Building a Carbon Capture Unit and Air Quality Monitor

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Contents

1 Introduction

From rising sea levels, frequent extreme weather events to detrimental impacts on wildlife and human health, the effects of climate change are far-reaching and remain a significant threat to mankind. A major contributor is air pollution from the burning of fossil fuels such as coal, oil, and natural gas. The emission from these sources contains a cocktail of harmful pollutants. When inhaled, these toxins cause a range of health problems including respiratory issues, cardiovascular disease, and various types of cancers. The risk is particularly high for populations that are exposed to high levels of air pollution over an extended period of time (spare the air, 2019). As fossil fuels continue to be burned at an increasing rate, the problem of air pollution and its associated health impacts will only continue to grow, making it a pressing issue that needs to be addressed in order to protect public health. While Central Europe as a whole boasts of favourable air quality, Maastricht stands in stark contrast with its subpar air quality levels. For the past 15 years, the air quality situation in Maastricht has been the centre of intense discussion. The record-high levels of particulate matter, including ash and dust, have prompted growing numbers of residents to advocate for action to be taken to address this time-sensitive matter (Groen & Bouthoorn, 2018).

Proposed solutions include the creation of a low-emission zone in Maastricht (Groen & Bouthoorn, 2018) and the implementation of advanced air-filtering systems in university buildings (, 2022).

The importance of air quality in the context of climate change cannot be overstated, but a major focus must be placed on reducing carbon dioxide emissions (CO_2). CO_2 is the leading contributor to global warming, originating from sources such as non-electric cars, industrial facilities, coal mines, and more (NASA, 2017). The need for carbon sinks, areas such as forests, soils, and oceans that absorb CO_2 naturally, is pressing (Communications, 2020). A key component of the natural carbon sink system is Photosynthesis, the process by which plants convert CO_2 into energy. "The process by which plants synthesize organic compounds from inorganic raw materials in the presence of light", occurs according to the following equation (Hall & Rao, 1999):

$$CO_2 + H_2O \xrightarrow{\text{sunlight}} (CH_2O) + O_2 \tag{1}$$

Through the process of photosynthesis, plants absorb CO_2 from the air and release oxygen, improving air quality. Numerous studies have evaluated the ability of various houseplants to capture Volatile Organic Compound (VOC) gases (Wolverton, Johnson, Bounds, ALCA, & NASA, 1989) and CO_2 (Shamsuri et al., 2016) (Sowa et al., 2019) (Suhaimi et al., 2016), with the conclusion that they can significantly enhance indoor air quality.

The urgent environmental concerns of deforestation, water pollution, and excessive CO_2 emissions have driven the development of innovative solutions, such as artificial carbon sinks. Carbon capture, the process of capturing CO_2 emissions, is already widely used, with power plants and industrial facilities being able to capture up to 90% of their CO_2 emissions through industrial-sized Carbon Capture Units (CCUs) (for Climate & Solutions, 2018). This technology is crucial in the decarbonization of the industrial sector, allowing it to reach the United Nations' goal of reducing greenhouse gas emissions by 2050 (Nations, 2021). The general mechanism of a CCU includes the separation of CO_2 from other gases, and the subsequent storage and transportation of the captured carbon, which can be re-injected into underground rock formations or used in bacteria growth for further decarbonisation (Grid, 2012) (Bailey, 2019).

Maastricht's poor air quality and the already existing industrial scale solutions were the inspiration for the following project. To establish the severity of the pollution in the city, building an Air Quality Monitor (AQM) became the first part of the project. The AQM is based on an Arduino microcontroller and various environmental sensors. To directly counteract CO_2 emissions, a second branch of the project was opened: creating a small scale carbon-sink, a CCU. Inspired by how industrial units work, the CCU is based on household items to capture carbon from the surrounding air, utilising a simple chemical reaction. While technological solutions are much sought after, true change can only be achieved by making the community stand behind the issues. Therefore an outreach subproject was created: coding a website that showcases the workings of the AQM and the CCU, as well as displaying data collected by the AQM. This threefold project will be explained in the following paper. As the project predominantly focused on engineering, the bulk of the report details the construction process.

2 Theory

2.1 Air Quality Monitor

The AQM's main components, which measure CO_2 concentration and particulate matter in the air, are the MH-Z19 sensor and PMS5003 sensor, respectively. The MH-Z19 works by using non-dispersive infrared detection because gas molecules, such as CO_2, absorb light at the specific wavelength of $4.3\mu m$. In the optical cavity of the sensor (see Figure 1), the CO_2 molecules absorb a fraction of the emitted light, and the concentration of CO_2 (ppm) can therefore be inferred using the ratio of the intensities of *emitted/detected* light. The benefit of this detection method is that it can be used for inert gases with high precision, extensive range, and long-term viability (Zhou, He, Zhang, & Zhang, 2021).

The PMS5003 detects particles with a diameter of 2.5μm to 10μm using a real-time Optical Particle Counter (OPC). More specifically, the microprocessor creates a steady airflow carrying particles into the sensor; these particles refract light from the laser beam uniquely according to their size, and algorithms can extract the mass concentration of each size (μg/m3) (see Figure 2).

These sensors communicate their measurements via UART digital communication to an Arduino microcontroller which then records the data onto an SD card for later analysis. Alternatively, an LCD screen can also output the gas and particle counts in real time.

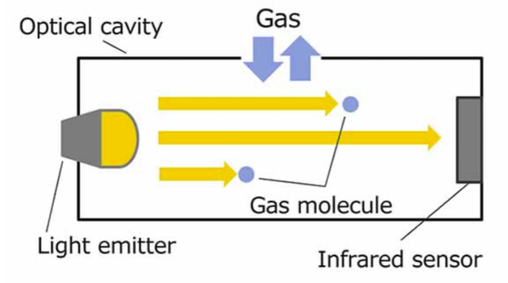

Figure 1: Diagram of NDIR sensor (AKM, n.d.)

2.2 Carbon Capture Unit

The purpose of the CCU is to create a portable means of removing CO_2. This provides an opportunity for individuals to directly experience carbon removal and improve air quality in confined spaces. It is based on a simple process in which CO_2 molecules bind to sorbent molecules. This mechanism occurs inside the CCU and consists of 2 steps. First, a strong alkaline sorbent solution is put in a container inside the unit. The container has a hole on the top, where a humidifier is placed. Secondly, the humidifier sprays the alkaline solution to the air, where it reacts with CO_2 forming a carbonate aqueous solution which condensates on the walls and lid of the CCU. For this project, potassium hydroxide (KOH) was used as the strong base solution, forming potassium bicarbonate ($KHCO_3$) (Firman, Noor, Zakir, Maming, & Fathurrahman, 2021) (Gambhir & Tavoni, 2019):

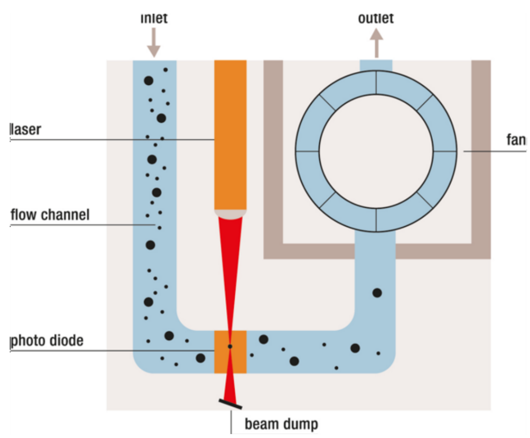

Figure 2: Diagram of an Optical Particle Counter (Latanzzio, 2021)

$$\mathrm{KOH(aq)} + \mathrm{CO_2(g)} \longrightarrow \mathrm{KHCO_3(aq)} \tag{2}$$

The CCU design follows the construction requirements of the chemical reaction. It has a ventilation mechanism to ensure constant air flow and a filtering mechanism which captures the carbon. The ventilation mechanism consists of a fan attached to the side of a rectangular box. It is the only air intake for the unit besides the discharge tube, to ensure maximum suction of the surrounding air into the CCU.

The whole unit is angled with one of its corners as a pivot point. This ascertains that all the $KHCO_3$ flows towards the corner, where a discharge tube leads the final product out of the CCU.

The walls and corners of the unit are coated with a hydrophobic layer to maximise water flow. This establishes autonomous working of the CCU for long periods without needing maintenance.

3 Materials

This project required very specific materials that were partly difficult to find. In the planning phase, thorough search was conducted to find other suitable projects in order to create a list of necessary materials. This was crucial for the air quality monitor, as many of the electronics parts take weeks to be delivered. The parts ordered were based on 'How To Mechatronics' founder Dejan Nedelkovski's project 'DIY Air Quality Monitor' . However, this was not possible as there are limited vendors the university can buy from, which led to finding similar parts with which to replace the ones that were unable to be found. As a result, fake Arduino Nanos were accidentally ordered which introduced several problems in the construction. from Austria was found.

3.1 Air Quality Monitor

The AQM consists of several different sensors:

- DHT22 Temperature and Humidity Sensor
- SP07 Volatile Organic Compound (VOC) Sensor
- PMS5003 Particulate Matter Sensor (PMS)
- MH-Z19 CO2 Sensor
- Gravity: I2C Ozone Sensor
- DS3231 Real Time Clock (RTC) Sensor
- 2,4" Nextion Display LED Screen
- Arduino Nano Board
- SD Card Module

All of the sensors were ordered before the start of the project. Furthermore, specific electronics components were used for prototyping the device:

- Various Resistors
- LEDs
- Breadboard
- Cables
- Headers
- Oscilloscope
- DC power supply

- Multimeter

Most of these components are based on the How To Mechatronics project.(Nedelkovski, 2020) Due to the university's limited access to vendor sites, some of the components had to be replaced because of the lack of availability, which caused issues later in the device's construction. Because of these changes, the project had to include many adaptations; most importantly, the pre-designed printed circuit board (PCB) could not be ordered from Nedelkovski's project as it would not fit the other components. The problem-solving of these issues will be explored more in depth in the methods section.

3.2 Carbon Capture Unit

For the initial design of the carbon capture unit, a fan, a plastic box, an empty ice cream container and an aquarium pump was used. Once optimized, the aquarium pump was replaced by a humidifier. Moreover, an Arduino Nano and a humidity sensor were introduced as well as PVC pipes and a good air filter. Various pieces such as a box for the KOH and an encasing for the electronics were 3D printed. This was done using Chad Ellington's 3D printer and his filament (PETG). To make the box waterproof, hydrophobic spray, silicone and epoxy glue were utilized. Using a perforated board and copper wire the electronics circuit was made permanent. In the construction, tape and electrical tape found their application. All of these parts were ordered or bought during the course of the project, since they are easily available in hardware stores or rapidly deliverable by Dutch vendors.

3.2.1 3D Printing

During the project, the intention was to design 3D printed parts in order to aid in the construction of the AQM and CCU. A Creality 'Ender 3 V2' 3D printer was used (Creality, n.d.). The polylactic acid (PLA) filament was replaced with recycled plastic filament in the attempt of making the project carbon neutral. For designing and modelling 3D printable parts Autodesk Fusion 360 was used. Fusion 360 is a professional grade modelling and design software (Autodesk, n.d.).

4 Construction Methods

4.1 Air Quality Monitor

The first step in assembling the AQM was becoming familiar with its independent components. To do so, the sensor's libraries were studied to perform isolated tests on each of them. They were examined in a simple Arduino circuit to guarantee their proper functioning. All the libraries and codes used in this project are available on our Git Hub .

4.1.1 MH-Z19 CO2 Sensor

The CO2 sensor in this project was tested using the MH-Z19 Arduino library on a breadboard circuit. Using the official datasheet from the manufacturer the power and data streams were wired. With the additional SoftwareSerial.h library, some of the Arduino's digital pins were converted to Tx/Rx serial pins and thus the transmission and reception of data to and from the Arduino was possible. Initially, the values for both the concentration of CO_2(ppm) and temperature (°C) measurements were much greater than standard background expected values (around 3000ppm and 40°C). However, after following the manufacturers recommendation and running the device for 20 minutes before trusting any results, the sensor yielded reasonable results.

4.1.2 PMS5003 Particulate Matter Sensor

The PMS5003 sensor was challenging for different reasons. The library for this sensor was not adapted to the Arduino Nano which was solved using the SoftwareSerial library. Additionally the sensor uses a 3.3V logic to communicate with an Arduino, yet this model had an operating voltage of 5V. Thus, a voltage divider was fashioned out of 1kΩ and 2kΩ resistors. Moreover, initial tests indicated normal levels of particles of diameter less than $1\mu m$, but no particles above this size were recorded. The functioning of the sensor was tested by reading the digital data using an oscilloscope.

4.1.3 Gravity: I2C Ozone Sensor

The Gravity: I2C Ozone sensor was easily tested and proven to work in isolation using its specific library "DFRobot_OzoneSensor" . Although this sensor was operative, when tested it read constant values at around 20-25 ppb (particles per billion). This was thought to be because it had not yet been calibrated as it was discovered that the sensor might need up to 24 hours of recording data to be reliable.The type of Ozone sensor used was not the preferred one as it differs from the original component in Dejan Nedelkovski's project, especially in the type of connection. This further challenged the assembly of the AQM, which will be discussed in the assembly section of the methods. Furthermore, the main AQM code had to be adapted to the library used by the replacement Ozone sensor.

4.1.4 SP07 Volatile Organic Compound Sensor

The SP07 sensor was easy to test as it only has analog outputs and needs no sensor specific library. It outputs four different values, indicating clean air, slight air pollution, middle air pollution and heavy air pollution.

4.1.5 DHT22 Temperature and Humidity Sensor

Setup and isolated testing of the DHT22 was straightforward. Testing and getting values was easily accomplished using example codes from the sensor's library, "DHTlib".

4.1.6 DS3231 Real Time Clock Sensor

The DS3231 sensor is a crucial part of the AQM since it records time while data is being collected. Initially, problems with setting the baud rate (a unit of measurement dictating the speed of communication of data) occurred and thus the sketch in use was not set on the appropriate speed of data reception. This was quickly fixed and the RTC started tracking accurate time. In parallel to understanding baud rate, another possible solution was to purchase a battery for the sensor. The battery was bought, but it was later realized that this battery simply allows the real time clock to run without a source of power, once it has been set through an Arduino.

4.1.7 SD Card Module

To display data on a website built for the project, different ways to store and retrieve data were considered. All the measured data was recorded on a SD card using an SD card module from Arduino and an Arduino SD card. The set up of the SD card reader was uncomplicated after research on the module.

4.1.8 Nextion Display

The display was used to present the sensors' data in real-time. This model used an interface called the Nextion Display Editor (only available for Windows) which allowed dynamic touch reactive displays of our data to be coded. The code was uploaded onto the device through an SD card formatted in FAT32. To send and receive commands from the Arduino the device also uses Serial communication, but for the final project, the actual hardware serial pins were used.

4.1.9 Arduino Assembly

For this assembly process, the schematic in figure 3 was consulted. Firstly, all the replaced sensors had to be adapted into the circuit. A problem occurred when plugging in the ozone sensor because instead of the standard UART connection protocol it needed an I2C connection. Since the knowledge required to set up the sensor with I2C is very extensive and there was a limited amount of time left, it was decided to leave the Ozone sensor out of the AQM circuit.

More problems were encountered when plugging the PMS sensor into the circuit, as it started fuming and was unplugged. Consequently the sensor was no longer working. The cause of this malfunction was assumed to be due to a makeshift cable made to connect the sensor to the breadboard which might have caused the V_{in} and GND pins to touch and thus created a short circuit. A second attempt was made with a new sensor which was mistakenly reversely polarized leading to it breaking. In the third attempt the PMS sensor was successfully connected.

Finally, the SD card was to be added to the circuit and as it was not a part of the original project, the main code had to be modified so that all the data recorded by the sensors could be uploaded on the SD card. Once the code was successfully edited, it was noticed that the Arduino Nano's memory was not large enough to have both sensors and the SD card working simultaneously. Therefore it was decided to further modify the code to remove some parts that were not necessary. Unfortunately, the VOC sensor had to be removed from the circuit to free up space for the SD card reader. Lastly, to make the device mobile, the entire circuit was soldered to a perforated board.

4.1.10 Arduino and Nextion Code

To tie all of the sensors together and recuperate their data using an Arduino Nano, a code was written in C++. The code works in coordination with all the sensor libraries to request their data using UART or SPI protocols and then send them concurrently to the Nextion display and the SD card module. The Arduino and display code files can be found in the GitHub repository under codes.

4.2 Carbon Capture Unit

As the CCU was inspired by the CYAN openair project (Winters, 2019), the first attempt was to replicate their unit. To that end, an aquarium pump, an empty ice cream box, a mask, a big plastic

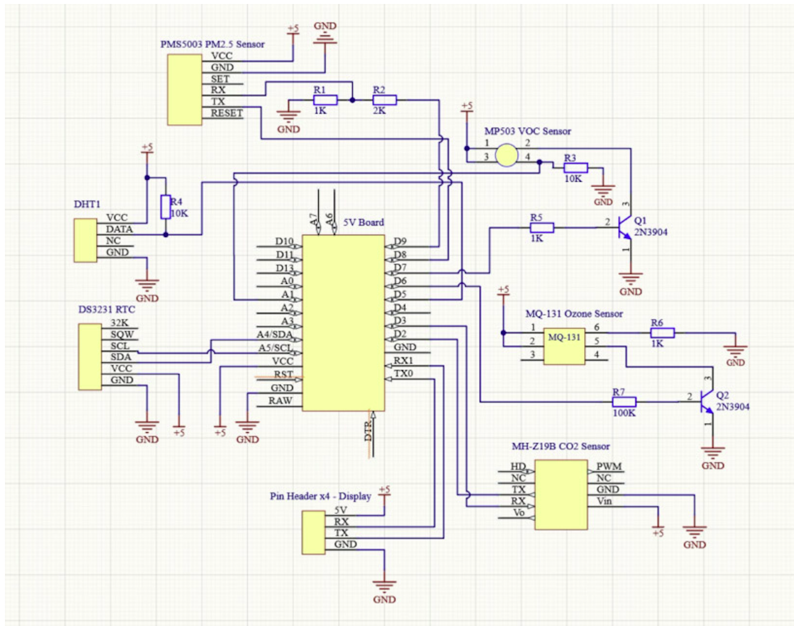

Figure 3: Circuit Diagram inspiration for the AQM. Some sensors (Ozone, VOC) were removed and another module was used to upload data to the SD card.

container, and KOH pellets were used. The ice cream box was filled with water and put inside the plastic container, while the aquarium pump was connected to electricity and placed into the water. Once turned on, the pump proceeded to humidify the plastic container. Then the KOH pellets were positioned in the mask which in turn was stretched over the ice cream box. These were the basic components necessary for the chemical reaction to occur. As there was no CO2 sensor available, we could not test the box. After thus having understood the process and parts necessary, the carbon capture unit was optimized.

4.2.1 Optimisation of Original CCU

Arduino-powered humidifiers were ordered to replace the aquarium pump, increasing the effectiveness and autonomy of the humidifying process. Instead of placing KOH pellets in moisturized air, they were to be dissolved in water and this solution was then to be the liquid that the humidifier uses to create mist. To ensure a constant circulation of air in the CCU, fans were ordered, a smaller plastic box and PVC pipes were bought, as well as necessary pieces designed in Fusion 360 to 3D print. After these parts were combined and powered using one Arduino Nano that was initially ordered for the AQM project, it was decided to also incorporate an additional humidity sensor from the AQM to measure the humidity inside the CCU. Since the chemical reaction that binds carbon to potassium hydroxide requires a certain level of humidity, a circuit was created incorporating the sensor that constantly checks the humidity level and turns on the humidifier once the humidity level drops below 75%.

4.2.2 Electronics

When creating the initial circuit which consisted of the fan and humidifier, an issue was encountered. Both the fan and humidifier required a voltage of 5V. The digital pins of the Arduino can be used for this, as when set to HIGH in the code, they should output 5V. For some reason, this however did not suffice to turn on the humidifier or fan which led to a voltmeter being used to ensure that the output of the pin was the right voltage. Since the source of the issue was unclear, it was decided to simply power the fan and humidifier through the 5V pin but turn it on and off with transistors acting as a switch. After trying to use PNP transistors since these were readily available in the labs and failing, it was decided to try NPN transistors instead. This solved the problem and the electronics for the box were finished.

To make the circuit permanent, a perforated board and copper wire were put to use. Every connection and cable was replaced by soldering copper wire to the necessary points, which in turn were soldered to the perforated board. This process was not without difficulties as the soldering material did not stick to the pins or the perforated board. Heating the perforated board additionally produced fumes that hurt people's respiratory systems, which prolonged the soldering process extensively. Once finished, the circuit did not work due to issues with the soldering of the 5V and the ground line. While solving this turned on the fan, it did not work for the humidifier and humidity sensor. After extensive experimentation, the problem turned out to be with the soldering of the Arduino. In conclusion, the electronics took more time and effort than initially planned but they were completed by the end of week 2.

4.2.3 Constructing the Box

While the electronics and the code were created for the CCU, another part of the group focused on optimizing the plastic box in which the reaction was to occur. Initially, the plan was to 3D print a ramp to put in the box so that the liquid collects on one end. Due to printer issues, it was decided to construct a ramp from scrap plastic and silicone the holes. While this worked, it was neither particularly aesthetic nor waterproof. The box was therefore tilted instead of adding a ramp. To that end, a stand was made by gluing three wooden blocks together to create the ideal angle for the box. As the box did not have a smooth bottom, it was made even using silicone. Since the humidified potassium hydroxide is mildly toxic, the CCU needed to be airtight - while at the same time having a constant airflow. This problem was solved by letting the fan run constantly and having one angled air tube at the top with a high-quality air filter at the end. Once the KOH box and the encasing for the electronics were printed, the box was assembled.

4.2.4 Assembly of the Box

Due to superglue not sufficing as construction means, epoxy glue, double-sided tape, gorilla tape, and electrical tape were used to build the unit. As the amount of force the PVC pipes were to face was underestimated, these had to be reglued and siliconed twice. When attempting to attach the electronics to the outside of the unit, the circuit was compressed which destroyed some connections that had to be resoldered. To avoid this problem in future, a piece was designed, printed, and glued. This is the only part that was printed using our 3D printer. Once this assembly was finished, the first test was done with water. Due to faulty construction and lacking experience with 3D printing, neither the KOH container nor its connection to the wall of the box was waterproof. The two pieces were therefore reglued and the bottom and sides of the KOH container were covered with a layer of epoxy glue, two layers of hydrophobic spray, and one layer of silicone.

4.2.5 Testing of the CCU

After the setup was finished, the water test was repeated. This succeeded, and the humidity rose to 60%. The next step was mixing 16.8 g of KOH with 300ml of distilled water and placing it in the CCU. After approximately one minute of testing however, the humidifier stopped working. This issue was attempted to be fixed by using the spare humidifier and powering it from an outside power source. A few seconds after the power source was turned on, the humidifier started smoking and broke, so it was disconnected. Then an attempt was made to repair the original humidifier but without success. To still be able to test the reaction, the aquarium pump of the original design was put into the CCU, but since its humidification is less powerful than the humidifier with which this setup was designed, no reliable measurements were made.

As this happened on the last day of the project, there was no time to buy new humidifiers and repair the box.

4.3 3D Printing

During the construction of the CCU and AQM it was decided which parts needed to be designed and 3D printed. Using digital callipers and rulers,dimensions of pieces were determined and used to create a 3D sketch in Fusion 360. Figure 3 depicts a 3D sketch of a fan bracket for the CCU.

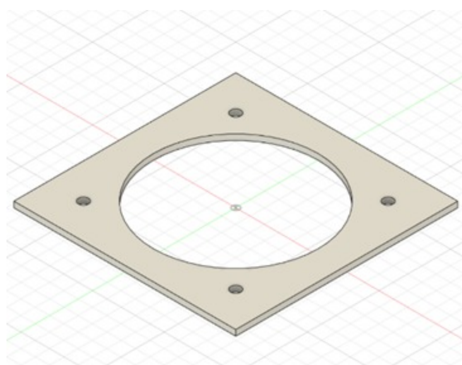

Figure 4: 3D sketch

Once a given part was sketched, it was 3D printed. Although the initial plan was to use the Creality 'Ender 3 V2' 3D printer in the lab, ongoing issues with the printer prevented it from being used extensively during the project. In most cases, an offsite 3D printer was used to print previously designed parts. However, a limited number of small parts were printed using the lab's printer. Figure 4 shows the print of a bracket which attached the CCU electronic box to the main box.

The Creality Ender 3 V2 printer was challenging to work with due to faulty equipment and lack of 3D printing experience. Examples of such issues include lack of bed-adhesion, ground down extruder gear, and blocked filaments. Although troubleshooting the 3D printer was not a difficult

Figure 5: Printed bracket for electronics box

task, the process did prove to be very time intensive. Finding solutions to problems was challenging due to the lack of technical vocabulary and proficiency. In addition, it took upwards of two hours to print test pieces which made repeated testing unattainable.

4.4 Website

To spread awareness about air pollution, a website was coded. As only one project member had any prior experience in web development, the first step was acquiring the necessary web development skills such as html, CSS and java script. To give the website a professional feel, inspiration was taken from various notable websites from companies such as SpaceX, Apple and Nature-Science. A homepage was created with links to multiple other pages where more detail could be provided on several different aspects of the project. Pieces were added to the website one by one, such as the header, navigation bar, body and footer. These were then styled in the CSS files to achieve an appropriate design. To host the website publicly instead of on local servers, it was uploaded to github. After the report was finished, each section of the website was filled with content. The graphic design was based on a black/white scheme. The only drops of color came from the background pictures, which were also kept simple as not to interfere with the text.

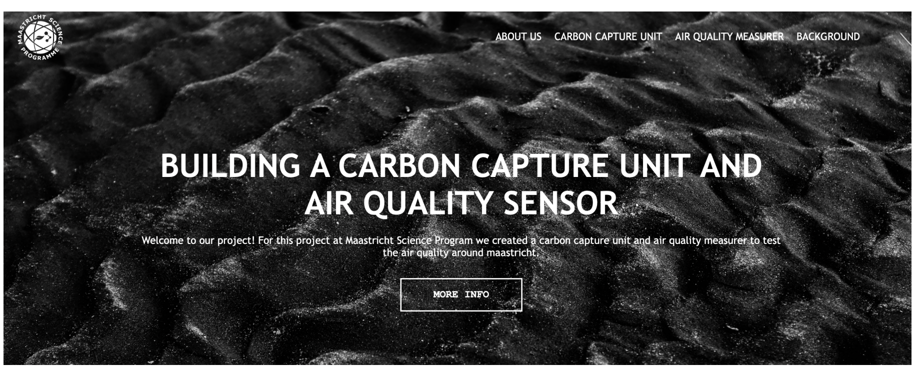

Figure 6: Homepage of the Website

Difficulties arose mostly due to the lack of programming practice and some design changes had to be made to accommodate for the general skill level. For example, a standard top navigation bar was used in the header instead of a hamburger menu. Troubleshooting the code was challenging as there could be a multitude of reasons the code was not working. In some cases entire sections of code had to be deleted and rewritten, or worked through on a separate file before being added back in. There were also issues with making the page mobile interactive and smooth in that aspect of design. If there had been more time it would have been possible to fully create a mobile working website, as well as adding more interesting features to the design.

5 Results

After building the AQM, measurements were taken. In Figure 7 the fully finished device can be seen. Testing was conducted in a project member's apartment over the period of 24 hours. An overview of events which occurred at the measurement sight are annotated on the figures.

The 24 hour time period across which the AQM was monitoring can be seen throughout figure 8. Overall figure 8 shows that VOC, temperature and humidity stayed at constant levels. However, temperature and humidity decreased and increased respectively. These peaks happened as a meal was being cooked in the same confined space the measurements were being taken in. From the data it can be inferred that the cooking caused the increase in humidity. During the cooking, pm2.5 and pm10 values also rapidly increased, leading to the same conclusion as for the humidity. As can be seen in figure 9 below, the dip in temperature had a delayed response when compared to the rise in humidity. This can be explained by the annotations. At 13:55 a window was opened and ventilation turned on. This potentially explains the drop in temperature and the drop in CO2.

Another significant peak can be seen in figure 8, where the value of CO2 peaks as measurements began. This high starting value comes as a result of the sensor having just been turned on and needing to adjust. As time passed, the CO2 value stabilized and eventually reached a value of around 800 ppm. The CO2 levels decreasing significantly could be due to the person leaving the room at around 19:15. In addition, the CO2 levels can be seen quickly rising to above 1000 ppm when the person returned to the room at around 3:30. All these trends can be observed in figure 9 .

Since the CCU was not fully functional by the end of week 3 due to components breaking on Friday, there are no results available from test runs with KOH. The water test run however worked, so one could say that the box was operational before. Every part of the CCU was optimized compared to the original CYAN project. As visible in figure 11, the electronics box was attached to the outside, the humidifier and humidity sensor were inside the box and the refill tube for the KOH was taped facing upwards, to avoid leakage. In the Erlenmeyer flask the chemical was mixed with distilled water. Once that solution was added to the CCU, the humidifier broke. The result is therefore the concept and planning of a functional CCU, but no data from test runs.

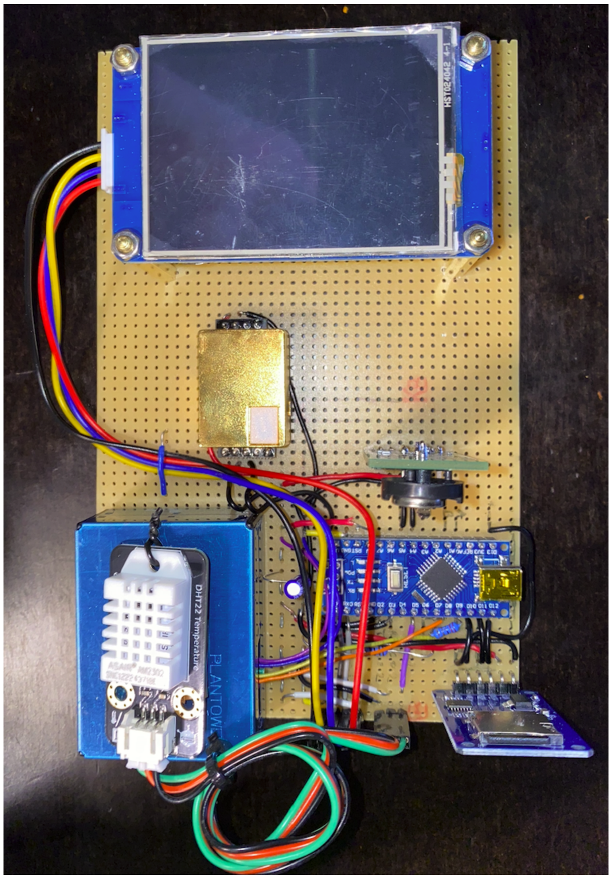

Figure 7: Final Prototype of the AQM

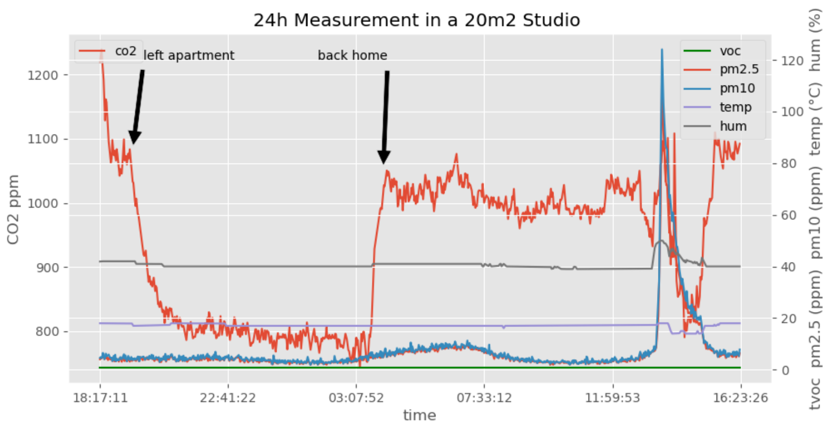

Figure 8: Graph of CO2, PM2.5, PM10, temperature and humidity throughout the 24h

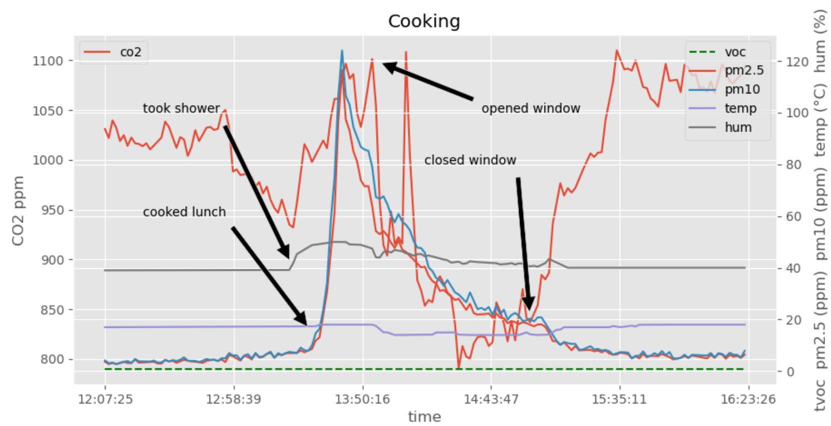

Figure 9: Graph of CO2, PM2.5, PM10, temperature and humidity while cooking in the 20m2 room

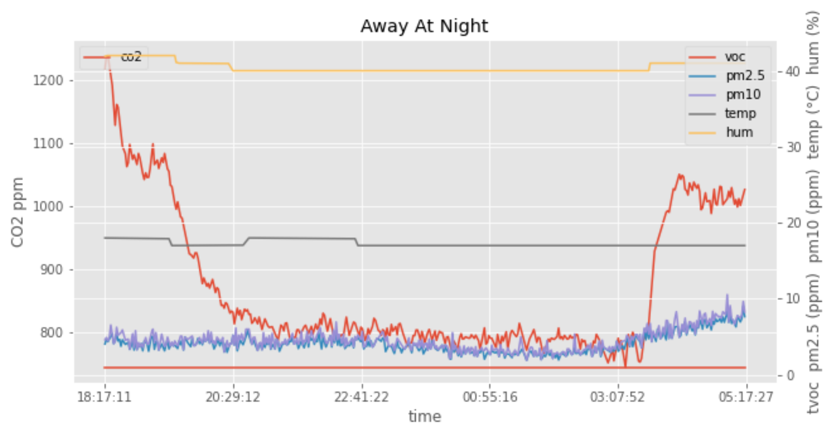

Figure 10: Graph of CO2, PM2.5, PM10, temperature and humidity while no person was present in the 20m2 room

Figure 11: Final box

6 Discussion

6.1 Chemicals

6.1.1 Chemicals Used as Input

In order to capture atmospheric CO2, strong base solutions or solid sorbents, such as potassium hydroxide (NaOH), could have been used.(Gambhir & Tavoni, 2019) (Firman et al., 2021)However, a KOH solution was chosen due to the reasons discussed below.

The two most used CO_2 absorbents are NaOH and KOH (Gambhir & Tavoni, 2019). However, KOH has proven to be more efficient than NaOH at removing CO_2 from the atmosphere by previous studies(Mahmoudkhani, Heidel, Ferreira, Keith, & Cherry, 2009) (Tagar, Sahito, Kumar, & Mubarak, 2022). Therefore KOH was chosen as the alkaline sorbent.

In order to choose between a solid or a solution, a test was conducted. In a first attempt at building an effective CCU, KOH pellets were used. This setup proved to be disadvantageous as water accumulated on the mask. Possible solutions would have been to either change the filter more frequently or add an extra filtration step to the mechanism. Both options would have made the CCU less autonomous and thus, a KOH solution was used in the following attempts, as it allowed for a more efficient setup where the solution could be refilled without opening the CCU.

6.1.2 Output of CCU

The small amounts of potassium bicarbonate solution, gathered as a product of the CCU, can be reutilized as it can be used to prevent and treat plant fungal infections such as powdery mildew, which can affect houseplants. When the solution completely covers an infected leaf, it can slow down the growth of mold spores as it acts as an organic fungicide (Database, 1999). When applying the same principle of the CCU on an industrial scale, the leftover $KHCO_3$ can also be used in medicine, as an antacid and a food supplement, as well as in agricultural and laboratory chemicals (*Potassium bicarbonate (compound)*, n.d.).

6.2 Improvements

6.2.1 Improvements for AQM

Building the AQM took more time than initially expected since several different problems occurred during the building process. There are still many improvements that could be made in the future to the AQM. To upload live data measured by the AQM to the website, a single board computer (Raspberry Pi) could be integrated in the AQM. The final version of the AQM included several different sensors that were connected and soldered. To improve this setup a PCB should be included to connect the different sensors of the AQM and a box that can store the electronics safely can be 3D printed.

Measurements conducted for this project were limited to one 24 hour measurement which showed the AQM is working and things such as the humidity, VOC, temperature etc. changes in accordance with conditions changing in the room. In a next step, the air quality in various places around Maastricht could be measured. Especially, the air quality in educational institutions such as kindergartens, schools or universities are of interest but eventually also data in private places should be measured.

6.2.2 Improvements for CCU

As the CCU was inspired by the CYAN openair project, there was an attempt to create an upgraded version. Yet, there are still flaws which could be ameliorated in the future. With a working 3D printer, many parts could have been designed, printed and improved. This would have led to an earlier assembly of all parts - issues would have been worked out faster and ultimately more time for testing would have been left. Despite these issues, the CCU showed significant improvement from the CYAN project. Furthermore the CCU was working on the last day - not during the scientifically crucial KOH test but during the water test, This shows that the general outline and design were working. In another iteration more care will have to be put into understanding how the electronics components work to avoid faulty equipment.

Another possible improvement is the selection of the box structure. The initial aim was to create a box structure component with the 3D-printer. Due to the aforementioned issues with the printer a household storage box was bought as replacement. Its was however not perfectly rectangular, leading to various construction issues. Since the box structure plays a profound role in determining the orientation and functionality of the CCU, one could even seek external help from a commercial 3D-printing company to create the box in the future.

Another refinement is the size of the carbon capture unit. The necessary volume for the box was grossly exaggerated in the planning phase, as there was a lack of understanding of how the separate components would be put together. In another iteration of the project, a much smaller design could be implemented. The above design significantly hampers the portability of the CCU and creates hindrance when selecting location for testing. The electronics for the box could be extended to also include a CO2 sensor and an LED screen to read off the effectiveness. A next step would be designing a printed circuit board (PCB) to avoid construction and soldering issues. Furthermore comparisons with natural carbon sinks such as houseplants could be taken: comparing the amount of CO_2 a plant removes from a closed room in 24 hours to the quantity the CCU captures.

6.2.3 Website

There were several different issues when building the website such as including a hamburger menu and making the website interactive. Thus, with more time the website could be improved by making it accessible for smartphone users and mobile interactive. Moreover, the website should be consistently updated when changes to the project are made and more background information could be added.

6.2.4 Combining the Subprojects

Further advances would be combining the three subprojects. A first step would be connecting the air quality monitor to the website by using a raspberry pi and thus being able to display live data and control the sensors remotely. By linking the carbon capture unit with the air quality monitor, its workings could be controlled via the website as well. Another step could be coding an app - based on the contents of the website - to remotely control the device from mobile phones. This combination opens up the possibility for commercialisation. Once paired up, the CCU and AQM become a machine that every household could use. Being able to check the air quality and thus decide on the safety will become an increasingly useful tool in order to decide whether safety measures (e.g. masks) are necessary. While this is not yet the normalcy in central Europe, it is already a reality for large areas of Asia. 4 billion people - 92% of Aisa's and the Pacific's populations are at risk for certain illnesses due to hazardous levels of air pollution (*Air pollution measures for Asia and the Pacific*, 2018). Having access to a reliable air quality monitor will become necessary and having a carbon sink to balance the air pollution is an added bonus. The individual components of the project therefore serve as a proof of concept for such a device. While combining them is no small task, it is very doable since the separate aspects have been worked out.

7 Conclusion

Fighting climate change is the daunting, unrewarding but crucial task of this generation. Without technical solutions to the challenges posed by global warming, rising sea levels, and air pollution, earth's biosphere will be altered unrecognisably. In a time when governments still value old contracts with coal mining companies over the goals set by the Paris agreement, over keeping global warming below 1.5 degrees and over the life-threatening dangers stemming from increased fossil fuel emissions, it is an obligation for scientists to solve these issues. With large amounts of coal being burned not even an hour from Maastricht, subpar air quality and high levels of particulate matter come as no surprise in this student city. While social science students fight for more equity, equality and sustainability by changing policies, it is the role of natural science students to work on small-scale solutions to big problems. This project therefore used an interdisciplinary approach to create a functioning Carbon Capture Unit and Air Quality Monitor. The AQM was used throughout a 24 hour period to test its capabilities. It effectively measured the temperature, humidity, CO_2, VOC, pm2.5 and pm10 levels. Various changes were performed in the room, such as cooking or the presence of people, which was reflected in the data. The AQM can therefore be regarded as fully functional. Due to a multitude of unforeseen challenges the CCU was however unsuccessful in capturing carbon. As a consequence of unexpected issues in the construction, only one day was left for testing and once a part of the electronics broke, the unit could no longer be fixed. Both apparati had complex construction processes and required a wide range of skills such as coding, 3D modelling, and building and soldering circuits. The devices were fully automated via coded inputs. To combine the two aspects of the project, a website was created as an outreach project. Future goals of the project would be to use the AQM to measure the air quality around various indoor and outdoor locations in Maastricht. This data could then be displayed on the website and be used to inform the public on the quality of the air they are breathing and raise awareness for the dangers of air pollution. The CCU could be further improved with more reliable materials and electronics and, once functioning be combined with the AQM. While not every part of the project was concluded as desired, the main goal was fulfilled: the two devices were built, the mechanisms understood and another step towards educating people about climate change was taken. This project did not make a significant impact, but many initiatives like this have the ability to alter the course of our earth, the course of history. Fighting - researching - for solutions to improve the world is the responsibility of science.

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9 Appendix

Group Member	Report Contribution	Project Contribution
Sophia Widmer	Construction and electronics of CCU, Materials, Methods, Results, Joining the two projects, Introduction, Conclusion, Editing	CCU (planning, assembly and electronics)
Jeremy Palmerio	Theory, Materials, Methods, Result, Discussion, Referencing, Editing, Data Capture and Analysis	AQM (electronics, code, assembly, soldering)
Leonor Veloso	Discussion, Referencing, Introduction, Theory, Editing	Research, CCU(planning, assembly and electronics)
Mathilda Lopuszanski	Website, Discussion, Editing	Research, Website, CCU (Planning)
Nathalie Sowden	Website, Conclusion, Editing	Research, Website, CCU (Planning)
Guglielmo Ranaudo	Methods, Results, Appendix	AQM(electronics, code, assembly, soldering)
Niels Bodewes	3D Printing,	3D Printing
Konstantinos Ioannou	Introduction, Theory	CCU(planning and assembly)
Wang Hei Kan	Website, Discussion	CCU(planning and assembly)