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A New Framework for Classifying Mosque Energy Models

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ABSTRACT

Energy usage is significantly impacted by mosque designs, building envelops, and the use of various ventilation systems. Factors including geographic location, climate, and social and cultural origins have less significant impact on mosque architecture in Malaysia. Given Malaysia's tropical environment, social and cultural factors which might differ by region have a greater impact on mosque architecture than weather. Since Thematic Analysis (TA) is a comprehensive and successful approach in qualitative research, it has been used in this study to deepen our understanding of mosque classifications. In order to create a categorisation model for mosques, the study focuses on occupancy, design features, envelopes, and ventilation systems. Classifying mosques according to these attributes is crucial since they have an impact on energy use.

INTRODUCTION

Green Building Index (GBI), being Malaysia’s most recognised green rating tools has separate categories on new construction and existing building for residential and non-residential developments with further classification for different types of buildings. Due to voluntary nature of GBI’s participation, buildings submitted for GBI rating are mostly non-residential building with new construction category while the number of submissions for non-residential: existing building is negligible (Mun, 2009). From GBI websites, types of non-residential buildings category submitted for GBI rating include office, hotel, resort, hospital, shopping complex, institutional building, sport complex. Meanwhile, places for religious assembly such as mosques which also fall under category of non-residential building so far has recorded very low participation in GBI rating. With different mosques profile, classification of mosque is needed in identifying

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mosque energy performance. One of the key benefit of having mosque classification in energy performance is improved energy efficiency and cost saving.

The objective of this paper is to survey a potential in developing mosque buildings classification to establish a new framework for mosque energy models. The outcome of this paper will develop the new framework of mosque building Classification of intermittent use and can be useful as a standard in building performance studies.

As of today, there are no standards to establish building classification as a reference. The existing buildings classifications were made normally for marketing, property values, and functions. Dascalaki et al. (2011), the classification of buildings can be done according to the purpose of the classification requirements, such as for performance purposes, classification using features that determine performance will be used as a model. This clearly shows that the building classifications features depend on the purposes of respective classifications.

LITERATURE REVIEW

Building Categories in Malaysia

Building categories play a vital role in urban planning and construction management by providing a systematic framework for categorising structures based on their usage and characteristics. This is useful for economic and recognition purposes. In the new era, building classifications play an important role in rating and marketing strategies (commercial purposes). Sustainable, eco-friendly, user-friendly, hi-tech safety, and smart building concepts are always introduced in new projects for marketing purposes. Nonetheless, buildings can be classified into two (2) major categories which are commercial-non-commercial, and public-private buildings. In line with sustainable promotion by the government, the developers highly promoted their buildings as sustainable with rating status. As a government agency, the classification of the buildings is based on function. Economy Planning Unit (EPU, 2015) classified buildings into eleven categories focusing on public or government buildings. There is office, multi-purpose halls, auditorium buildings, education buildings, health buildings, security buildings (police, army, prison, fire, and rescue), court buildings, embassy buildings, mosques buildings, library, quarters, hostel, and sports facilities buildings. Meanwhile, private agencies, are more towards commercial and private buildings. Whereas, International Law Book Services, (2015) set buildings based on purposes (institutional, residential, office, assembly place, shop, factory, and storage). Thus, Mun (2009a) set holistic building categories regardless of functions and purposes into public or private and commercial and non-commercial classification through the GBI tool for assessing building performance in the identification of the sustainable status of buildings as tabled in Table 1.

Table 1. Categories of Buildings

Category	Commercial Buildings	Non-commercial Buildings
Public buildings	Multi-purpose halls	Hospital
	Shopping mall/shop	Mosque
	Sport facilities	School
		Library
Private buildings	Factory	Office
	Hotel	Residential
		Quarter

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	Hostel

Source: Authors (2024)

Religious Building as a Public Buildings

Mosque, church, temple, are among a few religious buildings that are found all over the world to cater for various religious practices. According to the worldmeter, (2023), with a world population of 8.04 billion, the distribution of worshippers among major religions in descending order are Christians 31% (2.17 billion), Muslims 23% (1.59 billion), Hindus 15% (1.03 billion), Buddhists 7% (487 million) and Jews 0.2% (13.8 million). For Muslims, mosque is a very important building for the community. During the caliphate, apart from for the purpose of worship, the mosque was also used as a social centre, economic development centre, education centre and also a centre for the propagation of religion ("*dakwah*"). Since then, mosques have seen various transformation while still maintaining the hierarchy of spaces of early caliphate mosques. (Hillenbrand, 1999) From the beginning of Islamic history, strong emphasis is given on mosque architecture as it symbolises Islam. This can be seen with the variety of elements and styles of mosques that have been used throughout history starting from the construction of the first mosque built by Prophet Mohammad (Pbuh) which is the Quba mosque in 622 during his migration to Medina. According to Islamic belief, the first mosque in the world was the Kaaba which was built by Prophet Ibrahim (a.s).

Since then, mosques have been constructed all over the world with various architectural styles with some even adopts local characteristics and culture. In Malaysia, the uniqueness of mosque architecture is influenced by the various phases of historically significant such as archipelago style from the Malay sultanate era, Anglo Indian Moorish style from colonial British era, Chinese style from Chinese trading partners and modern style from architectural movement. Regardless of the design featured, the main function of the mosque remains the same (Omer, 2010). However, this diverse architecture to some extent affects comfort and energy consumption today. Therefore, the classification of mosques is also seen as very important to identify framework of mosques that are suitable for environmental conditions and at the same time reduce the impact on the natural environment.

Many studies related to rating classification have been carried out on commercial buildings such as hotels and offices since different hierarchy of classification can influence their market value (Daud, et. al., 2011). However limited study related to mosque classification had been done due to their non-profit operation whereby the rating has no contribution towards their commercial value. Therefore, the mosque classification shall concentrate on the impact to the environment. This is to support the national agenda in promoting sustainable development contributing towards environmental sustainability and energy efficiency.

Mosque Governance in Malaysia

From the total of 33.93 million Malaysian's population in the 14 states of Malaysia, 21.54 million or equivalent to 63.5% are Muslims. It is estimated 7.04 million people reside in Selangor with 4.3 million or equivalent to 12.88% are Muslims which make it the most populated state in Malaysia. JAKIM latest 2020 website listed there is a total of 6468 mosques in Malaysia with 424 mosques to serve the 4.3 million Muslims in Selangor. Selangor as the most developed state in Malaysia with Gross Domestic Product (GDP) 23.5% followed by Kuala Lumpur Federal Territory 14.6% and Johor 7.9%, Sarawak 7.8%, Pulau Pinang 6.7% has the most number or urban mosques and semi-urban mosques due to the availability of physical resources, human resources and financial resources. Therefore, a study of mosques in Selangor would cover a broader perspective in term of governance and administration representative mosque in Malaysia.

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JAKIM, (2022) At the federal level, The Department of Islamic Development (JAKIM) is responsible for standardisation of method of administration for each state in Malaysia. While the administration of Islamic affairs at the state level are done by two (2) organisations: The Islamic religious Council (IRC) responsible for policy making and Islamic Religious Department (IRD) responsible for carrying out policies and procedures for developing and advancing Islam in each state.

There are five (5) categories of Mosques in Selangor; State Mosque, Royal Mosque, Institutional Mosque, District Mosque, and parish Mosque which distribution within the state are as shown in Table 2.

Table 2. Categories and Number of Mosques in Selangor by Respective Districts

Mosque/ District	Sabak Bernam	Kuala Selangor	Klang	Kuala Langat	Sepang	Hulu Langat	Gombak	Hulu Selangor	Petaling	Total
State	-	-	-	-	-	-	-	-	1	1
District	1	1	1	1	1	1	1	1	1	9
Royal	-	-	3	1	1	-	-	-	1	1
Institution	-	1	-	-	4	5	2	-	5	17
Parish	47	55	43	31	20	46	43	23	67	375
Upgraded	-	1	1	-	1	1	-	1	11	16
Total	48	58	48	33	27	53	46	25	86	424

Source: Authors (2024)

RESEARCH METHODOLOGY

Descriptive study is used to provide clear picture on existing phenomena in an accurate situation in presenting a picture of specific details of social setting and relationship (Saunders et al., 2009). Therefore, descriptive study was conducted to identify the mosque typology for development of framework for classification of Mosque Energy Model (MEM). There is no standard yet in developing MEM. Therefore, the establishing MEM are referred to building energy model developed by the United State Department of Energy (DOE) for Commercial Reference Buildings Models with EnergyPlus and the same references has been used by ASHRAE for energy design guide for school buildings (Deru et al., 2023; EIA, 2018). As related to school, due the similarity in term of high occupancy with intermittent usage, reaching up to four (4) times and more compared per square meter than in typical office building (EPU, 2015).

This paper involves 130 mosques with capacity more than 1000 worshipers fall under Class A classification for places of assembly in Uniform Building By-Law 1984 is used due to significant impact to the energy consumption and building performance (International Law Book Services, 2015; SIRIM, 2019) and went for further study due to typical building characteristics in term of shapes or designs factor, building envelope, layout, systems used (Air-conditioning Mechanical Ventilation-ACMV) (ASHRAE, 2018; Parasonis et al., 2012; Ye et al., 2019).

Buildings can be differentiated by their features (shapes, design, layout and building envelope), as well as their operating schedule and systems used. However, classifying buildings into specific categories can be challenging because of these differences. This section proposes a new methodology systematically create MEM to meet the above requirements. To create MEM, data analytics is applied to a mosque's dataset sources using thematic analysis (TA). Fig. 1 illustrates the key steps of method for determining MEM inputs by TA. Step 1 is to identify the mosque model features for MEM development and requirements needed for

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energy model inputs. In order to determine the model input values, Step 2 is collecting data for the specific building features. Step 3 is categorising the mosque building features by themes. Step 4 transform the data into model inputs.

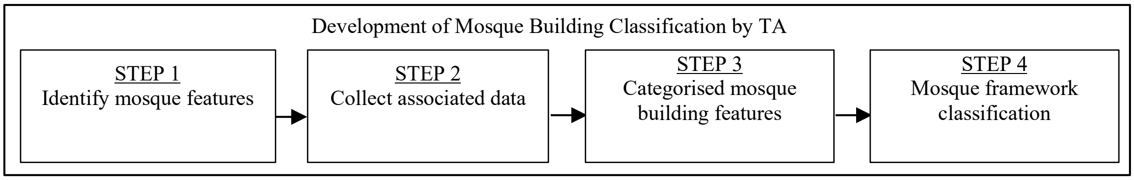

Fig. 1. Workflow of Development Mosque Building Classification

Source: Authors (2024)

ANALYSIS AND DISCUSSION

Design Factor-Size

From the total of 375 Parish mosques in nine (9) districts in Selangor, 130 mosques had been identified that fall under the Class A category (UBBL) with a capacity of >1000 occupants. Mosque with a capacity of more than 1,000 worshipers has a significant effect on the energy used and thermal comfort level as compared to a smaller mosque due to a smaller footprint and reduced congestion (Elliott et al., 2020; Harputlugil & de Wilde, 2021; Millward-Hopkins et al., 2020). Table 3 shows the details of the breakdown of mosque capacity by district.

From the below table, it can be seen that the districts with high population density (Gombak, Hulu Langat, Klang, Kuala Langat and Petaling Jaya) have a total number of mosques with a capacity of more than 1000 worshipers. While other districts located in semi -urban areas have more mosque with below 1000 worshippers.

Table 3. Capacity of Mosques According to Districts

No.	District	Total Number of Mosque	Capacity (more than 1000)	Capacity (300-1000)	Capacity (100-300)
1	Gombak	39	19	16	4
2	Hulu	55	19	21	15
3	Hulu	26	7	8	11
4	Klang	42	30	12	-
5	Kuala	28	14	9	5
6	Kuala	56	8	10	38
7	Petaling	76	18	58	-
8	Sabak	24	7	7	10
9	Sepang	29	8	13	8
	Total	375	130 (35%)	154 (41%)	91 (24%)

Source: Authors (2024)

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Design Factor-Ceiling Height

Most mosques are often built with domes which are synonymous with mosque architecture. Design of domes in mosques can be fully exposed shape visible from below while some are purely decorative only visible from the outside being incorporated purely for symbolic reasons. Some mosques with high double volume space sometimes may have a mezzanine level which is a common design feature for mosques built during the pre-independent era until the late 90s. The design of a fully exposed functional dome is to take advantage of the high ceiling that follows the shape of the dome to create a unique atmosphere to the internal space. To facilitate the height classification, this paper classified floor to ceilings into two (2) categories; less than 4 meters and more than 4 meters as per the study done by Numan (1999a) and technical guideline used in BSEEP (BSEEP, 2017).

Table 4. Findings on Ceiling high in Mosques

No.	Roof Design Classification	No.	Percentage (%)
1	Low ceiling (< 4 meter)	4	3%
2	High ceiling (> 4 meter)	126	97%
	Total	130	100%

Source: Authors (2024)

Mosque Characteristics

Mosque characteristics can be divided into two (2) aspects namely the physical design elements and the building operation. Roof design has a great influence on comfort in mosques due to different ceiling heights. Supporting space in mosques such as *"riwaq"* also has significant effects due to the location that acts as the shading device for the mosque's main prayer halls. Meanwhile, building envelope materials with their various physical properties may also have a substantial effect. Time and period of operation in mosques may also contribute to energy consumption which is measured by multiplying the number of power units consumed within the period over which it has been consumed. Thus, all the above factors are necessary in establishing MEM.

Roof Design

A study by Woroniak & Piotrowska-Woroniak (2014), on energy consumption at five (5) churches in Poland with different roof heights found that roofs with triple volume showed the highest energy savings. Meanwhile, (Terrill et al., 2015), who conducted a study on two (2) different churches in different climatic conditions in the USA also found a significant energy savings pattern. A church located in Western USA has more savings than Southern USA. A study on the effect of roof height and roof type on energy saving levels in mosques conducted by Numan et al. (1999b) found that savings of 6% to 8% for height differences between 4 to 6 meters high. Apart from that, the double-layer roof type also has a different energy saving effect. Findings gathered from 130 mosques on roof design can be classified into fourteen classifications and these designs give directly affect to the internal ceiling height either vault or flat. Table 5 tabulated the fourteen classifications of roof design and Table 6 tabulated findings on 3 categories of ceiling height.

Table 5. Findings on Ceiling high in Mosques

No	Roof form classification	Short form	Total (in no.)	Percentage (%)
1	Hipped roof with decorative dome	HDD	39	30%
2	Pyramid roof with decorative dome	PDD	29	22%

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3	Pyramid roof with dome	PD	17	13%
4	Gable end with decorative dome	GDD	14	11%
5	Hipped roof with dome	HD	14	11%
6	Flat roof with dome	FD	6	5%
7	Multilayer hipped roof	MHR	2	2%
8	Gable end roof	GR	2	2%
9	Hipped roof	HR	2	2%
10	Portal frame	PFR	1	1%
11	Flat roof with decorative dome	FDD	1	1%
12	Barrel vault with dome	BVD	1	1%
13	Dutch Gable end roof	DGR	1	1%
14	Hexagon Hipped roof with dome	HeD	1	1%

Source: Authors (2024)

Table 6. Findings on Roof Design Classification

Item	Roof Design Classification	No.	Percentage (%)
1	Low level with flat ceiling (< 4 meter)	4	3%
2	High level with flat ceiling (> 4 meter)	37	28.5%
3	High ceiling with dome (> 4 meter)	89	68.5%
	Total	130	100%

Source: Authors (2024)

From Table 5, five (5) types of roofs with a percentage of more than 10% is Hipped roof followed by decorative dome (HDD) of 39 mosques (30%), the second highest is Pyramid roof with decorative dome (HDD) of 29 mosques (22%), the third highest is Pyramid roof with dome (PD) as many as 17 mosques (13%) and Gable end with decorative dome (GDD) and Hipped roof with dome each as many as 14 mosques (11%).

As for the breakdown for mosques built with domes and decorative domes, mosques with decorative dome element are 83 mosques (65%) (HDD, PDD, GDD, FDD). While the mosques built using the dome element are 40 mosques (30%) (PD, HD, FD, BVD, HeD). The remaining 7 mosques use roofs from the type of Multilayer hipped roof (MHR), Gable end (GB), Hipped roof (HR), Portal frame (PFR), and Dutch Gable end roof (DGR) which is one (1) for each type. For mosques built with dome elements usually have high ceilings. Unlike mosques that are built with decorative dome elements, the ceiling level is often lowered with another layer of ceiling. This is because the functions of parish mosque are to meet the needs of the community, therefore the architecture is simpler if compared to landmark mosques such as the royal mosque, state mosque and mosques that have historically significant.

Building Envelope

The building envelope is responsible for a significant portion of the total energy consumption in buildings. The findings show that each component of the building envelope properties has no huge differences except for the window-to-wall (WWR) ratio. Information related to transparency for window and door elements in terms of ratio should be considered because it involves with heat transmission from outside to inside the mosque. A study made by (Alghoul, et. al., 2017) and (Q.Yang et al., 2015), found that the total energy consumption according to the WWR will differ based on the orientation of window position,

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type of material (glass) and AC system used. While report produced by BSEEP shows that WWR 15% use less energy compared to WWR 70% which is triple. Similarly, "*riwaq*" element has significant impact to energy consumption due to shading effects. (Anzi & Al-shammeri, 2010). Majority of wall use common bricks and plastered on both sides and painted without insulation (un-insulated sand bricks plastered) that cover the entire perimeter of the building. There are cases where ventilation blocks are used as an intermediate wall in between the "*riwaq*" space and the main prayer halls. For roof covering, most mosques used metal decking (99%) and only 1% use clay roof tiles and concrete roof tiles.

Most of the floor construction in mosques adopted reinforced concrete floors with tiles finish and covered with carpet at the main prayer hall. Tiles or stone finishes to the *"riwaq"* to suit the covered open-air nature of the area. Meanwhile, the majority doors and windows used glass panels.

Fig. 2. Typical Doors for Mosque – Sliding Door with Glass Panel

Source: Authors (2024)

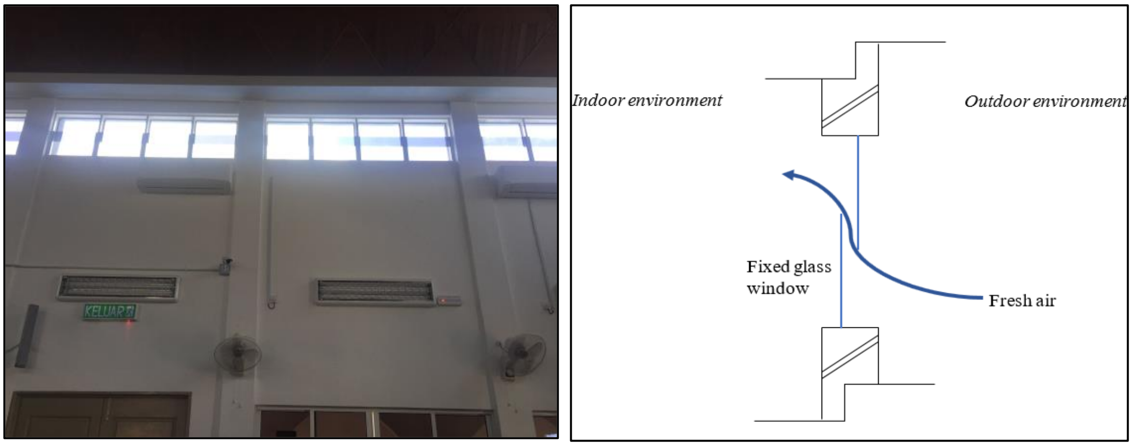

Fig. 3. Typical Window Design Located at Roof Top Area for Ventilation Purposes

Source: Authors (2024)

For the door element, most of the mosques used sliding doors with glass infill panels whose thickness varies between 6mm to 12mm. Window elements were mostly fixed to create air tightness in the main prayer hall while a small portion was openable for ventilation purposes. Only mosques that combined

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natural and mechanical ventilation had more openable windows. High level fixed windows were also placed at the roof level for easy maintenance, allow natural lighting and to prevent birds from entering the main prayer halls. Some windows were designed with two (2) lapping glass panels to allow air circulation. Table 7 shows the summary on findings of building envelopes.

Building Operation Systems

Systems consume the most energy in buildings followed by lighting system. The cooling system consumes about 60% of the total daily usage of energy in buildings. Meanwhile, MV only consumes 2% of total energy use (Energy Commission, 2020). Building operational systems in mosques, are not as complicated compared to commercial building that needs to be equipped with various systems as part of the overall building systems. Other than ACMV and lighting, public address (PA) and sound system is the most common system in mosques. Their function is to amplify the call of prayer (*"adzan"*), and the voice of imams to reach worshippers even at the last row so that prayer can be performed in full synchronisation. Ventilation systems are another type of classification for building systems in mosques. Based on the survey conducted on the total of 130 Parish mosques in Selangor, there are mosques that do not use AC systems and rely fully on natural and mechanical ventilation systems.

Table 7. Findings on Roof Design Classification

Item	Elements	Properties	Remarks
1	External Wall	Half-brickwall with plaster both sides and paints	Typical
2	Internal wall	Half-brickwall with plaster both sides and paints Vent block with decorative pattern	Typical
3	Roof covering	Steel Metal decking Concrete Roof tiles	127 mosques 3 mosques
4	Floor	Concrete floor with tiles finish covered with carpet (at main prayer hall only)	Typical
5	External doors	Sliding door with glass panel (size varies) Panel door (main entrance only)	Typical
6	Internal doors	Sliding door with glass panel (size varies) Panel door (in between internal spaces)	Typical
7	Windows	Casement window (openable) Fixed window glass panel Adjustable louvers	Typical
	WWR	Below 15% 15% to 70%	57 mosques 73 mosques

Source: Authors (2024)

Most mosques combine AC and MV in their operation system. For mosques built before the availability of AC in the market, some retrofits have been made by adding AC to the existing system. Meanwhile, for mosques built in the 20s, the AC system has been considered in the early design stages. Even mosques with AC have done some retrofit by increasing the total number of AC units to improve the comfort level.

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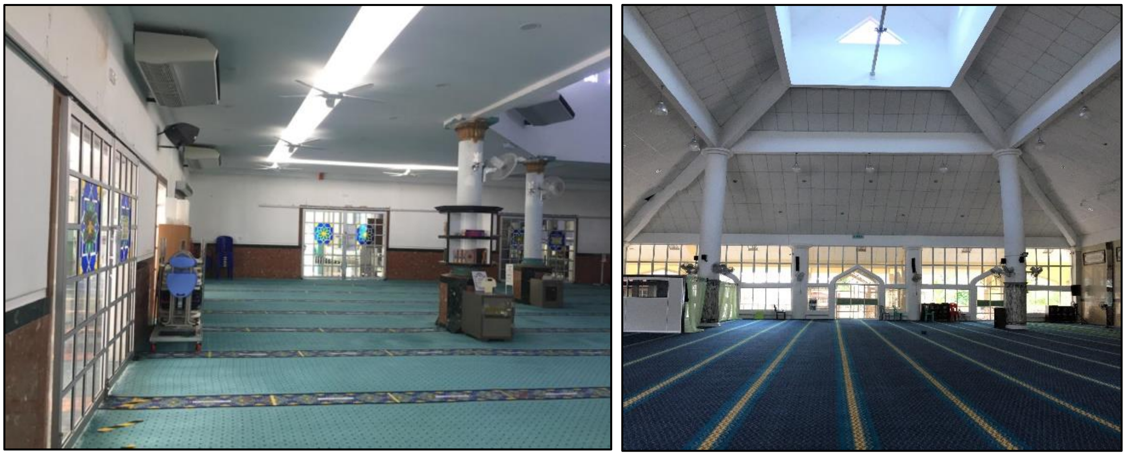

Fig. 4. (Left) Combine Systems-ACMV. (Right) Single System only-MV

Source: Authors (2024)

Fig. 5. AC with Ducting System.

Source: Authors (2024)

The most common types of AC used are split units either wall-mounted or ceiling-mounted while fewer mosques used cassette type, and portable AC. Only one (1) mosque used a centralised system. The mosque's ability to implement major retrofit with centralised AC system was due to their strong financial status from donation drive under *"wakaf"* engagement programme with the community. Table 8 shows the summary on number of mosques equipped with ACMV or MV system only. For MV, there are various types of MV used, among them are ceiling fan, standing fan (floor), wall fan and giant fan (giant fan).

Table 8. Summary on Selangor parish mosques with system use (ACMV)

Item	Ventilation System	No	Percentage (%)
1	ACMV (with ceiling fan / giant fan)	114	88%
2	Portable AC	4	4%

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3	MV only (ceiling fan / giant fan)	8	8%
	Total	130	100%

Source: Authors (2024)

CONCLUSION

The results from the survey conducted on 130 parish mosques in Selangor with a capacity of more than 1000 worshippers were obtained to establish a new framework of mosque building Classification for an in-depth study on energy consumption tabulated in Figure 6.

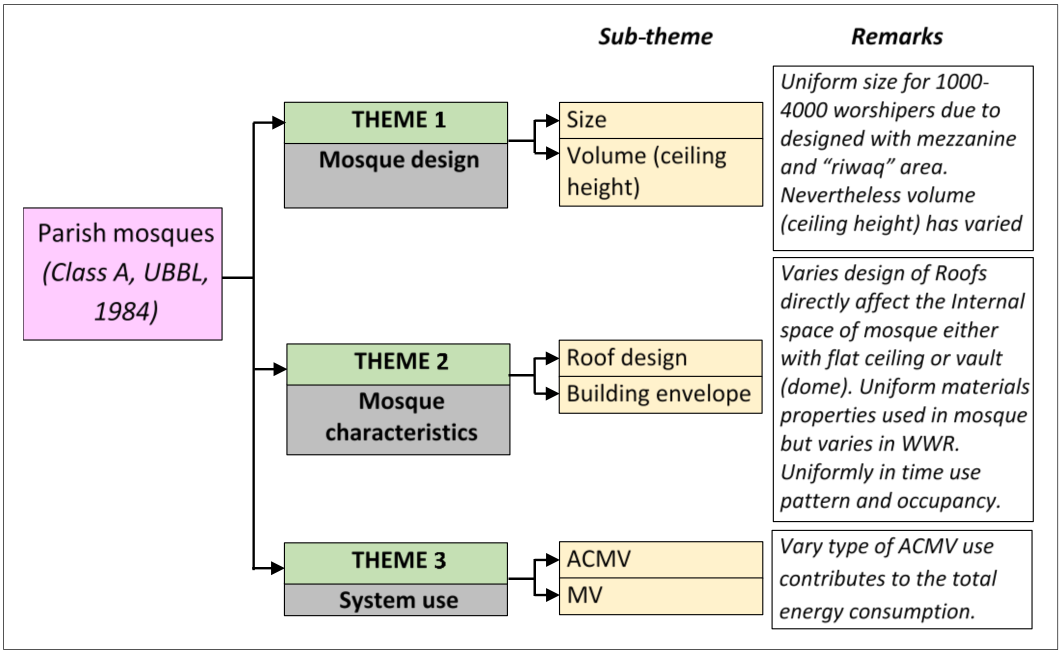

Fig. 6. AC with Ducting System.

Source: Authors (2024)

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CONFLICT OF INTEREST STATEMENT

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare the absence of conflicting interests with the funders.

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AUTHORS' CONTRIBUTIONS

Nurul Asra Abd Rahman designed the study, Zainab Mohmad Zainordin and Zarina Alias compiling the data, Syahrul Nizam Kamaruzzaman and Farid Wajdi reviewed the results and approved the final version of the manuscript.

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