



# Unified Monitoring System For Air Quality In Urban Ecosystems

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**Abstract:** The rise in transportation, population density, global warming, and abrupt climate changes has made air quality a critical parameter for monitoring in today's urban ecosystems. This paper explores the challenges, infrastructure, and methodologies for developing and deploying an integrated system for real-time air quality monitoring in both indoor and outdoor environments. The proposed system measures concentrations of gases such as carbon monoxide (CO) and carbon dioxide (CO<sub>2</sub>), along with temperature and humidity, to provide comprehensive air quality alerts. Experimental validations demonstrate the system's efficiency in real-time monitoring and alert generation

**Index Terms** - Real-time, Urban ecosystems, Indoor and outdoor monitoring, Gases, Air quality alerts

## 1. INTRODUCTION

Air pollution is a critical global concern, with studies indicating that 50,000 to 100,000 premature deaths occur annually in the United States alone due to air quality issues. In the European Union, this figure reaches 300,000, and globally, over 3 million people succumb to the effects of polluted air each year. The Internet of Things (IoT) has emerged as a transformative solution for monitoring air quality by enabling the detection of pollutants such as carbon dioxide (CO<sub>2</sub>), smoke, alcohol, benzene, ammonia (NH<sub>3</sub>), liquefied petroleum gas (LPG), and nitrogen oxides (NO<sub>x</sub>). IoT systems provide real-time data displayed in parts per million (PPM) on both LCD screens and web platforms, ensuring accessibility and ease of use. A notable feature of such systems is the inclusion of LPG sensors, which are particularly suited for domestic applications. These systems are versatile and can be installed in both commercial and residential areas where gas detection is crucial. Alerts are triggered when pollution levels exceed safe thresholds, ensuring timely intervention. Recent advancements in smart sensor networks and wireless technologies have enhanced the capacity to monitor pollutants like carbon monoxide (CO), nitrogen dioxide (NO<sub>2</sub>), and sulfur dioxide (SO<sub>2</sub>). These systems often rely on microcontrollers and network-enabled processors for data acquisition and analysis, transmitting the information to centralized servers for further processing. Wireless sensor networks and pollution detection systems have been deployed to monitor organic compounds in biological and industrial environments. For instance, a network comprising 24 sensors and 10 routers has been implemented to provide pollution alerts based on site-specific conditions. High-definition surveillance cameras further enhance monitoring capabilities by integrating visual data with pollutant detection. Pollution is a significant factor affecting quality of life, health, and the environment. Emissions from vehicles, industrial activities, and natural events such as volcanic eruptions and wildfires contribute significantly to air pollution, leading to health risks like cancer, asthma, and premature death. Additionally, industrial operations release pollutants, causing temperature increases and global warming. Noise and other industrial byproducts further exacerbate environmental degradation. To address these issues, IoT-based pollution monitoring systems have proven to be cost-effective and efficient. By leveraging GSM technology and sensors integrated with Arduino Uno, these systems monitor and transmit real-time data on pollutants, temperature, and other environmental factors. This enables authorities to assess pollution levels, make informed decisions, and, if necessary, deactivate polluting energy sources to control

emissions. Globally, many countries have established frameworks and standards to combat air pollution. For example, the United States Environmental Protection Agency (US EPA) enforces National Ambient Air Quality Standards (NAAQS) for six major pollutants and uses the Air Quality Index (AQI) to measure air quality and safeguard public health. However, industrialization and urbanization continue to exacerbate air quality challenges, particularly in cities like Beijing and Delhi, where residents are often compelled to wear masks and limit outdoor activities due to hazardous conditions. The integration of IoT and smart sensor networks provides a promising pathway to monitor, manage, and mitigate air pollution, ensuring a healthier and more sustainable future.

## 2 Processes and Materials

The rapid growth of industries in today's economy has significantly increased carbon dioxide emissions, contributing to global warming, ozone layer depletion, and adverse effects on human health. Current pollution monitoring systems, which rely heavily on manual labor, are often inefficient and prone to oversight. Pollution from various industries, such as paper and cement, is escalating, with the cement industry being particularly hazardous to air and water quality. This proposed system leverages IoT technology to address these challenges. By integrating IoT, the system monitors pollution levels and triggers alarms if thresholds are exceeded, ensuring timely interventions. This approach promotes environmental sustainability and enhances agricultural productivity by encouraging eco-friendly practices. The system is built upon components such as the MQ-2 CO sensor, ESP32 controller, 16x2 LCD, buzzer, Arduino ATmega328P microcontroller, DHT11 sensor, and MQ series CO2 sensor, forming a robust foundation for energy and pollution monitoring.

### 2.1 Components and Integration

#### 2.1.1 MQ-2CO Sensor

The MQ-2 CO sensor is a critical component for detecting carbon monoxide (CO) in various environments. It operates by sensing changes in conductivity caused by CO gas interactions, converting these changes into electrical signals that are processed by a microcontroller. Known for its high sensitivity, compact size, affordability, and ease of integration, this sensor is ideal for applications in industrial facilities, households with gas appliances, and vehicles. Using a tin dioxide (SnO<sub>2</sub>) semiconductor, the sensor facilitates accurate CO level monitoring and real-time analysis when integrated with microcontrollers.

#### 2.1.2 ESP32 Controller

The ESP32 controller is a versatile and high-performance microcontroller, equipped with dual-core processors, built-in Wi-Fi, and Bluetooth capabilities. It serves as the system's central hub, enabling seamless communication between sensors, peripherals, and cloud services. Its rich hardware features, including GPIO pins and ADCs, allow flexible interaction with various devices, making it a preferred choice for IoT applications. The controller efficiently manages power consumption and data transfer while ensuring reliable connectivity.

#### 2.1.3 16x2 LCD

The 16x2 LCD is a user-friendly display module that provides real-time visual feedback on system parameters such as temperature, humidity, CO levels, and CO<sub>2</sub> concentration. Using liquid crystal technology, it displays alphanumeric data and simple graphics. Its integration involves connecting the LCD to the microcontroller via GPIO pins and optimizing algorithms to reduce power consumption without compromising readability.

#### 2.1.4 Buzzer

The buzzer enhances the system by providing audio alerts for abnormal conditions, such as exceeding pollution thresholds. It generates sound by vibrating a diaphragm in response to electrical current and can be configured using GPIO pins for specific sound patterns or frequencies. Pulse width modulation (PWM) technology enables control over the intensity and duration of the sound, ensuring adaptability to various environments.

#### 2.1.5 Arduino ATmega328P Microcontroller

The Arduino ATmega328P is a widely used microcontroller platform for embedded systems and IoT applications. It balances computing power and processing efficiency, supporting a range of sensors and actuators. The Arduino ecosystem, with its IDE and extensive libraries, simplifies prototyping and accelerates development. Integration involves coding the microcontroller to initialize sensor modules, collect data, and

perform preprocessing for analysis and decision-making.

### 2.1.6 DHT11 Sensor

The DHT11 sensor combines a capacitive humidity sensor and a thermistor for temperature measurement, offering accurate readings with low power consumption. Its simple digital interface makes it suitable for battery-powered and resource-limited applications. This sensor is widely used in environmental monitoring and weather forecasting due to its reliability and efficiency.

### 2.1.7 MQ Series CO2 Sensor

The MQ series CO2 sensor is designed to detect carbon dioxide concentrations, ensuring optimal air quality in indoor and outdoor environments. Using a semiconductor-based sensitive element, it measures CO2 levels and provides data for ventilation control and air monitoring. Integration involves establishing UART or I2C communication with the microcontroller, enabling real-time CO2 analysis for proactive health and environmental interventions.

## 2.2 Supporting Technologies

### 2.2.1 Arduino Software (IDE)

The Arduino IDE is an open-source platform for programming Arduino microcontrollers. It simplifies development with a user-friendly interface, libraries, and a streamlined workflow for writing and uploading code. Designed for beginners and experienced developers, it facilitates hardware interaction and rapid prototyping.

### 2.2.2 Embedded C Language

Embedded C is tailored for resource-efficient programming of embedded systems. It extends the standard C language with features optimized for microcontrollers, enabling direct hardware interaction through bitwise operations and memory management. Embedded C is instrumental in developing robust, high-performance software for IoT and embedded applications.

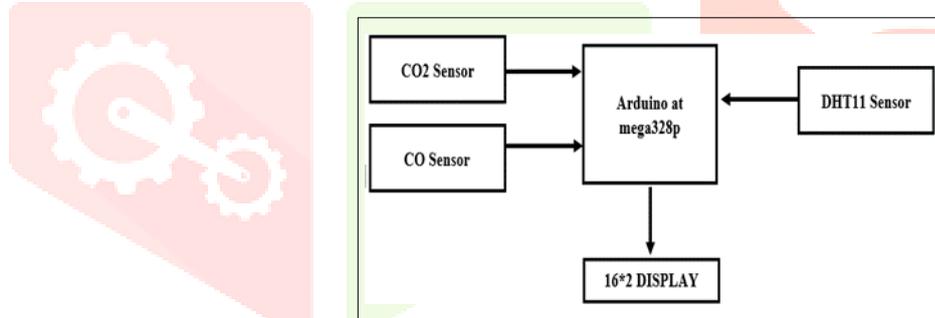


Figure 2.1 Block diagram of Air Quality Sensing and Monitoring

## 3. METHODOLOGY

The proposed methodology focuses on establishing a robust air quality measurement and monitoring system using sensors such as the MQ2 for CO and CO2 detection, and the DHT11 for temperature and humidity measurements. The project begins with a comprehensive understanding of the sensor characteristics, including operational modes, sensitivity, and data feedback mechanisms

Table 3.1 The Design specification

S/N	Components Required	Quantity
1	MQ2 (CO & CO2) sensor	2
2	(16x2) LCD Display	1
3	PCB	1
4	RMC	1
5	Arduino-uno Atmega328	1
6	DHT11 Sensor	1
7	Voltage Regulators	1
8	Buzzer	1
9	Node-mcu esp8266	1

### 3.1.Key Steps in the Methodology

- 3.1.1 **Sensor Calibration:** Calibration is a critical step to ensure accurate readings. Sensors are exposed to known concentrations of target gases or controlled ambient conditions, and their responses are adjusted accordingly to facilitate reliable data interpretation.
- 3.1.2 **Hardware Integration:** Sensors are integrated with a microcontroller platform, such as Arduino, which serves as the processing unit. This involves setting up hardware connections and configuring the system for optimal functionality.
- 3.1.3 **Data Collection:** Data is collected continuously, with readings taken at regular intervals. Real-time monitoring features enable rapid feedback on adverse environmental conditions, enhancing responsiveness to air quality issues.
- 3.1.4 **Data Processing and Analysis:** Raw data is processed to convert sensor readings into meaningful metrics, such as temperature, humidity, and pollutant concentrations in parts per million (ppm). Statistical analysis identifies trends, patterns, and anomalies in the data, enabling a deeper understanding of air quality variations.
- 3.1.5 **IoT Integration:** Incorporating IoT technology allows for real-time remote access to data. This feature facilitates automatic notifications, alerts, and report generation, providing actionable insights to users or authorities.
- 3.1.6 **System Maintenance:** Regular inspections, sensor recalibration, and hardware maintenance are performed to prevent sensor drift or degradation, ensuring the system's reliability over time.

This comprehensive methodology covers all aspects, from understanding and calibration to data acquisition, analysis, visualization, and system upkeep. It ensures effective and reliable monitoring, making it a valuable tool in analysing and addressing air quality challenges

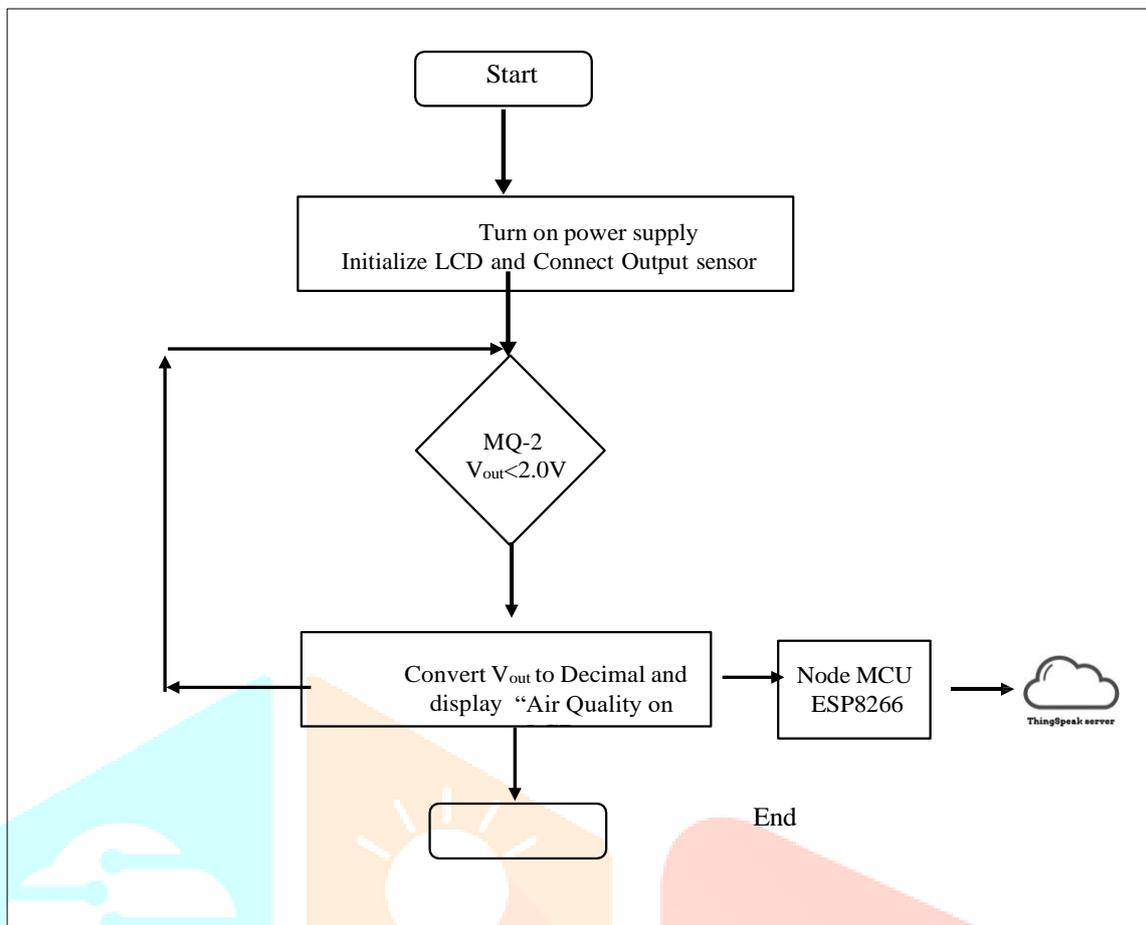


Figure 3. 1 Flow-chart of the proposed system

#### 4. Results and Discussion

The integration of MQ-2 CO sensors, buzzers, DHT11 sensors, and MQ Series CO<sub>2</sub> sensors into air quality and monitoring projects enhances environmental awareness by providing real-time data on air quality. The MQ-2 CO sensor is particularly effective at detecting carbon monoxide (CO), a colorless, odorless gas that poses significant health risks, especially in high concentrations. This sensor helps to identify variations in the environment, particularly in areas with high traffic and industrial activity, where CO<sub>2</sub> levels tend to be elevated. The presence of a buzzer in the system provides an audible alert when carbon dioxide levels surpass a set threshold, notifying individuals of potential air quality concerns. The system serves as an awareness tool, urging public measures to combat air pollution. By incorporating multiple sensors and microcontrollers, it enables comprehensive data collection and analysis, which can inform effective air quality management strategies. The main objective of the research is to enhance the capacity to measure and monitor key air quality parameters such as carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), temperature, and humidity. The integration of MQ-2, MQ Series CO<sub>2</sub>, and DHT11 sensors, along with the Arduino ATmega328P microcontroller, ESP32 controller, 16x2 LCD, and buzzer, allows for real-time indoor air quality monitoring.

The system performs efficiently in detecting various pollutants and maintaining a safe indoor environment. By continuously monitoring CO and CO<sub>2</sub> levels, the system helps protect against harmful exposure to these gases. Additionally, the inclusion of temperature and humidity sensors adds to the overall functionality, providing a holistic assessment of indoor air quality and ensuring a safer living environment. As shown in Figure 4.1 to 4.10

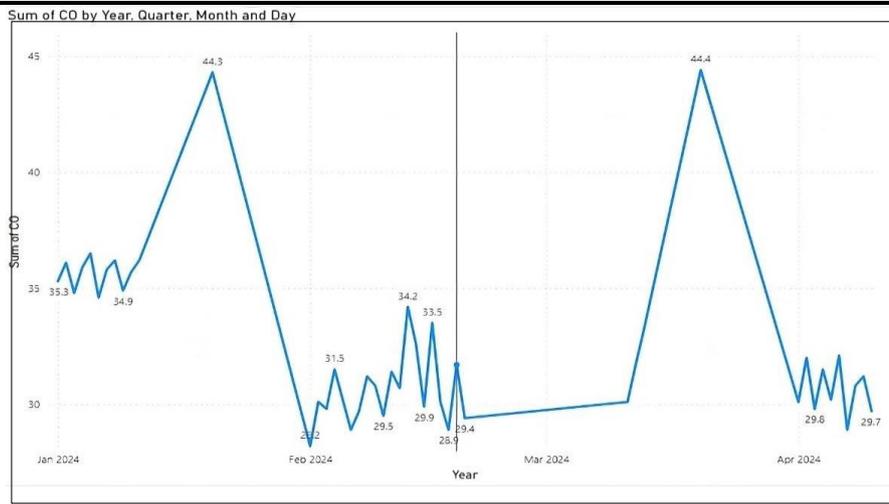


Figure 4.1 Year-Monthly range of CO

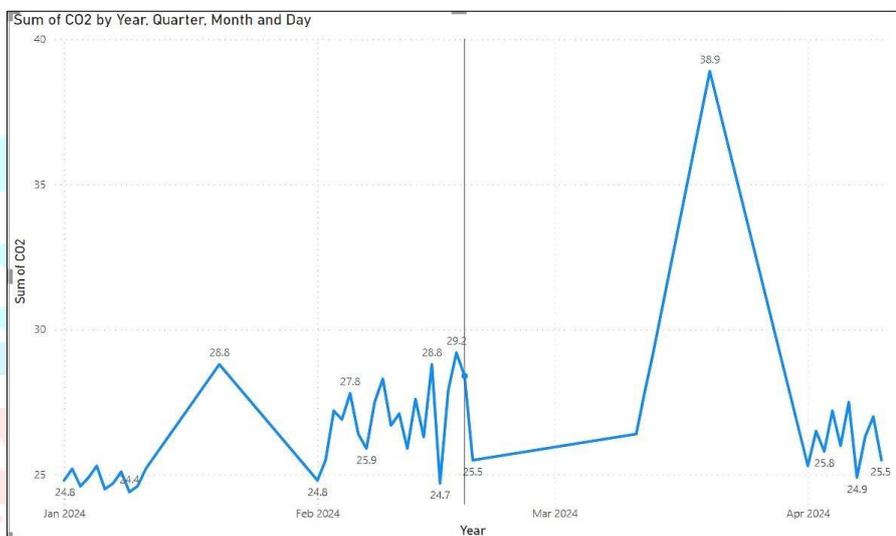


Figure 4.2 Year-Monthly range of CO2

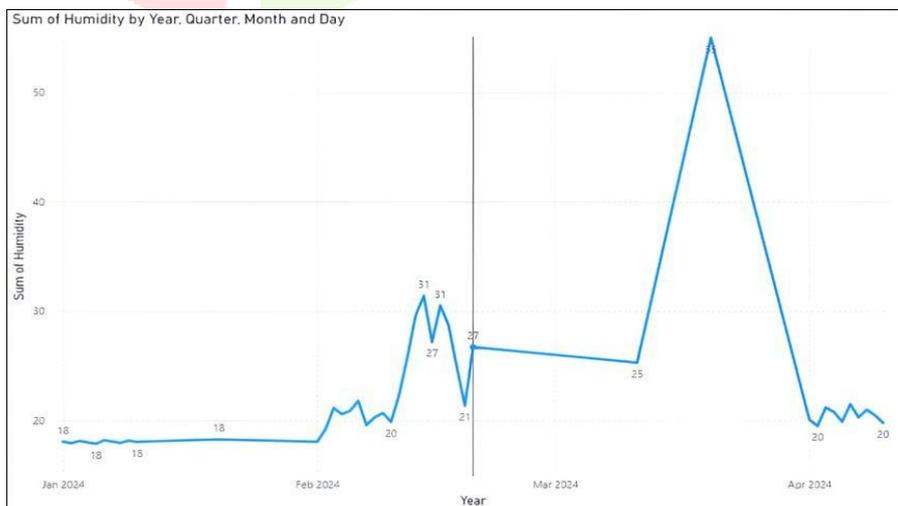


Figure 4.3 Year-Monthly range of Humidity

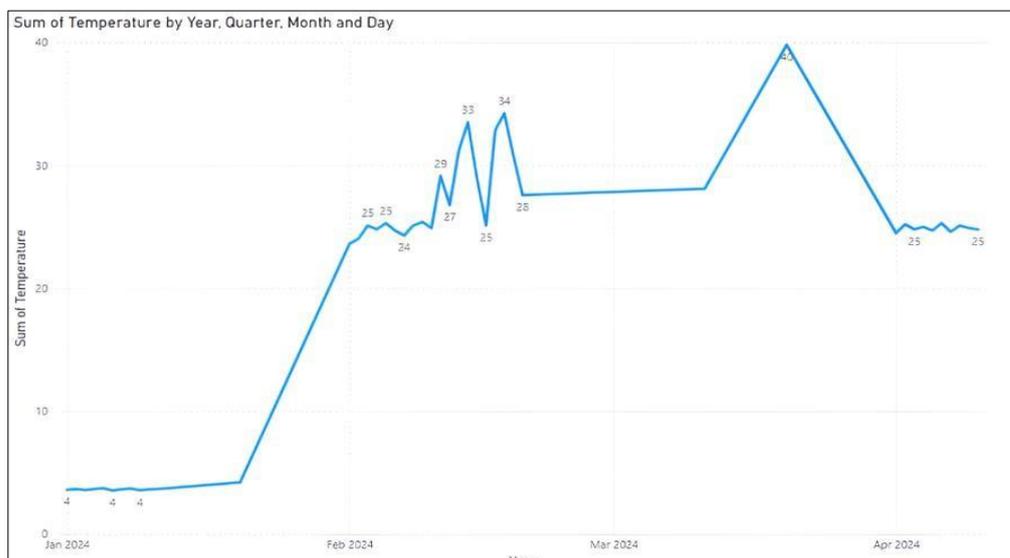


Figure 4.4 Year-Monthly range of Temperature

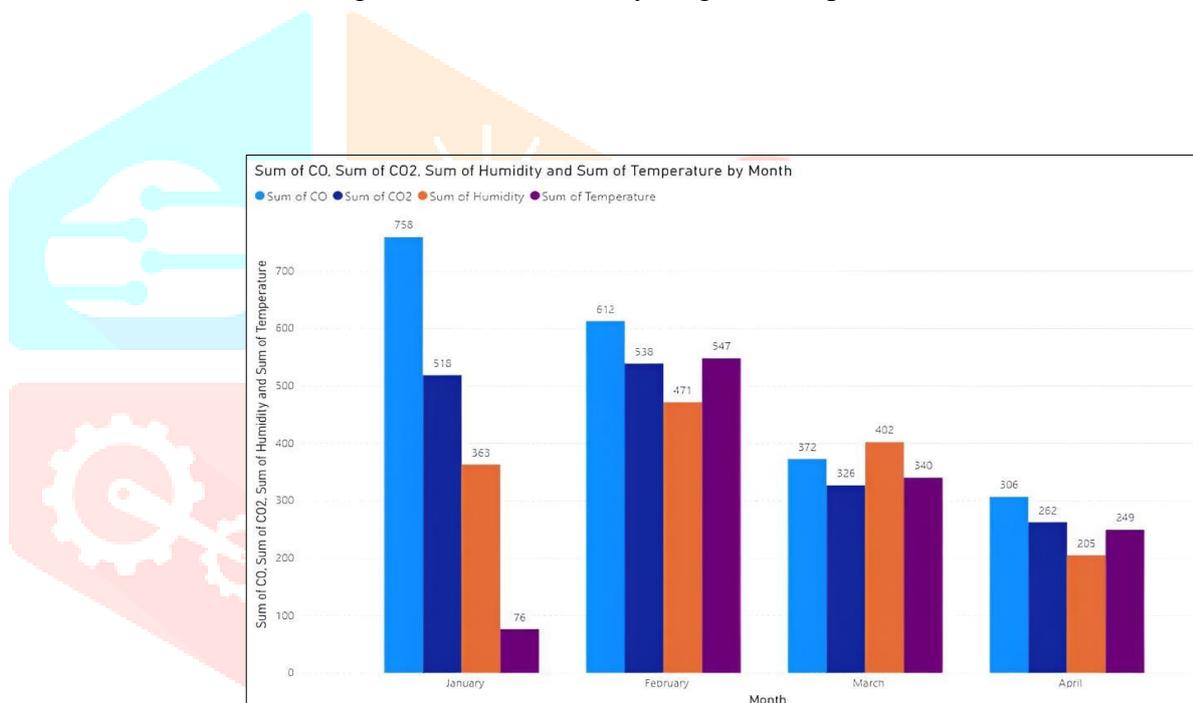


Figure 4.5 :Sum of CO,CO2, Humidity, Temperature

Displaying real-time data on the LCD screen provides users with an intuitive and accessible way to monitor indoor air quality levels. The clear and understandable display ensures that vital information is readily available, enabling timely interventions to improve air quality when needed. The addition of a voice warning further enhances user safety by increasing the warning time in adverse conditions, allowing users more time to react before taking corrective action.

In situations that require immediate attention, such as when CO2 levels reach dangerous thresholds, the buzzer acts as a critical alert mechanism, prompting users to take necessary actions to mitigate risks. The strong and efficient power of the buzzer makes it suitable for use across a wide range of environments, including residential, commercial, and industrial spaces. Unlike traditional air quality monitors, which can be costly and cumbersome to install, the system offers an affordable, easy-to-use solution for continuous indoor air quality monitoring.

The design, along with the wireless connection capabilities of the ESP32 controller, allows for seamless integration into existing systems, making it accessible to many users. Furthermore, remote control functionality ensures that the system can be monitored and managed from a distance. Data is analyzed and displayed in the form of graphs or charts, providing users with visual insights into air quality trends. These graphs are also tied to weather conditions, adding an additional layer of context for better understanding and action planning

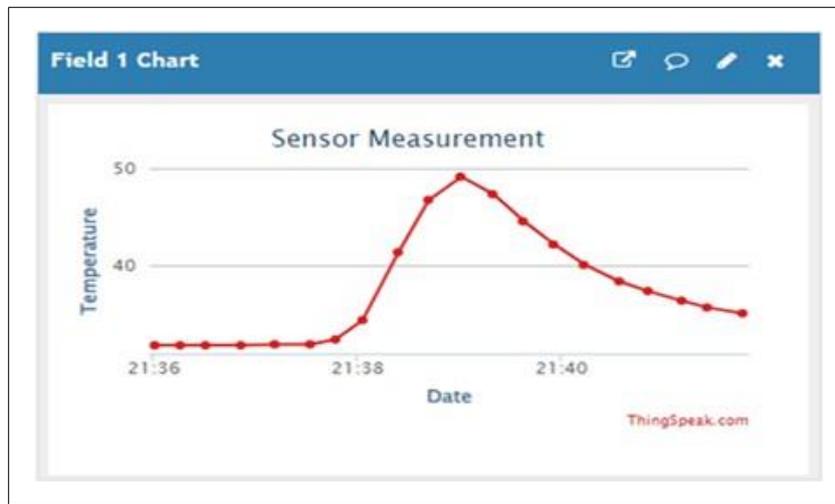


Figure 4.6 Air quality measurement as seen online of Temperature



Figure 4.7 :Air quality measurement as seen online of Humidity



Figure 4.8 Air quality measurement as seen online of CO2



Figure 4.9 Air quality measurement as seen online of CO

The potential applications of our air quality measurement and monitoring systems are broad and impactful across various sectors. The system can significantly enhance the quality of life for homeowners by providing a way to monitor pollution levels in residential areas and make adjustments to ventilation systems when necessary. In business and industrial settings, the system contributes to improving workplace safety and productivity by identifying harmful indoor air pollutants and helping reduce exposure to them. Additionally, the data collected from the system can be a valuable resource for policymakers, environmental organizations, and governments. It provides actionable insights that can inform the development of expanded climate protection and environmental management strategies. By helping authorities identify pollution hotspots and track environmental trends, this system aids in the creation of targeted response plans and policies designed to improve overall air quality.

The system comprises various components such as the MQ sensor, DHT11 sensor, ESP32 controller, LCD screen, buzzer, and Arduino ATmega328P microcontroller. Its ability to detect multiple types of pollutants and environmental contaminants makes it an effective tool for monitoring indoor air quality and ensuring a healthier environment. Future developments will focus on integrating the system with cloud-based platforms, enabling remote monitoring and advanced data analysis. This will also optimize the system for more specific applications, further increasing its versatility and accessibility.

Overall, our research and system contribute significantly to the advancement of air quality monitoring technology. With its potential to solve environmental issues associated with air pollution, it offers an affordable, effective solution that can be deployed across various industries and geographical locations. By continuously monitoring air quality and displaying real-time data, users can make more informed decisions about air quality management and take timely action when necessary.

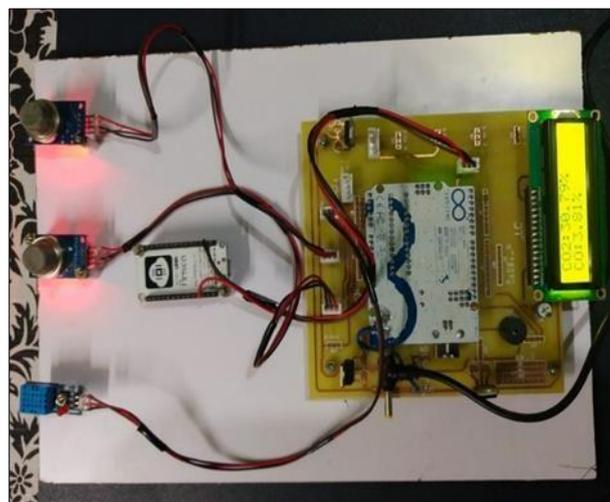


Figure 4.10 Prototype of our project

## 5.CONCLUSION

The integration of diverse products and processes is foundational to effective environmental care. By harnessing the unique capabilities of various technologies, scientists and experts can develop solutions that reduce environmental harm, protect public health, and enhance safety across numerous sectors. Embedded systems, specifically through the use of specialized programming languages like Embedded C, play a crucial role in this process. Embedded C programming is particularly valuable due to its focus on resource efficiency, fast processing, and low-cost interoperability, making it an essential tool for developers creating a wide range of applications, including automotive systems, electronics, business automation, and IoT devices. Mastering Embedded C allows developers to fully leverage the potential of embedded systems, resulting in the creation of powerful, reliable, and high-performance solutions. In the context of air quality monitoring, the integration of sensors, microcontrollers, and software contributes significantly to environmental protection. By utilizing such technology, we can ensure better air quality management and foster healthier environments for all.

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