Architectural Sustainability on the Impacts of Different Air-Conditioning Operational Profiles and Temperature Setpoints on Energy Consumption: Comparison between Mosques with and Without HVLS Fan in the City Center Mosques

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The use of air-conditioning (AC) in conjunction with high-volume, low-speed (HVLS) fans has become a trend in retrofitted mosque buildings in Malaysia to improve thermal comfort conditions. However, the energy impact of operating AC and HVLS fan simultaneously is unknown. This study compares the annual energy consumptions between mosques with and without HVLS fan installed and investigates the optimum temperature setpoints and operational profile to improve the mosques' energy efficiency. The Building Energy Intensity (BEI) comparison did not clearly show the superiority between the two groups in terms of energy performance. The study found that both studied mosques could produce around 1-4.9% energy reduction when the AC temperature setpoint was increased by 1˚C and could result in the highest cost-saving of about 4.9% when the temperature was set at 27˚C. A 30-minute AC operation during each daily prayer, except *Subuh*, could save between 14.8-16.7% annual energy consumption and about 15.2-16.6% annual energy cost. The paper concludes that the selection of 24-27˚C temperature setpoints with a 30-minute AC operational profile during prayers time, considering Friday prayers and Ramadhan activities, produced 18.4-20.6% savings in energy cost. This study calls for reevaluations of AC temperature setpoints configuration standards and operational characteristics in mosque buildings to reduce energy consumption. This paper contributes to the development of future energy standards for mosque designs and operations in Malaysia.

Keywords*: Temperature Setpoints, Operational Profile, Building Energy Intensity (BEI), High-Volume Low-Speed (HVLS) Fan, Air-Conditioning, Mosques, Malaysia*

1. INTRODUCTION

Mosques are a religious building type that is an essential part of any Muslim civil society. They are unique buildings in terms of their function and operation. Mosques are used not only for praying and religious purposes but also for community functions. Operationally, they are occupied intermittently for performing prayers five times a day, all year round. Each occupancy is either partial or full and lasts at the most for an hour. Worshippers do not usually arrive or leave the mosque simultaneously during this hour but rather at random. However, a maximum occupancy generally occurs during each prayer's actual performance, which lasts between 15 to 20 minutes. Some exceptions to this pattern of occupancy occur during weekly *Friday* prayers, the *Taraweeh* prayers during the nights of the month of Ramadhan (fasting month), and during other special occasions such as lecturing and seminar activities, where people tend to stay longer in the mosques (Al-Homoud et al., 2005a). Understanding the functions and operations of mosques reflect the importance of thermal design for occupants' comfortable praying experience. Intermittent occupancy means mosques may not perform thermally the same as typical commercial buildings. Installations of air-conditioning (AC) systems in mosque buildings to achieve the required thermal comfort have become common in the hot and humid climate region, particularly in Malaysian urban areas (Department of Standards Malaysia, 2014; Hussin et al., 2014). AC systems are responsible for the significant percentage of energy consumption in buildings. Malaysia's building sector contributes 40.5% of total national energy consumption (Malaysia Energy Commission, 2019) and 43.4% of total carbon dioxide emissions (Mohd Safaai et al., 2011).

Recently, the use of AC system in conjunction with high-volume, low-speed (HVLS) fans to achieve the desired thermal comfort in the main prayer halls has become a common trend in mosques located in Malaysian urban areas, such as in Kuala Lumpur, Selangor and Johor (Othman et al., 2019; Yendo et al., 2015). As shown in Figure 1, the HVLS fan is a new generation of ceiling fan with a large fan diameter design that can cover a large area at a slow-motion speed (Moshfeghi et al., 2014). Specifically, it has airfoil blades measuring a minimum of 2.1-meter in diameter with a rotation in the range of 50-125 revolutions per minute to produce a minimum airflow of 140,000 cubic feet per minute (Moshfeghi et al., 2014). HVLS fan does not only provide comfort, but the fan's motor is also energy efficient (Shah et al., 2015). However, the extent to which the concurrent operation of both AC and HVLS fans affects the mosques' energy performance still remains unclear. Do these mosques achieve the required thermal comfort while consuming the least energy? This paper argues that when the operations of both AC system and HVLS fans are improperly designed, it could result in additional, unnecessary amounts of energy.

An AC system's ultimate goal is to provide better indoor thermal comfort for building occupants; hence, the system's proper operations must avoid energy wastage. The comfort level is higher when an air-conditioned room is integrated with a ceiling fan (Chen et al., 2020). The air movement created by the ceiling fan keeps the building's occupants feeling comfortable, although the setpoint temperature of the AC is high. A study by Wang and Lin (2013) found that 40% of energy saving can be achieved in an intelligent building using a smart control AC and ceiling fan. They explained that the airflow from a ceiling fan could provide a cooling sensation to the occupants. The strategy of increasing the AC thermostat temperature and adjusting the ceiling fan speed to the medium can help achieve a comfortable and energy-efficient environment (Hawaii Natural Energy Institute, 2017).

Figure 1: High-volume low-speed (HVLS) fan
Source: Author

Currently, little information on energy performance or building energy intensity (BEI) of mosque buildings is available. An early study by Al-Homoud et al. (2005a) showed that the average BEI value of five mosques in Saudi Arabia was 167 kWh/yr/m$^{2.}$ The figure increased to 181.9 kWh/yr/m^2 after the subsequent data collections and analyses (Al-Homoud et al., 2005b). In Malaysia, a recent study by Hussin et al. (2019) on five retrofitted air-conditioned mosques in Penang revealed that three of the mosques demonstrated BEI values of between 70 to 124 kWh/yr/m^2, which are lower than the BEI of office buildings by Saidur and Masjuki (130 kWh/yr/m^2). The fourth mosque's BEI was 135 kWh/yr/m^2, while the fifth was 323 kWh/yr/m^2, a significantly higher value than the BEI of hospitals (244.8 kWh/yr/m^2) by Moghimi et al. (2011). As Hussin et al. (2019) is so far the only study on mosque BEI in Malaysia, it was considered appropriate for their BEI values to be used as the baseline in this paper. The high BEI results from Al-Homoud et al. (2005b) and Hussin et al. (2019) highlight the need for more energy retrofit measures in mosque buildings. Although these studies focused on air-conditioned mosques, they ignored the usage of HVLS fans.

Energy retrofit is one of the instruments used to improve buildings' energy performance (Rogeau et al., 2020). There are two types of energy retrofits: technical configurations and behavioural interventions (i.e. human-based retrofits). Technical configurations involve rearranging, replacing, adding and deleting some existing components of the buildings (Brown et al., 2014; Mancini & Nastasi, 2019; Sánka & Petráš, 2019). The discussion of this approach revolved around better bioclimatic designs and more energy-efficient insulation, windows and HVAC systems (Ariosto et al., 2019; Fang & Cho, 2019; Jankovic, 2019). Technical configurations type of energy retrofits has been widely studied for schools (Ali & Hashlamun, 2019; Tahsildoost & Zomorodian, 2015), commercial (Li et al., 2020), offices (Mohamad et al., 2018; Somasundaram et al., 2020) and residential buildings (Friedman et al., 2014; Wu et al., 2017). Despite their advantages, such retrofit measures are complex as they involve large-scale modifications, high upfront capital cost, and long implementation time (Cajot et al., 2017; Mirakyan & De Guio, 2013)

Behavioural intervention or human-based retrofits, on the other hand, refers to modifications of human (occupants or building managers) behaviour or actions that they can take to improve the existing building operation towards achieving energy efficiency (Ascione et al., 2020; Barthelmes et al., 2017; Pan et al., 2017). Examples of such actions include adjusting the HVAC thermostat setpoints, opening windows for natural ventilation, reducing the use of artificial lightings, equipment and appliances, to name a few (Dall'O' et al., 2012). Many studies have been conducted on behavioural intervention types of retrofits (Dall'O' et al., 2012). Human-based retrofits are generally more cost-effective (i.e. they come with little or no implementation costs) and practical than technical retrofits (Xia et al., 2019). However, the success depends on the occupants-building interaction and the occupants' and management staff's level of commitment (Jami et al., 2020; Xu et al., 2013).

Among the behavioural interventions to reduce energy consumption are fine-tuning the AC temperature setpoints and revisiting the AC operational profiles. An adjustment to the AC temperature setpoints is made according to the desired indoor thermal comfort (Aghniaey & Lawrence, 2018; Yan et al., 2019b), but research has shown that an increase of 1ºC in AC temperature setpoint will reduce at least 7% of energy consumption (Ho et al., 2009). A growing number of studies conducted in hot climatic regions show that adjustments to the AC temperature setpoints significantly impact building energy consumption. These studies were conducted in Singapore (Tom, 2008; Tushar et al., 2016), Malaysia (Mustapa et al., 2017), Thailand (Yamtraipat et al., 2005), Indonesia (Hamzah et al., 2018; Sunardi et al., 2020) and South Africa (Wang et al., 2013). These studies have recommended different ranges of temperature setpoints for thermal comfort. Although there is no specific point when the effect of temperature is dissatisfactory in terms of thermal comfort to the users, controlling the AC temperature setpoints has been reported to be one of the means of managing the building energy consumption (Aghniaey & Lawrence, 2018).

A reevaluation of the AC operational profile, on the other hand, involves strategising the AC operation schedule based on a deep understanding of the building usage, occupancy load, climate factors, and occupancy duration of the building (Knight, 2016; Xia et al., 2019; Yang & Becerik-gerber, 2014). For example, the AC operational profile for a mosque may differ from other building types as mosques generally have intermittent occupancy. Previous literature has also suggested that AC operating profiles are expected to significantly impact the mosques' thermal and energy performance (Al-Homoud et al., 2005b; Al-Shaaban & Alohaly, 2017; Budaiwi & Abdou, 2013; Omar et al., 2020). Furthermore, the effectiveness of the operational profile depends on the understanding of the AC response time and the amount of time needed for the AC system to cool down space to the temperature setpoint (Hui et al., 2017). The function and operational strategies of a mosque depend on the end-users, of whom the designers have no or less control (Atmaca & Gedik, 2019; Hussin et al., 2019). Therefore, it is crucial to involve the end-users in implementing energy conservation measures without compromising the indoor environmental conditions of building users. It could be argued that behavioural interventions or human-based retrofits are more suitable for buildings with intermittent occupancy such as mosques than technical retrofits.

The evidence gathered here suggests that behavioural interventions through AC temperature setpoints and operational profile optimisations can achieve cooling energy reduction and thermal comfort improvement. It is also necessary to determine a suitable range of AC temperature setpoints and integrate the cooling duration into AC operating profiles of mosques in Malaysia. Moreover, there is a need for a clear understanding of the energy impacts of operating AC and HVLS fans in mosques and how behavioural interventions could be undertaken to minimise the energy consumption without compromising their indoor thermal comfort levels. To the best of our knowledge, there is no academic paper in the building literature that focuses on this aspect. This paper aims to fill this gap. The objectives of this paper are 1) to analyse and compare the BEI between air-conditioned mosques with and without HVLS fan, and 2) to assess the energy-saving potential of air-conditioned mosques through different AC temperature setpoints and operational profiles adjustments. The findings motivate the need to revisit AC setpoint configuration and operational profile standards in mosque buildings, either as a segment of individual building retrofit preparation or as a segment of energy standards for mosque designs and operations in Malaysia.

This paper is structured as follows. The second part of the paper reviews the recent studies on the proper use and control of AC systems for energy efficiency and HVLS fans' applications for thermal comfort. The third part discusses the study's methodological details, which comprise the techniques in selecting the mosques, collecting the electricity bills, and conducting energy simulations. The comparison of BEI results between mosques with and without HVLS fans through behavioural interventions is presented in the fourth section, whilst the fifth section discusses their implications and existing limitations. Finally, the paper concludes with a summary of the essential findings and recommendations for future work.

2. METHODOLOGY

2.1 Site Description and Mosque Selection

The mosques selected for the study are located in the Klang Valley (lying between 2.6817^{o} N and 101.6813 ^{o} E), an urban conglomeration in Malaysia centred in Kuala Lumpur. Klang Valley includes adjoining cities and towns in Selangor, namely, Klang, Hulu Langat, Gombak, Sepang and Petaling Jaya. Malaysia's climate is categorised as hot and humid throughout the year, with the mean radiant temperature of 28^{o} and the average highest daytime temperature of 38^{o}C. The relative humidity ranges between 65% to 90%, with the annual rainfall between 1800mm and 3900mm. Generally, Malaysia's climate characteristics are uniform temperature, high humidity, light wind, and copious rainfall (Malaysia Meteorological Department, 2019). All countries in the Southeast Asia region have the same tropical climate type (Mcknight & Hess, 2000).

As of 2019, there were 6,446 mosques in Malaysia, 396 of which were located in Selangor, and 71 in Kuala Lumpur. The number of mosques is expected to increase due to the growth of the Muslim population in Malaysia (Department of Statistic Malaysia, 2019). About 70% of the mosques in Malaysia can accommodate between 1000 to 3500 worshippers at a time (Department of Islamic Development Malaysia, 2020). Therefore, the mosques of this size were selected for this study. Although a mosque can generally accommodate 3000 people, the calculation of area per worshipper revealed that the main praying hall could only hold about 550 worshippers (Malaysia Economic Planning Unit, 2015). Architecturally, mosques are generally rectangular in plan with walled enclosures, windows and a prominent roof above the main prayer hall. The building height varies from one to three stories, with a void above the prayer hall.

2.2 Case Studies: Selection Parameters, Instrumentation and Limits

The selection of specific mosques for the study was based on the following parameters: 1) located in areas with the same weather profile and prayer times, 2) no older than 20 years old, 3) built with similar building materials, 4) have similar operational profiles and use split-unit AC system type in the main prayer halls, and 5) able to provide two years of electricity bill data (January 2017 to December 2018). The study identified 54 mosques that met the research parameters 1 and 2. In order to confirm parameters 3 and 4, site visits were conducted to all 54 mosques. During the visits, the survey form by Ibrahim (2015) was used to record data of the mosques. The survey form contained three sections. The first section recorded the general building information such as roof type, year of construction, total area and total praying hall area, dimensions of the mosque, window types, and any internal shading used. The second section recorded the building operation schedules, including the zoning of the mosque, air-conditioned area and the type of verandah. The final section required inputs on the descriptions of the building energy usage such as the type of lighting system, type of AC system, types of fans, power distribution panel, and socket points. Floor plans were sketched in the form if drawings were not available.

The study finally confirmed that the 54 identified mosques met the research parameters 1-4, and they were classified into two groups, i.e., mosques with HVLS fan (Group A: 14 nos.) and those without HVLS fans (Group B: 40 nos.). However, due to time and cost constraints and some restrictions in obtaining permission from the mosques' management, only three mosques from each group were selected. Their general descriptions are shown in Table 1. These six mosques were considered representative. They met all the selection parameters, including parameter 5. Floor plans were obtained except for two mosques (A3 and B3), of which detailed measurements had to be conducted due to the nonexistence of architectural drawings. More site visits were conducted to all these six mosques. Specifically, detailed walk-throughs were performed to understand the mosques' layout and identify the cooling areas and parts of the buildings that differed from the original building plans. Interviews with the mosques' administration staff were carried out to have insights into the mechanical ventilation operations.

2.3 Comparison of energy consumption and cost

The Building Energy Intensity (BEI) was calculated to compare the energy consumption levels among the selected mosques and between the mosques and the Malaysian Standard (MS1525: 2019)(Department of Standards Malaysia, 2019) as well as results from previous studies on mosques. In light of the lack of green mosques in Malaysia, the study used the Malaysia Standard (MS1525: 2019) and previous studies as the basis of comparison. MS1525 stated that the BEI for office buildings should be less than 200 kWh/year/m^2, while Moghimi et al. (2011) revealed the BEI for hospital buildings is 245 kWh/year/m^2. Since mosques do not have a similar cooling floor area, energy consumption and energy cost need to be generalised. The usage of AC relatively affects the thermal comfort of the occupants. Therefore, the variables that affect the mosques' cooling load and indoor thermal comfort were considered in this study. Any sensible heat gain and latent heat gain, lightings, fans, computers and plug points were considered. The U-value of the mosques' walls, roof materials, and opening types were also recorded.

This study adopted the formula by Saidur and Masjuki (2008) to calculate the Energy Intensity Index (ACEII) in kW/m^2/yr, as shown below:

$$ACEII = \frac{\sum_i^n AEC}{CFA} \qquad (1)$$

where AEC is the total value of energy consumption of equipment i to n and CFA is the cooling floor area (m^2). The air conditioning cost index (ACCI) in RM/year/m^2 was estimated using the following equation:

$$ACCI = \frac{\sum_i^n ACE}{CFA} \qquad (2)$$

where the ratio is the sum of energy consumed in Malaysia Ringgit (RM) to the cooling floor area (m^2) (Saidur & Masjuki, 2008).

Three mosques using HVLS fan (Group A) and three mosques without HVLS fan (Group B) were selected as case studies. Although the sample size is small, the results would help the mosques' management to make wise decisions on energy conservation measures. The BEI values of mosques in both groups were calculated by using two-year electricity bill data (January 2017 to December 2018) and formula equations (1)(2) above.

2.4 Data Analysis

The values of the normalised total energy consumption and cost of all mosques were analysed by using SPSS statistical software. All data on energy used (kWh) and cost (RM), which were generalised for two years, were keyed in. Data of each mosque were sorted according to months and years. Later two separate independent sample t-tests were performed to compare mosques in both groups regarding energy consumption and cost within a two-year timeframe. Each mosque in group A was compared to the other three mosques in group B, resulting in 9 t-tests for each group, hence, 18 t-tests in total. The independent t-test results determined whether the two groups of mosques are statistically different in terms of their level of energy consumption. This was made by producing a statistical mean (i.e. the average used to derive the central tendency of the data for two years). The annual mean values of electricity consumption and cost of all mosques were generated, compared and ranked using the SPSS software. From the ranking, the mosque with the highest "mean energy consumption" and "mean energy cost" was selected to represent each group. The hypothesis for the t-test is explained in the result section.

2.5 Energy Simulation

The mosque with the highest BEI from each group was simulated using IESVE Software to determine the best temperature setpoints and operational profile that resulted in the most significant reduction in energy consumption. The simulation's input data include the building's geographical location, the three-dimensional geometry form and orientation, the building materials' thermal abilities, the type and efficiencies of the cooling and lighting elements, and the internal gains from electrical appliances and building occupants. These data were obtained from the architectural drawings and official construction plans. The occupants' energy usage data were gathered from the interviews that asked about their daily prayers routines.

The data were subsequently drawn in Model IT before the main module software ApacheSim was used to perform the numerous dynamic thermal simulations. The software also allowed the customisation of lighting, equipment, and occupancy profiles based on the internal heat gain value. This study utilised the default settings of "one occupant per 1.4m^2 floor area" for the occupancy and 70W/person for the sensible heat gain. In the ApacheSim module, the building's specific construction elements were built based on the specification data gathered during the walk-through audit. Building areas were grouped according to their thermal zones, i.e. air-conditioned or non-air-conditioned areas. A one-year period of electricity bill data of both case studies was used to validate the model, hence establishing reasonable confidence in the simulation results. The operational profile used for the simulation reflected the existing occupancy patterns of the mosques, i.e. five times daily prayers, Friday prayers, and Ramadhan month timings. The operational profile also took into account the lightings, fans and air conditioners used in the buildings. Both mosques used split units AC with different capacities. The size of the air-conditioners used was assumed to be adequate for the total area covered. The temperature setpoint was recorded at 19°C. External climatic data used in the simulation were real data obtained from the Malaysian Meteorological Department. A simulation period of one year was selected with a simulation time step of 10 minutes, a reporting interval of 60 minutes, and a preconditioning period of 10 days, as recommended in the IESVE guidelines.

3. RESULTS

3.1 Energy consumption and cost impact using Building Energy Intensity (BEI)

Figure 2 shows the BEI value of each mosque. Although the highest BEI is a mosque from group A, the second highest is from group B. The two mosques that had exhibited the highest BEI values were A1 (Wangsa Melawati Mosque) and B2 (UTM Mosque), with the values of 230 kW/m^2/yr 191 kW/m^2/yr, respectively. The lowest BEI among the six case studies was produced by mosque A3 (Alam Damai Mosque.

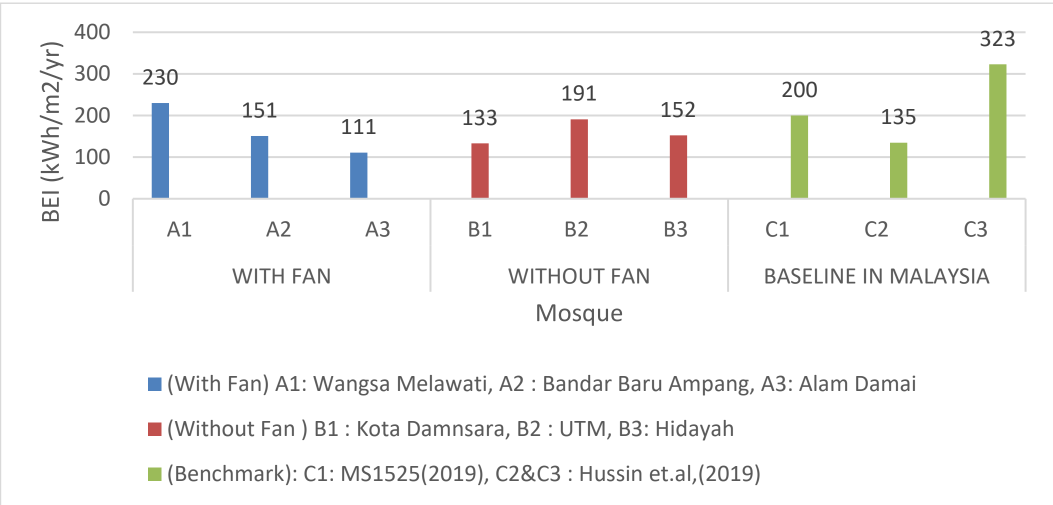


Figure 2: Building Energy Intensity (BEI) of the six studied mosques

Table 1: Selected six mosques as case studies

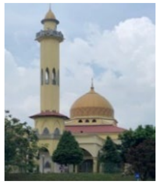
	GROUP A: WITH HVLS FAN			**GROUP B: WITHOUT HVLS FAN**		
Code and name	A1: Wangsa Melawati Mosque	A2: Bandar Baru Ampang Mosque	A3: Alam Damai Mosque	B1: Kota Damansara Mosque	B2: UTM Mosque	B3: Hidayah Mosque
Image (Source : Author)						
Location	Wangsa Melawati, Kuala Lumpur	Ampang, Selangor	Cheras, Selangor	Petaling, Selangor	Kuala Lumpur	Sg. Penchala Kuala Lumpur
Total floor area (m^2)	930	1669	2120	2226	2818	2672
Total cooling Area (m^2)	550	712	700	1122	919	784
No. of storey	1 1/2	1	2	1 1/2	1 1/2	2
Roof material	Metal dome on Flat roof with 6mm perimeter floating glass	Metal dome roof on metal pitch roof with 6mm perimeter floating glass	Metal dome on Flat roof with 6mm perimeter floating glass	Metal dome roof on metal pitch roof with 6mm perimeter floating glass	Metal dome on Flat roof with 6mm perimeter floating glass	Metal dome on Flat roof with 6mm perimeter floating glass
Type of construction	Brick wall and plaster					
Window type	Three-sided perimeter casement/louvres and three-sided sliding door					
Verandah	Three-sided verandah					
Fan	Ceiling, wall and stand fans					
AC type	Wall type, approximately 32horse power					
Lighting System	Dominated by fluorescent lighting					

Table 2 compares the BEI values from this study with the previous studies by a few scholars. It is interesting to note that the BEI values of these two mosques are higher than those reported by Al-Homoud, et al., i.e. 167 kW/m^2/year (Al-Homoud et al., 2005a) and 181.9 kW/m^2/yr (Al-Homoud et al., 2005b), and by Hussin et al. (2019), i.e. 135 kW/m^2/yr.

Table 2 : Results of Building Energy Intensity (BEI) and cost

Description	RM/ yr	kWh/yr	CFA	ACCI	Average BEI (kW/m²/yr)
Mosques from this Study (Group A: With HVLS fan)					
A1: Wangsa Melawati Mosque	70,399	133,502	550	128	230
A2: Bandar Baru Ampang Mosque	64,936	10,467	712	91.2	151
A3: Alam Damai Mosque	38,884	76,741	700	55.6	111
Mosques from this Study (Group B: Without HVLS fan)					
B1: Kota Damansara Mosque	70,454	148,945	1122	62.8	133
B2: UTM Mosque	93,601	177,693	919	101.9	191
B3: Hidayah Mosque	66,680	122,026	784	85.1	152
Mosques from Other Studies					
Hussin et al. (2019):					
• **Mosques 1-4 (split unit AC)**					<135
• **Mosque 5 (centralised AC)**				152.8	323
Al-Homoud et al. (2009)					<202
Al-Homoud et al. (2005a)					167
Al-Homoud et al. (2005b)					181.9
MS1525: 2019 (Department of Standards Malaysia, 2019)					200
Moghimi et.al (2011)					245

Note: *CFA= Cooling Floor Area; ACCI = Air Conditioning Cost Index*
The exchange rate of Malaysia Ringgit to U.S. Dollars is 0.24 (as of 9 August 2021)

3.2 Comparison of Mosque in terms of Energy Consumption and Cost

The independent t-tests were conducted to determine whether the two groups of mosques differed regarding the level of energy consumption. The results of the energy consumption comparisons, i.e. the *p*-values produced by independent t-tests, associated with the six mosques identified the most energy-efficient air-conditioned mosque. The assumed hypothesis of the t-tests is as follows:

Null hypothesis (H_0): The two compared buildings ($\mu_1 = \mu_2$) are equal in energy consumption, therefore H_0: $\mu_1 = \mu_2$

Alternative hypothesis (H_1): The two compared buildings are unequal in energy consumption, therefore H1: $\mu_1 \neq \mu_2$.

The t-test results of the electricity cost comparison associated with the six mosques identified the most energy-efficient mosque. Similar to the energy consumption comparisons, the electricity cost comparisons also involved nine separate t-tests.

The t-test results of energy consumption in Table 3 show that seven pairs of compared mosques had *p*-value < 0.05; hence, the null hypothesis was rejected. This indicates that there were statistically significant differences in energy consumptions between the compared mosques. However, the comparison between A2 (Bandar Baru Ampang Mosque) and B1 (Kota Damansara Mosque), as well as A2 (Bandar Baru Ampang Mosque) and B3 (Hidayah Mosque), resulted in *p*-value > 0.05; hence the null hypothesis was accepted, indicating that the differences in energy consumptions were negligible. Regarding the t-test results of energy costs, Table 3 indicates that there were statistically significant differences between all compared mosques (*p*-values < 0.05), except between mosque A2 (Bandar Baru Ampang Mosque) and mosque B3 (Hidayah Mosque), where the difference was negligible (*p*-value > 0.05).

Based on the mean values presented in Table 3, a ranking of the mosques is shown in Table 4, where number "1" indicates the best mosque and number "6" indicates the worst mosque in terms of mean energy consumption and cost. The ranking is a subjective ranking of the annual mean of energy consumption and cost. Table 4 shows that the ranking based on energy consumption is similar to the ranking based on energy cost. This similarity is unsurprising since energy consumption is closely related to energy cost. Interestingly, both the best and the worst mosques, namely, A3 (Alam Damai Mosque) and A1 (Wangsa Melawati Mosque), respectively, were mosques with HVLS fans. However, the second-best mosque was a mosque without the HVLS fan, i.e. B1 (Kota Damansara Mosque). This unclear pattern of rankings between mosques with and without HVLS fans may be due to different AC and fan operation profiles used.

Table 3 : T-tests results of energy consumption and cost

HYPOTHESIS (MOSQUES)	RESULTS FOR ENERGY CONSUMPTION			RESULTS FOR ENERGY COST		
	Mean (Standard Deviation)		Probability (p-value)	Mean (Standard Deviation)		Probability (p-value)
A1 and B1	A1	B1		A1	B1	
Wangsa Melawati Mosque and Kota Damansara Mosque	19.2 (±1.91)	11.0 (±2.2)	**0.001**	10.3 (±1.00)	5.4 (±1.03)	**0.001**
A1 and B2	A1	B2		A1	B2	
Wangsa Melawati Mosque and UTM Mosque	19.2 (±1.91)	17.3 (±2.12)	**0.001**	10.3 (±1.00)	8.6 (±1.01)	**0.001**
A1 and B3	A1	B3		A1	B3	
Wangsa Melawati Mosque and Hidayah Mosque	19.2 (±1.91)	12.6 (±3.33)	**0.001**	10.3 (±1.00)	7.3 (±1.44)	**0.001**
A2 and B1	A2	B1		A2	B1	
Bandar Baru Ampang Mosque and Kota Damansara Mosque	12.6 (±3.31)	11.0 (±2.22)	0.06	6.9 (±1.55)	5.4 (±1.02)	**0.001**
A2 and B2	A2	B2		A2	B2	
Bandar Baru Ampang Mosque and UTM Mosque	12.6 (±3.31)	17.3 (±2.13)	**0.001**	6.9 (±1.55)	8.6 (±1.02)	**0.001**
A2 and B3	A2	B3		A2	B3	
Bandar Baru Ampang Mosque and Hidayah Mosque	12.6 (±3.31)	12.6 (±3.33)	1.00	6.9 (±1.55)	7.3 (±1.45)	0.35
A3 and B1	A3	B1		A3	B1	
Alam Damai Mosque and Kota Damansara Mosque	9.3 (±0.96)	11.0 (±2.22)	**0.001**	4.9 (±0.54)	5.4 (±1.03)	**0.04**
A3 and B2	A3	B2		A3	B2	
Alam Damai Mosque and UTM Mosque	9.3 (±0.96)	17.3 (±2.13)	**0.001**	4.9 (±0.54)	8.5 (±1.01)	**0.001**
A3 and B3	A3	B3		A3	B3	
Alam Damai Mosque and Hidayah Mosque	9.3 (±0.96)	12.6 (±3.33)	**0.001**	4.9 (±0.54)	7.3 (±1.44)	**0.001**

Table 4 : Ranking of mosques in terms of energy consumption and cost

Ranking	Building Name	HVLS Fan	Mean (Energy Consumption)	Mean (Energy Cost)
1	A3: Alam Damai Mosque	Yes	9.3	4.9
2	B1: Kota Damansara Mosque	No	11.0	5.4
3	A2: Bandar Baru Ampang Mosque	Yes	12.6	6.9
4	B3: Hidayah Mosque	No	12.6	7.3
5	B2: UTM Mosque	No	17.3	8.6
6	A1: Wangsa Melawati Mosque	Yes	19.2	10.3

Subsequently, the mosque with the highest energy consumption and cost from each group was brought into the simulation process to determine the best operational profiles and temperature setpoints to improve its energy efficiency. Therefore, A1 (Wangsa Melawati Mosque), ranked last in energy consumption and cost, and B2 (UTM Mosque), ranked fifth, were chosen to represent a mosque with and without HVLS fan, respectively.

3.3 Validation of Stimulation Models

Before the simulations on temperature setpoints and operational profiles were conducted, the developed models were validated by comparing the simulated monthly annual energy consumption results with the mosques' actual energy consumption, i.e. monthly annual electricity bills for 2017. The results showed that the simulated energy profile was not more than 8.4% of the actual electricity bills; hence, the models were validated, and there was good confidence that the simulation results would be reliable and valid**.**

3.4 Energy Simulation Result On Temperature Setpoints

According to the actual usage, the temperature setpoint for A1 (Wangsa Melawati Mosque) and B2 (UTM Mosque) was set at 19˚C; hence, used as a baseline for this study. From this baseline temperature, it was increased at 1ºC to up to 27˚C.
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The resulted energy consumption, BEI and energy cost from each 1ºC temperature increment for both mosques are summarised in Table 5. Only the temperature setpoints were increased for this simulation, while the baseline AC operational profile remained the same. The results showed that the total energy and cost savings for Wangsa Melawati Mosque were 4.6% and RM3106.00, respectively. For UTM Mosque, the respective total energy and cost savings were 3.8% and RM3456.00. It appears that the adjustment to AC temperature setpoints could result in higher energy and cost savings for A1 (Wangsa Melawati Mosque) than B2 (UTM Mosque)

Table 5 **:** Simulation results based on different temperature setpoints for Wangsa Melawati Mosque and UTM Mosque

A1: Wangsa Melawati Mosque (with HVLS fan)									
Temperature setpoint (°C)	19°C	20°C	21°C	22°C	23 °C	24°C	25°C	26°C	27°C
Total Energy Consumption (kWh)	119,343	118,655	117,889	117,122	116,350	115,577	114,780	114,035	113,325
Cooling area (m2)	550	550	550	550	550	550	550	550	550
BEI (kWh/yr/m^2)	216	215	214	213	212	210	209	207	206
% BEI Saving	-	0.5	0.9	1.4	1.9	2.8	3.2	4.2	4.6
Cost (RM)	60,901	60,513	60,213	59,732	59,338	58,944	58,547	58,157	57,795
Saving (RM)	-	388	688	1169	1563	1957	2354	2744	3106
B2: UTM Mosque (without HVLS fan)									
Total Energy Consumption (kWh)	171,269	170,434	169,597	168,754	167,909	167,057	166,205	165,353	164,493
Cooling area (m2)	919	919	919	919	919	919	919	919	919
BEI (kWh/yr/m^2)	186	185	184	183	182	182	181	180	179
% BEI Saving	-	0.5	1.1	1.6	2.2	2.2	2.7	3.2	3.8
Cost (RM)	87,347	86,921	86,494	86,064	85,633	85,198	84,764	84,330	83,891
Saving (RM)	-	426	853	1283	1714	2149	2583	3017	3456

Note: The exchange rate of Malaysia Ringgit to U.S. Dollars is 0.24 (as of 9 August 2021)

3.5 Occupancy Profile

Understanding a building's occupancy profile or pattern is important in scheduling the building's AC operation. The uniqueness of mosque buildings is seen from their intermittent occupancy profile, primarily based on prayer times. The operational profiles of the Wangsa Melawati Mosque and UTM Mosque are similar, as explained below. It is important to note that the AC operational profile of both studied mosques also included the mosques' administration office because the space was air-conditioned and operated daily from 8:00 to 17:00 except for Saturday, Sunday and public holidays.

The baseline AC operation profiles are grouped according to the three occupancy profiles as follows:

1. Daily profile: This was according to the five prayer times, namely *Subuh* (dawn, before sunrise, 5:30 to 6:30), *Zohor* (midday, after the sun passes its highest, 12:30 to 13:30), *Asar* (the late part of the afternoon, 16:00 to 17:00), *Maghrib* and *Isyak* (between sunset and midnight, 19:00 to 21:00).

2. **Friday profile:** This was similar to the daily profile except during *Zohor* from12:30 to 15:00, which is longer in duration to accommodate Friday's sermon.

3. **Ramadhan profile:** This had different daily operation time during *Zohor, Maghrib and Isyak*. Most worshippers would spend some time during the *Zohor* hours in the month of Ramadhan for *itikaf* (period of retreat in a mosque) or *tadarus* (recite Quran in a group*)*. Therefore, the operations time of *Zohor* during Ramadhan is 12:30 until 14:00. The operation time for *Maghrib* and *Isyak* are continuous from sunset until almost midnight (19:00 to 23:00). This is because worshippers begin to break their fast at the mosque during *Maghrib* and continue with *Isyak* prayer, followed by *Tarawikh* prayer (additional prayer after *Isyak* prayer).

It is of paramount importance to understand the outdoor air temperature and building thermal comfort to determine the best AC operational profile, including the temperature setpoint. Tang et al. (2017) highlighted that the average dry bulb temperature of Kuala Lumpur at 7:00 am is 26˚C and subsequently increase and peak at 31.5˚C at around 3:00 pm before going back down to 28˚C at 6:00 pm and further down to 25˚C by midnight. These data were based on 21 years of weather data from the Malaysian Meteorological Station in Subang, Klang Valley, Selangor. This explanation indicates the trend of low and high air temperature within a day, which can be mapped to the prayer times. For example, during *Zohor* prayer (after midday), the air temperature is uncomfortably high. However, the temperature during *Subuh* (dawn) is within an acceptable thermal range. The air temperature decreases during *Asar* (afternoon) and further down until *Isyak* (nighttime). Therefore, with an appropriate AC operational profile strategy, thermal comfort can be achieved during prayer times.

With the understanding of the air temperature and acceptable thermal comfort, Table 6 (top half) shows the baseline and proposed operational profiles (1A-1F) for both selected mosques. The columns marked with (√) follows the time of the baseline profile (existing profile). In contrast, those marked with (X) indicates no air-conditioning was operated during that particular period. Under the proposed operation profile, the new AC operation duration is stated in relevant columns using a 24-hour time format. The adjustments of AC operation times were made by considering the air temperature profile and the time needed to cool down spaces.

Table 6 **:** Simulation results based on different operational profiles at 19^{0}C temperature setpoint for Wangsa Melawati Mosque (A1) and UTM Mosque (B2)

Operation profile	***Baseline***	***1A***	***1B***	***1C***	***1D***	***1E***	***1F***
Setting Cooling point	***19ºC***	***19ºC***	***19ºC***	***19ºC***	***19ºC***	***19ºC***	***19ºC***
Subuh							
Daily/Friday/ Ramadhan 0530-0630	√	X	X	X	X	X	X
Zohor							
Daily 1230-1330	√	√	√	√	1300-1330	√	1300-1330
Friday only 1230-1500	√	√	√	√	√	√	1230-1430
Ramadhan only 1230-1400	√	√	√	√	√	√	1300-1400
Asar							
Daily/Friday/ Ramadhan 1600-1700	√	√	1630-1700	1630-1700	1630-1700	1630-1700	1630-1700
Maghrib &Isyak							
Daily /Friday 1900-2100	√	√	√	X	X	1900-2030	X
Maghrib Daily/Friday	X	X	X	1900-1930	1900-1930	X	1900-1930
Isyak							
Daily/Friday	X	X	X	2000-2030	2000-2030	X	2000-2030

Ramadhan only 1900-2300	√	√	√	√	1900-2200	1900-2200	1900-2200
Total energy							
Wangsa Melawati Mosque (A1)	119,343	114,939	110,871	105,918	102,205	107,646	101,323
UTM Mosque (B2)	171,269	159,113	154,767	148,539	143,717	149,545	142,904
Total BEI ($kWh/yr/m^2$)							
Wangsa Melawati Mosque (A1)	216	208	201	192	185	195	184
UTM Mosque (B2)	186	173	168	161	156	162	155
Cost Index (RM)							
Wangsa Melawati Mosque (A1)	60,901	58,619	56,544	54,018	52,124	54,899	51,674
UTM Mosque (B2)	87,347	81,147	78,930	75,754	73,295	76,267	72,881
% Saving in BEI							
Wangsa Melawati Mosque (A1)	-	3.7	6.9	11.1	14.4	9.7	14.8
UTM Mosque (B2)		6.9	9.7	13.4	16.1	12.9	16.7
% Saving in Cost							
Wangsa Melawati Mosque (A1)	-	3.7	7.2	11.3	14.4	9.9	15.2
UTM Mosque (B2)	-	7.1	9.6	13.3	16.1	12.7	16.6

Notes :
(√) indicates that the air conditioner is operated during that prayer time using the existing profile.
(X) indicates that the air conditioner is not operated.
The exchange rate of Malaysia Ringgit to U.S. Dollars is 0.24 (as of 9 August 2021)
: Amended operation profile from existing.

3.6 Building Energy Simulation Result on Operational Profiles

Using the baseline temperature setpoint of 19˚C, both mosques were simulated using six different operational profiles, labelled as "1A to 1F". The results presented in Table 7 (bottom half) show that the operational profile 1F produced lower BEI for UTM Mosque (155kWh/yr/m^2) than Wangsa Melawati Mosque (184 kWh/yr/m^2). The BEI percentage reduction for UTM Mosque and Wangsa Melawati Mosque was 16.7% and 14.8%, respectively, while the cost-saving percentage was 16.6% for UTM and 15.2% for Wangsa Melawati Mosque.

Table 7 **:** Simulation results based on 1F operational profile with different temperature setpoints for Wangsa Melawati Mosque (A1) and UTM Mosque (B2)

	Existing	**Alternative**	**Different setpoint with 1F operational profile**			
Operation profile	Baseline	1F	2	3	4	5
Setting Cooling point	19°C	19°C	24°C	25°C	26°C	27°C
A1: Wangsa Melawati Mosque						
Total energy (kW)	119,343	101,323	97,441	96,656	95,876	95,146
Total BEI ($kWh/yr/m^2$)	216	184	177	176	174	172
Energy Saving (%)	-	14.8	18.1	18.5	19.4	20.3
Cost (RM)	60,901	51,574	49,694	49,294	48,896	48,524
Saving in Cost (RM)		9327	11,207	11,607	12,005	12,377
B2: UTM Mosque						

Total energy (kW)	171,269	142,904	138,593	137,721	136,845	135,965
Total BEI (kWh/yr/m^2)	186	155	151	150	149	148
Energy Saving (%)	-	16.7	18.8	19.4	19.9	20.4
Cost (RM)	87,347	72,881	70,682	70,237	69,790	69,342
Saving in Cost (RM)	-	14,466	16,665	17,110	17,557	18,005

Note: The exchange rate of Malaysia Ringgit to U.S. Dollars is 0.24 (as of 9 August 2021)

Subsequently, further simulations were carried out on both mosques to investigate the energy impacts of 1F operational profile and different temperature setpoints. The selected temperature setpoints were in the range of 24˚C and 27˚C based on the thermal comfort temperature recommended in MS1525 (Department of Standards Malaysia, 2019) and findings by Hussin et al. (2019). The operation considered the lighting profile, internal heat gains from equipment, such as fans and computers, and the occupants (i.e., full occupancy was assumed based on the cooling area). As shown in Table 7, a reduction in energy consumption and cost could be seen when 1F operational profile was used. The range of energy and cost reductions for UTM Mosque were 18.8-20.4% and RM14,466.00-18,005.00, respectively. For Wangsa Melawati Mosque, the range of energy reduction was 14.8-20.3%, while the range of energy cost reduction was RM 9327.00-12,377.00.

4. DISCUSSION

The key results of this study are summarised in Table 8. The table shows that only two out of six studied mosques had a BEI below the baseline level of 135 kWh/m^2/yr as suggested by Hussin et al. (2019), namely A3 (Alam Damai Mosque) and B1 (Kota Damansara Mosque). The remaining four mosques with higher BEI than the baseline level of 200 kWh/m^2/yr as in MS1525 (2019) were A1 (Wangsa Melawati Mosque), A2 (Bandar Baru Ampang Mosque), B2 (UTM Mosque), and B3 (Hidayah Mosque) with a respective BEI of 230 kWh/m^2/yr, 151 kWh/m^2/yr, 191 kWh/m^2/yr and 152 kWh/m^2/yr. These mixed results between mosques in group A (with HVLS fans) and group B (without HVLS fans) do not clearly show the superiority of one group over the other in terms of energy performance. This indicates that mosques equipped with an HVLS fan may or may not consume more energy than mosques without any HVLS fan.

Table 8 **:** Summary of key results

MOSQUES	BEI (kWh/m^2/yr)			
	Statistical analysis (SPSS) of 2-year electricity bills	Simulations (IESVE)		
		Adjusted Setpoints Temp. (27^{0}C)	Operational profile (1F)	Setpoints Temp. (27^{0}C) and operational profile (1F)
MOSQUE WITH HVLS FAN				
A1: Wangsa Melawati Mosque	230	206	184	172
A2: Bandar Baru Ampang Mosque	151			
A3: Alam Damai Mosque	111			
MOSQUE WITHOUT HVLS FAN				
B1:Kota Damansara Mosque	133			
B2: UTM Mosque	191	179	155	148
B3:Hidayah Mosque	152			

The mosques ranked first (A3: Alam Damai Mosque) and last (A1: Wangsa Melawati Mosque) in terms of energy consumption and electricity cost were those with HVLS fan. This result does not support the notion that using a ceiling fan in an air-conditioned area should help reduce building energy consumption (Shah et al., 2015). The observation found that Wangsa Melawati Mosque used the HVLS fan while maintaining the AC temperature setpoint at a minimum of 19˚C. The reason for this was that the air conditioners in the main prayer hall were undersized; thus, a setting of 19˚C was done to help cooling down the hall faster. Research has shown that AC temperature setpoints of 26˚C to 28˚C are more comfortable when a fan is provided than a temperature of 24˚C without a fan (Zhai et al., 2019). Furthermore, the combination of air movement from the fan and the air conditioners help to shorten the period to cool down the temperature. Indeed, using both HVLS fan and air conditioners can reduce the building energy consumption if the AC temperature setpoint is increased to a certain degree.

The best profile of operating air-conditioners and fans simultaneously to avoid energy wastage is essential for building operators to consider. Wai et al. (2015) pointed out that understanding how the cooling device work can reduce power consumption. Since mosques are unique in terms of function and operation, building operators need to understand the mosques' occupancy profile to monitor and control the building energy usage, mainly when the occupancy level is high.

The study's simulation results indicate that a combination strategy of temperature setpoint and operational profile adjustments can produce energy- and cost-savings. The study found that both studied mosques could produce around 1-4.9% energy reduction when the AC temperature setpoint was increased by 1˚C and could result in the highest cost-saving of about RM3,456.00 when the temperature was set at 27˚C. This finding is in line with Armin and Sarip (2016), who proved that reducing AC temperature by 1˚C could result in a 4-5% increment of building energy consumption and the highest consumption, about 40% when the temperature was set at 19.89˚C. Since the temperature setpoint directly impacts energy consumption, it is vital to look into occupants behaviour, particularly in terms of AC temperature settings and duration of usage (Yan et al., 2019a). Indeed, adjustments to higher AC temperature setpoints are effective for energy savings (Wang et al., 2013).

Unlike office buildings with a fixed operational profile of 9:00 am to 5:00 pm, mosques' operational profile is based on prayer times. By linking these prayer times with the local annual air temperature, one can estimate the duration required to run the AC. For example, data from the Malaysian Meteorological Department presented in Tang et al., (2017) highlighted that the daily average, maximum, and minimum dry bulb temperature of Kuala Lumpur. A strategy for AC operation for each daily prayer time was developed for energy efficiency guided by these weather data. For instance, during *Subuh* prayer time, which usually begins between 5:00 am to 6:00 am (Malaysia time zone), the average air temperature is 24˚C, as shown in Figure 3. This temperature falls within an acceptable thermal range; hence, it is sensible to suggest that AC's operation is not required during this time. AC system operation may be necessary during *Zohor* prayer time, which is around 12:30 pm to 2:00 pm since the average air temperature is as high as 31˚C.

However, it is also important to consider the duration of the AC operation. The current AC operation during weekly Friday prayer, which is performed at *Zohor* time from 12:00 pm to 3:00 pm, is acceptable as the air temperature is high, and occupants stay longer in the mosque compared to everyday *Zohor* prayer. During *Asar* prayer, which is generally performed between 4:00 pm to 5:00 pm, it is essential to operate the AC as the average temperature is around 28˚C. During *Maghrib* and *Isyak* prayers, the operation of the AC system may need to be reconsidered as the temperature during these hours is at 26˚C. During the daytime in the Ramadhan month, AC systems are typically run from 1:00 pm to 2:00 pm, which is acceptable considering the high air temperature. Furthermore, many activities (e.g. itiqaf) are held during this time that attracts worshippers to spend a longer time at the mosque. During *Maghrib* and *Isyak* times in the Ramadhan month, the AC system is necessary as worshippers tend to stay for long hours in the mosque to perform three prayers almost consecutively (i.e. *Maghrib, Isyak*, and *Taraweh).*

From the foregoing discussion, it appears that the AC system operation is necessary during every prayer time except for *Subuh*, during which the air temperature is acceptable for thermal comfort. Notably, however, the duration required for the AC to run during each prayer session needs to be further analysed to avoid energy wastage. The study revealed that mosques operated their AC systems every day for 30 minutes during *Subuh* prayer, 1 hour each for *Zohor* and *Asar*; and a continuous operation during *Maghrib* and *Isyak.* Furthermore, the mosques ran their AC systems for 2.5 hours during weekly Friday prayers and 4 hours during *Maghrib* and *Isyak* prayers in the month of Ramadhan. The study argues that these baseline operational profiles could be adjusted for energy efficiency.

Therefore, a few simulations were performed on two mosques ranked lowest in energy consumption and cost using a 19˚C temperature setpoint to investigate the impacts of using different operational profiles (labelled as 1A to 1F) building energy consumption. As shown in Table 7, operation profile 1F produced the highest reduction in BEI for both mosques: 184 kWh/year/m^2 for Wangsa Melawati Mosque (A1) and 155 kWh/year/m^2 for UTM Mosque (B2). The research evidence indicates that the most efficient daily AC operation profile is to use the AC system for 30 minutes during *Zohor, Asar, Maghrib* and *Isyak,* and leave the mosque naturally ventilated during *Subuh* prayer. Instead of continuously operating the AC system from *Maghrib* to *Isyak,* as currently practised, it would be more efficient to operate for 30 minutes during *Maghrib*, and 30 minutes during *Isyak*. The study also demonstrates that it is more energy efficient to shorten the AC operation for 30 minutes during Friday prayers, i.e. to end at 14:30 hour instead of 15:00 hours. For the Ramadhan month, the study suggests that the AC operation time be 1 hour during *Zohor* time but reduced from 4 to 3 hours during nighttime.

A 30-minute duration for AC operation is enough to cool down mosque spaces. Previous studies have confirmed that it takes 15 minutes for the AC system to operate before the prayer time to allow pre-cooling of the space, and the next 15 minutes during the prayer time is adequate to remove the indoor warm air (Stadler et al., 2009; Wai et al., 2015; Welguisz et al., 1998). The 15-minute duration is assumed as the air temperature supply factor where the constant air volume meets the cooling load in the occupied zone (Cheng et al., 2018). Furthermore, the daily prayer time lasts about 15 minutes from the start of *Azan* (Al-Homoud et al., 2005a). Once the prayer is completed, the indoor air temperature can last for another 10-15 minutes after the air-conditioner is turned off, assuming the AC system's ideal cycle.

Still using the operation profile 1F as the baseline, further simulations were conducted on the studied mosques by incorporating the temperature setpoints within the thermal comfort range as recommended in the Malaysia Standard MS 15252:2019, and Hussin et al. (2014). Table 7 presents the summary of the results with temperature setpoints between 24˚C and 27˚C. These recommended four temperature setpoints produced an energy savings range of 14.8% to 20.4% and cost savings of between RM12,377.00 to RM18,005.00. These findings support earlier findings that suggest the temperature range of between 24˚C to 27˚C is acceptable for thermal comfort in hot and humid climates (Djamila et al., 2013; Khalid et al., 2019). Although this study revealed that 27˚C of AC temperature setting produced the highest reduction in BEI (average 20% energy saving and 20% cost saving), mosque operators can adjust the temperature setpoint according to the thermal preference of the worshippers. From the results of the Wangsa Melawati Mosque and UTM Mosque simulations, a temperature setpoint of 27˚C produced a BEI of 172 kWh/yr/m^2 and 148 kWh/yr/m^2, respectively. These values are lower than 200 kWh/yr/m^2 in MS1525:2019 and 181.9 kWh/yr/m^2 in Al-Homoud et al. (2005b).

Concerning the simultaneous usage of AC and HVLS fans, the study recommends the following measures:

- **AC temperature setpoints:** AC system consumes less energy when the temperature setting is higher. Understanding the optimum AC temperature setting when an HVLS fan is operated together is vital to avoid energy wastage without compromising the occupants' thermal comfort. It is worth considering the 10-minute cycle time for the AC system to cool down spaces before the prayer begins to have better indoor thermal comfort (Mustapa et al., 2017; Papadopoulos et al., 2019).
- **Building operation profile:** Mosque operates according to prayer time; hence, the operation of mechanical ventilation should follow the prayer time. Dry bulb air temperature should be considered in the operation setting (temperature and timing) of the mechanical ventilation system (Budaiwi & Abdou, 2013)
- **Energy management knowledge of building operators:** The government should initiate educational programmes (e.g. practical training or short seminars) for mosque operators, especially those with no technical background, such as mosque officers. Such programmes would allow them to enhance their knowledge of the proper handling of the mechanical ventilation system to achieve energy efficiency. A standard operating procedure (SOP) or guideline would be useful for them (Hussin et al., 2014)
- **Equipment performance:** Designer and maintenance personnel should be trained better to understand the types of air conditioners and fans to avoid installing undersized or oversized equipment, which would result in high energy consumption (Shah et al., 2015). For HVLS fan, the size and motor efficiency should be considered. While the fan's air movement contributes to occupants' comfort, its usage does not reduce the ambient temperature. The type of blade, dimension and fan speed play an essential role in air distribution (Othman et al., 2019; Zhai et al., 2019).

5. CONCLUSION

This study has revealed the energy consumption patterns of six studied air-conditioned mosques, with and without HVLS fan installed. Integration of an HVLS fan in an air-conditioned mosque can reduce the building energy consumption without compromising the occupants' thermal comfort if both systems are operated optimally through proper temperature setpoints and operational profiles. This study has shown that increasing the AC temperature by 1˚C could result in 1-4.9% energy saving. A 30-minute AC operation during each daily prayer (except *Subuh*) could achieve 14.8-16.7% annual energy saving and about 15.2-16.6% annual energy cost. This study has also shown that a combined strategy of adjusting the AC thermostat setting between 24-27˚C and operating the AC for 30 minutes at every prayer time (but no AC operation during *Subuh* prayer) can produce up to 20% energy saving. In other words, the adjustment of temperature setpoints alone will reduce minimal energy consumption. The combined strategies of appropriate temperature setpoints and building operational profiles are vital to maximising energy efficiency and minimising energy cost without compromising the occupant's thermal comfort.

6. LIMITATION AND RECOMMENDATION

Since this study focuses on mosque buildings with intermittent occupancy, the results may not apply to other building types with predictable occupancies, such as commercial buildings. Another limitation is that the study did not consider the future weather profiles, as climate change will affect the air temperature. One potential extension of this study is to obtain the mosques' detail monitoring energy data, including their indoor air temperatures, to optimise the mosques' setpoint temperatures. The study recommends these outcomes be considered in the energy management guidelines for mosque buildings in Kuala Lumpur. Relevant educational programmes for mosque operators, especially those without any technical background, are vital to lowering mosques' energy consumption while maintaining indoor thermal comfort.

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