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Evaluating the interior thermal performance of mosques in the tropical environment

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Abstract. This study introduces the methodology applied in conducting data collection and data analysis. Data collection is the process of gathering and measuring information on targeted variables in an established systematic method. Qualitative and quantitative methods are combined in collecting data from government departments, site experiments and observation. Furthermore, analysing the indoor thermal performance data in the heritage and new mosques were used thermal monitoring tests, while validation will be made by meteorology data. Origin 8 version of the software is used to analyse all the data. Comparison techniques were applied to analyse several factors that influence the indoor thermal performance of mosques, namely building envelope include floor area, opening, and material used. Building orientation, location, surrounding vegetation and water elements are also recorded as supported building primary data. The comparison of primary data using these variables for four mosques include heritage and new buildings were revealed.

1. Introduction

Religious building such as mosque symbolizes the surrounding community's religious affiliation and it's cultural during it is built. The architecture and design of mosque emphasize three primary potential benefit includes social, economic and environmental. The mosque is an important religious institute and multi-functional building in Islamic societies to accommodate their daily education, spiritual and social activities. Better architecture and design of mosque can preserve the environment ecosystem, and improve the quality of ambient air and protection of natural resources as well as minimize the adverse impact with the surrounding environment. Lower operation and maintenance costs of the mosque will help on economic aspects. The building could improve the occupant's productivity and advance of life-cycle achievement. Moreover, it also can minimize the energy consumption of the mosque, while improving the quality of thermal comfort level and health of the users are in the category of potential social benefits. Heritage mosque building has a unique design and architecture and high value of art and technology. This heritage building is a precious national asset and should be preserved [14]. Heritage building is a historical retreat that plays an important role in society to convey the cultural and artistic heritage that exists in addition to modern development. In this study context, two types of building development are chosen; the old and new era mosque. In this context of study, the aged mosque is labelled as heritage category of building, while the ordinary mosques are new mosque. Both categories of the building have its context in architecture, construction and its surrounding environment. It's internal building architecture and exterior environmental context influences the interior thermal performances. Tropical climate with hot and humid atmosphere are the most demanding parts and as a primary parameter aspects to enhance through building design. This study analyses and evaluates the factors that can influence the indoor thermal performance of mosque in a tropical environment.

2. Literature Review

The early architecture era of a mosque in Malaysia is basic and straightforward in line with the simple and practical teachings of Islam. During the 15^{th} century, the mosque architectural style and its construction materials were similar with the local traditional Malay houses, where the majority of the Islamic religious practitioners are Malays [14]. Since 19th century in the British colonial period mosque architecture in Malaya has changed, and influenced by British colonial style. Moreover, in early 20th century, the mosque architecture was further extended by the introduction of modernist style. Each heritage mosque has its own uniqueness and this clearly seen in an architectural point of view, settings and layout the cultural landscape and origin of materials. Identity is variations images of places, to distinguish each of it from another [7]. The component of heritage creates an identity in a place by the old existing buildings. The technical aspects of the importance of technology innovation and creativity are an important evidence of creation [11,13]. Mostly heritage mosques may tell their own history and certain old mosques still used as a royal mosque which has continued till today. Some of the historic building and monuments are still used as palaces and a place of worship or religious buildings; and some are preserved as a monumental heritage in such of statues and ruins [6].

Thermal performance of a building can be referred to as the process of modelling the heat transfer between the buildings and its surroundings. It calculates and estimates the indoor temperature variation, heating, cooling load and the duration of uncomfortable periods. Designing a building that responds to the natural environment can provide the desired level of comfort in the prevailing environment [3]. Health factors in sustainable building design are commonly associated with the comfort level. In architecture, comfort level can be achieved by application of passive design (e.g., natural lighting, natural ventilation and solar gain) and active design elements (e.g., renewable and energy saving gadgets). In contrast to active design, the passive design is sustainable to the environmental, social and cultural perspectives [1,5], which offers healthy condition, and the design does not depend on the mechanical system [10]. There are several criteria that support the sustainable design of heritage and modern mosque such as building orientation, natural ventilation, opening, building envelope, water element, and vegetation. Besides, building orientation is a significant design consideration, mainly with regard to solar radiation and wind flow through building envelope such as windows, building openings as well as external opaque walls and roofs.

The building envelope is the physical separator between the interior and exterior of a building [4]. Components of the envelope are typically: floors, walls, roofs, doors and fenestrations such as opening in the structure: windows, skylights, and clerestories. Envelope design on thermal performance is one of the most important components with respect to total heat gain of whole building and overall heat transfer coefficient which determines heat gain through the building envelope [2]. There are two types of parameters that strongly affect the thermal performance of a building, which is (i) climatic condition (i.e. solar radiation, cloud layer, ambient temperature, wind speed and relative humidity); and (ii) the design features (i.e. geometrical dimensions of building envelope, orientation, opening, shading devices and building material properties [8,9]. Local climate greatly affects the indoor thermal environment in buildings. In tropical climates, buildings are overheated during the day due to solar heat gain through the building envelope and solar penetration through windows [12].

3. Methodology

Three mosques were selected to be used as the case study. These mosques were located in Selangor and the locations are quite near to each other. The primary data on the actual sites were collected and recorded, while the secondary data will be used as supporting documents. The combination of both data sets can validate and ensure the accuracy of the results. The data are as follows:

3.1. Weather data.

Weather data will be used to validate the recorded data. This are obtained from the nearest Meteorology Department. The data includes temperature, relative humidity, wind speed and cloud covers in a same day of collected primary data. The nearby Meteorology Department involved are Subang Airport and Mardi Klang Stations.

3.2. Building construction plan

The Public Works Department provides building plan for the new mosque, and National Heritage Department, Kuala Lumpur provides a documented measured drawings of heritage mosques. The working and detail drawings of each mosque are used to understand the physical character of building in the beginning stage of the study. The study involved basic information on architecture, design, construction, material and any related factors or aspects of heritage and new mosques. The focus of studies are on the floor plan and all angle of building envelopes. Roof, walls and openings and material are the most critical parts to understand and study details. The floor plan of the prayer hall is studied to support the weather data recorded and on site and building observations.

3.3. Experimental survey

The experimental survey conducted in interior and exterior of the buildings are recorded a quantitative data that involve with the numbers, amounts, or quantities, of all variables. The experimental data are measured and recorded by equipment as shown in Figure 1. The recorded and measured data are the temperature, relative humidity and wind velocity. The main users use the space in the mosques as early as 5.00 am and their activities will finish at 10.00pm. As the state of art of the case study, hence the data collection exercise was conducted with a very careful consideration, because this is a noble and holy place for Muslim to do their prayers five times a day. The weather data are collected as early as 08.00 am till 19.00 pm in 30 minutes time interval. Four stations and checkpoints have been set for data recording and the focus area are in the exterior and interior of the main prayer halls of the mosques.

Figure 1. Tsi velocicals (left), and anemometer (right)

3.4. Observation

The in-situ observation is very important to collect the primary data in the real situation on site. The observation takes place at the physical building and their surroundings. The data need to collect by observation are building construction and building envelope elements, The other data is building orientation, material use and surrounding site elements and neighbourhood or site context of the study area. The comparison data from two categories of mosques are more specific and easy to analyse as well as to finalize the data findings. The primary data collection on site are illustrated and measured in detail along with floor plan, section and elevation drawings, supported by photographs and documented as a result of the study.

3.5. Analysis
All secondary and primary data were gathered using quantitative and qualitative analysis. The quantitative data from the experimental method are tested and analysed using Origin 8 software. The primary idea of the data analysis is to examine the differences of the interior thermal performance of each mosque. Origin 8 software can help to produce results in form of interactive scientific tabling and graphing. The results are formed in technical numbers, validated with the existing data and will be compared accurately for each mosque. While the data collected from observation/qualitative are set up and inventoried in tables to clarify the building criteria and it surrounding which influenced by the size, orientation, design and architecture of the building envelope of the mosques, and similarly, can influence its interior thermal performance. Both quantitative and qualitative results are analysed and supported by specific photographs and drawings.

4. Results and discussion
The selected mosques located in Klang, Port Klang and Shah Alam respectively. One of the mosque is 85 years old and this building is gazetted as National Heritage. The two new mosques age ranges are between 10 and 20 years old. The architecture of all mosques adopted few aspects of sustainable design in tropical climates such as a general building direction toward north and south, applied passive lighting and ventilation system by designing suitable type of openings in it building envelope; walls and roof. These green design aspects potentially can affect the interior thermal quality of the buildings. The architecture style and design of the building envelopes and interior spaces of each mosque is varied but the size and volume of interior of worship halls are relatively the same. The worship hall is a primary space of the mosque was used to evaluate its indoor thermal performance.

4.1 Mosque buildings and spaces
The Royal Mosque of Sultan Suleiman was built on 1932, categorised as historical building. This mosque was designed by Leofric Kesteven, a British architect. On Friday, the Sultan of Selangor always visits this mosque for Friday prayer. The management office and the mosque areas are administered by Islamic Religious Department of Selangor (JAIS), while for daily social activities was conducted by mosque committee members. The hall of this mosque can hold more than 1000 congregation at a time of prayer. The Al-Munawarah mosque is a two-storey mosque that was built on 1998. This building signifies the strength and dignity of Islam as official religion to the local residents of Section 27, Shah Alam. The prayer hall is huge, it can accommodate 3900 people at one prayer time. Total site area is almost 6-acre. Other facilities provided; conference rooms, committee members' rooms, etc. The second new mosque, Kg. Raja Uda mosque was built on 2007, located at 3.8 acres site. The size of the worship hall is medium, can hold 3500 people at one prayer time. Other facilities provided around and near this mosque are a public multipurpose hall, meeting rooms, and rooms for committee members.


Figure 2. Three mosques as case study models; Royal Mosque of Sultan Suleiman (above left), Al-Munawarah (above right), and Kampung Raja Uda (below)

4.2. Mosque construction and materials

The construction styles and materials used in all mosques were marginally diverse. The heritage mosque was built during British administration in Malaya in 1932 was influenced by Western Art Deco and Neoclassical cathedral style architecture. The floor plan of the mosque is designed with a simple geometric Islamic calligraphy in a proportion symmetry shape. The roof of the mosque is decorated by a semicircle dome fixed at the top of the worship hall to provide a high volume space, the design of the mosque is reinforced with the pillars, while small domes are added as classical symbols for the mosque buildings. The new mosque's design practised current style of architecture in Malaysia, modern contemporary style. The royal Mosque of Sultan Sulaiman and Al-Munawarah Mosques built in two-storey, while Kg. Raja Uda is a single storey mosque. The primary structures and foundations, and walls material and construction of all mosques were similar, used reinforced concrete and bricks, but different applied roof construction and materials. The heritage mosque covers it roof by concrete material and dome while new mosques used metal decking as roof covers.

4.3. Mosque orientation and passive ventilation

In a tropical climate, building position on site is the essential criteria for reaching a comfort level in interior spaces. The location of the mosque is referred to the location of the sun path and the direction of the wind. In this case study, the orientation of the three mosques was similar to each other in the direction of the Qibla and for having a square plan for prayer halls. The Royal Mosque of Sultan Suleiman neighbourhood contexts are the main roads, open areas, and Alam Shah Palace. Adjacent to the east side facing the open areas (a garden and a parking lot) recorded moderate increase from the morning and achieved the highest wind speed of approximately 7.1m/s at 17.00 hours and the north side facing the new building. Al Munawarah mosque is closed to a housing area at Section 27. The general wind speed adjacent to the south of an open area reached the highest level at the average of 7.7–10.2m/s in the morning and gradually fell in fluctuating patterns from noon until evening. On average, wind speed around the Kg Raja Uda Mosque was approximately 0-4.2m/s for south direction all day, while on the east side, the mosque recorded the wind pattern reaching the lowest speed of approximately 1m/s at 19.30 hours.

4.4. Mosque envelope

The heritage mosque and new mosques of Kg. Raja Uda has almost similar areas of building envelope; walls areas are around 915m^2, roofs cover areas are about 2135m^2 and 750m^2 base floor areas. During mid-day, the heritage mosque received high temperatures adjacent to the worship walls. The high temperature contributed by dome roof cover located above the worship hall. This is because it was decorated with stained glass and decorative grilles which allow direct solar radiation. Glass windows on the wall allow direct sunlight penetration and potentially raise the interior temperature. Therefore, the worship hall in the heritage mosque increases its temperature during mid-day in the range of 1.5–1.8°C. This temperature is higher compared to the interior space of new mosques. Solar reflectance from light colour walls or roofs for all mosques contributed to reducing gain entering the worship hall in the mosque. All wall used light-coloured paint and different colours for roof-covering. Interior ceiling heights are between 9 and 10 metres, this high volume of interior spaces can help to maintain a low temperature.

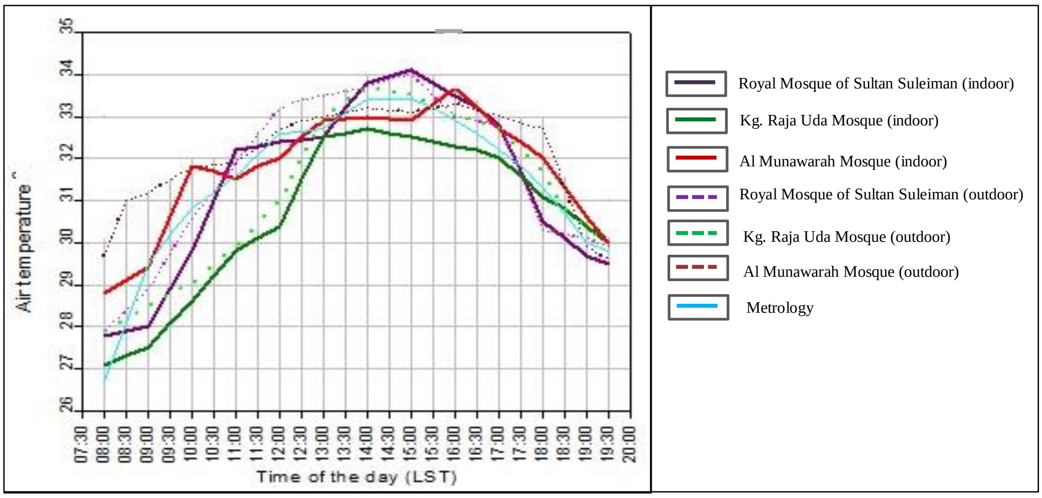

Figure 3. Temperature adjacent to the South wall of the three mosques.

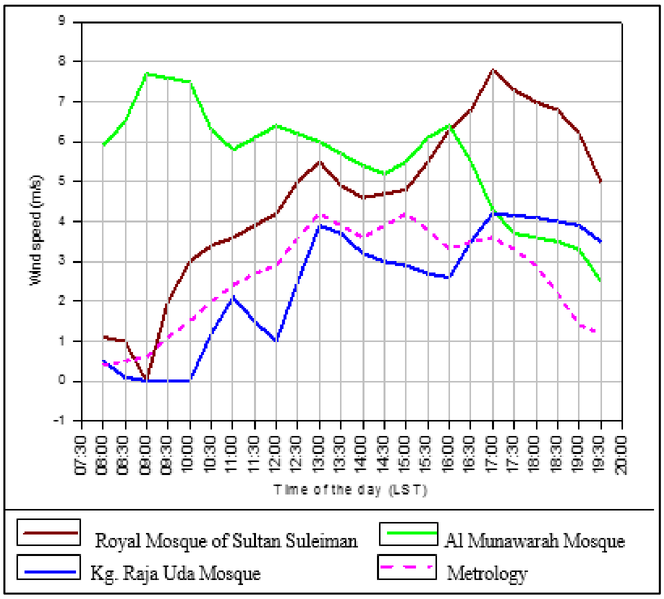

Figure 4. Wind speed adjacent to the South wall of the three mosques.

4.5. Glass and another opening

Each mosque practice passive lighting systems during daytime, and natural ventilation all the time. Opening systems located in building envelopes such as doors, windows, art ornaments, top hung windows, and roof and floor openings are widely applied to encourage cross ventilation and stack effect in interior spaces of the mosque. Cool air from the exterior will circulate and replacing the hot temperature inside the mosque especially in the prayer hall. Each mosque also has different total areas of openings, include glasses, and doors. The first of new mosque, Al Munawarah has the most number of glass surface areas in the building envelope. Oppositely, Kg. Raja Uda as a second new mosque category has the least total of glass surface areas. While heritage mosque has medium areas of glass surfaces which primarily located in all wall sides at the first level of the mosque. The other openings such as doors and art ornaments are in the all walls angle located at the lower level except the west.

Ornament openings with Islamic calligraphy designs also can encourage passive ventilation in heritage mosque. The surrounding areas such as open space or garden may allow wind flow and circulate around building envelope. Balcony in upper level can act as shading device to cover the glass window surfaces from the penetrating of solar radiation during mid-day.

5. Conclusion

The method of the study briefly clarified the approach taken in primary data collection and analysing the interior thermal performance of two categories of mosque buildings; heritage and new mosques. The thermal data were recorded, tested and listed using technical equipment. Both categories of mosques have similar technology in construction and building orientation towards in the direction of the Qibla. However, both categories of mosques have different ages, building materials, total glass areas, and numbers for openings (ornaments). Two stages of collecting primary data; observation and experimental were gathered and analysed accurately. Finally, this study summarised that the heritage mosque has practised and applied the green aspects in design but the surrounding climate of hot and humid together with urban heat island effects produces high interior temperature as much as 1.8°C. State Islamic Department should collaborate with National Heritage Department for the better green design practice in order to achieve good thermal comfort quality in interior spaces of heritage mosque.

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