Healthy Breath

In Partial Fulfilment of the Requirements in

Project Air Quality

Client:

BreedSaam

Max Post

Jana Ehmke

20 October 2016, Breda

Colophon

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Summary

In instruction of the client BreedSaam the air quality of 3 classrooms in KBs de Griffioen (indoor) and also the school playground (outdoor) are being evaluated. The buildings currently being maintained by BreedSaam are old and might require renovation as the air quality is presumed to not hold up to the current norms. The purpose is to measure the air quality in terms of indoor (carbon dioxide, temperature and humidity) and outdoor (PM_{10}) and based on the findings provide BreedSaam with an advice on possible improvements. The results obtained by the measurements are analyzed and compared to the air quality models provided by Avans. Unfortunately, the group that measured indoor air quality did not receive a activity log leaving the group unable to make conclusions based on the results. The measurement results did show the average CO_2 values are too high and definitely require improvement in the ventilation aspect. The measurement results did show that the school environment is not unhealthy to the children but does in fact negatively affect the children's productivity and thinking capabilities. Installing ventilation systems to decrease the average CO_2 concentration is definitely required if improvement of the air quality is desired as other options would not have enough of an effect. The measurements results of the outdoor group show that at specific times letting the children play outside does introduce them to high values of PM_{10} with all the negative complications attached. Letting the children play outside during times of low traffic would make quite the difference in PM_{10} concentrations. Building green walls to block the PM_{10} would also be recommended to decrease amount children come in contact with PM_{10}.

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1 Introduction

Air pollution affects people all over the world in both factors indoors and outdoors. It is estimated that 7 million people annually die prematurely due to air pollution. (1) Due to shocking statistics, it is of utmost importance that society considers this as a reality and action is taken against it. Studies have shown that air pollution leads to several acute and chronic diseases, thus limit values or standards have been set by the WHO (World Health Organization) and the EU (European Union). It is crucial for governments to imply these limit values for a healthier population. Unfortunately, around 90% of Europeans living in cities are exposed to air pollution concentrations that are higher than what the WHO regards safe. In addition, even low level concentrations are damaging to human health if they are exposed to it for longer periods of time.

BreedSaam, the client of this project is responsible for the maintenance of numerous primary schools. Therefore, measurements need to be acquired of the current state of the buildings to realise whether improvements need to be done to ensure the health of the students. Both indoor and outdoor data is required to realise what levels these children are exposed to.

An interesting organisation, Stad van Morgen is linked to this project. It is their goal to raise the public's awareness on the health and safety of air quality. Their intentions also imply that it is the responsibility of the public and municipality to improve air quality standards.

Since this project focuses on levels of pollutants at the primary school KBs de Griffioen it is essential to realise that air pollution affects children more severely.

1.2 Project goal

The main goal of this project is to investigate the current levels of pollutants in the air, outdoors and indoors of the primary school KBS de Griffioen. The product of this investigation will then be used to advise BreedSaam and Stad van Morgen on how to improve the air quality in and around the primary school.

With the main goal in mind the project has been divided into 2 parts or sub-goals. One part focuses on the indoor measurements which include CO_2, humidity and temperature with the other being the outdoor part which includes PM_{10} only.

1.3 Boundaries

There are many outdoor pollutants that have a negative effect on human health but for this project the main focus will be on PM_{10} for the outdoors section. The times of the physical measurements were taken on 2 days, a week apart. The measurements were taken at the same place of the school. Since the time and days of measuring were limited, as well as changing weather patterns that influence results. Therefore, it was only possible, with the information gathered to make an estimate on what the problem might be and what can be done to lessen or solve the problem.

As for the indoor measurements, only CO_2 concentrations as well as temperature and humidity were measured. In the school building, 3 rooms were pre-selected for the group to place the indoor measurement devices. Even though the indoor results seemed accurate and reliable, the lows and peaks at certain times cannot be explained due to absent information during the measurements. PM indoors is not measured due to lack of equipment available.

1.4 Reading guide

This report consists of 6 main chapters which consists of the introduction, theoretical background, methods, results, discussion, conclusion and advice. Every individual chapter will contain information regarding indoor and outdoor air quality which will be represented in different sub chapters. In the first chapter, the introduction, will describe the project goal and the boundaries the group had to work with. In the second chapter, theoretical background, the effects of different kinds of air pollution on human health are discussed, which include CO_2 concentration, ambient temperature, relative humidity and particulate matter 10. In the third chapter, methods, the different methods used to measure are described followed by the specifications of the classrooms and indoor models. The fourth chapter, results, provides the analysed results followed by an description of the measurements. In the fifth chapter, discussion, the measurement results are discussed to be able to provide conclusions and advice based on the discussed measurement results. In the final chapter, conclusion and advice, conclusions are provided based on the discussed measurement results for the client BreedSaam.

2 Theoretical background

2.1 Indoor

In this chapter relevant information is provided regarding the effects of indoor CO_2 concentrations, ambient temperature, relative humidity and outdoor PM_{10} on human health and environment.

2.1.1 Effect of CO_2 concentration on indoor air quality

Carbon dioxide is a colorless, odorless and tasteless gas. Commonly known to be an outdoor air pollutant, mainly originating from sources such as industry and transport. Carbon dioxide is a product of completed carbon combustion and the by-product of biological respiration. Carbon dioxide poisoning can occur when exposed to high concentrations of carbon dioxide. The carbon dioxide percentage in the blood level rises, which is referred to as hypercapnia or hypercarbia. Symptoms such as headaches can appear and when the concentration increases, a person can become unconscious and possibly die (2). Furthermore, people might experience other health effects when present in building with high CO_2 concentrations. Even though most symptoms are usually because of different contaminants that are also present in the air because of insufficient ventilation. Carbon dioxide can cause headaches, dizziness, nausea and other symptoms when exposed to high concentrations of over 5000 ppm for multiple hours at the time. CO_2 poisoning is not something that occurs very often (3).

Primary indoor carbon dioxide sources are mainly the occupants of the room who breathe out the gas, the CO_2 concentration increases over time if there is insufficient ventilation present in the room. Secondary sources of increased CO_2 concentrations indoor are mostly present in developing countries as these people use appliances such as gas stoves and wooden fires for cooking or heating up the house. Carbon dioxide produced by transport and industry might enter inside through open windows or poor ventilation systems (4).

The level of CO_2 concentrations depends on the amount of people present, the duration a certain area has been occupied, ventilation capacity of fresh air from outside, size of the area and the outdoor concentration (5).

2.1.2 Limit values of CO_2 concentrations indoor

The indoor CO_2 concentration should generally not reach any higher than 5000 ppm (6), this value is considered safe and will not have an impact on the human health if it does not exceed this limit. In working conditions however an average of 10.000 ppm during an 8-hour working day is allowed, but should not exceed an average of 30.000 ppm for a 15-minute period. These limits are set as standard requirement for safety indication in working conditions, anything exceeding these limits is considered dangerous and definitely not safe for the human health (7). According to the information provided in the 'Air Quality' workshop the maximum CO_2 concentration indoors should not exceed 1200 ppm and will therefore be used as the CO_2 concentration limit in this report.

2.1.3 How to decrease CO_2 concentrations indoors

Reducing the CO_2 concentration in a room can be achieved in a few different ways. Ventilation is the most common and most effective method to decrease the CO_2 concentration in a room and can be accomplished by either installing ventilation systems or leaving open any doors and windows. Ventilation systems remove the air with high CO_2 concentrations and replace it with clean air. Opening doors and windows will cause the air inside, with high CO_2 concentrations, to dilute with the low CO_2 concentrated air outside the room. Plants are another way of reducing the CO_2 concentration inside as the plants use CO_2 for photosynthesis and release clean oxygen in the process (8).

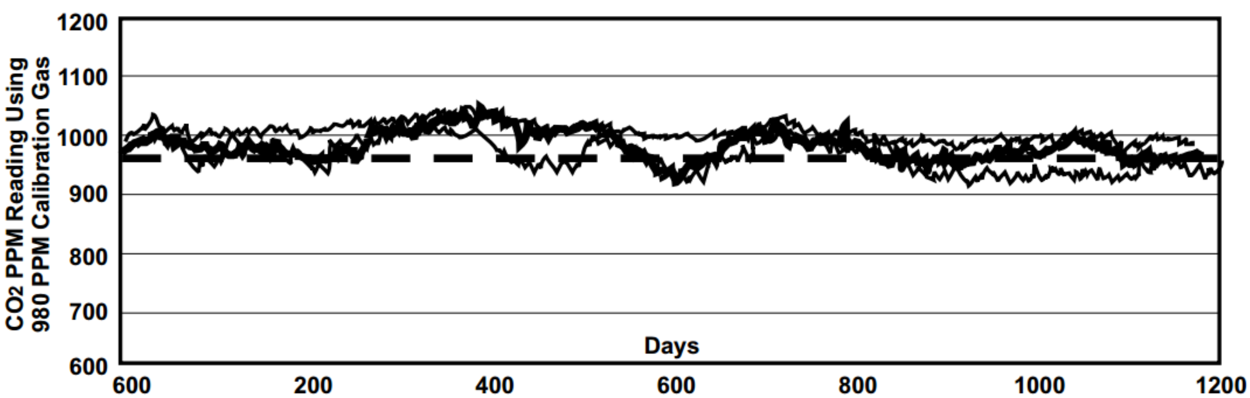
2.1.4 Effect of ambient temperature and relative humidity on indoor air quality

Temperature and humidity are not directly affecting the indoor air quality, but more the way people perceive the air quality. When the temperature is too high or too low people become uncomfortable which results in less productivity. Humidity has to be controlled as well because a high humidity percentage in the air can cause molds and other biological contaminants to grow. When the humidity level is too low people experience irritated mucous membranes, dry eyes and sinus discomfort (9).

2.1.5 Principle

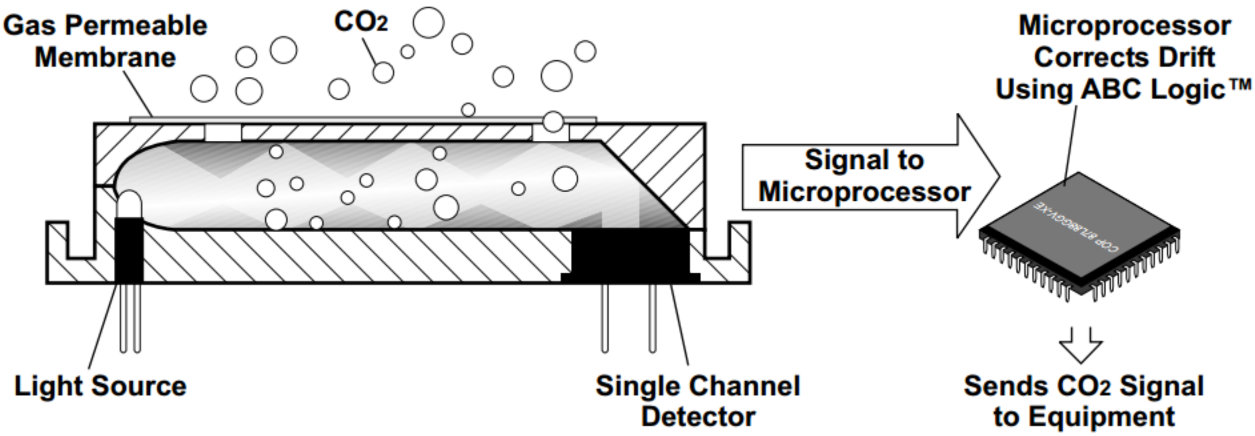
The CO_2 concentration device:

The device used for measuring the CO_2 concentration is the Ventostat 8001/8002 Single Beam CO_2 Ventilation Controllers. This device can be used in many different scenarios such as office buildings, conference rooms, schools, retail stores, restaurants, gymnasiums, and movie theaters. Therefore, it is perfectly suitable for the location where the measurements are done. The device can be conceived as an indicator for the ventilation of a room and an indicator for clean air. The CO_2 measuring device uses the patented ABC Logic (Automatic Background Calibration) self-Calibration system that virtually eliminates the need for manual calibration in applications where the indoor CO_2 level drops to outside levels during unoccupied periods. The ABC Logic is a special software routine in the sensor that registers the background readings for 14 consecutive evenings and calculates if there is sensor drift and then corrects for it. The classrooms in question are never unoccupied for more than 3 days at the time (the weekend) therefore the measurement devices can be trusted to deliver accurate readings.



How does the commercial grade sensor actually work?

Gases that are present in the air will absorb light at very specific wavelengths in the infrared spectrum, because of this the sensor can detect these gases. Gases will diffuse through a permeable membrane inside the device and enter the sample chamber. The gas permeable membrane will allow gas molecules to enter the sample chamber but prevents the entry of particulates. There is a light source present at the end of the chamber which generates a broad band of infrared energy that is directed through the sample chamber. The walls of the sample chamber are gold plated which causes the light to bounce which in turn establishes a longer effective sample path in a relatively small distance. A special optical filter is installed at the other end of the sensor which is designed to only admit light at the wavelength where CO_2 is known to absorb light. A change in CO_2 concentration causes a small change in light intensity will then be measured by the detector and converted into a CO_2 measurement by a microprocessor.



Temperature and relative humidity data logger:

The second device is connected by cable to the Ventostat 8001/8002 Single Beam CO_2 Ventilation Controller. This device is called Logger ATV-13, which measures the ambient temperature and relative humidity while also logging the data of the CO_2 measurement device.

2.2 Theoretical background outdoors

Around 3.7 million people world-wide prematurely die due to ambient air pollution annually. This number includes both cities and rural areas. (1) This is the most recent estimation made for the year 2012 by the WHO. The number is much higher than expected and portrays the reality of the dangers of air pollution concerning human health.

2.2.1 Particulate matter

There is a wide range of air pollutants that affect human health and the environment at large. Particulate matter (PM) is a variety of small particles that are suspended throughout the air. The particles range from ultrafine $PM_{0.1}$, fine $PM_{2.5}$ to PM_{10}. $PM_{2.5}$ accounts for 50-70% of particulate matter in most places of European air. (10) The main focus in this project however will be on PM_{10}. The concentrations of PM are usually measured in μg/m^3.

These particles can be in liquid or solid phases and are mainly composed of chemical constituents and inorganic ions. To name a few; ammonium, sulphates, nitrates, magnesium, calcium, sodium, organic carbon and elemental carbon. Biological components can also be found in PM as various allergens (pollen and spores) and these can also be water bound. The number of various constituents varies due to the distance and type of the source.

2.2.2 Sources

PM comes from a number of sources. They are mainly primary pollutants but are able to combine with gases such as sulphur and nitrates and form secondary pollutants. The main sources are industries (energy production and constructing building materials like bricks, tiles and other) and cars exhaust fumes. In addition, PM also comes from construction and the wear of roads and sidewalks as they are used with time passing on. Agriculture and its methods like ploughing, harvesting, transportation and keeping livestock also contributes to PM in the air. (11) These influences are all Anthropogenic (caused by humans). Natural sources include volcanic activity and volcanic eruptions. Biological components that are suspended within the air may also come from natural sources such as hay and other plants.

2.2.3 Health affects

Exposure to PM has acute and chronic health effects on animals (including humans). Acute effects include irritation of the eyes, nose and throat. In addition, it worsens the effects of asthma and could lead to strokes and heart attacks to people with heart diseases. These are effects of short term exposure and can affect sensitive people immediately. If people are exposed to PM over a long period of time it will reduce lung function, can lead to the development of circulatory and respiratory diseases and it can worsen the effects of existing diseases. Therefore, it definitely reduces life expectancies. (12) The finer the PM the larger the health risk factor, as particles with the size of 2.5μm and 0.1μm can settle deep within the lungs and cause a number of health problems.

2.2.4 Health effects on children

Children on the other hand are much more vulnerable and susceptible to contracting diseases from a high concentration of air pollution. Due to the fact that the average European child (as well as most other children) spends more time outdoors than an adult, it is clear to note that children are more exposed to ambient air pollution. Another factor which makes them more vulnerable is that children inhale a larger amount of pollutants than adults when compared to the weights of their bodies. In addition, the arteries of children are much narrower than those of an adult, this results in greater airway obstructions. PM affects lung development in children and may lead to a reduced rate of lung growth and function. In the long term, it may lead to the discontinuation of lung growth and lung functions as they grow older. Ultimately this can lead to a premature death. (10)

Knowing the effects air pollution has on humans and the environment it is important to record and measure air pollutants to note where and how severe the problem is. It is then possible to find solutions to decrease concentrations or remediate a part the pollutants for a safer and more comfortable environment to live in.

2.2.5 Monitoring system

For the outdoor measurements of PM_{10} a Casella MicroDust Pro Aerosol Monitoring System was used. This instrument measures in particular the PM such as dust, smoke, exhaust fumes, pollen and aerosols of which it’s sources have been mentioned earlier. It is a device that is easily portable and measures PM concentrations in mg/m^3. It also has a detachable probe that can be used to measure PM in relatively inaccessible areas. With this instrument a software called Casella insight can be installed and the measurements can be imported from the probe to a laptop. Thereafter, graphical representations of concentration trends can be constructed on the software and can then be studied easily.

2.2.6 Principle

The measurement probe uses the principle of light scattering namely; diffraction, refraction and reflection. Figure 1 shows the Sampling probe of a MicroDust system. (13)

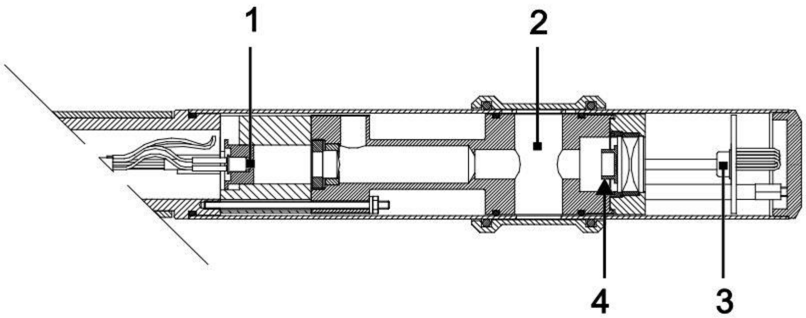


figure 1 Sampling probe

1. Infra-red emitter
2. Sample volume
3. Infra-red detector
4. Light stop

As the instrument is switched on, the Infra-red emitter emits a beam of light that passes through a focusing lens and the sample volume. If the air is very clean there will be no dust particles or PM present in the Sample volume and will cause the light to directly hit the light stop, no light will therefore hit the infra-red detector and the device will present a 0.00 mg/m^3 signal and reading on the screen.

If, however the air contains particulates they will be present in the sample volume and the emitted infra-red light will be scattered by diffraction, refraction and reflection. This will cause the light to pass alongside the light stop and a signal will be detected on the Infra-red detector. The concentration of PM is related to the strength of the signal, meaning that the more PM is present the more light will be scattered and the higher the concentration on the screen will be presented.

The measurement device is stored in a suitcase that protects it from rain, dirt wind and is shock proof. *Figure 3* shows this suitcase that contains a MicroDust Pro probe (2), where the PM is introduced and measurements are taken, a MicroDust Pro Instrument (4), which is used for programming and data storage. The Instrument is battery operated. The probe is fitted with a filter that measures PM_{10} which is what was used for this project. It also has a tuff pump (3) which is used to suck air through the probe and a tuff pump charging unit, which is used to charge the tuff pump. As *figure 2* represents the suitcase can also be fitted with a chimney (1) that is connected to the probe for measuring over longer periods of time.

figure 2

figure 3

3. Materials and Methods

Different methods and devices were used to measure the air quality in this project and are described in the corresponding sections. The measurements were done over a period of 2 weeks with the indoor group continuously measuring and the outdoor group at specific times.

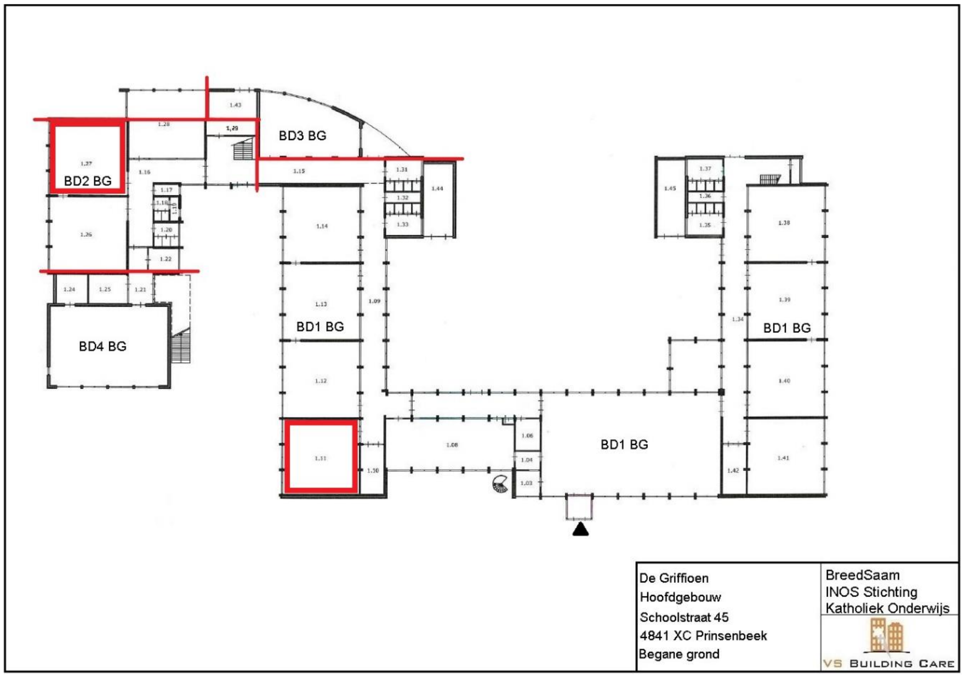
3.1 Indoor Air quality measurement

Measuring indoor air quality, the decision has been made on measuring the CO_2 concentrations pared with the ambient temperature and relative humidity present in the classrooms. To be able to measure the CO_2 concentration, ambient temperature and relative humidity two specific measuring devices are required. One device, which measures the CO_2 concentrations and another device which acts as a data logger while also measuring the ambient temperature and relative humidity levels. The device measured every 5 minutes continuously for 2 weeks, no problems have occurred thus reliable data was gathered. All three devices were placed at about 150 centimeters height as this would be the most desirable height when measuring air quality for children. All devices were placed near the wall out of sight of the children and not near any source of warmth, making sure the measurements would not be affected.

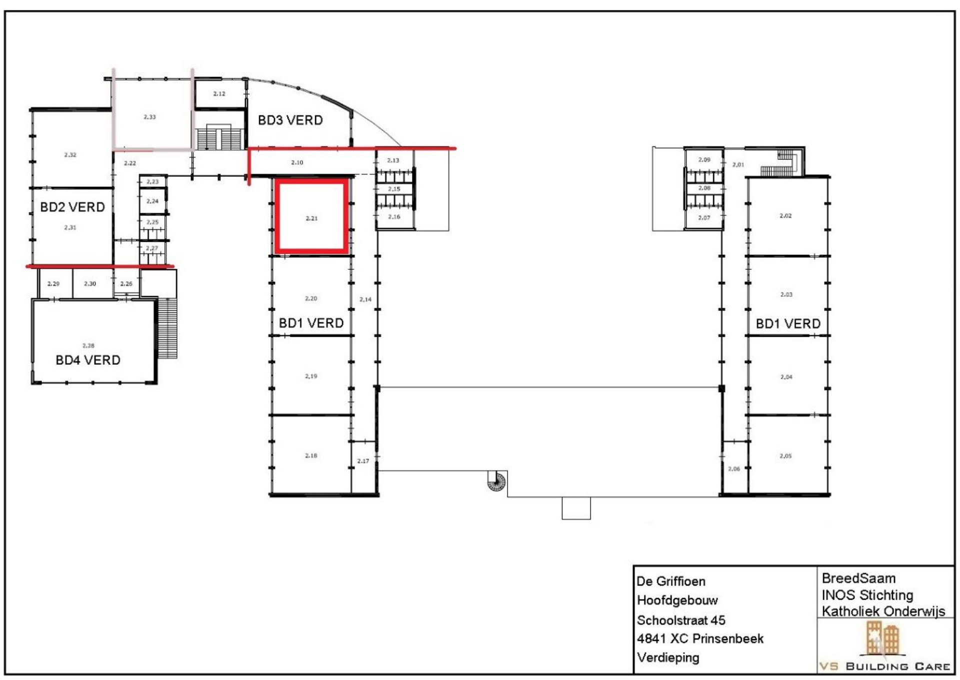
3.2 Specification Classrooms

The three classrooms that were chosen for the measurements consist of the exact same dimensions which are 7-meter-long, 7-meter-wide and 3.2-meter high, which comes to 156.8 m^3 of volume. There were multiple windows present and one door. The windows were not opened as the building was quite old already and windows were stuck thus requiring a lot of effort to open. The windows were 2 meters wide and 1.5 meters high. There was no ventilation system installed in the school building and neither were there any plants or CO_2 reducing objects present. The exception during the times of measurements was one Christmas tree per classroom because of the time of year.

The occupants of the classrooms were 19 children and 1 teacher.



As illustrated in the figure above the first device was placed in room 1.11 while the second device was placed in room 1.27.



The third device was placed on the second floor of the building in room 2.21

3.3 Indoor model

The indoor measurements results are compared to the indoor model provided in the project documents.

Indoor model is based on the following formula:

$$C(t) = C_i - (C_i - C_0) \cdot e^{-\varphi/V \cdot t}$$

Which each factor is

C(t) is function of start concentration: C_0

C(t) is function of concentration ambient air and # persons in a room: C_I

C(t) is function of ventilation m3/h: φ

C(t) is function of volume of room: V

Using the numbers gathered from research the following calculation was done:

Volume = 156.8m^3

Window surface 2m x 1.5m = 3m^2

People = 20

Ventilation = window surface (3m^2) x 720 m/h (reference value for wind speed) = 2160 m^3/h

Adding these numbers in the model results in values that do not compare with the measurement results therefore some adjustments had to be done with the model to provide more realistic values. The values differ as the windows is not actually opened all day, probably not even opened at all.

Using a ventilation capacity of 170 m^3/h resulted in ppm values that were similar to the measurements. Therefore this number will be used in the comparison with the results from the measurements.

3.2 Materials and Methods Outdoors

In this project, only PM_{10} was measured outdoors, in front of the primary school. The device that was used is the Casella MicroDust Pro Aerosol Monitoring System. It was decided by the group to only take the measurements directly at the playground of the school where the children spend most of their time during recess. Since there were 4 people that were responsible for the outdoors measurements it was decided to split this group up into 2 separate groups (Group 1 and Group 2), Group 1 measured early in the morning from 07:30 – 09:30 and 11:00 – 13:00, Group 2 was responsible for measuring lunch time again (11:00 – 13:00) and the afternoon from 14:00 – 16:00. The weather forecast and the car count was to be recorded. The car count was done on site and the weather forecast was simply acquired from the Internet. As Group 2 arrived at the site of taking measurement it was decided to only count the cars that were in the area of the oncoming wind.

The results would then be compared to the limit values as presented by the EU and WHO to come to a concrete conclusion whether an action should be taken to improve the air quality at the playground and to decide what advice or what plan can be made to take action.

4. Results

In this chapter there are two main parts; the results of the indoor measurements and outdoor measurements.

4.1 Indoor

In this chapter the results of the indoor measurements will be provided, together with the indoor model. Three different measurements have been done in the school in three different classrooms which have been assigned by BreedSaam.

4.1.1 Measurements & Calculations

In this chapter the measurements of the three different classrooms will be presented one by one starting with the Carbon Dioxide measurement followed by the Ambient Temperature and last the Relative Humidity.

Classroom 1 has a more in depth description of the measurements taken in week 1 to emphasize on the schedule of the school and explaining the difference in measurements during the days. The other classrooms will not be given an as much in depth explanation to the measurements as the schedule of the children will be similar, only exceptions in measurements such as extreme highs or lows will be focused on.

Classroom 1 CO_2 Concentration 28th of November – 13th of December

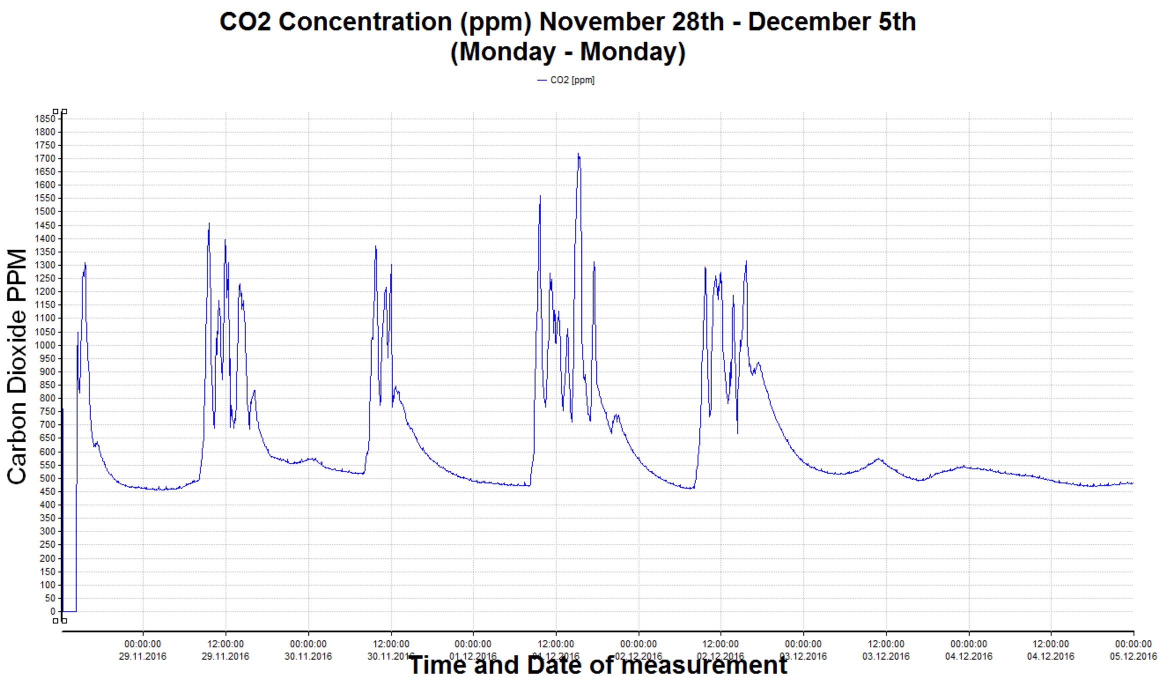


figure 4

figure 4 (November 28th – December 5th) shows the first CO_2 concentration measurements that were performed by the indoor project group. The devices are places at about 150 cm of height as this would be the optimal position when measuring the CO_2 concentration for children. Monday the 28th the measurement devices are placed and ready to start measuring at 12:10. The device starts calibrating first before any trusted measurements can be presented. At 14:20 the first measurements are taken and the starting value is 953 ppm which increases to the maximum of the day where the measurement reaches a maximum of 1311 ppm at 15:30. The school day finishes at 15:30 which explains the drop in CO_2 concentration which slowly declines until it stabilizes at around 450-500ppm from 20:00 – 8:00 the next morning.

Starting 8:00 the next day, Tuesday 29th, the CO_2 concentration slowly increases again as the teachers and staff are starting their work day. The school starts at 8:45 every morning which is clearly visible as the CO_2 concentration increases very rapidly from this time on.

The CO_2 concentration reaches a maximum value around 9:30 of 1459 ppm and will then slowly start decreasing. We can see the CO_2 concentration has some ups and downs in the following hours which can be explained by the children doing activities outside of the classroom and inside. Between the hours 12:00 – 13:15 the children leave to school for their daily midday break in which they go home to have lunch. It is quite noticeable that when the children leave at around 12:00 the CO_2 concentration increases a little bit as the measurement devices was placed near the entrance of the classroom. When the children have all left the classroom the CO_2 concentration instantly starts decreasing and reaches around 750 ppm until the children come back from their midday break and the CO_2 concentration starts rising once again. The CO_2 concentration is rising and reaches levels between 1150-1250 ppm until the school day is over and the children leave the school again. The CO_2 concentration drop in the following hours and when the staff leaves the school as well the CO_2 concentration stabilizes around 550-600 ppm. The CO_2 concentration in the night of Tuesday the 29th – 30th are on average 100 ppm higher compared to the CO_2 concentration of the previous night Monday the 28th – 29th.

Every Wednesday the school closes its doors around 12:00. Wednesday the 30th the CO_2 concentration slowly starts increasing around 8:00, and increases more rapidly from 8:45 until 9:45 when the children arrive. This is comparable to the previous day and does not show much difference when we look at the average CO_2 concentration. Then there is a significant drop in CO_2 concentration as the concentration levels plummet from 1372 ppm at 9:45 until 775 ppm at 10:25. CO_2 concentration start rising again quite rapidly and average between 1100-1200 ppm until the school day is over at 12:00. When the children leave the school the CO_2 concentration starts slowly decreasing over time but does not decrease very rapidly. Around 17:00 the CO_2 concentration reaches 600 ppm and eventually stabilizes between 450-500 ppm until the next morning.

Thursday the 1st of December the CO_2 concentrations have stabilized overnight and just as the previous days slowly start increasing around 8:00. Then around 8:45 the children enter the school and the CO_2 concentrations start rising more rapidly as was seen in the previous days. The CO_2 concentration reaches up to 1559 ppm at 9:40. As seen in the previous days the CO_2 concentration increases very rapidly between 8:45 and reaches very high values around 9:40 and then slowly starts decreasing again until it reaches 995 ppm at 10:50.

The CO_2 concentration then averages 1150-1250 ppm until 12:00 when the children leave school for the midday break. When the children return as seen in the previous days the values start rising very quick. The CO_2 concentrations start rising when the children return around 13:15, but not for very long as there is a sudden drop from 13:40 until 14:15. The CO_2 concentration starts rising from this moment and reaches a maximum of 1706 ppm at 15:25 before decreasing once again. Normally the CO_2 concentration should now we decreasing as the children have left school but today there is a small increase around 17:05 until 17:30. From this point the levels start decreasing and eventually stabilizes around 450 ppm.

Friday the 2nd is the last day of the week where the CO_2 concentration start rising from 450 ppm around 8:00. As seen in the previous days the CO_2 concentration starts increasing more rapidly the moment the children enter the school. We can see once again the rapid increase that occurs daily between 8:45 – 9:40 and then the CO_2 concentration starts slowly decreasing until 10:20 from where the levels start rising again until the children leave the school around 12:00 for their midday break.

CO_2 concentration slowly drop in this time frame and as expected slowly rise once the children enter the school again. Like every day, except Wednesday, the levels rise until after 15:00 when the children leave school and celebrate their weekend. CO_2 concentrations drop slightly slower overnight as was seen in the previous days and reach an average between 500-550 ppm. Saturday the 3rd the CO_2 concentrations start decreasing more during the day but the levels stay between 450-550 ppm during the weekend.

The first week of measuring yields solid results which seems to be quite identical over all the days of the week with the exception of Wednesday as the children will only be present for half the day.

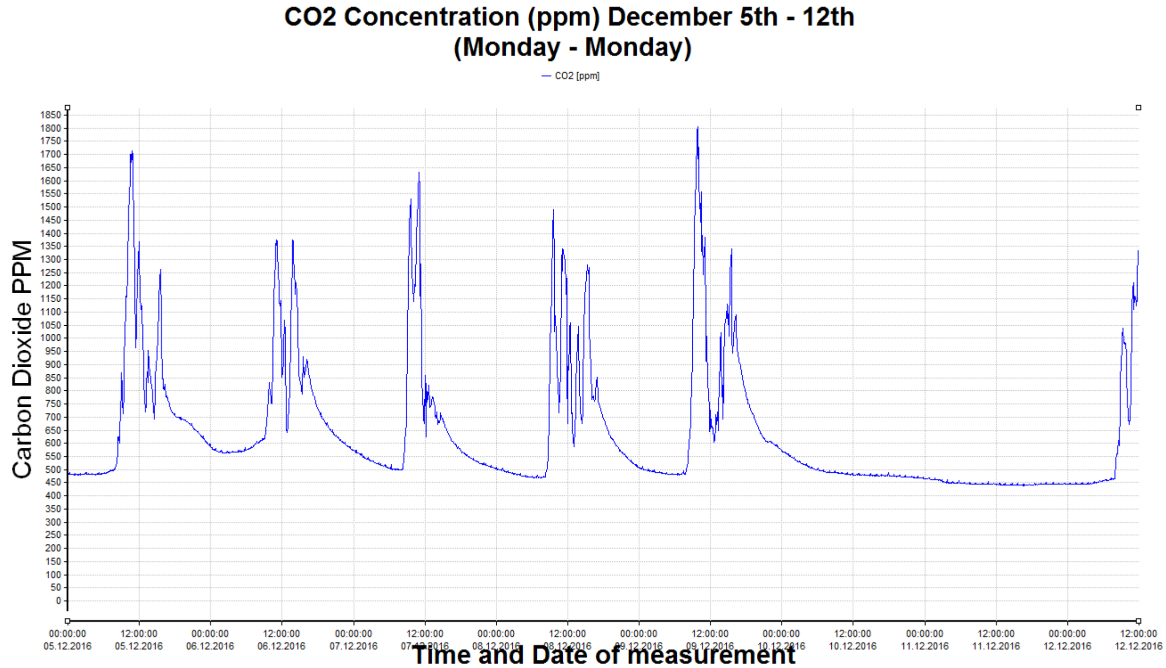


figure 5

The second week of measuring the CO_2 concentrations in classroom 1 are not much different than the measurements taken in this classroom the week before. Every morning there is a rise in CO_2 concentration when the staff arrives at school which is shortly followed by a rapid increase in CO_2 concentration when the children arrive at school. When looking at the big picture there are almost no differences to be spotted except for the fact that there are higher peaks this week compared to the last one.

Monday the 5th of December there is a very significant peak visible at around 10:45 where the CO_2 concentration reaches levels of 1716 ppm before it slowly declines again when the children leave school that day. Comparing the measurements of the second week to the measurements taken on the first week what is immediately visible are the maximum ppm values measured at the start of week 2 compared to the maximum ppm values measured at the start of week 1. Furthermore, the measurements taken over every day in week 2 follow a similar pattern to the measurements taken from week 1.

Ambient Temperature and Relative Humidity Classroom 1

Figure 6 & figure 7 describe the results which are gathered at the same time and location as the Carbon Dioxide measuring device.

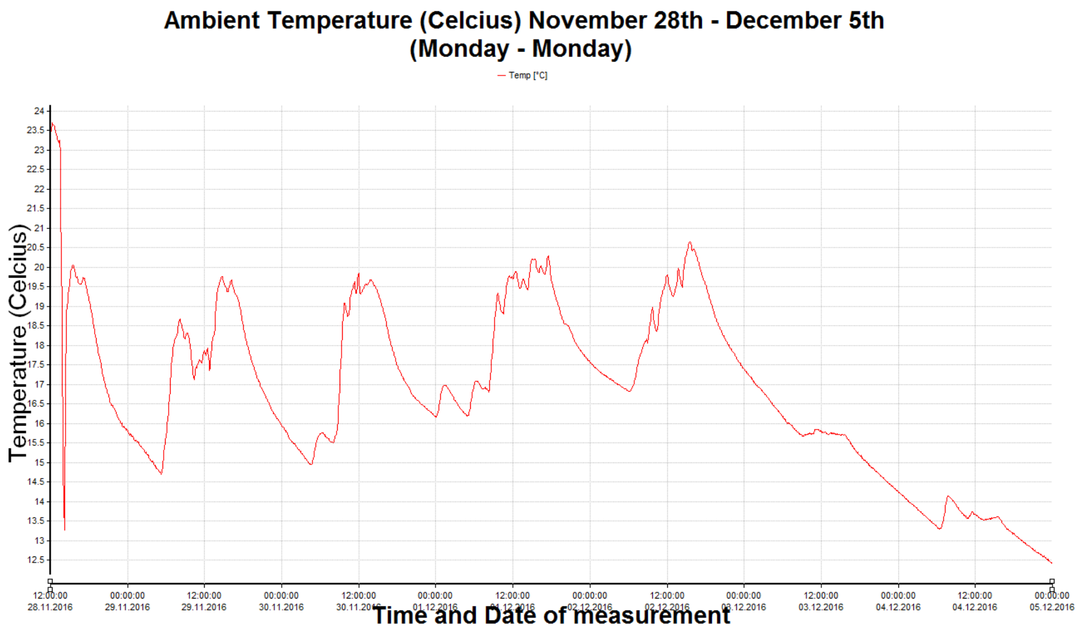


figure 6

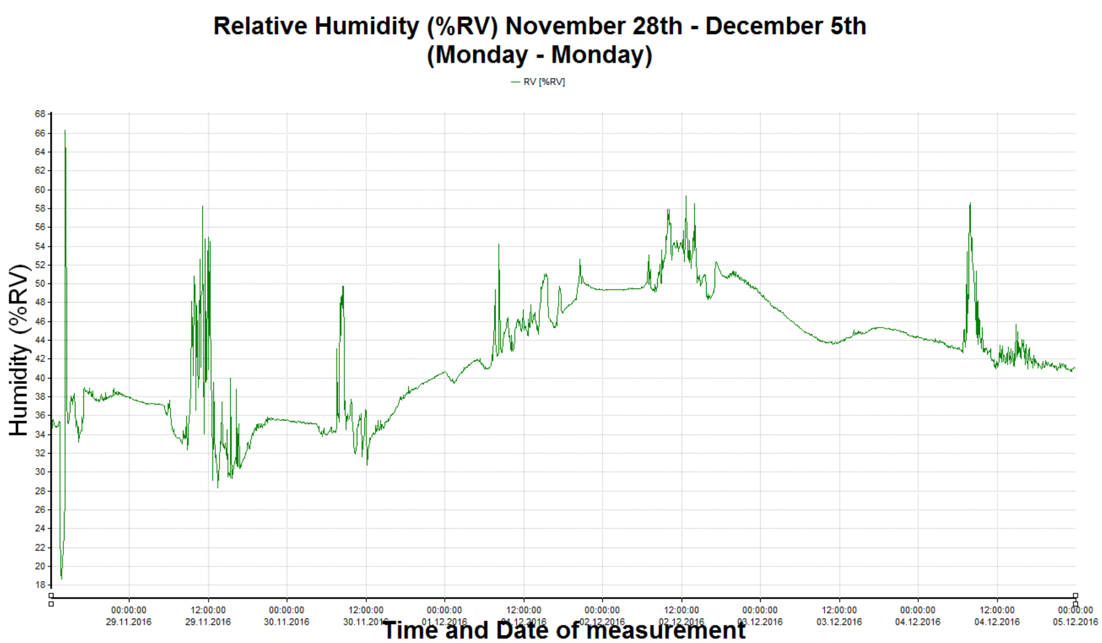


figure 7

Figure 6 & figure 7 show the temperature and humidity measured in classroom 1 from November the 28th until December the 5th (week 1). The moment the device starts measuring the given measurements are very high which probably happened because of the calibration of the device. Monday the 28th, the temperature would reach about 20℃ during the day and slowly decrease during the night where it would reach about 14.5℃. Every day during the week the peak temperature would reach around 20℃, but the lowest temperature would slightly increase over the week from a minimum of 14.5℃ at the start of the week till reaching almost 17℃ on Friday. The humidity levels would do almost exactly the opposite as the temperature. When the temperature was rising the humidity tended to decrease but as shown in the graphs, this would not always be the case.

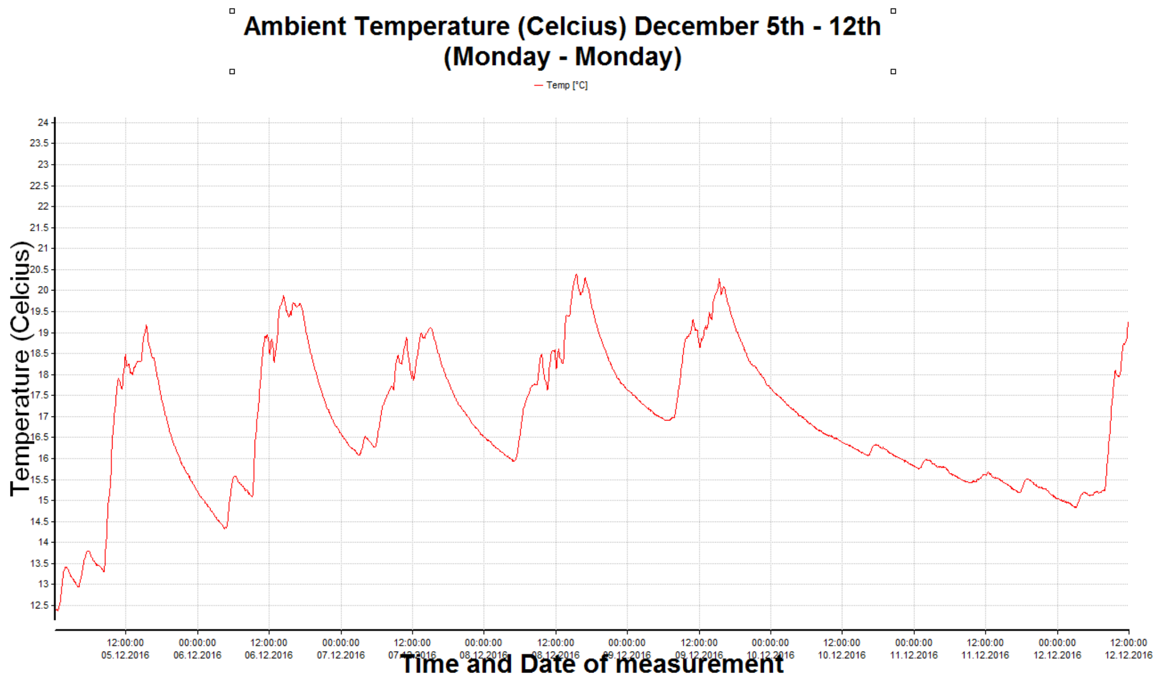


figure 8

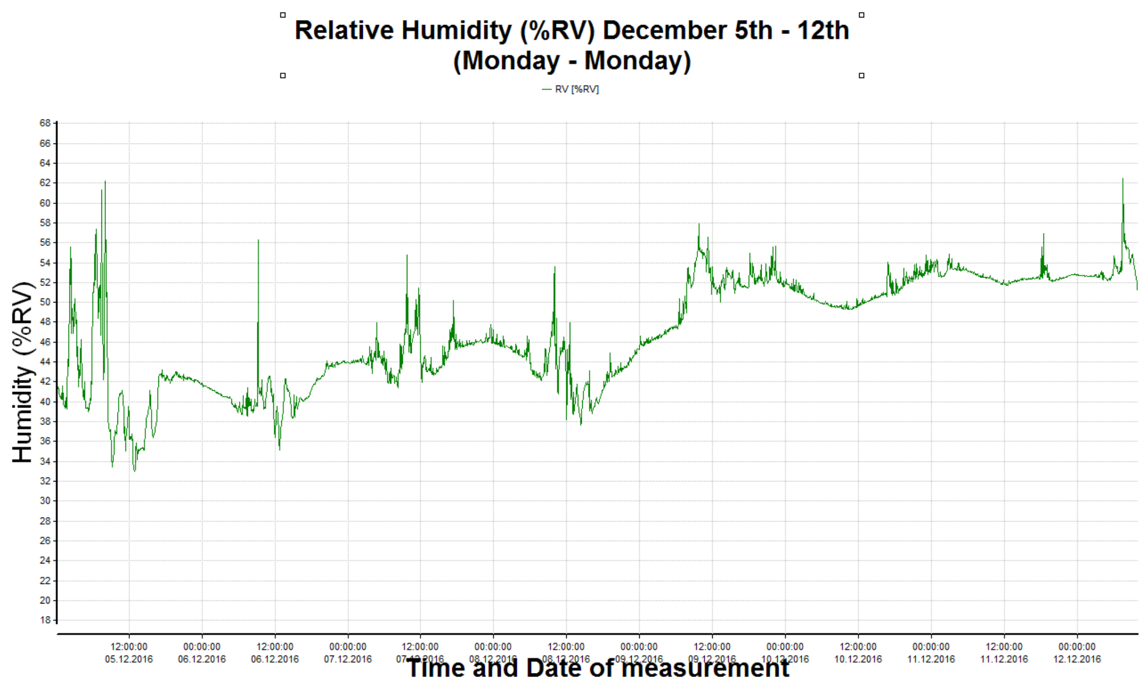


figure 9

Figure 8 & figure 9 illustrating the temperature and humidity of classroom 1 from December the 5th until the 12th (week 2) seem to not show very different measurements when compared to the graphs of week 1. The temperature of the school building during the weekend went down considerably and is rising the moment school starts again. The peak temperature of the school during the day would once again be around 20°C. From the start of the week until the end the minimum temperature would again slightly rise from the start of the week at 13°C until the end of the week at 17°C. The humidity seems to not act very different as to the measurements taken in week 1.

Classroom 2

CO_2 Concentrations:

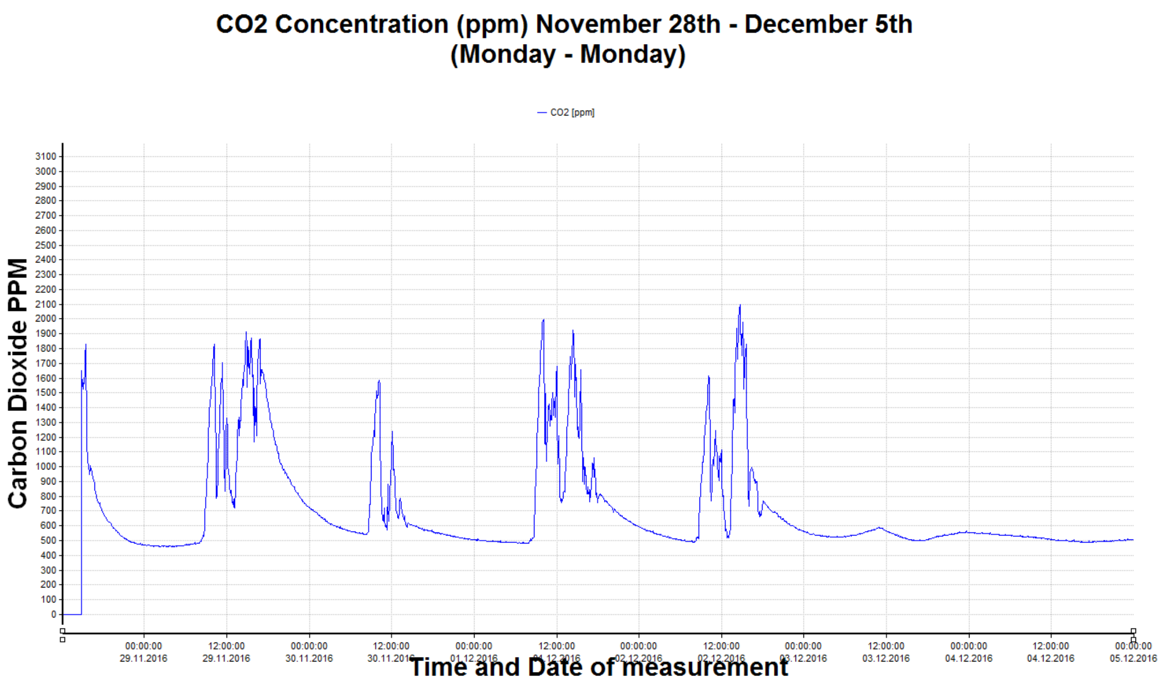


figure 10

In *figure 10* above the CO_2 concentration is illustrated of classroom 2 from November the 28th until December the 5th (week 1). As seen in classroom 1 the CO_2 concentration raises slowly at the start of the day around 8:00 and sees a rapid increase around 8:45 when the children enter the classroom. Followed by a small decrease of CO_2 levels before rising once again until the midday break. During the midday break the CO_2 concentration decreases quite a significant amount and raises again when the children return to school. Classroom 2 does not show much different results in week 1 compared to classroom 1. No abundant peaks or lows and the pattern visible in classroom 1 during measurements of week 1 and week 2 are quite similar.

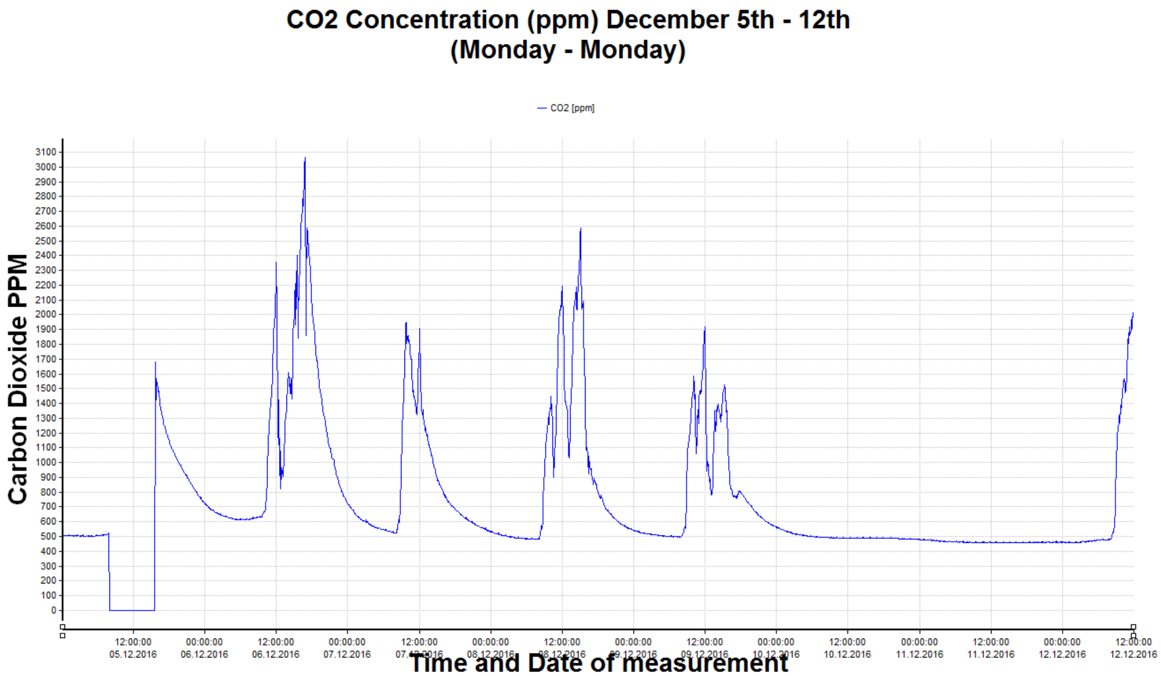


figure 11

In *figure 11* the CO_2 concentration of classroom 2 is shown from December the 5^{th} until the 12^{th} (week 2). At the start of the graph an error is clearly visible in the measurement device as the measurements of the CO_2 concentration drop instantly to 0 ppm before returning straight to 1700 ppm the next day. The measurements in week 2 of classroom 2 are quite different compared to the measurements of week 1. The overall trend is followed once again where the CO_2 levels rise in the morning with a rapid increase when the children enter the room but the peaks during the whole week are way higher compared to previous measurements. Tuesday the 6^{th} of December the CO_2 concentration reach a peak level of 3050 ppm which is almost double the maximum measurements of the previous week and all measurements of classroom 1. The following day, Wednesday the 7^{th} the measurements are quite normal again but are followed up by the measurements of Thursday the 8^{th} where the CO_2 concentration reaches a level of 2600 ppm.

Towards the weekend the CO_2 concentration drops as is expected and stabilizes at an average of 450-550 ppm.

Ambient Temperature (Celsius):

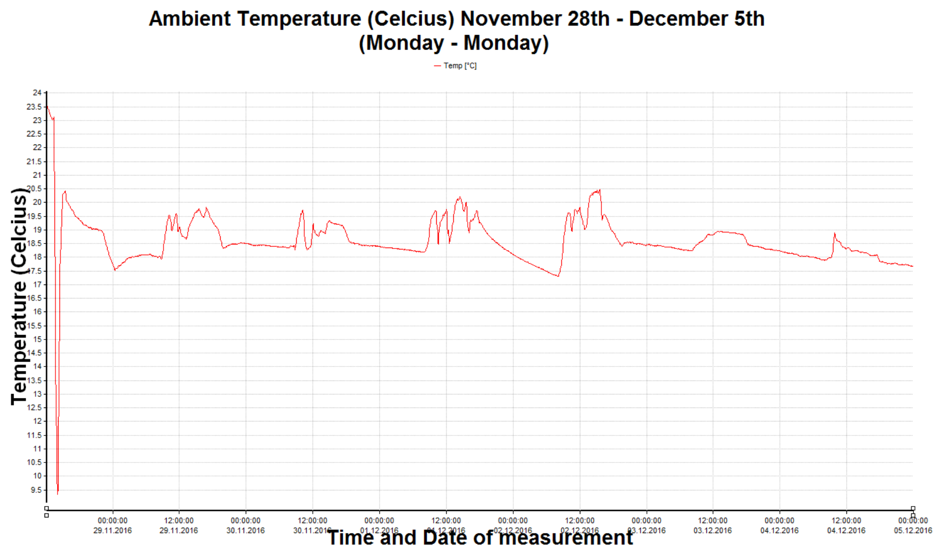


figure 12

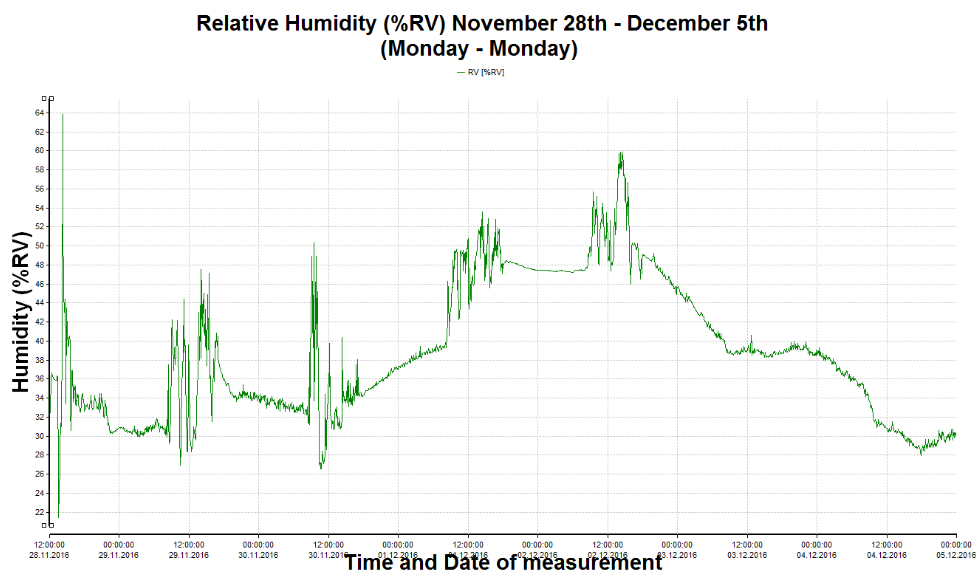


figure 13

In *figure 12 & figure 13* the temperature and humidity are illustrated from November the 28th until December the 5th (week 1). At the start of the graph the device is calibrating which explains the absurd peak. The temperature of classroom 2 during the measurements of week 1 peak during midday at around 20℃ and slowly decrease at the end of the day. The minimum temperature is lowest at the start of the week and slowly increases during the week starting at 17.5℃ and increasing until 18.5℃. On the night of Thursday the 1st to Friday the 2nd the temperature does peak at a minimum of 17.3℃. The humidity during the week 1 of measuring in classroom 2 does show quite some drastic peaks reaching a minimum of 27% on Wednesday the 30th and a maximum of 60% on Friday the 2nd.

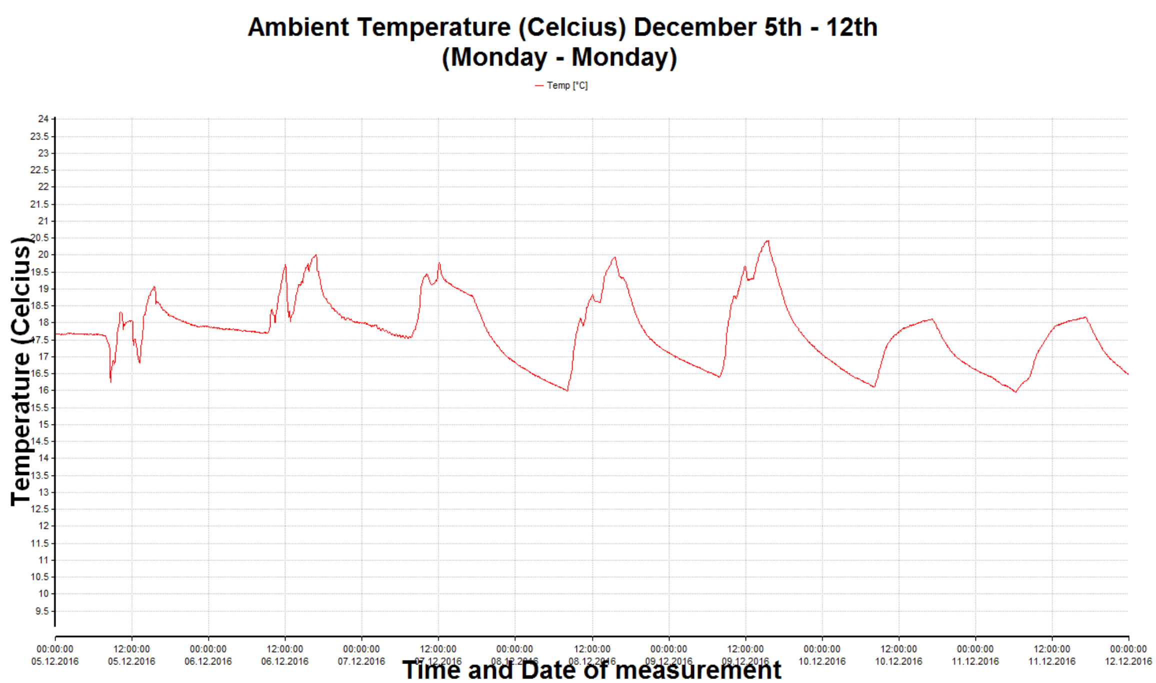


figure 14

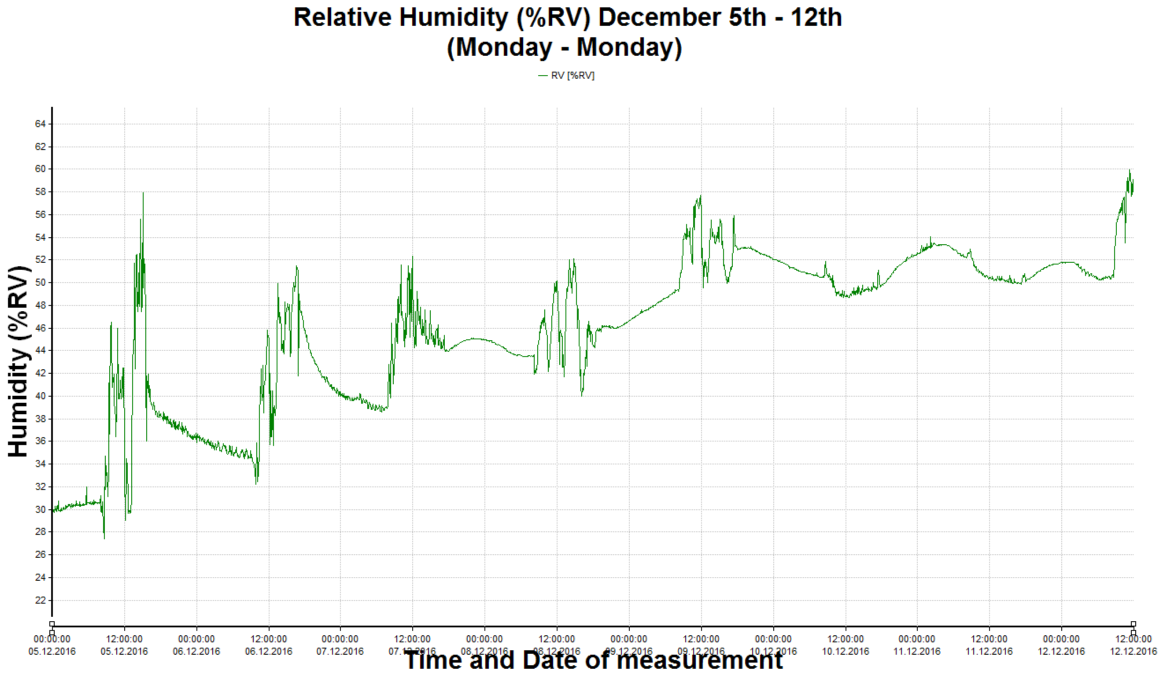


figure 15

In *figure 14 & figure 15* the temperatures and humidity are illustrated from December the 5th until the 12th (week 2). During this week the maximum temperature differs quite a lot everyday starting at Monday the 5th with a maximum temperature of 19°C compared to the maximum temperature of Friday the 9th of 20.5°C. The minimum temperature during the week does increase as well which is probably due to the outside weather conditions as the minimum temperature of the week starts Monday the 5th at 16.5°C. Then continues to Tuesday the 6th at 17.8°C, Wednesday the 7th at 17.5°C and then falls to 16°C on Thursday the 8th. It seems the lower the minimum temperature gets during the week the higher the humidity percentage becomes. This trend was clearly visible in the measurements of classroom 1 where the humidity percentage would increase when the temperature decreased.

Classroom 3

CO_2 Concentrations:

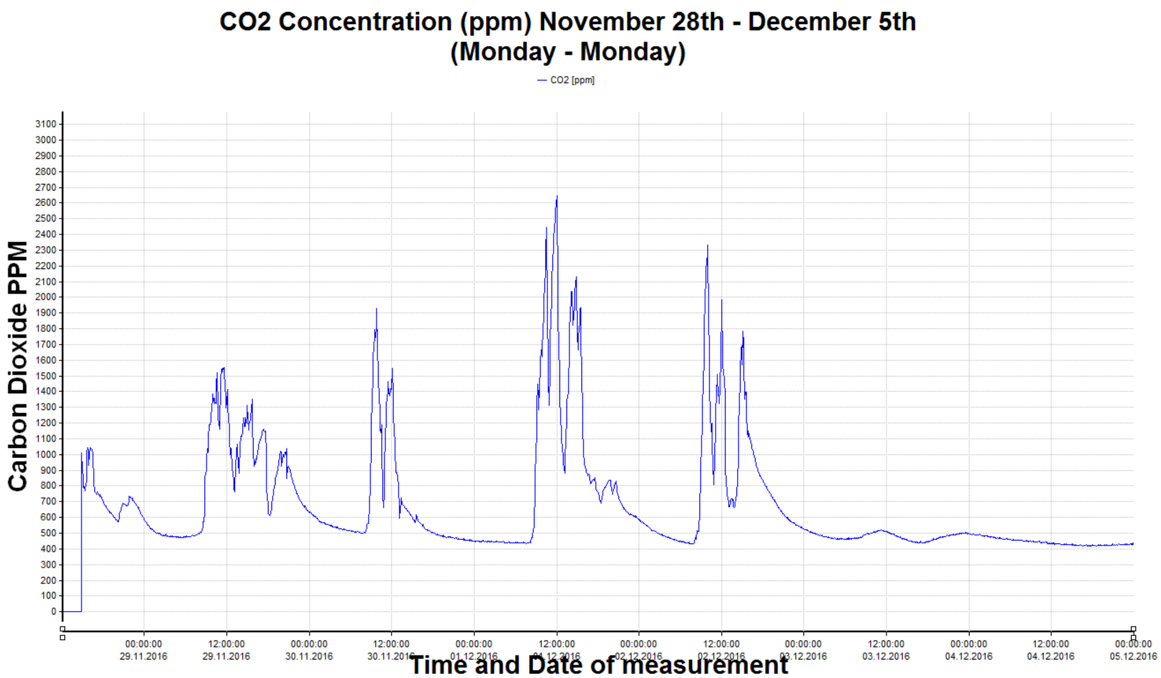


figure 16

In *figure 16* above the CO_2 concentration is illustrated from November the 28th until December the 5th (week 1). Monday the 28th the CO_2 levels are following the same trend shown in the measurements of the previous classrooms but seems to not reach higher than 1050 ppm. The following day, Tuesday the 29th an increase of the CO_2 concentration is clearly visible as the maximum reaches a value of 1550 ppm before decreasing and following the daily trend. The measurements taken of classroom 3 in week 1 clearly show an increase of CO_2 concentration during the week as the starting value at Monday the 28th is 1050 ppm and increases to a maximum at Thursday the 1st of 2650 ppm followed by 2350 ppm the next day. These values are very high compared to classroom 1 and show a similar trend to the measurements taken in week 2 of classroom 2.

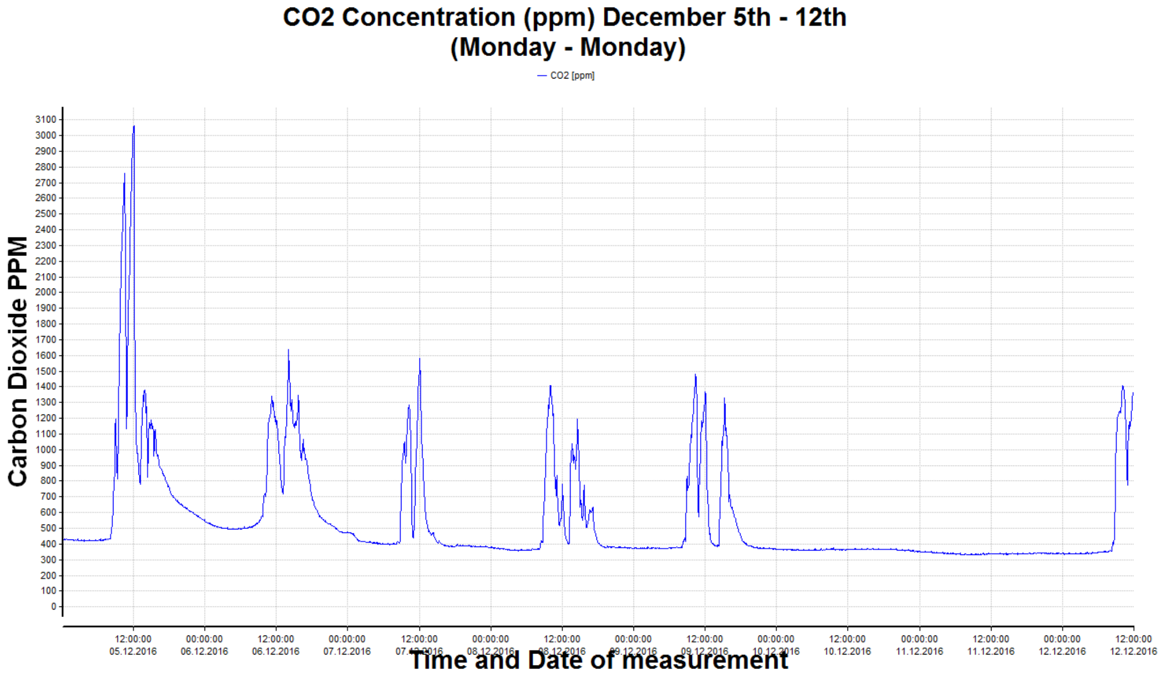


figure 17

In the *figure 17* the CO_2 concentration is illustrated from December the 5th until the 12th (week 2). Week 2 starts with very strong numbers as the maximum value of Monday the 5th reaches 3000 ppm during the day and rapidly decreases as the day goes by. Other maximum values during the measurements of week 2 seem to be very stable and between 1650 ppm at Tuesday the 6th and 1500 ppm at Friday the 9th.

Ambient Temperature (Celcius):

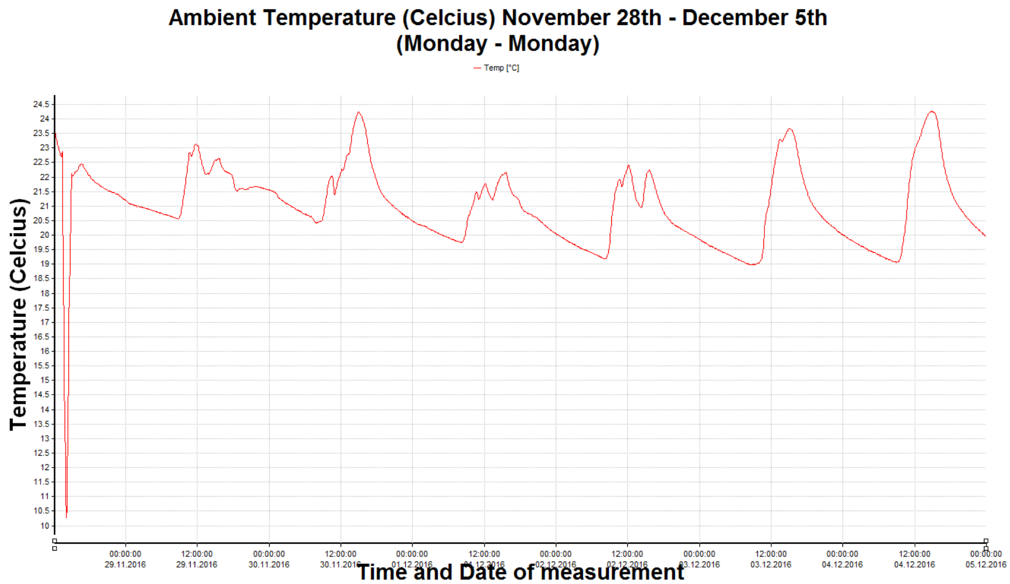


figure 18

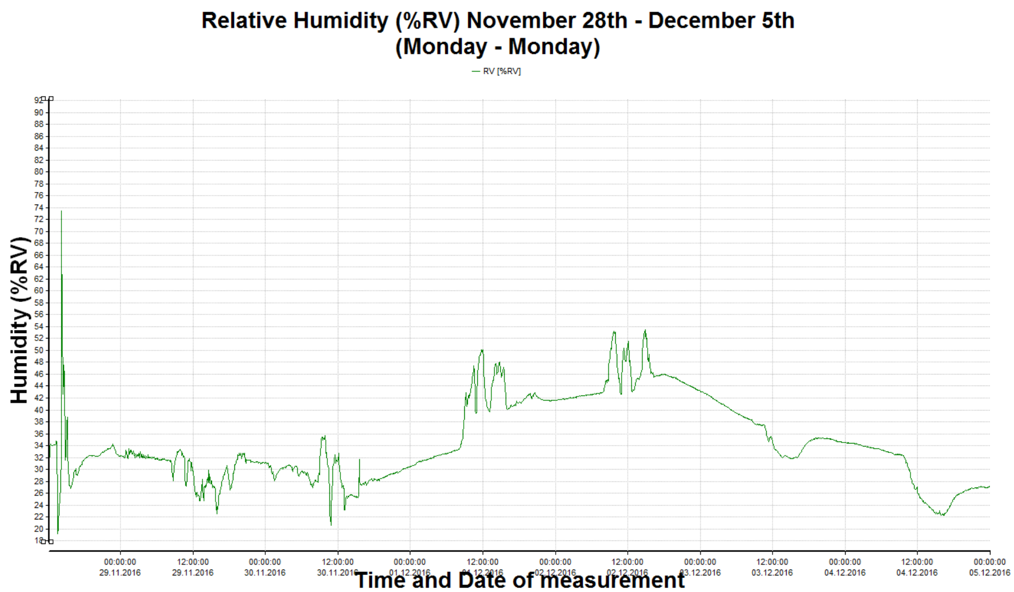


figure 19

In *figure 18 & figure 19* the temperature and humidity are illustrated from November the 28th until December the 5th (week 1). What is clearly visible is the difference in maximum temperature compared to the other classrooms. At the start of the week the minimum temperature is almost similar to the maximum temperature of the other classrooms. Even though the minimum temperature does lower during the week the maximum temperature tended to stay quite high during the week with a maximum of 24.8°C on Wednesday the 30th. Another difference between classroom 3 and the other measured classrooms is the temperature during the weekend which clearly rises during this time. The humidity reaches very low values in this classroom compared to the others, this is probably caused by the increased temperature as was also the case in classroom 1 and 2.

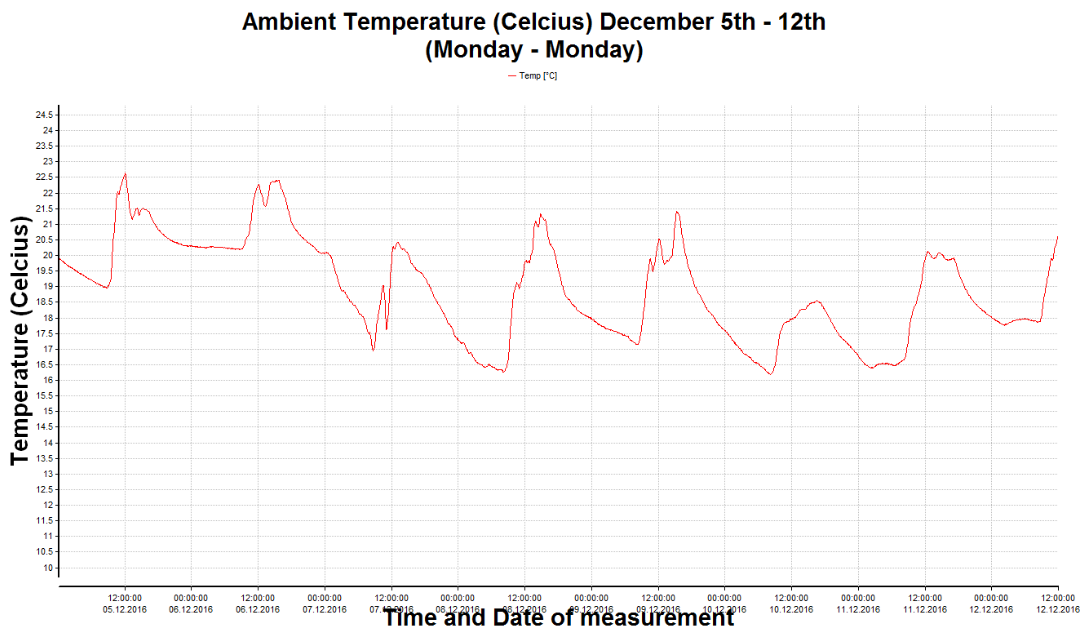


figure 10

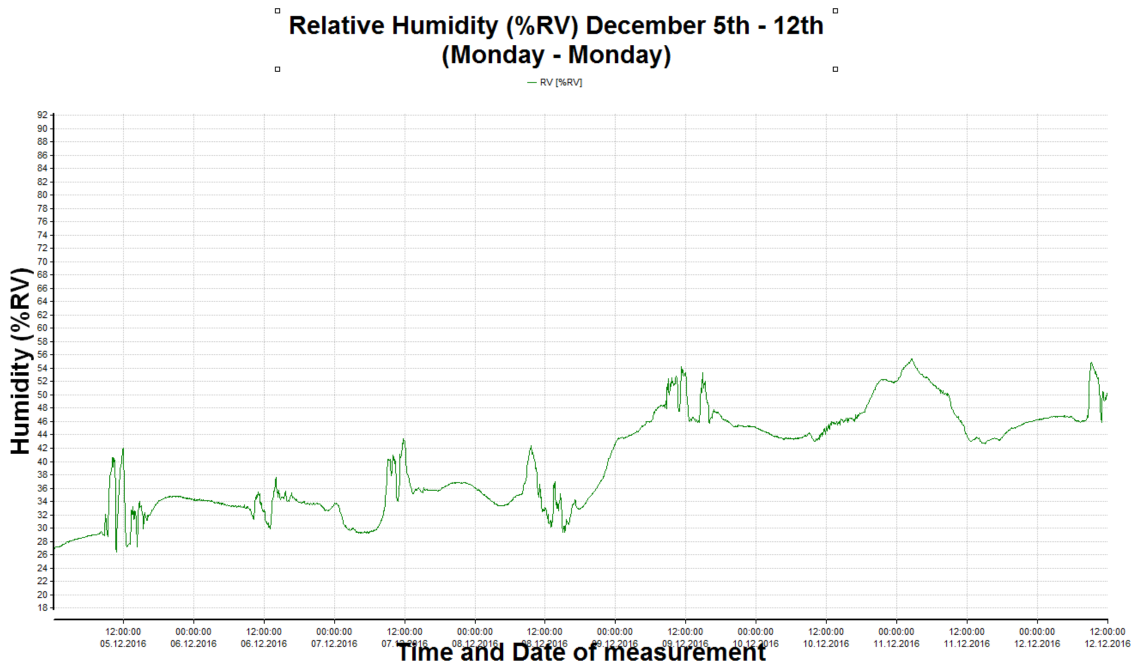


figure 11

In *figure 21* the temperature and humidity are illustrated from December the 5th until the 12th (week 2). Measurements during week 2 clearly show a lower maximum temperature present over the whole week, but still surpassing the maximum temperatures of classroom 1 and 2. The minimum temperature is also considerably lower compared to the measurements taken in week 1. Therefore, an increase of humidity is visible in the graph but the percentage is still very low compared to classroom 1 and 2.

4.2 Outdoor Results

As mentioned in the previous section the weather forecast and count of cars was to be recorded. The results are as follows:

Group 1

Time	Measur-ement	Temperature (°C)	Precipitation (%)	Humidity (%)	Wind speed (km/h)	Wind direction	Car count
07:54 – 09:25	**M1**	9		90	13	SSW	18
11:11 – 12:41	**M2**				13	SSW	2

Table 1

Group 2

Time	Measur-ement	Temperature (°C)	Precipitation (%)	Humidity (%)	Wind speed (km/h)	Wind direction	Car count
11:03 – 13:01	**M3**	3	6	90 – 95	8	NNW	113
13:57 – 15:57	**M4**	7	5	90 – 95	6	NNW	75

Table 2

Figure 21 and 22 are the measurements from luchmeetnet.nl at the Breda-Bastenaakenstraat station:

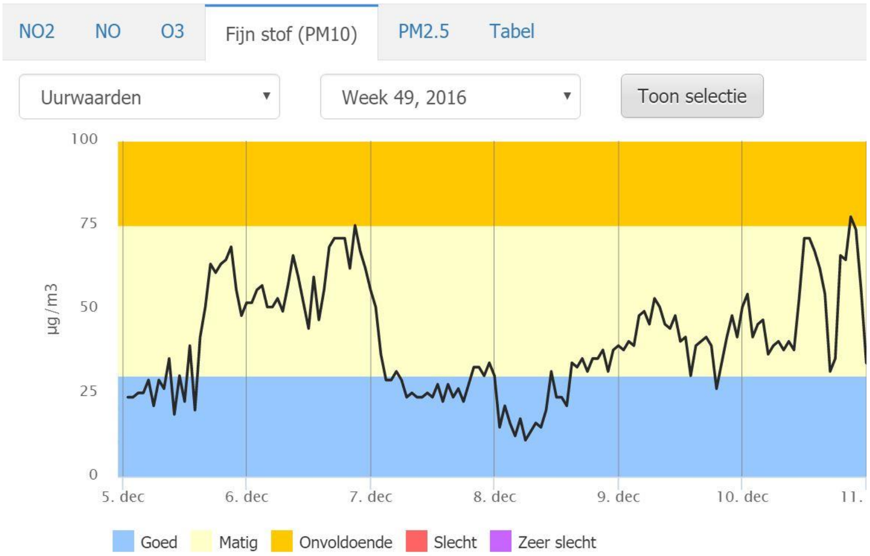


figure 21

Figure 21 represents the measurements over a period of days taken at Bastenaakenstraat station. On the 9th of December measurements were also taken at KBs de Griffioen primary school.

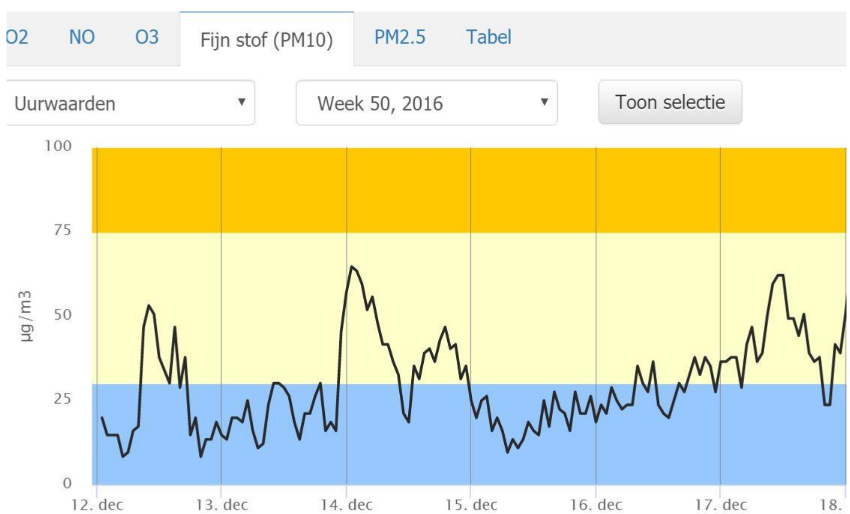


figure 22

Figure 22 represents the measurements also done by Bastenaakenstraat station. On the 16th of December PM_{10} measurements were also taken at the primary school.

The chart below shows the measurements that have been taken on the 09th of December (M1 & M2) as well as on the 16th of December (M3 & M4)

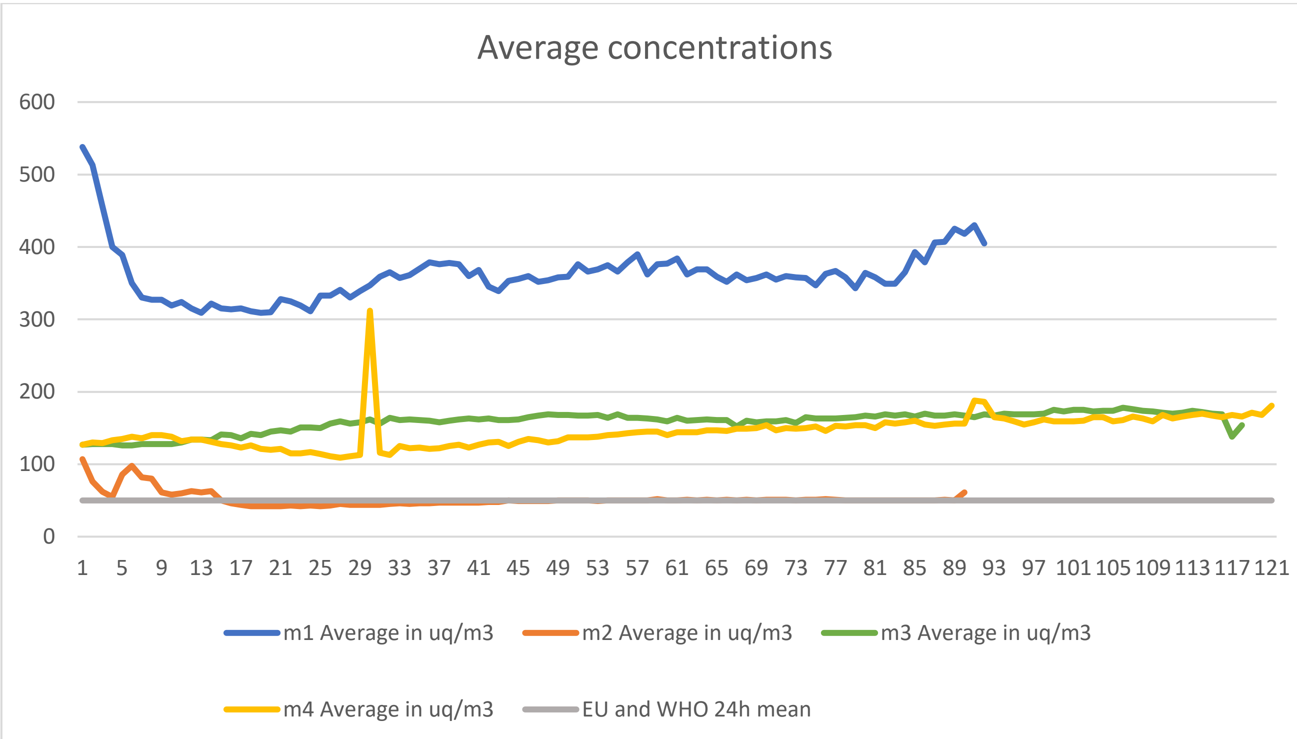


figure 23

Measurement 1 (M1) and measurement 2 (M2) were taken on the 9th of December. Measurement 3 (M3) and measurement 4 (M4) were taken on the 16th of December. They were both taken at KBs de Griffioen, both at the back of the school, where the children have recess every day.

The prevailing winds in the year 2016 is shown below in figure 24:

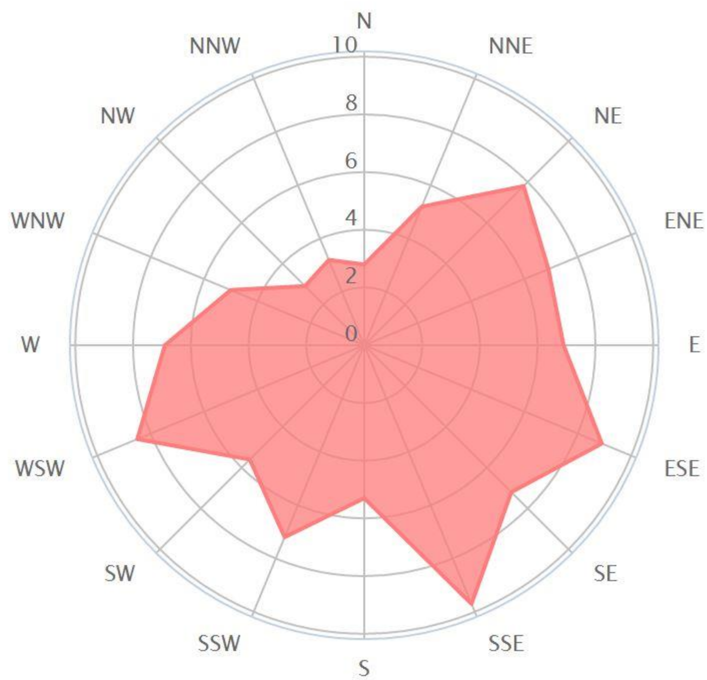


figure 24 (14)

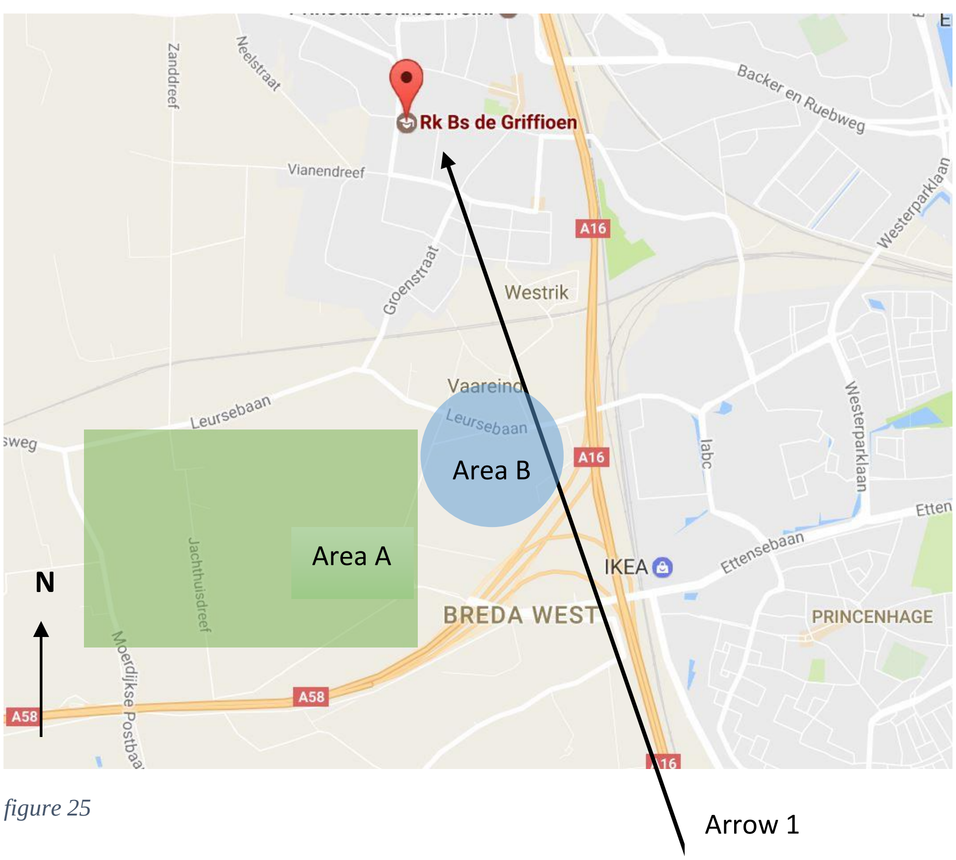


figure 25

5. Discussion

5.1 Indoor

The group expected to gather the results and be able to derive a lot of information from these values. Even though the measurements taken seemed to be very accurate as there were no anomalies present, they did not meet expectations of the group as the average values were exceeded by quite a lot. The results of all classrooms are very similar when comparing them on a daily base. The children and teachers had a very similar schedule, which repeated itself every day. Unfortunately, there was no possibility for the group to explain why the CO_2 concentration would spike at certain times of the days and would drop significantly because of the lack of activity log. It is possible to assume what happened in these times of significant increase of CO_2 concentrations as these were probably the times the children would enter the classroom. The windows were not opened very often especially not in the winter as the building was very old and the windows would not cooperate that easily. Another reason the assumption of the windows not being opened all day is that the temperature would not go down when CO_2 concentration went up. Therefore the assumption is that at times of significant reduced CO_2 concentrations the children were either not present in the classroom or performing activities that required them to not produce a lot of CO_2. When looking at the different classrooms one thing that is easily explained is the significant increase in CO_2 on the 5th of December as this day is the celebration of Sinterklaas which makes children be very active. After comparing the results gained from the measurements there was no way to compare them with the indoor model as the values were way off. The estimated ventilation capacity is 170 m^3/h which results in an average ppm value of 2000 ppm which comes very close to the measurement results. In the workshop 'Air Quality' the value of 1200 ppm was given as a limit value of CO_2 concentration but according to the WHO (World Health Organization) a limit value of 800 ppm would be more desirable. Therefore using the indoor model to reach the value of 800 ppm a ventilation capacity of 800 m^3/h is required to reach an average ppm value of ~ 800. If the school wishes to improve the air quality an increase in ventilation capacity of 630 m^3/h minimum is required and should be possible to achieve.

Looking at the ambient temperature of classroom 3 during both weeks of measurement there is something strange going on as the measurement temperature seems to be very high especially when compared to the other classrooms. Another strange thing is the fact that the temperature does actually not go down during the weekend like it does in the other classrooms. This leaves the group with the question if the measurements taken were incorrect or something else was happening in the weekend like extra classes or other activities. This does still not explain the higher temperatures recorded.

The lack of an activity log left the group having to assume a lot of factors which could have been way clearer if provided. Therefore the results do not have that much meaning as the group would have wished.

5.2 Outdoor

According to the physical measurements taken by the group presented by *figure 23*, the values seem to be very high when compared to the Bastenaakenstraat station (15) measurements *(figure 21* and *22*). As well as when it is compared to the limit values of the WHO and the EU, all measurements, except M2, done by the group were exceptionally high. M1 is especially high. It was reported though that on the morning of M1 there was a lot of fog. Since PM can easily be carried in a liquid form it is highly probable that a large amount of PM was water bound and since it was steadily around the device higher readings were recorded. M2 was taken on the same day, it was reported that as group 1 took measurements for M2 the fog has disappeared by 10:30 and noticeably the PM concentration decreased exponentially. When comparing measurements from *figure 21*, on the 9th of December to *figure 23*'s M1 and M2 the measurements are really high, it is still unknown why it is the way it was. Even M3 and M4 when compared to *figure 22* (day of the16th) are very high. It may be due to a human error of which the group still has not come across.

The car count of group 2 was not very high. Although, during the physical measurement period the cars were counted form the direction of where the wind came from only, this direction, as was judged by human perception it came from the eastern side, unlike the weather forecast from Table 2, which stated that it came from the NNW side. As *Figure 24* shows where the prevailing wind comes from SSE. (14) The A16 highway is the 4th busiest highway in the Netherlands which mainly connects Breda to Rotterdam and from Breda to Antwerp. (16) Highway A58 is also an important east to west connection but contributes to a lot of air pollution and noise pollution.

Arrow 1 on *figure 25* presents the prevailing wind and according to *figure 22* one can clearly see that the 2 connecting highways A16 and A58 might have an impact on the pollutants that could be carried towards the area of the primary school. The highway connection of A16 and A58 is a maximum of 5km away from the primary school. Since PM_{10} is coarser and heavier, it therefore can deposit easily and it will naturally travel with wind at a distance of approximately less than 10km, (17) but there is still the chance of it reaching the school. The speed of the wind will also have a direct effect on how far the particles are able to travel. In addition, as the particles may settle on a road or side walk it can again be blown up by winds or passers-by and carried further, into different directions according to wind direction.

Area A (the green rectangle) contains a lot of Trees as it is a park called Liesbos. This park would not cause a threat towards the air that might reach the school. On the other hand, next to Area A, Area B is an area used for growing trees mainly, and some other crops probably. Some greenhouses are present but there are also some open fields where crops are planted and harvested. This may also contribute to PM such as ammonia and nitrogen particles. Some allergens, like pollen, are also an added factor and can be carried towards the school.

Notice was taken that the children only play outdoors at the back of the school. This may be a positive factor as quite a busy road leads in front of the school. The back of the school though faces the southern side, which means that the prevailing winds of the south and south east winds may affect the children.

6. Conclusion and advice

6.1 Indoor

The general results that were gathered from the measurements taken show that the air quality in all three classrooms does not reach sufficient quality, as some measurements reach values which have been proven to not positively affect the working environment in these classrooms. As CO_2 concentrations in certain classrooms reach maximum values of almost three times the limit value at certain times of the days. These values can very much decrease the ability to work productive and efficient on any task given. Assuming the ventilation capacity is 170 m^3/h and would need to be at least 800 m^3/h to reach values that are considered good. To reach the desired 800 m^3/h ventilation capacity the recommendation would be to install a ventilation system that has a ventilation capacity of at least 630 m^3/h. Opening windows would be another option but seems way less realistic as opening a window the size of 3m^2 would reduce temperature inside which leads to very uncomfortable situations. Placing plants in the classrooms is a legit option, but would not reduce the CO_2 concentration considerably. Investing in a ventilation system might be tough once but the benefits are huge as has been proven many times.

The temperature and humidity in classroom 1 and 2, according to the results, are in the limits of acceptable range (according to the literature study) thus not impacting the indoor air quality in general as a whole. The temperature in classroom 3 might actually be a problem as the measured temperatures exceeded the optimal temperature by a lot. Assuming the measurements of classroom 3 are indeed correct, the temperature of this classroom should be decreased to improve general comfort.

6.2 Outdoor

It is possible to advise teachers to only let children play outside of times when PM is at its lowest. Notice was taken during measuring that there were children playing outside almost all of the time. Therefore, a better and less restricting idea might be beneficial. An idea and possibility was to build green walls that would face the side of the prevailing winds. This would greatly reduce the pollutants reaching the school and could contribute to a great community project which will not only look good but will have mutual benefits for the community at large.

As mentioned in the discussion that a busier road leads in front of the school, it is advisable to lower speeds of 60kmh to 30kmh. This would reduce the PM concentrations by 65%. (18) Speed bumps may be the most effective to lower the speeds of cars.

Since the measurements of the group were very high in front of the school green walls may be a valuable resource to remediate the air as well as for other purposes. Green walls are basically like a vertical garden, they contain a growing medium like soil and can sometimes be fitted with an automated watering system or can be watered manually. Green walls would be a great thing for a school, it would make the area look much more attractive as well as raise the value of the property and of course it would contribute to cleaner fresh air. For a matter of fact green walls reduce PM by 60% and NO_2 levels by 40% as a study of Lancaster University stated. (19) It could teach children a lot and may again increase the biodiversity of small animals.

The playground at Rk Bs de Griffeon is only covered by concrete and there it is a reasonable size to build some green walls. Building some green walls against the wall of the schools could also be beneficial, it would keep the building warmer and run off water could be used to water the plants. On a social level with green walls around it can improve overall psychological wellbeing of a person, it can increase focus levels and has a relaxing effect on people.

Figure 26 below represents an idea of where green walls can be constructed, B represents the front of the school and C represents the back of the school where the playground is, this is where the children spend most of their time of the day. It is therefore fairly important to create a safe and comfortable haven for children to optimally develop and grow healthily. The green lines represent the possible locations for green walls to be built and Arrows 1.2 and 2 represent the direction of the prevailing winds. The green line A (a green wall) would be beneficial in this place because it would filter the polluting winds that may come from the highway A16 and directly the road next to it where many larger cars like delivery vehicles were spotted during the measurement day.

It is also possible to construct green walls next to the highways themselves. This will not only filter the emissions and dust coming from the highways, but it will also serve as noise barriers.

figure 26

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