# IoT System for Indoor Air Quality Monitoring Using ThingSpeak: Promoting Healthy Work Environments

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***Abstract*— This article presents the development of an embedded system for air quality monitoring in enclosed environments, utilizing the ESP8266 microcontroller and the Arduino® IDE. The system integrates DHT11 and MQ-4 sensors to measure temperature, humidity, and $CO_2$ concentration, respectively. The collected data is displayed on an LCD screen and stored on a 4GB microSD card in Comma-Separated Values (CSV) format, ensuring easy access for further analysis. A DS3231 real-time clock module timestamps each measurement, enhancing data organization. Additionally, an alert system is implemented to log events when $CO_2$ levels exceed a predefined threshold. To enable remote monitoring, the system transmits data in real-time to the ThingSpeak platform using the ESP8266's WiFi connectivity, allowing for interactive visualization and analysis. This implementation provides a low-cost, scalable solution for air quality assessment, facilitating decision-making in indoor environmental management.**

***Keywords—Air quality monitoring; ESP8266-embedded system; Internet of Things; ThingSpeak.***

## I. INTRODUCTION

Monitoring indoor air quality is essential for protecting health and well-being, as prolonged exposure to high carbon dioxide levels ($CO_2$) and other pollutants can cause headaches, fatigue, and cognitive impairment. While elevated $CO_2$ levels in classrooms do not pose direct health risks, they indicate insufficient ventilation for the number of occupants, as human exhalation increases these levels. Therefore, ensuring proper ventilation is crucial to maintaining air quality [1], [2].

To address this issue, a monitoring system based on the ESP8266 microcontroller was designed, incorporating $CO_2$, temperature, and humidity sensors. Measuring temperature and humidity helps establish correlations between $CO_2$ concentration and the presence and number of people in the monitored space using artificial intelligence techniques, although this analysis falls outside the scope of this article.

The electronic device displays the measured variables on an LCD screen, records critical $CO_2$ levels in a local storage module, and transmits the data in real-time to MathWorks®' ThingSpeak, an Internet of Things (IoT) platform. The system is programmed in C/C++, using the Arduino® IDE, which allows efficient control of the microcontroller's resources and facilitates the integration of essential functionalities to ensure optimal system performance.

This paper is organized as follows: Section 2 – Related Work reviews prior research and recent developments in air quality monitoring systems and IoT platforms. Section 3 – Materials and Methods describes the hardware selection process and the algorithmic logic implemented for data acquisition and processing. Section 4 – Results and Discussion presents the collected IoT data along with a detailed cost analysis. Finally, Section 5 – Conclusion and Future Work summarizes the key findings and outlines potential improvements for future implementations.

## II. RELATED WORK

Several studies have explored microcontroller- and sensor-based platforms for environmental monitoring. Chouhan et al. [3] found that the MQ-4 sensor effectively detects variations in $CO_2$ concentration. Kadir et al. [4] demonstrated that the ThingSpeak platform is well-documented for its capability to store and display real-time data, facilitating remote analysis and decision-making.

Srivatsa et al. [5] propose an IoT system comprising three main components: a network of wireless sensors to monitor $CO_2$ levels, a wireless access point that transmits data via Wi-Fi, and a server that processes and stores the information while issuing alerts when $CO_2$ levels rise. Salamone et al. [6] present a wireless system for indoor air quality control using an Arduino UNO, a K30 $CO_2$ sensor, an XBee S2 communication module, and a DS1307 RTC module.

Bhattacharya et al. [7] describe a wireless solution for monitoring indoor air quality, measuring temperature, humidity, gaseous pollutants, and particulate matter. The system utilizes the Air Quality Index to regulate ventilation and air conditioning in smart buildings. Similarly, Wang et al. [8] investigate the impact of air quality on students' concentration during classes by measuring temperature, relative humidity, and $CO_2$ levels using a wireless system with DHT11 and MG-811 sensors. The system was installed in two classrooms, and the results revealed a significant correlation between environmental parameters and students' academic performance. Beyond indoor applications, Liu et al. [9] developed a monitoring system for urban air pollution, consisting of a sensor node, a gateway, and a LabVIEW™-controlled platform. This system was deployed on major streets in Taipei to measure carbon monoxide (CO) levels from vehicle emissions.

Finally, Kang et al. [10] designed an advanced air quality monitoring system integrating multiple communication technologies. The system employs Wi-Fi for Internet connectivity, Bluetooth for smart device setup, and a Radio Frequency (RF) module (IEEE 802.15.4g) for home network integration. Based on the TI MSP430 processor, it includes sensors for particulate matter, volatile organic compounds, carbon monoxide, temperature, and humidity, while supporting additional sensors via Universal Asynchronous Receiver-Transmitter (UART), Serial Peripheral Interface (SPI), and Inter-Integrated Circuit (I²C) interfaces. The results demonstrated that the system enables real-time air quality monitoring with high resolution.

## III. MATERIALS AND METHODS

Poor Indoor Air Quality (IAQ) poses a significant threat to public health, as individuals spend over 90% of their time indoors, where pollutants such as tobacco smoke, carbon, CO, $CO_2$, $NO_2$, and microorganisms can negatively impact health [11]. Although temperature and humidity monitoring is common, real-time air quality monitoring is rarely implemented in most buildings. To address this gap, an IoT-based monitoring system was developed to provide a low-cost, easy-to-install solution capable of measuring key air pollutants in real-time and generating alerts when excessive concentrations are detected.

The embedded system consists of an ESP8266 microcontroller module for Wi-Fi communication, a sensor unit integrating an MQ-4 sensor for $CO_2$ measurement and a DHT11 sensor for temperature and humidity monitoring, a DS3231 Real-Time Clock (RTC) module for precise timestamping of data, and a 4GB microSD module for local data storage. The recorded data is stored in CSV format, ensuring compatibility with text editors and advanced analysis software such as Microsoft Excel and IBM SPSS Statistics, among others. This electronic system was developed as a final project for the Microcontrollers Course (Semester II-2024) at the School of Electronic Engineering of the Pedagogical and Technological University of Colombia, Tunja Campus. The project was conducted following the Project-Based Learning (PBL) methodology.

While the current implementation measures a single gas, the system can be expanded by integrating additional MQ-series sensors to enhance its monitoring capabilities. The collected data is stored on the ThingSpeak platform (See Fig. 1), allowing remote access via a website or mobile application. The system's software is structured following a flowchart-based design, ensuring continuous measurement of environmental variables, real-time visualization, and data transmission to the cloud at 15-second intervals.

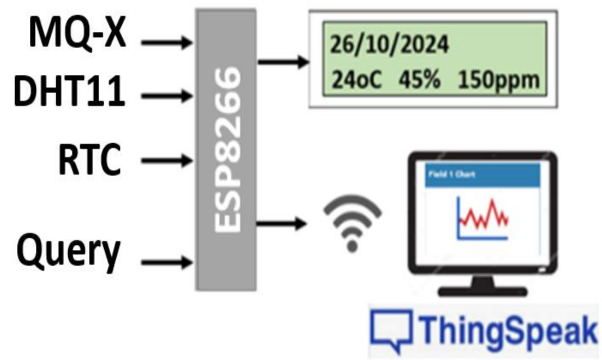


Figure 1. Embedded system block diagram.

Additionally, an alert mechanism was implemented to notify users when $CO_2$ levels exceed 700 ppm for more than 10 seconds, with this information being stored in Electrical Erasable Programmable Read-Only Memory (EEPROM) memory for future reference.

Once the block diagram was structured, the flowchart was developed, incorporating the main program logic and interrupt routines. This design ensures the orderly execution of the system, optimizes process integration, and facilitates interaction between the sensors, real-time clock module, LCD, and communication with the ThingSpeak IoT platform.

A critical component of the system is the CONSULT interrupt routine, which allows the user to display on the LCD screen the latest alert events related to exposure to excessive gas levels. According to NTC 6199 [12], the permissible $CO_2$ concentration is set at 700 ppm for an exposure time ranging from 1 to 8 hours. In real-time applications, as shown in Fig. 2, the use of interrupts to manage high-priority events is essential, as it enables immediate system response without disrupting the execution of the main algorithm.

To validate the system's functionality, preliminary testing was conducted using ISIS Proteus 8.17 SP2 simulation software [13], as shown in Fig. 3. The simulation included the Tensilica L106 microcontroller integrated into the ESP8266 module, which provides Wi-Fi connectivity for transmitting data to the ThingSpeak platform.

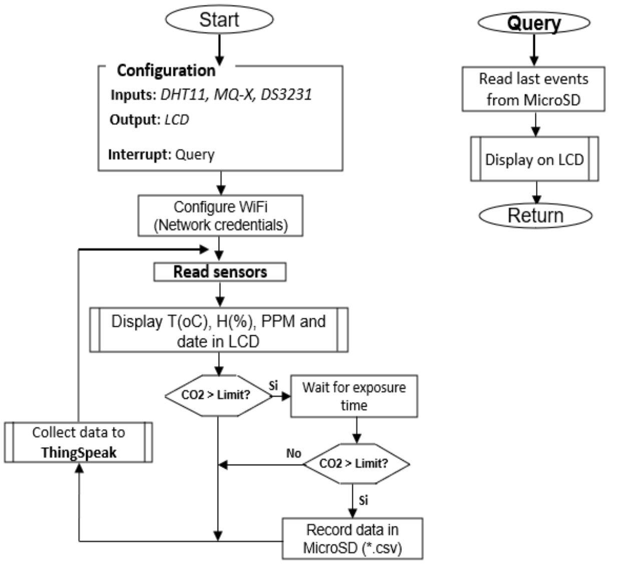


Figure 2. Flowchart and system interrupt routine for indoor air quality monitoring.

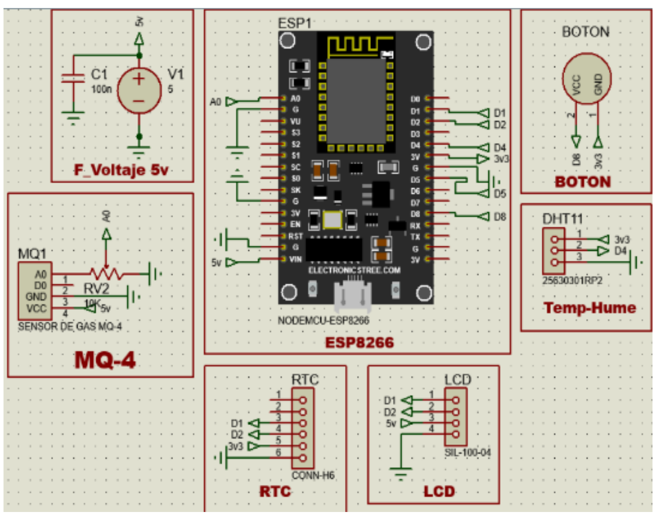


Figure 3. Simulation of monitoring system in ISIS Proteus.

The simulation integrates the DHT11 temperature and humidity sensor, the MQ-4 sensor for $CO_2$ concentration detection, the DS3231 RTC digital calendar module to label the data with date and time, and a 16x2 LCD with $I^2C$ adapter. In addition, there is a button to display on the screen the latest events recorded when $CO_2$ levels exceed the established limit.

The Schematic Capture and Printed Circuit Board (PCB) Layout functionalities of the ISIS Proteus software were used to design and generate the system's PCB (See Fig. 4).

These tools enable seamless integration between the schematic and the physical layout, facilitating the organization of components and the routing of connections essential for the device's proper operation.

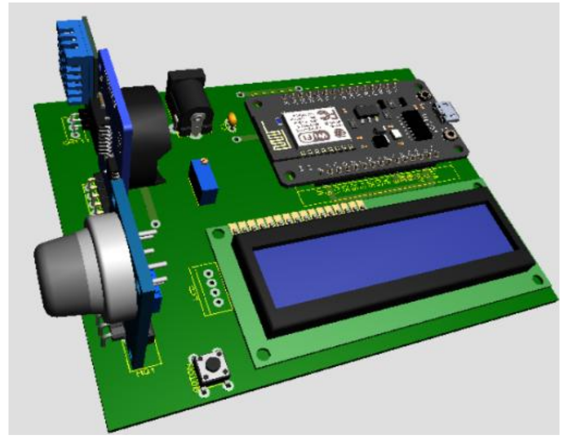

Figure 4. PCB design of the monitoring device in ISIS Proteus.

## IV. RESULTS AND DISCUSSION

The developed system enables data retrieval in multiple formats: as numerical values displayed on the LCD screen, as graphical representations via the ThingSpeak IoT platform, and optionally through a smartphone interface using ThingView – ThingSpeak Viewer, available on the Google Play Store for Android devices. Sample data collected by the system are presented in Fig. 5 and Fig. 6, demonstrating its capability to effectively monitor and visualize environmental conditions.

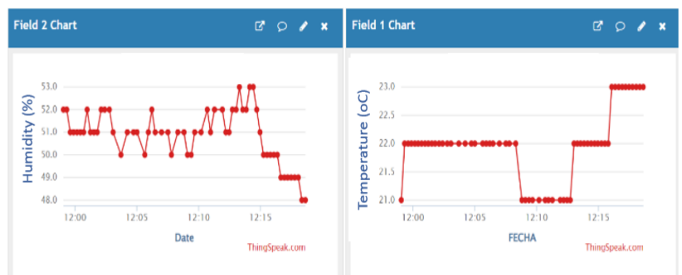


Figure 5. Humidity and temperature were recorded during testing.

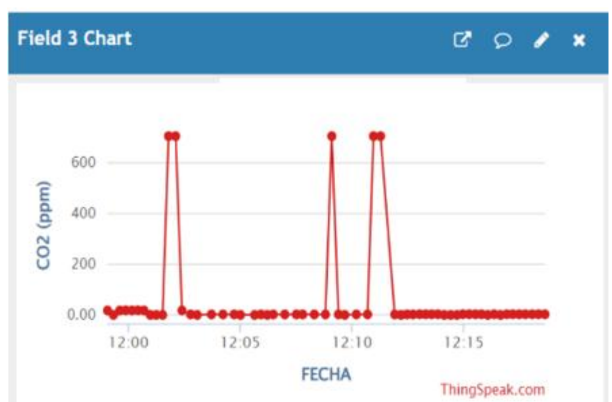


Figure 6. Concentration of Carbon Dioxide ($CO_2$) obtained in the tests.

To conduct the tests, environmental conditions in the Digital Electronics Laboratory of the School of Electronic Engineering at the Pedagogical and Technological University of Colombia, Tunja campus, were monitored. To modify $CO_2$ levels in a controlled manner, the device was exposed to a lighter or briquette, which contains gases such as butane ($C_4H_{10}$), propane ($C_3H_8$), and methane ($CH_4$). When burned, these gases generate carbon dioxide ($CO_2$) and small amounts of Volatile Organic Compounds (VOCs).

For a rapid evaluation of the alert system, a critical exposure time of 10 seconds was configured, differing from the NTC 6199 standard [14], which establishes maximum exposure times of 1 hour and 8 hours based on permissible levels. The exposure time parameter can be adjusted in the algorithm to ensure compliance with regulatory requirements in real-world applications. Fig. 7 illustrates some of the alert events recorded during testing.

Alarm events are logged on a 4GB microSD card in **.txt* format, structured for compatibility with CSV files to facilitate further analysis. A sample of the recorded alarm logs is shown in Fig. 7, illustrating the comparison between these records and the data transmitted to ThingSpeak, resulting in an accuracy of 87%. The observed discrepancy in timestamp synchronization is attributed to the 30-second latency inherent to the free version of ThingSpeak.

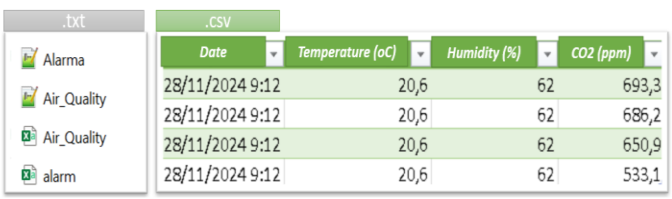


Figure 7. Alarm log stored in CSV-compliant TXT file.

The system systematically stores alert events on the microSD card, building a database for future applications involving Artificial Intelligence IA-based analysis. Although email or SMS notifications were not implemented, these functionalities are available through ThingSpeak, and their configuration can be referenced in the MathWorks® Help Center.

Finally, the IoT-based air quality monitoring system is a cost-effective solution, with a total development cost of 26.64 USD. Fig. 8 and Table I provide detailed cost breakdowns. The component prices were obtained from the Mouser Electronics website [18].

The proposed system improves upon previous air quality monitoring approaches by integrating real-time IoT capabilities and efficient data storage. Chouhan et al. [3] employed the MQ-4 sensor for $CO_2$ detection; however, their system lacked cloud connectivity, limiting remote monitoring capabilities. Similarly, Bhattacharya et al. [7] implemented a wireless sensor network for comprehensive indoor air quality assessment, but its complexity and cost reduce its accessibility.

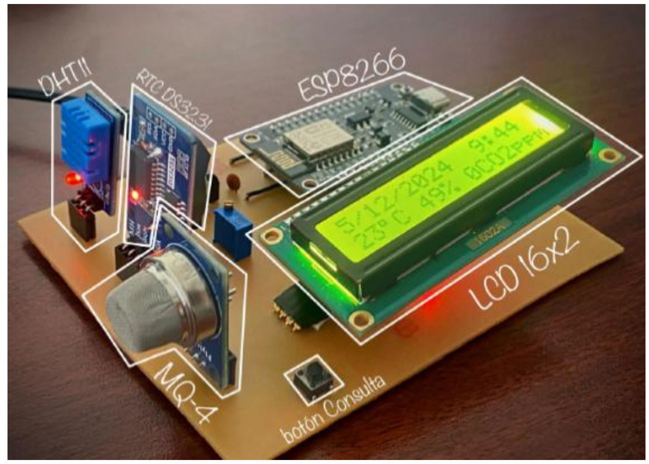


Figure 8. Implementation of the IoT air quality monitoring system.

TABLE I. COST OF AIR QUALITY MONITORING IOT SYSTEM.

| Component | Cost |
|---|---|
| ESP32 | 8.0 USD |
| MQ-4 | 2.17 USD |
| DHT11 | 1.83 USD |
| DS3231 | 4.35 USD |
| MicroSD Module 4GB | 4.57 USD |
| Cables and box | 5.72 USD |
| **Total** | **26.64 USD** |

In contrast, the system presented in this work employs the MQ-135 sensor for multi-gas detection, systematically logs alarm events on a microSD card, and supports future AI-based analysis. The total development cost of the proposed system was 26.64 USD, substantially lower than the USD 122 required for the Klein Tools ET120 [15] gas detector and the USD 485 for the AR8900 Smart Sensor [16], underscoring its economic feasibility compared to commercial alternatives. Although the current implementation focuses on $CO_2$ monitoring, the system is designed to be scalable, enabling the integration of additional MQ-X series sensors for multi-gas detection and broader environmental monitoring capabilities.

## V. CONCLUSION AND FUTURE WORK

Systems for monitoring and controlling environmental variables—such as temperature, humidity, and gas concentrations—are essential in critical environments such as laboratories and offices, where sudden fluctuations can pose health and safety risks. These systems enable early warning mechanisms, enhance occupational health and safety, and ensure compliance with regulations such as [14] and ASHRAE 62-2001 [17], which define critical gas concentration limits in enclosed spaces. By adhering to air quality standards, these systems contribute to maintaining a healthy and safe indoor environment.

The ESP8266 board is well-suited for IoT applications due to its versatility, integrated Wi-Fi™ module, and compatibility with serial communication protocols. Its seamless integration with the Arduino IDE and extensive library support simplifies its implementation in complex projects, offering efficient and flexible connectivity. Additionally, for more demanding applications, the ESP32 board presents a superior alternative, featuring increased RAM capacity (from 64 KB to 512 KB), higher processing speed (from 80 MHz to 240 MHz), and improved Analog-Digital Converter (ADC) resolution from 10 bits to 12 bits, among other enhancements.

However, a key limitation of the current prototype is its dependence on the free tier of ThingSpeak, which introduces a 30-second latency in data updates. Additionally, the absence of real-time notifications via email or SMS may delay critical alerts in emergencies. Future research could address these limitations by integrating IoT platforms with lower latency, implementing edge computing for local decision-making, and incorporating artificial intelligence algorithms for predictive air quality analysis. These enhancements would significantly improve system performance, responsiveness, and reliability in real-world applications.

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