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Dependency of Biological Contaminants on Temperature and Relative Humidity within Praying Halls of Mosques

(Pergantungan Pencemaran Biologi pada Suhu dan Kelembapan di dalam Ruang Solat Masjid)

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ABSTRACT

The widespread use of Air Conditioning Split Units (ACSU) to cool the air inside mosques may pose potential adverse health effects, secondary to exposure to biological contaminants. To address this issue, the dependencies of biological contaminants (bacteria and fungi) on temperature (T) and relative humidity (RH) of the 'mosques' indoor air were evaluated. A total of 25 mosques were investigated during the periods in which their respective congregators were performing Zohor *or* Friday, *and* Asar *prayers. The recorded average indoor bacteria and fungi concentrations were 382.6±143.9 cfu/m³ and 229.4±165.5 cfu/m³, respectively. However, the study found that masses of bacteria aerosol within the indoors of certain mosques (10 out of 17 ACSU mosques and 1 out of 8 non-ACSU mosques) exceeded the limit recommended by Malaysian standard for indoor air quality (500 cfu/m³). Meanwhile, the results of regression analyses suggested that T and RH of the indoor air have high influence on airborne bacteria and fungi. The variations in bacteria concentrations due to the influence of T and RH in ACSU mosques (T= 92.3%; RH= 90.3%) were higher than in non-ACSU mosques (T= 82.75%; RH= 81.7%) whereas the variations in fungi concentrations in non-ACSU mosques (T=70.45%; RH= 71.45%) were higher than in ACSU mosques (T= 66.05%; RH= 60.7%). This research shows that the growth of bacteria and fungi within the prayer halls of mosques in Malaysia is very much dependent on its indoor T and RH.*

Keywords: Biological contaminants; indoor air; mosque; relative humidity; temperature

ABSTRAK

Penggunaan meluas Penyaman Udara Unit Pisah (ACSU) untuk menyejukkan udara di dalam masjid boleh menimbulkan potensi kesan kesihatan yang buruk, membawa pendedahan kepada bahan cemar biologi. Bagi menangani isu ini, kebergantungan bahan cemar biologi (bakteria dan kulat) terhadap suhu (T) dan kelembapan relatif (RH) daripada udara dalaman masjid telah dinilai. Sebanyak 25 buah masjid telah dikaji dalam tempoh para jemaah masing-masing sedang melaksanakan solat Zohor *atau* Jumaat, *dan* Asar. *Purata kepekatan bakteria dan kulat di ruang dalaman yang direkodkan masing-masing adalah 382.6 ± 143.9 cfu/m³ dan 229.4 ± 165.5 cfu/m³. Walau bagaimanapun, kajian ini mendapati bahawa jisim aerosol bakteria di dalam ruang dalaman bangunan masjid tertentu (10 daripada 17 masjid ACSU dan 1 daripada 8 masjid bukan ACSU) melebihi had yang disyorkan oleh piawai Malaysia bagi kualiti udara dalaman (500 cfu/m³). Sementara itu, hasil daripada analisis regresi menunjukkan bahawa T dan RH daripada udara dalaman mempunyai pengaruh yang tinggi terhadap bakteria bawaan udara dan kulat. Variasi dalam kepekatan bakteria akibat pengaruh T dan RH di masjid ACSU (T = 92.3%; RH = 90.3%) adalah lebih tinggi daripada di masjid bukan ACSU (T = 82.75%; RH = 81.7%) manakala variasi dalam kepekatan kulat di masjid bukan ACSU (T = 70.45%; RH = 71.45%) adalah lebih tinggi daripada di masjid ACSU (T = 66.05%; RH = 60.7%). Kajian ini menunjukkan bahawa pertumbuhan bakteria dan kulat di dalam dewan solat masjid di Malaysia sangat bergantung kepada T dan RH bagi udara dalamannya.*

Kata kunci: Bahan cemar biologi; kelembapan relatif; masjid; suhu; udara dalaman

INTRODUCTION

Many studies have been carried out on biological contaminants (bacteria and fungi) levels in different building environments, such as mosques, schools, offices, restaurants and industrial processes (Alananbeh et al. 2017; Backman et al. 2014; Bornehag et al. 2001; Hameed & Habeeballah, 2013; Kousar et al. 2013; Mashat 2015; Meklin et al. 2002; Mendell et al. 2014; Nahar & Mahyudin 2018). The results showed that in indoor environments, one of the strongest and most consistent risk factors for health problems, which include sick building syndrome (SBS), asthma and allergies and respiratory illnesses, is moisture problems in buildings, known broadly as 'dampness'. Dampness may be caused by the use of multiple Air Conditioning Split Units (ACSU) for reducing the indoor temperature to reach comfort. Due to this, a number of chemical and biological agents have been suspected to be the causal agents in the relationship between atopic diseases and dampness in buildings. Therefore, the Malaysia's Industry

Code of Practice (ICOP) has recommended the acceptable guideline limit for biological contaminants (bacteria and fungi) to provide a safer indoor environment for building occupants. The guideline limits for bacteria and fungi are 500 cfu/m^3 and 1000 cfu/m^3, respectively (DOSH 2010).

As a tropical climate country, low ventilation rates combined with high outdoor pollutants may affect the indoor air quality (IAQ) of buildings in Malaysia. Furthermore, high humidity and high temperature conditions increase the risk of thermal discomfort and moisture problems indoors (Hamimah et al. 2010). Several previous IAQ studies in Malaysia reported that IAQ, thermal comfort and SBS have become common issues in buildings in Malaysia (Kamaruzzaman & Razak 2011; Makhtar et al. 2010; Mustapha et al. 2008; Norhidayah et al. 2013; Sulaiman et al. 2005). Mosques, which are places of worship for Muslims, have unique functional requirements and operational characteristics. Worshippers in mosques need to feel comfortable and calm during daily and weekly prayers and leave with a feeling of tranquility and peace.

Therefore, a comprehensive investigation of biological contaminant levels in mosque buildings across representative and typical mosque buildings in Malaysia is needed. Moreover, information on the effects of ventilation strategies in mosque buildings in terms of ventilation system and biological contaminant levels is lacking. The purpose of this research was to investigate the dependency of bacteria and fungi on temperature (T) and relative humidity (RH) in the mosque building environments within different ventilation systems in the tropical climate conditions.

Materials and Methods

MONITORING AND SAMPLING LOCATION

Monitoring and sampling were conducted at 24 mosques in the South Seberang Perai District and one (1) mosque in the Northeast District, of Pulau Pinang, Malaysia. The 25 mosques represented the *qariah*/*jamek* mosques of Malaysia (MS 2014). Monitoring and sampling were carried out at two different categories of mosques based on their active ventilation systems, namely ACSU (17 mosques) and non-ACSU (8 mosques).

PHYSICAL PARAMETERS MONITORING METHOD

Monitoring of the physical parameters i.e. temperature (T), relative humidity (RH) and air movement (AM) were conducted before *Zohor*/*Friday* prayer (1200 - 1300 h), during *Zohor*/*Friday* prayer (1300 - 1400/1430 h), between *Zohor*/*Friday* prayer (1400/1430 - 1600 h) and during *Asar* prayer (1600 - 1700/1730 h). To account for ventilation approaches, two different types of ventilation, passive and active, were considered in this study. Before and after the prayer sessions, all active ventilation equipment, such as fans and ACSU, were not in operation as there were no worshippers inside the prayer halls; whereas during the prayer sessions, fans and ACSU were operated due to the presence of worshippers. The instrument (Indoor Air Quality probe (IQ-610)) was placed on a tripod, and monitoring was conducted at ~1.3 m above the floor with one (1) min intervals.

SAMPLING METHOD FOR BIOLOGICAL CONTAMINANTS

Biological contaminants (bacteria and fungi) were sampled in two conditions, before, and after vacuuming the carpets of (3 m × 3 m) square area, as to force the uplifting of biological contaminants into the air. A Microbial Air Sampler (100 Model Eco Pump, Merck, Darmstadt, Germany) was used for all sample collections, with a flow rate of 100 L/min and a sampling time of 5 min to avoid the collection of unaccountable microorganisms. A total of four (4) samples were collected for each mosque, at the height of ~ 0.6 m above the floor. The airborne microorganisms were targeted one after another using a 20 mL nutrient plate (tryptic soy agar, TSA) for bacteria, and Sabouraud dextrose agar with chloramphenicol (SDAC) for fungi, which was coupled inside the stage sampler. The Petri plates, with duplicates, for both bacteria and fungi contaminants were prepared. The biological sampling was conducted according to the National Institute for Occupational Safety and Health (NIOSH) 0800 method - Bioaerosol Sampling (Indoor Air) (NIOSH 1998). When changing the collection plates, the stage hole was sterilised with 70% ethanol solution to prevent cross-contamination. Upon completion of sample collections, the agar plates were transported to the laboratory and incubated at 35 ± 1°C for 24 h for bacteria and at 25 ± 1°C for 5 days for fungi. Colony forming units per cubic meter of air sampled (cfu/m^3) are calculated as in (1) (DM 2001).

$$\text{Total bacterial or fungal counts (cfu/m}^3\text{)} = \frac{\text{Bacteria or fungi counts (cfu)}}{\text{Volume of air sampled (m}^3\text{)}} \quad (1)$$

LINEAR REGRESSION ANALYSIS

The strength of linear association between two variables is quantified by R^2, which represents the fraction of the variation in one variable that may be explained by the other variable. R^2 can be calculated using (2) (Junninen et al. 2004).

$$R^2 = \frac{\sum \left(Y_i - \bar{Y}\right)\left(X_i - \bar{X}\right)}{nS_Y S_X} \quad (2)$$

where n is the number of data; X_i is the total bacterial count/total fungal count; Y_i is the T/RH; $\bar{X}$ is the mean of total bacterial count/total fungal count; $\bar{Y}$ is the mean of T/RH; S_X is the standard deviation of total bacterial count/total fungal count; and S_Y is the standard deviation of T/RH. If the R^2 value is near 1, the relationship is almost perfectly associated with each other, whereas if the value is close to 0, no association between the variables exists (Mukaka 2012).

RESULTS AND DISCUSSION

DESCRIPTIVE STATISTIC

Table 1 provides the details of physical parameters (T, RH and AM) in ACSU and non-ACSU mosques during *Zohor-Asar* and *Friday-Asar* prayers. Geographically, Malaysia is in a tropical zone, which has relatively high air temperature, abundant rainfall and high humidity throughout the year. The mean T for all prayer times at ACSU mosques was 26.06±0.90°C to 35.63±0.89°C and 31.08±0.52°C to 33.23±0.72°C in non-ACSU mosques. In both categories of buildings, the T was higher than the acceptable limit range provided by the ICOP, which is 23°C to 26°C. *Zohor/Friday* and *Asar* are performed during the hottest times of the day, which is between afternoon and evening. During these hours, active ventilation systems (ACSU and fans) are preferred to 'cool down' the area inside the mosques.

Natural ventilation may help improving the thermal comfort inside mosque buildings because the air movement in and out of these buildings can decrease the T within the space (Noman et al. 2016). Unfortunately, we observed that the sliding windows (majority of the mosques have this window panel type) were only opened during the prayer sessions due to security reason. The mean RH for all prayer times at ACSU mosques was 51.36±2.32% to 72.27±3.19% and 56.41±3.46% to 69.66±1.43% at non-ACSU mosques. RH which was 40% to 70% for non-ACSU mosques, was in the range of ICOP's acceptable limit. AM at ACSU mosques was 0.03±0.02 m/s to 0.38±1.47 m/s and 0.06±0.08 m/s to 0.65±0.29 m/s at non-ACSU mosques.

The results showed that the average indoor bacteria (382.6±143.9 cfu/m^3) and fungi (229.4±165.5 cfu/m^3) did not exceed the respective acceptable limits of 500 cfu/m^3 and 1000 cfu/m^3 by ICOP (DOSH 2010). However, the study found that bacteria concentrations in 10 out of 17 ACSU mosques and in 1 out of 8 non-ACSU mosques had exceeded the limits. Meanwhile, the fungi concentrations did not exceed the permissible limit in both ACSU and non-ACSU mosques. Conversely, Zock et al. (2002) found that dampness had caused indoor mold growth in houses, which eventually had an adverse effect on adult asthma.

REGRESSION ANALYSIS

Regression analyses of air T during sampling and biological contaminants (bacteria and fungi) for ACSU and non-ACSU mosques (before and after vacuum) were conducted to determine the dependency of biological contaminants on indoor air T, as shown in Figure 1(a) to 1(d). The R^2 values of T with total bacterial count before and after carpet vacuuming for ACSU mosques were 0.924 and 0.922, respectively, whereas the values were 0.866 and 0.789 for non-ACSU mosques, respectively. Meanwhile, R^2 values of T with total fungal count before and after carpet vacuuming in ACSU mosques were 0.653 and 0.668, respectively, whereas the values for non-ACSU mosques were 0.730 and 0.679, respectively. These indicate that on average, 92.3% (bacteria in ACSU mosques), 82.75% (bacteria in non-ACSU mosques), 66.05% (fungi in ACSU mosques) and 70.45% (fungi in non-ACSU mosques) of the variations in biological contaminants were influenced by T.

The plots illustrated a strong positive relationship between T and bacteria for ACSU and non-ACSU mosques. However, a strong relationship between T and fungi was only found in non-ACSU mosques, whereas the relationship was moderate for ACSU mosques. Therefore, we can justify that T has a significant effect towards bacteria and fungi growth. T is a significant variation factor for airborne bacteria, and it governs the rate of water vapour change and the exchange of heat between the surface and environment (Mouli et al. 2005). Furthermore, T affects the viability of airborne bacteria through the evaporation of their cellular water. In addition, although biological contaminants can reproduce within different T ranges, the typical span for bacteria ranges between 35°C and 40°C, and 25°C to 30°C for fungi (Ross & Nichols 2014).

The relationships between RH and biological contaminants (bacteria and fungi) are shown in Figure 2(a) to 2(d). The R^2 values between RH and bacteria before and after carpet vacuuming were 0.926 and 0.880, respectively, for ACSU mosques, whereas for non-ACSU mosques, the R^2 values were 0.872 and 0.762, respectively. The R^2 values between RH and fungi before and after carpet vacuuming were 0.595 and 0.619, respectively, for ACSU mosques, and 0.732 and 0.697 for non-ACSU mosques, respectively.

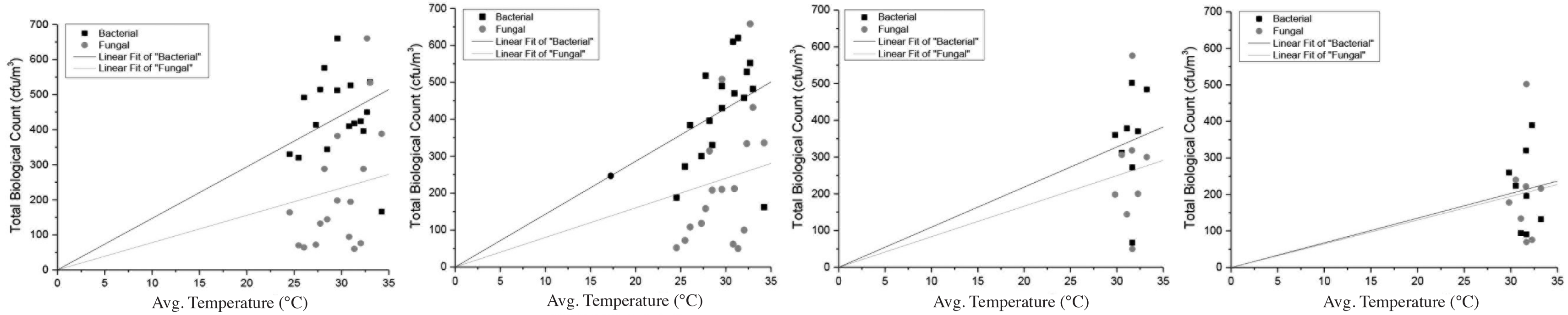
Therefore, on average, 90.3% (bacteria in ACSU mosques), 81.7% (bacteria in non-ACSU mosques), 60.7% (fungi in ACSU mosques) and 71.45% (fungi in non-ACSU mosques) of the variations in biological contaminants were influenced by RH. Thus, RH also has a significant factor for bacteria and fungi growths. The plots illustrated a strong positive relationship between RH and bacteria for ACSU and non-ACSU mosques; and between RH and fungi for non-ACSU mosques. Moreover, a high RH percentage may favour the viability of biological contaminants (Mouli et al. 2005). Rajasekar and Balasubramanian (2011) found a similar result, wherein the indoor fungal growth was positively correlated with RH.

The results of this research show that in ACSU mosques, the growth of bacteria and fungi were high at T and RH in the range between 26.06±0.90°C to 35.63±0.89°C and 51.36±2.32% to 72.27±3.19%, respectively, while in non-ACSU mosques, their growth were found to be high at T and RH in the range between 31.08±0.52°C and 33.23±0.72°C and 56.41±3.46% and 69.66±1.43%, respectively.

TABLE 1. Details of physical parameters (T, RH, AM and total counts of bacteria and fungi) of ACSU and Non-ACSU mosques

Ventilation system	Coordinate	T (°C)	RH (%)	AM (m/s)	Total bacterial counts (cfu/m³) BV	Total bacterial counts (cfu/m³) AV	Total fungal counts (cfu/m³) BV	Total fungal counts (cfu/m³) AV
ACSU Mosques	*Zohor-Asar*							
	N5.162445, E100.515366	29.03 ± 1.14	59.65 ± 1.78	0.10 ± 0.49	526*	470	194	212
	N5.353761, E100.301634	26.06 ± 0.90	66.72 ± 2.05	0.03 ± 0.02	492	384	64	108
	N5.132205, E100.479464	29.73 ± 1.37	64.96 ± 1.03	0.18 ± 0.60	344	330	144	208
	N5.225988, E100.495166	29.53 ± 1.65	66.90 ± 2.26	0.32 ± 0.99	330	188	164	52
	N5.127116, E100.443831	31.64 ± 1.74	63.57 ± 1.89	0.17 ± 0.68	660*	430	382	508
	N5.144331, E100.465058	28.80 ± 2.96	62.48 ± 1.60	0.22 ± 0.59	414	300	72	118
	N5.146839, E100.450196	29.59 ± 1.39	52.98 ± 3.14	0.19 ± 0.68	320	272	70	72
	N5.152006, E100.465278	31.74 ± 1.40	53.83 ± 1.84	0.06 ± 0.41	418	620*	60	50
	N5.197372, E100.468805	31.86 ± 1.52	58.28 ± 2.57	0.10 ± 0.36	410	610*	94	62
	N5.282590, E100.475739	27.49 ± 2.73	64.08 ± 1.42	0.06 ± 0.05	514*	518*	132	158
	N5.146025, E100.408756	31.96 ± 1.07	65.00 ± 3.48	0.10 ± 0.09	424	458	76	100
	N5.124312, E100.418896	32.99 ± 0.83	56.73 ± 4.05	0.18 ± 0.17	536*	482	534	432
	N5.209307, E100.527626	27.95 ± 1.86	72.27 ± 3.19	0.03 ± 0.04	576*	396	288	314
	N5.276925, E100.517778	32.86 ± 0.56	61.84 ± 1.99	0.32 ± 0.75	396	528*	288	334
	N5.274137, E100.444558	35.63 ± 0.89	51.36 ± 2.32	0.09 ± 0.10	166	162	388	336
	Friday-Asar							
	N5.284348, E100.495882	29.39 ± 1.69	60.56 ± 1.32	0.26 ± 0.16	512*	490	198	210
	N5.275097, E100.427235	32.97 ± 1.04	60.54 ± 5.07	0.38 ± 1.47	450	552*	660	658
Non-ACSU Mosques	*Zohor-Asar*							
	N5.144766, E100.494040	31.08 ± 0.52	69.60 ± 4.63	0.21 ± 0.94	378	94	144	134
	N5.174619, E100.541203	33.23 ± 0.72	56.41 ± 3.46	0.06 ± 0.08	484	132	300	216
	N5.284583, E100.509856	31.28 ± 0.88	63.40 ± 2.80	0.06 ± 0.07	312	224	306	240
	Friday-Asar							
	N5.148894, E100.487500	31.58 ± 0.47	68.05 ± 3.18	0.24 ± 0.21	502*	320	318	222
	N5.168175, E100.477498	32.27 ± 0.69	61.73 ± 2.30	0.28 ± 0.11	370	390	200	76
	N5.167577, E100.493589	32.80 ± 0.54	57.38 ± 1.79	0.36 ± 0.78	360	260	198	178
	N5.148779, E100.420434	31.67 ± 0.34	69.66 ± 1.43	0.65 ± 0.29	67	91	50	70
	N5.221623, E100.497009	31.71 ± 0.95	66.80 ± 7.04	0.23 ± 0.13	272	196	576	502

Indicator: * - Exceeded ICOP limit; ACSU – Air Conditioning Split Unit; Non-ACSU – Non-Air Conditioning Split Unit, BV - Before Vacuum; AV - After Vacuum; T - Temperature; RH- Relative Humidity; AM - Air Movement



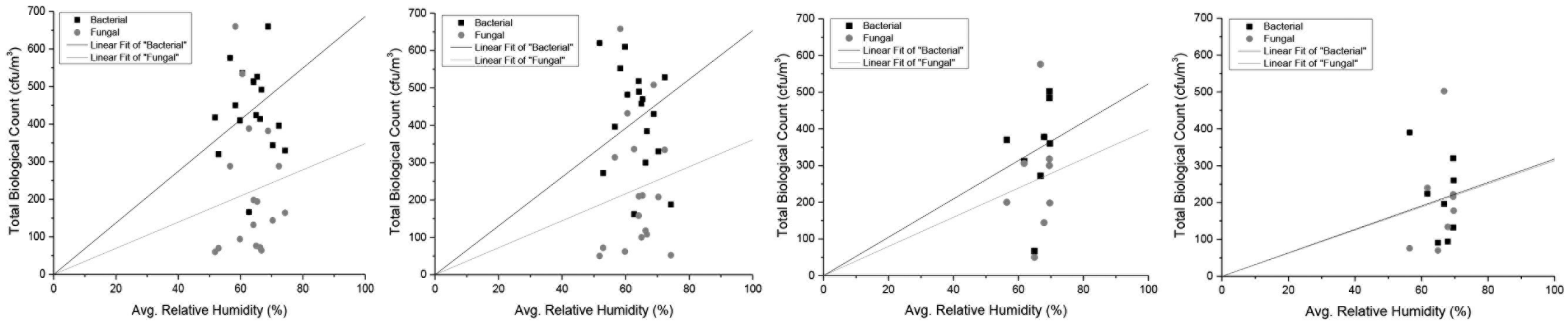
(a) Bacteria: $R^2 = 0.924$; Fungi: $R^2 = 0.653$

(b) Bacteria: $R^2 = 0.922$; Fungi: $R^2 = 0.668$

(c) Bacteria: $R^2 = 0.866$; Fungi: $R^2 = 0.730$

(d) Bacteria: $R^2 = 0.789$; Fungi: $R^2 = 0.679$

FIGURE 1. Regression plots of total biological count vs. avg. T of (a) ACSU mosques (before vacuum) (b) ACSU mosques (after vacuum) (c) non-ACSU mosques (before vacuum) (d) non-ACSU mosques (after vacuum)



(a) Bacteria: $R^2 = 0.926$; Fungi: $R^2 = 0.595$

(b) Bacteria: $R^2 = 0.880$; Fungi: $R^2 = 0.619$

(c) Bacteria: $R^2 = 0.872$; Fungi: $R^2 = 0.732$

(d) Bacteria: $R^2 = 0.762$; Fungi: $R^2 = 0.697$

FIGURE 2. Regression plots of total biological count vs. avg. RH of (a) ACSU mosques (before vacuum) (b) ACSU mosques (after vacuum) (c) non-ACSU mosques (before vacuum) (d) non-ACSU mosques (after vacuum)

CONCLUSION

Total bacteria and fungi were sampled from the air within prayer halls of the studied mosques and then cultured to determine their growths, in which the results suggested several exceedances of total bacterial count above the 500 cfu/m^3 limit as recommended by ICOP. High growth of bacteria and fungi were found in the ACSU mosques at T and RH in the range between 28.74±1.08°C and 31.93±0.20°C and 61.85±0.74% and 64.76±1.39%, respectively. As for the non-ACSU mosques, the growth bacteria and fungi were high at respective T and RH in the range between 31.12±0.25°C and 32.13±0.40°C and 62.01±1.58% and 70.57±0.72%. The variations in bacteria concentrations due to the influence of T and RH in ACSU mosques (T= 92.3%; RH= 90.3%) were higher than the ones in non-ACSU mosques (T= 82.75%; RH= 81.7%), whereas the variations in fungi concentrations in non-ACSU mosques (T= 70.45%; RH= 71.45%) were higher than the variations in ACSU mosques (T= 66.05%; RH= 60.7%). This research shows that the growth of bacteria and fungi within the prayer halls of mosques in Malaysia is very much dependent on its indoor T and RH. It can be indicated that the tropical hot and humid climate of Malaysia provides a suitable environment for the growth of bacteria and fungi, therefore, the indoor air within mosques should be maintained at an acceptable quality to protect the worshippers from being exposed to health risks. The findings from this study could act as a guide for relevant authorities to prepare an operations and maintenance (O&M) standard for mosques in term of controlling the T and RH; and managing the carpet cleaning within the main prayer halls of mosques as to eliminate the bacterial and fungal growth for a sustainable life of worshippers.

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