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Research paper

A Review on Indoor Air Quality Monitoring using IoT at Campus Environment

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Abstract

Indoor Air Quality (IAQ) systems provide a feasible way to maintain a healthy environment. The purpose of this study is to investigate IAQ monitoring systems, summarize existing studies, and to recommend research on IAQ monitoring that using the Internet of Things (IoT). In this systematic review the author analyzes and summarizes articles about IAQ using IoT, obtained from three databases. Based on the criteria, there were 36 studies selected that discusses IAQ, 24 are system development, six are evaluation and comparative articles, three studies proposes methods, and the other three are review articles. From the articles, there are only six researchers have conducted research on campus environment. The relevant past research was reviewed and provided discussion material on monitoring systems, sensors, devices used, and Internet of Things for Indoor Air Quality.

Keywords: *Air Pollution; Indoor Air Quality (IAQ); Internet of Things (IoT); Monitoring System; Systematic Review.*

1. Introduction

Air and good air quality are vital for humans being in conducting day-to-day activity. Daily activities are often conducted indoor by majorities, whereby, 90% of their time was at indoor environment [1]. Many other things that are often done indoors be it for work, school, study, and many others [2].

Environmental pollution, such as air pollution is a common topic of concern. Pollution does not only exist in outdoor areas, harmful substances are also found indoors. Houses and buildings built without standards often correlate with higher exposure to indoor pollutants, and ultimately cause negative health effects [3]. Many substances that can cause health problems and are parameters of Indoor Air Quality (IAQ) based on the World Health Organization (WHO) guidelines for indoor information sources at the exposure level [4].

There are approximately 1.5 million deaths per year, caused by the burning of solid fuel while cooking in the kitchen [5]. Researches and surveys have been conducted from 2011 until 2016 to learn about effects of air quality for health and socialization about IAQ [6]. According to the EPA (Environmental Protection Agency) at United States, those exposed to poor IAQ may experience symptoms of the disease such as irritation of the eyes, nose, throat, headaches, dizziness, and fatigue. Poor IAQ can worsen asthma, and health [7].

Indoor air pollution can be monitored with a system that can show the level of air quality. With the integration of the Internet of Things (IoT), data parameters from IAQ can be collected from the environment [8]. As it is important to analyze and monitor IAQ. This paper investigates IAQ with the advent of IoT, through a systematic review of the literature.

2. Systematic review methods

A systematic review is done by following the guidance of systematic reviews and Meta-Analysis (PRISMA) that guides to create a systematic literature review and was published in 2009, with example of flow diagrams and explanations of systematic review [9]. A systematic review should establish a protocol explaining the reasoning, hypotheses, and methods of the planned review. Furthermore, some reviews report whether there is a new protocol that can be used and provide recommendation [10].

2.1. Search Strategy

A systematic search is done by identifying research information articles from three database. The search on the database is based on the query that has been created. Selected database have a background in science and engineering. There is an IEEE Xplore digital library (https://ieeexplore.ieee.org/Xplore/home.jsp), Science Direct (https://www.sciencedirect.com/), and Association for Computing Machinery (https://dl.acm.org/). The search is done by advanced search mode, on March 2, 2018.

In all database authors complete a search methods by entering the string "*air quality*" or "*air pollution*" with the following keywords "*IAQ*" or "*Indoor Air Quality*" and monitoring or "*wireless sensor*" or "*sensor*", and to further clarify the scope the author add keywords "*IoT*" or "*Internet of Things*". Article publication year is from 2013 to 2018, which are published in English language, and only journals and conference papers were chosen. Table 1 contains the search strategy used to conduct a search query.

Table 1: Search Strategy Query Setting

Digital Library	IEEE Xplore	ScienceDirect	ACM
Languages	English	English	English
Years	2013-2018	2013-2018	2013-2018
Run On	Full Text	Full Text	Full Text
Type	Paper, Journal	Paper, Journal	Paper, Journal
Access date of running a search	March 2018	March 2018	March 2018

2.2. Eligibility Criteria

Only studies that mention Indoor Air Quality are selected for the investigation. The studies on IAQ collected from the three database were mapped. Studies on a monitoring system that used to measure the air quality in the room, and also articles about IAQ using IoT for the methods is similar. Studies selected focuses on the technology that can be used for monitoring air quality at indoor area. The eligibility criteria choose articles in English language published less than four years. Duplicate articles were not considered, and authors removed all the articles that did not fulfill the eligibility criteria.

2.3. Identification and Data Processing

Therefore, the selection of the study is done on all three database, first by selecting titles, eliminating unrelated and duplicate papers. Next is selecting the abstract and reading it carefully to find relevance to the topic for further full reading of the selected paper. Then, the authors grouped the most related papers, and summarized research conducted and, process it using EXCEL along with the existing data.

3. Results

Search is identified 69 articles from the three research database namely IEEE explore, Science Direct and ACM (Association for Computing Machinery).

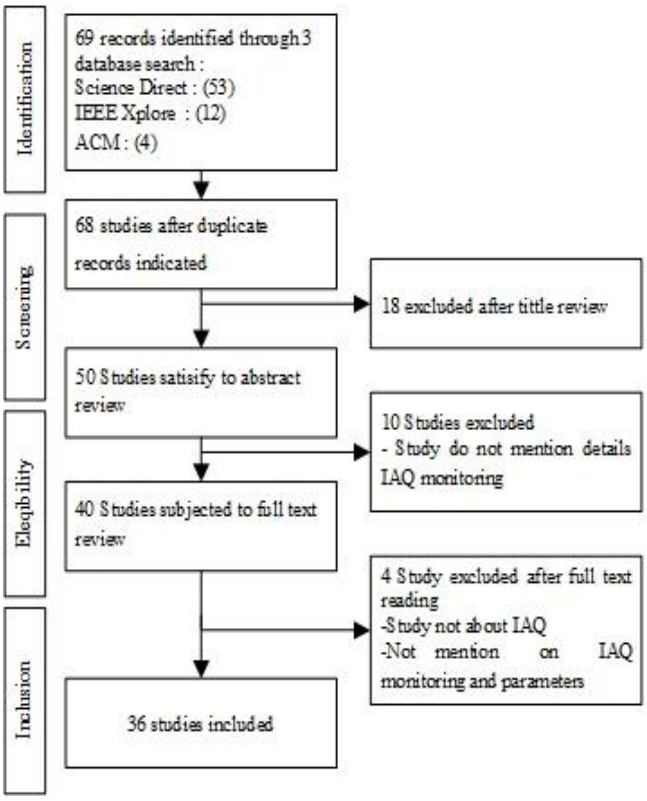

Fig. 1: Flow diagram of research literature and selection process

The query reached 53 articles from Science Direct, 12 from IEEE Xplore, and 4 from ACM. Only one article was indicated as duplicate record and author deleted it. After the tittle review, 50 studies were employed for abstract review, and 10 articles were excluded because did not mention details about IAQ, did not mention IoT, and failed to describe IAQ parameters.
Only 40 studies had the abstract reviewed and were subjected to full-text review. The author read all the articles carefully and focused on the studies pertaining IAQ using IoT, and four research were excluded as the studies discussed the IAQ but indicated different purpose and scope as desired criteria.
Although some of the studies had similar areas, however, these articles focused on various different of purpose, and 36 studies met the selected criteria. A diagram, in Figure 1, illustrates diagram flow of articles selection process in three database.

3.1. Methodology Analysis

This section classifies the results of the reviews that made on the previously selected research papers and summarizes the data obtained.

3.1.1. Type of Research

There are four types categories for research articles categories, review and survey, proposed method, system development, and evaluation comparative article. The results of classification from existing studies and most of the papers and journals that discussed the IAQ used development system methods as shown in Figure 2. The researchers developed a new method from similar studies that already exist.

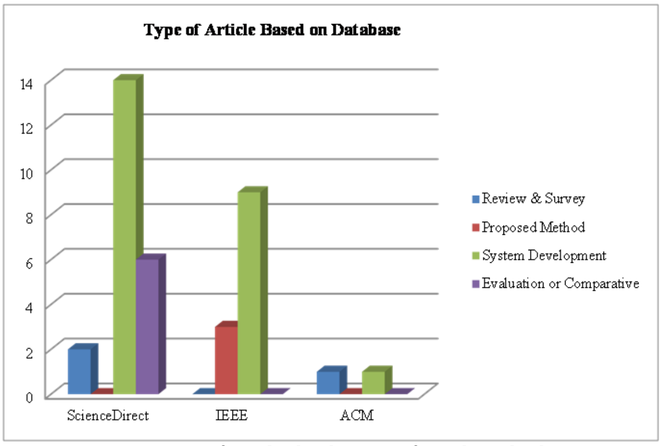

Fig. 2: Amount of articles by their type from three database

3.1.2. Place of Research

Most of the studies used a laboratory (10 studies), where researchers create prototypes for their data retrieval. Nine studies collected data at residential environment. Most studies on the IAQ also performed data collection on some other environments such as offices, and campus areas. Research on IAQ continues to be developed by several countries in the world, including IAQ by using the Internet of Things.

3.1.3. Pollutants

Measurable pollutants are air quality parameters and most studies have been using temperature and humidity for their data followed with the concentration of carbon dioxide (CO2), Volatile Organic Compounds (VOC), Particulate Matter (PM) and Carbon Monoxide (CO). In most studies, the type of pollutant used was already mentioned in an existing guidebook and also documented the adverse effects of air pollution [11].

3.1.4. Indoor Air Quality and Internet of Things

Research on IAQ using the IoT is evolving and discusses exciting topics for research since 2014 and continues to increase every year. IoT simplifies and assists in monitoring parameters of IAQ. Data parameters of air quality can be accessed through internet, hence, faster and efficient to access. Air quality monitoring is becoming more progressive in the presence of technologies such as IoT.

3.2. Analysis of Results

Based on the results retrieved on existing research, indicate that 24/36 studies are on system development, 6/36 are an evaluation or comparative studies, 3/36 proposed methods and the other 3/36 are review articles. Research that proposes development system uses sensors and a microcontroller to built IAQ monitoring. Data retrieval for IAQ is mostly done on a special lab prepared for retrieval of data parameters from existing pollutants. However, several studies verified data on the winery environment as conducted by Madrid and Boulton [12], and performed system implementation directly. From 36 studies selected, only six studies were implemented at campus environment. Seven categories of environment were identified for observation and implementation.
The frequently observed pollutant data is temperature and humidity. Twenty-four studies utilized temperature and humidity data in their articles. Most studies showed temperature and humidity data along with other pollutant concentration data such as carbon dioxide (CO2), VOC, PM, carbon monoxide (CO) and other types of pollutants. There are 36 related studies obtained and only six studies did not discuss IAQ by using IoT. Most studies employed IoT, sensor and microcontroller devices to monitor IAQ.

4. Discussion

The aim of this study is to investigate Indoor Air Quality (IAQ) monitoring system using Internet of Things (IoT) method at campus area by a systematic review of studies conducted. To further explore the theme, the results of the articles were selected into five categories. The categories are IAQ monitoring system, IAQ at campus environment, data collection from IAQ, monitoring IAQ using Internet of Things, and the challenges of IAQ using Internet of Things. This study only focused on literature and categorized another study that discussed IAQ. The data obtained comes from the process of reading it carefully and thoroughly from sources related to the topic area. This section also will be discussing challenges and recommendation regarding the topic.

4.1. Indoor Air Quality Monitoring System

Based on survey, selected articles from three database were categorized into four type and most articles discuss the monitoring system for IAQ. From the articles that review paper, proposed method, evaluation or comparisons, and also system development, many research discuss monitoring system. The different types and devices for parameter monitoring for IAQ are also discussed and reviewed. According to an existing review, health problems such as respiratory diseases and allergies raise the importance of monitoring tools and information within the IAQ [13].
The method of conducting continuous monitoring at a low price is by using an Arduino microcontroller and low-cost sensors were proposed by [14]. Evaluation and comparison were also made to IAQ monitoring tools, to know the efficiency and performance of the sensors used in the monitoring system [15]. The most common type of articles on IAQ is system development. One of the system development is the comparison of four monitoring periods of IAQ and [16] clearly demonstrate effectiveness of the automatic control and implemented using the new pervasive technology. The following is a classification of sensors used for monitoring IAQ on the development of existing systems.
A summary of observed pollutant data and the type of sensors used in the study are described in Table 3. There is 24 studies pertaining system development that contain the summary of the pollutants used by previous researchers that developed an air quality monitoring system. From existing research authors know that various types of sensors were also used. Most sensors are used to monitor temperature and humidity.

4.2. IAQ At Campus Environment

Various places needed IAQ monitoring. Many researchers from various countries are interested in the topic of IAQ as shown in Figure 3. Researchers on IAQ were from all the continents of the world, from America, Europe, to Asia. One of IAQ monitoring system in educational facilities is done on a research in Seoul, South Korea. The researcher placed a monitoring device in selected classrooms [17]. Based on data from selected studies, Korea and United States of America (USA) are the countries with the highest contribution of research on IAQ. A large number of researchers from various countries indicate the IAQ is becoming an important topic for discussion.

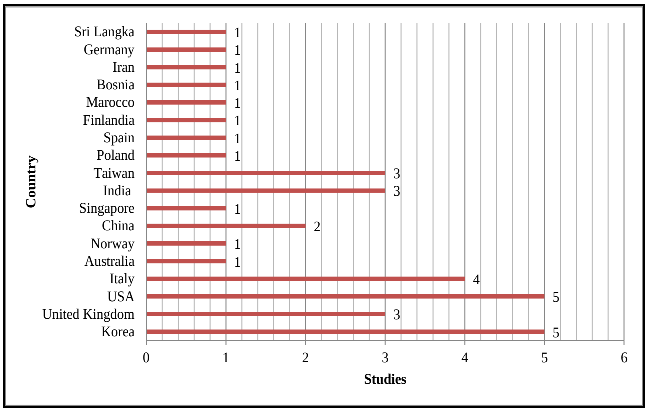

Fig. 3: Country of IAQ Authors

The development of building technology is now evolving into a smart building that supports its inhabitants with data information. Therefore, the building that has evolved is not only residential, but also service and information, source and the topic of the intelligent building become important. The system applied to the building at [18] that operates 94 smart sensors and is called Brescia Smart Campus Demonstrator. Sensor networks at campus-area forming an integrated system, and allows in obtaining information around the campus area and proved to be a healthy environment.
Laboratory is often used for data retrieval and implementation of IAQ monitoring systems, by conditioning a space as a subject and the place of testing of tools for research [19].

Table 2: Place for Observation

No	Place	Amount
1	Office	5
2	Laboratory	11
3	Campus	6
4	House	9
5	Healthcare	1
6	Winery	1
7	Other	3
Total		36

Table 3: Monitoring Air Quality Parameters and Pollutant

No	Citation	Pollutants	Sensor
1	Belussi et al., 2017	Temperature, Humidity, CO2	DHT 11, K30
2	Ciribini et al., 2017	Temperature, Humidity, CO2	Z-wave
3	Scale et al., 2017	CO2, VOC, CO, Particulate, HCHO, NO2, Temp, Humid	Telaire T6713, MiCS-5524, Itead DSM501A, WSP2110, MiCS-2714, DHT-22
4	Molka-danielsen, Engelseth, & Wang, 2018	Temperature,Humidity,CO2	MQ-135, STM32 Nucleo
5	He, Xu, Wang, & Wang, 2017	Temperature, Humidity, CH2O	TGS2600, TGS2602, QS-01
6	Shah & Mishra, 2016	Temperature, Humidity, Light intensity	SHT11, TSL2561
7	Yang, Chen, Den, & Wang, 2018	Temperature, Humidity, Formaldehyde, VOC, CO, CO2	Series WHT, CTX 300, OLCT 100 XP, OLCT 20 D, ZGw08VRC
8	Jeon et al., 2018	PM 2.5, PM 10, Temperature, Humidity	SEN017, DHT22
9	Malek, Kharbouch, Khoukhi, Bakhouya, & Florio, 2017	CO2, O2	Not mention it
10	Järvinen, Simone, & Rautio, 2017	Temperature, Humidity, Gasses	DHT22, gas sensor
11	Madrid & Boulton, 2017	VOC, PM 2.5, Temperature, Humidity, RH, CO2	IAQ-2000 VOC, DC1700, GC-0021 COZIR
12	Martín-garín, Millán-garcía, Baïri, Millán-medel, & Sala-lizarraga, 2018	Temperature, Humidity,CO2	DHT, SHT21, BMP180, BME280
13	Ray, 2016	Temperature, Humidity	DHT 11
14	Nastasi, Scuderi, Endres, Hell, & Bock, 2014	Temperature, Humidity,CO2	RTD sensor
15	X. Yang, Yang, & Zhang, 2017	PM 2.5, PM 10, Temperature, Humidity	SDS011, DHT 22
16	Wang, Hsu, Jian, & Chen, 2016	Temperature, Humidity, CO2	HRV
17	M. Choi et al., 2017	VOC, CO2, Temperature, Humidity	I-HVAC
18	J. Choi, Park, Chang, & Lee, 2017	VOC	TGS 2620
19	Tsai, 2016	O2, CO2, Dust, Temperature, Humidity	Bio Tank
20	Sudantha & Karunaratne, 2017	Ozone	Semiconductor O3 sensor
21	Zimmermann, Member, Weigel, & Fischer, 2017	CO2, VOC	Nondispersive infrared spectroscopy, TVOC, Temperature Humidity sensor
22	Spachos, 2016	PM 2.5	UMDS
23	Lohani & Acharya, 2016	Temperature,Humidity,CO2	DHT 22, Gas sensor
24	Fang, Xu, Park, & Zhang, 2016	PM 2.5, VOC, Temperature, Humidity	Dylos DC1700, AppliedSensor IAQ-engine, SHT15

The mechanism that can be used for the system is classified into three stages, namely, data collection, data processing, and information monitoring applied to the system in the campus environment [20]. Figure 4 is a categorization of IAQ system based on the location of implementation.

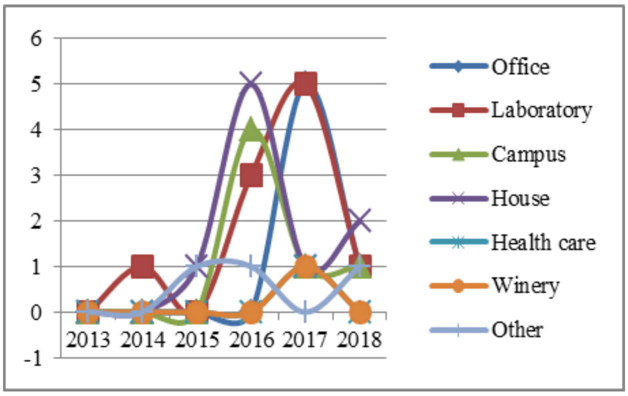

Fig. 4: Number of IAQ studies by location and year

IAQ monitoring is still ongoing from 2013 to 2018 and has a growing number of researchers, the highest occurring in 2016 to 2017, based on data obtained from the results of studies, and the research in the campus environment is mostly done in 2016. Researcher [21] attempted to implement IAQ in 2016, in a campus environment, by creating a smartphone based monitoring system. The problem encountered while conducting in a campus environment has a room with a different condition, due to irregular occupancy rate. However, the testing of IAQ is advisable to be done with a regular occupancy rate [22]. A smart campus system can be measured, monitored by controlling the comfort of IAQ and HVAC parameters such as thermal, humidity, CO2, Volatile Organic Compound (VOC) and other IAQ parameters [23].

4.3. Data collecting from IAQ

IAQ investigation requires several steps, which is gathering data, and analyzing the data. Measuring and attaining the data throughout the building, possibly including temperature, humidity, CO2, CO, particles, VOCs, chemicals, and bio-aerosols [24]. Based on the results of the study obtained the parameters of the data obtained for research is to measure temperature, humidity, and CO2. Data from the pollutants comprises many data variants such as hydrogen sulfide - H2S, carbon monoxide - CO, and others [25]. According to [26], the selection of sensors used to monitor data in classes based on key factors of accuracy, ease of deployment, communication systems, breakdown, pricing, and availability. Indoor Air Quality monitoring is deployed for collected data parameters that are a pollutant or hazardous gases. Testing for data retrieval can also be done by injecting gas into a room and observing the data changes generated by the installed sensor [27]. Data retrieval can also be done by comparing the conditions of two different rooms [28].

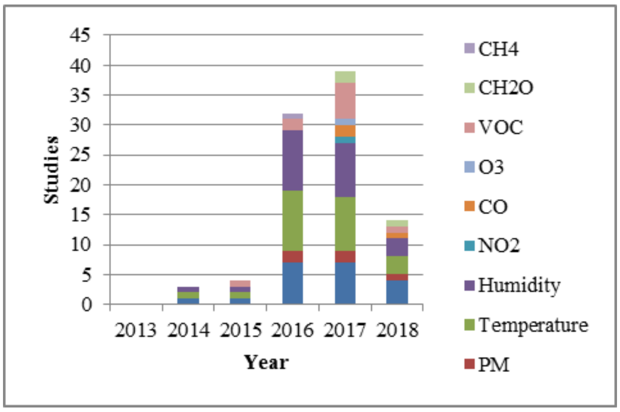

Fig.5: Type of pollutant utilized for measurement

Usable data from research on the IAQ monitoring is not always about the parameters of existing pollutant on the guidelines. The data was also derived from the power consumption of the system and was investigated by [29], as well as the transmission of data packets from the system network.

Table 4: IAQ research by pollutant and the period investigation

No	Data	Studies	Period
1	Temperature	24	2014-2018
2	Humidity	24	2014-2018
3	CO_2	20	2014-2018
4	VOC	10	2015-2018
5	PM	5	2016-2018
6	CO	3	2016-2018
7	CH_2O	3	2016-2018
8	NO_2	1	2017-2018
9	CH_4	1	2016
10	O_3	1	2017

Such as indicated by [30] the data also demonstrated that the use of power consumption in its IAQ monitoring system is more efficient than existing systems. Researchers [31] have also demonstrated a multi-sensor measurement system with an accurate microcontroller and qualified very low energy usage.

4.4. Monitoring IAQ using Internet of Things

Internet has made life better, convenience with easily information accessible [32]. The use of the Internet of Things for the environment using WSN (Wireless Sensor Network) technology is highly efficient because data from node sensor can be received and recorded on a PC with a GUI (Graphical User Interface that simple and easy for users [33]. IoT and Big data are the latest technology to collect data and display real-time information [34]. To react to environmental changes and is expected to make the lives of its users more comfortable at that location. Therefore, the use of systems with IoT keeps increasing. Building monitoring systems using IoT can be done by assembling module devices for data retrieval such as Arduino microcontroller board, additional devices like Wi-Fi modules and RTC (Real Time Clock), and sensors [35].
Research on IoT conducted by [36] using the open public cloud API based (https://plot.ly) and (https://thingspeak.com) with a real-time system to monitor thermal and humidity. One of the recent protocols used for IoT is by using MQTT, [37] proposes a monitoring system using Wi-Fi and MQTT broker as the communication system of sensor node.

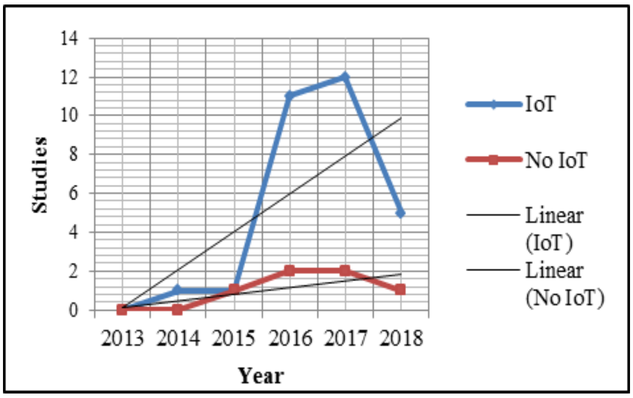

Fig.6: Studies of IAQ using IoT over the year

Monitoring systems with IoT can make an environment intelligent, such as research by [34] that is able to create monitoring and controlling systems for IAQ, with the ability to work automatically. The use of Internet of Things simplifies the user to monitor an environment anywhere, by using Wi-Fi or ethernet connection [38].

Table 5: Device & protocol used for IAQ monitoring

Author	Microcontroller	Protocol
(Malek, Kharbouch, Khoukhi, Bakhouya, & Florio, 2017)	Raspberry, Arduino	MQTT
(Molka-danielsen, Engelseth, & Wang, 2018)	RFM70	-
(He, Xu, Wang, & Wang, 2017)	STM32, STM32, XBee S6B	TCP/IP, UDP
(Shah & Mishra, 2016)	PIC24F161CA102, nRF24L01	Enhanced Shock Burst
(Järvinen, Simone, & Rautio, 2017)	ATMEGA328P-PU, RaspberryPi 2	SPI
(Ray, 2016)	Arduino Uno,	TCP/UDP,
(X. Yang, Yang, & Zhang, 2017)	Arduino Pro Mini, ESP-12F	TCP/UDP, , MQTT
(Wang, Hsu, Jian, & Chen, 2016)	STM32 Nucleo, Seed Studio Wi-Fi	TCP/IP, UDP
(M. Choi et al., 2017)	Zigbee	-
(J. Choi, Park, Chang, & Lee, 2017)	CC3200	TCP/UDP,
(Zimmermann, Member, Weigel, & Fischer, 2017)	Bluetooth	NTP
(Fang, Xu, Park, & Zhang, 2016)	Arduino	SPI

4.5. Data collecting from IAQ

The lack of knowledge on the source of pollution that is apparently present in the home and building environment creates a challenge to further improve the knowledge of the importance of air quality monitoring systems [39]. According to [40] the challenge for the future is divided into two directions, namely the direct implementation in measurement, and the other is learning evaluation of the algorithm. In the future, the monitoring system will continue to grow along with the cloud computing. Next challenges from IAQ monitoring system is to improve the accuracy of sensor with the condition of '< 1ppm' [41], development system challenges to implement an interactive and friendly system, but with energy-efficient usage [42]. The challenge in any research on is to implement IAQ monitoring system for continuous use and not just individual experiments [43]. A direct test of the system needed to answer the question of how well the work of the system was made to detect other internal pollutants [44]. Another challenge is to create an affordable system from the IAQ and have energy efficient for real-time monitoring, and can also be added with notice of the network status being used [45].

5. Conclusion

This study is conducted for facilitating researchers to create a monitoring system for the Indoor Air Quality by using the Internet of Things. This paper categorizes the previous related studies and explores the systems. The discussion material on monitoring system used sensors, protocols, and Internet of Things against IAQ. MQ gas sensor, DHT, SHT are some type of cheap sensors that are often used and can be an option for built IAQ monitoring system. The paper also proves that some countries discuss the need for installation of monitoring tools for an indoor area. Evidence that many researchers examine IAQ every year, proves IAQ is still an interesting topic to be discussed. IAQ topics using the Internet of Things also need to be developed for sustainable development.
Pollutants most commonly are used in observations are temperature, humidity, and CO_2. Developments in information systems make it easy to conduct and build an integrated monitoring system and produce accurate and efficient data. With the existence of this review, continuous research on IAQ monitoring system is expected to be continued.

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