Applications of IoT in Indoor Air Quality Monitoring Systems

Jagriti Saini and Maitreyee Dutta

Abstract This book chapter explores the applications of the Internet of Things (IoT) in the Indoor Air Quality (IAQ) monitoring systems. Indoor air pollution is an important area of concern for most developing countries as it is directly related to mortality and morbidity. Around 3 billion people throughout the world use coal and biomass (crop residues, wood, dung, and charcoal) as the primary source of domestic energy. Moreover, humans spend 80–90% of their routine time indoors, so indoor air quality leaves a direct impact on overall health and work efficiency. This book chapter provides insights into the implementation of high-performance IAQ monitoring systems using IoT. Being the most emerging technology in the world, IoT has huge potential to mitigate the challenges associated with designing efficient and reliable real-time monitoring systems. The ultimate goal of this extensive analysis is to provide a detailed study on factors associated with indoor air pollution, public health, the current status of research, associated challenges, and possible research recommendations from the IoT world. After going through this chapter, readers will gain a deep understanding of the development of feature-rich and cost-effective IAQ monitoring systems using IoT.

Keywords Indoor air pollution · Internet of things · Work efficiency · Developing countries · Public health

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1 Introduction

The Internet of things, or in short IoT, is all about extending the potential of the Internet beyond smartphones and computers to cover the entire range of processes, things, and environments. Those wirelessly connected things can share information both ways by working as a transmitter and receiver as well. In general, IoT provides a network to people and businesses to stay connected with the world around them while producing more meaningful results.

Getting connected through the Internet is probably the most wonderful thing for the current generation. It gives us plenty of benefits that were beyond imagination before. Although IoT appears a pretty simple concept: "connecting the world to the Internet", it has the potential to make the world act smartly and being smart is always good. There are unlimited applications of IoT, the most amazing ones are in the field of disaster management, health care management, smart farming, smart energy management, smart transport facilities, and smart homes as well.

In this chapter, we are mainly focusing on using IoT for Indoor Air Quality (IAQ) Monitoring, one of the essential applications for occupational health and pollution control. Human beings spend 80–90% of their routine time indoors, so IAQ leaves a direct impact on overall health and work efficiency as well. Moreover, 90% of the rural households in the most developing countries and around 50% of the world's population makes use of unprocessed biomass for open fires and poorly functioning cooking stoves indoors. Indoor Air Pollution (IAP) is an important area of concern for most developing countries as it is directly related to mortality and morbidity. This chapter presents an in-depth study on the development of Indoor Air Pollution Monitoring (IAPM) system using IoT technology.

The first section of this chapter covers the basics of IoT. It will provide readers with some valuable insights about the history of IoT along with its potential to serve almost every sector with advanced applications in the coming years. The second section introduces factors affecting IAP and associated medical health issues. It will also describe the motivation behind the development of IAPM systems. The third section provides an in-depth survey on existing IAQM systems along with the gap in the literature. This section will help readers to understand new opportunities and challenges in the field of IAPM system development.

This chapter is focused on developing a clear understanding among new age researchers about the development of IAPM systems using IoT technology.

2 Basic Concepts of IoT

Well, defining Internet of things is the real challenge; probably due to the newness of this domain and the wide range of possibilities associated with it. IoT is not just about any one type of hardware; rather it represents a unique combination of a variety of hardware units that are otherwise existing as unconnected units in the world. Some experts define it as a system of some interrelated computing devices, objects, people, animals, and digital and mechanical machines that communicate through Unique Identifiers (UIDs). The things connected through this network have the potential to communicate data without requiring any human to a computer or human-to-human interaction. Note that a "thing" in teams of IoT can be a person carrying heart monitor implant in his body, a farm animal with some biochip transponder, some vehicle with built-in sensors that send alert signals to the driver on road or any other man-made as well as natural object. However, in order to transfer data over a dedicated network, the object or thing is desired to have an IP address [1].

In most cases, communication through IoT networks is completed through RFID tags, although the goal can be also accomplished through QR codes and other wireless technologies. IoT has more significance in our life because it gives a different ability to the nonliving objects as well by assigning them a digital identity. When many such objects in the IoT world act in unison, they are supposed to have ambient intelligence.

2.1 History of IoT

The term IoT was coined in the year 1999 by the executive director and co-founder of Massachusetts Institute of Technology's Auto-ID Center, Kevin Ashton. The organization was later replaced by research-oriented Auto-ID Labs in the year 2003. The term Internet of things was seen for the first time as the title of a presentation that Ashton made for Procter and Gamble when he was working as a brand manager in that company. Before presenting his work to the senior executives of the Procter and Gamble, Ashton came to know that certain shade of lipstick from the list of cosmetics that he was supposed to launch got sold out at a fast rate from local stores. With that incident, Ashton started thinking hard about how the products in the line can be made trackable so that one can get an instant update about their availability at a specific time. At the same time, the market was getting influenced by the efficiency of RFID tags that could transfer data wirelessly to the dedicated systems. Ultimately, the project that Ashton presented to Procter and Gamble proposed the idea of using RFID tags to manage the supply chain of the corporation so that stock, as well as store location of all items, can be monitored with higher accuracy [2].

With a simple analysis of the product line, Ashton gave the world an idea about developing a technology that can build direct connections between almost anything around. After getting inspired through this idea, LG Electronics in the year 2000 designed a refrigerator with a connection to the Internet. This product was named as Internet Digital DIOS Refrigerator, and it was capable enough to keep perfect track of all the food items stored inside. By scanning the respective RFID tags of each item inside the refrigerator, the system was even able to provide direct insights about the quantity as well. Sadly, the company was not able to make considerable profits for this product as people found it much expensive to buy at that time. But this advanced and feature-rich refrigerator provided a way to connect various household objects and gadgets together to the Internet [3]. Since then, IoT technology experienced huge growth in the market starting from the connections between few hosts to a network of billions of interconnected devices. As per the current scenario, the number of closely connected things to the Internet is quite high as compared to the numbers of people connected on this planet. By the year 2020, this connectivity is believed to experience the estimated growth of 24 billion devices.

2.2 IoT: Everywhere Around Us

There is no doubt to say that IoT has revolutionized our lifestyles—it is working actively almost everywhere in this world. In simple terms, IoT is a new wearable, portable, implantable, and connected universe that transforms various physical objects into a potential ecosystem of valuable information. IoT technology has changed the way we used to perform our routine work a few years ago; today, it is showing its impact on almost every industry [4] (Fig. 1).

Below is the list of impressive applications of IoT from the world around us:

- IoT technology is the most efficient solution to design smart parking with the ability to monitor all parking spaces in the city.

Fig. 1 Applications of IoT [5]

- It works for structural health improvement by monitoring material conditions and vibration levels in buildings, historical monuments, and bridges as well.
- Real-time sound monitoring applications at centric zones and bar areas.
- Detect any Android device, iPhone, or any other gadget that works with Bluetooth and Wi-Fi interfaces.
- Easy measurement of radiations from Wi-Fi routers and cell stations.
- Efficient monitoring of pedestrian levels and vehicles on the road to optimize walking routes and driving tracks.
- Smart lighting solutions for streets with weather adaptive and intelligent features.
- Automated waste management systems with highly optimized trash collection routes.
- Intelligent highways with quick alert systems for adverse climate conditions, diversions, and traffic jams to improve transportation experience.
- Monitoring of preemptive fire conditions and combustion gases to define alert zones in forests.
- Air pollution management by controlling CO_2 emissions, farm generated toxic gases, and vehicle pollution as well.
- IoT systems can monitor avalanche conditions and quality of ski tracks to ensure higher safety.
- Monitoring land conditions to detect dangerous patterns related to vibrations, soil moisture, and earth density as well.
- Early detection of the earthquake so that losses can be minimized or avoided at target locations.
- Ability to monitor the quality of tap water in overcrowded cities.
- A detection system for factory generated wastes and leakages into rivers and sea areas.
- Controlling swimming pool conditions from remote locations to ensure a safe experience to the community.
- Monitoring and detection of liquid outside tanks to avoid water leakage while controlling the pressure variations within the pipes.
- Active monitoring of variations in water level at reservoirs, dams, and rivers as well.
- Smart grid designs to lead efficient monitoring and management of energy consumption.
- Radiation measurement at nuclear power stations to generate leakage alert from time to time.
- Detection of hazardous and explosive gases around chemical factories and mines as well.
- Ability to track products in the supply chains to ensure proper inventory in the big industries.
- IoT leads to awesome shopping experience as per unique customer habits, preferences, likes, and dislikes.
- Temperature controlling in an industrial environment, health centers, and sensitive merchandise.

- IAQ monitoring to ensure safe work conditions without deteriorating health of occupants.
- Greenhouse development with efficient control of micro-climate conditions to maximize the production of vegetables and fruits.
- Product quality testing systems to ensure quality designs.
- Animal tracking, offspring care, and monitoring of toxic gas levels with smart farming solutions.
- Smart home design with remote controlled appliances, intrusion detection systems, energy, and water consumption monitoring.
- Advanced patient surveillance systems, fall detection, sportsmen care, and measurement of ultraviolet radiations to create healthy living conditions.

In short, IoT is everywhere around us, and it has the potential to automate our life with the highly efficient interconnection of objects to the Internet.

2.3 Extensively Growing IoT Market: The Stats

The wide range of applications draws attention to the market share of IoT that has an extensive growth rate in coming years. In the year 2011, the market value of IoT technology was observed somewhere around $44.0 billion. However, the comprehensive market research performed by RnRMarketSearch reveals that IoT and M2M market share will grow beyond $498.92 billion by the end of 2019 and this market is expected to hit $1423.09 billion in the year 2020. Moreover, the Internet of Nano Things (IoNT) is also playing an impressive role in the market and is expected to hold the value of around $9.69 billion by the end of the year 2020. Furthermore, the information-sharing practices and cooperation among leading companies in the IoT sector such as Ecobee Inc., Fujitsu, ARM, Intel, Cisco, Samsung, Google, IBM, and Microsoft along with the small business communities are expected to boost the market growth and IoT adoption rate by a great extent. Reports reveal that the numbers of connected devices in the year 2014 were only 6033.63 million; in the year 2017, this count reached 13,142.30 million and the growth is expected to cross the range of 27,858.35 million connected devices by the year 2020 [4].

3 Indoor Air Quality

3.1 Background

Several decades ago, when human beings first moved to the temperate climates, the problem of IAP started affecting the lifestyle. In the prehistoric times, during the growth stage of humanity, people started feeling the importance of comfortable shelters. They also started using fire for cooking, warmth, and light; however, it was later observed that soot found in various prehistoric caves is the primary cause of environmental pollution [6]. Today as well, more than 90% of people in the rural areas of developing countries or even approximately 50% of the world's population use unprocessed biomass for open fires and poorly functioning cooking stoves. These inadequate methods of cooking lead to IAP while affecting the overall health of women and young children who spend much of their routine time in the polluted environment [7]. Biomass and coal smoke carry various harmful pollutants such as Particulate Matter (PM), Sulfur Oxides (SO_x), Nitrogen Dioxide (NO_2), polycyclic organic matter, Carbon Monoxide (CO), and formaldehyde [8, 9]. Routine combustion of solid fuels causes repeated exposure to IAP, and it is considered as the common cause behind harmful diseases in developing countries. Some of the most common diseases spread by IAP are Acute Respiratory Infections (ARI), Chronic Obstructive Pulmonary Disease (COPD), asthma, otitis media, tuberculosis, low birth rate, lung cancer, cancer of larynx and nasopharynx, perinatal conditions, and severe eye diseases that can further lead to permanent blindness [6, 10].

The impact of modernization leads to a significant shift in cooking and heating practices. Instead of using biomass fuels such as petroleum products and wood, people are now buying electricity-based appliances. In the early 1900s, biomass fuels used to drive approximately 50% of global energy proportion. However, in the year 2000, it was significantly reduced to only 13%. It is believed that the types of fuels typically used for household needs can become more efficient and cleaner only if people start moving upward on the energy ladder. Note that animal dung is the lowest level of this ladder and the successive steps are built with crop residues, wood, charcoal, kerosene, gas, and electricity [9]. The energy ladder diagram is shown in Fig. 2. People try to move upward on this energy ladder with the changing socioeconomic conditions and lifestyle habits, but it is observed that poverty is the principal hurdle in shifting toward cleaner fuels. Sadly, the slower development cycles in many corners of the world show that the consumption of biomass fuels will continue in poor households even for the decades ahead.

One of the essential factors associated with the measurement of IAQ is ventilation; in general, it can be defined as the circulation of air into the closed structures from the outside world. In the case of poor ventilation arrangements within buildings, the IAQ levels fall below the threshold, and the indoor premises become unhealthy to live. Studies reveal IAP associated with poor ventilation arrangements is observed as the primary cause of increasing health issues. Approximately 66 percent of households in the rural and 44 percent of households in the urban areas are suffering from poor ventilation arrangements. Some stats about IAP are shown in Fig. 3. One of the prime reasons for the improved housing conditions in the urban areas as compared to the rural ones is the better educational and occupational status. These conditions have a direct relationship with the fuel selection for cooking and consequently leave a considerable impact on IAQ.

Stats reveal that poor IAQ is the second major cause behind the higher mortality rate in India. It leads to more than 1.3 million deaths per year in the country. Note that almost 70% of the population in India belongs to rural areas, out of which almost 80% are dependent on biomass fuel to fulfill their routine household requirements. Clearly,

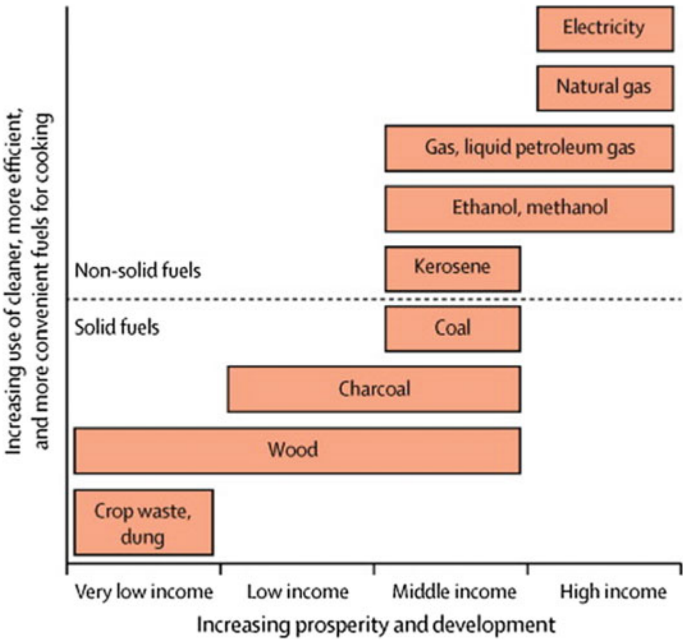
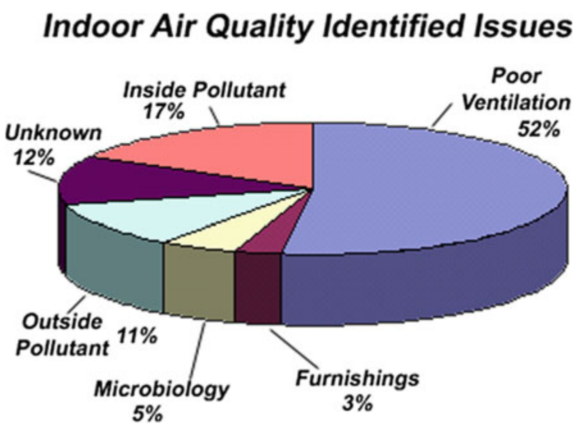


Fig. 2 Energy ladder diagram [11]

Fig. 3 Stats about indoor air quality [12]



the largest population in the nation lacks access to efficient sources of fuel to meet their cooking needs. In developing countries, excessive use of kerosene and biomass fuels is the prime reason behind stillbirth. In India itself, it is possible to reduce cases of stillbirths by 12% by just switching to cleaner fuel consumption in the household. Similar studies conducted in other developing countries such as Bangladesh, Kenya, Nepal, and Peru reveal that IAP is leading to serious health hazards. Hence, it is important to address the challenges, especially for indoor cooking practices in rural areas. As a lack of awareness about the benefits of cleaner cooking solutions is the main cause of adverse health conditions, it is important to train the affected sectors to improve their lifestyle. At the same time, experts need to work for the development of some efficient and affordable household cooking solutions so that traditional stoves can be avoided. Note that it can be done only if we study the behavioral patterns of the low-income population in the affected parts of the world.

The upliftment in economic conditions contributes to a reduction in IAP caused by harmful biomass fuels. However, there are few adverse effects of the modern lifestyle as well. It is observed that with the improvement in the living standards, instead of using natural ventilation systems, modern homes are furnished with indoor heating and cooling systems [9]. This scenario is further contributing to Sick Building Syndrome (SBS), and terribly, the cases of SBS have increased from 30% to 200% in just a few years [13]. Some of the most common factors affecting the indoor environment in the buildings include the rate of air exchange, temperature, humidity, ventilation, particle pollutants, biological pollutants, and gaseous pollutants. The modern homes are more airtight and packed with advanced insulation materials. Although they help to reduce the energy losses and may save on electricity bills, sadly, it leads to a reduction in the fresh air circulation in the premises. At the same time, the increasing consumption of synthetic materials and chemical products in residential and commercial buildings give rise to Volatile Organic Compounds (VOC). It is also considered as the principal causes of compound hypersensitiveness [14]. Hence, it is fair to say that even with the improved lifestyle and economic conditions, we are still unsafe from hazards associated with IAP.

Numerous researchers around the world these days are working for the development of efficient IAQM systems to deal with the increased cases of mortality and morbidity due to IAP. As the maximum population in the world spend 80% to 90% of their time indoors while working at home or in offices; it is necessary to take immediate steps to improve the IAQ. The idea is to identify some healthy solutions that can contribute to enhancement of living environment while reducing the chances of medical health consequences.

3.2 Medical Health Consequences

When we talk about health hazards associated with indoor air environment, it relates to every unusual suspended material that may interfere with the normal functionality of organs; all such elements are termed as air toxicants. Also, the estimation for IAP and health hazards cannot be determined by just calculating pollution levels; rather it is greatly affected by the average time that a person spends indoors while breathing in the polluted air. Medical health professionals and researchers have reported the occurrence of several harmful diseases due to IAP. Hence, in order to improve building environment and health conditions for occupations, it is important to work on the ultrafine indoor particles, their impact on the environment as well as on the living beings. The sections below describe some of the most common health hazards associated with IAP.

- *Respiratory illness*

It is well understood that most of the air pollutants find their way to the human body through airways; the respiratory system is on high risk due to poor IAQ. Depending upon the level of exposure to the pollutants and their deposition on the target cells, they may cause severe damage to the respiratory system. Acute lower respiratory infections are the main cause of mortality in kids; stats reveal that almost 2 million children below 5 years age group die per year just because of poor IAQ. Also, the repeated exposure to IAP in households in developing countries leads to several cases of acute law respiratory infections per year [15–17]. Biomass fuel smoke is another common cause of acute respiratory illness in kids; it leaves a major impact on the upper respiratory tract. It further leads to some disturbances in voice. Studies reveal that middle ear infection is an uncommon fatal symptom of this disease; however, it can also lead to morbidity, and deafness, etc. If this health issue is not treated on time; it may even cause mastoiditis [18], lung cancer and asthma [19]. The potential air pollutants such as PMs and many other respirable chemicals as like O_3, dust, benzene, etc., can cause serious trouble to the respiratory tract.

- *Cardiovascular dysfunctions*

Numbers of epidemiologic and experimental studies have proven a direct connection between IAP and cardiac-related illness [20, 21]. These harmful air pollutants also cause some unwanted alterations in the count of white blood cells that ultimately affect the normal functionality of the cardiovascular system. On the other hand, the studies conducted on animal models describe a close relationship between IAP and hypertension [22]. The higher concentration of NO_2 in the building environment hampers left and right ventricular hypertrophy. Various findings report the high risk of potential diseases due to repeated exposure to combustion of kerosene/diesel; however, such issues can be easily eliminated by using a clean cooking solution in the households. As per the experiments conducted in the rural households, the estimated increase of 10% was observed for cardiovascular mortality in 10 years; however, it was reduced to 6% in the areas where primary sources of cooking are gas or cleaner fuel [23].

- *Neuropsychiatric complications*

There is a strong relationship between air suspended toxic materials and nervous system performance; these harmful substances cause long-term damage to the nerves. People who spend more time in the toxic indoor air are likely to suffer psychiatric disorders and neurological complications. Some of the most common psychiatric disorders include aggression, antisocial behaviors, and stress, whereas neurological impairment includes some devastating consequences that are more common among infants. Terribly, IAP also leads to age-inappropriate behaviors, neurological hyperactivity, the risk of neuroinflammation [24], Parkinson's disease, and Alzheimer's disease [25].

- *Chronic pulmonary disease*

As per a study conducted on indoor biomass smoke pollution in New Guinea, communities were observed to report higher cases of chronic pulmonary disease [26]. Chronic Obstructive Pulmonary Disease (COPD) can be defined as a progressive inflammatory condition of pulmonary vessels, lung parenchyma, and airways; it is reported as a third common cause of death and fifth most reported the cause of disability worldwide. People who breath more often in the areas with higher combustion of solid fuels are likely to suffer severe damage to the lungs. That is why woman and kids that spend more time indoors are found to be at higher risk of COPD [18].

- *Cancer*

One of the main causes behind increasing cases of lung cancer worldwide is the repeated exposure to tobacco smoke. But as per studies carried by health professionals, even nonsmokers, especially woman, in the developing countries are also affected by lung cancer. Around two-thirds of female lung cancer patients in India [27], Mexico [28], and China [29] were nonsmokers. The Chinese population is highly affected by lung cancer. As per a study conducted in the year 2008, the estimated number of deaths in China due to lung cancer were 452,813, whereas the newly reported cases were somewhere around 522,050 [30]. The major cause behind woman suffering from lung cancer in China was observed to be the repeated and excessive exposure to coal smoke while cooking. Low-income population in China make use of smoky coal, and it is found to be highly carcinogenic as compared to wood smoke and cleaner coal. One study shows that cooking for three hours in biomass smoke exposes a woman to an equal amount of benzo[a]pyrene that is otherwise caused by smoking of two packets of cigarettes per day [18].

- *Pulmonary tuberculosis*

A recent study carried on approximately 200,000 Indian adults; researchers found a close association between wood smoke exposure and self-reported tuberculosis [31]. Generally, people who use biomass for burning needs are at higher risk of tuberculosis as compared to those who make use of cleaner fuels; the ratio of odds for this study is 2:58 (1.98–3.37) with appropriate adjustment of socioeconomic factors. These findings are quite similar to the studies carried on North India that describe a direct connection between biomass fuel and tuberculosis.

- *Low birth rate and infant mortality*

As per a recent study carried on rural areas of Guatemala with adequate adjustment of various maternal and socioeconomic factors, women that spend more time in wood fuel conditions were observed to deliver babies with 63 grams lesser weight as that of the women that use electricity and gas for cooking needs. Although there are limited evidence in support of this fact, some researchers observed that tobacco smoke and increased exposure to carbon monoxide are the prime reasons behind this condition. It is well proven that the concentration of carbon monoxide usually goes higher in households where biomass fuels are commonly used. Some evidence also links ambient air pollution to lesser birth weight [32, 33]; however, only one study shows a direct relationship with carbon monoxide [34]. The worldwide burden of mortality attributes to the IAP; stats collected in the year 2012 reveal almost 4.3 million deaths along with 7.7% of global mortality.

- *Cataract*

Biomass fuel combustion is the primary cause of eye irritation, and the excessive exposure may even lead to cataracts [35]; cases of cataracts are quite high in developing countries where most of the population is dependent on solid fuels for their routine cooking and heating needs [36]. Various epidemiological studies from India and Nepal also demonstrate poor indoor cooking standards as the main cause of blindness and cataracts. A recent study carried out in the hospital at Delhi evidenced a direct relationship of liquid petroleum gas with the development of nuclear, cortical, and mixed cataract; however, most cases of posterior subcapsular cataracts are reported due to repeated exposure to wood and cow dung [37]. In developing countries, the main cause of increasing cases of cataracts is the lack of awareness and knowledge about factors that have a direct impact on vision. During a study on 89,000 households in India, the estimated odds ratio of 1:3 was observed for blindness in females who use biomass fuel in the home [18].

- *Sick building syndrome*

As people spend most of their time indoors, IAQ has a direct connection with Sick Building Syndrome (SBS); commonly, it happens due to insufficient ventilation arrangement in the living spaces. Chemical contaminants that lead to considerable emission of VOCs in the building environment include upholstered furniture, cleaning agents, carpeting, adhesives, and paint. VOCs are considered as a primary cause of SBS with symptoms like mental fatigue, dizziness, headache, skin irritation, nausea, eye irritation, and difficulty in concentrating as well. Other than this, factors that contribute to SBS are dust, mold, harmful organisms, toxic gases, bacteria, chemical vapors, harmful compounds, etc. [38].

It is observed that rural women suffer more due to IAP than urban women due to the improved quality of living standards. The lack of knowledge and the unavailability of essential resources make it difficult for the rural woman to improve health conditions.

3.3 Motivation for the Design

As described in Sect. 3.3, poor IAQ is the major cause behind increasing cases of serious medical health consequences. As human beings spend most of their routine time indoors, it is important to ensure a healthy building environment to avoid risks associated with occupational and building health. The IAQM systems are the best solution to deal with such issues, and the IoT technology has huge efficiency in providing the most reliable and feature-rich solution to the world. The high-performance IAQM systems can generate alerts for bad indoor air levels so that appropriate ventilation arrangements can be made on time. It is a thought for the development of healthy work conditions for the coming generations as well.

4 IoT for Indoor Air Quality Monitoring

By considering the huge potential of IoT technology, researchers these days are working on the development of IAQM systems to improve the indoor work environment. This section highlights the contribution of early researchers in this field while describing the gaps and challenges for the future.

4.1 Survey on IoT-Based IAQ Monitoring Systems

Idrees et al. [39] investigated the computational complexity, infrastructure, issues, and procedures for designing real-time IAQ monitoring systems. The prototype for this study was designed using the IBM Watson IoT platform and Arduino board. The sensing module used eight different sensors: humidity, temperature, O_3, SO_2, NO_2, CO, $PM_{2.5,}$ and PM_{10}. The major advantage of this system was its ability to reduce the computational burden of the sensing nodes by almost 70% leading to longer battery life. Authors used automatic calibration setup to ensure higher accuracy of sensors and a data transmission strategy was used to minimize the power consumption along with redundant network traffic. This model reported a reduction of 23% in the overall power consumption and the performance was validated by setting the system in different environments.

Kang and Hwang [40] introduced an air quality monitoring system to test the relevance of the Comprehensive Air Quality Index (CAQI) for accurate IAQ indication. Authors also proposed a real-time Comprehensive Indoor Air Quality Indicator (CIAQI) system that can work effectively against all dynamic changes and is quite efficient in processing ability along with memory overhead. In order to develop the experimental setup for realistic indoor air environment monitoring, the authors used VOC, PM_{10}, CO, temperature, and humidity sensors. Authors also compared the proposed system performance with section average (AVG) used for ambient AQI as well as with Simple Moving Average (SMA) scheme and observed that proposed CIAQI system is more adaptive to real-time changes in the IAQ. Also, this system utilized small memory, and hence, it was proven to be the best solution for the Internet of Things (IoT) based and budget-friendly air quality monitoring.

Firdhous et al. [41] proposed an IoT-based IAQM system for tracking concentrations of ozone near the photocopy machine. Researchers designed an experimental system using semiconductor sensors that were capable enough to monitor ozone concentrations in the area surrounding a high-volume Xerox machine. The interconnected IoT devices were programed for efficient collection and transmission of data for the estimated duration of 5 min over the Bluetooth network. Sensors transmitted data to a gateway node that further makes use of Wi-Fi LAN to communicate with the processing nodes. Note that all the sensors for this system were calibrated using proven calibration techniques. The proposed IAQM system was also able to generate warnings for the exceeding range of pollution levels in the indoor environment.

Benammar et al. [42] presented an end-to-end IAQM system for measuring relative humidity, ambient temperature, Cl_2, O_3, NO_2, SO_2, CO, and CO_2. The prime role of the gateway in this study is to process the IAQ data and perform reliable dissemination via a web server. This system was adapted to open source IoT web server platform, named as Emoncms to ensure long-term storage as well as live monitoring of IAQM data. Seamless integration of smart mobile standards, WSN, and many other sensing technologies is performed to design the ultimate scalable smart system to monitor IAP.

Srivatsa and Pandhare [43] proposed a system containing a sensor network that was connected through IoT to provide efficient IAQM services. The system had three prime sections that work together to provide complete analysis; the first one is a wireless sensor network that collected PPM reading for CO_2 from the dedicated room; at the second level, this information was passed to the wireless access point, and details were stored on the server machine. Finally, the server side containing user interface and notification system functionalities processes this data to provide alerts for IAP.

Panghurian et al. [44] developed an IAQM system based on the measurement of PM2.5, CO_2, CO, humidity, and temperature. The communication was performed over IEEE 802.11 b/g wireless network. The prime focus for development of this system was to reduce power consumption of the sensor network so that the network can also function better in emergency situations like fire, etc. The monitoring for this system was done remotely through a web application.

Marques and Pitarma [45] proposed iAQ as an advanced system based on IoT technology for monitoring air quality in the indoor environment. The system incorporates Xbee technologies, ESP8266 and Arduino for data processing and transmission whereas microsensors were utilized for data acquisition. In this system, it was possible to collect data through mobile application and web system as well; even doctors can access this data instantly to lead effective medical diagnostic procedures. Researchers in this study focused on five natural parameters: glow, carbon dioxide, carbon monoxide, moistures, and air temperatures as well.

Cynthia et al. [46] proposed an IAQM system for monitoring live air quality in the area using IoT technology. This system makes use of air sensors to collect information about harmful compounds and gases, and the data was further processed through PIC16F877A microcontroller. The microcontroller transmits this data over the Internet, and the gas level variations can be monitored over a web page from any corner of the world.

4.2 Challenges

Although it is possible to use conventional analytical instruments for measurement of pollutants affecting IAQ, they are not considered a practical solution due to a few potential reasons:

- They are too bulky and hence are not a feasible solution for practical measurement.
- These sensors are noisy so are an inadequate solution for indoor use.
- These sensors are expensive to install.
- The operation often goes quite complicated; they demand experienced professionals to handle the process.
- They consume more power.

At present, researchers need to find some low-power, battery-operated devices that can be readily deployed at various locations. The great news is that recent advances in the technologies have presented a wide range of measuring units for the indoor air pollutants such as PM, SO_2, NO_2, O_3, CO_2, CO, and VOCs. In ideal conditions, these sensors are expected to have a fast response time, ensure high performance in the practical environment and are robust solutions for the real-time measurements. With time, these devices are also becoming lightweight, compact, and inexpensive while ensuring great performance for selectivity, sensitivity, and measurement efficiency. A wide range of sensors in the market are wearable and mobile, and they allow data transfers over Wi-Fi and Bluetooth networks as well.

The real-time data collection systems are managed by ATmega microcontroller; however, Raspberry Pi is another common choice for setting up a sensor network in the target environment. WSN is an ad hoc network, where sensor networks consume huge energy while transmitting data in multiple hops. At the same time, the time taken by sensors to send a signal to the monitoring unit was observed to be considerably high. In such situations, researchers needed to work on battery power management to improve overall system performance. The prime limitation of gas sensors is that they suffer from short life span. Considering the battery life expectancy and reliable single-hop communication abilities, IoT monitoring systems are known as the most reliable solutions for IAQ measurement. With lower latencies and lesser power consumption, these systems also demand lesser efforts on maintenance procedures. IoT-based real-time monitoring systems are known as smart systems; hence, most of the researchers and industrial manufacturers are more attracted to this technology. Experts reveal that IoT systems have the ability to monitor a large number of parameters even without compromising system performance.

One of the prime concerns in the development of IAQ systems is the higher cost and huge power consumption of sensor nodes. If we consider the real-time applications of IAQ systems, the sensor units are usually installed in an industrial environment, inside homes, offices, and outdoor areas as well. But in all these cases, the design of the sensor unit demands more focus on size, design cost, power consumption, communication protocol, and performance dependence on changes in temperature and humidity. Sensor calibration is currently the biggest challenge in front of future researchers to ensure accurate real-time monitoring. Although Metal Oxide Semiconductor (MOS) sensors are cheaper when compared to the optical and electromechanical sensors (some examples are TGS 2442 and TGS416), they work on the resistive heating; hence, consume loads of energy from limited battery unit of wireless motes. As a result, it reduces the overall lifetime of the network. A considerable solution to solve this problem is placing motes in sleep mode when they are not working actively in the system. Some studies also reveal that high-quality micro-gas sensors are able to perform better in variable humidity and temperature conditions. One advanced solution to air quality monitoring is MAQS—personalized mobile sensing system that is gaining huge popularity due to its portable, energy-efficient, and inexpensive design. Most of the researchers have used ZigBee to establish a communication network between sensor nodes and controller unit, but its prime disadvantages of ZigBee modules are short communicating range and low network stability with high maintenance cost. The highly efficient IoT systems bring a new scope to this field; the best idea is to combine them with a Raspberry Pi controller that comes with the in-built Wi-Fi communication module ensuring fast data transfer. Note that Arduino boards do not offer direct network connectivity; users need to add one extra chip for Ethernet port that also demands extensive coding for connection development. One preferably used Wi-Fi module for Arduino boards is ESP8266 chip, but it needs an external converter for 5-3 logic shifting and cannot even handle complex data inputs. Moreover, it leads to additional cost and energy consumption. Also, the clock speed of Arduino is approximately 40 times lesser than Raspberry Pi, and the RAM for the later unit is 12,800 times larger than the Arduino.

Beyond these technical challenges, another major point of concern for IAQ management is social issues. Although several systems are already designed by early researchers to address this problem, not all of them are accessible to the sufferers, especially those who live in rural areas and have limited financial sources. Moreover, the lack of awareness about IAP and associated hazards brings millions of people under risk of serious medical health consequences. In order to improve the quality of building environment and living conditions of occupations, government agencies, health care experts, and researchers need to work together. New policies must be designed to focus on all socioeconomic sectors, especially the rural population in the developing countries. The efforts should not be limited to planning rather ground level implementations for all aspects must be ensured. Then only the latest technologies like IoT can be actually useful to address problems associated with IAP.

4.3 Requirements of Future IAQM Systems

The above sections of this chapter must have cleared most of your doubts regarding the development of IAQM systems, but before you move ahead to the designing world, it is first important to understand the requirements of future IAQM systems. In order to design the best equipment to serve the community, first of all, one must consider the common preferences and needs of the buyers. This analysis can help in making more appropriate decisions at each level during the entire design process, and the ultimate product will ensure more efficient outcomes in the real-time environment.

Below are a few essential points that must be considered for designing a new age IAQM system:

- *Accuracy of the system*:

Indeed, this is the prime concern for the development of a future system to measure IAQ. People will buy equipment only when it can ensure reliable results and can keep them safe from hazardous variations in the IAQ levels. The accuracy of an IAQM system relies on three factors:

i. Precision: The ability to deliver consistent output.
ii. Calibration: The device must be adjusted to achieve maximum accuracy in all variable environments.
iii. Resolution: The sensitivity of the sensor system to minute changes in the measured parameters.

Other than this, researchers need to set an appropriate range for their monitoring systems by indicating clear thresholds for the performance.

- *Convenient to use*:

The standard IAQM systems are required to be easy to use, and they must be accessible to all. IAQ affects 90% of the world's population; hence, it is important to design a system that can fit the universal needs. It must be simple to use, efficient in producing results and convenient to access as well. The thoughtfully designed system can ensure an intuitive experience to the end users.

- *Portable and power-efficient design*:

In this fast pacing world, immobile systems are of no use. People need IAQM systems for home, office, and probably for their cars as well but it does not mean that they must buy separate equipment to address issues all these places. Rather, future researchers need to design mobile, lightweight, and portable solutions to meet the requirements of coming generations. While making a portable system, it is also important to work on the battery life of the equipment. It must be capable enough to serve people for long hours without risking their lives in emergency situations.

- *Essential features and qualities*:

Well, there is no specific list of features that an IAQM system must have because it varies from user to user as per their individual needs. However, in general, one needs to consider response time, connectivity, and noise as prime concerns for designing process. *Response* time indicates that the sensor can display readings faster without compromising for accuracy. *Connectivity* is a measure of making your device suitable for modern smart homes. The new-age equipment must provide easy access to output on web portals, mobile apps while the alerts can be sent through e-mails as well. Also, the system must be less noisy so that it can be used by sensitive sleepers as well.

5 Conclusion

This chapter presents an in-depth study of IoT-based IAQM systems by focusing on several design aspects. A smart approach in designing high-performance systems can provide reliable results to address the serious medical health consequences associated with IAP. Although there are several open research challenges to work in this direction, a systematic approach can provide a considerable solution. As IoT has huge potential to serve design requirements of highly efficient monitoring and control systems in every field, it is possible to address the issues in the IAQ management as well.

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