University of Cape Town

EEE4022

FINAL YEAR PROJECT

Smart Ventilator Design using E-waste for Airborne Diseases

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Submitted to the Department of Electrical Engineering at the University of Cape Town in partial fulfilment of the academic requirements for Electrical and Computer Engineering

Declaration

1. I know that plagiarism is wrong. Plagiarism is to use another's work and pretend that it is one's own.

2. I have used the IEEE convention for citation and referencing. Each contribution to, and quotation in, this final year project report from the work(s) of other people, has been attributed and has been cited and referenced.

3. This final year project report is my own work.

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Acknowledgments

I want to thank my supervisor, Prof. Amit Mishra, for his constant supervision and guidance, helping me understand key fundamental concepts and techniques, without which I would not have been able to complete this project.

To my family, their love and sacrifice enabled me to embark on this pivotal journey, and everything I've ever achieved is in their honor.

To my friend James from Menzies Design lab for allowing me to use the lab during the weekend and for the words of advice I received from him that allowed me to embark on this pivotal journey

To my friends and peers who have made my time at university both memorable and incredibly fun, I admire you for also becoming my support structure during my hardships.

Abstract

TB has been a significant killer in sub-Saharan Africa,so community spaces are major spots where it spreads. South African Statistics show the country's population to be about 54 million, residing in the nine provinces, with most of the country's population being the youth and young pupils aged 15 years and younger. The country's birth rate was estimated at 2.3 births per woman in 2013. other estimates show that the country has a relatively low life expectancy while having TB as the leading cause of death, influenza, pneumonia, etc.

The World Health Organization's strategic agenda for 2016-202 was based on four main strategic priorities to help combat these health issues highlighted above. The most appealing to the current study is STRATEGIC PRIORITY 2, which aims to reduce the burden of communicable diseases, especially HIV, TB, STIs, hepatitis, and vaccine-preventable diseases. In South Africa, from 3 January 2020 to 4:36 pm CET, 4 November 2022, there have been 4,029,027 confirmed cases of COVID-19, with 102,311 deaths reported to WHO. As of 30 October 2022, 37,796,915 vaccine doses have been administered. These very dangerous airborne killers still exist in local communities the fight to minimize them continues.

This waste study aims to design an intelligent ventilation system using electronic components, specifically old computer fans, to automate the ventilation processes and meet this ventilation requirement for airborne diseases. In this project, the design of a simple ventilator intelligent system using fans from old computers will be presented. In this, a CO2 sensor would be used to measure the level of CO2. CO2 is a proxy for ventilation in a room. Tests were conducted in a simulated environment and in a real UCT Classroom.

Contents

1 Introduction

1.1 Background to the study

South African Statistics show the country's population to be about 54 million, residing in the nine provinces, with most of the country's population being the youth and young pupils aged 15 years and younger. The country's birth rate was estimated at 2.3 births per woman in 2013. other estimates show that the country has a relatively low life expectancy while having TB as the leading cause of death, influenza, pneumonia, etc. Other water-borne diseases pose a high risk to South Africans by 2013.

The World Health Organization's strategic agenda for 2016-202 was based on four main strategic priorities to help combat these health issues highlighted above. The most appealing to the current study is STRATEGIC PRIORITY 2, which aims to reduce the burden of communicable diseases, especially HIV, TB, STIs, hepatitis, and vaccine-preventable diseases. This further shows the impact of TB has been a significant problem on south African communities and other airborne diseases. Another wave of illness went through the population of South Africa starting in early 2020. In South Africa, from 3 January 2020 to 4:36 pm CET, 4 November 2022, there have been 4,029,027 confirmed cases of COVID-19, with 102,311 deaths reported to WHO. As of 30 October 2022, 37,796,915 vaccine doses have been administered. These very dangerous airborne killers still exist in local communities the fight to minimize them continues. Staying in well-ventilated rooms and enclosed environments is a significant and most effective measure implemented to reduce the risk of transmission.

1.2 Objectives of this study

1.2.1 Problems to be investigated

TB has been a significant killer in sub-Saharan Africa. It is airborne(like Covid), so community spaces are major spots where it spreads. This study aims to design an intelligent ventilation system using electronic waste components, specifically old computer fans, to automate the ventilation processes and meet this ventilation requirement for airborne diseases. In this project, the design of a simple ventilator intelligent system using fans from old computers will be presented. In this, a CO2 sensor would be used to measure the level of CO2. CO2 is a proxy for ventilation in a room. This would then be used to control the fan's operation. The setup would be used in a local school classroom to collect long-term measurements. It is expected that while attempting to achieve the main objective, issues will arise in the process of designing the subsystems. To address these problems, The design will be modular for easy debugging. To achieve this, the project should be completed in iterations of the spiral methodology, with subsystems added and improved in each step.

1.2.2 Purpose of the study

The project's purpose is to investigate the creation of an intelligent, cost-effective ventilation system to combat the negative effect and health risks posed by exposure to high levels of carbon dioxide levels in enclosed environments, and this can include classrooms, homes, and office spaces. To name a few risk factors, occupants occupying the same room that is not ventilated are at high risk of transmitting airborne diseases to each other since they are breathing the same air, putting them at high risk of contracting TB, Covid-19, etc. In classrooms, high levels of carbon dioxide create a non-conjusive learning environment for students while lowering their concentration span. In office spaces, exposure to high levels of CO2 and temperature leads to employees taking more breaks due to being uncomfortable this can result in less productivity and loss of profits in the long run

1.3 Scope

This study consists of off the shelve electronic components of the most part of the hardware implementation, further components were salvaged the fans, with the software section the code implemented is a detection algorithm that tests in equal intervals how much co2 is present in the room and based on that signal the fans are switch on in pairs.Time constraint approximately 3 months to complete and deliver the project, The aim of building a cost effective system somehow limits the spending on a project with a budget of R2000, as it did to this project.One of the intended, and main use cases of the project is the deployment of the smart ventilating system in classrooms form local schools, the targeted schools would be low income schools where the school is in most cases underfunded and has little to no resources, ranging from teaching material to WiFi or connectivity within the premises. This is a huge factor or limitation in the design. Since the system sends real time data to a google sheet this functionality once be active in such environments, but it would be able to work as usual.

2 Literature Review

This review considers recent findings by Merle De Haan, Kathleen Dennill, and Sharon on Health in southern Africa: Ventilation. It also feels recent results presented by J. G. Taylor, * T. A. Yates, M. Mthethwa, F. Tenser, I. Abubakar, and H. Altamirano on Measuring ventilation and modeling M. tuberculosis transmission in indoor congregate settings, rural KwaZulu-Natal. Further looks at recent findings presented by the paper “indoor CO_2, potential criticalities and solutions “. The report highlights the role of carbon dioxide on the health and well-being of occupants of indoor spaces. And A study of CO2 influence on student activity in the classroom. A study whose main parameters look at environmental air quality and environmental comfort in seminar rooms, namely air temperature, air velocity, median radiant temperature, relative humidity, and CO2 content, was used to determine how they influence students.

According to **?**, clean water, sanitation and adequate nutrition, clean air, suitable ventilation, light, heat, and housing are needed to ensure public health. At the same time, air is essential to life, as all cells require a constant supply of oxygen for the metabolic processes and will die if deprived. The composition of the atmosphere is presented below.

	Inspired air	Expired air
Nitrogen	78.09	78,09
Oxygen	20,94	16,94
Carbon dioxide	0,03	4,03
Water-vapoure	Variable	Saturated
Temperature	Variable	Body temperature, i.e., 37 °C
Other gases such as argon	0.94	0.94

Table 1: Air Composition

As shown above [1] further examines oxygen content of expired air that it is decreased, the carbon-dioxide content is increased, the air becomes saturated with water vapour and the temperature of the air is raised If people in the room or the dwelling are suffering from diseases such as pulmonary tuberculosis, the common cold, meningitis, etc., the causative organisms of these diseases will be present in the air that they breathe out. Nitrogen is a colourless, odourless, tasteless gas that serves to dilute the oxygen. The human body does not use it, but the bacteria present on the roots of certain plants, such as legumes, are able to 'fix' this nitrogen in the soil and then make use of it. Oxygen maintains life because it supports combustion and so makes metabolism possible. It acts as a purifier because it combines with organic substances that it changes and, in some cases, destroys. It will, for example, destroy bacteria. This process is known as oxidation. Carbon dioxide is a waste product of respiration and all metabolic processes. It is continually being added to the air, yet the amount remains constant because the carbon is utilised by green plants for photosynthesis. Photosynthesis is the process whereby plants use the sun's energy to synthesise, or manufacture, carbohydrate. Water-vapour is the amount of moisture present in the air is known as the humidity of the air. The humidity of the air is influenced by its temperature, for warm air can hold more moisture than cold air. We say that air is saturated with water when it cannot take up any more moisture at a given temperature

[1] further implies Impurities are continually being added to the air and all processes that use up oxygen and add carbon dioxide to the atmosphere are sources of pollution. Soot, smoke, sulphur dioxide, lead, carbon particles and odours are all pollutants which may be Purification of the air is also taking place continuously. Green plants purify the air because they remove carbon dioxide from it and convert it into carbohydrate in the presence of sunlight. Many of the organic impurities are destroyed by oxidation. Rain washes impurities out of the air as it passes through it. The ultra-violet rays of the sun are bactericidal and destroy organisms. The action of these forces keeps the composition of the air remarkably constant, but they may not always be able to do so and unless steps are taken to guard against the excessive pollution of the atmosphere, harmful changes in the composition and the temperature of the atmosphere may occur. adequate ventilation is ensured I the temperature and the composition of the air are changed and lead to certain ill effects. These are not due to a decrease in the oxygen content nor to an increase in the

amount of carbon dioxide as was once thought but they are due to an increase in the temperature and the humidity of the air. Only under the most extreme conditions will the oxygen content of the air fall so low that it threatens life

The consequences of inadequate ventilation the consequences of inadequate ventilation are as follows: People in a poorly ventilated room experience a feeling of stuffiness and discomfort which is due to the stagnation of the air. This is followed by a feeling of lassitude and loss of energy, and efficiency is decreased. poor that the temperature of the air rises above that of the body, then the body cannot lose heat by conduction; and if it becomes saturated with water-vapour, then sweat cannot evaporate because the air is unable to take up any more water-vapour. As a result, the body temperature will start rising. Unless the situation can be remedied heat stroke may occur and, in extreme cases, death may follow. The bacterial content of the air in a poorly ventilated room rises, and one of the most serious consequences of poor ventilation is the spread of infections such as tuberculosis, streptococcal infections of the throat and meningitis. In securing efficient ventilation, natural forces are employed as far as possible; but where circumstances make this impossible, artificial means of ventilation must be used. In large urban areas more and more public buildings, including hospitals and schools, as well agmarge department stores, places of entertainment and factories, rely entirely on artificial ventilation Now considering findings presented by J. G. Taylor, * T. A. Yates, M. Mthethwa, F. Tenser, I. Abubakar, and H. Altamirano on Measuring ventilation and modelling M. tuberculosis transmission in indoor congregate settings, rural KwaZulu-Natal.

According to [5] TB has shown to be a leading factor on deaths globally in Southern Africa [5] suggests that a fair proportion of TB is due to transmissions between people from the same home, but a far greater amount of TB cases is due to transmissions outside the household with an 84(percent) of this occurrence to take place.

These transmissions are predicted to take place in workplaces, schools, and public transport this further takes place in in spaces such as health care facilities such as local clinics, moreover in south African communities' establishments as drinking places and churches. [5] further mentions that previous research shows a strong correlation between transmissions of airborne pathogens such as Mycobacterium tuberculosis and building ventilation, which is important to understand when dealing with hotspot sites. As proposed by [5] one possible reduction on the rate of transmission is adequate ventilation as advocated in TB infection control guidelines. [5] provides two effective methods of estimating indoor M. tuberculosis transmission risk using measured rate of decay of CO2 realised inside buildings which is used to estimate ventilation rate and the second approach being using the idea of rebreathed air by occupants in the building which is also closely related with indoor air quality which is critically analysed on previous sections According to [5] the aim of this research is to estimate transmission risks in indoor congregations specifically focusing on KwaZulu-Natal South Africa and below are the target hot spot areas or locations the investigation is based on namely the photographs, clockwise from top left, of the clinic waiting room, the church, the high school classroom, and the tavern where data were collected. The fraction of indoor air in each space that was exhaled breath during the hours the buildings were open to the public is presented in Figure 1. The results show that, during services, the church had the highest average fraction of rebreathed air (range 0.012–0.022), with the clinic waiting room briefly reaching the greatest fraction (0.026) for a 10-min period. The estimated probabilities of an individual being. The classroom and church were estimated to have the highest risk, largely due to the frequency of visits, the length of time spent indoors and the number of occupants. The risk of transmission to health care workers was also predicted to be high as a solution to this problem of high risks of transmission. [5] Suggested several low-cost potential building adaptations to be modelled, including enlarging the area of the existing windows by 25(percent), the creation of two additional windows of the same size as the existing windows in locations that promote cross-ventilation and the installation of a mechanical extractor fan with a constant flow of 200 m3/h on the roof.

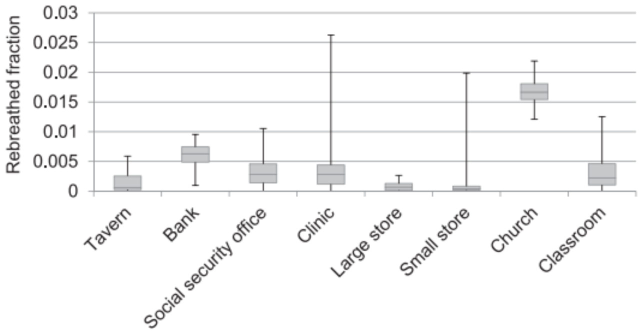


Figure 1: Data

Figure 2: Hot spot loactions

[5] ventilation measurements suggest that visits to the church and clinic waiting room would carry the highest risk of M. tuberculosis transmission because of overcrowding

and poor ventilation. However, after accounting for time spent inside each building over the course of the year, our results indicate that the classroom and the church are potentially the most important locations for M. tuberculosis transmission. [5] also predict high risks of transmission to patients regularly visiting the clinic and to clinic staff. The classroom was well designed, with operational windows down either side of the room allowing for high levels of natural ventilation. [5] predicted M. tuberculosis transmission risk in the classroom was driven by the long periods of time students spend in the space. Conversely, the church and clinic waiting room were poorly designed, leading to a high risk of infection over a much shorter periods of time. To reduce transmission in indoor congregate environments, we should therefore consider intervening in both buildings where occupants spend large amounts of time together as well as in poorly ventilated buildings

These results indicate a wide range of transmission risks inside different public buildings in rural South Africa. Churches and clinic waiting rooms were both found to contain high levels of rebreathed air, predicting elevated transmission risk. Predicted risks were also high for students in the well-designed classroom due to the protracted length of time spent indoors. Modelling indicates that low-cost adaptations may dramatically reduce the risk of transmission within buildings, particularly for staff. Our results provide a strong case for intervention studies quantifying the impact on M. tuberculosis transmission of retrofits in congregate settings. Looking at findings presented by the paper "indoor CO2, potential criticalities and solutions "

According to [3] carbon dioxide has been originally looked at as a major problem globally, this is because of the very much known or well researched effects of fossil fuel combustion to the climate of the planet and its atmosphere. Indoor air quality is increasingly becoming a matter of concern especially in the last decade says [3].

Recent predictions state that about 7 million deaths per year in the world are caused by air pollution. The concept of exposure to air pollutants looks at the effect of air pollutant on the health of human body and that is related not only the time of contact but also the contaminants concentration. These contaminants primary route of exposure is through air, and they are usually inhaled. The social cost that associates with this pollutant are huge due to hospitalization. Furthermore [3] notes that as much as past researchers focused on micro- and micro- pollutants for example NO2, CO2, PM and other volatile organic compounds but IAQ is greatly affected by CO2 which Is usually neglected. In indoor environment e.g., classroom, the CO2 concentration is typically in the range of 300-400pm, but in high traffic density this couple double or triple especially in indoor environments with poor ventilation and air exchange where CO2 concentration can reach thousands of ppm. Therefore, at concentrations up to 5,000 ppm, symptoms like sleepiness, headache and loss of attention become evident. In indoor environments with the absence of specific sources, the excess CO2 that may accumulate above its natural levels is due to the human metabolism. If not adequately controlled, the inhalation of air with high CO2 concentrations (within certain limits) may cause reversible, though negative, effects on the people exposed

Additionally [3] continues to propose ways of controlling and management of CO2 exposure Following episodes that lead to an accumulation of CO2 in indoor spaces, CO2 concentrations could be taken back to the “hygienically insignificant” range if a regular ventilation or a sufficient exchange of air was granted. In this sense, automatic air extraction systems are the best option to ensure adequate air exchange. Another strategical aspect for the correct management of indoor CO2 concentration is represented by CO2 monitoring. Low-cost CO2 monitoring sensors could be conveniently used in school/university rooms where automatic air extraction systems are absent and when their installation is not feasible. The monitoring of the CO2 concentration would reveal possible critical episodes. If the indoor CO2 concentration exceeded the "hygienically insignificant" threshold, the teacher/lecturer could put some simple actions into practice, like opening windows, doors and proposing a break to the students. The most known low-cost method for CO2 monitoring is based on nondispersive infrared digital sensors, which are commercially available, and which normally measure the CO2 concentration in the range 0–5,000 ppm, which is suitable for most of the cases. The technological advances of the last years have decreased more and more the size of air quality sensors, allowing for converting fixed sensors into portable devices, like the recent Sensor drone.

on A study of CO2 influence on student activity in classroom was conducted by [4]. A study whose main parameters look at environmental air quality, environmental comfort in seminar rooms namely air temperature, air velocity, median radiant temperature, relative humidity, and CO2 content which was used to determine how they influence students. These parameters are based on the PMV and PPD indices. This study further calculated the parameters efficiency using data obtained form conducted experiments. Lastly the review look at a proposed model to estimate the influence of carbon dioxide content with regards to students' performance in during class.[4] mansions that Indoor air quality in closed and confined environments, can affect students in several different ways such as negative health implications, the students comfort levels can drop, their productivity can be negatively affected and their efficiency of learning during a lesson can be lowered significantly this includes their attention during classes. The paper notes the amount of effort and research that has gone into thermal comfort conditions in offices and the implications it has int the workers productivity, has been significant in the past but less has gone into investigating schools, university, and student's performance during school hours. The paper has noted that co2 content is increased by reducing the intake of fresh air and mental performance of students in secondary school is decreased based on another study performed by Smedje at al. To measure the parameter of interest which are air velocity, median radiant temperature, relative humidity, CO2 content and thermal comfort the paper mentions PMV and PPD, predicted Mena Vote and Predicted Percentage Dissatisfied index where PMV shows the mean value of the vote for a group of people in a 7- point thermal sensation scale. PMV is based on a couple of factors namely, air temperature, mean radiant temperature, air velocity, humidity, activity, and clothing, below is a PMV scale

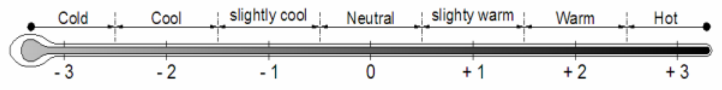


Figure 3: scale

The PMV index is expressed and simplified to the equation below, where M is the metabolic rate of human body, L is the heat load. And lastly PPD index helps with quantitatively predicting the percentage of people dissatisfied which is also shown below

$$\mathrm{PMV} = \left(0.303 \cdot e^{-0.036 \cdot M} + 0.028\right) \cdot L$$

Figure 4: PVM

The study was realized in Timisoara, located in the western part of Romania with a temperate continental climate, with an average annual outdoor temperature of 11.1 °C. The experiment was realized in a period of 2.15 h (8:00 to 10:15) during the summer months from June to July. The room of interest seminar room was in on the ground floor. And the parameter of interest was monitored using sensors. Thus, the obtained results are shown below.

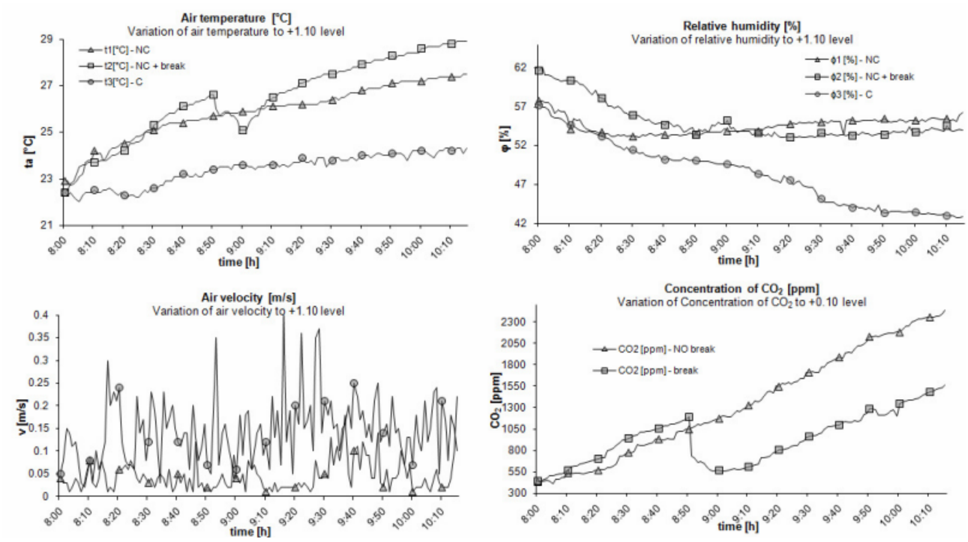


Figure 5: Data

The variation of climate parameters can be seen that the temperature showed a constant increase enough sharply from 22.4 °C to 28.9 °C when the air conditioning did not work and kept a constant value in that case when the air conditioning was turned on. The temperature decreased during the break with approximately 1.5 °C, in all this time the room was empty. CO2 being the focus one can see in the data provided by the study that CO2 level increased above optimal level reaching a value of 2400 ppm more than the normal 1000 ppm within the period of two hours. For the purpose of estimating the effect of influence co2 has on students' performance a linear regression was chosen and fitted with the data. Basis of the model has took the form :

$$\mathrm{p}(x) = a * x + b$$

Figure 6: Model

The data below was present as the model was fitted and estimates where done:

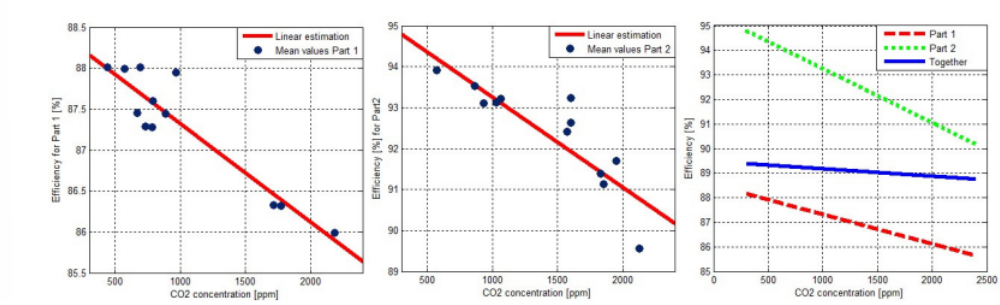


Figure 7: Model prediction

Validation of this model was made in other two seminars. Thus, the proposed model provides an error of 2.2(percent) as it concern the determination of students' efficiency during the seminar depending on the CO2 concentration

3 Design methodology

3.1 Design overview

The overview of the system will consist of a microcontroller that creates the link between the sensor, the display, the power, and the fans. It will facilitate the collection of co2 data for transmission from the sensor to be displayed for the users and process that very same data in the central part of the system, which is the microcontroller itself. Its core purpose is to ensure that the sensors, fans, power, and display modules are carefully managed to ensure low power consumption and smooth communication between these modules. It will do this using low-level device sleep and data collection at precise intervals, thus taking data in specific small, short intervals using the sleep method. The system will need to use the data collected from the carbon dioxide sensor to control the fans; therefore, this process needs to be an utterly synchronous service to achieve the system's goal. The goal of the design is to maintain the indoor air quality or the carbon dioxide levels in the following manner:

- In case of high levels of CO2 in the given enclosed environment, e.g., a classroom.m
- The Co2 sensor will collect the data from the environment and send it to the microcontroller
- During processing the received data, the microcontroller will detect a high level of CO2 concentration, thus sending a trigger signal to the fans to switch on while displaying the received data on the Display module.
- During the fan's operation time, CO2 sensors continue to send data to the microcontroller; thus, upon detection of a low level of CO2 concentration during data processing, a kill command is sent to stop the fans from operating.

Regarding delays, it is not a concern as delays accumulated through the data collection and transmission process will not impact the entire chain of delivery operations. The sensor module or subsystem will feature a carbon dioxide sensor built into a PCB or soldered to the Veroboard, which will also hold the microcontroller. Powering the microcontroller will then power the other subsystems, for example, the sensor and the fans, including possibly the display module. The design choices will also revolve around the microcontroller's need for at least 5V DC, a current rating of 1A from the batteries or power supply or a rechargeable battery. The aspects that are being considered in the decision-making process will be cost, technical maturity, ease of manufacturing, availability, implementation, testing, reliability, and maintenance. In addition, a Mechanical module or subsystem, which will mainly be for protection and safety for the project, will be designed. Below is the overall system beak down into individual subsystems

3.2 User requirements and Traceability Matrix

This section outlines the steps taken to identify the user requirements and translate them into hardware subsystems. These requirements resulted in well-defined measurement objectives for the device and the selection of subsystems critical to the device's functions. A high-level system diagram was created to show the interaction of the subsystems within the system. This allowed for the selection of hardware components to satisfy the requirements for each subsystem. Requirement analysis aims to transform the needs and high-level requirements into unambiguous, traceable, complete, consistent, and stakeholder-approved requirements.

User Requirement ID	**Description**
UR001	The system must ensure that data is sent successfully to required modules
UR002	The system must use minimal power
UR003	The system must provide accurate data
UR004	Battery or power supply should last at least 12 hours without switching off
UR005	The system must be cost-effective and ecofriendly
UR006	The system must have a protective casing that is durable
UR007	The system must display the current CO level so you can quickly check if the current conditions are safe or not.

Table 1: User Requirements

3.2.1 Analysis of R.U.001

'The system must ensure that data is sent successfully to required modules' All data sent from the sensors to the microcontroller and respective modules such as the display module. If the data is not received by the display, lags on the data can be ignored as the system is not a hard-real time system but this requirement is to ensure that there are less bugs on the system and that there are no unnoticed errors which course the system to glitch.

.ID	Requirement Text	Derived From
FR001	The system must ensure that data is sent successfully	UR001

Table 2: Analysis of R.U.001

3.2.2 Verification

Test Case ID	Test Case Description
T.C.001	Test the system under a robust reading on environmental data

Table 3: Verification

3.2.3 Analysis of R.U.002

"The system must use minimal power" The system must need or use as little power as possible. This is since it will be expected to run for extended periods and must be able to last for longer duration. The power consumption must be optimized through hardware by selecting the optimal hardware to ensure that the overall power draw on the power supply will be low. The hardware includes the sensors and display modules and fans thus they need to be carefully selected.

Req.ID	Requirement Text	Derived From
FR002	The microcontroller must use minimal power and efficient code for the execution of the system	UR002

Table 4: Analysis of R.U.002

3.2.4 Verification

Test Case ID	Test Case Description
T.C.002	Power supply selection such that the power supply covers the minimum power requirement of the total amount fans

Table 5: Verification

3.2.5 Analysis of R.U.003

"The system must provide accurate data" The sensors that are selected must provide accurate data since very small changes in environment conditions affects how the system responds. Accuracy has to do with how close the sensor reading is to the true value while Precision refers to the ability of the sensor to detect small changes thus selection of the sensors is crucial.

Req.ID	Requirement Text	Derived From
FR003	The sensors must provide accurate data, sensors with high accuracy	UR003

Table 6: Analysis of R.U.003

3.2.6 Verification

Test Case ID	Test Case Description
T.C.003	The proper way to test carbon dioxide detector is to blow Co2 from burning paper directly to the sensor and to confirm sensor functions, the use of an LED and buzzer alarm operation. "bump testing"

Table 7: Verification

3.2.7 Analysis of R.U.004

"Power supply should last at least 12 hours" The microcontroller will most likely be running for a full working day, consequently the power supply needs to be able to last for a long period of time. Therefore, the user does not have to be concerned with charging the battery during working hours.

Req.ID	Requirement Text	Derived From
FR004	To have a battery last approximately 12 hours, the appropriate battery size must be considered. Battery capacity needs to be around 2200MAh with a rated current of 5A and 12V output, the larger the battery capacity and the lower the rated current will allow increase battery life the or the use of an AC to DC supply.	UR004

Table 8: Analysis of R.U.004

3.2.8 Verification

Test Case ID	Test Case Description
T.C.004	During the battery's normal working conditions to verify how long it can last and use a multi-meter to test the current being drawn at different operations of the microcontroller to ensure constant current is being drawn.

Table 9: Verification

3.2.9 Analysis of R.U.005

'The system must be eco-friendly and cost-effective' This means that the systeme must be built in a green manner or use electronic waste to reduce waste or a form of recycling, thus avoiding having one-time use components such as batteries that are then thrown away is harmful as it only increases amount of discarded of metals like mercury and lead.Rechargeable are also easier to recycle in comparison to disposable batteries.A wall power supply may eliminate this issue as it it reusable.

Req.ID	Requirement Text	Derived From
FR005	The battery must have option of being re-chargeable, or the use of a cost effective power supply	UR005

Table 10: Analysis of R.U.005

3.2.10 Verification

Test Case ID	Test Case Description
T.C.005	The price comparison will be done, and time of operations for the selection of the power supply.

Table 11: Verification

3.3 Functional requirements

This is a section that specifies the function of a system or its component, where a function is described as a specification of behavior between outputs and inputs. Analysis of the user requirements resulted in the procurement of a set of functional requirements that dictate how the system will function. The functional requirements above were used to determine the best possible system possible to meet the requirements as mentioned above. The requirements were further used to identify the important system breakdown which is presented below thus this will form the subsystems for the overall solution.

RequirementID	Description	User Req Address
FR001	The system must ensure that data is sent successfully	UR002
FR002	The microcontroller must use minimal power and efficient code for the execution of the system	UR002
FR003	The sensors must provide accurate data, sensors must have high accuracy	UR003
FR004	. Power supply or battery capacity needs to be around 2200MAh with a rated current of at least 5A and 12v output	UR004
FR005	The battery must have option of being re-chargeable, or the use of a cost effective power supply	UR005
FR006	The case must use shock-absorbent material, that is also strong, such the device is less susceptible to damage	UR006

Table 12: Functional requirements

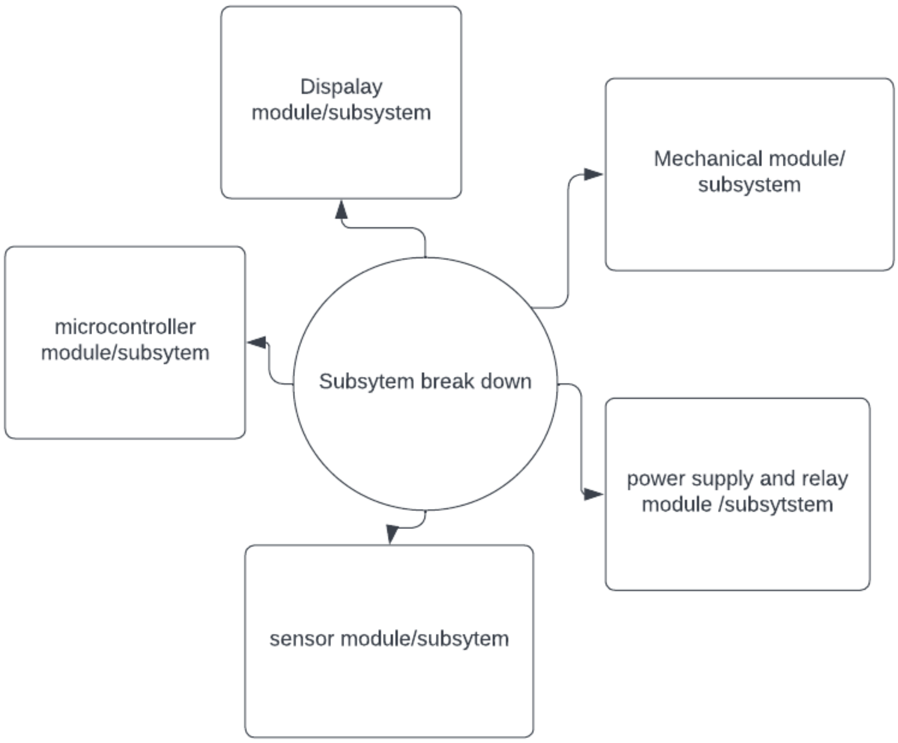


Figure 8: Subsystem Breakdown

3.4 Acceptance Test Protocols

Listed below are the various acceptance test protocols to determine whether or not the previously mentioned requirements have been met. However, some tests might not be applicable to all iterations of the project. When this is the case, the protocol will include a note detailing adaptations for the respective versions of the project

ATP:ID	Test procedure	Associated Requirement(s)
ATP1	The soldering of the circuit must be done carefully such that there are no shorts or disconected lines in the Vero board	UR002, FR001
ATP2	The material used for the case must be rated for top tensile strength of above 50 MPa or 7000 PSI. Melting point of above 100 degrees Celsius. A shrink Rate of less than 0.5	UR007,FR006
ATP3	The calibration of the carbon dioxide sensor must be done correctly if needed. Otherwise, the offset must be compensated for having a zero reference for the carbon dioxide concentration of 450 ppm	UR003, FR003
ATP4	A bill of materials used in the project will be made and the corresponding prices of the parts ordered will be collected, If the overall cost if below R700 that will be a pass	UR001, UR002, UR003, UR004, UR005, FR001, FR002, FR003, FR004,FR005
ATP5	The system uses two techniques for displaying the current readings of the system. A comparison of the serial monitor with the actual displays will be done. A match is a pass	UR005
ATP6	Creation of a test environment for the entire system. Using a fire extinguisher to simulate a real-world scenario	UR006
ATP7	Measuring the noise levels for the entire duration of operation of the system to test for the amount of noise from the system	UR006

Table 13: ATP(S)

4 System design choices

The hardware design methods are thoroughly examined in this portion of the paper. This section elaborates on the system's implementation in light of the user and functional requirements covered in earlier sections. This section explains the work that went into creating the first and second prototypes of the system, showing where improvements were made. This section outlines the electronic parts chosen for the design and how each helps make the system functional and realizable.

4.1 Electronic Components

The best electronics for the specified application, which would be for the sensor module, microcontroller, fans set up, and power circuits, would be chosen throughout the selection phase of the electrical components for the system. The system was developed using widely accessible, off-the-shelf components, ideally components in the white lab, to meet the time restrictions set. These parts must be low-powered, long-lasting, economical, sturdy, and efficient. The procedure for choosing the components is shown below.

4.2 Microcontroller

4.2.1 Option-A: NODEMCU ESP8266

This microcontroller has additional features, such as WiFi capability, which may also be found with integrated chips on the PCB, including flash memory and an antenna. The development board nodemcu features the ESP8266 and the same firmware. The ESP microprocessors operate at 3.3V.

Figure 9: ESP8266

ESP will have a longer running life span when linked to a battery power supply since the board can function under 4V. However, this board has no difference when attached to the mains.ESP8266 boards range in power supply from 2.5 V to 12 V depending on the specific board, whereas Arduino boards have a greater power supply between 7V and 12V. The difference won't make a big difference. The ESP8266 microcontroller, on which the nodemcu is built, has a remarkably low current consumption range of 15µA to 400 mA, which may be further reduced to 0.5 µA by activating the deep sleep mode..

4.2.2 Option-B: ARDUINO: UNO, Nano or Mega

The UNO is a microcontroller that contains 14 I/O pins, 6 of which may be utilized as PWM outputs, an eight-bit ATmega328P microprocessor, a crystal oscillator serial communication voltage regulator, and other features.

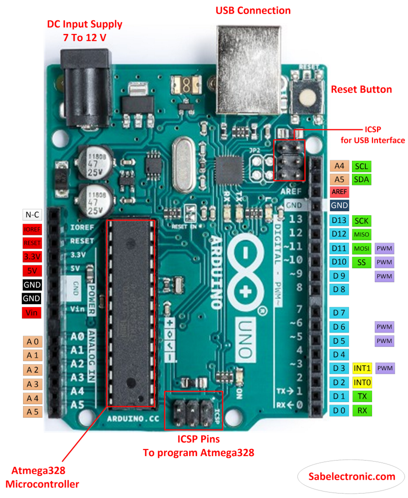


Figure 10: ARDUINO UNO

The Uno requires 5V to function. When this board is linked to the mains, there is no significant difference; however, the Uno's operational time will be reduced when it is attached to a battery power source. For the Arduino Uno with 35 mA, deep sleep mode current usage is 70000 times greater. The difference in the digital I/O pins across all boards is almost nil.There are two variations of the Arduino Uno. One with on board WiFi and one without. There are several ways to access WiFi even without an inbuilt WiFi chip, Either utilize an Arduino WiFi shield or establish a WiFi connection between the Arduino board and the ESP-01.

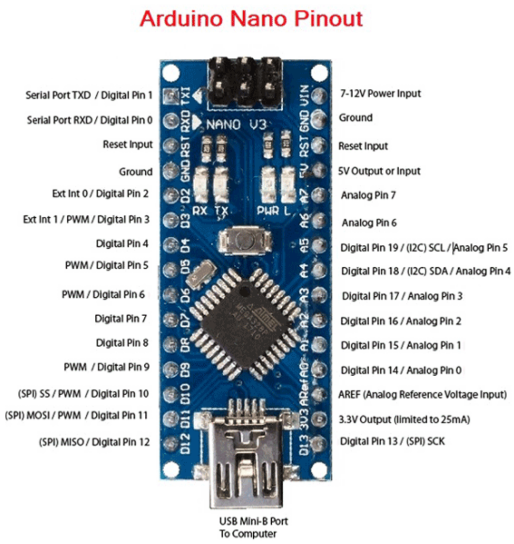


Figure 11: ARDUINO NANO

Compared to the Raspberry Pi, the Arduino Nano has fewer general-purpose input/output pins and a significantly smaller connection line. The smaller size and improved power consumption of this Arduino make it possible to develop smaller solutions.

4.3 Sensors

4.3.1 Option-A: MH-Z19C

The most popular form of CO2 sensor, with good precision and low power requirements, is the NDIR (nondispersive infrared) CO2 sensor. Prices range widely. The MH-Z19 sensor has excellent qualities and is very affordable. The MH-Z19C sensor has some of the technical parameters listed below.

Working voltage	4.7 V to 5.1V DC
Average current	less than 85 mA
Interface level	3.3 V
Measuring range	0 5 tollarance
Output signal	PWM, UART
Weight	15 g
Lifespan	more than 5 year durable
Range	0 -5000ppm

Table 14: MH-Z19C Properties

Figure 12: MH-Z19C

4.3.2 Option-B: MQ135-GAS-SENSOR-MODULE

The sensor detects NH3, NOx, alcohol, benzene, smoke, and CO2. It has poor precision even after applying temperature and humidity correction. It has high power consumption (800mw) and over 24h preheating time.

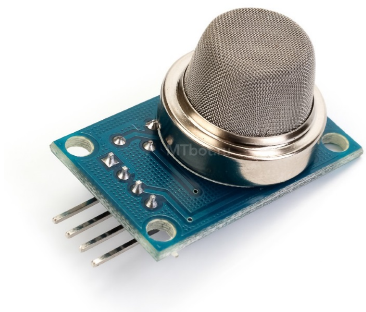


Figure 13: MQ135

4.4 Power Supply and Relays

4.4.1 Option-A: Mains Power

Before electricity reaches homes, it must first go from a power plant to meter boxes and then through a series of circuits to a powerpoint built into a wall. Any electric item may be connected to and switched on from the wall; as a result, this electricity is referred to as mains power and is provided to the general public and their homes. At 240 volts, this electricity passes from the power plants to residences. This is the supply used to power the fans and which may be controlled from AC to dc voltage. This has ample power and a steady flow of voltage, current, and power.

4.4.2 Option-B: Batteries, Power bank

When there is no access to mains power, batteries are an excellent option to deliver electricity. In the form of chemicals, these devices store electrical energy. Batteries come in a wide range of sizes and forms because they serve so many various functions, from powering toys to storing solar energy. Use of a power bank is the worst possible choice. A connected ESP8266 utilizes an LDO (low drop-out voltage regulator) to lower the 5 volts to 3.3 volts after a power bank internally converts the 3.7V lithium battery's internal voltage to 5 volts with loss. This is a nightmare in terms of energy efficiency because several conversions use a lot of power continuously (i.e., even though the ESP8266 only needs 7 A). Additionally, some power banks shut down automatically because they believe that no loads are connected due to the ESP8266's low power consumption.

4.5 Fans

4.5.1 Option-A: General purpose fans

DC-sealed sleeve axial fans offer a multipurpose, space-saving, and dependable solution for numerous applications. Ball-bearing fans can be replaced with sealed sleeve technology, which has a longer lifespan than conventional sleeve-bearing fans. Each model is incredibly dependable and of the highest calibre. In all sectors where the cooling of parts or equipment is crucial, axial fans are used. These fans operate by pushing out hot air to cool a surface or pulling air over the target surface to cool it . In this instance, or project, the fans will move cleaner air into the desired room from "the outside environment." The technical description below is that of the fans

Working voltage	24 V dc
Average current	50mA
AC or DC Operation	DC
Depth	25mm
Dimensions	80 x 80 x 25mm
Air Flow	26cfm
Lifespan	more than 5 year durable
Fan Speed	2100rpm
Power Consumption	490mW
Bearing Type	Sleeve

Table 15: General purpose fans Properties

4.5.2 Option-B: R89F Series Axial Fan, 92 x 92 x 38mm, 100 $\rightarrow$ 240 V ac, AC Operation, 1.5m^3/min, 4.5W

These fans work by drawing air across a surface or pushing hot air away to cool it. In this case, the fans will bring cleaner air from outside "the atmosphere 'to the targeted room. These fans draw too much heat due to the ball bearing with increased noise levels per fan; these fans also operate with alternating current compared to the low-cost general-purpose fan. The fans specification

Working voltage	100 $\rightarrow$ 240 V ac
Average current	80mA
AC or DC Operation	AC
Depth	92mm
Dimensions	92 x 92 x 38mm
Air Flow	1.5m^3/min
Lifespan	more than 5 year durable
Fan Speed	2100rpm
Power Consumption	4.5W
Bearing Type	Ball

Table 16: R89F Series Axial Fan, 92 x 92 x 38mm, 100 $\rightarrow$ 240 V ac, AC Operation, 1.5m^3/min, 4.5W

4.5.3 Selection Summary

The final decisions for the implementations were to use the NODEMCU ESP8266, due to its adaptability, WiFi onboard and low current requirement. The MH-Z19C sensor is the best for this application due to it cost effectiveness and high sensitivity. The best power supply is mains power due to its constant supply of electricity which is more reliable than the use of batteries and power banks. The use of general purpose fans is ideal and most appealing due to its dc ratings.

5 System design and implementation

This Section outlines the System design and implementation methodology for Smart-Ventilator-Design-using E-waste for Airborne Diseases based on the hardware design and components selections in the previous Section. This section describes the Arduino cope written for the first version of the Smart-Ventilator-Design-using E-waste for Airborne Diseases system. This version contains the MH-Z19C NDIR CO2 sensor, two LEDs, and ESP8266 a low-powered microcontroller with Wi-Fi onboard. Separately powered 8X12v,0.16A,16w fans.

5.1 Hardware Version1

The system consists of a microcontroller esp266 which will create the link between the sensor MH-Z19C , the LCD, and the Fans. It will facilitate the collection of environmental and co2 data . The Figure below is the desired setup of the fans

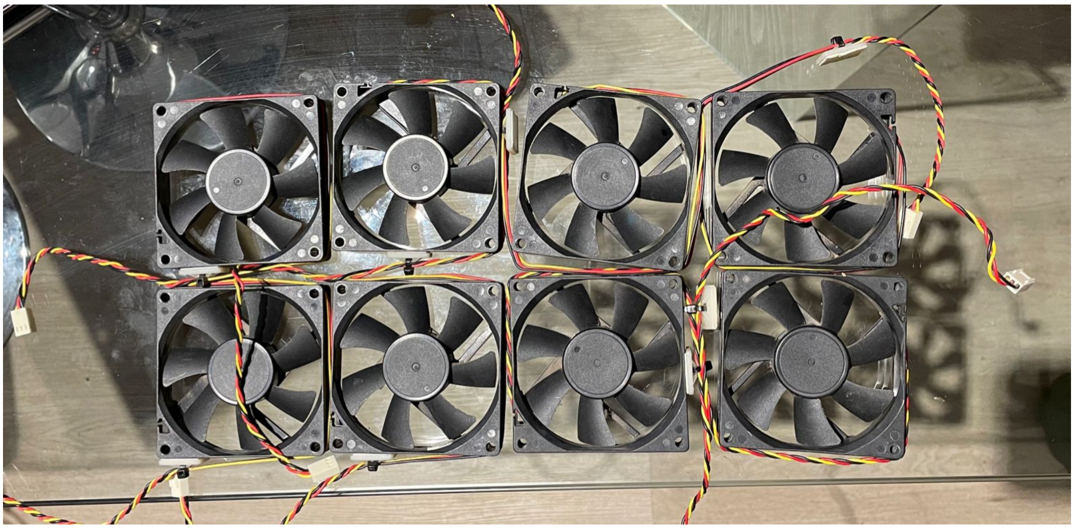


Figure 14: 8, 12V0.16A 1.92W fans

Parallel operation is the parallel use of two or more fans. The volume of air generated by the parallel connection of two fans is only twice the air volume of a single fan in free space conditions. When the parallel fan is used in the case of higher system impedance, the higher the system impedance, the more the parallel fan can increase. The lower the air volume. Therefore, the parallel application is used only with low system impedance, ie the fan operates with almost complete free air supply. The connection below are such that parallel operation is achieved.

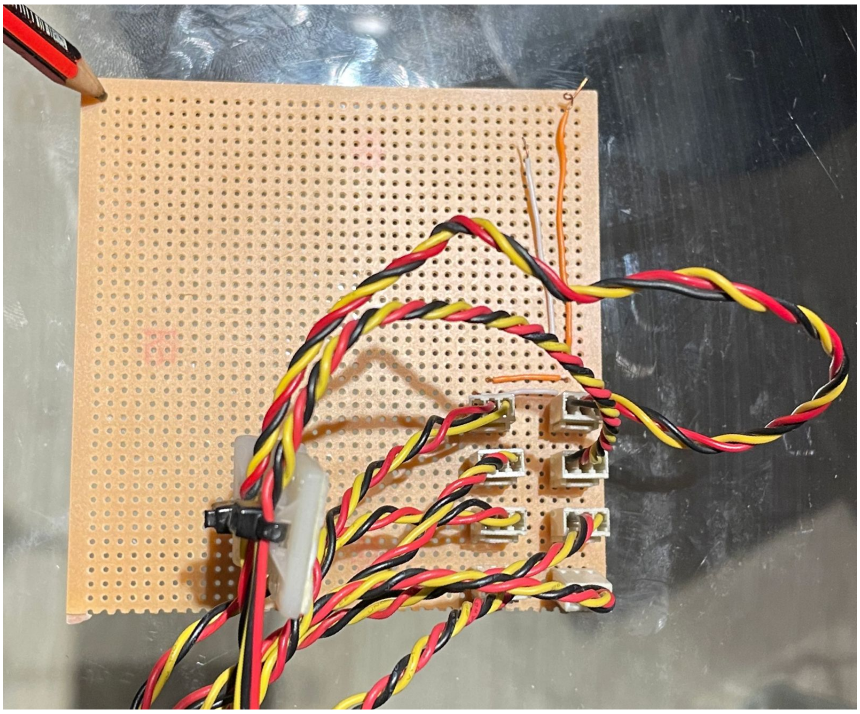


Figure 15: fan connection point

The main part of the system which is the microcontroller itself. Its core purpose is to ensure that the sensors, Fans and LCD modules are carefully managed to ensure a low power consumption is achieved and a smooth communication between these modules. It will do this by means of low-level device sleep and data collection at very specific intervals thus taking data and specific small, short intervals. The system will need to make use of the data that is collected from the carbon dioxide sensor to control the fans therefore this process needs to be a completely synchronous service to achieve the goal of the system.The figure below shows the main part of the entire system.

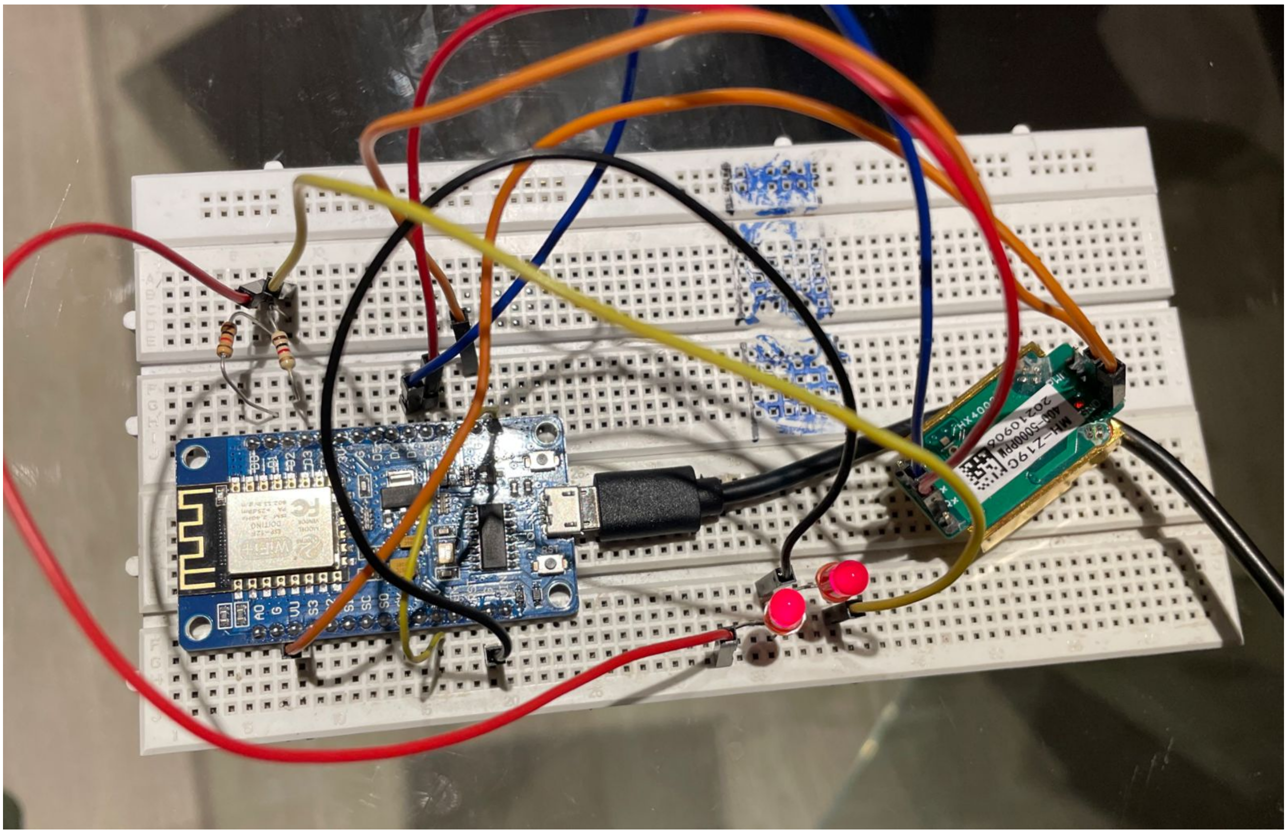


Figure 16: main system Esp8266, Co2 senso

The fan need a booster from 9V to 12V since the available power supply is a 9v battery, which is only for the temporal use for testing and collecting data since the 12v 3A wall adater is still being ordered.Below is the temporal 9V to 12V booster.

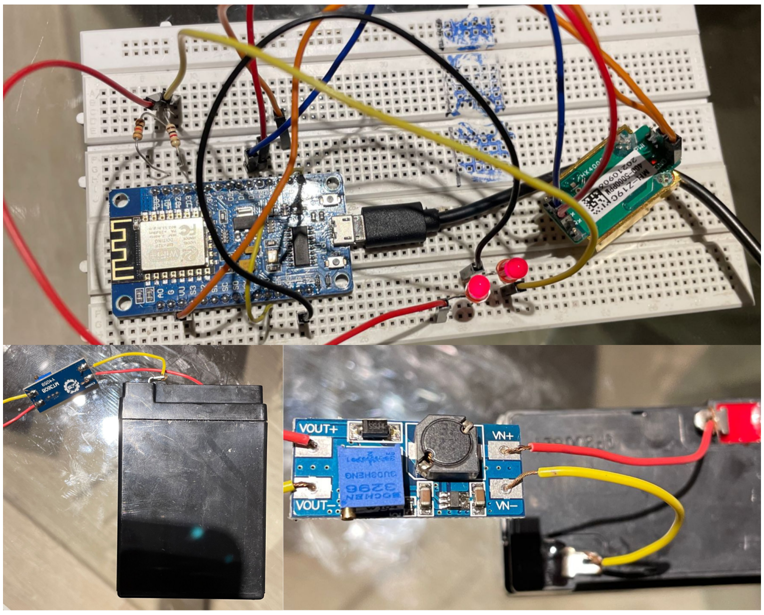


Figure 17: 9v temporal battery and 9V to 12V regulator

5.2 Hardware Version 2

This section of the report focuses on the second implementation of the project, these improvements were made based on the first versions of the system and the associated drawbacks. Presented below is the final system of the second iteration of this project. The final circuitry is presented together with the selected final power supply. Further on the Mechanical section of the project is presented, the mounting frame, the stand and the protection case which is mostly for the support and protection of the implanted circuit and the protection and safety of the occupants.

5.2.1 Final Circuitry

The final circuitry consists of a few major improvements. The transition from breadboard to veroboard was a huge improvement when it comes to portability and the lifespan of the project. Veroboard's cost significantly less than printed PCB's is a great consideration for the project as one of the requirements is that the system be cost-effective, which is a huge factor when looking at the use cases of the current project. It's not only simple but easy to replace or modify circuits on Veroboard than a PCB and they are easily available which is one of the aims of this project. To use off-the-shelf components and parts. As stated in the above sections, the maximum current that this project requires is 5A, and each track of the Veroboard is rated at a maximum of 5A.

Power for this implementation is also a huge factor and significant requirement. The final selection Option-A: Mains Power. Batteries and Power banks as mentioned above are one of the worse options to use in a system with a requirement to operate extended amounts of hours, the minimum being 12 hours of operation non-stop.

5.2.2 Mechanical

This section of the final circuitry or final version of the project focuses mainly on safety and protection. Safety encompasses all the safety conditions in paces of deployment. This includes the protection of users and operators of the unit/ system and bypassing anticipated hazards through the setup. One example of safety features the system exhibit is the connectivity issue, the system has a fail-safe measure such that if it were not to be connected to the internet it would carry on working as normal this shift or completely remove a single point of failure due to connectivity issues. Below is the mounting frame for the fans. The figure below that is the stand for the frame,

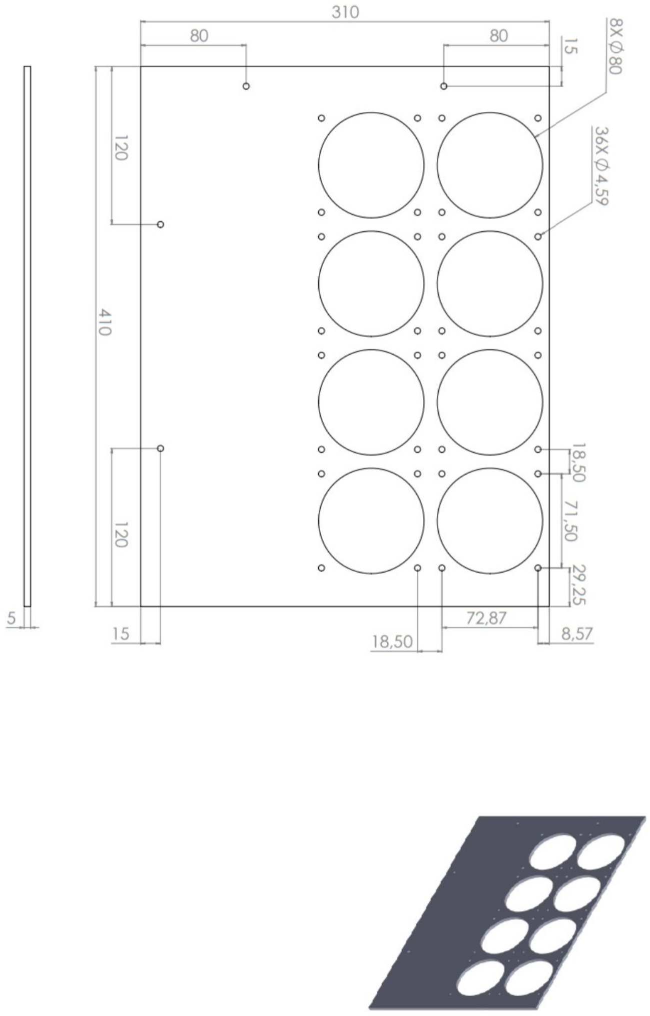


Figure 18: Mounting Frame Design

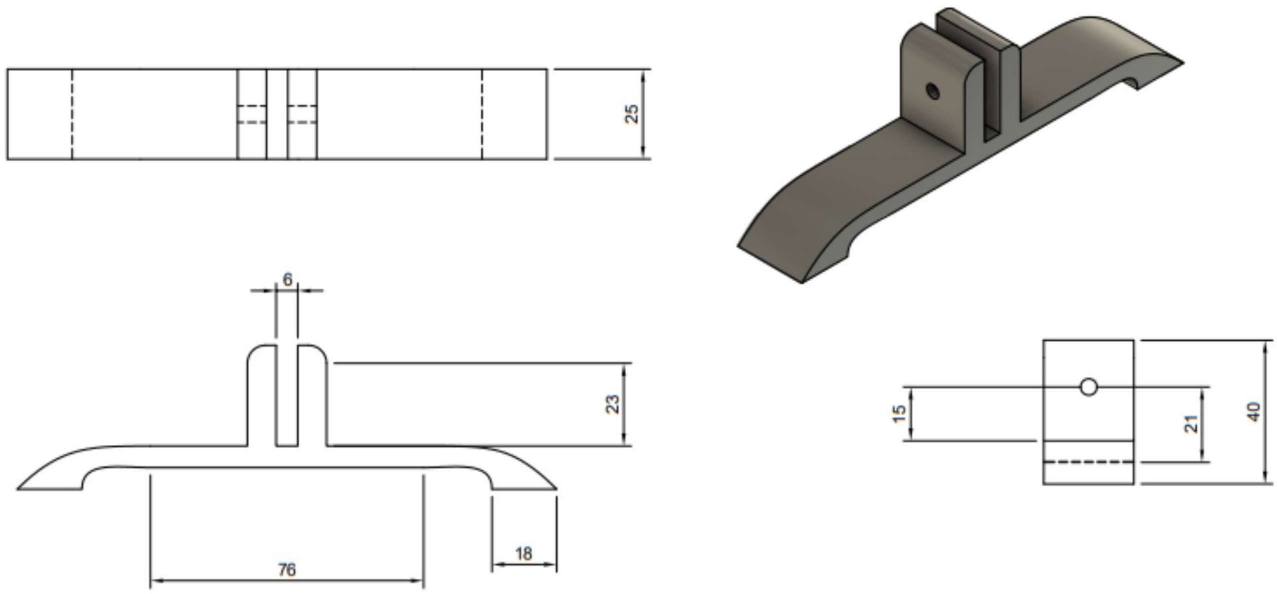


Figure 19: Stand Design

5.3 Software Version 1

Microcontrollers are typically programmed in higher-level languages such as C++ or Java. One of the essential tools needed to program a microcontroller is an integrated development environment (IDE). Below is the code run on the IDE to achieve the desired functionality of for the Smart Ventilator Design using E-waste for Airborne Diseases System.

The CO2 sensor SAMPLE section below is importing required classes and declaring important global variabels to describe each pins function, and set them equal to the pin number on the board to make coding more intuitive. The Google sheets sections logs in an already deployed google sheet web app to log the that and store it remotely, this will bw discussed in following sections. “Void Setup()” section. Digital pins on the microcontroller are used as inputs or outputs. This section, the pins are defined as inputs or outputs depending on their implementation, as well as other parameters are initialized. Lastly, “Void Loop()” section. This section is where the function of microcontroller are written. Any actions that require reading or writing values from pins, or computing the values of different variables is done here as seen below.

```
/* ------------------------------------------------------------
 MH-Z19 CO2 sensor  SAMPLE
------------------------------------------------------------ */
#include "TRIGGER_WIFI.h"               /*Includes ESP8266WiFi.h and WiFiClientSecure.h, just have these two libraries downloaded before*/
#include "TRIGGER_GOOGLESHEETS.h"       /*Library file for Google Sheets, has to be used after Wi-Fi Client Secure declaration, here everything is in Trigger_WIFI.h, so using it after Trigger_WIFI.h*/
#include "MHZ19.h"

const int LED1 =05; // Led in NodeMCU at pin GPIO16 (D0).
const int LED2 =04; // Led in NodeMCU at pin GPIO16 (D0).
const int rx_pin = 13; //Serial rx pin no
const int tx_pin = 15; //Serial tx pin no
const int threshold1 = 450;
```

```
const int threshold2 = 900;


/**********Google Sheets Definations***********/
char column_name_in_sheets[ ][20] = {"Co2_level"};  /*1. The Total no of column depends on how many value you have created in Script of Sheets;2. It has to be in order as per the rows decided in google sheets*/
String Sheets_GAS_ID = "AKfycbzXRzgxscNcOXL3BLLtks--GtuaQGSJHKwim2TBkLMq0D-tT-FhUKV7v3YulGX9tCE";/* (AKfycbzXRzgxscNcOXL3BLLtks--GtuaQGSJHKwim2TBkLMq0D-tT-FhUKV7v3YulGX9tCE) This is the Sheets GAS ID, you need to look for your sheets id*/
int No_of_Parameters = 1;
MHZ19 *mhz19_uart = new MHZ19(rx_pin,tx_pin);


/*----------------------------------------------------------

    MH-Z19 CO2 sensor  setup
  ----------------------------------------------------------*/
void setup()
{

    WIFI_Connect("hp_lindani","lindan1t1"); /*Provide you
```

```
    Wi-Fi SSID and password to connect to Wi-Fi*/
  Google_Sheets_Init(column_name_in_sheets, Sheets_GAS_ID
    , No_of_Parameters );
  pinMode(LED2, OUTPUT); // set the digital pin as output
    .
  pinMode(LED1, OUTPUT); // set the digital pin as output
    .
  Serial.begin(115200);
  mhz19_uart->begin(rx_pin, tx_pin);
  mhz19_uart->setAutoCalibration(false);
  delay(300);
  Serial.print("MH-Z19 now warming up...  status:");
  Serial.println(mhz19_uart->getStatus());
  delay(100);
}

/*
    ------------------------------------------------------------

  MH-Z19 CO2 sensor  loop
  ------------------------------------------------------------
    */
void loop()
{
   float a = 1;
  measurement_t m = mhz19_uart->getMeasurement();
  //LED CONTROL AND DISPLAYING CO2 LEVELS.
```

```
    Serial.print("co2:␣");
    if (m.co2_ppm > threshold1) {
      digitalWrite(LED1, HIGH);
      Serial.println(m.co2_ppm);
      a=m.co2_ppm;
      Data_to_Sheets(No_of_Parameters,  a);
    } else {
      digitalWrite(LED1, LOW);
      Serial.println(m.co2_ppm);
      a=m.co2_ppm;
      Data_to_Sheets(No_of_Parameters,  a);
    }

    if (m.co2_ppm > threshold2) {
      digitalWrite(LED2, HIGH);
      Serial.println(m.co2_ppm);
      a=m.co2_ppm;
      Data_to_Sheets(No_of_Parameters,  a);
    } else {
      digitalWrite(LED2, LOW);
      Serial.println(m.co2_ppm);
      a=m.co2_ppm;
      Data_to_Sheets(No_of_Parameters,  a);
    }
    delay(10000);
}
```

For data logging and recording the code below is responsible for connecting google sheet.This is done through creating a Google Spreadsheet which will function as a remote storage to log sensor data into and later connecting it to the ESP8266, through the onboard WiFi functionality of the microcontroller

```

function doGet(e) {
  Logger.log( JSON.stringify(e) );  // view parameters
  var result = 'Ok'; // assume success
  if (e.parameter == 'undefined') {
    result = 'No Parameters';
  }
  else {
    var sheet_id = '1gAPnOyZhqcwwW7NLB6_Am0U4pJgw-swfAm5U5HKxuns';    // Spreadsheet ID
    var sheet = SpreadsheetApp.openById(sheet_id).getActiveSheet();   // get Active sheet
    var newRow = sheet.getLastRow() + 1;
    var rowData = [];
    d=new Date();
    rowData[0] = d; // Timestamp in column A
    rowData[1] = d.toLocaleTimeString(); // Timestamp in column A

    for (var param in e.parameter) {
      Logger.log('In for loop, param=' + param);
      var value = stripQuotes(e.parameter[param]);
      Logger.log(param + ':' + e.parameter[param]);
```

```
      switch (param) {
        case 'Co2_level': //Parameter 1, It has to be updated in Column in Sheets in the code, orderwise
          rowData[2] = value; //Value in column A
          result = 'Written on column A';
          break;
        default:
          result = "unsupported parameter";
      }
    }
    Logger.log(JSON.stringify(rowData));
    // Write new row below
    var newRange = sheet.getRange(newRow, 1, 1, rowData.length);
    newRange.setValues([rowData]);
  }
  // Return result of operation
  return ContentService.createTextOutput(result);
}
function stripQuotes( value ) {
  return value.replace(/^["']|['"]$/g, "");
}
```

5.4 Software Version 2

```
  /*
     ----------------------------------------------------------
```

```
  MH-Z19 CO2 sensor
---------------------------------------------------------
  */
#include "TRIGGER_WIFI.h"               /*Includes
  ESP8266WiFi.h and WiFiClientSecure.h*/
#include "TRIGGER_GOOGLESHEETS.h"       /*Library file for
  Google Sheets, has to be used after Wi-Fi Client Secure
  declaration, here everything is in Trigger_WIFI.h, so
  using it after Trigger_WIFI.h*/
#include "MHZ19.h"


const int s1 = 05; // SWITH 1 2FANS
const int s2 = 04; // SWITH 2 2FANS
const int s3 = D0; // SWITH 3 2FANS00
const int s0 = 00; // SWITH 0 2FANSD0





const int rx_pin = 13; //Serial rx pin no
const int tx_pin = 15; //Serial tx pin no
const int threshold1 = 450;
const int threshold2 = 900;
const int threshold3 = 1500;
```

```
const int threshold4 = 3000;


/*********Google Sheets Definations**********/
char column_name_in_sheets[ ][20] = {"Co2_level"};
String Sheets_GAS_ID = "
    AKfycbwLAr6ufztOrVqh1N1eg0CyohRs5AlT4Ym0jtOBloeOQKHz5A9VD4UoGb1WXdsDX
    ";                                              /*
    AKfycbxaZI5uyH-Sbw2sBrRr5PAaIrFOW1_EEaewqkbw-
    GWdXF0hqCw4p_0eQbDGfKijGk84

( AKfycbzXRzgxscNcOXL3BLLtks--GtuaQGSJHKwim2TBkLMq0D-tT-
    FhUKV7v3YulGX9tCE ) This is the Sheets GAS ID, you need
    to look for your sheets id*/
int No_of_Parameters = 1;
MHZ19 *mhz19_uart = new MHZ19(rx_pin, tx_pin);


/*
    ----------------------------------------------------------


     MH-Z19 CO2 sensor  setup
  ----------------------------------------------------------
      */
void setup()
{
  pinMode(s0, OUTPUT);
```

```
  pinMode(s1, OUTPUT);
  pinMode(s2, OUTPUT);
  pinMode(s3, OUTPUT);
  digitalWrite(s0, LOW);
  digitalWrite(s1, LOW );
  digitalWrite(s2, LOW );
  digitalWrite(s3, LOW );


  WIFI_Connect("hp_lindani", "lindan1t1");                          /*
     Provide you Wi-Fi SSID and password to connect to Wi-
     Fi*/
  Google_Sheets_Init(column_name_in_sheets, Sheets_GAS_ID,
     No_of_Parameters );
  Serial.begin(115200);
  mhz19_uart->begin(rx_pin, tx_pin);
  mhz19_uart->setAutoCalibration(false);
  delay(300);
  Serial.print("MH-Z19 now warming up...  status:");
  Serial.println(mhz19_uart->getStatus());
  delay(100);
}


void loopx () {
  digitalWrite(s0, HIGH);
```

```
  delay (5000);
  digitalWrite(s1, HIGH);
  delay (5000);
  digitalWrite(s2, HIGH);
  delay (5000);
  digitalWrite(s3, HIGH);
  delay (5000);


}
/*
    -----------------------------------------------------------

    MH-Z19 CO2 sensor  loop
      digitalWrite(s0, LOW);
  delay (5000);
  digitalWrite(s1, LOW);
  delay (5000);
  digitalWrite(s2, LOW);
  delay (5000);
  digitalWrite(s3, LOW);
  delay (5000);

    digitalWrite(s0, HIGH);
  digitalWrite(s1, HIGH);
  digitalWrite(s2, HIGH);
  digitalWrite(s3, HIGH);
```

```
  ------------------------------------------------------------
     */
void loop()
{


  float a = 1, b = 0 ,c=0;
  float fanNumber =0;

  measurement_t m = mhz19_uart->getMeasurement();


  Serial.print("co2: ");
  if (m.co2_ppm > threshold1) {
    digitalWrite(s0, HIGH);
    fanNumber =fanNumber+2 ;

    if (m.co2_ppm > threshold2) {
      digitalWrite(s1, HIGH);
      fanNumber =fanNumber+2 ;
      if (m.co2_ppm > threshold3) {
        digitalWrite(s2, HIGH);
        fanNumber =fanNumber+2 ;
        if (m.co2_ppm > threshold4) {
          digitalWrite(s3, HIGH);
          //fanNumber =fanNumber+2 ;
        } else {
```

```
          digitalWrite(s3, LOW);
         // fanNumber =fanNumber-2 ;
        }
      } else {
        digitalWrite(s2, LOW);
         //fanNumber =fanNumber-2 ;
      }
    } else {
      digitalWrite(s1, LOW);
      // fanNumber =fanNumber-2 ;
    }

  } else  {
    digitalWrite(s0, LOW);
     //fanNumber =fanNumber-2 ;



  } //else if (m.co2_ppm > threshold2) {
  //digitalWrite(s1, HIGH);
  // } else if (m.co2_ppm <= threshold2) {
  // digitalWrite(s1, LOW);
  // }
  b=fanNumber;
  a = m.co2_ppm;
  Serial.println(a);
  Serial.println(b);
```

```
  Data_to_Sheets(No_of_Parameters,a );
  delay(10000);

}
```

6 Testing and Results data

This section describes the testing protocols undertaken and followed to validate the system. The test is separated to target specific functionality of the subsystems. The tests are separated as follows: Sensor Tests and Result, remote storage tests and results, fan-setup tests and results, circuity test and results, system test and results, system noise est an results

6.1 Sensor Test and Results

Outside away from people and buildings, the sensor should read between 400 and 500 ppm as this is shown by previous research to be the normal atmospheric levels of CO2 concentration. Breathing directly on the sensor, it should read over 1000 and up to 3000 ppm this is a logical test to perform since Inhaled air has about 0.04 percent of carbon dioxide. This is also the amount of carbon dioxide present in the atmosphere. The exhaled air contains all the carbon dioxide that is a by-product of the cellular metabolic processes. Hence, the percentage of carbon dioxide in the exhaled air is 4.4 percent.The sensor is very sensitive to nearby sources of CO2.The graph below represent the collected data over a a period of 24 hours, each segment of the graph id detailed in terms of the activities during the time of testing. The file can be found here (`https://docs.google.com/spreadsheets/d/1gAPnOyZhqcwwW7NLB6_Am0U4pJgw-swfAm5U5HKxuns/edit#gid=0`

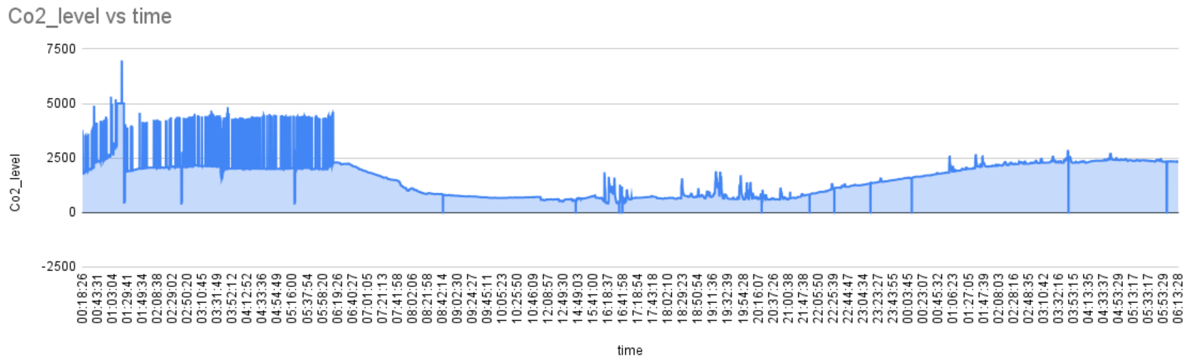


Figure :CO2level(ppm) VS time

A more detailed view of the graph, during phase A, one occupant of a 53 square meter apartment was sleeping with windows sealed and door closed. During phase B the occupant woke up, swicthed on a heater and jumped in a shower. During phase phase C windows were opened for some morning breeze and fresh air and for the rest of the day the windows and front sliding door was opened. Below is the graph corresponding to the described phases.

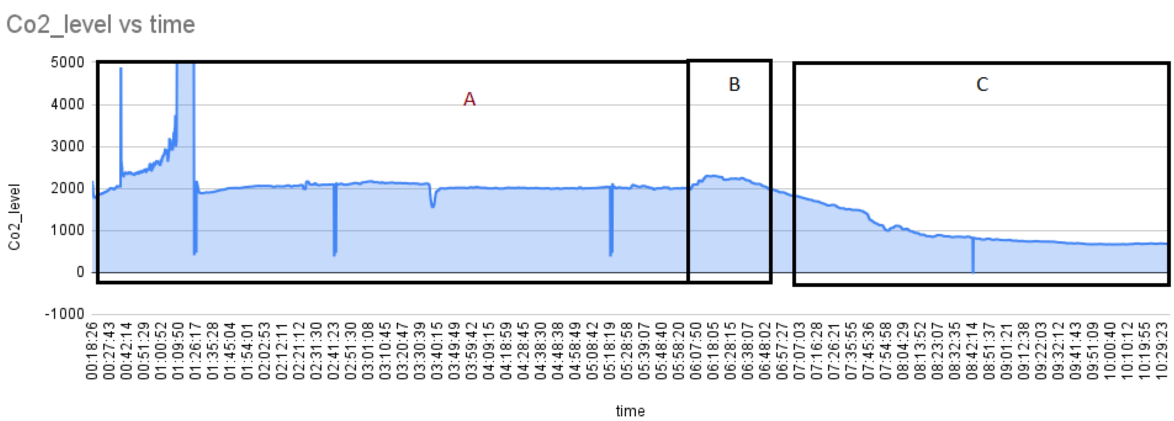
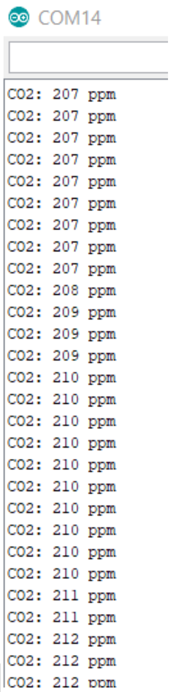


Figure :CO2level(ppm) VS time

6.2 Remote Display Tests and results

ATP5 the system uses two techniques for displaying the current readings of the system. A comparison of the serial monitor with the actual displays will be done. A match is a pass. The serial monitor is the 'tether' between the computer and the micro controller it allows the sending and receiving of text messages, handy for debugging and also controlling the Arduino from a keyboard it is the transmission highway from the Arduino and the computer's USB port. Which can be accessed through, simply clicking the Serial Monitor icon. The icon is located to the right of the other icons in Arduino or going to tool and scrolling down to Serial Monitor. The other option is to press on "ctrl+shift+M".Serial monitor comes with any and all version of the Arduino IDE. Once The IDE and Serial Monitor is operational a comparison of the data that is sent to the google sheet is also collected, these will be compared.



COM14

```
CO2: 207 ppm
CO2: 207 ppm
CO2: 207 ppm
CO2: 207 ppm
CO2: 207 ppm
CO2: 207 ppm
CO2: 207 ppm
CO2: 207 ppm
CO2: 207 ppm
CO2: 208 ppm
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CO2: 212 ppm
CO2: 212 ppm
```
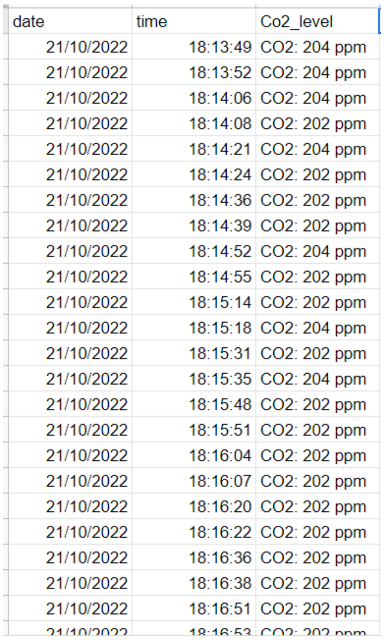

[IDE]



date	time	Co2_level
21/10/2022	18:13:49	CO2: 204 ppm
21/10/2022	18:13:52	CO2: 204 ppm
21/10/2022	18:14:06	CO2: 204 ppm
21/10/2022	18:14:08	CO2: 202 ppm
21/10/2022	18:14:21	CO2: 204 ppm
21/10/2022	18:14:24	CO2: 202 ppm
21/10/2022	18:14:36	CO2: 202 ppm
21/10/2022	18:14:39	CO2: 202 ppm
21/10/2022	18:14:52	CO2: 204 ppm
21/10/2022	18:14:55	CO2: 202 ppm
21/10/2022	18:15:14	CO2: 202 ppm
21/10/2022	18:15:18	CO2: 204 ppm
21/10/2022	18:15:31	CO2: 202 ppm
21/10/2022	18:15:35	CO2: 204 ppm
21/10/2022	18:15:48	CO2: 202 ppm
21/10/2022	18:15:51	CO2: 202 ppm
21/10/2022	18:16:04	CO2: 202 ppm
21/10/2022	18:16:07	CO2: 202 ppm
21/10/2022	18:16:20	CO2: 202 ppm
21/10/2022	18:16:22	CO2: 202 ppm
21/10/2022	18:16:36	CO2: 202 ppm
21/10/2022	18:16:38	CO2: 202 ppm
21/10/2022	18:16:51	CO2: 202 ppm

[Google sheet]

Figure 20: Results

6.3 Fan-setup Tests and results

The fan-setup test is more of a hardware test, who's aim is to determine the time it take for the system to clear out the CO2 levels in a room or enclosed space this is such that the created or simulated situation resembles the real world set up. This experiment would be to place the sensor in a controlled environment where it would be possible to introduce a change in that environment and would reflect on the reading i.e, later to introduce air from outside the controlled environment through the fans of the system and an opening left so that air can circulate through. Possible controlled environments would be a storage box

The most important variables to keep track of would be the triggers in the environment the time it takes for the fans to reduce the amount of co2 and how many fans were used. This information would be well recorded to an online google sheet. In case the esp board is not connected to the internet the system would still work accordingly only there would be no data sent to the Remote storage and display. This is more of a fail safe measure taken by the system. The Figure below is the setup of the experiment.

Picture A this is the front of the system the intake of the fans, B show the back of the system, the outlet/ outtake this is where the fans take in far from outside the room and sucks it in the test environment. D show the test environment for this test and a fire extinguisher that is used to introduce change in the environment

Figure: Setup

6.4 Circuity Test and result

The Circuity of the second and last version of the system requires a soldered circuit which if done incorrectly may result in a short this my lead to drawing of too much current and may damage the implementation. A simulated circuit was drawn and the implementation of that prevented any mistakes or wrong connection. In case if the CO2 sensor,any slight change in current and voltage provided to it will lead to incorrect readings.

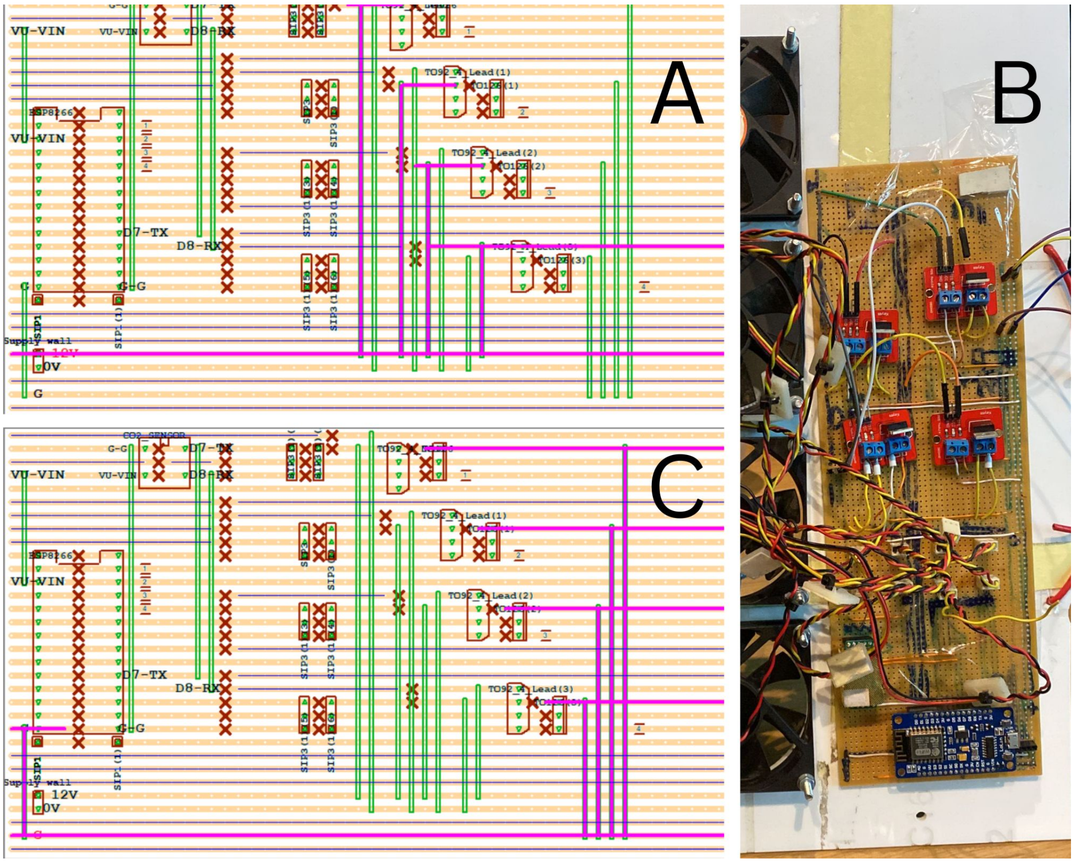


Figure: Vera board simulating and testing software and Result

6.5 System Test and Results

Four (8) participants were secured and safely put in the room and all windows and the door closed, this is to prevent fresh air from from outside this will result in the accumulation of carbon dioxide, of which without the system the carbon dioxide would become detrimental to the occupants health when not cleared out over extended periods. The system was switched on for the accumulation but the fans disabled to allow the accumulation. Once the carbon-dioxide levels reached 200ppm the fans were enabled and they kicked in below is the room and set up of the experiment lastly The fan setup.

Figure 21: Experiment classroom

Figure 22: Fan setup

The pass condition for this test would be when one realizes the desired trends on the data meaning the carbon dioxide level going down once the fans were activated. Below is are the results from the test.

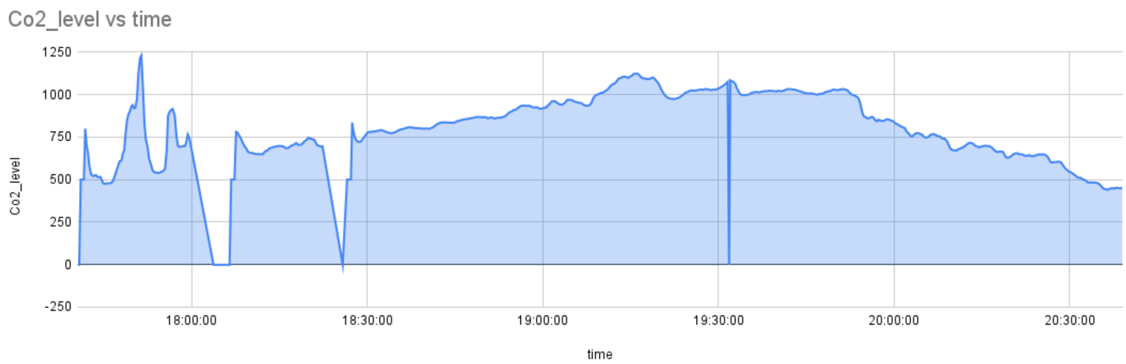


Figure 23: Results

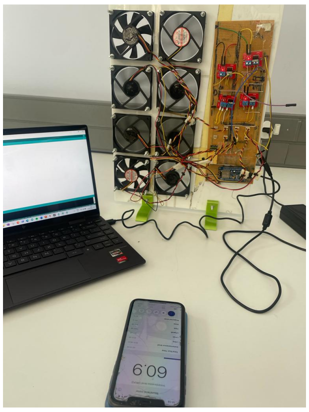
Below is the bill of materials used for the project specifically for the hardware implementation.

Bill of Materials.						
Order Date	Ordering Location	Common Name	Item Link	Price (R)	QTY	Total (R)
19/09/2022	Comminuca (Local)	HKD MQ135 GAS SENSOR MODULE	https://www.communica.co.za/products/hkd-mq135-gas-sensor-module?variant=39350912811081	50	2	100
19/09/2022	Comminuca (Local)	ARD UNO REV3	https://www.communica.co.za/products/ard-uno-rev3	370	1	370
19/09/2022	Comminuca (Local)	CMU LCD 16X2 - YELLOW BACKLIGHT	https://www.communica.co.za/products/cmu-lcd-16x2-yellow-backlight?variant=17567195562057	55	2	110
19/09/2022	Comminuca (Local)	RM-PSL10-101-1134	https://www.communica.co.za/products/rm-psl10-101-1134	264	1	264
19/09/2022	Comminuca (Local)	HKD SD CARD READ/WRITE MODULE	https://www.communica.co.za/products/hkd-sd-card-read-write-module?variant=39359979651145	25	2	50
26/09/2022	MicroRobotics	Relay 12V (2 Pack)	https://www.robotics.org.za/SLA-12VDC-SL-C	36	2	72
26/09/2022	MicroRobotics	DC Jack Power Jack Module, 2.1 /5.5mm	https://www.robotics.org.za/DC-2155?search=12v%20power	8	5	40
26/09/2022	MicroRobotics	AC Adapter 12V 5A - 2155 Standard	https://www.robotics.org.za/AC-12V5A-2155?search=12v%20power	180	1	180
26/09/2022	MicroRobotics	DC Power Splitter 2.1/5.5mm	https://www.robotics.org.za/SPLIT-2155	13	5	65
18/09/2022	Ali express	NDIR CO2 SENSOR	https://m.aliexpress.com/item/1005001840934833.html?spm=a2g0n.productlist.0.0.76d0PogmPogmQl&browser_id=974e21c7d06543e3858b551aacf4165a&aff_trace_key=&aff_platform=msite&m_page_id=elcvg2l16xscawnp18355c75db510f557b4e114446&gclid=&pdp_npi=2%40dis%21ZAR%21411.06%21370.01%21%21%2190.92%21%21%4021031a55166359148483437 24eac78%2112000017815114067%21sea&curPageLogUid=3fblm3P2Tfwq&algo_pvid=e394221e-7b7d-478d-8c7a-ef242b0977b6	350	1	350
18/10/2022	White lab	veroboard	n/a	80	1	80
					sum	1681

Figure 24: BOM

6.6 System Noise Test and Results

This test is conducted to verify that the system is not posing as a noise hazard to its users. The experiment is setup such that the fans are fully operational all eight of the fans. A noise measurement software is used to measure the noise from the fans starting from about 1 meters away from the fans up to 5 meters away from the fans. This movement is dope in a linear pattern. Results from the experiment are presented below the set of results obtained from the experiment executed above. The experiment lasted for a duration of 11 minutes..

[Test 1] 

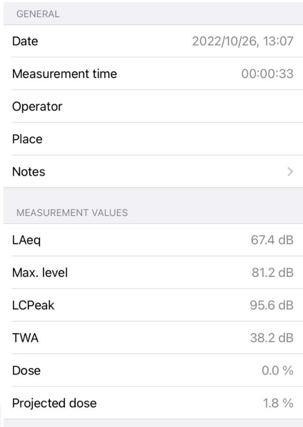
[Test 2] 

Figure 25: Noise test setup and Results

7 Discussion

Results are discussed in this portion of the report together with their relevance to the theory and literature review in subsequent from prior sections

7.1 Sensor Results discussion

The sensor results prove to be logically correct as it is know that in open and out door environments the sensor should read between 400 and 500 ppm as this is shown by previous research to be the normal atmospheric levels of CO2 concentration. Breathing directly on the sensor, it should read over 1000 and up to 3000 ppm this is a logical test to perform since Inhaled air has about 0.04 percent of carbon dioxide. This is also the amount of carbon dioxide present in the atmosphere. The exhaled air contains all the carbon dioxide that is a by- product of the cellular metabolic processes. Hence, the percentage of carbon dioxide 57 in the exhaled air is 4.4 percent.The sensor is very sensitive to nearby sources of CO2. From the activities that were performed during each phase of the results the theory corresponds to the obtained results.

7.1.1 Associated ATP: ATP3

ATP3 is the calibration of the carbon dioxide sensor which must be done correctly if needed. Otherwise, the offset must be compensated for having a zero reference for the carbon dioxide concentration of 450 ppm. The MH-Z19C module has two methods for zero point calibration, hand-operated method and self-calibration. All the zero point is at 400ppm CO2.Hand-operated method is done by connecting the module's HD pin to low level(0V), lasting for 7 seconds at least. Before calibrating the zero point, the sensor needs to be stable for more than 20 minutes at 400ppm ambient environment. For the target system the zero point calibration is manually done by compensating for the 400ppm. Otherwise the sensor comes well calibrated.

7.2 Remote Storage Results discussion

The serial monitor is the 'tether' between the computer and the micro controller it allows the sending and receiving of text messages, handy for debugging and also controlling the Arduino from a keyboard it is the transmission highway from the Arduino and the computer's USB port Which can be accessed through, simply clicking the Serial Monitor icon. The icon is located to the right of the other icons in Arduino or going to tool and scrolling down to Serial Monitor.

The other option is to press on "ctrl+shift+M".Serial monitor comes with any and all version of the Arduino IDE. Once The IDE and Serial Monitor is operational a comparison of the data that is sent to the google sheet is also collected, when comparing the results there are corresponding numbers on either side of the communication channel the Serial monitor and the google sheet this clearly verifies the display module to be working as expected and not producing false results.

7.2.1 Associated ATP: ATP5

The this is s software concentrated test procedure which test for the communication of the micro-controller with the deployed web-app google sheet which acts both as the Remote Storage and Remote display a better version of the solution as it has dual functionality. The pass condition is when the Serial monitor show the same data being sent from the CO2 sensor readings to the google sheet. The fail condition would be when there is no data being sent over the WiFi or data in an incorrect format is being sent. This test procedure passed ATP5

7.3 Fan-setup Results discussion

The most important variables to keep track of would be the triggers in the environment the time it takes for the fans to reduce the amount of co2 and how many fans were used. This information would be well recorded to an online google sheet. In case the esp board is not connected to the internet the system would still work accordingly only there would be no data sent to the Remote storage and display. This is more of a fail safe measure taken by the system. The table in the Appendix 'sample data' clearly show all the important variable. This the test prove the theory to be correct.

7.3.1 Associated ATP: ATP6

ATP6 is the creation of a test environment for the entire system. Using a fire extinguisher to simulate a real-world scenario. the pass condition would be to observe a decrease in CO2 as soon as the fans are triggered. In case of an increase in C02 levels the system would respond by increasing the amount of fans operational in a linear manner for 2,4,6,8 fans based on the thresholds stated above.

7.4 Circuity Results discussion

Any shorts in the final circuit will result in a In the collapse of the entire system. The pass condition will be an entirely working system that successfully operates as desired. The system shows to be a fully intelligent and operational system from the tests conducted above.

7.4.1 Associated ATP: ATP1

ATP1 the soldering of the circuit must be done carefully such that there are no shorts or disconnects lines in the Vera board. This will result in a In the collapse of the entire system. The pass condition will be an entirely working system that successfully operates as desired

7.5 System Results discussion

The overall system is a smart ventilation system that operate to reduce or counter effect the amount of carbon dioxide in an enclosed classroom, based on the signal from a the carbon dioxide sensor. The system test is set up as follows. A UCT classroom was identified with poor to no ventilation measures. Below is an example of one classroom with a ventilation measures.

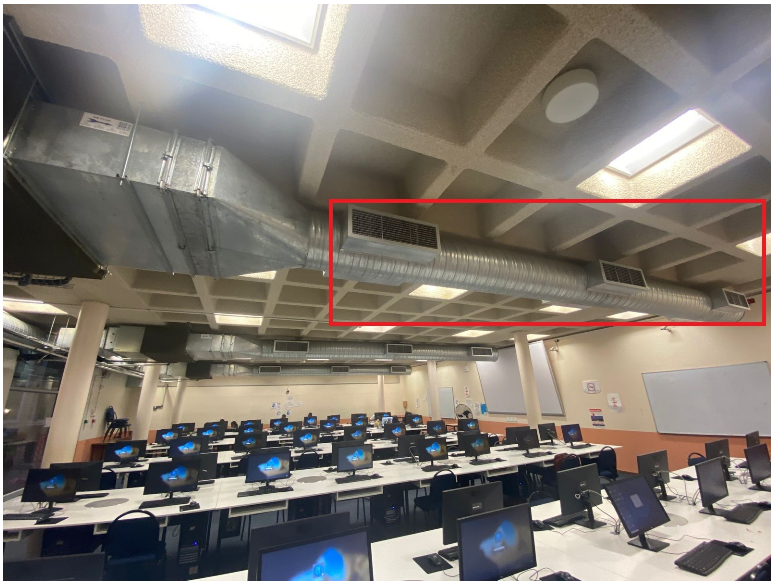


Figure 26: Classroom/Lab with a ventilation measure

The purpose of this experiment is to test if the system operates as required, The identified room below is where the test was dope. The procedure was to collect as much people to participate in the experiment where they will be the source of carbon dioxide

7.5.1 Associated ATP: ATP1,4 and 6

The soldering of the circuit must be done carefully such that there are no shorts of dissected lines in the Veroboard. Creation of a test environment for the entire system. Using a fire extinguisher to simulate a realworld scenario. This test passes both ATP1 and ATP6 since test1 is the real world example of test2.ATP4 A bill of materials used in the project will be made and the corresponding prices of the parts ordered will be collected,If the overall cost if below R700 that will be a pass. ATP 4 failed due to costing over the set limit.

7.6 System Noise Results discussion

For occupational hygiene reasons, the noise level is used to determine the noise exposures of works and people who occupy that particular building. The technique of measuring noise in the work place is for reducing high exposure to noise. but not all noises are problematic for example in a quite room there is still noise present but it is not hazardous or problematic to occupants. The average ambient noise in any quite room is about 40-50dB. Below are example of hazardous noise levels:

- Noise is louder than busy city traffic.
- People have to raise their voice to talk to someone at one metre (3 feet) away
- At the end of work shift people have to increase the volume of their radio or TV to a level too loud for others.
- People hear a ringing or humming noise when they leave work
- After working for a few years at that workplace, employees find it difficult to communicate in a crowd or party situation where there are other sounds or many voices.

7.6.1 Associated ATP: ATP7

Measuring the noise levels for the entire duration of operation of the system to test for the amount of noise from the system. The pass condition for this test is that for the system to produce noise level below 80db and the fail condition is noise levels above 80db. This is due to the fact that the this system will be deployed in learning environments such as local schools. external noise can be a distraction to the learners if not controlled. From the results the system clearly never reach 80db. This test is a success.

8 Conclusion and future recommendations

8.1 Conclusion

The realized capability of intelligent ventilation systems using E-waste for airborne diseases is presented not only in theory and design but also tested, from the first version of the system to the second version. The research's goal was to determine whether a small, compact, and cost-effective design could be realized to solve the ventilation problem. If solved correctly will reduce the negative health impacts on occupants and improve indoor air quality. It is safe to conclude that the system works as desired, drawing from the tests and Results.

A detailed design methodology was followed before the implementation of the system, which resulted in the first version of the system, whose Implementation was tested and improved to the second version. A deep and intensive study of previous work and research that have been done across the globe was done in support of the design and implementation presented in the literature review. The ordering of the shelf components due to time constraints, which components were done locally and cost-effectively. The aim was to go for the was successful. The long phase of verifying and testing for user and functional requirements was performed accordingly and is well elaborated under the Tests and Results section of the report. Finally, a fully automatic ventilation system is realized that uses electronic waste, specifically old computer fans, to meet the ventilation requirement in poorly ventilated classrooms

8.2 Project Limitations

From the beginning to the end of the project, a few issues or challenges arose and were handled most appropriately; as in any engineering project, challenges and setbacks do arise, but with an excellent strategy, they can be mitigated. The first and biggest challenge was the time constraint of approximately three months to complete and deliver the project; this constraint is managed by proper planning, and online tools are helpful in such conditions. The aim of building a cost-effective system somehow limits the spending on a project, as it did for this project. This issue of a limited budget inhabits the use of high-quality components and build of costly solutions, of which, in this case, an expensive solution would contradict most of the use cases of the project. One most significant challenges associated with the two above main issues showed itself by failure to secure an LCD as initially planned for the system, which was mitigated by using WiFi capabilities to display real-time data.

One of the intended and primary use cases of the project is the deployment of the intelligent ventilating system in classrooms from local schools; the targeted schools would be low-income schools where the school is, in most cases, underfunded and has little to no resources, ranging from teaching material to WiFi or connectivity within the premises. This is a huge factor or limitation in the design. Since the system sends real-time data to a google sheet, this functionality once is active in such environments, but it would be able to work as usual.

8.3 Future Work

It is only logical to imagine a distributed version of the current system; this new system would be the 3rd version in the spiral rations which would come at a higher cost but more efficiency. This system will be implemented the same as the current one. The new improvement would be to introduce a Lora module that would transmit data to the central unit that acts as a master; each deployment would have five enslaved people distributed across the classroom and one slaver that controls the fans on each enslaved person separately based on the control signals from the respective enslaved person. This solution is much more efficient than the current one as it evens the workload of the overall system and shares it with the enslaved people. The CO2 sensors become more sensitive to closer Co2 sources, of which the 3rd version would achieve closer and all-around distances of the designated or targeted classroom.

The second Improvement of the system would be the 4th version of the spiral rotation; this would have all the discussed improvements thus far, with an additional feature such that the system is set up to use any sensor or any sensor. This new implantation would be to set the system not to explicitly measure CO2 only but a bunch of other gases, meaning the system can sense other toxic gases in addition to CO2; this is useful in mining environments, Urban or indoor farming

9 References

[1] title=The health of southern Africa, author=De Haan, Merle and Dennill, Kathleen and Vasuthevan, Sharon, year=2005, publisher=Juta and Company Ltd

[2] title=Indoor CO2: Potential criticalities and solutions, author=Schiavon, Marco and Adami, Luca and Magaril, Elena and Ragazzi, Marco, year=2019, publisher=EDP Sciences

[3] title=Measuring ventilation and modelling M. tuberculosis transmission in indoor congregate settings, rural KwaZulu-Natal, author=Taylor, JG and Yates, TA and Mthethwa, M and Tanser, F and Abubakar, I and Altamirano, H, journal=The International Journal of Tuberculosis and Lung Disease, volume=20, number=9, pages=1155–1161, year=2016, publisher=International Union Against Tuberculosis and Lung Disease

[4] title=A study of CO2 influence on student activity in classroom/Studiul influ-

entei continutului de CO2 asupra activitatii studentilor în scoli, author=Pacurar, Cristian and Cernazanu, Cosmin, journal=Revista Romana de Inginerie Civila, volume=4, number=2, pages=81, year=2013, publisher=Matrix Rom

[5] title=Investigation of indoor environment quality in classroom-case study, author=Vilčeková, Silvia and Kapalo, Peter and Mečiarová, L'udmila and Burdová, Eva Krídlová and Imreczeová, Veronika, journal=Procedia engineering, volume=190, pages=496–503, year=2017, publisher=Elsevier

[6] title=The effect of natural ventilation on the indoor air quality in classroom of the el-ementary school without heating equipments during winter season, author=Iwashita, G and Yoshino, H, year=2007

[7] title=CO2 monitoring to assess ventilation rate: practical suggestions from a laboratory study, author=Zhang, Dadi and Bluyssen, Philomena M, booktitle=CLIMA 2022 conference, year=2022

10 Appendix

date	time (SAST)	Co2level (ppm)	1st set of fans	2nd set of fans	3rd set of fans	4th set of fans
01/11/2022	17:40:34	-1	OF	OFF	OFF	OF
01/11/2022	17:40:49	-1	OF	OF	OFF	OF
01/11/2022	17:41:05	500	ON	OF	OFF	ON
01/11/2022	17:41:20	500	ON	OF	OFF	ON
01/11/2022	17:41:37	500	ON	OF	OFF	ON
01/11/2022	17:41:51	800	ON	OF	OFF	ON
01/11/2022	17:42:05	702	ON	OF	OFF	ON
01/11/2022	17:42:19	659	ON	OF	OFF	ON
01/11/2022	17:42:33	581	ON	OF	OFF	ON
01/11/2022	17:42:50	533	ON	OF	OFF	ON
01/11/2022	17:43:10	521	ON	OF	OFF	ON
01/11/2022	17:43:24	524	ON	OF	OFF	ON
01/11/2022	17:43:42	526	ON	OF	OFF	ON
01/11/2022	17:43:55	516	ON	OF	OFF	ON
01/11/2022	17:44:09	515	ON	OF	OFF	ON
01/11/2022	17:44:26	516	ON	OF	OFF	ON
01/11/2022	17:44:43	495	ON	OF	OFF	ON

Table 17: Sample Data