Malaysian Journal of Chemical Engineering & Technology 4(2) (2021) 107–113

Malaysian Journal of Chemical Engineering & Technology

e-ISSN: 2682-8588

Journal Homepage: http://myjms.mohe.gov.my/index.php/mjcet

Real-time indoor air quality monitoring association with humidity, temperature, and carbon monoxide level in the residential environment

[a, b] Mahanijah Md Kamal*, [a] Ahmad Syahir Sazali, [a] Suzi Seroja Sarnin

[a]School of Electrical Engineering, College of Engineering, Universiti Teknologi MARA, Selangor, Malaysia
[b]Innovative Electromobility Research Laboratory, College of Engineering, Universiti Teknologi MARA, Selangor, Malaysia

*Corresponding email: mahani724@uitm.edu.my

Abstract

Indoor Air Quality (IAQ) is the air quality in or around a building that can affect the comfort and health of building occupants. Polluted air contains toxic gases emitted by industry, vehicle emissions, and increased concentrations of harmful gases and particles in the atmosphere. The use of IoT can monitor IAQ reading levels and update IAQ real-time information parameters at different locations in the residential environment for the comfort and health of the occupants. The focus of this work is to measure the level of carbon monoxide (CO) as well as other important parameters such as temperature and relative humidity (RH) as recommended by ASHRAE 55-1992 and MS:1525. The developed system was built using NodeMCU as a microcontroller, MQ-7 to measure CO levels, and DHT22 sensor to measure the humidity and temperature levels. The experiment was conducted in a residential building located in Paya Jaras Tengah, Sungai Buloh, Selangor. The developed system was measured in three different locations, namely the living room, kitchen, and bedroom. In the morning, as the RH increased, the temperature also increased. Since the living room is located nearby the main road, the CO reading was higher than the other two locations, in which the highest value of 12 ppm was recorded. The results obtained showed that the system works well and can record the readings of RH, temperature, and CO level in the residential environment. Therefore, a reliable system can be developed to help the residential occupants monitor the level of IAQ in the house.

Article Info

https://doi.org/10.24191/mjcet.v4i2.14916

Article history:

Received date: 21 August 2021
Accepted date: 3 October 2021
Published date: 31 October 2021

Keywords:

Indoor air quality
Relative humidity
Temperature
Carbon monoxide
Residential

1.0 Introduction

Appropriate indoor air quality (IAQ) is necessary for healthy environment (Yu & Kim, 2011). Several short-term and long-term problems regarding health and productivity are associated to poor IAQ that is caused by inappropriate levels of temperature, humidity, air velocity, lighting, noise, and CO_2 (Kumar & Mahdavi, 2001). In Malaysia, Industry Code of Practice for Indoor Air Quality (ICOP-IAQ) 2010 of the Department of Occupational Safety and Health (DOSH) addresses the recommendation on the allowable limit for the concentration of indoor bioaerosols (DOSH, 2010). Bad IAQ can lead to sick building syndrome (SBS), a condition where people experience uneasiness such as headache, sleepiness, or inability to concentrate. SBS is caused by the presence of high concentrations of indoor air pollutants, especially biological agents (Takigawa et al., 2009). In recent years, IAQ has been the focus of attention by the scientific community, governments, and international organizations (Abdul-Wahab et al., 2015). It is a known fact that we spend more than 90% of our time indoors, and that the levels of the observed factors associated to air quality are often higher than those recorded outdoors. Thus, the health risks from exposure to indoor air pollution may be larger than those associated with outdoor pollution. Poor IAQ can be especially detrimental to vulnerable groups such as children, young adults, the elderly, or those suffering from chronic respiratory and/or cardiovascular diseases (Cincinelli & Martellini, 2017). However, lately, the environment factors such as air movement, humidity and indoor air quality have captured research interest. Humidity is a factor that is related to thermal comfort. The raising of relative humidity reduces the ability to lose heat through perspiration and evaporation, and hence, the effect is similar to the temperature raising (Jayamurugan et al., 2013). Extreme humidity can also create other IAQ problems. Excessively high or low relative humidity can both produce discomfort. In addition, high relative humidity can promote the growth of mould and mildew. Temperature and humidity influence both the comfort level of individuals and their wellbeing. If the temperature continues to rise, discomfort increases and symptoms such as fatigue, stuffiness, and headaches can appear (Fang et al., 1998). Effect of humidity and temperature on individual comfort in a building such as hospital (Azizpour et al., 2013; Sattayakorn et al., 2017), universities (Zaki et al, 2017; Alves et al., 2013; Wardhani et al., 2020), schools (Salthammer et al., 2016), and residential houses (Abdul-Wahab, 2017; Amir et al., 2019; Vilčeková et al., 2017; Mlakar & Štrancar, 2013) have attracted many attentions.

Real-time indoor air monitoring based on Internet of Things (IoT) platform is widely used to measure airborne particles in the environment and have become increasingly important in various monitoring applications especially for IAQ monitoring (Chanthakit & Rattanapoka, 2018; Benammar et al., 2018; Ha et al., 2020; Kumar et al., 2016; Tran et al., 2020; Hojaiji et al., 2017). Thermal comfort might be occasionally achieved at very high indoor air temperatures and humidity levels under hot-dry climate conditions like Malaysia. Humidity could affect thermal comfort in a residential house. Due to the increasing industrialization and the massive urbanization at Sungai Buloh, the IAQ is one of the major concerns to the residential occupants. In addition, the residential buildings have been occupied for more than 10 years. Due to the humid tropics of Malaysia, the aim of this work is to develop and monitor the IAQ environment based on measurements of three factors: temperature, relative humidity (RH), and carbon monoxide (CO) level in an identified residential house during Movement Control Order (MCO) due to the COVID-19 pandemic.

2.0 Methodology

2.1 Field measurement

The field measurement was conducted in a residential house located at Paya Jaras Tengah, Sungai Buloh, Selangor, Malaysia. Kampung Paya Jaras is one of the traditional villages in Mukim Sungai Buloh and has been around for more than 10 years. The residential house unit under study has nine windows and an air conditioning unit with five bedrooms, a kitchen, a toilet, and a living room area of 173.70 m^2 where a length of 15.25 m^2 and a width of 13.39 m^2. Fig. 1 shows the residential house of this type built near the main road. The sampling was done at three different areas in the house.

2.2 Hardware development

In this work, NodeMCU ESP8266 was used as the microcontroller. NodeMCU is an open-source firmware and development kit that helps to build IoT product. NodeMCU is developed to make the use of advanced API for hardware IO easier. The API can reduce redundant work for configuring and manipulating hardware (Durani et al., 2018). NodeMCU uses ESP 8266, which is the lowest cost Wi-Fi MCU. ESP8266 is the most integrated Wi-Fi chips. The size of the chip is 5 mm × 5 mm (Al-Kuwari et al., 2018). In this work, two types of sensors were used to measure the value of IAQ factors, i.e., the humidity, temperature, and CO level. Thermistor and capacitive humidity sensor used DHT22 to measure the surrounding air (Al Marouf et al., 2019). DHT22 enables users to read and measure a large range of temperature reading of −40 to 125 °C more accurately compared to DHT11 (Panghurian et al., 2018).

MQ-7 sensor was used to detect the level of the CO content in the indoor air. It has good sensitivity to CO in a wide range, and has advantages such as long lifespan, low cost, and simple drive circuit (Falohun et al., 2016). The concentration of carbon monoxide gas was measured using the MQ7 sensor produced by Sparkfun. This sensor takes 60–90 seconds to warm up before detecting gas with the required power of 350 mW at a 5 V supply voltage. The concentration of carbon monoxide that can be detected is in the range of 20 to 2,000 ppm with a slope rate of less than 0.5 (Muladi et al., 2018).

Fig. 1: The type of residential building used as field measurement

For calibration purposes, the MQ-7 CO gas sensor can detect CO gas concentrations from 20 to 2000 ppm. The MQ-7 sensor has sensitivity and selectivity to detect various types of gas such as carbon monoxide (CO), hydrogen (H_2), butane (LPG), methane (CH_4), alcohol, and air. However, in this work, only CO was measured.

The sensitivity characteristics of the MQ-7 sensor for various gases can be seen in Fig. 2 where the x-axis indicates the ppm value while y-axis indicates the ratio of Rs and Ro. Here, Rs is the sensor resistance at various concentrations of gases and Ro is the sensor resistance at 100 ppm CO in clean air.

The size of the prototype is 180 mm length, 95 mm width and 55 mm height. Fig. 3 shows the prototype of IAQ monitoring device used to monitor the levels of temperature, humidity, and CO. The weight of the prototype of IAQ monitoring device is 158.4 g. Table 1 shows the overall costing of this IAQ prototype of a total cost of RM 66.18.

CO can also be found inside any house at the level of 0.5–30 ppm because it can be produced from the combustion of household utilities such as heater, stove, fireplace, and automobile exhaust in the attached household garage. As CO is a colourless and an odourless, CO detectors need to be installed to monitor the CO concentration in a working environment (Wang et al., 2010).

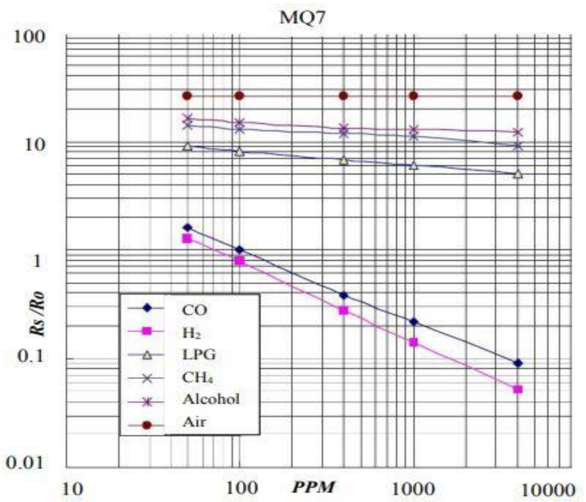

Fig. 2: Data sheet of MQ-7 sensor sensitivity chart

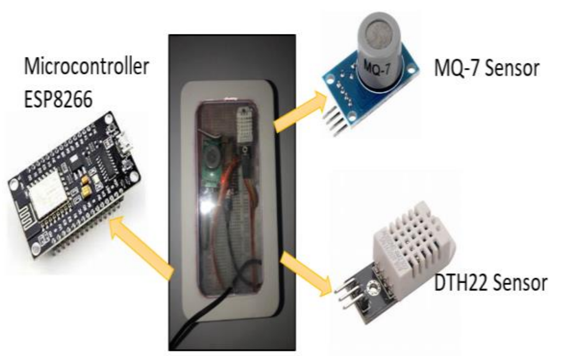

Fig. 3: Prototype of IAQ monitoring devices

2.3 Indoor environmental standards

There are many standards for describing thermal comfort in indoor environment. The most frequently used standards are American Society of Heating, Air conditioning & refrigeration Engineers, US (ASHRAE) Standard 55-1992 (ASHRAE 55-192, 1992), and Malaysian Standard MS:1525 (DOSH, 2010). ASHRAE 55-1992 sets the maximum air relative humidity at 60%. Department of Standards Malaysia, 2007 has published a guideline for a standard indoor environment design for Malaysian climate, in which it recommends the indoor temperature to be in the range of 23 to 26 °C (DOSH, 2010)(Lee & Chang, 2000). For non-residential building, three elements have been chosen as a guideline in evaluating and monitoring of IAQ. The elements are heating, ventilation and air conditioning (HVAC), which make a system that reflects the thermal comfort of the building. On the other hand, for residential building, to date, there have been no specific elements being measured to test the IAQ.

2.4 Data collection

The measurements were conducted at three different rooms of the residential house under study to measure the three IAQ parameters. The rooms were the kitchen, bedroom and living room, indicated by red circles in the house layout shown in Fig. 4. The parameters were recorded at an interval of 100 ms using the IAQ prototype. Data collection started from the 5th of May 2020 and ended on the 16th of June 2020. The measurement was taken in the morning (8:00 a.m.), afternoon (12:00 noon) and at night (8:00 p.m.) in every two days for 20 min in each measurement session. Air-conditioning is only installed in the living room area. The picture in Fig. 5 shows the data collection in the living room area.

3.0 Results and discussion

3.1 Indoor temperature

Referring to Table 2, temperature is higher in the afternoon compared to the morning and night. Based on standard (ASHRAE 55-1992), the range of acceptable heat comfort is from 23 to 27 °C. Since

Malaysia is one of the tropical countries, the range of house temperatures will usually be higher than in the standard ASHRAE environment, which is at 26 to 30.7 °C. From the results obtained, the average indoor temperature was from 24 to 31 °C, which was slightly higher compares to the range of MS:1525 that is of the range of 23 to 26 °C.

3.2 *Relative humidity*

From Table 3, the living room, the kitchen, and the bedroom environment can be categorised as non-humid. ASHRAE Standard 55-1992 recommends maintaining the indoor RH level between 30% and 60%, while according to MS:1525, the recommended RH is between 55% to 70%. If RH is below 30%, it is considered unacceptable because it can give effect of dry air on the eyes and skin. On the other hand, if RH is above 60%, it may support the growth of pathogenic or allergenic microorganisms in the environment. Based on the values in Table 3, the average RH is very high which is ≥ 75% in average.

3.3 *Carbon Monoxide*

The average concentrations of CO obtained in the three locations are given in Table 4. During the data collection, there were only two people in the living room with the windows open and the air-conditioning was on switch-off mode. The maximum CO level

Table 1: Total cost of IAQ prototype

Item	Material	Quantity	Unit Price (RM)	Total (RM)
Microcontroller	NodeMCU ESP8266	1	19.90	19.90
Humidity & Temperature Sensor	DHT22	1	17.70	17.70
Carbon Monoxide Sensor	MQ-7	1	7.50	7.50
Breadboard	MB-102	1	4.20	4.20
Wire Jumper Cable	Duport Wire Jumper	6	0.28	1.68
USB Cable	Micro USB Cable	1	10.00	10.00
Total (RM)				**68.18**

Table 2: Summary of average indoor temperature at three different times

Location	Min (°C)	Average (°C)	Max (°C)	MS:1525 Limit value (°C)	ASHRAE 55-1992 Limit value (°C)
Kitchen					
Morning	26.0	27.6	30.5	23.0–26.0	20.0–26.0
Afternoon	25.5	30.8	32.5	23.0–26.0	20.0–26.0
Night	24.7	25.7	29.8	23.0–26.0	20.0–26.0
Living Room					
Morning	26.1	27.3	29.5	23.0–26.0	20.0–26.0
Afternoon	25.2	30.8	32.7	23.0–26.0	20.0–26.0
Night	24.9	28.5	29.9	23.0–26.0	20.0–26.0
Bedroom					
Morning	26.0	24.6	29.5	23.0–26.0	20.0–26.0
Afternoon	25.6	30.6	32.8	23.0–26.0	20.0–26.0
Night	24.6	28.2	29.6	23.0–26.0	20.0–26.0

Fig. 4: Layout plan of the house with IAQ device

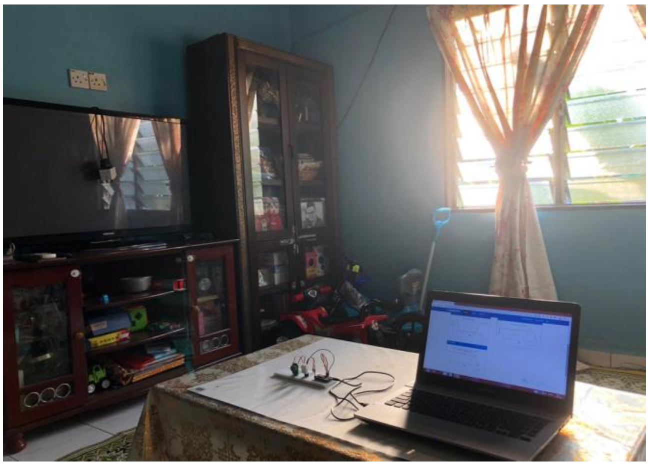

Fig. 5: Data collection in the living room area

Table 3: Summary of average relative humidity (%) at three different times

Location	Min (%)	Average (%)	Max (%)	MS:1525 Limit value (%)	ASHRAE 55-1992 Limit value (%)
Kitchen					
Morning	68.8	76.8	79.9	55–70	30–60
Afternoon	70.3	79.2	88.5	55–70	30–60
Night	78.1	83.3	88.2	55–70	30–60
Living Room					
Morning	68.2	76.0	79.3	55–70	30–60
Afternoon	69.5	78.3	87.4	55–70	30–60
Night	78.3	81.7	88.0	55–70	30–60
Bedroom					
Morning	69.3	77.2	80.5	55–70	30–60
Afternoon	70.9	79.7	89.0	55–70	30–60
Night	80.1	84.0	89.3	55–70	30–60

Table 4: Summary of average carbon monoxide at three different times

Location	Min (ppm)	Average (ppm)	Max (ppm)
Kitchen			
Morning	7.0	7.6	8.0
Afternoon	7.0	7.6	9.0
Night	7.0	9.7	12.0
Living Room			
Morning	9.0	10.6	12.0
Afternoon	8.0	9.9	12.0
Night	7.0	9.5	12.0
Bedroom			
Morning	7.0	8.0	9.0
Afternoon	8.0	8.1	9.0
Night	7.0	7.5	8.0

measured in the living room was 12 ppm, and in the kitchen and bedroom, the level was 9.6 ppm and 8.6 ppm respectively. The CO value was higher in the living room compared with the kitchen and bedroom due to the former's location nearby the main road, in which the poor-quality air containing higher CO content traveled into the house through the open windows. The recommended values for CO exposure based on indoor air quality standards set by DOSH (2010), Singapore (1996) and Hong Kong (1996) is 1000 ppm for an 8-hour period. It was measured that the average concentrations of CO in the three locations did not exceed the recommended standard level. The highest concentration of CO measured was in the living room (10.8 ppm), while the lowest concentration of CO was measured in the bedroom at night (7.5 ppm). However, all the CO levels recorded were in the acceptable range in the ASHRAE standard.

4.0 Conclusion

Based on the results obtained, it shows that the measurement of indoor air quality based on the temperature, relative humidity and CO level in the air was successfully carried out in a-real time platform. The IAQ device was used to measure the said parameters in the kitchen, living room and bedroom of the selected residential house. Overall, the average temperature in the residential unit was in the range of 24 to 31 ℃, indicating indoor temperature higher than the recommendation set by the standards. In addition, the average of RH was also higher than the recommended values set by the standard, whereby the RH was ≥ 75% in all the three locations. The CO readings measured was lower than 20 ppm and therefore, was at safe level. It can be concluded that the IAQ in this residential unit was considered uncomfortable for its occupants based on the recommended values in MS:1525 and ASHRAE 55-1992. For future work, it is recommended to calculate the standard deviations and standard errors of the IAQ data for a more in-depth statistical analysis.

Acknowledgement

The authors would like to thank School of Electrical Engineering, College of Engineering, Universiti Teknologi MARA Shah Alam for their support

References

Abdul-Wahab, S.A., En, S.C.F., Elkamel, A., Ahmadi, L. & Yetilmezsoy, K. (2015). A review of standards and guidelines set by international bodies for the parameters of indoor air quality. *Atmospheric Pollution Research*, *6*(5), 751–767. https://doi.org/10.5094/APR.2015.084

Abdul-Wahab, S.A., (2017). Study of the indoor air quality in two residential houses according to their ages. *Proceeding of International Conference on Chemical, Agricultural, Biological and Health Sciences (CABHS-2017)*. 98–102. https://doi.org/10.17758/EIRAI.F0217201

Alves, C. A., Calvo, A. I., Castro, A., Fraile, R., Evtyugina, M., & Bate-Epey, E. F. (2013). Indoor air quality in two university sports facilities. *Aerosol and air quality Research*, *13*(6), 1723–1730. https://doi.org/10.4209/aaqr.2013.02.0045

Al-Kuwari, M., Ramadan, A., Ismael, Y., Al-Sughair, L., Gastli, A. & Benammar, M. (2018), Smart-home automation using IoT-based sensing and monitoring platform. *Proceedings of 2018 IEEE 12th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG 2018)*, 1–6. https://doi.org/10.1109/CPE.2018.8372548.

Amir, A., Mohamed, M.F., Sulaiman, M.K.A.M., & Yusoff, W.F.M. (2019). Assessment of indoor thermal condition of a low-cost single story detached house: A case study in Malaysia. *International Journal of Sustainable Tropical Design Research and Practice*, *12*(1), 80–88.

ASHRAE Standard 55-1992. (1992). Thermal environmental conditions for human occupancy 55-1992. *American Society of Heating, Refrigerating, and Air-Conditioning Engineers*, Inc., 1992(ANSI/ASHRAE Standard 55-1992).

Azizpour F, Moghimi S, Lim CH, Mat S, Salleh E, Sopian K. (2013). A thermal comfort investigation of a facility department of a hospital in hot-humid climate: Correlation between objective and subjective measurements. *Indoor and Built Environment*, *22*(5), 836–845. https://doi.org/10.1177%2F1420326X12460067

Al Marouf, A., Islam, S., & Chakraborty, N. R. (2019). IoT-based smart meeting room weather detection system using Arduino and relative sensors. *International Journal of Computer Applications*, *178* (17), *44-51*.

Benammar, M., Abdaoui, A., Ahmad, S. H., Touati, F., & Kadri, A. (2018). A modular IoT platform for real-time indoor air quality monitoring. *Sensors*, *18*(2), 581. https://doi.org/10.3390/s18020581

Chanthakit, S., & Rattanapoka, C. (2018). MQTT based air quality monitoring system using node MCU and Node-RED. *Seventh ICT International Student Project Conference (ICT-ISPC)*, 1–5.

Cincinelli, A., & Martellini, T. (2017). Indoor air quality and health. *International Journal of Environmental Research and Public Health*, *14*(11), 1286. https://doi.org/10.3390/ijerph14111286

Department of Occupational Safety and Health. Ministry of Human Resources. Industry code of practice on indoor air quality. 2010. JKKP DP (S) 127/379/4-39.

Durani, H., Sheth, M., Vaghasia, M., & Kotech, S. (2018). Smart automated home application using IoT with Blynk App. *Proceeding of the Second International Conference on Inventive Communication and Computational Technologies* (ICICCT). 393–397. https://doi.org/10.1109/ICICCT.2018.8473224

Falohun, A. S., Oke, A. O., Abolaji, B. M., & Oladejo, O. E. (2016). Dangerous gas detection using an integrated circuit and MQ-9. *International Journal of Computer Applications*, *135*(7), 30-34.

Fang, L., Clausen, G., & Fanger, P.O. (1998). Impact of temperature and humidity on perception of indoor air quality during immediate and longer whole-body exposures. *Indoor Air*, *8*(4), 276–284.

Ha, Q.P., Metia, S., & Phung, M.D. (2020). Sensing data fusion for enhanced indoor air quality monitoring. *IEEE Sensors Journal*, *20*(8), 4430–4441. https://doi.org/10.1109/JSEN.2020.2964396.

Hojaiji, H., Kalantarian, H., Bui, A.A., King, C.E., & Sarrafzadeh, M. (2017). Temperature and humidity calibration of a low-cost wireless dust sensor for real-time monitoring. *Proceedings of 2017 IEEE Sensors Applications Symposium (SAS 2017)*, 3–8. https://doi.org/10.1109/SAS.2017.7894056

Jayamurugan, R., Kumaravel, B., Palanivelraja, S., & Chockalingam, M.P. (2013). Influence of temperature, relative humidity, and seasonal variability on ambient air quality in a coastal urban area. *International Journal of Atmospheric Sciences*, *2013*.

Kumar, P., Skouloudis, A.N., Bell, M., Viana, M., Carotta, M.C., Biskos, G., & Morawska, L. (2016). Real-time sensors for indoor air monitoring and challenges ahead in deploying them to urban buildings. *Science of the Total Environment*, *560*, 150–159. https://doi.org/10.1016/j.scitotenv.2016.04.032

Kumar, S., & Mahdavi, A. (2001). Integrating thermal comfort field data analysis in a case-based building simulation environment. *Building and Environment*, *36*(6), 711–720. https://doi.org/10.1016/S0360-1323(00)00064-0

Mlakar, J., & Štrancar, J. (2013). Temperature and humidity profiles in passive-house building blocks. *Building and Environment*, *60*, 185–193. https://doi.org/10.1016/j.buildenv.2012.11.018

Muladi, M., Sendari, S., & Widiyaningtyas, T. (2018). Real time indoor air quality monitoring using internet of things at university. *2018 2nd Borneo International Conference on Applied Mathematics and Engineering (BICAME 2018)*, 169-173. https://doi.org/10.1109/BICAME45512.2018.1570509614.

Panghurian, F.P., Surantha, N., & Zahra, A. (2018). A low-power scenario for IOT-based indoor air quality monitoring system at workplace. *IOP Conference Series: Earth and Environmental Science*, *195*.

Salthammer, T., Uhde, E., Schripp, T., Schieweck, A., Morawska, L., Mazaheri, M., Clifford, S., He, C., Buonanno, G., Querol, X., & Viana, M. (2016). Children's well-being at schools: Impact of climatic conditions and air pollution. *Environment International*, *94*, 196–210. https://doi.org/10.1016/j.envint.2016.05.009

Sattayakorn, S., Ichinose, M., & Sasaki, R. (2017). Clarifying thermal comfort of healthcare occupants in tropical region: A case of indoor environment in Thai hospitals. *Energy and buildings*, *149*, 45–57. https://doi.org/10.1016/j.enbuild.2017.05.025

Takigawa, T., Wang, B. L., Sakano, N., Wang, D. H., Ogino, K., & Kishi, R. (2009). A longitudinal study of environmental risk factors for subjective symptoms associated with sick building syndrome in new dwellings. *Science of The Total Environment*, *407*(19), 5223–5228. https://doi.org/10.1016/j.scitotenv.2009.06.023

Tran, V.V., Park, D., & Lee, Y.C. (2020). Indoor air pollution related human diseases, and recent trends in the control and improvement of indoor air quality. *International Journal of Environmental Research and Public Health*, *17*(8), 2927. https://doi.org/10.3390/ijerph17082927

Vilčeková, S., Apostoloski, I.Z., Mečiarová, Ľ., Burdová, E.K., & Kiseľák, J. (2017). Investigation of indoor air quality in houses of Macedonia. *International Journal of Environmental Research and Public Health*, *14*(1), 37. https://doi.org/10.3390/ijerph14010037

Wang, D., Agrawal, D.P., Toruksa, W., Chaiwatpongsakorn, C., Lu, M., & Keener, T.C. (2010). Monitoring ambient air quality with carbon monoxide sensor-based wireless network. *Communications of the ACM*, *53*(5), 138–141.

Wardhani, D.K., Anastasia, M., & Setiando, M.J. (2020). Indoor health and comfort for the green workplace at the university. *ARTEKS: Jurnal Teknik Arsitektur*, *5*(3), 441–448. https://doi.org/10.30822/arteks.v5i3.582

Yu, C.W., & Kim, J.T. (2011). Building environmental assessment schemes for rating of IAQ in sustainable buildings. *Indoor and Built Environment*, *20*(1), 5–15. https://doi.org/10.1177%2F1420326X10397780

Zaki, S.A., Damiati, S.A., Rijal, H.B., Hagishima, A., & Abd Razak, A. (2017). Adaptive thermal comfort in university classrooms in Malaysia and Japan. *Building and Environment*, *122*, 294–306. https://doi.org/10.1016/j.buildenv.2017.06.016