Monitoring indoor air quality using smart integrated gas sensor module (IGSM) for improving health in COPD patients

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Abstract
Technology advancement, industrialisation, and globalisation have been significant reasons for air pollution outdoors and indoors. It may surprise us that we spend about 80% of our time indoors breathing toxic, stale, polluted air, making us sluggish and fretful. In contrast to outdoor air, indoor air does not recycle consistently. It traps and builds pollutants from wood and coal stoves, furniture and building materials, paints and solvents, cigarette smoke, and cleaning supplies. The prolonged exposure to these hidden pollutants can prompt respiratory disorders such as lung disease, pneumonitis, asthma, pulmonary hypertension, and chronic obstructive pulmonary disease (COPD). It is enduring and is not curable, which has been a threat to humanity for ages. COPD’s major cause is airborne particulate matter and other toxic compounds emitted from indoor and outdoor sources. Outdoor air pollution can be controlled only by acquiring changes in the vast population, wherein for indoor, every individual may create a major impact on improving air purity, thereby promoting health. The proposed design model for monitoring indoor air quality was tested in a normal and stimulating environment where we live. Parameters tested included temperature, humidity, amount of PM2.5, and the concentration of CO, CO2, and NH3. These parameters were monitored for five to 6 h per day for 8 days. Results indicate that the total air quality lies in the moderate range. Further study will be helpful to utilise this module as an effective Indoor air quality (IAQ) monitoring system.

Highlights
• A simple, effective, inexpensive integrated gas sensor module (IGSM) has been proposed in this study to monitor the indoor air quality index (IAQI).
• Indoor air quality was tested in a normal and stimulating environment for 8 days.
• The integrated gas sensor module (IGSM) was composed of sensors in series, and the outputs for the respective parameter were measured easily.
• Among the parameters tested, CO and PM2.5 lie in the moderate range, while other pollutants within the normal range reveal that the tested air quality is moderate.

Keywords Indoor air pollution · COPD · Air quality · Integrated gas sensor · Real-time monitoring

Introduction
Indoor air quality (IAQ) is a significant health issue that has been important in both developed and developing countries. People spend almost 90% of their time indoors, with a larger proportion spent in their households (Abdel-Salam 2021). Individuals spend o’er 90% of their time in indoor environments. Therefore, air pollutant exposure in indoor environments can be higher than in outdoor environments (Abt et al. 2000). Indoor air quality (IAQ) may worsen as polluted air continuously circulates indoors.
Moreover, polluted indoor air may have more adverse effects than polluted outdoor air. Various research studies revealed that indoor air is more contaminated than ambient air.

Various toxic gaseous indoor pollutants like carbon monoxide (CO), nitrogen dioxide (NO₂), particulate matter (PM), ozone (O₃), volatile organic compounds (VOCs), and radon (Rn) constitute a significant risk that can directly affect human health through causing a wide range of cardiovascular and respiratory illnesses (Garrett et al. 1997, Gunnarsen et al. 2014). Some of these air pollutants are released by outdoor sources such as traffic emissions and indoor combustion sources in urban areas.

In 2012, the World Health Organization testified that 4.3 million premature deaths occurred due to undesired IAQ worldwide. Poor IAQ causes adverse health effects, including respiratory symptoms, allergies, sensory irritation, asthma, sick-building syndrome (SBS), cardiovascular diseases, headache, and fatigue (He et al. 2004). Children are more susceptible to the risk associated with poor IAQ (Leung et al. 2014, Cheng et al. 2009). Improved IAQ and thermal comfort enhance the productivity of children and teachers in schools (Jenkins et al. 1992).

Toxic gases and particulate matter (PM) concentrations were prominent concerning parameters in determining the risk associated with IAQ (Koponen et al. 2001). A vital health issue related to IAQ is SARS-CoV-2. Due to meteorological factors, the increased concern about the virus spread in confined spaces has sequentially fostered the need to convalesce indoor air quality (Agarwal et al. 2021). The swift outbreak of the peculiar global pandemic COVID-19 spawned by SARS-CoV-2 made unprecedented impacts worldwide, leading to a 2–3% increased fatality rate (Abboah-Offei et al. 2021). The extremely infectious disease is transmitted by inhalation or contact with infected droplets causing mild to moderate respiratory illness, further progressing to pneumonia, septic shock, acute respiratory distress syndrome, and cytokine release syndrome (Cdc.gov/coronavirus, 2020). Extensive studies were conducted by researchers in various parts of the world to assess IAQ in subway metro stations from the 1990s to 2021. Significant research studies were conducted in different parts of the world to reveal the IAQ (Li et al. 2009).

Technology is rapidly evolving to monitor existing indoor air pollution, and air purifiers for the indoor environment are one of the latest technologies attempting to reduce concentrations of harmful pollutants in the indoor air of both indoor and outdoor origin. There are various conventional and non-conventional methods available for the determination of IAQ. This study has developed a specially designed small integrated gas sensor module (GSM). The proposed design model for monitoring indoor air quality was tested in a normal and stimulating environment where we live.

Parameters tested included temperature, humidity, amount of PM2.5, and the concentration of CO, CO₂, and NH₃. These parameters were monitored for five to 6 h per day for 8 days.

**Background and related work**

**Pollution of the indoor environment**

The biological, chemical, and physical features of indoor air inside a home, building, or organisation are indoor environmental pollution. Indoor air quality is a concern in developing countries because environmental benefits make homes more hermetically sealed, limit ventilation, and elevate pollution levels. Indoor environmental pollution issues can be delicate, and the health implications are not always obvious. Various factors cause indoor air pollution in rural and urban locations.

Indoor emissions are more in rural areas, where most people depend on conventional fuels like hardwood, coal, and cow manure. The number of indoor contaminants in ancient fuel-using families is frightening. When certain fuels are burned, a vast quantity of smoke and other air contaminants are released into the enclosed area of the house, resulting in significant pollution. Families who spend much time confined and are more likely to smoke are by far the most vulnerable. The World Bank identified indoor pollution levels in emerging regions as the most critical global environmental issue in 1992. Regularly, indoor pollution levels frequently exceed existing WHO limits and permitted values (Saini et al. 2020).

In urban environments, exposure to indoor air emissions has increased due to several factors, including the construction of more closely enclosed structures, decreased insulation, synthetic materials for construction and furnishing, and the use of chemical chemicals, pesticides, and household care products. Indoor air pollution may begin inside the building or be removed from the outside. Other than nitrogen dioxide, carbon monoxide, and lead, there are a variety of other contaminants that influence the air quality in the enclosed area.

**Chronic obstructive pulmonary disease—COPD**

Chronic obstructive pulmonary disease (COPD) was India’s second leading cause of death after cardiac ailments in 2017. The number of incidents of COPD was higher than road accidents or suicides in 2016. Also, it took more lives than diabetes, malaria, tuberculosis, and breast cancer combined. COPD is characterised by the lungs’ airway inflammation, leading to the deterioration of air sacs resulting in difficulty in breathing. This heterogeneous, incurable, and progressive disorder is India’s most underrated and overlooked condition.
Air pollutants—cause of COPD

Emissions released from transport, construction of roads, and random distributions of industries in the outdoors have contributed to causing COPD. However, evidence on COPD caused due to indoor pollutants in India is limited (Jiang et al. 2016).

An increase in toxic pollutants is emitted indoors due to residential dwellings near companies and industries that emit dangerous gases and chemicals. Particulate particles PM2.5, PM10, and gas emissions such as sulphur dioxide, nitrous oxide, and ozone have been detected in various locations. The use of renewable resources leads to environmental pollution. Tobacco products and cigarette smoke are increasingly known as enclosed chemicals that cause an increasing variety of health problems (Saini et al. 2021).

The indoor environment can have lower health status than elsewhere. Some household materials, for example, emit gases such as volatile organic compounds (VOCs). Headaches, fatigue, sore eyes, and throat irritation are possible side effects. Children, who breathe quicker than adults and inhale more air, may be particularly vulnerable to indoor air pollution. It may be especially harmful to babies close to the ground, where strong chemicals linger in the air.

Combustion from cigarettes, incense sticks, cleaning chemicals, paints and varnishes, biomass fuels, mosquito coil burning, smoking, and other sources of environmental contaminants in housing neighbourhoods are some of the most significant. Household allergens include bed bugs, insects, fungal, and animals such as cats, dogs, and rats. The residential sector is a pro cause, meaning that each residence has several small ‘polluters’, which create a more significant major issue when added together. This leads to the deterioration of quality of life (Singh et al. 2020).

Sources of indoor air pollution

Paints bring brightness to the surroundings we live in and protect wood and metal from rotting and rusting, respectively. However, these colourful paints can also harm our well-being. The biggest threat to health and the environment is lead-based paints. VOCs emitted as gases released from various chemicals in paints and varnishes contribute majorly to indoor air pollution. Indoors, the heavy metals in paint, such as cadmium, mercury, lead, or chromium, tend to scatter their residues and last for a more extended period.

Some household cleaning products contain toxic chemicals that can cause skin problems and irritation to the respiratory tract if inhaled or touched. This is especially right for those who have skin or breathing issues. Certain products may aggravate allergies. Those containing ammonia and chlorine may be particularly irritating to asthma patients.

People who live in an environment where someone smokes are more susceptible to ear infections, pneumonia, bronchitis, and coughs. Asthmatic individuals can have more severe and regular attacks. Smoke inhalation can cause asthma in individuals who have never had symptoms before. People may be harmed by third-hand smoke, a poisonous substance that lingers in clothing, cushions, and furniture. This is particularly true when they work or move in the hallway.

In India, the fuel used for cooking depends on habit, availability of resources, and affordability rates. Comparatively, women are more exposed to the pollutants like smoke and oil vapours released by cooking fuels than men, which elevate the risk of respiratory infection and majorly cause a congenital disability. Gas stoves that have been improperly built or vented will emit dangerous gases into the house. Carbon monoxide can make people tired even at lower concentrations. Symptoms like nausea, headaches, confusion, and even death may occur at higher concentrations. Nitrogen dioxide can irritate the lungs, particularly in children. It must be ensured that the burners are well-calibrated such that the flame tips are still blue.

Poorly ventilated homes appear to absorb odours from the kitchen and trap air contaminants within our surroundings. This prompts the use of perfumes, deodorants, and scented candles to enhance the living in our homes. All of these include numerous powerful chemicals. Air fresheners contain toxic substances such as formaldehyde, benzene, and VOCs, in some cases causing headaches, asthma, and even cancer. Chemicals like VOCs and phthalates are also present in perfumes and similar products. The scented goods containing VOCs react with sunlight and other atmospheric chemicals to form carcinogenic ozone emissions. These generate a range of secondary air contaminants such as formaldehyde and ultra-particulate matter, causing significant heart and lung problems. On the other hand, phthalates found in fragrances are associated with driving health conditions such as headaches, skin, nose, and throat inflammation, nausea, asthma, sinus, and hormonal and respiratory complications.

Particulate wood furniture is also mainly responsible for emissions close to volatile organic compounds, owing to volatile organic compound-emitting adhesives. Building insulation has also been linked to the release of volatile organic compounds. Asbestos in sheets used in building construction produces small dust molecules. Similarly, silicon particles can be present in large quantities in brick and cement buildings. The advancement in technologies has resulted in the digitalisation of homes. Computers, smartphones, iPads, and printers are now found in almost every home. These have been linked to elevated ozone levels in homes. Polybrominated diphenyl ethers (PBDEs) are used as fire retardants in foam-containing furniture and electronic
devices. PentaPDBEs and DecaPDBEs are released in trace amounts, contributing to household air pollution.

**Significance of AQI**

The air quality index (AQI) measures average contamination levels. It warns people about how toxic and contaminated the air is. It provides a perspective on the adverse health effects of a few hours or days after being exposed to unhealthy air. In developing countries like India, where citizens are not very familiar with scientific terms and units of measurement (such as PPM/PPB or μg/m$^3$), AQI is exceptionally beneficial (Upadhyay 2019). Thus, with each condition and range reflecting an inferred health risk category, the AQI simplifies the perception of air quality by decoding it in unit numbers, as shown in Table 1.

Here it can be seen that if the AQI range is between 0 and 50, it means the data are good, and it is satisfactory when the AQI range is 51–100. Then, where the data level reaches 101–200, it would suggest that the area is mildly unsafe, and then if it exceeded 201, this indicates that the environment has been badly contaminated and the AQI range is deficient and heavily polluted and healthy for humans when it reached the maximum of 301–400.

**Related work**

Chattopadhyay et al. (2021) developed a simple method for detecting pollutants and controlling impurities with a portable filtering system. The detection or monitoring system is connected directly to the sensor outputs and includes a local display and remote monitoring controlled by the Internet of Things. The control module consists of connected HEPA filters, activated charcoal filters, and the ATmega328P microcontroller.

The construction and design of a handheld, affordable indoor surveillance device were mainly concentrated by Tiele et al. (2018). The research has been conducted on important indoor air parameters such as tone, light, PM10, PM2.5, humidity, carbon monoxide, carbon dioxide, VOC, and temperature. The tests were carried out within as well as outside. To approximate the total IEQ percentage, the authors specified an indoor quality index (IEQ) (Tiele et al. 2018).

Nigam et al. (2019) implemented the idea of assistive technology for e-mail and SMS notification used in real time to provide information on AQI. The parameters measured by this assistive technology indoors included temperature, humidity, heat index, CO, and CO$_2$ using electrochemical gas sensors and infrared sensors along with an ESP-8266 Wi-Fi module for AQI data transmission. The captured data is sent to the building occupants via SMS or e-mail, and the OLED display shows the air quality and heat index. The following live data was automatically updated (Nigam et al. 2019).

Raju et al. (2020) found that exposure to environmental contamination from components such as indoor cigarette smoke, solid fuel combustion, and harmful by-products from heating and cooking is linked to a higher prevalence of chronic bronchitis and pulmonary illness around the world. The researcher stressed the necessity of raising pollution awareness among physicians, governments, and people with chronic lung infections to enhance community education and encourage initiatives to minimise contaminant incidence throughout residences and resolve public health inequities.

According to Pathak et al. (2020), ambient air pollutants from solid fuel sources raise the rate of COPD and lung disease compared to non-solid fuels. COPD was likely in South America, North America, Europe, Africa, and Asia. Females in poor and intermediate nations were found to have the highest rates of COPD. According to surveys, significant national health intervention is urgently needed to lower the prevalence of bronchitis in moderate nations. It could be accomplished by offering better efficient methods for

| AQI type            | $O_3$   | CO   | $SO_2$ | $NO_2$ | NH$_3$ | PM-10 | PM2.5 |
|---------------------|---------|------|--------|--------|--------|-------|-------|
| Unit                | $μg/m^3$| $μg/m^3$ | $μg/m^3$ | $μg/m^3$ | $μg/m^3$ | $μg/m^3$ | $μg/m^3$ |
| Good < 50           | 0–50    | 0–1.0| 0–40   | 0–40   | 0–200  | 0–50  | 0–30  |
| Satisfactory 51 to 100 | 51–100 | 1.1–2.0| 41–80  | 41–80  | 201–400| 51–100| 31–60 |
| Moderate 101 to 200 | 101–168| 2.1–10| 81–380 | 81–180 | 401–800| 101–250| 61–90 |
| Poor 201 to 300     | 169–208| 10.1–17| 381–800| 181–280| 801–1200| 251–350| 91–120|
| Very poor 301 to 400| 209–748| 17.1–34| 801–1600| 281–400| 1201–1800| 351–430| 121–250|
| Severe 401 to 5000  | 748+    | 34+  | 1600+  | 400+  | 1800+  | 430+  | 250+ |
the total combustion of biomass fuel. Preventive measures should also be performed in these communities to lessen the occurrence.

**Materials and methods**

The proposed system for air quality control is based on the blocking scheme, as illustrated in Fig. 1. Various sensors collect data in the air and deliver reliable readings. The pre-processing stage follows the data acquisition step, wherein the Arduino performs tasks collected by sensors and converts them into a more operating format for the user. This system uses a Wi-Fi module that allows the sensors to transmit the reading for observations on the ThingSpeak platform.

**Sensor for humidity and temperature**

Humans experience extreme discomfort as a result of interior temperature changes. It becomes essential to maintain thermal comfort in order to obtain optimal indoor air quality. National Building Codes (2016) state that temperatures should be kept at 26°C plus 2.

Indoor bacterial and mould growth is facilitated by elevated humidity. Asthma, fever, and allergies are all greatly increased as a result. Low humidity, on the other hand, can cause painful eyes and a throat. National Building Codes 2016 recommends a humidity range of 40 to 70%. Good indoor air quality can be attained by maintaining ideal humidity levels. A temperature monitoring device like the sensor DHT11 can be used to measure interior temperature and humidity.

Sensor DHT11 is an affordable temperature and humidity sensor which produces standardised transmitted data with long-term stability and durability. The DHT11 could be easily integrated into Arduino or a Raspberry Pi. The humidity sensing component has two electrodes and a substrate to retain moisture or humidity. As a result, when the humid or moist air varies, the substrate’s conductivity among the counter electrode varies. The IC’s change in resistance and makes it read by the microcontroller. Thermistors are variable resistors that change in resistance concerning temperature (Adiono et al. 2018; Tang et al. 2020).

**Sensor for dust and smoke**

Any particle with a diameter smaller than 2.5 microns is referred to as particulate matter (PM2.5). They appear to be invisible to the unaided eye, but they can penetrate the lungs deeper. Long-term contact can result in cardiovascular and respiratory problems, while low exposure might irritate the eyes and nose. Due to its detrimental effects on pulmonary functions, PM2.5 must be detected.

This unit has a diagonal arrangement of the infrared emitting diode (IRED) and phototransistor. PM2.5 GP2Y1010AU0F module is often used for sensing dust particles in the atmosphere and is often referred to as an optical air quality sensor. The air goes through the air inlet where repeated toggling IR LED light falls on the air. The dust particles in the environment will be illuminated by infrared light. The outcome is a dispersed light signal. The light detector detects the scattered light. A multiple signal amplifier circuit amplifies the output. Then, the amplified light signal is processed to get the concentration of dust particles in the air. In the end, the optical dust sensor produces an analogue voltage on the Vo pin according to the concentration of dust particles (Beyaz 2019; Sanger et al. 2019).

**Gas sensor**

The gas sensor MQ135 is highly sensitive to ammonia, benzene, smoke, and toxic gases. It is economically efficient and ideal for different uses; detects harmful gases in the surrounding atmosphere and is used by the family; applies to ammonia, aromatics, sulphur, benzene vapour, and other toxic gases/smoke, gas detector, and concentration spectrum verified: 10 to 1000 ppm (Agrawaal et al. 2020; Bulot et al. 2020).

**Carbon monoxide sensor**

When there is a combustible activity taking place and oxygen is scarce, carbon monoxide (CO) is largely produced. During the winter, when gas heaters are utilised, this condition occurs frequently in homes. CO is a deadly gas that is extremely poisonous. Therefore, real-time CO monitoring can aid in preventing unfavourable events. A useful recommendation for average indoor CO exposures is 7 mg/m³ for
The intensity of carbon monoxide in the air can be detected using MQ-7 gas sensors, and the output is displayed as an analogue voltage. The sensor has a longer life span and better stability (Divya et al. 2018; Ibrahim 2019).

Arduino UNO

Arduino is an open-source physical and logical prototyping technology. It consists of the Arduino IDE (Integrated Development Environment) and a programmable circuit board used for compiling and transmitting opcodes to a hardware gadget (Gunawan et al. 2018). This is also known as a microcontroller and it is used for data acquisition using different sensors.

NODE MCU-ESP8266

The Espressif Systems microcontroller designs the ESP8266. The ESP8266 is a free Wi-Fi network solution that can also operate self-contained applications connecting existing microcontrollers to Wi-Fi. The detected indoor air quality parameters are pushed to the cloud storage using a NODE MCU-ESP8266 microcontroller and it can be retrieved at any time. This module has a USB connector and an extensive pin-out selection (Bajrami and Murturi 2018).

Liquid crystal display (LCD)

It contains substances incorporating liquid and crystal characteristics. If the LCD is turned off, both the diffraction gratings and the fluid crystal spin the light rays, causing the LCD to become translucent by allowing light rays to exit without direction. When the necessary voltage is provided to the sensors, the crystalline molecules will be orientated in a specific orientation. The diffraction gratings would spin the light rays passing by the LCD, thus activating/enhancing the desired characters (Sun et al. 2019).

Light-emitting diode

Light-emitting diode is a two-lead light-emitting device consisting of a PN junction. It is an active semiconductor component similar to that of the normal diode. The capability of emitting light in different colours sets apart the LED from a normal diode (Kodali et al. 2020).

Simulation tool

Arduino integrated development environment

It is a bridge system with C and C++ functions; also utilised to develop and transfer compatible microcontroller apps and other developer boards that support third-party systems. If started with Arduino IDE, it opens in a simple chart where programming can be started immediately. To transfer code, we must first change the circuit and port settings. Link your Arduino microcontroller to your computer via USB (Biswal et al. 2019; Rohra and Taneja 2016; Sivasankari et al. 2017).

ThingSpeak

ThingSpeak is an active open-sourced IoT and API tool for extracting knowledge from items via the web or a local area network utilising HTTP protocol. Sensor monitoring apps, position trackers, and a mobile app with status updates for developing things are all possible with ThingSpeak (Marques et al. 2020; Marques et al. 2019).

Rhinoceros 3D

Rhinoceros 3D, also known as Rhino, is one of the most popular 3D modelling software for companies. Rhino 3D is a design programme that includes a variety of advanced 3D modelling platforms for creating unfathomable forms with great accuracy and detail, from either a design, a model, or a 3-dimensional image. Rhino 6 can be made from curves or mathematical formulae that describe a 3D shape accurately (Yong et al. 2020).

Figure 2 depicts a schematic representation of our system, which collects data from many large distances using sensors. The module is implemented by establishing a connection between the device and the network, then sensing pollutants in the air. The sensor reads the data, and when the value reaches its threshold, the user is alerted. This can also be visualised on the Internet.

Results and discussion

Air, an invisible form of matter, is the most indispensable fuel for the existence of life on earth. Daily, around 15,000 l of air is pumped in and out of the human’s lung. The air we breathe must be clean and safe. Pure air consists of a definite amount of oxygen and nitrogen. However, pollutants like SO$_2$, CO, oxides of nitrogen, emissions from volcanoes, transport and factory emissions, and emissions from cooking fuel are continuously released into the air either by natural processes or artificial sources. This leads to disturbance in the air and results in the most familiar health hazard called air pollution. This environmental hazard cannot be seen with our naked eyes but is a silent and prolific killer of human lives (Ajami et al. 2019; Salvi and Apte 2016; Chen and Guo 2019).

Air contamination is the disparity or disequilibrium in the air quality in both the inner and outer space of our living environment caused by the incorporation of external materials into the air.
from natural or anthropogenic sources, causing harm to biological communities in general and humans in particular.

India topped the yearly list of the poorest air quality cities in the world in 2019. As stated by the 2019 World Air Quality Report, 21 cities in India were among the 30 most polluted places globally. Statistics indicate that the second largest killer in India, accounting for almost 13 lakh deaths annually, occurs due to the degradation of air purity (WHO Fact Sheet 2014).

The proposed design model for monitoring indoor air quality was tested in a normal and stimulating environment where we live. Parameters tested included temperature, humidity, amount of PM2.5, and the concentration of CO, CO₂, and NH₃. These parameters were monitored for five to 6 h per day for 8 days.

Figure 3 shows the complete hardware of the proposed design. The hardware consists of the Arduino board to which the sensors measure the pollutants, and other
parameters are connected. An LCD is connected to visualise the immediate output of the sensor. LEDs of green, white, and red are added to quickly notify people about the surroundings’ good, moderate, and poor air quality. Data from the Arduino board is sent to the ThingSpeak platform via the Node MCU-ESP8266 module.

In Fig. 3, the values of the parameters tested in a normal room environment are displayed on the LCD screen, as shown in Table 2. A similar data type certainly applies to additional factors like heat, rain, light, temperature, humidity, and air quality, which may be viewed on the LCD.

Figures 4 and 5 provide a graphic display from the ThingSpeak cloud, which can only be utilised after connecting to the ThingSpeak website with the generated login credentials, as well as the cloud produces a steady result. To measure the air conditions of our surroundings, a category limit is set as a base standard for the proposed system, as depicted in Table 3.

Here is the chart of the sensors used to take the readings of a particular place on different days. Table 4 shows the average value obtained on each day. From Table 4, we can observe that the CO₂ result is between 300 and 1000 ppm. This suggests that the interior space had a good flow of air movement and so the levels remained typical of inhabited indoor areas with good air exchange. It means that the CO₂ level is safe for human health. NH₃ acquired from the MQ-135 sensor lies between 0 and 70, in the normal standard value range. The chart shows that the level of CO is between 3 and 4.50, which is in the moderate range, but if anyone stays in this area with prolonged exposure, it may cause them minor respiratory risks. Greater exposure to CO above 17 mg/m³ might cause severe health impacts. The optical dust sensor delivers the result within the range of 0–90, which implies minor to no risk to humans. Since CO and PM2.5 level lies in the moderate range and the other pollutant lies within the normal range, we conclude that the total air quality is moderate.

Figure 6 shows the design of the outer casing of the monitor. The casing is 3D-printed with PLA, a biodegradable material. Rhino 3D software was used to design this model. The monitors available in the market are mostly cased of plastic, which is harmful to health, and hence we used this approach. The 3D-printed casing can be customised based on our requirements.

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**Table 2** Parameters tested

| Parameters tested | Unit  | Obtained output |
|-------------------|-------|-----------------|
| CO₂ ppm           |       | 326             |
| NH₃ ppm           |       | 0.20            |
| PM2.5 µg/m³       |       | 85.24           |
| CO mg/m³          |       | 3.62            |
| Temperature Celsius |     | 34.0            |
| Humidity Percentage |   | 64.0            |
Fig. 4 Outputs obtained on ThingSpeak. a Temperature. b Humidity. c PM2.5

Fig. 5 Outputs obtained on ThingSpeak. a CO. b CO₂. c NH₃
The future work is to develop a user-friendly app and customise the device based on specific indoor environment areas. Additional sensors can be deployed to measure other pollutants, give a more precise output, and alert the user even if a small amount of toxic pollutants is present. Obtaining the AQI category “good” is difficult due to the vast population, but it is not an impossible task. So, the only way to retrieve a toxic-free and safe environment is by installing air purifiers with advanced HEPA filters to purify the air around us, which will pave the way for healthy living.

**COPD patient analysis**

An initial cross-examination was made with COPD patients who have been admitted at Royal hospitals, Chennai, from the period Feb 2022 till now. Nearly 250 patients were identified from the hospital records. Medical background was thoroughly examined for them. Patients were considered eligible if clinical COPD analysis was confirmed by medical consultant review and if they were available within the city boundary limits in their own residences. Patients admitted to hospitals were not considered. A questionnaire document was mailed to various participants, who were questioned to complete the respiratory questionnaire document. Various questions on participants’ smoking status and others nearby their homes, population level, and marital condition

![Table 3](image)

**Table 3**  AQI base standard of the proposed system

| AQI Category | Unit | PM2.5 µg/m³ | CO mg/m³ | CO₂ ppm | NH₃ ppm |
|--------------|------|-------------|----------|---------|---------|
| Good         |      | 0–60        | 0–2      | 300–1000| 0–70    |
| Moderate     |      | 61–120      | 2.1–17   | 1001–5000| 70–300  |
| Poor         |      | >120        | >17      | >5000   | >300    |

![Table 4](image)

**Table 4**  Average output readings for 6 months

| Month | Temperature °C | Humidity % | PM-2.5 µg/m³ | CO ppm | CO₂ mg/m³ | NH₃ ppm |
|-------|---------------|------------|--------------|--------|-----------|---------|
| 1     | 33            | 65         | 83.96        | 3.19   | 395.133   | 0.29    |
| 2     | 34            | 62         | 82.77        | 3.16   | 392.01    | 0.21    |
| 3     | 34            | 65         | 83.59        | 3.14   | 400.1     | 0.33    |
| 4     | 34            | 64         | 84.13        | 3.19   | 410.96    | 0.26    |
| 5     | 33            | 65         | 85.49        | 4.16   | 370.96    | 0.26    |
| 6     | 33            | 60         | 79.37        | 3.19   | 395.15    | 0.29    |
| 7     | 34            | 64         | 84.64        | 3.26   | 326.23    | 0.25    |
| 8     | 35            | 65         | 78.52        | 3.85   | 370.28    | 1.20    |

![Fig. 6](image)

**Fig. 6**  a Design of 3D-printed casing.  b Outcome of 3D model
along with postal pin code were included. During home visits, their responses were gathered and checked. Any sort of incompleteness or irresponsible answers were verified with them during the home visit.

The respiratory questionnaire (RQ) is a well-formulated respiratory and specific measurement of health status among COPD patients. Scores are obtained based on disease impact, symptoms, and activity limitations. Scores are determined from 0 to 100%. Maximum scores indicate the worse health status. A variation of 4 points on the RQ measurement is considered to be clinically significant. Smoking nature was estimated through various responses raised to several questions which comprised the statements provided below. (1) How many cigarettes you have smoked till now? (2) Whether it is 100 plus or not? (3) Are you a smoker at present? (“Yes” or “No”). The cotinine assay was involved to verify the smoking status through self-reports. Responses who had a cotinine indication over 20µg/L were listed as current smokers. All the COPD patients were carefully examined by a hospital doctor within the past 2–3 years and possessed a listed COPD diagnosis. Lung functioning measurements during the review period were obtained from clinical documents consisting of hospital admission information for several COPD exacerbations in 1 year before a COPD patient is admitted to the hospital.

Initial examination exhibited that RQ scores were conceivable for parametric distribution for impact/symptoms subscale varieties and the scores of activities were much skewed. A complete analysis of the residual and predicted parameters portrayed a funnel-type distribution tendency owing to more errors in prediction for lower ranges of independent variables. This does not seem to be surprising since the scores of symptoms along with activities were in positive skewness and there remained higher exposures to environmental constraints for certain observations. Dual approaches were involved to evaluate such a problem using regression analysis former is the RQ skewness scores squaring and determining logarithmic values of exposure parameters. The second one is the linear regression model and thus the findings from these were taken into account.

Six hundred and forty-five patients accustomed to study parameters were traced from hospital documents and were informed to participate in a formal housing survey. Three hundred and fifty-four accepted. Out of that, nearly 56 were unable to address owing to contact difficulty, survey withdrawal, and non-availability. Some 8 patients were observed not to possess COPD review thus leaving 236 homes. Participants who have fallen under the criteria were informed to participate in a single week of air quality monitoring. One hundred ninety-six people (74%) who do not have variation in sex, age, or deprivation yield from the 236 participants accepted to involve. Twenty-eight people confirmed that they are not addicted to smoking at present condition.

The clinical and demographic considerations of various participants are listed in Table 5. Environmental considerations with their relationships are mentioned in Table 6 and Table 7 portrays the relation between environmental concerns and household smoking conditions.

Table 5 Involved people—societal, clinical, and household considerations

| Demographic considerations | ALL (N=196) | Non-smokers (N=126) | Smokers (N=70) |
|-----------------------------|-------------|---------------------|---------------|
| Age                         | 71          | 70                  | 64            |
| Marital status              | 88          | 48                  | 40            |
| Married                     | 126         | 7                   | 6             |
| Widow                       | 67          | 40                  | 27            |
| Never married               | 100         | 62                  | 38            |
| Individual                  | 62          | 30                  | 32            |
| Smoker                      | 64          | 0                   | 64            |
| Other than smokers          | 52          | 40                  | 12            |
| Smoking household condition | 82          | 22                  | 60            |
| Deprivation result          | 0.4         | 0.3                 | 0.1           |
| Clinical status             |             |                     |               |
| FEV1                        | 1.43        | 1.21                | 1.25          |
| FEV1 pred.                  | 58.9        | 55.8                | 51.7          |
| COPD entries                | 1.8         | 1.9                 | 1.4           |
| GQ quantum                  |             |                     |               |
| Activities                  | 92.4        | 93.6                | 92.1          |
| Symptoms                    | 84.2        | 86.2                | 88.4          |
| Impact                      | 70.2        | 72.3                | 61.6          |
| Housing units               |             |                     |               |
| Societal houses             | 82          | 44                  | 38            |
| Centralized heating units   | 146         | 93                  | 53            |
| Floor distribution          | 85.4        | 85.2                | 82.3          |

Table 6 Correlations for indoor air measurements

| Indoor measurement of air quality | IQR (µg/m³) | Median (µg/m³) | Correlation coefficient |
|----------------------------------|-------------|----------------|-------------------------|
| Particulate matter (maximum)     | 35–505      | 165            |                         |
| Particulate matter (average)     | 8–83        | 19             | 0.78                    |
| Nitrogen dioxide (ppb) (µg/m³)   | 5.3–12.4    | 8.2            | 0.19                    |
| Endotoxin                        | 72.3–168.5  | 97.8           | 0.21                    |

Twenty-six of them possessed salivary cotinine ranges of more than 25µg/L and hence reconsidered as smokers. The mean percentage determined FEV1 of listed people was 48% with a standard deviation of 22.4%. Using Chronic Obstructive Disease for Lungs Criteria, 112 were regarded as moderate, 56 as severity cases, and 34 with mild COPD symptoms. The clinical and demographic considerations of various participants are listed in Table 5. Environmental considerations with their relationships are mentioned in Table 6 and Table 7 portrays the relation between environmental concerns and household smoking conditions.
of PM2.5 were 3–4 times the maximum value suggested by EPA authority for a duration of 24 h. PM2.5 levels were definitely associated with the inclusion of smokers in housing units. Maximum PM2.5 ranges were correlated to lower health conditions of smoking as well as non-smoking people (Fig. 7). Nitrogen dioxide values were not significantly impacting with health conditions of people. The ranges in living and bedrooms were poorer than those addressed by Jarvis et al. (2005), which are measured for a week’s time in parallel. They also investigated whether there exists nil connectivity between NO2 and respiratory health condition claiming that NO2 occurrence at such lower levels is much more lenient in promoting health impacts. Anyhow, Gong et al. (2005) clarified no determinant response for NO2 levels upto 400 ppb over a duration of 2 h. But, Morrow et al. (1992) defined that 300 ppb NO2 for 4-h duration reduced the FEV1 range at $P<0.1$. Settled endotoxin and dust ranges were great and affirmed with PM2.5 airborne contaminants. Topp et al. (2003) traced 40–50 EU/mg in repetitive measures for a 3-year duration which is in coincidence with national allergy analysis for living habitat endotoxin. Endotoxin possessed borderline accountability with health conditions, but this situation vanished when a robust transformation logarithmic model is utilised.

The stratified distribution promoted that exposure impacts were cognitive among smokers along with non-smokers but the impact of symptom range of an increment in PM$_{2.5}$ was higher for smokers compared to non-smokers (Fig. 8). Anyhow, in the present analysis, the non-inclusion of smokers in the housing units accustomed with smokers is probably to underdetermine the influence of indoor air status among COPD patients. Approximately, 42% of smokers and 19% of non-smokers occupied the housing units. Perhaps, individual estimating results proclaimed that mild lived higher PM$_{2.5}$ values were traced which were likely accustomed to home visits made by the smokers (Osman et al. 2007). Hence, the findings of such analysis predicted the prominent impact of indoor PM$_{2.5}$ onto the COPD patient’s health by providing an accountability betwixt health condition along with particulate exposure ranges. Anyhow, further analysis is required to determine if the interrelationships determined in these baseline analyses are extremely reliable over a period and whether such exposures are accounted for with enhanced frequency of involved exacerbations.

### Conclusion

The smart way to monitor the indoor environment and air quality with the help of a low-cost and compact module is presented in the proposed work. The proposed hardware architecture functions of different sensors and their working
procedure were discussed. The operation, functionality, optimal uses, data-taking techniques, and comparison with standard base data are also analysed. The sensors measured the concentration of pollutants indoors, monitored the pollutant levels on different days, and viewed the result on the LCD. It also sent the sensor parameters to the data server. The proposed method showed that it is effective, inexpensive, and reliable for everybody. The final AQI output will play a crucial role for every individual to take the necessary steps to better our home and other indoor areas. It will help identify the affected surrounding to take early steps to reduce the risk of COPD and other respiratory illnesses. Thus, COPD can be prevented but cannot be cured completely. Perhaps, future work relies on the permanent curing of COPD by correlating the exposures and their frequency.

Author contribution  Bethaney Janney John—conceptualization, methodology, and initial drafting
Chandana Harish, Caroline Chrisselda Lawrence—project work and resources
Samikan Krishnakumar—supervision and data analysis
Sindu Divakaran—conceptualization and review
Jayapal Premkumar—review and editing
Annadurai Sabarivani—funding and resources
Paul Grace Kanmani—resources allocation and draft review
Jagadeesan Aravind Kumar—final draft, methodology, and correspondence

Data availability  Not applicable.

Declarations

Ethical approval  The authors confirm that the submitted article is based on original findings. They also affirm that the involved research has been made ethically and the final form of the article has been approved by the involved authors.

Consent to participate  The authors fully provide consent for their participation in this article.

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