Breathe to Succeed

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1. Abstract

A lot has happened since the first days of air quality monitoring, where the 'devices' used were already small, but much less accurate. Namely, the 'devices' were canaries, a small species of birds used to check whether dangerous gases had accumulated in mines or cellars. Nowadays, the level of pollution has skyrocketed, and is affecting people all over the world. Indoor air pollution alone is responsible for an estimated 3.2 million deaths per year in 2020, including over 237 000 deaths of children under the age of five (Word Health Organization, 2022). Our goal is to provide an effective, low-cost option for schools, offices, and homes to monitor their indoor air quality, to create an optimised environment for studying and working, as well as to avoid negative health effects from bad air. To put this idea into practice, we used multiple sensors to monitor the concentration of CO_2, VOC, temperature, humidity, and PPM concentration of an enclosed space. The sensors were connected to an ESP32 microcontroller to collect the data, which was then received by a Raspberry Pi via MQTT. From there, we stored the data in a MySQL database, and visualised it on a webpage. There, the values and corresponding warnings and advice on how to improve the air quality were published. This allows the people in the room to act and restore ideal conditions. We conducted experiments with our device in a setting that resembled a typical classroom. The results showed that the air quality in a room of approximately 60x60 meters and a group of around 40 students would regularly fall below the ideal air quality, and that there were little options to improve it quickly. We also realized that it was necessary to receive direct propositions on how to improve the air in a certain respect.

2. Introduction

Meanwhile most of the population knows that polluted air is harmful to a human's health. As stated above, millions of people fall victim to the effects of long-term exposure to bad air each year (WHO, 2022). The goal of our device is to measure the air quality in closed rooms and give instruction to improve the current state. If the concentration of different particles is always too high this would show in the recorded data and helps to spot a bad ventilation system. Also, the number of people sitting in a room matters. If the device requests to open the windows very often the room is most likely not suited for so many people. This device should improve the productivity of the students or employees and do good to their health by giving instructions on how to better the air quality of a room. Polluted air can lead to a reduction of intellectual capacity in old age that is equivalent to losing a year of education, which is huge and especially as we spend so many hours in schools or in offices. People who spend most of their work time outside are better off with their cognitive functions when aging. (Sweeney, 2021)

To build our Prototype we have chosen three sensors. The SGP30 measures CO_2 and gas, the HM3301 measures dust and pollution particles and the DHT22 measures the temperature and humidity. More information about the ideal values will be provided later in this document. To decide on the sensors, we just researched about air components that are crucial for determining the air quality

As our gateway we decided to use a Raspberry Pi 3, mainly because Wi-Fi is already included in it. With an Arduino additional configuration would have been necessary. In terms of performance and capabilities the Raspberry Pi is better, and we thought it's also a good idea to try something else than on the hands-on exercises during class.

In addition, we are using an ESP32. It has integrated Wi-Fi, full TCP/IP stack for internet connection and Bluetooth. ESP32 is a lot faster and more powerful than Arduino. For our project the Arduino probably would've been enough, but it would've gotten very complicated to configure it properly. Also, again we were curious to discover new things here as well.

From the sensors the data gets transmitted to the ESP32 with the protocol I^2C. SPI is another protocol which is faster and has a better general performance. For our project I^2C was efficient and easy to use. The ESP32 then forwards this data via MQTT to the gateway. MQTT is the dominating protocol in IoT which was specially designed for IoT solutions therefore this was our best fit. Looking for alternatives we came across CoAP, XMPP, AMQP or DSS but they haven't convinced us as much.

The data will be saved temporarily on the laptop in a file. We decided to measure the values every 30 seconds. This way the data load doesn't grow as fast, and it is also not needed for our use case to compare the values too often. Depending on the measurement the system will give instruction to enhance the air quality of the room. As the OLED display is so small, we decided to not use it and show the details in a web GUI.

3. Related Work

Recent research is focusing on the field of indoor air quality monitoring, which was formerly less prominent but has been catapulted into the spotlight with the emergence of the Covid 19 pandemic. Even before this critical development, scientists had been warning about the danger of poor indoor which was responsible for approximately 3.5 million deaths in 2020 (WHO 2022). Having had a look at current papers, it is interesting to see an increased focus on portable air monitoring solutions. A particularly interesting approach to pair existing with new technology can be seen in "Internet of Things and Enhanced Living Environments: Measuring and Mapping Air Quality Using Cyber-Physical Systems and Mobile Computing Technologies." by Marques (2020). In this paper the researchers built a mobile application that displays PPM and CO_2 values in real time on user's smartphones. Data is collected with sensors connected to an ESPN32, and then stored in a MySQL Data base, from which the data is retrieved and sent via BLT to the described app. This approach is interesting as it allows portability and receiving real time information about the surrounding air quality. Nonetheless, it has the disadvantage of always having to have the sensors powered up and carried around with the user. In comparison, our system is not supposed to be carried around, but to be put in one place. It can still be moved, but for better accuracy it is necessary to stay in one spot. Additional interesting developments can be seen at the intersection of user comfort and energy efficiency. Given the recent rise of energy prices, many people are ill at ease when it comes to heating their homes or using air monitoring and ventilation systems that are among the biggest energy consumers. In papers like "Measuring the right factors: A review of variables and models for thermal comfort and indoor air quality," by Nan et al (2021), these issues are addressed. Unlike us, they focus specifically on thermal comfort and how it can be maintained with the support of Artificial Neural Networks and Reinforcement Learning while optimising the energy spent on these processes. Unfortunately, we do not have access to a well monitored building that is using air filters now but tapping into the field of energy efficiency and the use of artificial intelligence to optimise the monitoring of indoor air quality is clearly a future field of interest and appliance for our project.

3.1 Research about Air Quality

3.1.1 Temperature and Humidity

The feeling of ideal temperature changes from person to person but researchers found that there is a certain temperature range that fits most of the people to perform well, – of course, regarding learning or absorption capacity. This range is from 18°C to 22°C. In a room cool air is better and therefore the oxygen supply of your brain is a lot better. Cold hands and feet on the other hand, are not a good sign, as this tends to lead to colds and not to a better learning ability. Additionally, the humidity should be in the range between 40% to 70% and the windows should be opened occasionally, for fresh air. This is extremely important as we heat up the room with just sitting there. This is especially true for exam situations as the effect is even bigger then, and bad air can have consequences on how well students can focus. (“Die optimale Temperatur”, 2016)

3.1.2 Dust/Particle Pollution

In recent years, many studies have been carried out to better understand the effects of different particles on humans. Harvard analysed the cognitive functionality of employees in offices at different air qualities. Especially reaction time, ability to focus and productivity were investigated. PM2.5 stands for ‘particulate matter’ and is an air pollutant. For every increase in PM2.5 of 10ug/m3 they found (Laurent et al, 2021):

- 0.8% - 0.9% slower response time
- 0.8% - 1.7% lower throughput (correct responses per minute)

Our sensor HM3301 measures SPM1.0, SPM2.5, SPM10, AE1.0, AE2.5, AE10. SPM means suspended matter and the number always gives us the diameter of the maximum size of such a particle. SPM1.0 therefore measures the concentration of airborne particles with a diameter smaller than or equal to 10μm and normally gives it back as micrograms per cubic meter of air. The US Environmental Protection Agency (EPA) suggested a limit value of $15\mu/m^3$ to ensure that the air quality has no negative impact on one’s overall quality of life. (Hawkins, 2022)

3.1.2 CO_2 and TVOC

As above Havard has additionally tested the effect of a 500ppm increase of CO_2. Those results were even more impressive:

- 1.4% - 1.8% slower response time
- 2.1% - 2.4% lower throughput

The mass unit ppm stands for parts per million and can also be interpreted as milligrams per litre. What they didn’t mention was at what ppm value they have started. The latest measured ppm outside was on 4th November and was at 416.55 ppm. (Daily CO_2, 2022)

The French Agency for Food, Environmental and Occupational Health & Safety (ANSES) states that an exposure of only 1000ppm is enough to notice harmful effects and can lead to serious consequences. With Covid the High Council for Public Health (HCSP) and the French National Research and Safety Institute

(INRS) reported that the indoor air quality is essential to reduce the risk of transmission of viruses. The recommendation is to stay close to 400ppm so like the outdoor air and for sure below 800ppm. If this value is reached everyone should leave the room and renew the air by opening all the windows and/or doors. (Meersens, 2022)

For our project, we thought to stick to a maximum value of 600ppm as 400ppm is hard to reach in a full room without having the window constantly opened and it is still close to the outside value.

Total Volatile Organic compounds (TVOC) are organic chemicals that turn into gas at room temperature. The Indoor Air Quality Management Group of Hong Kong (IAQ) recommends keeping the TVOC value below 200 to have air quality ranged in the excellent class and below 600 to still be in the good class. Those values were defined regarding the exposure to this concentration for eight hours. This means that for short times the recommendation could be a lot higher as the immediate harm might not be that bad but over time it can be terrible. The TVOC is measured in $15\mu/m^3$.

4. System Design and Implementation

4.1 System Overview

Like many IoT projects, our approach starts with the collection of data via sensors. The one we chose for our project are a CO_2 and gas sensor, a temperature and humidity sensor, and a sensor for dust and pollution particles. These sensors are connected to an ESP32 microcontroller, via I^2C protocol. Once the data values are collected and forwarded, we transform our ESP32 into a broker, publishing via MQTT. Ready to receive this data is our Raspberry Pi 3, which is configured as a subscriber to the ESP32. Now that the real time exchange from sensors to our Gateway is ensured, we send the data to a laptop. The raw data is put into a JSON file, forwarded to a laptop on which we store it in a SQLite database. This database is then accessed, and the data contained in it are visualized in a web interface. This interface shows users the acceptable width of values, the current values, and instructions on how to handle the current situation. If a value like e.g., the CO_2 value hits a target number outside the recommended range, the instruction “Please open a window to lower the CO_2 levels” will be displayed. Of course, the instructions are different depending on which values are above or below the target numbers.

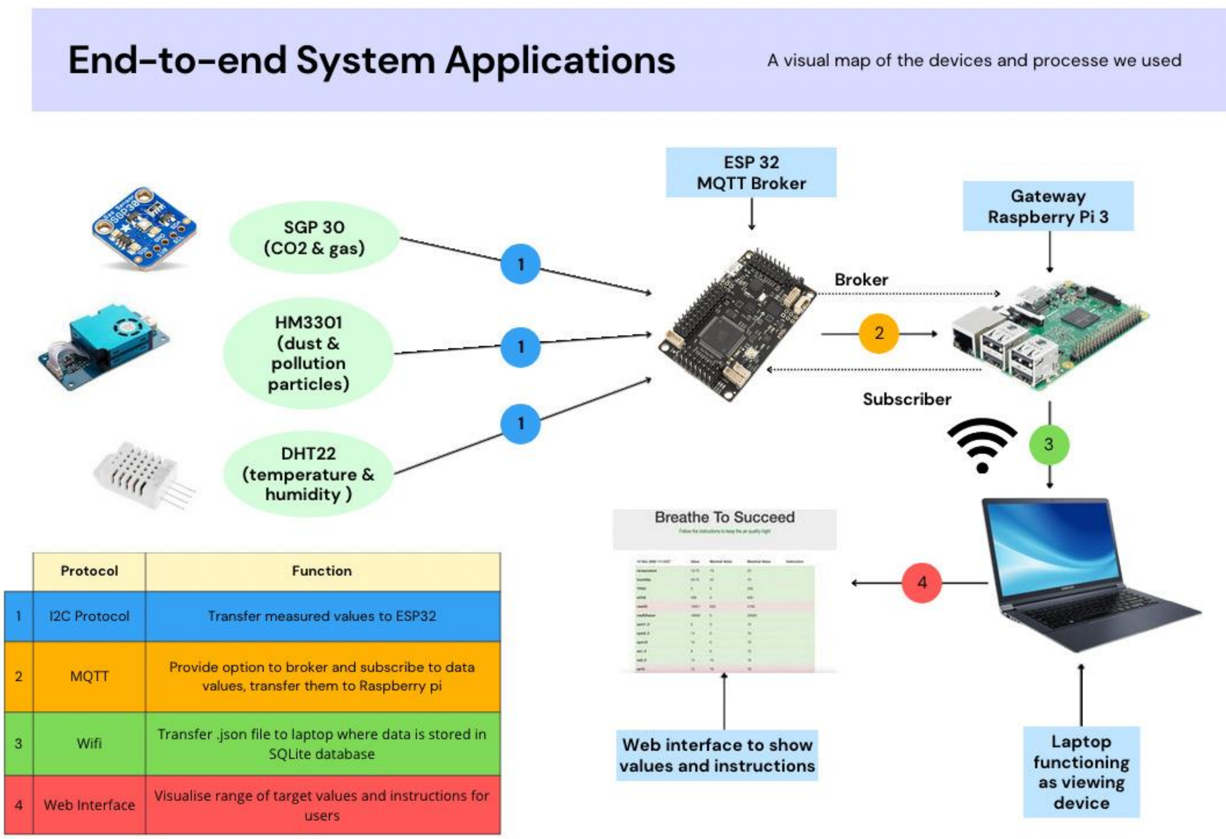


Figure 1: End to end system Application

4.2 System Architecture

The system at the lowest level uses I^2C to interact with the sensors, as this allows for modularity and scalability based on the specific requirements of each air quality monitoring application. To store the data, an SQLite database is used because the scope of the data is relatively simple, and it can be easily upgraded to a more powerful SQL database implementation if needed. To transmit the data from the database, HTTP requests are utilized.

All communication after the sensor data collection takes place over Wi-Fi, with the ESP32 using the default Arduino *WiFi.h* library to send the data to the central server. The Raspberry Pi can also connect to a potential cloud backend via Wi-Fi.

MQTT messages are routed through a *Mosquitto* MQTT broker, which runs on the Raspberry Pi. This acts as the central server between the ESP32 (which functions as a publisher) and the Pi (which acts as a subscriber). The ESP32 uses the *PubSubClient* library to handle MQTT, while the Pi uses the *paho-mqtt* library. All data is converted to JSON before being transmitted through MQTT to ensure uniformity and standardization. Once the data is parsed by the Pi, it uses the *sqlite3* library to store it in a local database along with metadata such as the timecode of receipt of the data.

The web-frontend, along with the data to be displayed, is served by an Express Node.js server that runs on the Raspberry Pi.

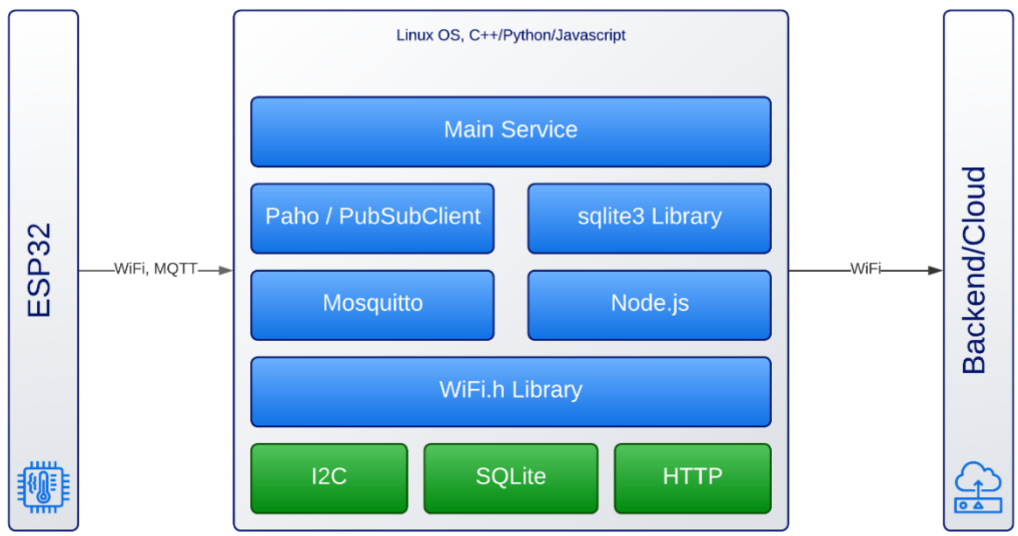


Figure 2: Software Stack

4.3 Software Architecture Layers & Modules

Application Layer

The web user interface is displayed as a webpage. For the project we have used the open source node.js server environment. The data is updated by a recurring GET request, which happens every 30 seconds. We use this HTTP method to get the newest entry of our recorded data. Regarding security we did not take any measures as the time was tight and we also do not measure sensible data. If somebody steals or deletes it, there are no relevant consequences. Before launching this prototype, we would still improve this and make sure that there is no way of manipulating or accessing the data through the URL.

Transport Layer

To bring our data from one device to another we have used MQTT as transport protocol which is a commonly used protocol in IOT projects. Other than that, on a lower level we have also used I^2C to get the measured values from the sensors to our ESP32.

Network Layer

In our prototype the Raspberry Pi is used as gateway which receives all the data and forwards it further into an SQLite database file. As this is only a prototype backend of the cloud.

Link Layer

The ESP32 and the Raspberry Pi are both connected to the Wi-Fi. Every message published from the ESP32 via MQTT is received over Wi-Fi from the Raspberry Pi as it is a subscriber. All devices need to be connected to Wi-Fi Router in the HSLU classroom.

Main Application – Public Interfaces	
Interface	**Description**
ESP32	
setupWifi()	Connects the ESP32 to Wi-Fi, keeps retrying if unable
reconnect()	Connects to the MQTT broker, keeps retrying if unable
publishSerialData()	Sends the given data as an MQTT message to the broker
Python / Gateway	
connectDB()	Connects to the local SQLite db, creates one if it doesn't exist
createTable()	Creates a table for air data if it doesn't exist
insertAirData()	Inserts the given data into the db, along with metadata (timecode)
JavaScript / Frontend	
loadResponse()	Gives back the latest data entry in a JSON format
buildTable()	Builds the table in the web interface
displayIdealValues()	Displays the min and max values, as well as instructions in the table
Uses – Protocols;	
I^2C	Used to get raw sensor data from the sensors
MQTT	Used for transmitting/receiving the data to/from the gateway
JSON	Used to standardize and structure data messages
Wi-Fi	Used on the link layer for data transmission
HTTP (web interface)	Used for web visualization and data loading
SQLite	Used for local air data storage and retrieval

Table 1: Main Application Interfaces

4.4 System Implementation / Functional Software Architecture

The base level edge devices, comprising of the ESP32 sensor clusters, run the low-level C++ code, and execute functions such as sensor initialization, data verification and error handling. After this, they collect the data from all the sensors at regular intervals (in practice 30 seconds), organise it into a JSON object, and publish the data via MQTT.

The data is then received by the combined server/gateway/broker device, a role assumed by the Raspberry Pi in our specific prototype. The code on the Raspberry Pi is written in the form of a Python script. The MQTT message containing the data is received by a Python subscriber via an MQTT broker running on the same Raspberry Pi. The JSON data is decoded, parsed, and stored on a local SQLite database on the same device, along with some other computed data such the timestamp of the data. We were also considering including the sender ID in case of monitoring parallelly in multiple classrooms.

On the Raspberry Pi, there is a Node.js web server with a frontend interface. This allows an easy visualisation of the retrieved data and other useful information, such as colour striking warnings when metrics exceed recommended limits along with instructions to restore them to safe levels. The displayed values refresh every 30 seconds to give the instructions in a real-time response to the environment. As this project was mainly about the prototype itself and not the proper research of air quality, we did not write instructions to all the measured values. It would have exceeded the scope of this project but would of course be of importance for the realization of this prototype. This data can also be used for a variety of short and long-term purposes such as:

- More advanced visualisation
- Upload to the cloud for greater accessibility
- Statistical analysis for identification of long-term patterns and predictions
- Control of devices such as air-purifiers, air-conditioning, etc. (to take automatic actions)
- External alerts such as alarms when a certain metric exceeds safe or recommended limits. (Fire alarm)

14 Dec 2022 11:13:27	Value	Minimal Value	Maximal Value	Instruction
temperature	19.70	18	22	
humidity	40.70	40	70	
TVOC	5	0	200	
eCO2	400	0	600	
rawH2	13631	900	4100	
rawEthanol	19066	0	20000	
spm1_0	9	0	15	
spm2_5	13	0	15	
spm10	13	0	15	
ae1_0	9	6	10	
ae2_5	13	10	16	
ae10	13	18	18	

Figure 3: Web interface hosted on Raspberry Pi

5. Evaluation/Experiments/Results/Discussion

Experiment:

The main idea of this project was to check the air quality in an indoor environment. The parameters needed for this experiment were to know the level of CO_2, humidity, temperature, volatile organic compounds, and dust particles. This project was conducted using ESP32, Raspberry pi, and different sensors. Using these devices all the data needed such as CO_2 level, humidity, temperature, and dust particles were collected on weekly basis.

Test Environment

The experiment was conducted in a room from the school's building (around the size 60m2) in a closed environment. The room was filled with approximately 20 – 40 people. The test was conducted every week using different times.

Used IOT Devices:

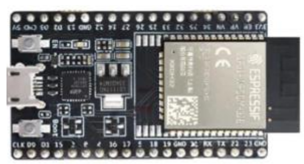
Devices/ Sensors	Description	Image
EPS 32	ESP32 is a low-cost, low-power system on a chip (SoC) series with Wi-Fi & dual-mode Bluetooth capabilities	
Raspberry Pi 3	Raspberry Pi 3 is a development board in PI series. It can be considered as a single board computer that works on LINUX operating system	
SGP30	Multigas(VOC and CO2 sensor)	
DHT22	Temperature and Humidity	
Grove- LaserPM 2.5	Dust Detection sensor	

Table 2: Used IOT Devices

Graph Plots of the retrieved data

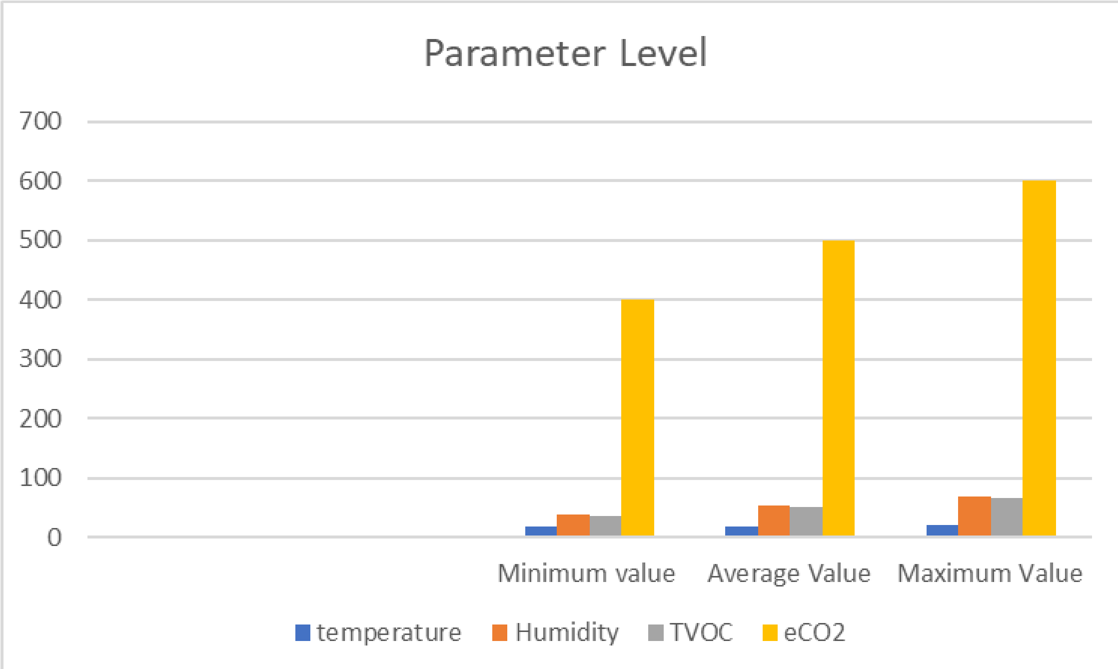


Figure 4: Parameter Levels

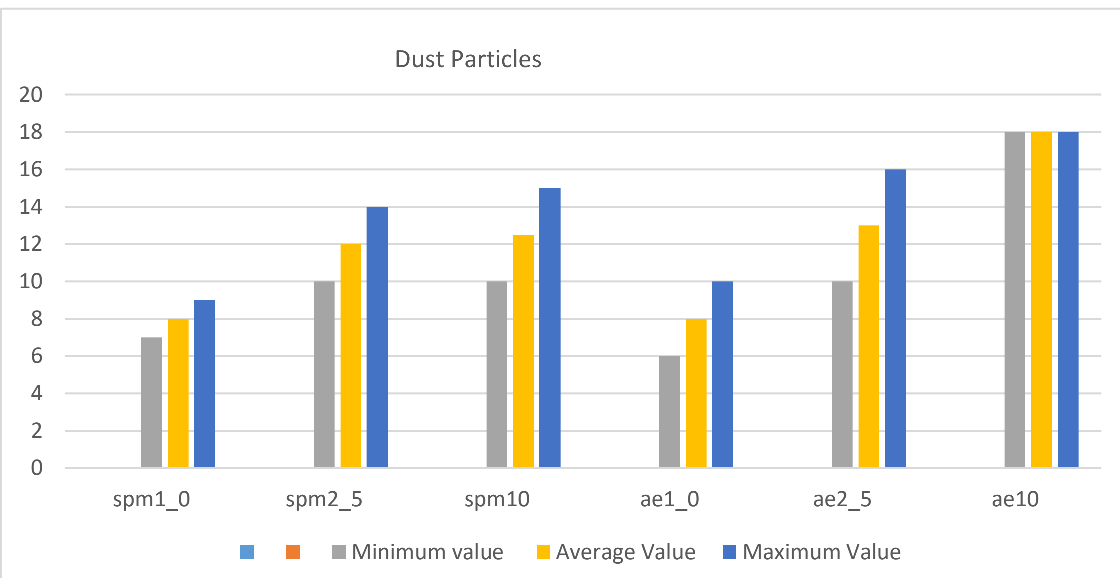


Figure 5: Dust Particles

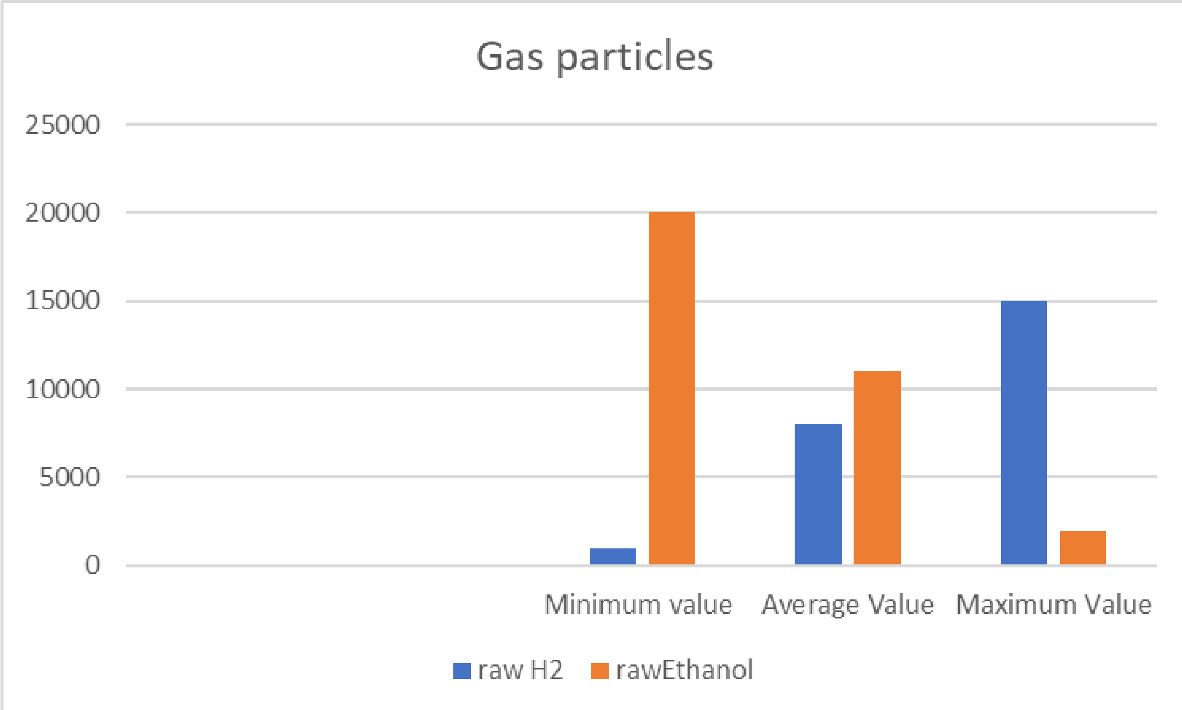


Figure 6: Gas Particles

Results

The obtained results from different parameters were compared to the parameters a normal indoor environment should have.

Parameters	Level (on avg.)	Evaluation
CO_2	500ppm	Normal CO_2 level in the indoor environment should be between 50 – 1000ppm. The result shows that the CO_2 level is inside the normal range.
VOC	51	0 to 400 ppb is the acceptable level of VOC indoors. The result shows that volatility compounds found in the rooms should not affect anyone's health inside the room.
Humidity	40%	The ideal relative humidity for health and comfort should be somewhere between 30-50% humidity. The result shows a good level of humidity in the tested room. This means that the air holds on average 40% of the maximum amount of moisture it can contain.
Gas & Dust Particles	normal	No harmful gas and dust particles that could affect person's health were detected.

Table 3: Obtained results

6. Application(s)

As briefly stated in our introduction, the impact of bad indoor air quality is often underestimated and the people suffering negative consequences from it are unaware of the dangerous environment they face. We consider our project an ideal solution for classrooms, in which especially vulnerable parts of the population such as children spend a considerable part of their days. A simple set of sensors in a classroom, connected to a device on which the teacher can monitor the collected data, and get simple error messages when values range above or below a target number will be the principal way to monitor the air quality. We will also display a set of advice that will tell the user directly how the air quality for certain areas can be improved. This can be as simple as opening a window or increasing the temperature in a room or switching on an air filtering system to avoid the spread of aerosols. The set of instructions we provide to our users is what differentiates our approach from the competitors. As we want to keep our instructions simple, teachers in schools could also project the numbers in their classroom and assign a responsible kid to keep an eye on the numbers. Therefore, kids could learn how to handle responsibilities, and feel empowered to act as the instructions can be followed easily. Next to classrooms, our device could be used in all indoor workspaces such as offices, co-working spaces or simply in the comfort of your own home. If we could be assured of the precision of our devices by calibrating them perfectly, we could even deploy them in homes for the elderly. This could be useful in two senses: first by simply improving the quality of life of especially vulnerable people, and in a second way by functioning as covid Given that we can measure the size of aerosols, we can print out a warning message and instructions for reducing their number once a critical value has been reached. In a way, our project serves not only in preventing the young from being exposed to bad air and minimizing their health risks for the future, but also to mitigate risk for elderly who have been exposed already and want to avoid having their health deteriorating more due to bad air. For the ones in the middle of their life, we offer the option to work in an environment that brings out the best in them and gives them the option to explore their full potential.

7. Conclusion

Using the IOT devices, we were able to collect the needed data to determine the quality of the air. This experiment was mainly tested in a particular room and the air quality of that room was good. Beside from that no harmful gas or dust particles were detected. The team members were very corporative, and we shared each other's knowledge and could learn from each other. We were able to finish the experiment on time. If we had more time or members, the following part improvements could be done.

Improvement/ Upgrades:

Other parameters such as the level of oxygen and ozone could be measured using additional sensors. With the help of additional parameters, air quality in an outdoor environment could also be checked. Additionally, an alert system could be established, which gives a warning signal in case the air quality is too harmful. With the alert system, a person can take immediate action to improve air quality. For example, opening the windows to improve the air flow.

8. Contributions / Acknowledgments

In this project we tried to work together in most parts just to get a clear understanding of all the single tasks and how they work together. To make it easier with the organisation we just gave everyone the lead in a specific part of the implementation.

Jana Omcikus was working mainly on the web user interface and therefore on the display of the different data. Through the research of the different particles the instructions were a lot easier to implement.

Julia Naderer made sure that the data is stored in an ideal way. It comes in a JSON message and then a SQLite data base is created and filled up with the collected data.

Rohan Gundala created the backend of our web interface with Python, which made the data available for the frontend. Other than that, he did the transfer of the data from the ESP32 to our Raspberry Pi.

Sabin Pun was responsible for the construction of our prototype and for getting the data from the sensors to our ESP32.

9. Major Milestones & Deliverables

All the project work progress has been documented using the web platform Monday. Monday provides the dashboards where every team member can work simultaneously and gives overview about the workflow. It keeps every team member updated about the task, the deliveries and the deadlines and every team member could see the responsible person for each specific task. Most importantly, this platform help us on our decision making, connected team members, and accelerate project delivery

9.1 Team and Roles

This section describes the team, members roles, and what work packages are working on.

TEAM	ROLE	OWNER
Group 5	Project lead	Julia Naderer
	Backend Tech	Rohan Gundala
	Research	Sabin Pun
	Frontend Tech	Jana Omcikus

Table 4: Team Roles

9.2 Project Planning, Timelines, Milestones & Deliverables

On the plan that we created on Monday shows all our Milestones and timelines that we tried to achieve. During the semester we had a lot of ups and downs also with other projects which sometimes made it a bit hard to stay on track but in the end it all worked out perfectly.

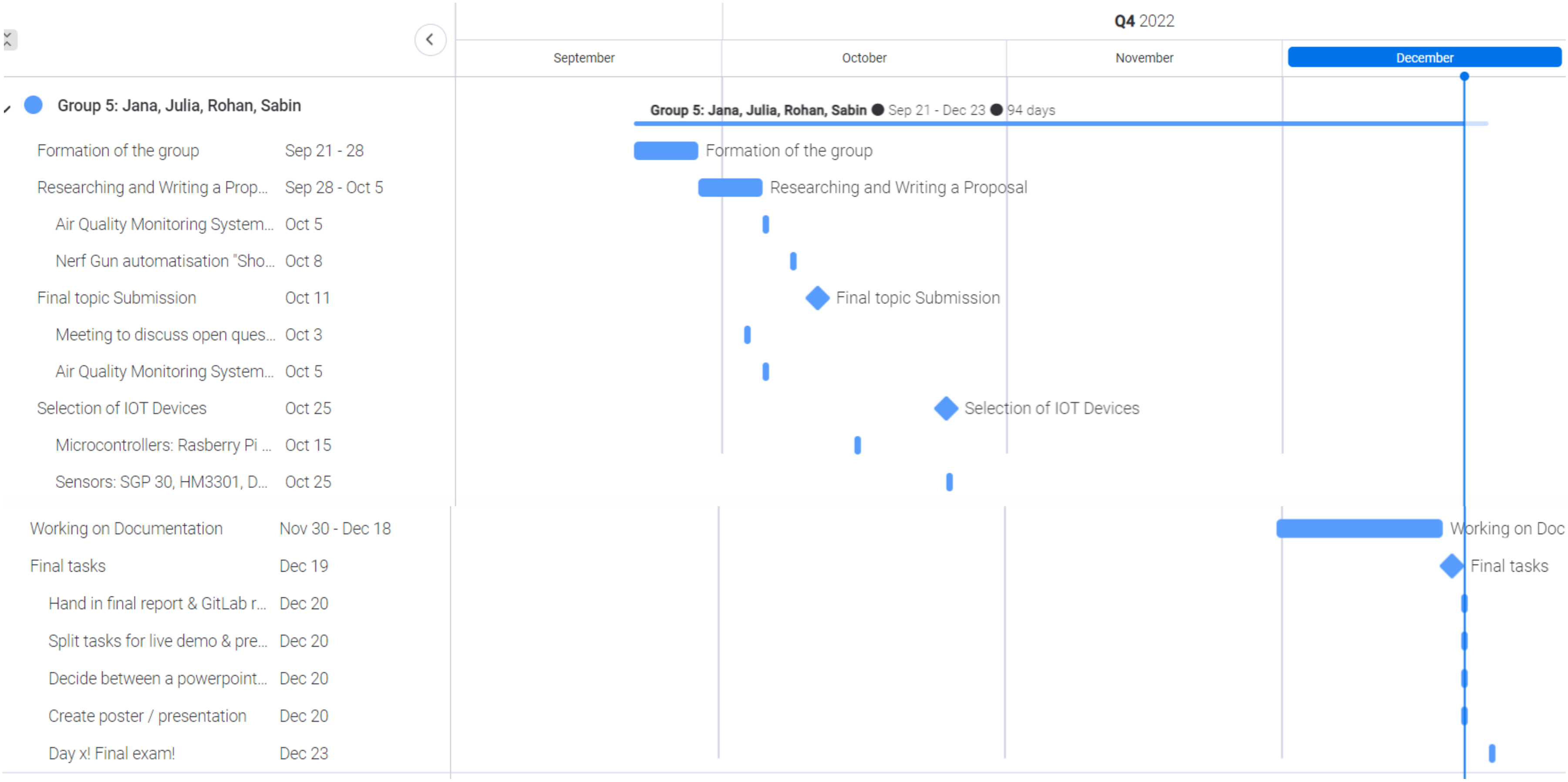


Figure 7: Project plan on monday

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