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MODELING A SMART IOT DEVICE FOR MONITORING INDOOR AND OUTDOOR ATMOSPHERIC POLLUTION

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Abstract. Air pollution is caused by chemical, physical, or biological components alters the fundamental properties of the atmosphere, and contaminates the interior or outdoor settings. With the rapid industrialization activity in recent years, there is an urgent need to monitor air quality. The proposed research provides a mechanism for monitoring air pollution in indoor and outdoor environments. The system consists of an IoT-based Arduino device. The Arduino IDE connects the Temperature and Humidity sensor, Grove light sensor, and air quality sensor to measure the air pollutants such as Carbon dioxide CO_2, Nitrogen oxide (NOx), and Particulate Matter PM2.5. The sensors work efficiently and provide qualitative findings from the environment when they are exposed to CO_2, gasoline, solvents, thinner, formaldehyde, and other harmful chemicals. The Wi-Fi module of the Blues Wireless Notehub is used for secure data routing to the IoT cloud. The Air Quality Index (AQI) measures provide information on whether there is something unsafe in indoor and outdoor environments. For collecting and analyzing the device data, the Notecard is intended to be used with a cloud storage service. Also, the indoor fire detector identifies the incident of fire intimates the users through the alarm, and measures the indoor pollutant at that time. The proposed smart IoT product model would be an excellent device for air quality monitoring because of its long-term consistency and low electricity consumption.

Key words: air pollution; air quality; Arduino; sensors; cloud; humidity; smart IoT; pollutants; temperature.

1. Introduction. The air is polluted due to the development in technology and rapid increase in industry. The government initiated different plans to control this pollution by introducing a sustainable green environment. The air pollution in indoor and external surface areas causes around five million people to die. This affects the GDP of the country [1]. The main source of air pollution is harmful gases and dust produced in the industry, CO_2, Nox, PM 2.5, etc [2]. The ocean has been primarily responsible for more than 90% of global warming over the past fifty years. According to the new research, warming in the upper water is responsible for approximately 63% of all warming. Since pressure increases when heated, rising ocean water raises the global sea level [3]. The annual mean global temperature is predicted to be between 1.1°C and 1.7°C higher than before the levels between 2022 and 2026. The likelihood of global surface temperature reaching 1.5°Cover the pre-industrial level for the year, 2022-2026 is nearly equal to 48%. The five-year mean has a slight 10% probability of reaching this limit. The probability of at least one year topping the hottest year on record, 2016, is 93% in 2022 - 2026. There is a 93% chance that the five-year mean for 2022-2026 will be higher than the five-year mean for 2017-2021[4]. The global temperature of land and surface on January 2022 was 0.89°c ie) 1.60°F. Many accidents happen nowadays due to the occurrence of fire in the kitchen. The number of air pollutants increased due to fire. This fire is caused by indoor and outdoor incidents [5]. When the fire is noticed, then manually it is controlled. The linkage to the smartphone and computer devices is used by the systems to operate the network equipment and enhance identification. So that it could successfully perform pre-disaster identification and warning, it could assess exhaustive fire smoke, humidity, light, as well as other numerous related characteristics. The indoor and outdoor pollutants are considered for analyzing the air quality to model the final device. Flame sensors are vital tools for spotting fires and are employed in diverse application fields, including automotive, firefighter robotic arms, parking safety gear, factories, and commercial and residential cooking spaces [6].

The following are the proposed study's major contributions:

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1. Using smart IoT devices for precise monitoring of indoor air quality.
2. Using cloud computing for real-time indoor and outdoor air quality analysis.
3. Developed a mobile application for the proposed IoT system with any time, anywhere capabilities.
4. The device has been tested for data reliability, and the platform has been implemented in a building to demonstrate its viability.

2. Literature Review. Air pollution is a big problem, particularly in modern cities owing to increased mobility and urban population. It is notable and has an impact on people's health. As a result, there is a need to track and control pollution, as well as to establish a non-toxic atmosphere in which humans, wildlife, trees and plants may live a sustainable life. Thus government and the NGOs made huge efforts [7]. Particulate matter (PM) less than PM 2.5 is harmful to the human body. It penetrates deep into the heart, lungs, and respiratory system [8-9]. AQI is the measure to indicate the number of pollutants in the air. Nitrogen oxide is one of the pollutants that damage the respiratory system. According to the latest findings, the nitrogen oxide in the air is the reason for COVID-19 deaths [10].

Because students and teachers expel carbon dioxide (CO2) when they breathe, measuring the level of this gas is a reliable method of assessing whether the air in the classroom is clean. High CO2 levels increase the likelihood of inhaling air that has previously been exhaled by someone else. As a result, CO2 was regarded as a critical indicator for ventilating educational facilities over the COVID-19 pandemic [11]. Buildings consume energy and emit carbon dioxide all through every stage of their life cycle, such as construction, use, deconstruction, and decommissioning. The most energy is consumed during the operational and building phases, in that order. The energy needed for preserving a comfortable environment is included in the use or functioning phase, with the most pertinent being energy for running Heating Ventilation and Air Conditioning (HVAC) systems, domestic hot water, illumination, and home appliances.The difference in primary energy usage among these two phases was extensively investigated, with the utilization of phases consuming more [12]. To develop accurate forecasting techniques and a predictive AQI model for four different gases—carbon dioxide, sulphur dioxide, nitrogen dioxide, and atmospheric particulate matter—three artificial intelligence algorithms such as Linear Regression, Support Vector Regression, and the Gradient Boosted Decision Tree model and analyze air qualities using various sensors [13].

Many recent studies on air pollution have mostly focused on predicting air quality concentrations [14-15] and measuring air quality [16-19]. Forecasting air quality has been popular, and various approaches have been created for this purpose, including the statistical HMM (Hidden Markov model) [11], grey model first order one variable [12], SVM (Support Vector Machine) [13], and fuzzy time series forecasting model [14-15]. Burkart et al [20] examined the impacts of air pollution, secondhand smoking, and indoor environmental contamination. Meta-Regression-Bayesian, Regularized, the Trimmed (MR-BRT) method is used to calculate the risk of occurrence of diabetes due to this air pollutant. The monitoring system was developed using IoT technology by M.V.C.Caya et al. [21]. IoT systems contain disparate devices from many vendors, which might pose compatibility concerns. Hojaiji et al. [22] developed single sensor nodes to track air pollutants. These portable devices can detect one or two pollutants, but their accuracy is relatively low. Zho Z et al. [23] described that the low-cost sensors provide adequate accuracy of data and a respectable sensing range, but they cannot compete with the accuracy provided by traditional monitoring systems. Akashdeep Sharma et al. [20] proposed a multi-model IoT and deep learning-based identification, distribution, and continuous tracking systems for intense fire areas. Aditya et al. [24] developed a rule-based method to measure carbon monoxide for identifying air pollution. There is a need for a device to measure the atmospheric air quality to find the pollution in the air. The proposed system considers the existing system and its limitations as well as its challenges.

2.1. Challenges. Monitoring air pollution in both indoor and outdoor environments presents several challenges.

1. Indoor and outdoor air pollution are caused by a variety of factors, and the pollutant levels vary significantly over time and space. This makes identifying and quantifying all pollutants present and obtaining a precise assessment of air quality is difficult [21].
2. There are no universally recognized norms or recommendations for indoor air quality, and installing and operating outdoor air quality monitoring stations are costly. This reduces the amount of data to be collected to render and compare the data on air quality is challenging [22].

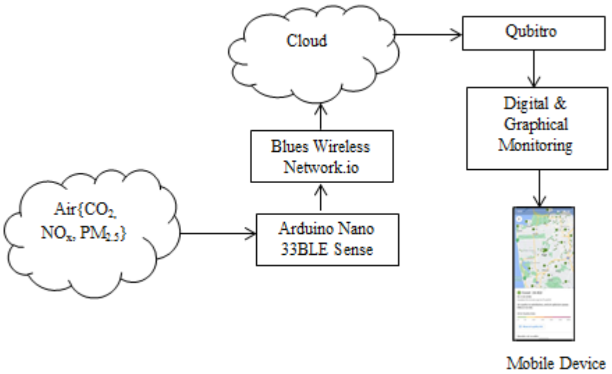

Fig. 3.1: The proposed smart IoT device to monitor indoor and outdoor atmospheric pollution

3. Some kinds of air pollutants, such as particulate matter and gaseous pollutants are difficult to monitor due to their small size [23].

3. Methodology. IoT is an efficient platform for handling scenarios without human intervention. The air is polluted due to indoor and outdoor pollutants. The smart IoT system collects information from the surroundings through various sensors, processes the huge data, and stores it in a cloud for historical review and usage. The proposed smart IoT system uses different sensors to analyze these pollutants and notify the dangerous situation where the pollutants are to be suppressed. There are several methods for tracking environmental data. An SD card in a controller is used for manually recording and transferring data from connected devices. This is to be handled by Wi-Fi or Bluetooth low-energy communication-based controllers. The cloud is a core part of every IoT system. The data collected by individual IoT sensors becomes helpful when combined with data from other relevant sensors. An approach to provide pervasive, effective, on-demand connectivity to the workstations, storage, frameworks, and capabilities of a massive pool of reconfigurable hardware and software is known as cloud computing. It takes little managerial effort or communication with service providers. A cloud system is expected to include features like on-demand consciousness, wide data services, virtualized resources, fast adaptability, and quantifiable services. As shown in Figure 3.1, the smart IoT system connects the APMS (Air Pollution Monitoring System) with Arduino Nano 33 BLE sense header. This smart IoT system can measure the number of pollutants present in the air. The Blue wireless notehub.io connects the devices with the cloud server. The observed data is stored over the cloud and Qubitro does the various statistical analyses of the data. The details of the pollutant are displayed on the user's mobile devices.

3.1. Indoor Pollutants. The indoor monitoring system is capable of identifying significant contaminants. Since these devices may be turned up immediately and the network life span can be prolonged as much as necessary, power is not a major problem for such devices. Carbon dioxide (CO_2) is an inert, tasteless, and colorless gas. Excessive exposures to CO_2 have significant health consequences. When large amounts of CO_2 are utilized, stored, or created, dangerously high concentrations may be the consequence. The harmful quantities of CO_2 are difficult to detect by the human eyes. CO_2 monitors are widely employed to limit the possibility of a CO_2 leak. A CO_2 sensor monitors the interior ambient levels fast and precisely, protecting employees, and facilities from injury or hazard. CO2 exposures have several negative health consequences. Migraine, nausea, agitation, numbness, or pins and needles sensation, chest tightness, restlessness, weariness, a faster heart rate, high blood pressure, unconsciousness, dyspnea, and tremors are some of the symptoms. Table 3.1 shows the standard Co2 measurements and their effects.

3.2. Models for the estimation of pollutants. Inside the building, the occurrence of fire produces hazardous carbon dioxide (Co2). Monitoring air pollution both indoors and outdoors with an Arduino UNO necessitates the use of a variety of sensors and components for measuring a few air quality parameters.

Table 3.1: Atmospheric Co_2 Pollutants level and its effects

Co2 Measurement (ppm)	Effects
400	Average atmospheric concentration
600-800	Indoor air quality acceptable
1,000-1,200	Good atmospheric concentration
5000	8-hour exposure period is the maximum allowed
6000-30,000	Concerning this exposure is just temporary
3-8 %	Increased breathing rate and headache
$\leq$ 10 %	Vomiting, nausea, and unconsciousness
$\geq$ 20%	Deaths due to sudden unconsciousness

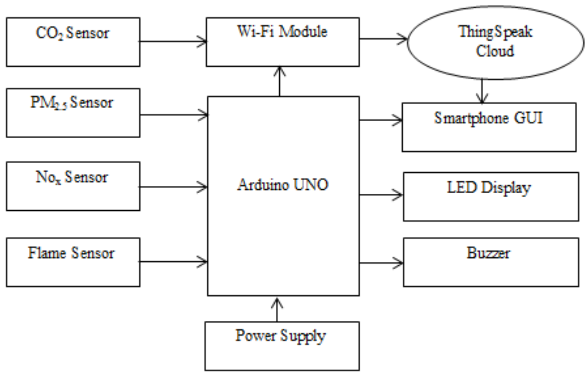

Fig. 3.2: Architectural diagram of the proposed IoT system for indoor air pollutant detection.

The Arduino UNO possesses six analog input pins that can be used to directly connect up to 6 sensors. After connecting the sensors to the Arduino UNO, the program will read the values from the sensors and show them on an LCD panel, send the data to a computer for processing and store it on the cloud, and trigger notifications or control other devices depending on the readings from the sensors.

These pollutants are present in the air for a long time after the incidents happened. Numerous call points and sensors are attached to the automatic fire alarm panels that make up the planned traditional smoke detector. The zonal circuit is used to connect a separate circuit for each level or fire section. There would be many zone bulbs on the fire alarm monitoring panel. The purpose of establishing zones is to provide an overall overview of where a flame has happened. The list of regions on a control panel, and hence the number of circuits wired inside the structure, determine the precision of understanding where a fire originated. The control panel then needs to be connected to at least two sounder circuits, which might include bells, a digital buzzer, and other such audible instruments. As illustrated in Figure 3.2, assemble the components and upload the program to Arduino. Hold a lighted lighter or a matchstick in front of the flame sensor to verify its operation.

The YG1006 NPN Photo Transistor is used in the flame sensor. This has been coated using black epoxy, which makes it capable of detecting infrared radiations, hence it is susceptible to infrared radiation in its wavelength range of 760nm to 1100nm. Using this type of flame sensor, it detects the Infrared Light from a distance of 100cm within its detection angles of 60 degrees.

The flame output frequency is 'high' within typical settings. Whenever the sensor senses fire, the output changes to 'low'. The buzzer is activated when Arduino detects a 'low' signal on its input pin.

3.3. Outdoor Pollutants. Nitrogen oxide (NOx) is a harmful gas molecule. Its chemical compounds of nitrogen and oxygen are an important element of air pollution. NOx pollutant is produced by cars and off-road

Table 3.2: Atmospheric NOx Pollutants concentration and AQI status

Nox Measurement (μg/m^3)	AQI Category
400+	Severe
281-400	Very Poor
181-280	Poor
81-180	Moderately polluted
41-80	Satisfactory
0-40	Good

Table 3.3: Atmospheric PM2.5 Pollutants concentration and AQI status

PM2.5 Measurement (μg/m^3)	AQI Category
35	Good
75	Moderate
115	Lightly polluted
150	Medially polluted
250	Heavily polluted
350	Severely polluted

vehicles like construction equipment, ships, and industrial emissions such as power stations, heating systems, cement factories, and windmills. NOx is commonly observed as a brownish smoke. Table 3.2 displays the baseline Nox measures as well as the AQI level.

3.4. PM 2.5. Particulate Matter 2.5 is the name given to tiny particles. They are minute granules or condensation in the atmosphere with a size of two and a half millimeters or less. According to the research, PM 2.5 levels of 12 g/m3 or even below are considered safe, with little to no risk of exposure. If the contribution makes or surpasses 35 g/m3 in 24 hours, the air is considered dangerous and may cause issues for people who already suffer from breathing difficulties. Recent epidemiological studies have linked PM exposure to impaired cognitive density, neurodegeneration, aberrant blood-brain barrier function, brain neuronal activation, and a higher likelihood of Alzheimer's disease, Parkinson's disease, and ischemic cerebral disease. Table 3.3 shows the standard PM 2.5 measurements and its AQI status.

3.5. Models for the estimation of pollutants. The outdoor pollutants are measured through the smart IoT system as shown in Figure 3.3. The device consists of the components of Arduino UNO, IIC/I2C/TWI/SPI serial interface board module for LCD, DHT11temperature and humidity sensor, sharp optical dust sensor (GP2Y1010AU0F), SD Card reader/writer module, RTC clock, and 16X2 LCD. The final display shows the temperature, humidity, time, and dust contents. AQI gives information about the risk level of pollutants in the air from 0 to 500. The proposed system is implemented through a three-step process.

1. It consists of the hardware setup, where the environmental data is collected using a fire sensor, air quality sensor, and light sensors. Arduino UNO connects the entire sensor. It is the controller to process all the data.
2. It includes the Notehub environmental setup. Here, the sensor data will be transferred to the Blues Notehub cloud through the Blues Notecard and Blues Notecarrier.
3. It is the environmental setup for Qubitro. The sensor data stored in the cloud is processed here. Hence, the sensor data is post-processed by Qubitro.

3.6. Implementation details of the proposed indoor and outdoor pollutant detection system.

1. Extract data of all pollutants from the sensors which are connected to the Arduino.
2. Based on its average concentration and the total number of pollutants, assign a risk category to each pollutant. R_1, R_2, ...R_n where 'n' is the number of pollutants.

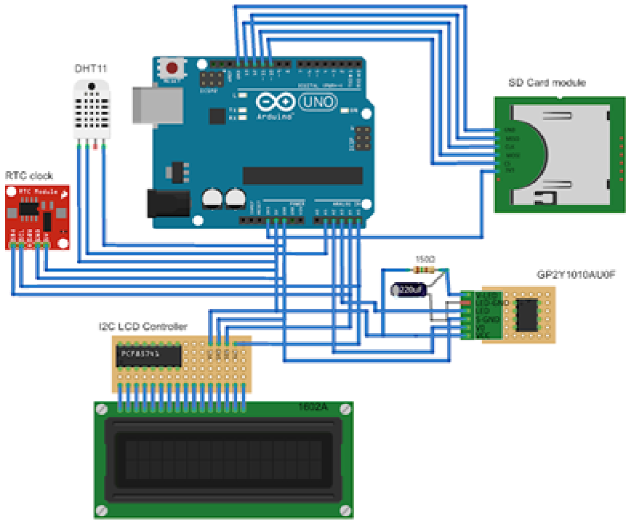

Fig. 3.3: Outdoor air pollutant monitoring system.

Table 3.4: Status of AQI related to health

AQI	Status	Color
0-50	Good	Green
51-100	Moderate	Yellow
101-150	Harmful	Orange
151-200	Unhealthy	Red
201-300	Very unhealthy	Purple
301-500	Hazardous	Maroon

3. Obtain the maximum value after sorting the risk groups in decreasing order as follows:

$$R(max), ..., R(min) \implies R(max)p \tag{3.1}$$

4. Calculate the air quality index is calculated as per the following equation.

$$I_{AQI} = \frac{I_{max} - I_{min}}{A_{upper} - A_{lower}}(AR_{upper} - AR_{lower}) + I_{min} \tag{3.2}$$

   where I_{AQI} is the final AQI value of the location, I_{max} is the upper AQI limit, I_{min} is the lower AQI limit, A_{upper} is the upper ambient limit, A_{lower} is the lower ambient limit, AR_{upper} is the real ambient limit.
5. Display the AQI status based on the measured value as shown in Table 3.4.
6. Based on the AQI measures display the scale of pollutants and match them with their corresponding color scale value.

3.7. Pseudocode to measure the air quality. The pseudocode to measure the air quality of indoor and outdoor environments is described as follows.

1. Initialize CO_2 sensor, NOx sensor, and PM2.5 sensor.
2. Initialize variables to store sensor readings (CO_2 reading, NOx reading, PM2.5 reading).
3. Initialize variables for calibration of sensors.
4. LOOP:

5. # Collect sensor data
6. READ CO_2 sensor data
7. READ Nox sensor data
8. READ PM2.5 sensor data
9. # Apply calibration to convert raw sensor values to actual units
10. IF calibration is required for the CO_2 sensor:
11. APPLY CO_2 calibration
12. IF calibration is required for the NOx sensor:
13. APPLY NOx calibration
14. IF calibration is required for the PM2.5 sensor:
15. APPLY PM2.5 calibration
16. # Calculate the Air Quality Index (AQI) for each pollutant
17. CALCULATE CO_2 AQI
18. CALCULATE NOx AQI
19. CALCULATE PM2.5 AQI
20. # Store or transmit the data
21. STORE CO_2 reading, NOx reading, PM2.5 reading, and AQI values
22. locally or transmit to a cloud
23. # Delay for a specified interval (every ‘n’ minutes)
24. DELAY for a specified time interval
25. END LOOP

The proposed method produced a smart air pollution prototype that purified the air using a flame sensor, PM2.5 sensor, CO_2 sensors, NOx sensor, an Arduino UNO, and multiple filters. The filters are filtering particles ranging in size from about 100 to 0.1 μm. The quantity and concentration of gases, smoke, CO_2, PM2.5, and NOx were measured by the sensors before and following the filtering process. The PM2.5 sensor recognizes Particulate Matter in the 0.2 to 8 micron range. The outputs of flame sensors and PM sensors are converted into particle concentrations by Arduino UNO. The Wi-Fi Module transmits these findings to the ThingSpeak Cloud platform. The sensor outputs are viewed in the ThingSpeak Cloud on any computer or mobile device. The concentrations of various gases and the corresponding particle size concentrations are plotted before and following filtration, and the findings are analyzed. It was discovered that the intended filter successfully filters all particles larger than 0.1 μm. Both the air monitoring system and air purifier systems are tested for reliability and effectiveness.

4. Results and Discussion. The goal of real-time data gathering and analysis in this research is to capture the CO_2, Nox, and PM 2.5 concentrations utilizing sensors. The smart IoT sensor node senses the values from the environmental parameters. The microcontroller board contains a sensor to monitor the sensed values from the sensor nodes. Then the data is transmitted through the Internet and stored in the cloud server. The sensors mounted on the node station send the collection to the online service, and the outcome of the process of determining air quality will be published on the Android devices as real-time information about the pollution. The sample collected input data are shown in Table 4.1.

Figure 4.1 shows the smart web-based interface through which one can know about the environmental air pollutants, their corresponding air quality index, and the status of the particular location on their mobile devices. Based on this information the public and the government may take necessary action to improve the quality of the air. The sensor started observing the pollutants and read the details, deciding to publish the air quality status as shown in Table 4.2.

The proposed system's primary functions include measuring AQI and converting the results into a format that is simple for any user to understand. The proposed technique will assess the aggregate AQI while accounting for the concentrations of all air contaminants. The smart IoT system will then be converted into a color scale to comprehend the findings and gauge the risk of entering a certain region due to air quality.

As shown in Figure 4.2, the proposed system identifies the sensor values accurately while compared with the competitive methods. Also, the AQI value of each location is verified with the manually calculated measurements.

Table 4.1: The sample observed data from the resources (June 2023 to August 2023) on air quality

Id	Date	Day	NOx	CO_2	PM2.5
1	1/7/23 1:00 AM	Saturday	0.02	0.19	7.2
5	2/7/23 1:00 AM	Sunday	0.015	0.16	6.4
241	12/8/23 1:00 PM	Saturday	0.009	0.1	9.2
246	12/8/23 2:00 AM	Saturday	0.015	0.16	6.2
248	12/8/23 3:00 PM	Saturday	0.018	0.16	3.5
...	....	....	....	....	....
56950	24/8/2023 3:00 AM	Thursday	0.024	0.08	7.2

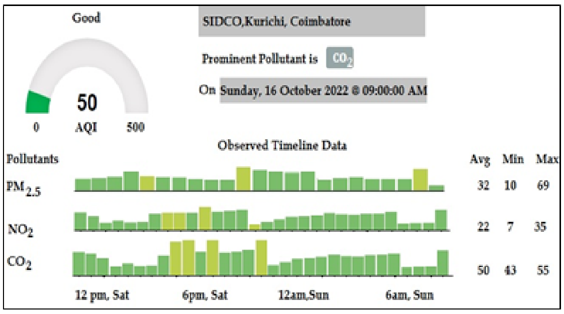

Fig. 4.1: Smart web-based IoT system interfaces to analyze the real-time air pollutants, air quality index, and status.

Table 4.2: Obtained results from the IoT sensors

AQ Sensor Value	16
Pollution Status	Fresh Air
Humidity	73 %
Temperature	28.6°C
Light Sensor	64 %
Dry Level	73 %

5. Conclusions. Air pollution is a huge danger to any country's health, economy, and biodiversity. The proposed smart IoT system discusses the causes and effects of air pollution, as well as a complete examination of air quality monitoring and an effective IoT-based method for air quality index measurement. Despite the existence of several outstanding smart air quality monitoring devices, the research topic remains challenging. This smart IoT-based AMPS model is an attempt to create smart, low-powered, and highly efficient air quality monitoring devices that can monitor continuously and send alerts or notifications about indoor and outdoor air pollution to the relevant people for further processing.

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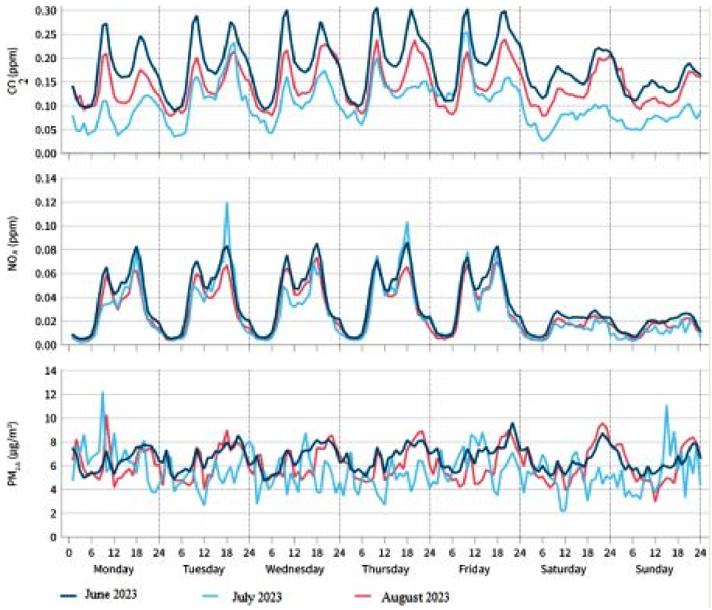

Fig. 4.2: The generated report from July 2023 to August 2023 on air quality based on the proposed IoT system

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