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IJIE

Journal homepage: http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

Indoor Chemical Air Contaminants in Main Prayer Hall during Jumaat Prayer in Mosques with Different Mechanical Ventilation

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DOI: https://doi.org/10.30880/ijie.2019.11.01.011
Received 01 June 2018; accepted 29 June 2018, available online 30 April 2019

Abstract Muslims generally pray five times a day. Every Friday, adult male Muslims congregate to perform Jumaat prayer, causing increased number of worshippers in mosques and vehicle movements. Consequently, indoor chemical air contaminants are produced inside and outside mosques. This study evaluated the compliance of indoor chemical air contaminants (CO, O_3, TVOC, CH_2O, and PM_{10}) during Jumaat and Asar prayers in two mosques having different mechanical ventilations (i.e., air conditioning and non-air conditioned system) with the guideline limit recommended by Malaysia's Industrial Code of Practice. Chemical air contaminants were monitored from 1200H to 1700H in the air-conditioned mosque and from 1200H to 1730H in the non-air conditioned system mosque, which were the times for Jumaat and Asar prayers. The monitoring was conducted from November 2016 to March 2017, during the Northeast monsoon. Results showed that the mean concentrations of the four chemical air contaminants in both mosques did not exceed the acceptable guideline limit. The mean CO, TVOC, CH_2O, and PM_{10} concentrations in the air-conditioned mosque were 0.29 ppm, 354.09 ppb, 31.28 ppb, and 13.45 μg/m^3; those in the non-air conditioned system mosque were 2.36 ppm, 344.32 ppb, 19.78 ppb, and 49.91 μg/m^3, respectively. However, the air-conditioned mosque's maximum PM_{10} concentration of 164.48 μg/m^3 exceeded the acceptable guideline limit of 150 μg/m^3. Moreover, both mosques' mean O_3 concentrations of 140 and 80 ppb exceeded the limit of 50 ppb, respectively. These results suggested that the concentrations of three chemical air contaminants (TVOC, O_3, and CH_2O) in the air-conditioned mosque were higher than those in the non-air conditioned system mosque possibly because of the inadequate ventilation system inside the air-conditioned building. Therefore, air-conditioned mosques should have a good ventilation system to provide suitable temperature and humidity for the Jemaah, as well as sufficient amounts of air to remove indoor chemical air contaminants.

Keywords: Carbon monoxide, formaldehyde, indoor air quality, ozone, particulate matter

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1. Introduction

Mosques are very symbolic landmarks because these are where Muslim communities pray in congregation five times a day and hold other social and cultural activities. The attendance of male Muslims during Zohor time on Friday (Jumaat) is compulsory; so many mosques need to accommodate a high number of people. To feel comfortable and calm in urban mosques, the indoor temperature should be suitable for worshippers [1]. A suitable temperature is very crucial because according to Ibrahim et al. [2], worshippers should gain a feeling of tranquility, peace, and serenity when praying in mosques. Hence, most mosques in Malaysia have started to install air-conditioning systems for worshippers so they can feel comfortable and calm. However, using air-conditioning is not sustainable because of the high electricity consumption that leads to increased carbon emission [1].

The quality of the indoor environment is also very important for a good quality of life [3], and such an environment requires good indoor air quality (IAQ). As mosque is always used by the public, so the IAQ needs to be monitored in many instances. According to Lee and Chang [4], indoor pollutant levels can be greater than outdoor levels. The IAQ is threatened with various contaminants from indoor and outdoor sources that greatly affect both the environment and human health [5].

The chemicals that affect IAQ are pollutants arising from drapes, cosmetics, paint, carpets, furniture, and environmental tobacco smoke. Some studies in Malaysia show that thermal comfort and sick building syndrome have become commons issue in Malaysian buildings [6], [7]. Studies on IAQ in mosques is scarce. Hameed and Habeeballah [8] found that Muslim gatherings in a mosque may affect IAQ and present many public health challenges. Accordingly, Malaysia's Industrial Code of Practice (ICOP) has been drawn up to ensure that employees and occupants are protected from poor IAQ that can adversely affect their health and well-being, thereby reducing their productivity [9].

Information about IAQ in mosque buildings has been reported by Ocak et al. [10] in their study in Turkey. The available but limited measurements of ventilation rates and CO_2 concentrations in mosque buildings suggest that based on current the ASHRAE ventilation standard, many mosque buildings are not adequately ventilated. Indeed, inadequate ventilation rates and high concentrations of CO_2, $PM_{2.5}$, and biological pollutants have been found in mosque building studies performed in Turkey and the Kingdom of Saudi Arabia [8], [10]. A study has also been conducted by Dewangan et al. [11], who showed that benzene has the highest emission factor among selected volatile organic compounds in all four different religious places at India. Moreover, the high VOC concentrations found in a 2012 Hajj study have been determined to be influenced by gasoline evaporation, vehicular exhaust, air conditioners, and liquefied petroleum gas [12].

Regulating fresh air intake is recommended only during prayer times to avoid a high build-up of CO2 concentrations because high CO_2 concentration peaks have been found every regular prayer. The highest CO_2 concentration peak has been found on Jumaat at high noon prayer, and this period represents the maximum occupancy in the mosque building [13].

Indeed, a comprehensive investigation of pollutant exposure in mosque buildings across representative and typical mosque buildings in Malaysia is needed. Thus, this research aimed to evaluate the compliance of indoor chemical air contaminants (CO, O_3, TVOC, CH_2O, and PM_{10}) during Jumaat and Asar prayers in two different mechanically ventilated mosques (i.e., air conditioned and fan only) with the guideline limit recommended by Malaysia's ICOP.

2. Material and Method

2.1 Sampling Locations

This research was conducted in two mosques within the Seberang Perai Selatan area, and measurements for both air-conditioned and fan- only mosques were made during Jumaat and Asar prayers. The air-conditioned mosque was Masjid Jamek Nibong Tebal, located in Nibong Tebal (15°10′05.0″ N and 100°28′39.4″ E). The non-air conditioned system mosque was Masjid Lama Sungai Bakap, located in Nibong Tebal (15°13′17.7″ N and 100°29′49.7″ E). The location maps of both mosques are illustrated in Fig. 1 and Fig. 2, respectively.

2.2 Selection of Monitoring Instruments

An IAQ probe (IQ-610) was used to monitor CO, TVOC, and O_3, and a Formaldehyde Multi Mode Monitor (FM-801) was used for CH_2O. Both instruments were Graywolf Model. An Airborne Particle Counter (Handheld 3016 IAQ) Light House Model was used to measure PM_{10}.

2.3 Sampling Method

The sampling at Masjid Jamek Nibong Tebal was conducted for 5 h from 1200H to 1700H, and the sampling at Masjid Lama Sungai Bakap was conducted for 5 h and 30 min from 1200H to 1730H. The discrepancies were due to the late entrance time of Asar and because the congregations finish by 1730H. The sampling schedule for Jumaat and Asar prayers is as shown in Table 1, and the sampling conditions at Masjid Jamek Nibong Tebal and Masjid Lama Sungai Bakap are shown in Fig. 3(a) and Fig. 3(b), respectively. The space design of the air-conditioned mosque was termed as single volume (about 10 ft or slightly more than 10 ft of floor-to-ceiling heght), and the non-air conditioned system mosque was a combination of single and double volume (more than 10 ft of floor-to-ceiling height at the area next to the mihrab).

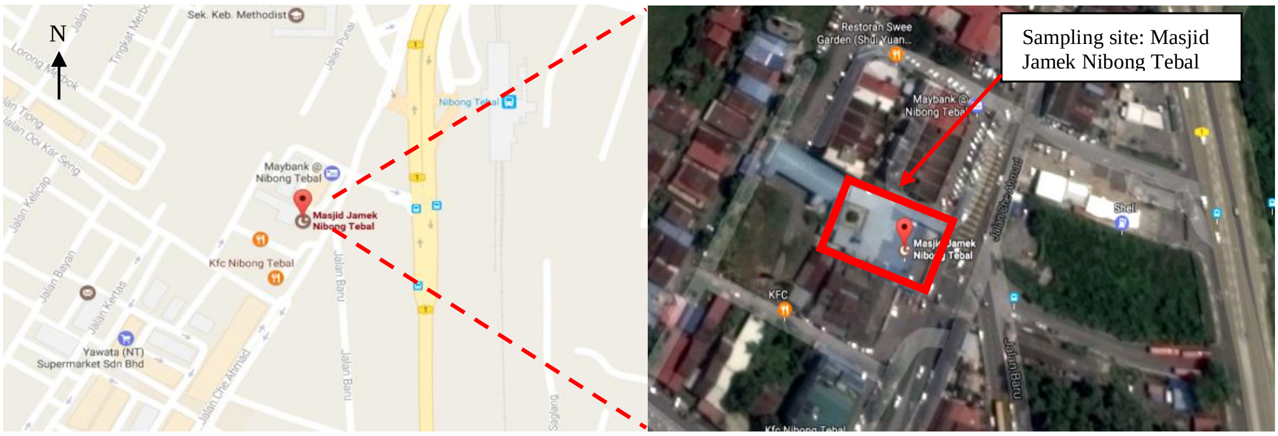


Fig. 1 - Location map of Masjid Jamek Nibong Tebal, Nibong Tebal

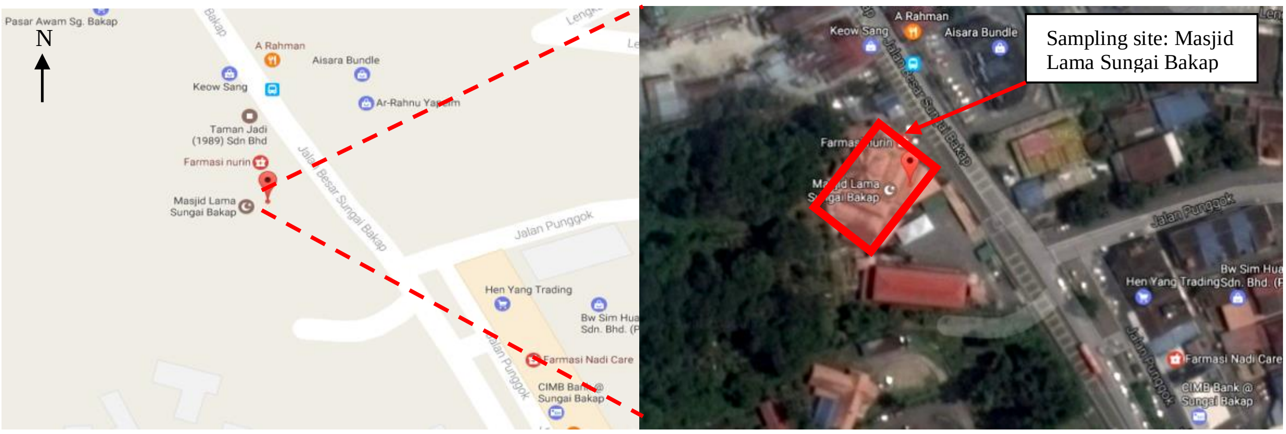


Fig. 2 - Location map of Masjid Lama Sungai Bakap, Nibong Tebal

3. Results and Discussion

The factors affecting IAQ include lack of ventilation, outdoor air quality, and existence of indoor contaminant sources [14]. However, indoor air contaminants that are generated from sources within the indoor environment (e.g., cleaning and construction materials, furniture, furnishings, chemical products, and other general activities) may lead to higher exposure than outdoor concentrations. For this study, the presence of indoor contaminants from the both mosques increased the IAQ.

Table 1 - Sampling schedule for Jumaat prayer

Session	Activities	Parameters Monitored
Jumaat and Asar prayer	a) Before worshipers start coming	CO, O_3, TVOC, CH_2O and PM_{10}
	b) Worshippers start coming	
	c) During sermon and Jumaat prayer	
	d) Worshippers dismiss	
	e) Before Asar prayer	
	f) During Asar prayer	

(a) (b)

Fig. 3 - Sampling conditions at the (a) air-conditioned, and (b) non-air conditioned system mosques

3.1. Chemical Contaminants at Main Prayer Hall

Fig. 4 shows the chemical air contaminants in both mosques, and Table 2 shows that a descriptive table of chemical air contaminant concentrations in accordance with the acceptable guideline limit recommended by Malaysia's ICOP (DOSH) [9].

Results showed that the mean CO concentration was 2.36 ppm (range = 1.5–3.3 ppm) in the non-air conditioned system mosque. This value was higher than the mean CO concentration of 0.29 ppm (range = 0–1.1 ppm) of the air-conditioned mosque. CO values were high between 1230H and 1330H (when worshippers start coming) and between 1400H and 1500H (when worshippers start leaving) for both mosques because of the increased number of vehicles transporting them on this holy day (Jumaat prayer). The reason was the exhaust gases from these vehicles and from other ones traveling near the mosques. Fernández et al. [14] reported that the common sources of CO emission are portable heaters that use kerosene, wood-burning fireplaces, automobile exhaust, and tobacco smoke. Although the acceptable guideline limit value of 10 ppm for CO concentration was not exceeded in both cases, the observed amount can still affect human health, in accordance with the study of Currie et al. [15]. They reported a 3.8% increase in absenteeism of school children and other health issued when the mean CO concentration is 2.73 ppm (range = 0.65–6.23 ppm).

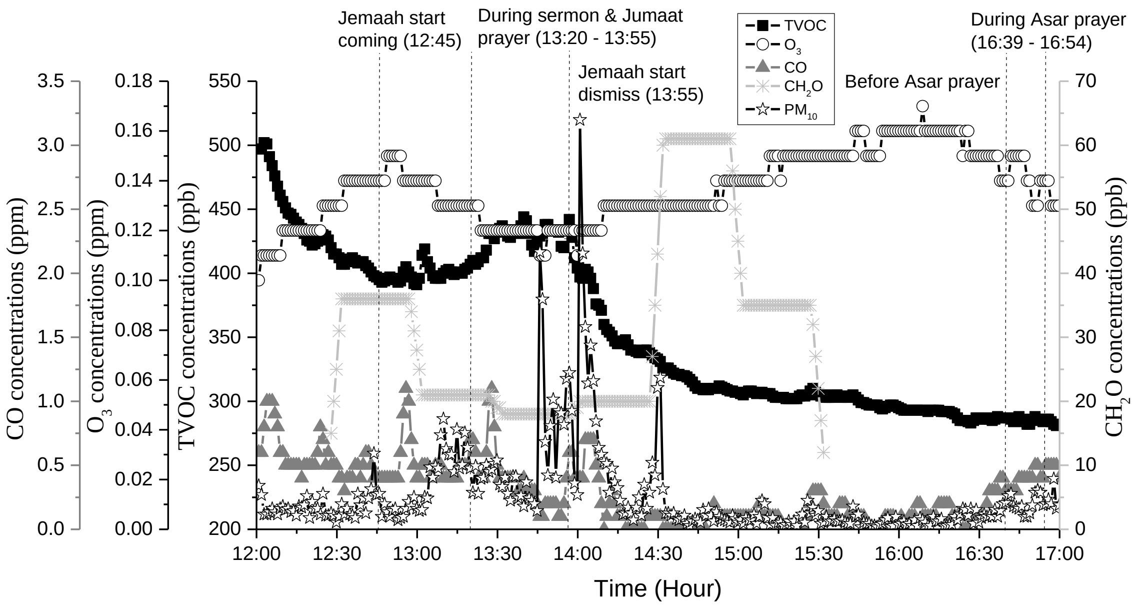
Meanwhile, our results suggested that the mean O_3 concentration in the air-conditioned mosque was 43% higher than the non-air conditioned system mosque. The mean O_3 concentrations in both mosque were 0.14 ppm (range = 0.1–0.17 ppm) and 0.08 ppm (range = 0.06–0.12 ppm), which exceeded the acceptable guideline limit of 0.05 ppm. Notably, O_3 is a secondary pollutant that can be influenced by precursor availability, local meteorology, and seasonal variability [16].

The mean TVOC concentration in the air-conditioned mosque was slightly higher than that in the non-air conditioned system mosque, i.e., 354.09 ppb (range = 281–502 ppb) and 344.32 ppb (range = 267–511 ppb), respectively. The TVOC concentrations for both mosques were high at 1200H (before Jumaat prayer) because only passive ventilation (i.e., through windows and doors) was available at that time. The values started to decrease at 1300H (when worshippers start coming) because of active ventilation (i.e. through air conditional and fans). Thus, air ventilation from the active ventilation inside the mosques started to decrease the TVOC concentration. However, although active ventilation was in operation during sermon and Jumaat prayer, TVOC concentrations started to increase during these times because the high number and the crowdedness of the Jemaah inside the mosques contributed to the inadequate ventilation system inside. The mean TVOC concentrations in both mosques were within the acceptable guideline limit of 3000 ppb.

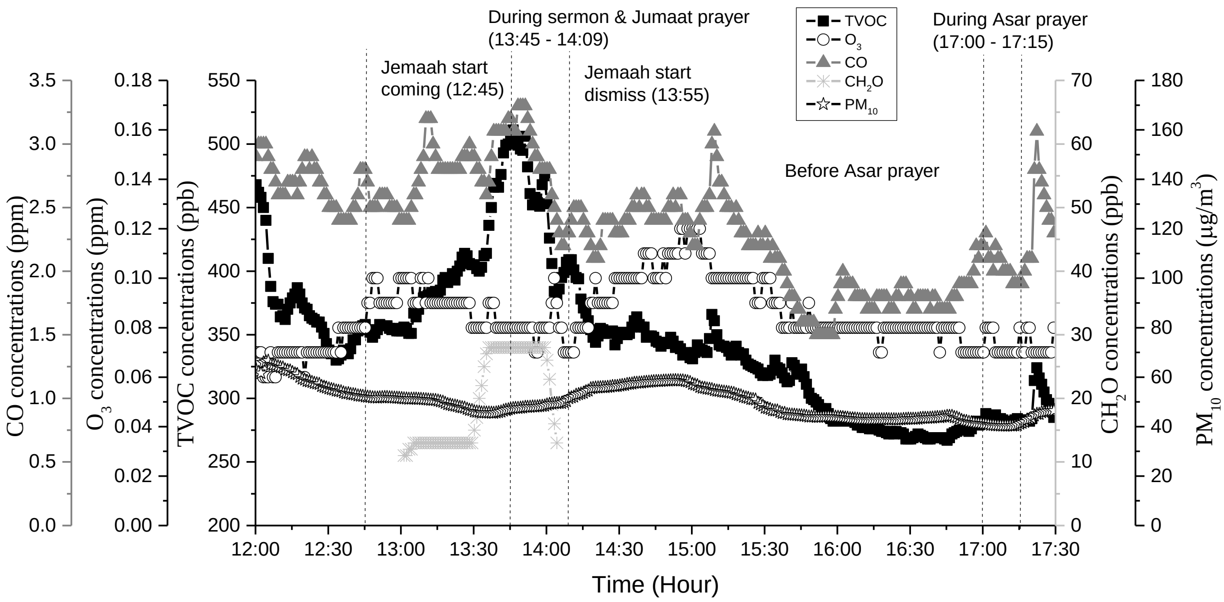
The mean CH_2O concentrations in the air-conditioned mosque was slightly higher than the mean CH_2O concentrations in the non-air conditioned system mosque, i.e., 31.28 ppb (range = 12–61 ppb) and 19.78 ppb (range = 16.5–28 ppb), respectively. The maximum CH_2O concentration in the air-conditioned mosque increased by 54% compared with the maximum CH_2O concentration in the non-air conditioned system mosque. This finding showed that good ventilation in the non-air conditioned system mosque induced the CH_2O molecules to easily disperse into the air. The CH_2O concentrations in air-conditioned mosque were high at 1230H and 1430H because only passive ventilation was available during nonprayer time. Nevertheless, the mean CH_2O concentrations in both mosques did not exceed the acceptable guideline limit of 100 ppb.

The mean PM_{10} concentration in the non-air conditioned system mosque was 49.91 $\mu g/m^3$ (range = 40.33–66.61 $\mu g/m^3$), which was slightly higher than the 13.45 $\mu g/m^3$ (range = 0.92–164.48 $\mu g/m^3$) in the air-conditioned mosque. Although the mean PM_{10} concentration in the non-air conditioned system mosque was higher than that in the air-conditioned mosque, the maximum PM_{10} concentration in the former was 60% higher than the maximum PM_{10}

concentration in the non-air conditioned system mosque. The maximum PM_{10} concentration in the air-conditioned mosque also exceeded the acceptable guideline limit of 150 μg/m^3. The PM_{10} concentration in the air-conditioned mosque was high and exceeded the acceptable limit at 1400H (when worshippers start leaving) because of the resuspension of settled dust and particles of carpet as worshippers started walking inside the mosques. Conversely, the PM_{10} concentrations in the non-air conditioned system mosque were high at 1200H and 1500H, which were non-prayer times, because only passive ventilation was available. Then, PM_{10} concentration decreased during prayer time as active ventilation was in operation. This finding showed that during prayer time, ventilation from the fans reduced the PM_{10} concentration by increasing the exchange between indoor and outdoor air.



(a)



(b)

Fig. 4 Chemical contaminants in the (a) air-conditioned, and (b) non-air conditioned system mosque

Table 2 - Descriptive table of chemical contaminant concentrations for air-conditioned and non-air conditioned system mosques

Indoor Chemical Air Contaminants				**Acceptable Limit**
CO concentrations (ppm)				10 ppm
Air conditioning system		Without air conditioning system		
N	300	N	330	
Minimum	0	Minimum	1.5	
Maximum	1.1	Maximum	3.3	
Mean	0.29	Mean	2.36	
Std. Deviation	0.24	Std. Deviation	0.44	
O_3 concentrations (ppm)				0.05 ppm
Air conditioning system		Without air conditioning system		
N	300	N	330	
Minimum	0.1	Minimum	0.06	
Maximum	0.17	Maximum	0.12	
Mean	0.14	Mean	0.08	
Std. Deviation	0.01	Std. Deviation	0.01	
TVOC concentrations (ppb)				3000 ppb
Air conditioning system		Without air conditioning system		
N	300	N	330	
Minimum	281	Minimum	267	
Maximum	502	Maximum	511	
Mean	354.09	Mean	344.32	
Std. Deviation	60.96	Std. Deviation	57.93	
CH_2O concentrations (ppb)				100 ppb
Air conditioning system		Without air conditioning system		
N	185	N	64	
Minimum	12	Minimum	11	
Maximum	61	Maximum	28	
Mean	31.28	Mean	19.78	
Std. Deviation	14.49	Std. Deviation	7.21	
PM_{10} concentrations ($\mu g/m^3$)				150 $\mu g/m^3$
Air conditioning system		Without air conditioning system		
N	300	N	330	
Minimum	0.92	Minimum	40.33	
Maximum	164.48	Maximum	66.61	
Mean	13.45	Mean	49.91	
Std. Deviation	18.32	Std. Deviation	6.37	

Various sources of indoor air contaminants include particle resuspension from the floor, outdoor particles infiltrating buildings, and secondary particle formation from the reaction of gaseous pollutants. Different global studies have reported that occupant activities and movements may either cause the resuspension of deposited coarse particles or delay particle deposition and are thus the major sources of indoor PM [17]-[22]. The samplings for both mosques were also conducted after vacuum cleaning, meaning that the particulate matter deposited on carpet surfaces was disrupted. Moreover, although a large amount of PM was trapped by the airstream and deposited into the filter of the vacuum cleaner, fine PM may not have been trapped by the filter and was then resuspended in the air. This finding was in accordance with those of Nielsen [23].

Results further showed that three of the studied chemical contaminants (O_3, TVOC, and CH_2O) in the air-conditioned mosque had higher concentrations than those in the non-air conditioned system mosque. This finding was due to the inadequate ventilation system inside the air-conditioned building, causing the air to just circulate inside the mosque. A good ventilation system inside the mosque is suggested because it can provide suitable temperature and humidity for the Jemaah and allow adequate amounts of air to circulate and thus remove indoor chemical air contaminants. For the non-air conditioned system mosque, the ventilation rate should be increased as the exchange between indoor and outdoor air can decrease the indoor chemical air contaminants.

4. Conclusion

The concentrations of four chemical air contaminants (CO, TVOC, CH_2O, and PM_{10}) for air-conditioned and non-air conditioned system mosques did not exceed the acceptable guideline limit recommended by Malaysia's ICOP (DOSH) [9]. However, the mean of O_3 concentrations of 140 and 80 ppb for the two mosques, respectively, exceeded the ICOP's concentration limit of 50 ppb. Moreover, three of the chemical contaminants in the air-conditioned mosque had higher concentrations than those in the non-air conditioned system mosque. Nevertheless, air-conditioning was still preferable in mosques for worshippers to feel comfortable and calm, but the amount of indoor chemical air contaminants should be regularly monitored to ensure that they remain within the acceptable ICOP limit and thus avert any possible adverse health effects on worshippers.

Acknowledgement

This work was funded by the Ministry of Science Technology and Innovation (MOSTI), E-Science Fund 305/PAWAM/6013607)-0601-05-SF0766.

References

[1] Abdullah, F. H., Majid, N. H. A., and Othman, R. (2016). Defining issue of thermal comfort control through urban mosque façade design. Procedia-Social and Behavioral Sciences, 234, 416-423.
[2] Ibrahim S. H., Baharun A., Nawi M. N. M., and Junaidi E. (2014). Assessment of thermal comfort in the mosque in Sarawak, Malaysia. International Journal of Energy and Environmental, 5(3), 327-334.
[3] Langer, S., Ramalho, O., Derbez, M., Riberon, J., Kirchner, S., and Mandin, C. (2016). Indoor environmental quality in French dwellings and building characteristics. Atmospheric Environment, 128, 82-91.
[4] Lee, S. C., and Chang, M. (2000). Indoor and outdoor air quality investigation at schools in Hong Kong. Chemosphere, 41(1-2), 109-113.
[5] Elbayoumi, M., Ramli, N. A., Md Yusof, N. F. F., Yahaya, A. S., Al Madhoun, W., and Ul-Saufie, A. Z. (2014). Multivariate methods for indoor PM_{10} and $PM_{2.5}$ modelling in naturally ventilated schools buildings. Atmospheric Environment, 94,11-21.
[6] Kamaruzzaman, K. and Tazilan, A. (2013). Thermal comfort assessment of a classroom in tropical climate conditions. Recent Advances in Energy, Environment and Development, pp 87-91.
[7] Norhidayah, A., Chia-Kuang, L., Azhar, M.and Nurulwahida, S. (2013). Indoor air quality and sick buildings syndrome in three selected buildings. Procedia Engineering, 53, 93-98.
[8] Hameed, A. A., and Habeeballah, T. (2013). Air microbial contamination at the Holy Mosque, Makkah, Saudi Arabia. Current World Environment, 8(2), 179-187.
[9] Department of Occupational Safety and Health (2010). Malaysia's industrial code of practice on indoor air quality. Kuala Lumpur: Health Ministry of Human Resources.
[10] Ocak, Y., Kılıçvuran, A., Eren, A. B., Sofuoglu, A., and Sofuoglu, S. C. (2012). Exposure to particulate matter in a mosque. Atmospheric Environment, 56, 169-176.
[11] Dewangan, S., Chakrabarty, R., Zielinska, B., and Pervez, S. (2013). Emission of volatile organic compounds from religious and ritual activities in India. Environmental Monitoring and Assessment, 185(11), 9279-9286.
[12] Simpson, I. J., Aburizaiza, O. S., Siddique, A., Barletta, B., Blake, N. J., Gartner, A., and Blake, D. R. (2014). Air quality in Mecca and surrounding holy places in Saudi Arabia during Hajj: Initial survey. Environmental Science and Technology, 48(15), 8529-8537.
[13] Al-Dabbous, A. N., Khan, A. R., Al-Rashidi, M. S., and Awadi, L. (2013), Carbon dioxide and volatile organic compounds levels in mosque in hot arid climate. Indoor and Built Environment, 22(2), 456-464.
[14] Fernández, L. C., Alvarez, R. F., Francisco Javier González-Barcala, F. J., and Portal, J. A. R. (2013). Indoor air contaminants and their impact on respiratory pathologies. Arch Bronconeumol, 49, 22-27.
[15] Currie, J., Hanushek, E. A., Kahn, E. M., Neidell, M., and Rivkin, S. G. (2009). Does pollution increase school absences?. The Review of Economics and Statistics, 91(4), 682-694.
[16] Lin, M., Horowitz, L. W., Cooper, O. R., Tarasick, D., Conley, S., Iraci, L. T., and Yates, E. L. (2015). Revisiting the evidence of increasing springtime ozone mixing ratios in the free troposphere over western North America. Geophysical Research Letters, 42(20), 8719-8728.
[17] Blondeau, P., Iordache, V., Poupard, O., Genin, D., and Allard, F. (2005), Relationship between outdoor and indoor air quality in eight French schools. Indoor Air, 15(1), 2-12.
[18] Diapouli, E., Chaloulakou, A., and Spyrellis, N. (2007). Levels of ultrafine particles in different microenvironments – implications to children exposure. Science of the Total Environment, 388(1), 128-136.
[19] Stranger, M., Potgieter-Vermaak, S. S., and Van Grieken, R. (2008). Characterization of indoor air quality in primary schools in Antwerp, Belgium. Indoor Air, 18(6), 454-463.
[20] Heudorf, U., Neitzert, V., and Spark, J. (2009). Particulate matter and carbon dioxide in classrooms–the impact of cleaning and ventilation. International Journal of Hygiene and Environmental Health, 212(1), 45-55.

[21] Goyal, R., and Khare, M. (2011), Indoor air quality modeling for PM10, PM2.5, and PM1.0 in naturally ventilated classrooms of an urban Indian school building. Environmental Monitoring and Assessment, 176(1), 501-516.
[22] Chithra, V. S., and Nagendra, S. S. (2012). Indoor air quality investigations in a naturally ventilated school building located close to an urban roadway in Chennai, India. Building and Environment, 54, 159-167.
[23] Nielsen, P. V. (2004). Computational fluid dynamics and room air movement. Indoor Air, 14, 134-143.