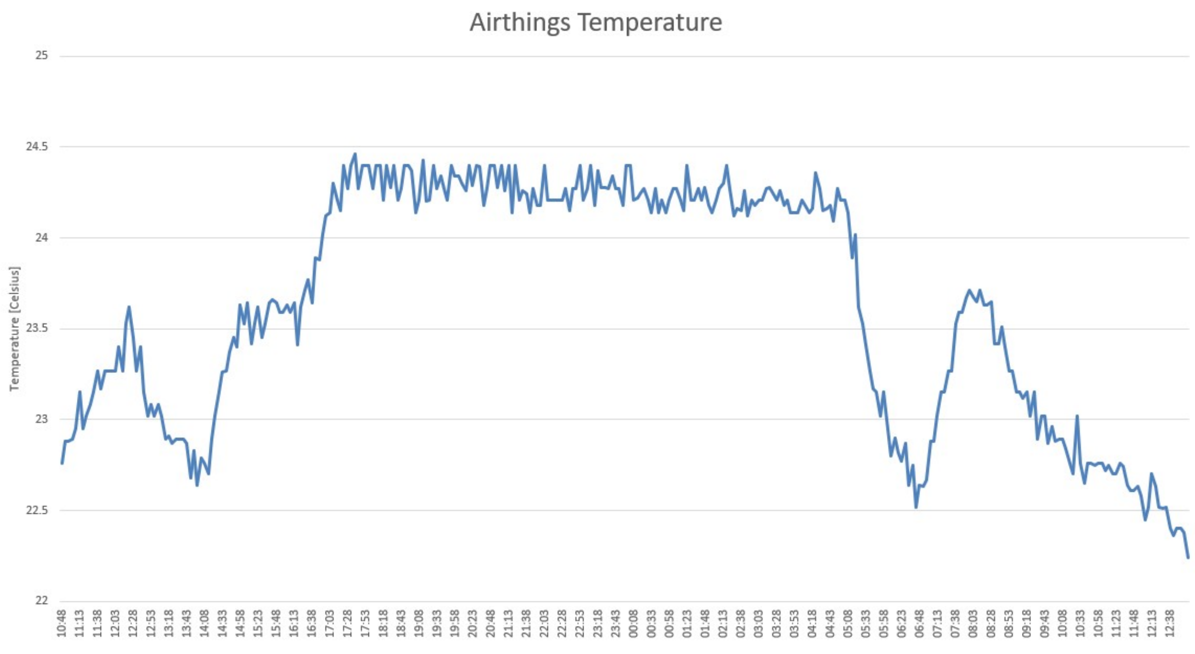
Pegasor AQ Indoor Calibration Process



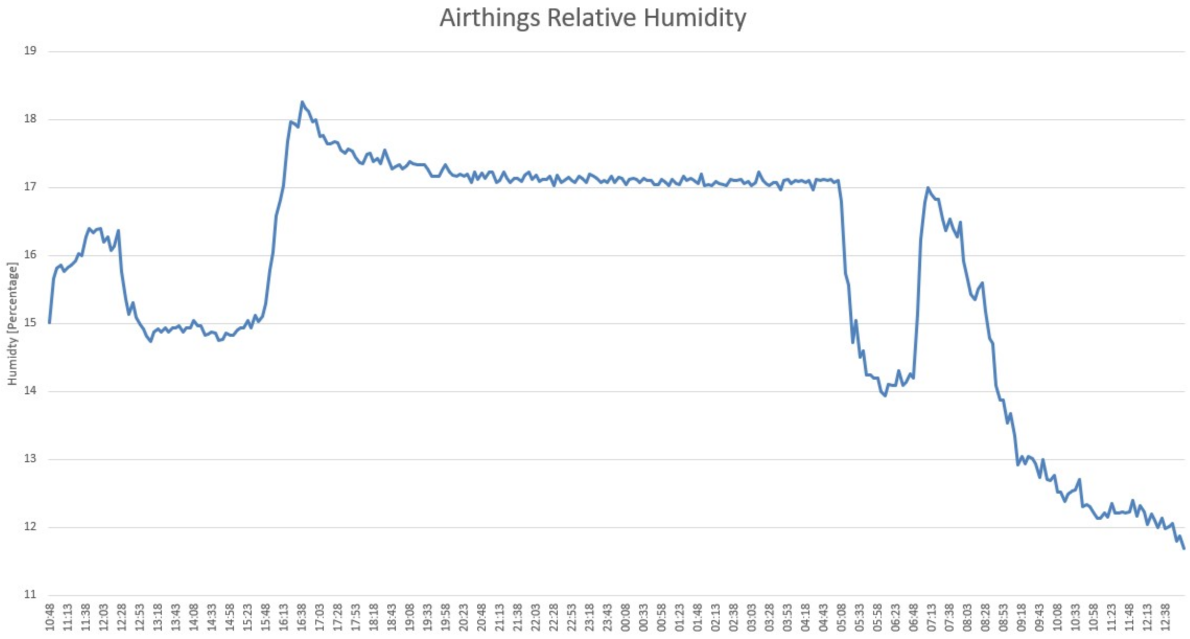
Whole measurement period with ELMA



Whole measurement period with Airthings CO2



Whole measurement period with Airthings Temperature



Whole measurement period with Airthings Relative Humidity

.3 Simulated Data

Solidworks simulation 5400 sek.SLDASM

Physical time [s]: 5400
Analysis interval: 185

Goal Name	PG Volume Fraction of CO2 1	PG Volume Fraction of CO2 2	PG Volume Fraction of CO2 3	PG Volume Fraction of CO2 4
Unit	[ ]	[ ]	[ ]	[ ]
Value	0.000687605	0.000694897	0.000724131	0.001109257
Averaged Value	0.000695786	0.000704134	0.000724469	0.000897092
Minimum Value	0.000675676	0.000627098	0.000694509	0.000695121
Maximum Value	0.000725166	0.0007502	0.00074636	0.001109257
Progress [%]	15	10.5	75.6	4.1
Use In Convergence	Yes	Yes	Yes	Yes
Delta	4.94899E-05	6.71323E-05	1.24083E-05	0.000230996
Criteria	7.46755E-06	7.05622E-06	9.38089E-06	9.58311E-06
Maximum in Calculation	0.000725166	0.0007502	0.000746362	0.001109257
Time of Maximum [s]	4047.777209	4749.413831	3818.793767	5400

Solidworks Simulation Data

INPUT DATA

Mesh

Global Mesh Settings

Automatic initial mesh: On
Result resolution level: 1
Advanced narrow channel refinement: Off

Geometry Resolution

Evaluation of minimum gap size: Automatic
Evaluation of minimum wall thickness: Automatic

Computational Domain

Size

X min: -0.010 m
X max: 9.660 m
Y min: -0.003 m
Y max: 2.901 m
Z min: -0.007 m
Z max: 7.057 m
X size: 9.669 m
Y size: 2.904 m
Z size: 7.064 m

Boundary Conditions

2D plane flow: None
At X min: Default
At X max: Default
At Y min: Default
At Y max: Default
At Z min: Default
At Z max: Default

EM Domain

Definition: Automatic

Physical Features

Heat conduction in solids: Off
Structural: Off
Electromagnetics: Off
Time dependent: On
Gravitational effects: On
Rotation: Off
Flow type: Laminar and turbulent
High Mach number flow: Off
Humidity: Off
Free surface: Off
Default roughness: 0 micrometer

Gravitational Settings

X component: 0 m/s^2
Y component: -9.81 m/s^2
Z component: 0 m/s^2
Default wall conditions: Adiabatic wall

Initial Conditions

Thermodynamic parameters

Static Pressure: 100058.00 Pa
Temperature: 23.00 °C

Velocity parameters

Velocity vector
Velocity in X direction: 0 m/s
Velocity in Y direction: 0 m/s

Velocity in Z direction: 0 m/s

Concentrations
Substance fraction by volume
Air
0.9996
CO2
0.0004

Turbulence parameters
Turbulence intensity and length
Intensity: 2.00 %
Length: 0.031 m

Material Settings

Fluids
Air
CO2

Fluid Subdomains

Fluid Subdomain 1
Default fluid type: Gas/Steam/Real Gas

Fluids
Air
CO2
Faces: Face<1>@Classroom Kuben-1
Coordinate system: Face Coordinate System
Reference axis: X

Thermodynamic Parameters
Static Pressure: 101325.44 Pa
Pressure potential (Gravity): Off
Temperature: 23.00 °C
Mach number in X direction: 0
Mach number in Y direction: 0
Mach number in Z direction: 0
Turbulence parameters type: Turbulence intensity and length
Intensity: 2.00 %
Length: 0.031 m
Flow type: Turbulent Only
Humidity: Off

Concentrations
Substance fraction by volume
Air
0.9996
CO2
0.0004

Boundary Conditions

Outlet Volume Flow 13
Type: Outlet Volume Flow
Faces: Face<1>@Classroom Kuben-1
Coordinate system: Face Coordinate System
Reference axis: X

Flow parameters
Flow vectors direction: Normal to face
Volume flow rate: 166.6667 l/s

Inlet Volume Flow 4
Type: Inlet Volume Flow
Faces: Face<1>@Human Body Model - Simple1-1

Coordinate system: Face Coordinate System
Reference axis: X

Flow parameters
Flow vectors direction: Normal to face
Volume flow rate: 0.0044 l/s
Fully developed flow: No
Inlet profile: 0

Thermodynamic parameters
Approximate pressure: 101325.00 Pa
Temperature type: Temperature of initial components
Temperature: 20.05 °C

Concentrations
Substance fraction by volume
Air
0
CO2
1.0000

Turbulence parameters
Turbulence intensity and length
Intensity: 7.00 %
Length: 0.031 m

Boundary layer parameters
Boundary layer type: Turbulent

Inlet Volume Flow 5
Type: Inlet Volume Flow
Faces: Face<1>@Human Body Model - Simple1-4
Coordinate system: Face Coordinate System
Reference axis: X

Flow parameters
Flow vectors direction: Normal to face
Volume flow rate: 0.0044 l/s
Fully developed flow: No
Inlet profile: 0

Thermodynamic parameters
Approximate pressure: 101325.00 Pa
Temperature type: Temperature of initial components
Temperature: 20.05 °C

Concentrations
Substance fraction by volume
Air
0
CO2
1.0000

Turbulence parameters
Turbulence intensity and length
Intensity: 7.00 %
Length: 0.031 m

Boundary layer parameters
Boundary layer type: Turbulent

Inlet Volume Flow 6
Type: Inlet Volume Flow
Faces: Face<1>@Human Body Model - Simple1-7
Coordinate system: Face Coordinate System
Reference axis: X

Flow parameters
Flow vectors direction: Normal to face
Volume flow rate: 0.0044 l/s
Fully developed flow: No
Inlet profile: 0

Thermodynamic parameters
Approximate pressure: 101325.00 Pa
Temperature type: Temperature of initial components
Temperature: 20.05 °C

Concentrations
Substance fraction by volume
Air
0
CO2
1.0000

Turbulence parameters
Turbulence intensity and length
Intensity: 7.00 %
Length: 0.031 m

Boundary layer parameters
Boundary layer type: Turbulent

Inlet Volume Flow 7
Type: Inlet Volume Flow
Faces: Face<1>@Human Body Model - Simple1-10
Coordinate system: Face Coordinate System
Reference axis: X

Flow parameters
Flow vectors direction: Normal to face
Volume flow rate: 0.0044 l/s
Fully developed flow: No
Inlet profile: 0

Thermodynamic parameters
Approximate pressure: 101325.00 Pa
Temperature type: Temperature of initial components
Temperature: 20.05 °C

Concentrations
Substance fraction by volume
Air
0
CO2
1.0000

Turbulence parameters
Turbulence intensity and length
Intensity: 7.00 %
Length: 0.031 m

Boundary layer parameters
Boundary layer type: Turbulent

Inlet Volume Flow 10
Type: Inlet Volume Flow
Faces: Face<1>@Human Body Model - Simple1-5
Coordinate system: Face Coordinate System
Reference axis: X

Flow parameters
Flow vectors direction: Normal to face
Volume flow rate: 0.0044 l/s

Fully developed flow: No
Inlet profile: 0

Thermodynamic parameters
Approximate pressure: 101325.00 Pa
Temperature type: Temperature of initial components
Temperature: 20.05 °C

Concentrations
Substance fraction by volume
Air
0
CO2
1.0000

Turbulence parameters
Turbulence intensity and length
Intensity: 7.00 %
Length: 0.031 m

Boundary layer parameters
Boundary layer type: Turbulent

Inlet Volume Flow 11
Type: Inlet Volume Flow
Faces: Face<1>@Human Body Model - Simple1-8
Coordinate system: Face Coordinate System
Reference axis: X

Flow parameters
Flow vectors direction: Normal to face
Volume flow rate: 0.0044 l/s
Fully developed flow: No
Inlet profile: 0

Thermodynamic parameters
Approximate pressure: 101325.00 Pa
Temperature type: Temperature of initial components
Temperature: 20.05 °C

Concentrations
Substance fraction by volume
Air
0
CO2
1.0000

Turbulence parameters
Turbulence intensity and length
Intensity: 7.00 %
Length: 0.031 m

Boundary layer parameters
Boundary layer type: Turbulent

Inlet Volume Flow 14
Type: Inlet Volume Flow
Faces: Face<1>@Human Body Model - Simple1-3
Coordinate system: Face Coordinate System
Reference axis: X

Flow parameters
Flow vectors direction: Normal to face
Volume flow rate: 0.0044 l/s
Fully developed flow: No
Inlet profile: 0

Thermodynamic parameters
Approximate pressure: 101325.00 Pa
Temperature type: Temperature of initial components
Temperature: 20.05 °C

Concentrations
Substance fraction by volume
Air
0
CO2
1.0000

Turbulence parameters
Turbulence intensity and length
Intensity: 7.00 %
Length: 0.031 m

Boundary layer parameters
Boundary layer type: Turbulent

Inlet Volume Flow 15
Type: Inlet Volume Flow
Faces: Face<1>@Human Body Model - Simple1-6
Coordinate system: Face Coordinate System
Reference axis: X

Flow parameters
Flow vectors direction: Normal to face
Volume flow rate: 0.0044 l/s
Fully developed flow: No
Inlet profile: 0

Thermodynamic parameters
Approximate pressure: 101325.00 Pa
Temperature type: Temperature of initial components
Temperature: 20.05 °C

Concentrations
Substance fraction by volume
Air
0
CO2
1.0000

Turbulence parameters
Turbulence intensity and length
Intensity: 7.00 %
Length: 0.031 m

Boundary layer parameters
Boundary layer type: Turbulent

Inlet Volume Flow 16
Type: Inlet Volume Flow
Faces: Face<1>@Human Body Model - Simple1-9
Coordinate system: Face Coordinate System
Reference axis: X

Flow parameters
Flow vectors direction: Normal to face
Volume flow rate: 0.0044 l/s
Fully developed flow: No
Inlet profile: 0

Thermodynamic parameters
Approximate pressure: 101325.00 Pa
Temperature type: Temperature of initial components

Temperature: 20.05 °C

Concentrations
Substance fraction by volume
Air
0
CO2
1.0000

Turbulence parameters
Turbulence intensity and length
Intensity: 7.00 %
Length: 0.031 m

Boundary layer parameters
Boundary layer type: Turbulent

Inlet Volume Flow 17
Type: Inlet Volume Flow
Faces: Face<1>@Human Body Model - Simple1-12
Coordinate system: Face Coordinate System
Reference axis: X

Flow parameters
Flow vectors direction: Normal to face
Volume flow rate: 0.0044 l/s
Fully developed flow: No
Inlet profile: 0

Thermodynamic parameters
Approximate pressure: 101325.00 Pa
Temperature type: Temperature of initial components
Temperature: 20.05 °C

Concentrations
Substance fraction by volume
Air
0
CO2
1.0000

Turbulence parameters
Turbulence intensity and length
Intensity: 7.00 %
Length: 0.031 m

Boundary layer parameters
Boundary layer type: Turbulent

Inlet Volume Flow 18
Type: Inlet Volume Flow
Faces: Face<1>@Human Body Model - Simple1-15
Coordinate system: Face Coordinate System
Reference axis: X

Flow parameters
Flow vectors direction: Normal to face
Volume flow rate: 0.0044 l/s
Fully developed flow: No
Inlet profile: 0

Thermodynamic parameters
Approximate pressure: 101325.00 Pa
Temperature type: Temperature of initial components
Temperature: 20.05 °C

Concentrations

Substance fraction by volume
Air
0
CO2
1.0000

Turbulence parameters
Turbulence intensity and length
Intensity: 7.00 %
Length: 0.031 m

Boundary layer parameters
Boundary layer type: Turbulent

Inlet Volume Flow 1
Type: Inlet Volume Flow
Faces: Face<1>@Classroom Kuben-1
Coordinate system: Face Coordinate System
Reference axis: X

Flow parameters
Flow vectors direction: Normal to face
Volume flow rate: 41.6667 l/s
Fully developed flow: No
Inlet profile: 0

Thermodynamic parameters
Approximate pressure: 100058.00 Pa
Temperature type: Temperature of initial components
Temperature: 20.00 °C

Concentrations
Substance fraction by volume
Air
0.9996
CO2
0.0004

Turbulence parameters
Turbulence intensity and length
Intensity: 5.00 %
Length: 0.031 m

Boundary layer parameters
Boundary layer type: Turbulent

Inlet Volume Flow 2
Type: Inlet Volume Flow
Faces: Face<1>@Classroom Kuben-1
Coordinate system: Face Coordinate System
Reference axis: X

Flow parameters
Flow vectors direction: Normal to face
Volume flow rate: 41.6667 l/s
Fully developed flow: No
Inlet profile: 0

Thermodynamic parameters
Approximate pressure: 100058.00 Pa
Temperature type: Temperature of initial components
Temperature: 20.00 °C

Concentrations
Substance fraction by volume
Air
0.9996

CO2
0.0004

Turbulence parameters
Turbulence intensity and length
Intensity: 5.00 %
Length: 0.031 m

Boundary layer parameters
Boundary layer type: Turbulent

Inlet Volume Flow 3
Type: Inlet Volume Flow
Faces: Face<1>@Classroom Kuben-1
Coordinate system: Face Coordinate System
Reference axis: X

Flow parameters
Flow vectors direction: Normal to face
Volume flow rate: 41.6667 l/s
Fully developed flow: No
Inlet profile: 0

Thermodynamic parameters
Approximate pressure: 100058.00 Pa
Temperature type: Temperature of initial components
Temperature: 20.00 °C

Concentrations
Substance fraction by volume
Air
0.9996
CO2
0.0004

Turbulence parameters
Turbulence intensity and length
Intensity: 5.00 %
Length: 0.031 m

Boundary layer parameters
Boundary layer type: Turbulent

Inlet Volume Flow 40
Type: Inlet Volume Flow
Faces: Face<1>@Classroom Kuben-1
Coordinate system: Face Coordinate System
Reference axis: X

Flow parameters
Flow vectors direction: Normal to face
Volume flow rate: 41.6667 l/s
Fully developed flow: No
Inlet profile: 0

Thermodynamic parameters
Approximate pressure: 100058.00 Pa
Temperature type: Temperature of initial components
Temperature: 20.00 °C

Concentrations
Substance fraction by volume
Air
0.9996
CO2
0.0004

Turbulence parameters
Turbulence intensity and length
Intensity: 5.00 %
Length: 0.031 m

Boundary layer parameters
Boundary layer type: Turbulent

Goals

Point Goals

PG Volume Fraction of CO2 1
Type: Point Goal
Goal type: Volume Fraction of
Coordinate system: Global Coordinate System
X: 0 m
Y: 1.200 m
Z: 3.900 m
Criteria: 1.0000
Use in convergence : On

PG Volume Fraction of CO2 2
Type: Point Goal
Goal type: Volume Fraction of
Coordinate system: Global Coordinate System
X: 2.000 m
Y: 1.200 m
Z: 0 m
Criteria: 1.0000
Use in convergence : On

PG Volume Fraction of CO2 3
Type: Point Goal
Goal type: Volume Fraction of
Coordinate system: Global Coordinate System
X: 6.700 m
Y: 1.200 m
Z: 0 m
Criteria: 1.0000
Use in convergence : On

PG Volume Fraction of CO2 4
Type: Point Goal
Goal type: Volume Fraction of
Coordinate system: Global Coordinate System
X: 7.000 m
Y: 1.200 m
Z: 7.000 m
Criteria: 1.0000
Use in convergence : On

Calculation Control Options

Finish Conditions
Finish Conditions: If one is satisfied
Maximum physical time: 5400.000 s

Solver Refinement
Refinement: Disabled

Solving

Electromagnetic Settings
Change material type to be linear: No
Non - linear convergence method: Newton - Raphson
Maximum Newton iteration: 50

Newton tolerance: 1.00 %
CG tolerance: 0.01 %
EM-Thermal synchronization: Periodic
Periodicity: 25
Maximum number of synchronizations: 3
Time step: 0.100 s
Total time: 1.000 s

Results Saving
Save before refinement: On

Periodic Saving
Units: Physical time
Period: 60.000 s

Advanced Control Options

Flow Freezing
Flow freezing strategy: Disabled
Manual time step (Freezing): Off
Manual time step: Off

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