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Analysis of energy usage in mosques in urban area with tropical climate: case study in Yogyakarta, Indonesia

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Analysis of energy usage in mosques in urban area with tropical climate: case study in Yogyakarta, Indonesia

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Abstract. The Mosque is a prayer place for Muslims, which has daily usage. For urban communities in Indonesia, mosques play an important role in social life. The Muslims carry out various kinds of activities in mosques besides praying. With its various activities, the mosque also has unique energy use characteristics when compared to other types of buildings such as houses, offices, and commercials. This paper presents an analysis of energy use in mosques in urban areas with tropical climate. Data was collected through a survey of mosques during 2018 to 2019 in Yogyakarta, Indonesia. The results show that the use of energy in mosques in urban areas in Yogyakarta on average consumes 182.2 kWh per day. The highest use is for air conditioning by 29.16%. Overall, the mosque energy consumption intensity varies from 0.16 to 4.54 kWh per square meter monthly and all of them meets criteria as very efficient buildings. In the other side, only 6 out of 15 mosques meet the national standard for lighting. In the term of green building standard, there are 9 out of 15 mosques meet the criteria in energy consumption aspect. This paper concludes that energy consumption in mosques in urban area with tropical climate is dominated by the air conditioning purposes.

1. Introduction

The development of the era is indicated by the rapid advancement of technology and modernization. This is in line with the increase in energy consumption in every sector of human life. One of the major energy consumptions is in the building sector [1]. The building sector contributed 36% of the total final energy consumption and 39% of emissions in 2018. Energy demand from buildings continues to increase driven by the rapid increase in building area and population. Meanwhile, efficiency efforts that are constantly being improved cannot keep up with the growth in energy consumption [2].

One effort to improve efficiency and reduce energy consumption in buildings is by applying rules and standards. Some standards apply internationally and nationally. In Indonesia, the Minister of Energy and Mineral Resources (MEMR) regulation No 13:2012 states that increasing electricity consumption savings should be done efficiently and rationally without reducing safety, comfortness and productivity. Buildings can be classified as efficient if they meet the Energy Consumption Intensity (ECI/IKE) standard, the Indonesian National Standard in lighting systems, and green building standards. Therefore, studies related to the buildings should be carried out.

Various studies have been carried out to analyze energy consumption in buildings. The research includes commercial, residential, and public buildings such as schools, universities, stations, and others. One unique study is the pattern of energy consumption in mosque buildings. Energy consumption at the

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mosque is unique because its energy usage is not used continuously and varies depending on the number of people who come and at a certain time period. Several studies have been carried out related to energy consumption in mosques in dry desert climates [3]. On the other hand, there are several related studies that discuss more about thermal comfort in mosques [4-5]. Meanwhile, there has not been much research related to energy consumption in mosques in tropical urban areas. Therefore, this research will investigate the level of energy consumption in mosques and compare them with the standards in Indonesia.

This study aims to conduct an analysis of energy consumption in mosques in tropical urban areas. Case study were conducted by surveying several mosques in and around the city of Yogyakarta, Indonesia. From the data obtained through the survey, the total energy consumption in each mosque will be calculated and then compared to the Energy Consumption Intensity (ECI) standard. In addition, an analysis of compliance with lighting and green building standards in Indonesia was carried out.

2. Classification of Mosques

Mosques can be classified into many categorizations. Based on the types of prayer halls, mosques have been classified into basic and non-basic [6]. For general categorization, mosques have been classified into sacred mosques, community mosques, madrasas, musalla, memorial mosques, jami mosque, and surau. Mosques were also categorized by its capacity into small with maximum 200 people, medium for until two thousand people, and large for above two thousand people. Furthermore, mosques have been classified by special significance into national, city central, center for dawah, and an historical important mosque [7].

In Indonesia, there are 264,452 mosques (until August, 2020) and have been classified by Ministry of Religious Affairs into eight groups. These are *masjid negara* (country mosque), *masjid raya*, *masjid agung* (great mosque), *masjid besar* (major mosque), *masjid jami*, historical mosque, mosque in public space, and national mosque. Among these various groups, the Jami mosque has the highest number, 216,076 where it is more than 80 percent of the total mosques in Indonesia [8]. In Yogyakarta, there are 219 mosques that are included in the Jami Mosque category. This confirms that the mosque which is widely used by the community in general is the jami mosque.

Mosque is included in the type of building which of the condition inside is influenced by climate. Local climate is used in various modeling of buildings and affects thermal comfort as well as the cooling or heating demand of the room [9]. This will affect energy consumption as well as energy requirements for lighting [10]. For the developing countries with tropical climates, the air conditioning becomes one of the most energy consuming technologies [11].

Yogyakarta and surrounding areas as the location of this case study has similar climate to Indonesia generally which can be classified as a hot and humid tropical climate [12]. The City of Yogyakarta has a type of tropical monsoon climate and a tropical savanna. According to geographical data on the Yogyakarta City Government Portal, the average rainfall in the city of Yogyakarta is 2,012 mm/year with 119 rain days with an average temperature of 27.2° C and an average humidity of 24.7%. In the rainy season, the blowing wind is a west monsoon with a direction of 220° which is usually characterized by high rainfall and is wet. Whereas in the dry season the southeast monsoon winds blow in the direction of ± 90 ° - 140 ° which is rather dry.

3. Methodology

In this study, there were 15 mosques with the category of the Jami mosque in Yogyakarta and surrounding areas studied. The mosques were randomly selected and surveyed in 2018 and 2019. The survey aims to collect data related to energy consumption used in electrical equipment. Electrical equipment is categorized based on its function, namely lighting, water, sound system, and air conditioning. Other miscellaneous equipment that is categorized into other groups.

The survey was conducted through interviews with mosque administrators or mosque guards. Questions asked include the number of electronic equipment including lamps, sound systems, water pumps, fan, air conditioners, digital clocks, televisions, internet routers, and others. In addition, questions were also asked regarding the power of each equipment and the duration of daily usage. This is used to obtain data for the calculation of total energy consumption. If the total energy data has been obtained, then the intensity of energy consumption can be calculated. In addition, lighting levels were also measured in the main room used for worship using the lux meter.

3.1. Electrical energy consumption

The energy used by an electric equipment is equal to the rate of energy use (power) multiplied by the time during which the tool is used. The power is equal to voltage multiplied by the current. Mathematically the formula of the electrical energy consumption by each electric equipment is presented by equation (1).

$$E = P \times t \tag{1}$$

Where
E : Electrical energy-daily (watthours)
P : Power of the electric equipment (watt)
T : Duration-daily (hours)

In the next step, the monthly electrical energy will be calculated by sum the daily electrical energy usage up from all equipments multiplied by 30 days. The formula as shown in equation (2).

$$TEEC = \sum E_e \times 30\ days \tag{2}$$

Where E_e is daily electrical energy consumption for each equipments categories.

3.2. Energy Consumption Intensity

Varies methods can be used in the process of evaluating energy use in buildings. One of them is through the energy consumption per unit area of the building floor [13]. In some studies, they use method of energy consumption per unit of person or energy per unit flow of passengers in the transportation sector building [14]. On the other hand, the energy consumption in buildings can be evaluated using its energy saving potential and energy efficiency index [15]. All of these methods aim to reach a conclusion whether the building is wasteful or not and what developments need to be done to optimize the use of energy.

In Indonesia, a method often used for the evaluation of energy consumption in buildings is the calculation of the Energy Consumption Intensity (ECI wellkown as IKE) value [16]. ECI is the ratio between the total energy used to the unit of building area in a certain period (kWh/m^2 per month or kWh/m^2 per year). ECI is calculated using the formula in equation (3).

$$ECI = \frac{TEEC}{TAB} \tag{3}$$

Where:
ECI : Energy consumption intensity in certain period (kilowatthours/squaremeter)
TEEC : Total electrical energy consumption (kilowatthours)
TAB : Total area of the building (squaremeter)

In implementing the evaluation process of the building performance and to obtain a picture of the potential energy efficiency of buildings in Indonesia, the Indonesian government has developed supporting regulations. It is contained in the regulation of the Minister of Energy and Mineral Resources (MEMR) No. 13/2012. In the regulation the building is divided into buildings with air conditioners and buildings without air conditioners. The building performance is labeled in four categories: wasteful, quite efficient, efficient, and very efficient [17]. Each category has a range and a value limit as shown in Table 1.

Table 1. Standard of energy consumption intensity by MEMR.

Categories	**With air conditioning** (kWh/sqrmeter/month)	**Without air conditioning** (kWh/sqrmeter/month)
Wasteful	>8.5	> 7.4
Quite efficient	14 – 18.5	5.6 – 7.4
Efficient	8.5 – 14	3.4 – 5.6
Very efficient	< 8.5	< 3.4

3.3. Lighting and green buildings analysis

Measurement of the light intensity is done by means of the area of the main worship space divided into several areas (m^2), and each area is measured by the intensity of the light using a lux meter with a measuring point of 0.75 meters above the floor (work plane). Based on the Indonesian National Standard 6197-2011 about the recommended lighting level for mosque buildings of at least 200 lux [18].

The next step is the calculation of energy consumption intensity, which is a comparison between the total energy use of the unit area and a certain period (kWh/m^2 per month or per year). Lighting level data and ECI values compared to green building standards. The green building standard value is obtained from one of the green building certification requirements, namely the use of power/area (W/m^2) must be 15% more efficient than the lighting reference stated in SNI 6197-2011 (10W/m^2) which means maximum use of power/area at the green building class is 8.5 W/m^2.

4. Results and discussion

Analysis of electricity usage patterns at mosques in Yogyakarta was carried out on a number of mosques in Yogyakarta and the results of the analysis were divided into several things namely electricity consumption, energy consumption intensity, lux (lighting), and also green buildings.

4.1. Electrical energy consumption in mosques

Electricity consumption in 15 mosques in Yogyakarta is grouped into five types of functional loads, namely lighting, water, sound system, air conditioning (air conditioners and fans), and miscellaneous equipments. Based on the data, the total energy in all mosques is 4000.9 kWh which consists of 729.03 kWh for lighting, 207 kWh for water, 32 kWh for sound systems, 1594.315 kWh for air conditioning and 841.25 kWh for miscellaneous. Average energy consumption of electricity most widely used in air conditioning in the form of the use of air conditioners and fans by 29.16%. While the lowest electricity consumption is used in the water pumps by 7.57%. Total energy consumption of electricity is most widely used in air conditioning in the form of the use of air conditioners and fans by 39.85%. While the lowest electricity consumption is used in the use of water pumps by 5.17%. The Table 2 presents the complete results of the survey.

Table 2. Daily energy consumption.

Groups	Daily energy consumption (kWh)-total	Total Percentage (%)	Daily energy consumption (kWh) - average	Average Percentage (%)
Lighting	729.03	18.2	48.60	26.7
Water	207.00	5.2	13.80	7.6
Sound System	629.33	15.7	41.96	23.0
Air Conditioning	1594.32	39.8	53.14	29.2
Miscellaneous	841.25	21.0	24.74	13.6
Total	4000.92	100.0	182.2	100.0

4.2. Energy consumption intensity

As shown in Table 3, the results for all mosques that have been surveyed are included in the very efficient criteria. Based on the ECI values, all mosques are less than 8.5 kWh/square meter for air-conditioned buildings and less than 3.4 kWh/square meter for non-air-conditioned buildings.

Table 3. ECI of all surveyed mosques and its criteria.

Name of mosque	Area (square meter)	Monthly TEEC (kWh)	ECI (kWh/square meter)	Criteria
Besar Sleman	300	642.45	2.14	Very efficient
Noor Jetis	156	368.82	2.36	Very efficient
Diponegoro Tegalrejo	132	188.88	1.43	Very efficient
Al-Hikmah Kota Yogyakarta	206	77.16	0.37	Very efficient
At-Taqwa Suronatan	850	520.86	0.61	Very efficient
Baitul Hikmah Gondokusuman	700	111.24	0.16	Very efficient
Jami’ Al-Huda Kalasan	450	174.85	0.39	Very efficient
Al-Huda Karangwaru	182	826.86	4.54	Very efficient
Mubarok Danurejan	200	230.97	1.15	Very efficient
Al-Hidaya Umbulharjo	300	197.01	0.66	Very efficient
Jami’ Al-Karim Terban	63	87.90	1.40	Very efficient
Jami’ Nidaul Jannah	188	52.41	0.28	Very efficient
Al-Fitroh Terban	300	151.20	0.50	Very efficient
Jami’ Baitul Qohar Terban	320	261.32	0.82	Very efficient
Jami’ At-Taqwa Gondokusuman	243	151.83	0.62	Very efficient

4.3. *Lighting*

The lighting system comparison in several mosques in Yogyakarta refers to SNI 6197: 2011. Wherein SNI 6197: 2011 states that the minimum level of lighting in places of worship, specifically mosques, is 200 lux. Based on the SNI reference, mosques that meet the standards and which do not meet the standards can be determined. Based on data collected, 6 out of 15 or 40% of mosques in Yogyakarta meet SNI for the minimum level of lighting for houses of worship while 9 out of 15 or 60% mosques in Yogyakarta do not meet SNI for minimum levels. The range of lighting levels of mosques in Yogyakarta between 1-456 lux with the highest lighting level is the Jami’ Nidaul Jannah Mosque and the lowest lighting level is the Diponegoro Tegalrejo Mosque. The comparison of lighting levels to Indonesian national standard is illustrated by figure 1.

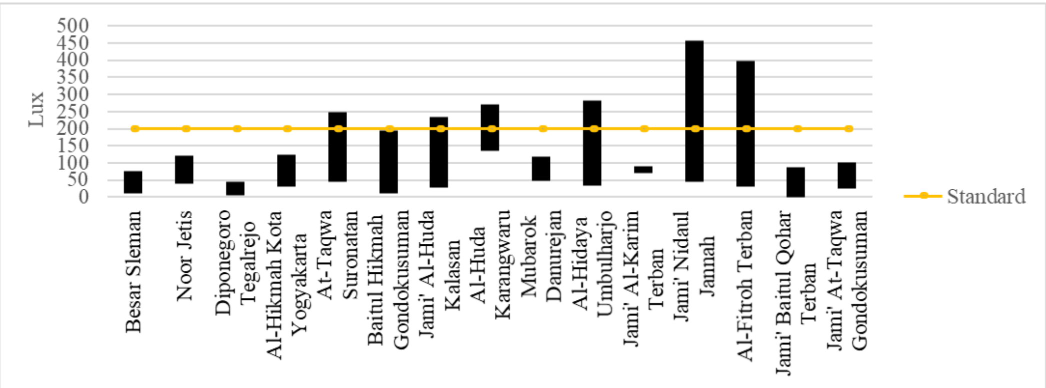

Figure 1. Comparison of lighting levels to Indonesian national standards.

4.4. *Green buildings standard for mosques*

Based on the calculation of green building standards, the value of 8.5 W/m^2 is obtained as the standard of power consumption per area of green buildings in the mosque. From this value, we can determine mosques that are classified as green buildings and those that are not.

Table 4. Mosques power consumption per square meter compared to green building standard.

Name of Mosque	Power/area (W/sqrmeter)	Standard (W/sqrmeter)	Criteria
Besar Sleman	20.23	8.5	Non-Green Building
Noor Jetis	12.78	8.5	Non-Green Building
Diponegoro Tegalrejo	15.05	8.5	Non-Green Building
Al-Hikmah Kota Yogyakarta	3.84	8.5	Green Building
At-Taqwa Suronatan	4.15	8.5	Green Building
Baitul Hikmah Gondokusuman	1.21	8.5	Green Building
Jami' Al-Huda Kalasan	4.47	8.5	Green Building
Al-Huda Karangwaru	75.10	8.5	Non-Green Building
Mubarok Danurejan	11.78	8.5	Non-Green Building
Al-Hidaya Umbulharjo	7.73	8.5	Green Building
Jami' Al-Karim Terban	13.01	8.5	Non-Green Building
Jami' Nidaul Jannah	4.20	8.5	Green Building
Masjid Al-Fitroh Terban	2.29	8.5	Green Building
Masjid Jami' Baitul Qohar Terban	3.16	8.5	Green Building
Majid Jami' At-Taqwa Gondokusuman	3.50	8.5	Green Building

As shown in Tabel 4, nine out of fifteen or 60% of mosques in Yogyakarta meet the standard of power use per area of green buildings while 6 of 15 or 40% of mosques in Yogyakarta do not meet the standard of power usage per area of green buildings. The range of power usage per area of mosques in Yogyakarta is between 75.1 W/m^2 - 1.21 W/m^2 with the highest use is the Al-Huda Karangwuru Mosque and the lowest power usage per area is the Baitul Hikmah Gondokusuman Mosque.

5. Conclusion

Based on energy consumption data, it is found that the average energy percentage of electricity consumption is most widely used in air conditioning which is consist of air conditioners and fans by 29.16%. While the lowest electricity consumption is used in water pumps by 7.57%. Total electricity consumption is used in air conditioning by 39.85% which is the highest while the lowest electricity consumption is used in water pumps by 5.17%.

The energy consumption intensity value of the mosque in Yogyakarta is included in the very efficient criterion. Based on the lighting system at the mosque in Yogyakarta which refers to SNI 6197: 2011, there are 40% mosques in Yogyakarta meet the SNI for minimum lighting levels of houses of worship while 60% mosques in Yogyakarta do not meet SNI for minimum lighting levels for houses of worship. Through the analysis of green building standards obtained 40% of mosques in Yogyakarta do not meet the standard of power per area of green building, while 60% of mosques in Yogyakarta meet the standard of power per area of green buildings.

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