Energy usage and energy saving potential of air conditioning Mosque in Penang Malaysia

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***Abstract*—Air conditioning has become a common feature in newly-constructed Malaysia buildings including mosque. Nevertheless, it has been a common practice to retrofit existing mosque with air conditioning systems of various types and capacity. Due to their functional and operational characteristics, mosque buildings relatively consume more energy than other types of buildings. Energy efficient design and proper operation of air conditioning system in mosque buildings can offer major opportunities for reduced energy consumption and contribute to sustainable development. This paper provides a case study of energy usage and indices from selected air-conditioned mosques in Penang Malaysia. Results from 5 sample mosques G1, G2, G3, G4 and G5 shows the large volume of energy has been consumed by air conditioning system. Mosque G5 has consumed the highest yearly electricity bills (RM 446,000.00), and followed by G3 (RM28,000.00), G2 (RM24,000.00), G4 (RM 20,000.00) and G1 (RM9,000.00), respectively. Mosque management need to pay this costs to get a good thermal performance in main prayer. Mosque G5 produced a very high Energy Intensity Index (323 kWh/m^2/yr) and cost index (RM 153/year/ m^2) due to influence factors. Retrofitted mosques are not comply with MS Standard which need several recommendation in term of energy saving strategies application near future.**

Keywords—mosque building, air conditioning, energy consumption, cost, energy index.

I. Introduction

Mosque is an important institution to the Islamic community, representing a central place for Muslim people to congregate for their five (5) daily prayers, as well as the weekly Friday prayer, the annual Eidul Fitri (fasting month) and Eidul Adha (Haj season) prayers, apart from other related religious function. Muslim who frequent come to mosque to perform their religious obligations deserve a dedicated and comfortable environment, especially in adverse climatic condition. They need a feeling calm and comfortable to perform their prayers in reverence.

Maintaining thermal comfort in buildings always related to heating, ventilation and air conditioning (HVAC) system. These systems are well known as a single largest energy and cost contributions to consumer that has been reported [1]. The temperature rises due to climate change is one of the factor that gives impact to cooling load and energy demand of the buildings [2].

In Malaysia, old traditional and historic mosques are naturally ventilated and cooled [3]. Some mosques were retrofitted with mechanical ventilated devices such as air conditioning system for maintaining indoor thermal performance [4]. However, poor strategies of energy saving application in mosques air conditioning system can constitutes to high energy consumption and cost. Approximately about 57 % of total energy in commercial buildings in Malaysia is from the air conditioning system [5]. In air conditioned mosque, the higher energy is cooling process of the air conditioning system, where the operation depend on the comfort temperature range as recommended by ASHRAE Standard 55 [6]. The large nature of the mosque spatial configuration as well as cooling floor areas are the main contributions. Hence, HVAC management in mosques should be fully attention and examine the efficient method to maintaining thermal requirement especially associated with energy usage.

In literature, there are limited studies related to energy and thermal comfort assessment in air-conditioned mosque buildings. A researcher [7] reported the monitoring study of energy used and indoor environment condition in a number of mosques during occupancy periods in such intermittent operation in city of Dammam and Al-Khobar, Saudi Arabia. The three different size and shape of mosques were used with fully air conditioning system to provide thermal comfort to worshippers. Result showed that the thermal comfort not achieved during peak load even though high energy used to produce cooling. The height of the supply air outlets should be located as low as possible and close to the occupied zone in order to reduce the energy requirement due to air stagnation at ceiling side. Overall finding concluded that zone operation can be considered at design stage for maintaining the thermal comfort as well as reducing energy consumption.

Similar study has been conducted in air conditioned mosques in provinces of Kuwait [8]. The researcher conducted a field study of six town mosques (such as *Capital*, *Hawalli, Aljahra, Alahamidi, Alfarwaniya* and *Mobarak-Alkabeir*) during summer season at mean daily maximum temperature of 45 °C. The mosques have similar size, shape, and built years. The mechanical system such as air conditioning system is used to cools the interior mosques as well as provide thermal comfort to worshippers during harsh summer seasons. Result indicates that the indoor air temperature varies from 18.5 °C and 28.6 °C, while neutral temperature was found 26.1 °C. The energy code of Kuwait aims to guide the designers to achieve energy efficient design of summer season dry bulb temperature difference between indoor and outdoor from 24 °C and 46 °C. The study recommended to increased indoor temperature setting and follow neutral temperature can achieve 20 % of energy saving. This recommendation was also extended to modified energy code of Kuwait and follow actual outdoor temperature of 45 °C which resulting to the energy saving.

Budaiwi & Abdou [9] reported case study of mosque building reflecting the HVAC system operational strategies for potential reducing the energy consumption. The study was conducted at Eastern Province of Saudi Arabia. The objective of the study was to investigate the impact of operational zoning system of HVAC operation on the energy performance at standard thermal comfort level using energy simulation modelling. Three difference size of mosques air conditioned floor area were used in the study such as 218 m^2, 506 m^2 and 1052 m^2. The results from the operation strategy of HVAC system can achieve up to 23 % reduction in annual cooling energy. Meanwhile appropriate operational zoning system can achieve about 30 % reduction. The zoning system is more pronounced in a large scale of mosque at partial daily worshipers. The insulation mosque installed with oversized of HVAC system operated for 1 hour during each prayer can reduced cooling energy consumption as much as 23 %. This results in an energy performance index of about 71 kWh/m2 yr for producing cooling energy.

A study from Hussin et al., [4] reported a case study of performance of air conditioned mosque during daily prayer time focus on the reliability of Predicted Mean Vote (PMV). The case study was conducted at Kepala Batas, Penang State of Malaysia. The mosque cooling floor area is about 640 m^2. The electricity cost for air conditioned mosque was collected for 1 year period. The average cost per month of actual electricity consumption was found approximately RM4, 000.00. The difference activities and operation time in mosque per month from those of an office building reflected the costs and energy usage from air conditioning cooling system.

The purpose of this study is to identify the energy efficient practices for mosques with regards to the air conditioning system. The study of selected mosques was performed and then results from this study are presented. The paper is organized as follows: The first section focus on the energy index and energy consumption from five identical mosques in Penang Malaysia. Relevant details about the energy is then summarized. The second section is analyzed the daily energy consumption pattern of one case study retrofitted mosque. Finally the potential improvement is suggested for energy efficient strategies and opportunities in daily mosque operation.

METHODOLOGY

A. *Electricity Consumption and Energy Index case study*

In early work, a pre-survey was conducted through 15 % samples of registered mosques located at entire Penang State in between January 2017 till March 2017 [10]. Mosque energy database was developed in to five groups (G1-G5) base on the current retrofitted air conditioned mosque information and operation. Accordingly, five (5) mosques presenting from each group G1 to G5 was then selected as a case study of the electricity consumption and energy index. The five mosque samples are sorting based on built year (> 1980), retrofitted with the highest horsepower (capacity) air conditioning system, highest monthly electricity bills expenses (from survey), and used 3 Phase and 415V power supply.

Furthermore, actual monthly electricity bills of G1 to G5 were collected in one year period from the Local Electricity Authority (*Tenaga National Berhad*, Penang State). Because the retrofitting of the air conditioning system in the mosques were done later, some of the mosque has reused the existing energy meter (electricity meter) and some mosque is separately installed new energy meter purposely to monitor the energy consumption of the air conditioning system. In this case, the mosques group G1, G2 and G3 have only one energy meter to monitor the energy consumption of the air conditioning system and others equipment such as lighting, ventilation fan and etc. Mosque G4 and G5 have two energy meter; one is for air conditioning and another is for monitoring the lighting system and ventilation fan.

(1)Building Energy Index (BEI)

A building defined as an efficient building based on its BEI. There is no BEI reference for mosque building but BEI for office is 135 kWh/ year/ m^2 [11] and 200 kWh/ year/ m^2 for hospital [12]. Hence, the BEI of this mosque was calculated and compared with office and hospital. The basic equation of the indices is followed from [5] such as:

(a) Energy Intensity Index

The Energy Intensity Index (ACEII) in kWh/ year/ m^2 is estimate using the following equation;

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

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

(b) Air conditioning cost index

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

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

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

B. *Monitoring actual electricity usage*

It was decided that only one samples representing the overall group of mosques were selected as a field case study. This is due to limitation of permission to conduct the case study in the mosque building. The monitoring is focus on the actual air conditioning electricity consumption during operation. Hence, sample criteria and consideration is based on the:

- Fully operated during daily prayer and Friday prayer
- Highest electricity consumption per year
- Use air conditioning centralize system

By fulfilling the above criteria, the group G5 mosque (Penang State Mosque) was selected as a case study model. The mosque is located at center of Penang main island at GPS 5.406N, 100.3006E. It was built and opened to public in 1981. The mosque building has a round type shape which consists of ground and mezzanine floor. The total floor area for main prayer hall at ground side is 2920 m2, while mezzanine floor area is 65.69 m2. Ground floor is opened daily and used for praying purpose, meanwhile mezzanine floor only opened during other special events and ceremony such as *IdulFitri* Prayer. Each side of the walls uses single layer shaded glass type. Attached together with the walls are six main entrance doors that used the same glass type. All the floor areas are fully carpet and built in pattern of *saf*, parallel to west wall. The dome was used as roof on top of the grand tower. The mosque can fully accommodate up to 5000 worshippers at one time. The management and supervision of this mosque was directly by Penang Religious Affairs Department. Figure 1 shows the picture of the mosque.

Figure 1: Photo of Penang State Mosque

C. *Air conditioning system description*

The Penang State mosque has been retrofitted with air conditioning system in 2003. The three identical air cooled chillers, with capacity 100 RT each were installed to produce good thermal environment as well as thermal comfort inside the main prayer hall. The main system consists of chiller (compressor, condenser, thermal expansion valve and evaporator), air handling unit (AHU), water pump system, air distribution system (ducting and diffusers) and electrical control panel. Air cooled chiller and it components, functions and benefits are describes in literature [13].

In an air cooled chillers component, the reciprocating (semi hermetic) compressor type is used with maximum power input of 235kW, each. Condenser type is an air system which uses the surrounding ambient air to cool down the heat rejection. The evaporator is from the shell type and tube flooded evaporator. Cooled water design temperature is 44 °C out and 54 °C in, produced from shell and tube flooded evaporator, while chilled water is then circulated to the Air Handling Unit (AHU) by a 3 nos centrifugal end-suction pump (10 horse power (HP) motor pump each) at the rate of 255 USGPM. There is 6 unit of air handling unit (AHU) located in AHU room beside of mosque. The supply air is drawn through ducting system and distributes the cool air to surrounding space at main prayer hall using jet diffusers at constant flowrate.

The source of electrical power panel was from 3 phase, 415V and 50Hz power supply. All the controls and power panel for chillers component including ON/OFF button are located in the special box panel near the chillers unit. The sequence of start-up components such as chillers, pump and AHU were synchronize with proper timer step control using single ON/OFF button. The air conditioning system started to operate (ON) at 3.00 PM and shutdown (OFF) at 9.30 PM, daily accepted Friday. In the Friday prayer time, the air conditioning system was ON and OFF starting from 10.00 AM until 9.30 PM. Table 1 shows the air conditioning system data nameplate.

Table 1. Air conditioning system data nameplate

Items	Capacity
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 & 4 = 24,000 CFM
	AHU 5 = 30,000 CFM
	AHU 6 = 18,000 CFM
Air distribution type	Ducting system with jet diffusers

D. *Instrumentation and measurements*

The site measurement at Penang State mosque was carryout from 17 May 2017 until 21 May 2017 (n=5 days). The purpose was to measure the electric power consumption from the air conditioning system. One unit laptop connected to power and energy data logger (PEL) Version 102 was used in the study. The PEL Ver.102 was kept in the electrical room in front of the air conditioning electrical power panel (Figure 2).

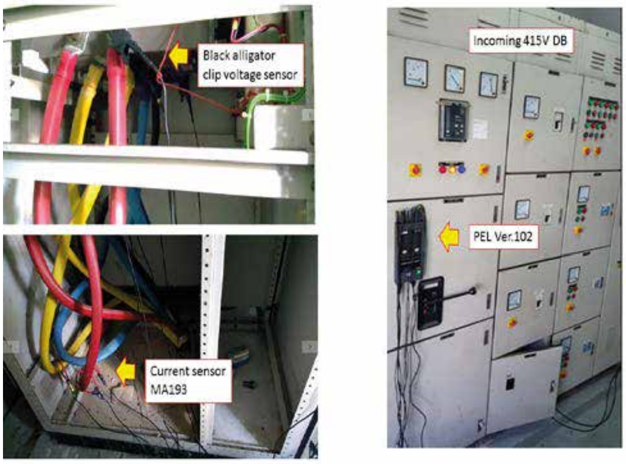

Figure 2: PEL instrument, sensors and electrical panel

The sensor such as MA193 flexible current sensor and black safety leads with black alligator clip voltage sensor was used to measure the instantaneous electric variables from incoming 415V terminal wire supply without opening the circuit. The 3 units of black alligator clip together with voltage sensor were clipped at the power supply terminal. Another 3 units of MA193 flexible current sensor was round clamped at red, yellow and blue power supply wire. The PEL Ver.102 was enabled to measure and record electrical power parameter such as instantaneous electric variables (Root Mean Square (RMS) current, RMS voltage, phase angle) and power (kW and kVA). The accuracy of the current and voltage probes is ± 1% ± 15A and ± 2.5% ± 0.4V, respectively. All instantaneous data is capture automatically at 5 minutes interval and directly save in the PEL memory card.

II. RESULT

The overall group G1 to G5 mosques monthly energy and cost usage, Energy Intensity Index, Cost index and daily energy consumption measurement from air conditioning case study mosques in Penang were investigated.

A. *Impact of air conditioning operation to cost and energy index*

The results of the five mosques physical data from G1 to G5 are summarized in Table 2. The mosques group G1, G2, G3, G4 and G5 consists of cooling floor area from 160 m^2, 315 m^2, 576 m^2, 632 m^2 and 2920 m^2, respectively. The ceiling height was measured at wall to wall side and varies from 4 m to 6.5 m. The retrofitting air conditioning capacity varies from 15 HP, 54 HP, 89.5 HP, 67.5 HP and 378 HP, respectively. The air conditioning types such as ceiling exposed split unit is the most common type of system found in mosques group G1 to G4, followed by wall mounted split unit. On the other hand, the mosque G5 used the centralized air cooled chiller with combination of AHU and ducting system. Ventilation fan such as wall fan is the majority found in mosques group G1 to G5, followed by stand fan in mosques group G4 to G5 and ceiling fan in mosques group G1 to G2. For lighting system, the most common lighting type was used the florescent lamp and followed with incandescent lamp.

Figure 3 shows the actual utility bills (energy and cost) consumed by the air conditioning system in one year period, Jan-Dec 2016. The yearly sum expenses for energy consumed from the air conditioned mosques group G1, G2, G3, G4 and G5 are 22 MWh, 39 MWh, 63 MWh, 44 MWh and 942 MWh, respectively. On the other hand, the yearly sum expenses for electricity cost from the air conditioned mosques group G1, G2, G3, G4 and G5 are RM9, 000.00, RM24, 000.00 RM28, 000.00, RM20, 000.00 and RM446, 000.00, respectively. Comparing to the average cost utility usage per month shows that mosque G5 was the highest (RM 37, 177.00), and followed by G3 (RM2, 320.00), G4 (RM1, 668.00), G2 (RM 1, 987.00) and G1 (RM765.00), respectively. The result shows that the total energy consumed in each group of mosques were equivalent to half of the electrify costs of each group of mosques. Meanwhile, there is a significant difference between energy and costs usage with increased of cooling floor area in each mosques except mosque G4. This may be due to actual air conditioning capacity (horsepower) at mosque G4 was installed below the estimated values as indicated in Table 2. Some mosques shows the fluctuation of energy usage in every month which need more investigation, either involves the increment of operation time or due to energy wastage (energy loss) associated with equipment less efficient or difference in the standard physical and operation procedure to meet the comfort expectations. For example, the mosque G3 shows the increasing energy usage and costs between January and July about 50 %. The highest usage was found in July which coincided with the Ramadhan fasting month, during which intensive activities normally take place in a mosque such as breaking the fast, the special night prayers of *terawikh* (pre-midnight) and *qiamullail* (after midnight) as well as *iktiqaf* (contemplation in MPH) besides the five daily prayers.

Table 2. Mosques physical data G1-G5

Descriptions	Mosque-G1	Mosque- G2	Mosque- G3	Mosque- G4	Mosque- G5
Group category	< 199 m^2	200 - 399 m^2	400 - 599 m^2	600 - 799 m^2	> 1000 m^2
Total cooling floor area (m^2)	159.42	314.11	576.56	632.11	2920
Floor to ceiling height (m)	4.5	4.5	4	5.5	6.5
Built year	1982	1998	2006	1986	1981
Maximum occupancy (person)	260	500	800	1200	5000
Floor shape	Long rectangular shape towards Qibla	Long rectangular shape towards Qibla	Short rectangular shape towards Qibla	Short rectangular shape towards Qibla	Square shape
Retrofitted air conditioned type and horse power (HP)					
Ceiling Exposed (HP)	15	50	88	67.5	-
Wall mounted (HP)	-	4	1.5	-	-
Air cooled chiller with AHU & duct (HP)	-	-	-	-	378
Air conditioning operation	Daily & Friday prayer	Daily & Friday prayer	Daily & Friday prayer	Daily & Friday prayer	Daily & Friday prayer
Survey monthly electricity cost (RM)	< 1499	1.5k-4.9k	5k - 9.9k	< 1499	> 10k
Type of indoor ventilation fan					
Stand fan qty	-	-	-	10	30
Ceiling fan qty	9	16	-	-	-
Wall fan qty	9	10	67	25	30
Type of lamp					
Fluorescent lamp (kW)	2.64	6	9.4	4.6	12
Incandescent lamp /spot light (kW)	0.9	0.9	-	1.6	7.2

Figure 4 shows the annual air conditioning Energy Intensity Index (kWh/year/m^2) for five mosques group. The lowest indices presented by the G4 (70 kWh/m^2/yr and RM 32/year/ m^2), followed by the G3 (110 kWh/m^2/yr and RM 48/year/ m^2), G1 (124 kWh/m^2/yr and RM 58/year/ m^2) and G2 (124 kWh/m^2/yr and RM 76/year/ m^2), respectively. While G5 mosque produced higher indices of 323 kWh/m^2/yr and RM 153/year/ m^2, almost 16 % different reported by [12]. Compared to current MS 1525 standard and equivalent researchers (Figure 4), the higher indices were produced which Mosque management need to pay higher costs to get a good thermal performance in main prayer hall area by using air conditioning system.

Figure 3: Actual energy and costs for G1-G5, one year period (Jan-Dec 2016)

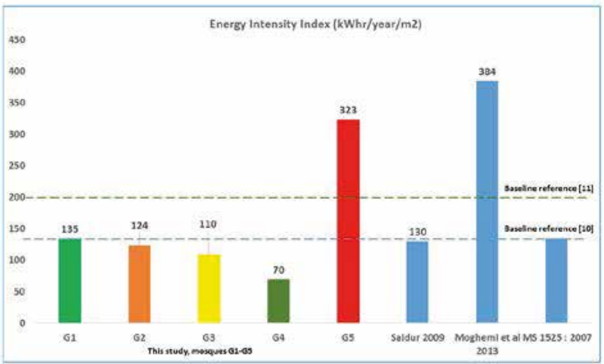

Figure 4: Annual Energy Intensity Index

B. *Actual Penang State Mosque energy usage*

Figure *5* and Figure *6* shows the total measured air conditioning current and power consumption as a function of time. The electric current (A) and power (kW) varies from 70 A to 145 A and 40 kW to 80 kW*,* respectively. It was observed that half values were indicated between weekdays/office days (Wednesday and Thursday) and weekends (Saturday and Sunday). The variations are due to chillers operation base on religious activity held inside. At weekday, a minimum of one chiller was operates. Meanwhile, at weekend or special religious function (Thursday night-cited *Al-quran*), at least two or all chillers were operates. Another contribution is from condenser pressure which cooled down by the variation of outdoor ambient temperature. On the other hands, Friday measurement results have drawn the current and power at 110A and 60 kW, respectively. This condition was observed to be a common practice where chiller start at 10.00 AM in order to cover the occupant peak load of Friday prayer which started at 12.00 PM until 2.00 PM.

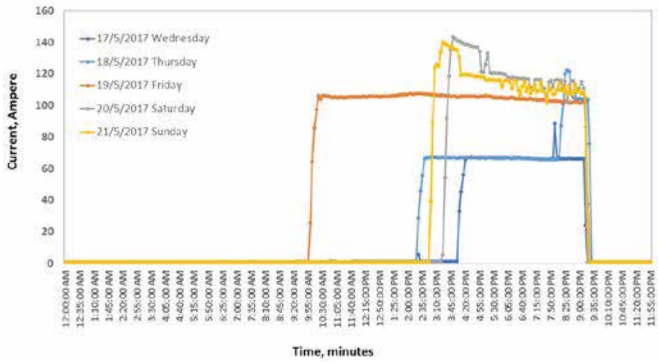

Figure 5. Measured current, (A) from air conditioning system 17th - 21st May 2017

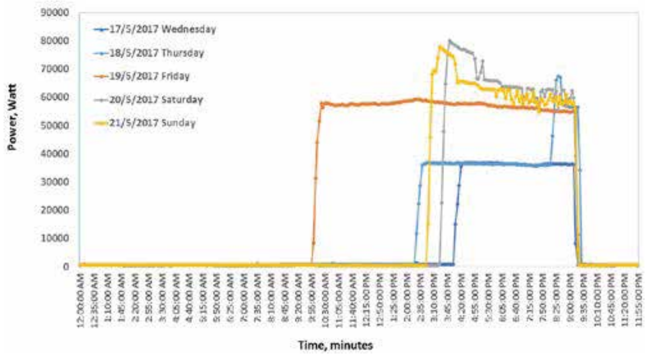

Figure 6. Measured Power, (W) from air conditioning system 17th - 21st May 2017

C. *Observations and suggestion air conditioning operation for energy efficient*

The impact of air conditioning operation to energy index and energy consumption of each mosques were observed and potential energy-saving opportunities in mosques air conditioning systems are proposed;

- Each mosques group has developed a different indices and costs due to influence factors such as floor area, year built, fabric & envelope, operating hours, energy price, occupancy load and equipment efficiency. These influence factors were similar reported in Malaysia office buildings [5].
- Mosque G5 produced higher Energy Intensity Index and Cost Index (about 1 to 1.5 times higher) compared to others baseline reference buildings such as office [5], hospital standard [12] and Malaysia Standard [11].
- ON and OFF chiller system at different hours and by manually has contributed un-constant operation time and varies every days. Observation showed that mosque officer has less knowledge and they don't have procedures to operate the air conditioning system. With un-proper handling skills and knowledge, mosque need to pay high electricity

cost due to un-fixed operation time. Apply timer to ON and OFF the chiller system can fixed the operation time.

- Energy consumption to produced comfort temperature is very high in each mosques. Some finding work of new comfort temperature in mosque from [4] and practices on rising the indoor set point temperature such as [14] and [15] can be a good references to save energy consumption which has a similar climatic.
- The power consumption when all air conditioning system at OFF mode were found to be 0.6 kW. This condition resulted to energy waste where mosque need to pay approximately RM3000 per year. Hence, apply the energy audits to check the energy waste has a significant role at low or no cost, just with best practices and reducing wastage in the buildings [16].
- Some oils was found at near joining compressors and condenser has dirt. The lack of preventive maintenance in air conditioning mosque led to equipment energy efficiency down. Frequently do maintenance by an expert to maintain the air conditioning system can avoid excessive wasted energy from faulty equipment or operation [17].
- The chiller system using R22 refrigerant was too old and almost operates since 16 years ago. Changing to new efficient refrigerant such as R290 without major modification can save the energy [18].
- G5 mosque was fully air-conditioned at average 6 hours daily even not in the prayer time and no occupant inside especially after *Asar* prayer which led to high energy waste and high energy use per unit area. Operation by zone is suggested in mosques [9].

III. CONCLUSION

This paper presented the field study of energy usage and improvement potentials of air conditioning systems considering energy saving at the retrofitted mosques. Due to influence factors, air conditioned mosques are less efficient and energy wastage which produced higher indices than MS standard and references building. Mosque management need to pay this costs to get a good thermal performance in main prayer hall area. From the study, several recommendation are suggested to mosques management. These recommendation take into consideration of minimal available source and budget for upgrade. The first recommendation is to ON/OFF the air conditioning system at fixed time using timer which can avoid fluctuation of energy usage. Additionally, set new comfort temperature or temperature adjustment which have potential of energy saving due to intermittent operation hours and occupant load. Properly maintenance air conditioning system with appropriate maintenance schedule can avoid waste energy from faulty parts or operation. In addition, drop in new efficient refrigerant such as R290 into the R22 system can counter back the efficiency of the machine. The last recommendation is to apply zoning operation which almost reduced the overall energy waste in main prayer hall of mosques.

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