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SHORT COMMUNICATION

Indoor air quality monitoring in urban areas using Smart Sensing Technology

P. Partheeban[1]*, R. Rani Hemamalini[2], B. Shanthini[3]

[1] *Department of civil Engineering, St. Peter's College of Engineering and Technology, Chennai, Tamil Nadu, India*

[2] *Department of Electrical and Electronics Engineering, St. Peter's Institute of Higher Education and Research, Chennai, Tamil Nadu, India*

[3] *Department of Information Technology, St. Peter's Institute of Higher Education and Research, Chennai, Tamil Nadu, India*

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ABSTRACT

Recently, indoor air quality has attracted the attention of policymakers and researchers as a critical issue like that of external air pollution. Indoor air quality is more important as people spend time longer indoors than outdoors. Indoor environments are closed compared to external environments providing less opportunity for the pollutants to dilute. The emissions contain many substances that are harmful to humans when exposed for a prolonged period or to certain levels of concentration. Internet of Things (IoT) technology is best and low-cost method of measuring air pollution. This paper proposes an IoT technology for an indoor air quality monitoring system to monitor urban homes. The pollution level observed in the Kodungayur (location 8) and Manali (location 9) exceeds the standards. Maximum outdoor pollution observed value of CO, SO2, NO2 and PM.25 are 9.2, 0.135, 0.102 and 0.215 respectively. Similarly, the indoor pollution levels are varying from 10% to 15 % lesser than that of the outdoor pollution values. The percentage of error varied from – 2.94% to + 2.94%. The percentage of error is within ± 5%, which shows its robustness. Outdoor air pollution does not influence indoor air pollution is the result of this study.

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INTRODUCTION

Indoor Air Quality (IAQ) refers to the nature of conditioned air that circulates throughout space/area where people work and live, that is, the air people breathe (Manoj Arya, 2011). IAQ refers not only to comfort, which is affected by temperature, humidity and odours but also to the harmful biological contaminants and chemicals present in the conditioned space. Indoor air pollution is recognised as a significant source of potential health risk (Gaurav Arora, 2018). Throughout the world, the population is exposed to such a health risk. Indoor air quality is a significant occupational health and safety concern. Energy conservation measures, instituted in the 1970s, often led to reduced intake of fresh outside air and thus increased the consequent build-up of internally generated pollutants including fungi, microbial contamination, house dust mites, particulates and toxic air contaminants (chemicals) - gases, vapours and odours. Indoor air quality depends on factors such as outdoor air quality and also on the design, maintenance and use of the buildings (Becher *et al*., 1996). Some of the causes of IAQ problems include (i) Airtight buildings that reduce energy consumption by Heating, Ventilation, and Air Conditioning (HVAC) systems (ii) Reduced intake of outside air (iii) Indoor

*Corresponding Author:
Email: *parthi011@yahoo.co.in*
Tel.: +91 9841159199
Fax: +91 44-26558091

environment – inadequate temperature, humidity, lighting, excessive noise (iv) Indoor air contaminants – chemicals, dust, moles, microbial contamination, gases, vapours, odours (v) Increase in the number of building occupants and time spent indoors. The Air Quality Index (AQI) is a rating scale for outdoor air suggested by the United States Environmental Protection Agency (US EPA) which is presented in Table 1.

Usually, air samples are collected using High Volume Samplers fixed at selected locations and the samples collected are tested at authorised laboratories using different techniques like Mass / Optical Spectroscopy, Gas Chromatography, Non-dispersive Infrared and Fourier Transform Infrared. The equipment above is expensive and involves lengthy procedures for the determination of concentrations of air pollutants. The proposed study uses the Internet of Things (IoT) technology to monitor air quality in an urban home. Further, this study aims to determine the relationship between indoor and outdoor concentrations on urban houses in the study area. An innovative approach to assess indoor air quality monitoring in urban housing is suggested in this study. The following are the objectives of the study:

- To design, develop and implement IoT technology to monitor the indoor air quality of the urban home.
- To conduct an Indoor Air Quality study in urban houses both inside and outside the house
- To suggest the best suitable measure to reduce indoor pollution

Air pollution has become a significant concern in India in recent years because that large parts of the Indian urban population is exposed to some of the highest pollutant levels in the world (Smith, 1991) and World Health Organization (Dietrich, 1999) health effects of air pollution have increased the hazard risks in major cities of India (Lippmann, 2009). Many cities in India have populations over 1 million, and some of them are ranked in the top 10 among the world's most polluted cities (Singh and Zubairul, 2012). Of the 3 million premature deaths in the world that occur each year due to outdoor and indoor air pollution, the highest number is assessed to happen in India (Singh and Zubairul, 2012). India has several pollution problems the most significant of which is air pollution. This is seen in the form of vehicular and industrial emissions. Continued urbanisation has exacerbated the problem of rapid industrialisation, as more and more people are adversely affected, and cities are unable to implement adequate pollution control mechanisms. There has been an exponential increase in the number of buildings, population density and number of motor vehicles. The industrialisation/ urbanisation process has had both positive and negative effects on IAQ in many cities of the world. People spend most of their time indoors; yet, most data on the concentrations of pollutants are based on measurements conducted outdoors, in one or more central monitoring sites. Outdoor pollutant concentrations may not be reliable indicators of indoor and personal pollutant sources (Wallace *et al*., 1997). Assessment of risk to the community resulting from exposure to airborne pollutants should ideally include measurements of concentration levels of the contaminants in all microenvironments, where people spend their time. Due to the multiplicity of different microenvironments, it is usually, however, not possible to conduct measurements in all of them. In many cases, the subdivision is between the indoor and outdoor environment, with questions posed as to

Table 1: Air quality index of air pollutants criteria

AQI Category	AQI Rating	PM_{10} (µg/m^3)	CO (ppm)	NO_2 (ppm)	SO_2 (ppm)
Very good (0-15)	A	0-50	0–2.0	0–0.02	0–0.02
Good (16-31)	B	51-75	2.1–4.0	0.02–0.03	0.02–0.03
Moderate (32-49)	C	76-100	4.1–6.0	0.03–0.04	0.03–0.04
Poor (50-99)	D	101-150	6.1–9.0	0.04–0.06	0.04–0.06
Very Poor (100 or over)	E	>150	>9.0	>0.06	>0.06

what extent indoor exposures could be predicted from measured concentrations of pollutants in outdoor pollutants (Morawska *et al*., 2001). Early studies on the relationship between indoor and outdoor pollutants conducted in the 1950s and summarised by Anderson, (1972) showed that there was a significant variation between indoor and outdoor ratio. Benson *et al*., (1972) concluded in their review that, in general, the ratios of indoor and outdoor pollutants concentrations were about 1. Pummakarnchana *et al*., (2005) think that economic growth and industrialization are proceeding at a rapid pace, accompanied by increase emissions of air polluting sources. They emphasize the urgent need for suitable monitoring systems to ensure timely detection of air pollution levels and for reliable quantification of polluting sources to prevent further deterioration in polluting standards. Prasad Raja, *et al.,* (2011) have attempted development of an effective solution for pollution monitoring using Wireless Sensor Networks (WSN) on a real-time basis, namely, real-time wireless air pollution monitoring system using commercially available discrete pre-calibrated gas sensors for sensing the concentration of gases like CO_2, NO_2, CO and O_2. These gas sensors were integrated with the wireless sensor motes/modules for field deployment at the Indian Institute of Technology, Hyderabad campus and the Hyderabad city using multi-hop data aggregation algorithm. A lightweight middleware and a web interface to view the live pollution data in the form of numbers and charts from the testbeds were developed. Prasad Raju and Partheeban (2014) conducted a study on Mobile Vehicular Air Pollution Monitoring Using GIS, GPS and Sensors at Ambattur in Chennai City. They used the device to monitor air quality at high traffic volume routes at Ambattur, Chennai. The average concentration of SO_2 varied between 0.009 and 0.033 ppm, NO_2 varied between 0.022 and 0.048 ppm, and CO ranged between 1.1 and 9.0 ppm. Benammar *et al*., (2018) conducted a study on A Modular IoT Platform for Real-Time Indoor Air Quality Monitoring. They developed an end-to-end IAQM system enabling measurement of CO_2, CO, SO_2, NO_2, O_3, Cl_2, ambient temperature, and relative humidity. They have monitored indoor air pollution for a week and concluded that the CO level is well below the standards. NO_2 values were very high than that of standards. Partheeban *et al*., (2018) have carried out a study on the Design and Implementation of Equipment for Air Quality Information Management System. The authors have designed and implemented an Air Quality Monitoring Instrument (AQMI) using solid-state gas sensors and GPS module and integrated it with the information management system. The AQMI was used to collect the air quality for some selected bus routes in Chennai city. The data collected in 2013 and 2017 were analyzed and generalized as air quality information management system. Esquiagola *et al*., (2018) have conducted a study on Monitoring Indoor Air Quality by using IoT Technology. They aimed to develop an IoT platform to monitor indoor air quality. They implemented on the Web of Things concept and used the Constrained Application Protocol (CoAP) to collect data from sensors. They deployed the system in an office and studied air quality behaviour during the day. It is learnt from the literature review that the air quality monitoring system can be designed and developed using IoT technology with the sensors, GIS, GPS and simultaneously information on the observed air pollution information that can be disseminated in real-time. Hence, it is proposed to carry out indoor air quality study in the Chennai Metropolitan Area using IoT Technology device connected with inputs, such as GPS receiver for identification of location (latitude and longitude, date and time) and five gas sensors CO_2, NO_2, SO_2, CO and PM2.5.

Rastogi et al., (2018) studied about the Solid-State Nuclear Track Detectors (SSNTDS) based twin-chamber dosimeter with LR-115 track detector for estimating Radon (222Rn) and Thoron (220Rn) gas concentration levels in the dwellings of Moradabad city. The total annual dose due to the exposure to radon was found to vary from3.7 to 6.2 mSv/y and thoron found to vary from 0.3 to 0.61 mSv/y. Assessment of indoor environmental impacts on human health was studied by Bano (2017) for the city Firozabad (India). He concluded that the high intensity of indoor pollution and disease are reported in peripheral and old parts of the city. Karbasi et.al (2019) conducted research to evaluate the personal exposure of benzene among the personnel working and living near oil pits. They concluded that the highest mean quantitative risk of cancers was observed in summer (1.21 ± 0.47). Mohammadizadeh et.al., (2016) have developed a hybrid model of Driving forces - Pressures - State - Impact - Responses (DPSIR) and fuzzy analytic hierarchy process (FAHP) to control air pollution for

Tehran. They have recorded the various factors top priority to improve air quality. A study on Prediction of energy consumption and urban air pollution reduction in e-shopping adoption by Tehrani et. al. (2009). The results of their study of 320,800 habitants and 87,241 persons possess private vehicles. Finally, they concluded that e-shopping can reduce air pollution and may lead to 71% energy saving. Tehrani and Karbassi (2005) Application of E-commerce in local home shopping and its consequences on energy consumption and air pollution reduction. They concluded that E-commerce might reduce energy consumption by 88% and air emission reduction by 20.12 tones/year.

The current study has been carried out in Chennai southern part of India and in 2018.

MATERIALS AND METHODS

The study area has taken in Chennai and formerly known as Madras, which is the capital of Tamil Nadu, India. It is located on the Coromandel Coast off the Bay of Bengal. It is one biggest industrial and commercial centre in South India and a significant cultural, economic and educational centre. Chennai lies on the thermal equator, and it is hot and humid for most of the year. The hottest part of the year is late May to early June with maximum temperatures around 35–40°C. The least temperature recorded is during January, with average temperatures around 15–22°C. Chennai has a diversified economic base anchored by automobile, software, hardware manufacturing, health care, financial services and industries.

Design, Development and Implementation of IoT System for Indoor Air Quality Monitoring

A system is designed and developed using IoT technology to monitor the indoor/outdoor air quality and is shown in Fig. 1. This IoT technology device consists of the solid-state gas sensor, Temperature, Humidity Sensor, Particle Matter Sensor and SIM808. Table 2 shows the various sensors used in this study and its characteristics.

Raspberry Pi 3 B+

The Raspberry Pi is a low-cost minicomputer of size 8.5 cm x 5 cm that plugs into a computer monitor or TV and uses a standard keyboard and mouse. This is a little capable device for all age groups to apply computing and programming in python. This device can also perform like that of computer such as browsing the internet, playing high-definition video, making spreadsheets, word-processing, and playing games (Halfacree, 2018). This can also be used for wide variety task such as digital maker projects, from music machines and parent detectors to weather stations and tweeting birdhouses with infra-red cameras. This device is also used by children to learn programming and understand how computers work.

SIM808 GSM Module

SIM808 module is a complete Quad-Band GSM/GPRS module which combines GPS technology for satellite navigation. The compact design which integrated GPRS and GPS in an SMT package will significantly save both time and costs for customers to develop GPS enabled applications (Uday Kumar Naidu and Prahlada Rao, 2017). The module consists of an industry-standard interface and provides GPS functioning as well. It also allows multiple assets to be tracked at any location and anytime with signal coverage.

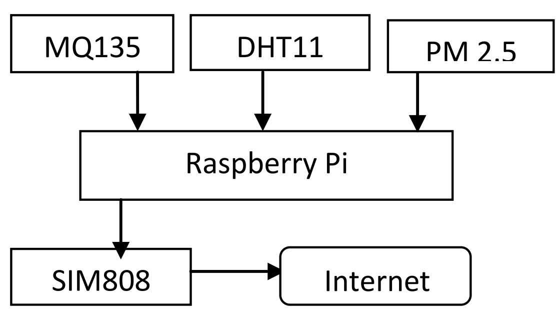


Fig. 1: Basic block diagram IoT device for air quality monitoring

Table 2: Sensors and Modules used in the Research and its Characteristics

Sensor/Module types	Sensor Characteristics
MQ135	Solid Electrolyte type for CO, NO, SO_2 detection
DHT11	Temperature and Humidity
SIM808	For Internet Connectivity & fetching Location Co-ordinates
PM 2.5 Sensor	Acquires the density of Dust Particles

MQ 135 Gas Sensor

The MQ-135 Gas sensors are used in air quality control equipment and are suitable for detecting or measuring of NH3, NOx, Alcohol, Benzene, Smoke and CO2. The MQ-135 sensor module comes with a Digital Pin, which makes this sensor to operate even without a microcontroller and that comes in handy when you are only trying to detect one particular gas. If you need to measure the gases in PPM the analog pin need to be used. The analog pin is TTL driven and works on 5V and so can be used with most common microcontrollers.

DHT11 Sensor

DHT11 is a Humidity and Temperature Sensor, which generates a calibrated digital output and can be connected to any popular microcontroller such as Arduino, Raspberry Pi, etc. and get instantaneous results. DHT11 also provides high reliability and long-term stability at very low costs (Deeksha, *et al.,* 2018).

PM 2.5 Sensor

Particulate matter (PM) describes the mixture of solid particles and liquid droplets in the air. It can be either human-made or naturally occurring. Some examples include dust, ash and sea-spray. Particulate matter is emitted during the combustion of solid and liquid fuels, such as for power generation, domestic heating and in vehicle engines. Particulate matter varies in size. PM 2.5 means the mass per cubic metre of air of particles with a diameter generally less than 2.5 µm. PM 2.5 is also known as fine particulate matter.

Description of Software

(a) Python

Python is an interpreted, high-level, general-purpose programming language which was created by Guido Van Rossum in the year 1991 (Balagurusamy, 2009). The design philosophy of Python emphasises on code readability and constructs that allow clear programming on any scale.

(b) Raspbian Operating System

Raspbian is a Debian-based computer operating system for Raspberry Pi. Multiple versions of Raspbian are present and this includes versions such as Raspbian Stretch and Raspbian Jessie. The Raspberry Pi Foundation have adopted Raspbian as their primary operating system since the year 2015 (Halfacree, 2018).

Software Architecture

The system software architecture consists of two layers: the physical layer and application layer.

(a) Physical Layer

This layer is responsible for acquiring the real-time data from the sensors and the physical location, time and date from the Internet using GSM Module. This information is encapsulated to the Raspberry Pi. Then the Raspberry Pi sends each frame to the GPRS interface, which is connected to Raspberry Pi for storage of data in the Internet server. The physical layer is implemented using Python language. The software applying the physical layer is composed of various functions that can be called from the main program, which is stored on and executed by the ARM7 Processor of the Raspberry Pi.

(b) Application Layer

The application layer is designed to have a website with a home page and a few web pages to log on, to see the pollutants' concentrations measured using the IoT system. The Central-Server (Third Party Hosting) is meant to collect and store pollutant data from the Raspberry Pi. This data can be retrieved at any time from the website (internet).

Quality Control (QC) and Quality Assurance (QA)

Sensors are calibrated before interfacing with the IoT device for precise measurements. The simulated data and real-time data were compared for the accuracy of sensors. Calibration by exposing the detectors to various gas levels was performed in the laboratory. Evaluations may include variable temperature and relative humidity conditions as well as introduction of known interfering pollutants. To validate the collected sensor data, have compared with the values measured by the Pollution Control Board data for the entire period with specific interval of time. All the data collected by the pollution control board are daily published and freely available on the website: http://aqicn.org/city/chennai//manali/.

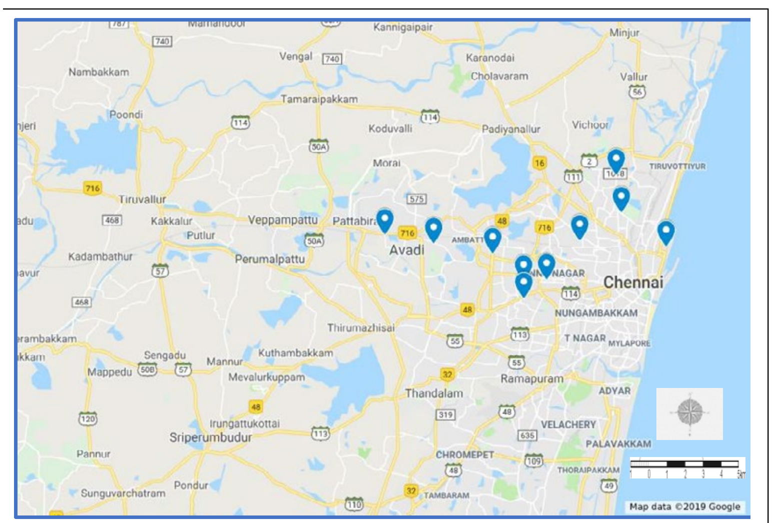
Data Collection Using IoT

In this study, locations for monitoring have been selected based on the factors of proximity high traffic intersection, industrial site, fully residential area, near education institutions, near seashore and solid waste disposal area. The observations of air pollution were conducted using IoT monitoring system at selected ten locations in the study area. On each location, five houses were selected to monitor the air quality inside and outside the houses.

Five houses were also selected in these ten locations were based on different types of house and types of indoor activity. Two types of monitoring have been carried out to find out the relationship between indoor and outdoor air pollutions in the study area. One of these is static monitoring at selected locations inside the houses and others outside the houses. The locations of the houses selected in the study area are shown in Fig. 2. The reason for taking different location in the study is to find out the external environment how much contributes to the indoor

India

Tamilnadu



Chennai

Fig. 2: Study Area Map Showing the location of Air Quality Monitoring

environment. The current study has been carried out in Chennai southern part of India and in 2018.

RESULTS AND DISCUSSIONS

CO, SO_2, NO_2 and PM2.5 concentrations monitored at indoor and outdoor for ten different locations (five houses in each location) are presented in Figs. 3, 4 5 and 6. At outdoor in location 2 (Ambattur) CO concentration is moderate level, but in location 7 (Kodugaiyur) and 8 (Manali) CO concentration is very poor. Indoor CO concentration is moderate at location 7 (Kodugaiyur), and 8 (Manali) and other locations are good. The main cause of this pollution of the 2 location CO concentration is due to the industrial and solid waste disposal areas. SO_2 outdoor concentration levels in 7 locations were within the ambient range, while 3 locations are above the ambient range. Regarding the indoor SO_2 concentration except locations 7 and eight are higher than the ambient values. NO_2 outdoor concentration levels in 8 locations are within the ambient range, while 2 locations are above the ambient range. Regarding the indoor NO_2 concentration except location 8 is higher than the ambient values._Regarding PM2.5 monitoring at Kodugnayur and Manlai locations the pollution level is higher than standards due to the location characteristics. These two locations are more industries and solid waste dump sites are located. Indoor air pollution concentration is affected in some cases due to the type of house and kind of ventilation. In some cases, not showing variation indoor variations are not much appreciable. It is

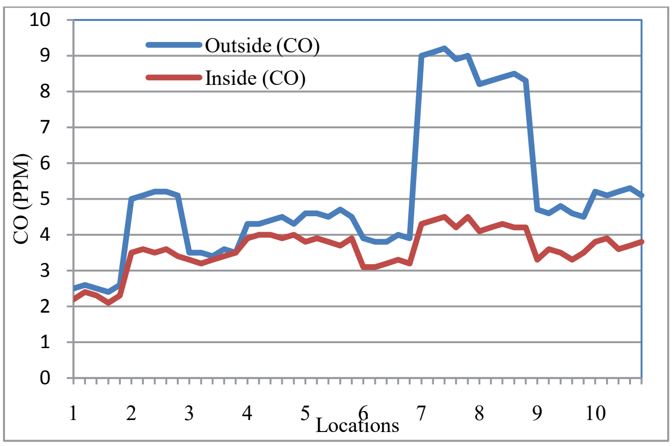


Fig. 3: Monitored CO Concentration Inside and Outside of Houses 10 Locations in the Study Area

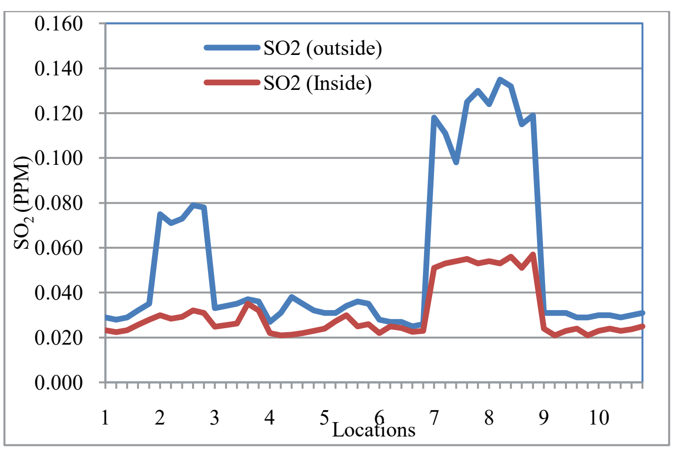


Fig. 4: Monitored SO_2 Concentrations Inside and Outside of Houses 10 Locations in the Study Area

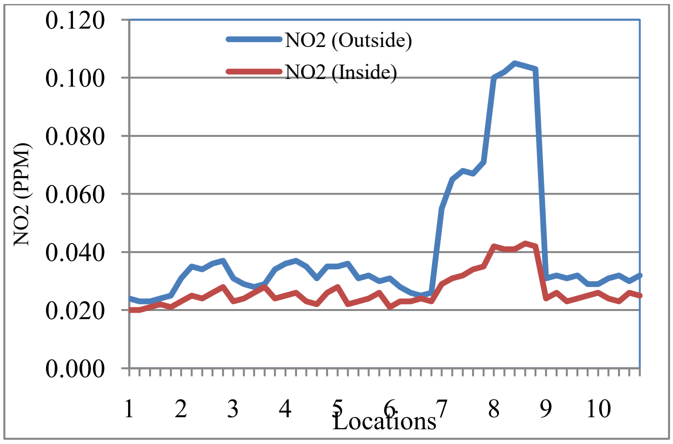


Fig. 5: Monitored NO_2 Concentrations Inside and Outside of Houses 10 Locations in the Study Area

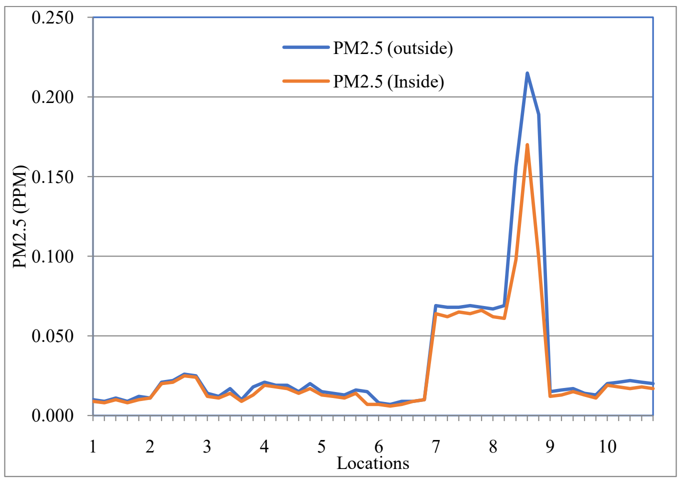


Fig. 6: Monitored PM2.5 Concentrations Inside and Outside of Houses 10 Locations in the Study Area

mainly due to the house doors that are for most of the times closed. It is seen from the observations that the effect of outdoor pollution has less impact on indoor pollution in the residential areas. But in industrial sectors and solid waste disposal sites have a higher impact on indoor pollution. An opinion survey was conducted to know about outdoor air pollution problems and their effects on human health.

A survey was conducted for the same 50 houses. From the opinion survey, 68% of people responded that outdoor pollution is a major cause of health effects. 25% responded that their outdoor is good, but indoor pollution affects health. 7% of them are not aware of the pollutions. In the opinion survey, the residence from the solid waste and industrial locations said that the indoor air pollution level is less due to closed doors mostly. Similarly, many of them in industrial location use air conditioners for their houses to protect themselves from air pollution. The pollutants are also monitored and analysed for these houses. The study was carried out using the IoT technology-based air quality monitoring system with sensors. This system collects a reliable source of real-time pollution data. This method of air pollution monitoring is a simple, less expensive and facilitating measurement in real-time. Nowadays, switching over to this method from the conventional method of monitoring in many urban areas all over the world is

Table 3: Comparison of CO concentrations observed from Optima Gas Analyser and IoT Device

S. No.	The concentration of CO in ppm		Error in %
	Gas Analyser	IoT Device	
1	3.4	3.5	+2.94
2	3.5	3.4	- 2.94
3	3.5	3.4	-2.94
4	3.5	3.6	+2.85
5	3.5	3.4	+ 2.94
6	3.4	3.4	0

very much desired and tried. Optima 7 gas analyser was used to validate the IoT device monitored air quality data. Optima 7 gas analyser and IoT device were fixed at same location (Avadi) and data were collected (Table 3) from both device for validation. The IoT technology-based air quality data was compared with gas analyser data. The percentage of error varied from – 2.94% to + 2.94%. The percentage of error is within ± 5%, which shows its robustness. AQI values arrived for Chennai city at the outdoor is 425 and in the indoor is 283.33.

CONCLUSIONS

The gaseous pollutants present in the atmosphere and indoor are very significant in urban areas due to their adverse impact on human health and properties. One of the major challenges to air quality management is related to adequate quantification of both the spatial and temporal variations of pollutants to implement necessary mitigation measures. The spatial and temporal variations of pollutant data obtained from this study will help the authorities to manage the air pollution problem. Therefore, with the rapid development of micro-electro-mechanical systems and wireless network technology, the creation of cost-effective and low power air quality monitoring systems has been useful. The integration of an air pollutant monitoring system with IoT technology and sensors with wireless network technology will reduce the installation cost and enables quick and easy acquisition of data and reconfiguration of air pollution control systems and implementation of mitigation measures. Some advantages of IoT technology-based air quality monitoring system includes Quick and easy acquisition of information on air pollution, Large area coverage in a short duration and easy to monitor, compact and portable, no skilled personnel required and Pollution warnings via e-mail or SMS. Government decisions regarding the design and use of public street space should be made giving priority to pedestrians, cyclists and public transport. Government officials (civic body) should ensure that the width of carriageways and other street elements in the street design is based on the function of the street rather than what is available as right-of-way on the street stretch. The newly developing and planned streets should support multiple uses, and provide safe, active and ample space to pedestrians, cyclists and public transport. Air pollutants ($PM_{2.5}$, CO, CO_2, SO_2, NO_2, temperature and humidity) inside and outside of selected urban houses were monitored using IoT technology. $PM_{2.5}$ concentration found was considerably higher near the high traffic junction houses and solid waste disposal sites. Furthermore, indoor air pollution was found to be affected due to activity in the house. In some houses, the effect of outdoor activities was not affected due to the closed doors for most of the times. It was found that most of the locations the indoor $PM_{2.5}$ levels we're exceeding the standards. Hence this study gives the rough idea to manage the various factors contributing to indoor air pollution levels in the urban houses.

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CONFLICT OF INTREST

The author declares that there is no conflict of interests regarding the publication of this manuscript. Besides, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

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