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Effects of Hoovering Activities on Biological Contaminants and Particulate Matter Levels in Main Prayer Halls of Malaysian Mosques

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Abstract

In Malaysia, carpets are commonly used as finishing flooring material in the main prayer halls of mosques. In cleaning carpets, hoovering has been the most popular method, but it directly triggers the uplifting of dust that may contain bacteria and fungi. Hoovering activities and ventilation strategies [air conditioning split units (ACSUs) or by active ventilation] can affect the prevalence of bacterial and fungal growth. This study aimed to establish the total bacterial counts, total fungal counts and also PM_{10} concentrations under different ventilation strategies (ACSUs and non-ACSUs) in the main prayer halls of mosques. Identification of bacterial and fungal species also took place in this study. Sampling was performed in 25 mosque buildings (17 ACSUs and 8 non-ACSUs) with carpeted flooring on *Zohor-Asar* and *Friday-Asar* prayer sessions at Pulau Pinang, Malaysia. Results revealed that the total bacterial counts, total fungal counts and mean PM_{10} concentrations were higher in mosques with ACSUs than in mosques with non-ACSUs at

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Airborne Particulate Matters; Air Conditioning Split Units; Biological Contaminants; Indoor Air Quality; Ventilation System.

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concentrations ranging from 166 cfu/m^3 to 660 cfu/m^3, from 118 cfu/m^3 to 660 cfu/m^3 and from 11.15 ± 9.32 µg/m^3 to 49.30 ± 13.13 µg/m^3, respectively. The total bacterial counts exceeded the acceptable guideline limit by the Industrial Code of Practice on Indoor Air Quality (ICOP), but the total fungal counts and PM_{10} concentrations did not. In some mosques, the total bacterial and fungal counts did not decrease even after hoovering activities were completed. The dominant types of bacteria found in the mosque buildings were *Staphylococcus* spp., *Bacillus* spp. and *Micrococci* spp., whilst the dominant fungal species was *Aspergillus niger*. Although the findings were not alarming, care should be taken by mosques authorities especially while and after hoovering, to ensure that, the indoor air quality in mosques are being maintained within permissible limit to protect worshippers from being exposed to bacteria and fungi.

Introduction

Problems with indoor air quality are important risk factors of human health in low-, middle- and high-income countries.[1,2] The concentrations of certain pollutants in indoor air may be 2 to 5 times and occasionally more than 100 times higher than those in outdoor air.[3,4] An indoor environment has numerous emission sources, such as materials, temperature, humidity, ventilation, air exchange between outdoor and indoor environments, human activities,[5,6] topography, micro-environmental conditions and amount of dust in air[7] which may influence indoor pollution concentrations including biological contaminants.[8] Understanding and identifying the sources and relationships of biological contaminants with the environment are important because biological contaminants have been implicated in many diseases.[2]

Indoor air quality at places of worship may be of concern for sensitive or susceptible subgroups within certain populations because of their potential allergic effects. Mosques are partially or fully occupied for about 1 h for five intermittent periods during the day. Moreover, worshippers do not arrive or depart at the same time. Instead, they do so on the basis of the time of congregation. Maximum occupancy is expected during the congregation of each prayer, which lasts about 20 min, and occupant density increases to more than 1.5 persons/m^2.[9] Many existing mosques have installed air conditioning split units (ACSUs) to cool the air inside mosques with a high indoor temperature in tropical areas. However, the use of ACSUs may produce moisture that favours bacterial and fungal growth.[10] Khan and Karuppayil[11] indicated that bacterial and fungal spores can be introduced into the air by anthropogenic means such as talking, sneezing, coughing, skin shedding, walking, ventilation ducts, carpets, soil and rice plants.[12,13]

In Turkey and Saudi Arabia,[14,15] inadequate ventilation rates and high CO_2, $PM_{2.5}$ and biological pollutant concentrations are amongst the problems faced by mosque buildings. However, many researchers for example, Noman *et al.*[16] focused only on thermal comfort and disregarded biological contaminants in mosques in Malaysia. Studying air and biological contaminants may help build mitigation strategies to decrease the negative effects of these contaminants, especially in crowded areas. Malaysia's Industry Code of Practice (ICOP) recommended that the acceptable guideline limits for bacteria and fungi are 500 and 1000 cfu/m^3, respectively.[17] This study investigated the total bacterial counts, total fungal counts and PM_{10} concentration in the main prayer halls of mosques with different ventilation strategies. It also looked into the dominant types of bacteria and fungi within these significant parts of mosques.

Materials and Methods

Study Area

Biological contaminants sampling and particulate matter monitoring were performed in 25 mosques in Pulau Pinang, Malaysia. The distribution of the selected mosques is shown in Fig. 1. Of the 25 mosques, 17 were categorised as mosques with ACSUs, and 8 were grouped as mosques with non-ACSUs.

Collection of Samples and Analysis

Monitoring schedules during *Zohor-Asar* and *Friday-Asar* prayers are shown in Table 1. An airborne particle counter (Lighthouse Handheld 3016 IAQ) used to measure the PM_{10} concentration was placed on a tripod, and monitoring was conducted at 1 m

above the ground with 1 min intervals in the main prayer halls for 5 h to 5.5 h. Lighthouse Handheld 3016 IAQ was equipped with a laser-diode light source and collection optics for particle detection.

Air samples were collected to measure the total count of both parameters in colony forming units per cubic metre of air and to identify the types of biological contaminants from the selected mosques. Bacteria and fungi were sampled under two conditions, namely, before and after the carpeted areas in the main prayer halls of the mosques were hoovered. The carpets were hoovered at an area of 9 m^2 (3 m × 3 m), and the samples were collected at 0.6 m above the ground level by using a microbial air sampler (100 Model Eco Pump, Merck, Darmstadt, Germany) with a flow rate of 100 l/min and a sampling time of 5 min. The bacteria and fungi were impacted in 20 ml of a nutrient plate containing tryptic soy agar and Sabouraud dextrose agar with chloramphenicol, respectively. The nutrient plates for bacteria and fungi were prepared in accordance with the sampler manufacturer's recommendations by referring to the National Institute for Occupational Safety and Health (NIOSH) Method 0800 – Bioaerosol Sampling (Indoor Air).[18] The stage hole was sterilised with 70% ethanol solution when the collection dishes were changed to prevent cross-contamination. The agar dishes were then transferred to the laboratory. The bacterial and fungal specimens were incubated at 35 ± 1 °C for 24 h and 25 ± 1 °C for 5 days, respectively.[19] The collected samples were kept in a cool box and transferred to the laboratory. Colony forming units per cubic meter of air sampled (cfu/m^3) are calculated as follows (Eq. 1).[20]

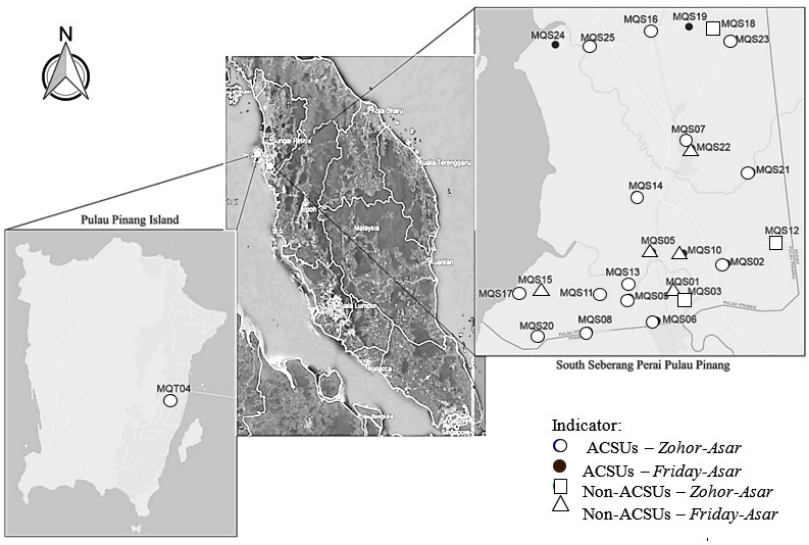

Fig. 1: Location of ACSUs and non-ACSUs mosques around Pulau Pinang, Malaysia (map not to scale)

Table 1: Monitoring schedule during *Zohor-Asar* and *Friday-Asar* prayers in the main prayer halls

***Zohor-Asar* Sessions**	**Time (hrs)**	***Friday-Asar* Sessions**	**Time (hrs)**
Before *Zohor* prayer	1200 – 1300	Before *Friday* prayer	1200 – 1300
During *Zohor* prayer	1300 – 1400	During *Friday* prayer	1300 – 1430
Between *Zohor* and *Asar* prayers	1400 – 1600	Between *Friday* and *Asar* prayers	1430 – 1600
During *Asar* prayer	1600 – 1700 or 1730	During *Asar* prayer	1600 – 1700 or 1730

Total bacterial or fungal counts (cfu/m^3) = Bacteria or fungi counts (cfu) / Volume of air sampled (m^3) ...(1)

Bacteria were partly identified using a Microgen GNA kit and Microgen ID software as extensively elaborated by Hussin *et al.*[21] Gram-negative bacteria were determined via an oxidase test performed by using Microgen GNA+B kit (for oxidase positive) and Microgen GNA kit (for oxidase negative). The culture suspension was prepared by emulsifying a single colony from a 24 h culture plate into 0.85% saline and mixed thoroughly. Biochemical test wells were inoculated with the suspension. The sample was then incubated aerobically at 35°C for 20–24 h.

For Gram-positive cocci, catalase and coagulase tests were conducted using Microgen ID Staph for catalase positive and Gram-positive cocci in clusters. A culture suspension was prepared by emulsifying a single colony of the target bacteria from a 24 h culture plate to the suspension supplied in the kit, and the sample was mixed thoroughly. Biochemical test wells were inoculated with the suspension, and the samples were incubated aerobically for 20–24 h.

A catalase test was performed to identify Gram-positive rod bacteria. The isolated bacteria should be tested for Gram-positive rods, catalase positive and spore positive. A culture suspension was prepared by emulsifying a single colony of the target bacteria from a 24 h culture plate to the suspension supplied in the kit, and the sample was mixed thoroughly. Then, the biochemical test wells were inoculated with the suspensions and incubated at 30 °C for 24 and 48 h. In all of the methods, the bacterial and fungal species were identified on the basis of their specific codes by using the Microgen ID software.

Table 2: Total bacterial counts and total fungal counts in the main prayer halls of mosques with ACSUs and non-ACSUs

	Sample	Total Bacterial Counts (cfu/m^3)		Total Fungal Counts (cfu/m^3)	
		BH	AH	BH	AH
ACSUs	MQS15	166	162	388	336
	MQS07	320	272	70	72
	MQS04	330	188	164	52
	MQS03	344	330	144	208
	MQS14	396	528	288	334
	MQS09	410	610	94	62
	MQS06	414	300	72	118
	MQS08	418	620	60	50
	MQS11	424	458	76	100
	MQS17	450	552	660	658
	MQS02	492	384	64	108
	MQS16	512	490	198	210
	MQS10	514	518	132	158
	MQS01	526	470	194	212
	MQS12	536	482	534	432
	MQS13	576	396	288	314
	MQS05	660	430	382	508
Non-ACSUs	MQS24	67	91	50	70
	MQS25	272	196	576	502
	MQS20	312	224	306	240
	MQS23	360	260	198	178
	MQS22	370	390	200	76
	MQS18	378	94	144	134
	MQS19	484	132	300	216
	MQS21	502	320	318	222

*Ranking is based on the total bacterial counts before hoovering; BH: Before hoovering; AH: After hoovering

Results and Discussion

Table 2 shows the total bacterial and fungal counts in the main prayer halls in mosques with ACSUs and non-ACSUs. The total bacterial counts in mosques with ACSUs before and after carpet hoovering ranged from 166 cfu/m^3 to 660 cfu/m^3 and from 162 cfu/m^3 to 620 cfu/m^3, respectively. The total bacterial counts in mosques with non-ACSUs before and after carpet hoovering ranged from 67 cfu/m^3 to 502 cfu/m^3 and from 91 cfu/m^3 to 390 cfu/m^3, respectively. The results showed that the total bacterial counts in mosques with non-ACSUs after hoovering activities did not exceed the acceptable guideline limit by ICOP[17] (500 cfu/m^3).

The total fungal counts in the mosques with ACSUs were 132 to 660 cfu/m^3 before carpet hoovering was performed. After carpet hoovering was conducted, the total fungal counts in the mosques were 118 to 658 cfu/m^3. Meanwhile, the total fungal counts in mosques with non-ACSUs before and after carpet hoovering ranged from 50 to 576 cfu/m^3 and from 70 cfu/m^3 to 502 cfu/m^3, respectively. The results

showed that the total fungal counts before and after hoovering activities in mosques with ACSUs and non-ACSUs did not exceed the acceptable guideline limit by ICOP[17] (1000 cfu/m^3). Gołofit-Szymczak[22] suggested that air conditioning systems should be efficiently and regularly maintained to ensure the proper hygienic quality of buildings and minimise biological contamination levels.

Table 3 shows the mean PM_{10} concentrations in the main prayer halls of mosques with ACSUs and non-ACSUs. The mean PM_{10} concentrations in mosques with ACSUs (29.44 µg/m^3) were higher than that in mosques with non-ACSUs (26.46 µg/m^3). Mean PM_{10} concentrations for both ACSUs and non-ACSUs did not exceed the acceptable guideline limit by ICOP[17] (150 µg/m^3). However, the mean PM_{10} concentrations in MQS12 (ACSUs mosque) was the highest and exceeded the acceptable guideline limit by ICOP[17] (150 µg/m^3) because of the mosque construction. Thus, the PM_{10} concentration in MQS12 was excluded in the average results. It is noteworthy to mention that airborne particulate matter is one of the major sources that can influence the bacterial and fungal growth.[23]

Table 3: Mean PM_{10} concentrations in the main prayer halls of mosques with ACSUs and non-ACSUs

ACSUs Mosques (n=16)		Non- ACSUs Mosques (n=8)	
Sample	**Mean ± SD PM_{10} (µg/m^3)**	**Sample**	**Mean ± SD PM_{10} (µg/m^3)**
MQS17	49.30 ± 13.13	MQS25	49.80 ± 6.37
MQS13	48.48 ± 6.98	MQS21	46.59 ± 40.09
MQS14	40.88 ± 5.33	MQS20	41.11 ± 9.43
MQS16	40.80 ± 43.05	MQS23	24.30 ± 10.11
MQS01	32.26 ± 2.98	MQS19	15.36 ± 12.31
MQS05	31.04 ± 11.99	MQS22	13.44 ± 18.76
MQS03	29.61 ± 8.98	MQS24	10.83 ± 8.33
MQS15	29.04 ± 2.03	MQS18	10.24 ± 9.79
MQS06	28.74 ± 7.81		
MQS02	26.54 ± 30.61		
MQS09	25.91 ± 15. 06		
MQS08	22.71 ± 11.17		
MQS07	22.47 ± 9.64		
MQS04	19.82 ± 4.38		
MQS10	12.22 ± 9.54		
MQS11	11.15 ± 9.32		
Average mean	29.44		26.46

*MQS12: 177.44 ± 89.75: Outlier point due to the mosque construction; n: number of data; SD: Standard Deviation; ACSUs: Air Conditioning Split Units

Figs. 2 and 3 respectively show the differences in the total bacterial and fungal counts on the samples incubated before and after hoovering activities in mosques with ACSUs and non-ACSUs. The results indicated that the percentage of the total bacterial counts in both mosques decreased by 64.71% and 75.00% after hoovering activities were performed, respectively. By comparison, the percentage of the total fungal counts in mosques with ACSUs increased by 64.71% after hoovering activities were accomplished. The percentage of the total fungal counts in mosques with non-ACSUs decreased by 87.50% after hoovering activities were completed.

In some mosques, total bacterial and fungal counts do not decrease after hoovering activities because fine particles may not be trapped by the filter of a vacuum cleaner and may be resuspended in air, even though large particles are trapped by the airstream

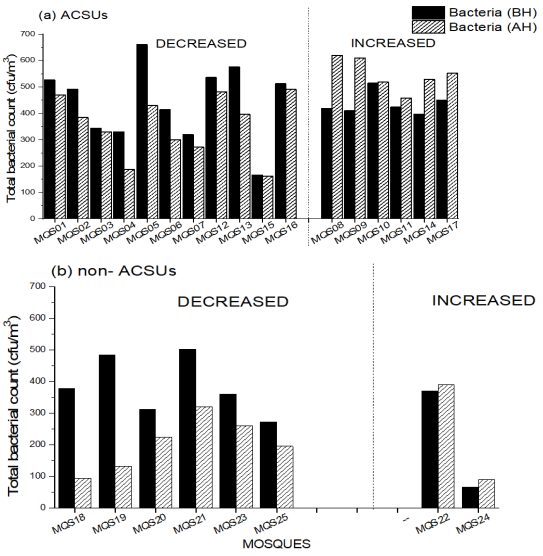

Fig. 2: Changes in total bacterial counts on samples incubated before and after hoovering activities in mosques with (a) ACSUs and (b) non-ACSUs

and deposited into the filter during hoovering.[24] Consequently, bacteria and fungi will be lifted into the air. In the present study, hoovering activities are inefficient in removing all bacteria and fungi on carpets. Durand *et al.*[25] found that dust collected by using a vacuum cleaner is dependent on the type of carpet, humidity and characteristics of a house. Knibbs *et al.*[26] stated that vacuum cleaner bags can also transmit considerable amounts of bioaerosols, especially airborne bacteria. Dust plays an important role in the aerosolisation and transportation of bacteria and may have important consequences associated with the spread of diseases.[27]

Total of 10 types of bacteria and 13 types of fungi were identified in mosques with ACSUs (Fig. 4) and non-ACSUs (Fig. 5). The identified bacteria consisted of *Staphylococcus* spp., *Bacillus* spp., *Micrococci* spp., Gram-negative bacteria - 1 type, Gram-negative bacteria, *Candida* spp. (yeast), *Streptococcus* spp., Gram-negative bacteria - 2 types, yeast and *Pseudomonas* spp. Moreover, the highest percentages of bacteria in mosques with ACSUs and non-ACSUs (before and after hoovering) were *Staphylococcus* spp. (100.00%) and *Bacillus* spp. (100.00%). The lowest percentages of bacteria recorded in mosques with ACSUs before carpet hoovering were Gram-negative bacteria - 2 types, yeast and *Pseudomonas* spp. with 5.88%, whereas yeast was not detected after carpet hoovering was performed. In mosques with non-ACSUs, yeast, *Streptococcus* spp. and *Pseudomonas* spp. were not detected before carpet hoovering. Similarly, Gram-negative bacteria - 2 types, yeast and *Pseudomonas* spp. were not observed after carpet hoovering. Few studies have been performed on airborne microorganisms in mosque buildings[7,15,28,29] in countries with a desert climate but not in countries in the tropics. These results showed that airborne bacteria are the main microbial contaminants. However, *Pseudomonas* bacteria have been found as the main emission sources from spray humidifiers.[15]

The identified fungi in this study included *Aspergillus* spp., *Aspergillus niger*, *Monila sithophila*, *Penicillium* spp., *Rhizopus* spp., *Monilliella acetoabutans, Mucor* spp., *Trichoderma* spp., *Cladosporium* spp., *Absidia* spp., *Sporotrichum* spp., *Monilia*

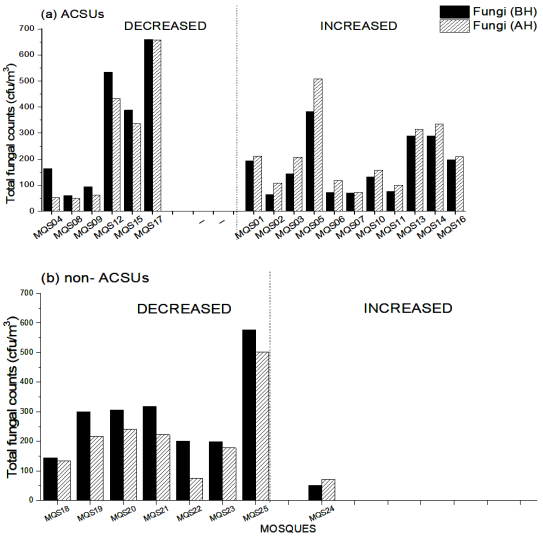

Fig. 3: Changes in total fungal counts on samples incubated before and after hoovering activities in mosques with (a) ACSUs and (b) non-ACSUs

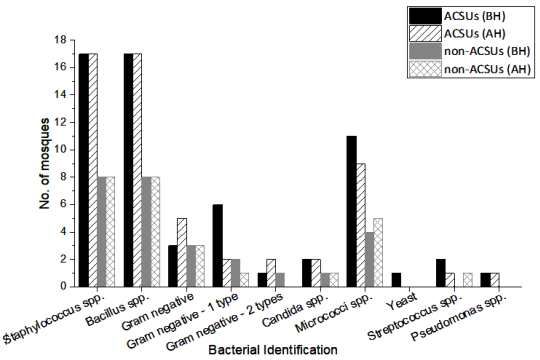

Fig. 4: Bacterial types in mosques with ACSUs and non-ACSUs

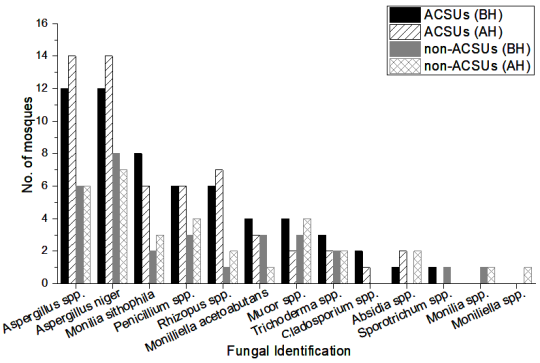

Fig. 5: Fungal types in mosques with ACSUs and non-ACSUs

spp. and *Moniliella* spp. The fungi with the highest percentages in mosques with ACSUs before and after carpet hoovering were dominated by *Aspergillus* spp. (70.59%) and *Aspergillus niger* (82.35%), respectively. Some of the fungal types were not detected before (*Monilia* spp. and *Moniliella* spp.) and after (*Sporotrichum* spp., *Monilia* spp. and *Moniliella* spp.) carpet hoovering. *Aspergillus niger* was the only fungus with the highest percentage in mosques with non-ACSUs before and after carpet hoovering, and their values were 100.00% and 87.50%, respectively. In mosques with non-ACSUs, *Cladosporium* spp., *Absidia* spp. and *Moniliella* spp. were not detected before carpet hoovering was conducted. After carpet hoovering was performed, *Cladosporium* spp. and *Sporotrichum* spp. were also not detected. Hameed and Habeeballah[15] found that *Aspergillus* species have the highest percentage and are the most common fungal types inside mosques.

Conclusions

In this study, 25 mosques with carpeted flooring were examined on *Zohor* or *Friday* and *Asar* prayer times in Pulau Pinang, Malaysia. The results demonstrated that the total bacterial counts, total fungal counts and mean PM_{10} concentrations, were higher in mosques with ACSUs than in mosques without. Their concentrations (ACSUs) ranged from 166 cfu/m^3 to 660 cfu/m^3, 118 cfu/m^3 to 660 cfu/m^3 and 11.15 ± 9.32 µg/m^3 to 49.30 ± 13.13 µg/m^3, respectively. The total bacterial counts slightly exceeded the acceptable guideline limit by ICOP, nevertheless, the total fungal counts and PM_{10} concentrations did not exceed the limit, possibly due to higher volume of air circulating inside mosques with ACSUs. The moisture caused by the installation of ACSUs in mosques could be favourable to bacterial and fungal growth. In some mosques, the total bacterial and fungal counts did not decrease after hoovering. These findings suggested that hoovering activities were not fully efficient in removing all biological contaminants from the carpet. The dominant types of bacteria found were *Staphylococcus* spp., *Bacillus* spp. and *Micrococci* spp. On the other hand, dominant fungal species was *Aspergillus niger*. In conclusion, while carrying out hoovering activities, indoor air within acceptable quality should be maintained via suitable ventilation strategies in mosques, to protect worshippers from being exposed to health risks due to infections from bacteria and fungi uplifted from carpets.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

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