AIR CONDITIONING ENERGY PROFILE AND INTENSITY INDEX FOR RETROFITTED MOSQUE BUILDING: A CASE STUDY IN MALAYSIA

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ABSTRACT

Mosques generally consume far lesser energy than other types of buildings owing to their functional and operational characteristics. Since an effective energy management with a proper handling of the air-conditioning system can offer benefits such as the reduction of energy consumption as well as contributing to a sustainable development of the mosque, this paper has therefore presented a field case study on the energy usage and optimization strategies from a few selected retrofitted air-conditioned mosques in Penang, Malaysia. The results derived from the mosque samples (n=5) had not only shown a high energy consumption of the current air-conditioning system, the field evaluation at the Penang State Mosque (G5) was also revealed to have demonstrated a very high Energy Intensity Index (323 kWh/m2/yr.) and non-compliance to the MS Standards. As such, this study had proposed a few short and long term energy savings strategies, which can be implemented by the management committee of the mosque in not only in providing optimum thermal comfort for the worshippers but also without incurring the high energy costs.

Keywords: *: Mosque, air conditioning, comfort, energy and cost.*

1. INTRODUCTION

The mounting energy use in developing countries that seek to meet the world's growing energy needs has now become a social and economic concern. As a result of economic development and a higher standard of living, Saudi Arabia had shown an annual average increase of 13% in the energy consumption of the building sectors (Fasiudin and Budaiwi, 2011), while in Malaysia, the surging economic growth has led to a dramatic increase of energy consumption in the recent years. Generally, commercial buildings consume almost 32% of total generated energy with the office buildings making up the other 18.5% of total energy consumption (Saidur, 2009). The percentage is almost similar to the office buildings in Thailand, where energy consumption had been about 21% of the total energy usage (Chirarattananon and Taweekun, 2003).

According to Pérez-Lombard et al., (2008), Heating, Ventilating and Air-Conditioning (HVAC) systems make up the largest building energy demands in the non-domestic sector, which can be influenced by the adjacent buildings and its surrounding environment (Ascione, 2017). For that reason, a few strategies and measures had been proposed in the reduction of energy consumption such as by improving the energy efficiency and conversion process through passive cooling techniques as well as the application of renewable energy resources. In one of their studies, Lin and Hong (2013) had included the indoor temperature (thermostat set-point), window type, air infiltration and internal loads in a detailed description of the HVAC's energy consumption. Although numerous studies had provided different strategies in the optimization of the HVAC, the focus of the research had always been the same, where the energy efficiency of the HVAC system could be further enhanced in providing a better level of thermal comfort. In one of their studies, Teke and Timur (2014) had evaluated the energy efficiency, energy savings and energy management of the HVAC system in the hospitals, while Afram and Janabi-Sharifi (2014) had studied the potential control methods with an emphasis on the theoretical and practical of model predictive control (MPC) for HVAC systems. Apart from Shaikh et al. (2014) who had reviewed the combination analysis of control systems, optimization methods and the simulation tools used in the building of energy and comfort management, Alfroz et al., (2018) had also conducted research on the strengths and weaknesses of the current modelling techniques used in the HVAC systems in terms of their applicability and ease of practice acceptance. With that in mind, this study had aimed to evaluate the air-conditioning usage from the mosque's energy systems. Essentially, mosque not only represents the central location in which people gather for their daily and weekly prayers, but is also regarded as a social centre for Muslims to congregate during the annual Eidul Fitri (fasting month) and Eidul Adha (Haj season) celebrations as well as for other religious matters. For this reason, the thermal design and operation of a mosque are seen as crucial in providing visiting Muslims with a comfortable ambience for performing their prayers and religious rituals. Terrill & Rasmussen, (2016) had studied the energy efficient practices on the heating, ventilation, and air conditioning (HVAC) usage and comfort of two religious facilities. The study found that common, low-cost energy efficiency measures (EEMs) in commercial buildings had equivalent or increased applicability to the studied church buildings. The finding had created a possibility in development of an efficient energy model for mosque that are located in a hot and humid climate such as those in Malaysia.

In Malaysia, most of the old and traditional mosques with excellent air ventilation (Ibrahim et al., 2014) rarely receive energy assessments because of its low average operational energy intensity as most of the load had only consisted of lightings and small fans. On the contrary, the newer mosques that were retrofitted with mechanical ventilated devices such as the air-conditioning systems (Hussin et al., 2015), are required to undergo energy audits because of its high energy intensity. With commercial buildings showing a tendency of consuming up to 57% of energy usage from an air-conditioning system (Saidur, 2009), the mosque's unique operation schedule can thus be regarded as a means for potentially reducing its energy consumption.

Most of the recent studies had focused on permanently occupied buildings such as schools and offices with very few energy monitoring studies documented for intermittent operations like those of the mosques. From a field measurement conducted on the energy used and indoor environment conditions of three mosques with different sizes and shapes during its occupancy periods with intermittent operation in Dammam and Al-Khobar, Saudi Arabia, Al-homoud et al., (2009) had concluded the energy consumption from the air-conditioning system of these mosques forming the bulk of the annual energy usage. In their study, the researchers had suggested that the air-conditioning with intermittent operation can somewhat reduce energy usage while maintaining an acceptable level of thermal comfort. In addition to energy savings strategy, they had also indicated the strong dependency of the mosque's energy use on the weather conditions and the importance of building envelope designs as a way of reducing electricity consumption. In 2010, Al-ajmi had conducted a field study on six air-conditioned town mosques in Kuwait provinces. The study had recommended increasing the indoor temperature setting to a neutral temperature, which shown to have saved up to 20% of energy consumption. As for Budaiwi and Abdou (2013), they had revealed the potential of HVAC system operational strategies in reducing the energy consumption of the mosque in the Eastern Province of Saudi Arabia by up to 23% reduction in its annual cooling energy. Apart from the recommended use of an appropriate operational zoning system in a large scale mosque, where it was shown to have contributed to about 30% reduction in its energy utilization, another study conducted by Hussin et al., (2014) had also discovered the synchronization of the operation time of an air-conditioned mosque with the daily activities and prayer times having an influence on the costs and energy usage reduction of the cooling system. The above studies had thus prompted the importance of investigating the energy performance, problems and the operational practices of the air-conditioning system in a Malaysian mosque. Since gaps had been revealed in the literature review on the monitoring of energy profile and the intensity index for retrofitted air-conditioned mosques, this study had therefore attempted to evaluate the air-conditioning energy use and intensity index through a field measurement study of a few selected mosques located in the Penang State of Malaysia. The findings together with the optimization strategies proposed in the enhancement of air-conditioning systems usage at the retrofitted mosques are summarized in the following subsections of the paper.

2. METHODS

2.1 Mosque characteristics

Generally, the design geometry of a mosque is based on a simple rectangular shape that is made up of various sizes (Budaiwi and Abdou, 2013). The design geometry usually consists of wall enclosures that are complemented with a roofed prayer hall, where one of the walls (usually described as a qibla wall) is oriented towards the direction of the holy mosque in the Makkah city, Saudi Arabia, and a niche wall or the mihrab that is located in the inner qibla wall. The mihrab also contains pulpits known as a mimbar, which is usually located on the right side of the mihrab but on an elevated floor and serves as a place for the Imam of the mosque to deliver his Friday sermons (or qutba). The floor of the main prayer hall is usually well-furnished with saf carpets that are placed in parallel and 1.2 m distance away from each other. Over the years, the characteristics of the mosque architecture, shape, space of the prayer hall, construction materials as well as its size had been subjected to modifications as a result of geographical and architectural design factors.

2.2 Energy profile and intensity case study

Based on the previous research study that was carried out from January until March 2017, an energy profile was created based on 15% of the 273 registered mosques located in the entire state of Penang (Hussin et al., 2018). The work flow of this study is shown in Figure 1. During the first stage, a total of 44 mosques had been evaluated by using standard questionnaires that were collected based on its current information and operational processes. Figure 2 shows the geometrical mosques configuration that is commonly built in the Penang State. As shown in Figure 3, these mosques were subsequently divided according to its cooling area namely G1, G2, G3, G4 to G5.

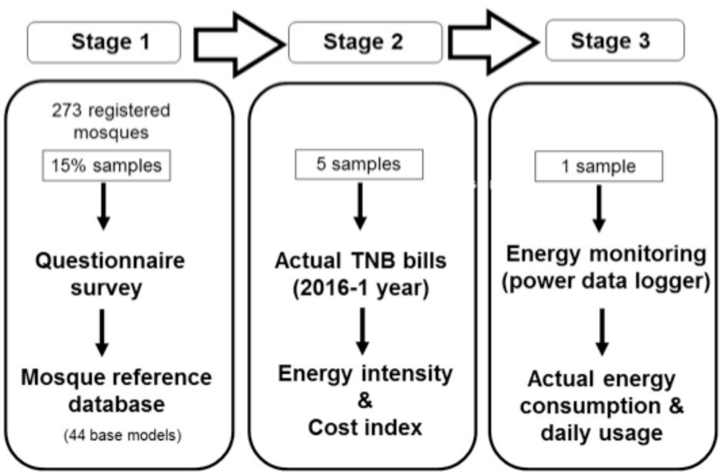
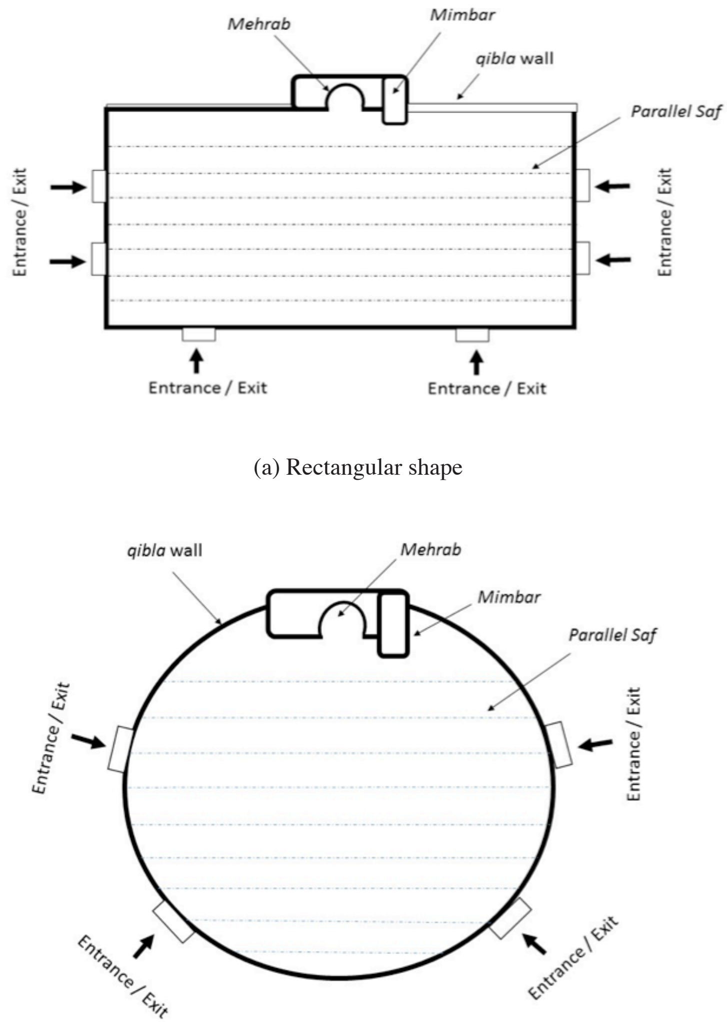


Figure 1: Workflow



(a) Rectangular shape

(b) Circular shape

Figure 2: Geometrical configuration of a commonly built Penang State mosque

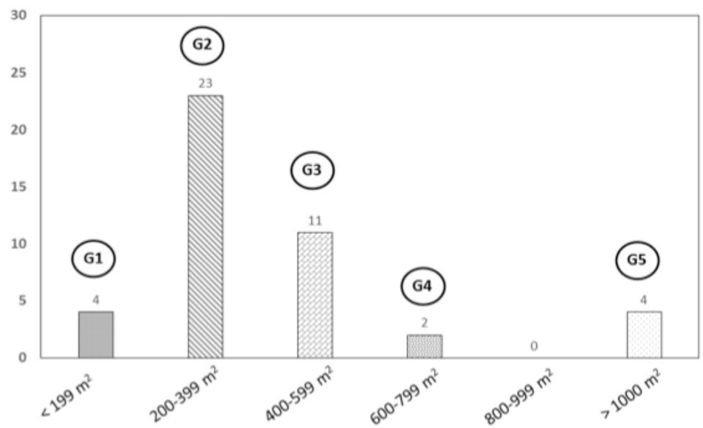


Figure 3: Mosques that are grouped according to floor areas

In the second stage of the process, five sampled mosques from each of the groups were selected for the energy profile and energy intensity case study. The sorting samples had been based on the highest figures of the installed air-conditioning capacity, the annual electricity expenses as well as the energy used with a 415V power supply system. The survey results from Stage 2 had indicated most of the common air-conditioning types found in mosques group G1 to G4 to be those with a ceiling exposed split air conditioning unit, while the centralized air cooled chiller with a combination of air handling unit (AHU) and the ducting system was used in the G5 mosque. The selected G1, G2, G3, G4 and G5 mosques with their respective floor areas and actual capacity of retrofitted air-conditioning systems are shown in Table 1, while the actual annual energy usage from January 2016 to December 2016 of the G1 to G5 groups had been obtained from a local electric utility company (Tenaga National Berhad). All of the data collected were used in the calculation of the energy profile and intensity case study.

Table 1: Selected mosques for the energy profile and energy intensity case study

Mosque name	Group	Cooling floor area (m^2)	Retrofitted capacity air conditioning (Horse Power)
Masjid Jame' Bakar Kapor Penaga	G1	160	15
Masjid Jame' Al Ihsaniah S.P.S	G2	315	54
Masjid Sembilang Seberang Jaya	G3	576	89.5
Masjid Pongsu Seribu Kepala Batas	G4	632	67.5
Masjid Negeri Pulau Pinang, Georgetown	G5	2920	378

(1)Building Energy Index (BEI)

A building is defined as an energy-efficient building by benchmarking its efficiency level on a Building Energy Index (BEI), where the BEI is the ratio of a building's total annual energy usage (kWh) to the total building area (m^2). Since the Malaysia Standard (MS 1525: 2014) had developed a standard BEI reference for office buildings (135 kWh/ year/ m^2) and the 200 kWh/ year/ m^2 reference for hospitals (Moghimi et al., 2014) with no BEI references for the mosques, the BEI of the mosque was then calculated and compared with the BEI values of the two former buildings. The basic equation of the indices had been based on those suggested by Saidur (2009):

(a) Energy Intensity Index

The Energy Intensity Index (ACEII) in kWh/ year/ m^2 is estimated by using the following equation:

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

where AEC is the sum of the annual energy consumption of equipment i to n and CFA is the cooling floor area (m^2).

(b) Air conditioning cost index

The air conditioning cost index (ACCI) in RM/year/m^2 is estimated by using the following equation:

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

where ACE is the annual sum of the energy consumed from equipment i to n in Malaysia Ringgit (RM) and CFA is the Cooling floor area (m^2).

2.3 Monitoring actual energy profile

In the third stage of the process, only one sample (n=1) from the respective mosque groups (G1-G5) is selected as a field case study due to its religious facility limitation (Figure 1). Hence, the selection criteria of the mosque had been based on the following:

- Daily operation of a cooling system (daily/Friday prayers)
- Daily operation time of more than 5 hours continuously
- Uses a centralized air-conditioning system
- Highest annual electricity consumption

By fulfilling all of the above criteria, the Penang State Mosque from the G5 group was then selected as a case study model. The mosque is centrally located in the Penang Island with GPS coordinates of 5.406N, 100.3006E, which was built and opened to the public in 1981. The mosque is built like a dome that contains the ground and mezzanine floors. With a total floor area of 2920 m^2, the main prayer hall on the ground floor is opened every day for praying purposes, while the mezzanine floor area that spans a total of 65.69 m^2 is only opened for special events and ceremonies such as the IdulFitri prayers and celebrations. Each of the walls had used a single layer shaded glass type with six main entrance doors using the same glass type. The floors are fully furnished with the saf carpets that are placed in parallel to the western part of the wall, while the dome is being used as the roof for the grand tower. The mosque can also fully accommodate up to 5,000 of worshippers at one time and is currently managed by the Penang Religious Affairs Department. A plan view of the Penang State Mosque is shown in Figure 4.

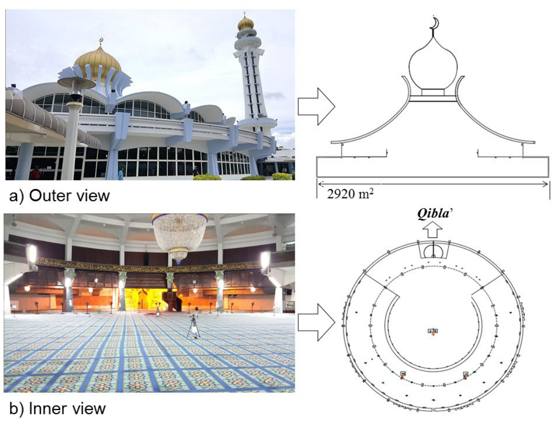


Figure 4: Plan view of Penang State mosque

2.4 Description of the air-conditioning system

The Penang State Mosque was retrofitted with an air-conditioning system in 2003. Each of the three identical air-cooled chillers with a capacity of 100 RT was installed to produce thermal comfort in the main prayer hall. The main air-conditioning system had consisted of a chiller (compressor, condenser, thermal expansion valve and evaporator), air handling unit (AHU), water pump system, air distribution system (ducting and diffusers) and an electrical control panel. A detailed explanation of an air cooled chiller system in the literature had been described by Teke and Timur (2014).

The air cooled chiller component had relied on a reciprocating (semi hermetic) compressor with a maximum power input of 235kW, an air system condenser that uses the surrounding ambient air for cooling down the heat rejection as well as a shell-and-tube evaporator. The cooled water had been designed with an entering water temperature of 54 °C and leaving water temperature of 44 °C from the shell-and-tube evaporator that is circulated to the Air Handling Unit (AHU) by a 3 nos centrifugal end-suction pump (10 horsepower (HP) motor pump each) at the rate of 255 USGPM. The five air handling units are located in the AHU room, which is located beside the mosque, where the continuous supply of air is drawn from a ducting system. The cool air is then distributed to the surrounding space of the main prayer hall by using jet diffusers that had been set at a constant flow rate. The source of the electrical power panel had come from the 3 phase, 415V and 50Hz power supply, where all the controls and power panels for the chiller component, including the ON/OFF button, are located in a special box panel near the chiller unit. The sequence of the start-up components such as chillers, pump and AHU had been synchronized with a proper timer step control by using the single ON/OFF button, where the air conditioning system had been set to operate (ON) at 3.00 PM and shutdown (OFF) at 9.30 PM from Sundays to Thursdays and from 10.00 in the morning until 9.30 at night on Fridays. The air-conditioning system and its physical data are shown in Table 2.

Table 2: Air conditioning system and physical data

Items	Physical data
Air cooled chiller	100RT each x 3 *nos*
Refrigerant	R22
Supply	3Phase/415V/50Hz
Air Handling Unit	AHU-1 = 25,200 CFM
	AHU-2 = 19,200 CFM
	AHU-3 = 24,000 CFM
	AHU 4 = 30,000 CFM
	AHU 5 = 18,000 CFM
Air distribution type	Conventional ducting system with jet diffusers

2.5 Instruments and measurements

The evaluation of the actual energy profile had been based on the measurement that was automatically recorded by the energy data logger, which is connected to the power supply panel of the air-conditioning system. The site measurement at the Penang State Mosque was carried out from 17 May 2017 until 21 May 2017 (n=5 days) with a laptop connected to the power and energy data logger (PEL) Version 102 as a way of measuring the electric power consumption from the air-conditioning system. As shown in Figure 5, the PEL Ver.102 is kept in the electrical room, which is located in front of the air-conditioning electrical power panel.

The MA193 flexible current sensors and black safety leads with black alligator clip voltage sensor were used to measure the instantaneous electric variables from the incoming 415V terminal wire supply without exposing the circuit. The 3 units of black alligator clips together with the voltage sensor had been clipped at the power supply terminal, while another 3 units of the MA193 flexible current sensor were round clamped at the red, yellow and blue power supply wires. The PEL Ver.102 had been enabled to record and measure the electrical power parameters such as the instantaneous electric variables (Root Mean Square (RMS) current, RMS voltage, and phase angle) as well as the power (kW and kVA) used. The accuracy of the current and voltage probes had been set at ± 1% ± 15A and ± 2.5% ± 0.4V, respectively. As shown in Figure 6, all of the instantaneous data were captured automatically at a 5-minute interval and saved directly in the PEL memory card.

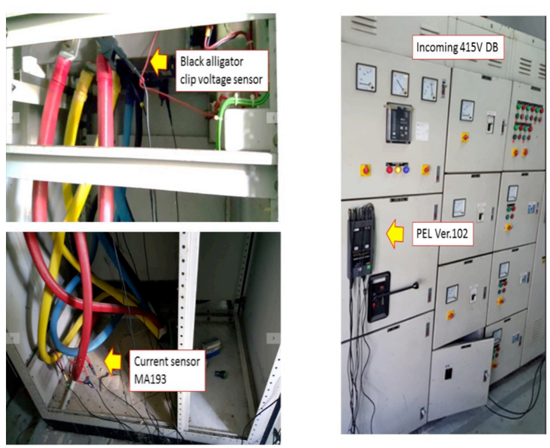


Figure 5: The location of PEL instrument and sensors at the 3 phase electrical panel.

Figure 6: The PEL instrument and sensors used

3. RESULTS AND DISCUSSIONS

3.1 Cost and energy intensity impact

As illustrated in Figures 7 and 8, the actual Tenaga Nasional Berhad (TNB) utility bills (energy and cost) that had incurred from Jan-Dec 2016 had shown the yearly energy consumed from the corresponding air-conditioned mosques group G1, G2, G3, G4 and G5 to be 22 MWh, 39 MWh, 63 MWh, 44 MWh and 942 MWh with a respective electricity cost of RM9, 000, RM24, 000, RM28, 000, RM20, 000 and RM446, 000. As seen from the data, the mosque from the G5 group had exhibited the highest average monthly utility cost usage of RM 37, 177.00, which were followed by those from the G3 (RM2, 320.00), G4 (RM1, 668.00), G2 (RM 1, 987.00) and G1 (RM765.00) groups, respectively. The results had also indicated the total energy consumed by the mosques from each of the group to be equivalent to half of the electricity costs. Furthermore, with the exception of the G4 mosque, a significant difference could be observed between the energy and costs usage with the increasing cooling floor area of each mosque. This may be due to the actual air conditioning capacity (horsepower) of the G4 mosque that had been installed below the estimated values as those indicated in Table 1.

All of the mosque samples had shown a fluctuation of the monthly energy usage, which could be due to the energy wastage (energy loss) associated with less efficient equipment. The actual horsepower of the retrofitted air conditioning system was actually found to have operated below the capacity level. This meant that although the air-conditioning system had seemed to work normally, it had hardly achieved the desired thermal comfort with its high energy consumption as shown by a similar case reported by Al-homoud et al., (2009) in Saudi Arabia. As part of the countermeasure, Al-homoud et al., 2009 had suggested for the height of the supply air outlets to be adjusted as low and as close as possible to the occupied zone as a way of reducing the energy requirement that resulted in air stagnation at the ceilings.

Another reason for the fluctuation in the monthly energy usage had been due to the operation time of the air-conditioning system. According to a majority of the mosque officers who were also assigned with the task of handling the air-conditioning system, the increment of the operation time (ON/OFF system) had been due to the daily preaching session conducted at the main prayer hall. The mosque in the G3 group for example, had shown a 50% increase of energy usage and costs between the months of January and July. The highest usage was found to have occurred in the month of July, where it had coincided with the Ramadhan fasting month, during which intensive activities such as the breaking the fast, special terawikh (pre-midnight) and qiamullail (after midnight) prayers as well as the iktiqaf (spiritual retreat) had been carried out in the mosque. As such, the air-conditioning system had been set to operate fully in meeting the comfort expectations of the devotees during the implementation of such activities, while neglecting the air-conditioning system's energy usage. The fluctuation of the energy usage had also been due to the untrained personnel in handling the system facilities, as corroborated by the study conducted by Terrill & Rasmussen (2016), as well as the different standard operating procedures in the operation of the air-conditioning system by each of the mosques.

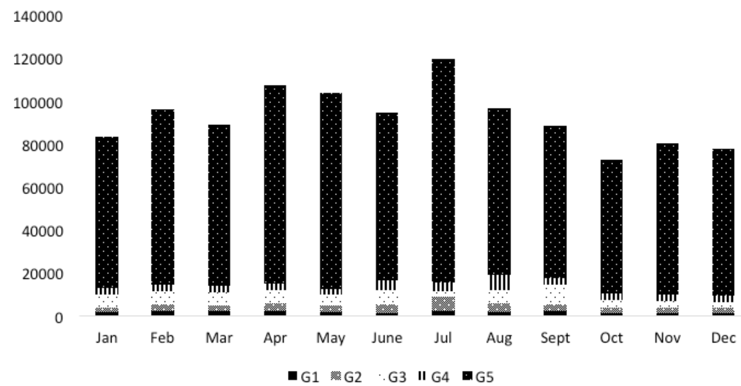


Figure 7: The actual annual energy consumption (kWh) for G1-G5 (Jan-Dec 2016)

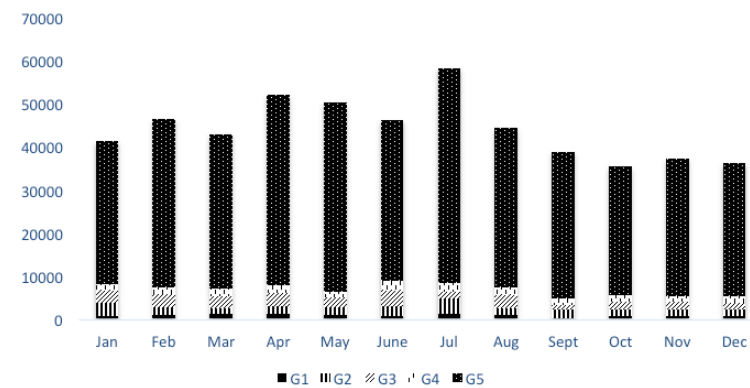


Figure 8: The actual annual TNB cost (RM) for G1-G5 (Jan-Dec 2016)

Table 3 shows the annual Energy Intensity Index (kWh/year/m2) of the five mosque groups. As shown from the data, the lowest indices could be observed in the G4 group (70 kWh/m2/yr. and RM 32/year/ m2), which is followed by the G3 (110 kWh/m2/yr and RM 48/year/ m2), G1 (124 kWh/ m2/yr and RM 58/year/ m2) and G2 (124 kWh/m2/yr and RM 76/year/ m2) groups, respectively, while the mosque from the G5 group had produced the highest indices of 323 kWh/m2/yr and RM 153/year/ m2 in order to produce a sufficient cooling ambience of the main prayer hall. The results had also shown the G1 mosque sharing the same energy indices as those with the Malaysia Standard (MS 1525: 2014), while those from the G2-G4 groups had produced energy indices below the MS 1525 and the study conducted by Saidur (2009). Since the mosque in the G5 group was found to have exhibited higher energy indices and almost 16% lower than the study conducted by Moghimi et al. (2014), this implies that the mosques in the G1-G4 groups can be defined as more efficient buildings as compared to those in the G5 group.

Table 3: Study mosques Building Energy Index and Cost Index

Descriptions	RM/yr	kWh/yr	CFA	ACCI	BEI
This Study, mosque G1	9180.28	21457	159	57.59	135
This Study, mosque G2	23845.60	38978	314	75.92	124
This Study, mosque G3	27844.64	63419	577	48.29	110
This Study, mosque G4	20016.17	44100	632	31.67	70
This Study, mosque G5	446134.11	942003	2920	152.79	323
Saidur, 2009		127752000	983000		130
Moghemi et al., 2014		57705036	150196		384
MS 1525 : 2014		Base reference			135

Note:

CFA = Cooling floor area

ACCI = Air conditioning cost Index

BEI = Building Energy Index (BEI)

3.2 Actual energy usage from the Penang State Mosque (G5)

As shown by the measured air-conditioning current (A) and power (kW) consumption as a function of time in Figures 9 and 10, the respective average current and power were found to have varied from 127 A to 239 A and 87 kW to 161 kW. Apart from the halved operation values exhibited on weekdays/ office days (Wednesday and Thursday) and weekends (Saturday and Sunday), the data had also shown a difference in the ON/OFF sequence of the chiller and its components between the working and non-working days. On the contrary, although the Friday measurement results had drawn a respective average current and power at 208A and 142 kW, this was found to be a common phenomenon since the chillers would have started operating at 10.00 a.m. as a way of covering the occupant peak load of Friday prayers between 12.00 p.m. until 2.00 p.m.

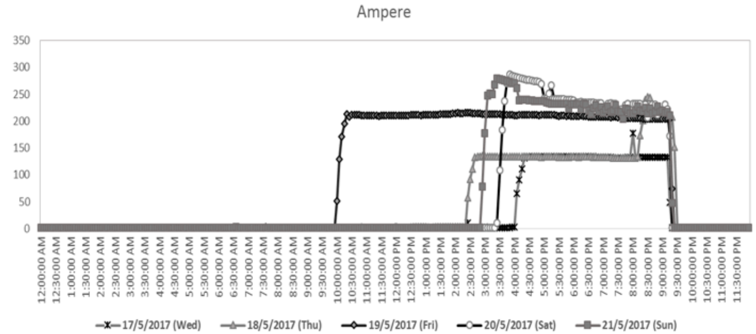


Figure 9: The measured Current, (A) of an air conditioning system for the period of 17th - 21st May 2017

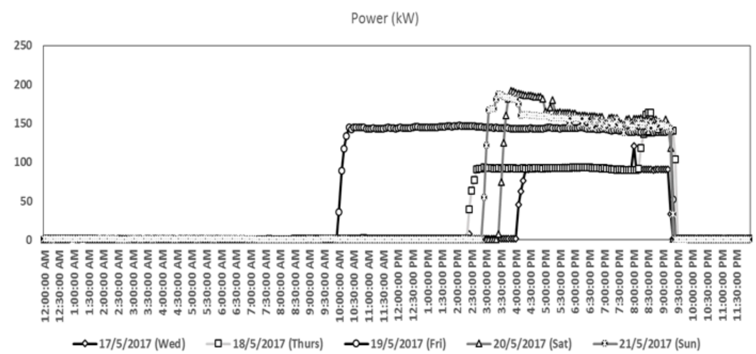


Figure 10: The measured Power, (kW) of an air-conditioning system for the period of 17th - 21st May 2017

Table 4 shows a statistical summary of the power consumption (kW) usage that had been obtained from the case study of the Penang State Mosque. The minimum and maximum power consumption were shown to have varied between 43.48 kW to 162.34 kW, with a respective mean and standard deviation values of 128.63 kW and 17.15. As illustrated from the actual monitoring data of the energy usage in the Penang State Mosque, it is obvious that air-conditioning had been the single largest energy consumed in the provision of thermal comfort for the worshippers, where a total of 63.7% was shown to be associated with the air-cooled chiller operation. The air-cooled chiller is categorized by its capacity and efficiency level, which are influenced by certain factors such as the difference in the physical and operation time as well as the air cooled chiller and the performance of its components such as the condenser. Condenser is considered one of the most important components, where the pressure is cooled down by the various outdoor ambient temperatures that reflect the energy usage. As a result of the climatic condition under a hot and humid weather with a temperature of 34 ºC, it is not only difficult to keep a condenser cooled, but also problematic to increase the energy usage with a polluted coil condenser. For that reason, Alves et al., (2016) had suggested the use of a Seasonal Energy Efficiency Ratio (SEER) in determining the various parameters such as the air conditioning operating time, operating mode (on/off thermostat), the various AC power of compressors and the efficiency degradation of an equipment as a way of checking the equipment's energy efficiency.

Table 4 : Summary power consumption (kW) usage, n=5 days

Descriptions	Mean	Min	Max	S.D
17/5/2017	86.99	33.63	121.01	10.83
18/5/2017	99.56	39.66	163.92	21.47
19/5/2017	141.83	36.01	147.17	13.15
20/5/2017	161.15	74.85	191.83	18.47
21/5/2017	153.61	33.26	187.77	21.79
Total mean (kW)	**128.63**	**43.48**	**162.34**	**17.15**

Note: S.D = Standard Deviation

3.3 Discussions on energy optimization and savings potential

Generally, there is an existing potential for energy-saving opportunities in a building's air-conditioning system. As seen from the above data, factors such as floor area, year of build, fabric and envelope designs, operating hours, costs of energy sources, occupancy load and equipment efficiency had contributed to the different costs and indices for each of the mosque groups, which are similar to those reported by Saidur, 2009 in his research on Malaysia's office buildings. The mosques from the G5 group were found to have produced Energy Intensity and Cost Indices (about 1 to 1.5 times higher) that are not only higher than the Malaysia Standard (MS 1525: 2014), but also the building baseline references of an office (Saidur, 2009) and a hospital (Moghimi et al., 2014). For this reason, the MS 1525 had recommended several low energy usage strategies that can be applied by the buildings (MS 1525: 2014). As indicated by the fluctuating electricity bill recorded from TNB, apart from the manual ON/OFF switch operation of the air conditioning system at different hours, inexperienced mosque officers, as well as the lack of procedures in operating the air conditioning system were also seen to have contributed to the daily inconsistent and varied operation time.

Based on the findings of the Penang State Mosque, the average energy consumed by the air cooled chiller system had been an approximate 128.63 kW, with a temperature of 15ºC set in the thermostat controller. According to the ASHRAE Standard (2013), the temperature level of 22ºC – 26ºC is regarded as a high energy consumption under Malaysia's climatic conditions. Based on the adaptation behaviour, since the worshippers in Malaysia had been shown to be more tolerable to cooler indoor conditions as a result of better body adjustment, the new findings of a favourable thermal comfort in mosques (Hussin et al., 2015) as well as the study conducted on the practices that were based on similar climatic conditions (Yamtraipat et al., 2006; Fasiuddin and Budaiwi, 2011), increasing the pre-set indoor temperature would therefore serve as a good reference for saving energy consumption. The air-conditioning system of the Penang State Mosque was also found to have operated continuously for 6.5 hours on a daily basis during both prayer and non-prayer times, where the emphasis had been on keeping the entire floor area cooled instead of considering the thermal comfort for the worshippers. Since no worshippers were observed during the intermittent prayer times and especially after the Asar prayers, the continuous operation time had therefore led to a high wastage of energy use. As such, apart from being well-informed on the proper operation of the air-conditioning system with regards to the prayer times, the committee members of the mosque can also consider applying for energy audits as a way of reducing energy wastage in the building (Sheikh et al., 2017). The overall findings as well as the suggested short and long term strategies that had considered the availability of budgets and resources of related departments in the Penang State Mosque are listed in Table 5.

Table 5: The findings and optimization strategies for the Penang State Mosque

Findings	Optimization strategy	Implementation
There had been a lack of preventive maintenance conducted in the system. The oil leakage near the adjoining compressor is believed to have originated from the refrigerant.	Frequent maintenance by an expert is required in the prevention of excessive energy wastage from possible faulty equipment or operation failure (Terrill & Rasmussin, 2016).	Short term
Inexperienced mosque officers and the lack of procedures in operating the air-conditioning system had led to the increase of energy usage.	Establishment of Standard Operating Procedures as well as intensive practical trainings to be provided to the mosque officers (Hussin et al., 2015).	Short term
The manual operation of the ON/OFF switch in the air-conditioning system at different hours had resulted in the varied and inconsistent operation time.	A timer can be designed and installed with the controller for the air-conditioning system to operate at a required specific time.	Short term
High energy consumption had occurred in the generation of thermal comfort in the main prayer hall. Although the thermostat setting was found to have been fixed at 15°C, the indoor temperature had recorded a minimum of 22 °C, which is not practical for mosque application.	To test the comfort temperature as suggested in the MS 1525: 2014 (24-26 °C) by using the Predicted Mean Vote (PMV) and Actual Mean Vote (AMV) Indicators with a deviation limit of ± 0.5 (Hussin et al., 2015). To validate the PMV indicators of the indoor climatic performance of a cooled floor area through a computer modelling (CFD) system.	Short term
A high wastage of energy use was observed from the air-cooled chiller, where it was left running at an average of 6.5 hours during prayer and non-prayer times, particularly after the *Asar* prayers.	To test the CFD of the supplied cooled air distribution in the mosque via an appropriate operational zoning system. As suggested by Budaiwi & Abdou, (2013), a large volume of the cooling area can be cooled according to the following proposed segregated zones: Concept 1: Zone 1 –Cooling is only required for the prayer area portion. Concept 2: Zone 2 – Cooling is required for the total floor area during Friday prayer.	Long term
The existing chiller was found to be too old (17 years) and not operating at its optimum level. The blockages that were found in the evaporator pipes had also compromised the cooling efficiency and heat transfer process.	To replace the existing chiller.	Long term

4. CONCLUSIONS

This paper describes the evaluation of the energy profile and the optimization strategies for mosques that had been retrofitted with air-conditioning systems. These air-conditioning systems were found to have performed below the required efficiency level and led to energy wastage as a result of certain factors that had influenced its energy consumption. While providing the best thermal environment for the main prayer hall area, most of these mosques had demonstrated energy indices that were higher than those of the MS 1525 standard and consequently, higher cost expenses. For this reason, this study had proposed several short and long term strategies by considering the available resources and budget such as the upgrading of the system and system knowledge in the optimization of energy usage. Apart from the installation of a timer that automatically operates the ON/OFF switch of the air-conditioning system at a specific time, the setting up of a new thermal comfort or temperature adjustment will also provide advantages in terms of intermittent operation hours and load occupancy. Last but not least, scheduled maintenance of the air-conditioning system as well as the application of zoning operation was also suggested as ways to mitigate the energy wastage of the main prayer hall in the Penang State Mosque.

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