Jurnal Kejuruteraan 35(3) 2023: 693-698
https://doi.org/10.17576/jkukm-2023-35(3)-17

Green Architecture Approach Toward Sustainable Mosques in Malaysia

Muhammad Azzam Ismail[a] & Fahanim Abdul Rashid[b]

[a]*Department of Architecture, Faculty of Built Environment, Universiti Malaya, Malaysia*
[b]*Department of Civil Engineering, Politeknik Port Dickson, Malaysia*

**Corresponding authors: ma.ismail@um.edu.my; fahanim@polipd.edu.my*

Received 5 August 2022, Received in revised form 2 November 2022
Accepted 3 December 2022, Available online 30 May 2023

ABSTRACT

Rising thermal comfort expectations during worship at mosques in Malaysia have led to increasingly high carbon emissions due to electricity consumption for cooling. An increasing number of existing mosques in urban and affluent areas are retrofitted with extensive air-conditioning systems. In addition, new mosques are designed with active rather than passive cooling techniques. At the same time, although widely promoted in Islam, sustainable ways of living, including water and resource conservation, equitable physical and knowledge access, and community bonding, are not being actively promoted and practiced by the mosques communities. Therefore, this paper presents a descriptive study of the Green Building Index certified Raja Fi Sabilillah Mosque in Cyberjaya, Malaysia. This study aims to uncover practical green and sustainable architecture elements that could be implemented at other mosques. This study observed a high amount of renewable energy generated at this large mosque. Further, energy is conserved by using passive cooling, natural daylighting, and LED indoor lighting. Other installed features are water-saving taps, wheelchair access, and a disabled ablution booth. Overall, this case study points toward a sustainable mosque through a green architecture approach that could be widely implemented for the betterment of the Ummah.

Keywords: Green architecture; sustainable mosques; passive cooling; renewable energy

INTRODUCTION

Mosques are important religious buildings that gathers large congregations and host periodic events of all sizes. The mosques usage pattern is predictable according to the five main prayers per day and the amount of worshippers increases and reduces between these prayers (Alquthami & Alaraishy 2021). Once a week, the mosque would be fully occupied during the midday Friday prayer and other religious and community events are held in between prayers. This unique occupancy pattern presents a challenge in ensuring thermal comfort among the worshippers as the outdoor weather changes throughout the year even in Tropical Malaysia. Positively, the sun path and angle over Malaysia is relatively constant with little variation throughout the year (Azmi & Kandar 2019; Mohammed & Ahmad 2012), making it convenient to protect buildings from the harsh daylight and heat. The distinctive monsoonal weather and wind direction changes also affords predictable façade and fenestration protection from the elements as mosques in Malaysia all are orientated towards the *Qiblah* in Makkah at 292.54^{o} according to the true north ("Kuala Lumpur Qibla Direction | Qibla Finder," n.d.). Therefore, using the green architecture approach especially natural ventilation and daylighting for thermal and visual comfort in mosques should be emphasized. However, increasingly, many mosques in Malaysia are being retrofitted with central air-conditioning irrespective of their large floor space (Hussin, Haw, & Salleh, 2018), without ensuring the air-tightness of their building envelopes for energy-efficiency. Current mosque air-conditioning practices are wasteful and must be rectified, as Islam forbids wastefulness. Past Malaysian research studied mosque energy consumption due to air-conditioning such as by Mohamed et al. (2021) which suggested ways to improve energy-efficiency while maintaining thermal comfort. This situation is consistent with other parts of the world, as studied by Alquthami and Alaraishy (2021) in Saudi Arabia, and Suhono et al. (2020) in Indonesia.

RESEARCH METHODOLOGY

This qualitative study was conducted through a comprehensive literature review and a case study. Documents concerning the selected case study were analysed and mosque itself was observed in detail from an architectural design perspective. Besides observing the case study through photography and sketching, the researcher experienced first-hand the indoor environmental condition of the selected case study, appraised the passive cooling and other passive solar design features, and made notes. All-in-all, this study is explorative and was conducted using a first-person account. Thermal comfort perception survey, indoor environmental, and energy use measurements are beyond the scope of this study.

FINDINGS

FIGURE 1. *Raja Fi Sabilillah* mosque, Cyberjaya.
Source: Author

The 94,500 square feet *Raja Fi-Sabilillah* mosque in Cyberjaya was designed as a low energy building with various design features that promote natural ventilation and natural lighting. This mosque is a certified green building by the Green Building Index (GBI) and can accommodate up to 8,300 worshippers. It has large openings which are protected by decorative yet permeable glass reinforced concrete (GRC) on the perimeter of the mosque (A. Aziz 2016a; Gunawan & Satwikasari 2021). These prominent screens not only protect the worshippers from the harsh daylight and driving rains, they also project decorative Islamic motifs onto the floors and walls according to the path of daylight throughout the day. The attractive decorative shadows enhance the religious feeling and ambience within the mosque. The high mosque façade shades the adjacent pools of water and landscaping, promoting intake air heat loss before entering the mosque. The shaded mosque surrounds also provide a calming effect for the worshippers, making them focus towards worship activities within the mosque. The façade is largely white in colour to reflect heat while the large flat roof over the terrace is covered with green artificial turf (A. Aziz, 2016a) which helps to reduce the urban heat island effect in the vicinity of the mosque. Originally, the whole artificial turfed area is to be sheltered by a large monocrystalline photovoltaic (PV) solar system to generate renewable energy. However, from observation, only approximately 25% of the planned 740 PV panels was installed (A. Aziz 2016a, 2016b). Nonetheless, the installed capacity greatly reduces the mosque's dependency on electricity from the grid.

FIGURE 2. Daylighting at *Raja Fi Sabilillah* mosque, Cyberjaya.
Source: Author

Capping the main prayer hall is a majestic dome that is cladded with low emissivity (low-e) glass (A. Aziz 2016a; Gunawan & Satwikasari 2021) rather than the usual metal cladding. This bold move floods the main prayer hall with natural daylighting while restricting heat transfer through conduction. The low-e glazed dome helps in limiting the use of artificial lights during day time. Regardless, fitted artificial lights are low energy and reliable LED lights which are mostly used during night time. Near to the top of the glazed dome is a band of clerestory louvers to allow spent hot air out of the mosque through stack effect (Gunawan & Satwikasari 2021). Air movement within the main prayer hall is unrestricted as long as the large glazed sliding doors connecting to surrounding terraces and adjacent water pools are kept open. Cross ventilation in any part of this mosque is hypothetical given the depth of plan. Nevertheless, there is ample single-sided natural ventilation throughout the mosque. During Friday, Aidil Fitri and Aidil Adha payers, and special events the highly-efficient variable refrigerant volume (VRV) air-conditioning system is used sparingly to maintain thermal comfort for these large congregations (A. Aziz 2016a).

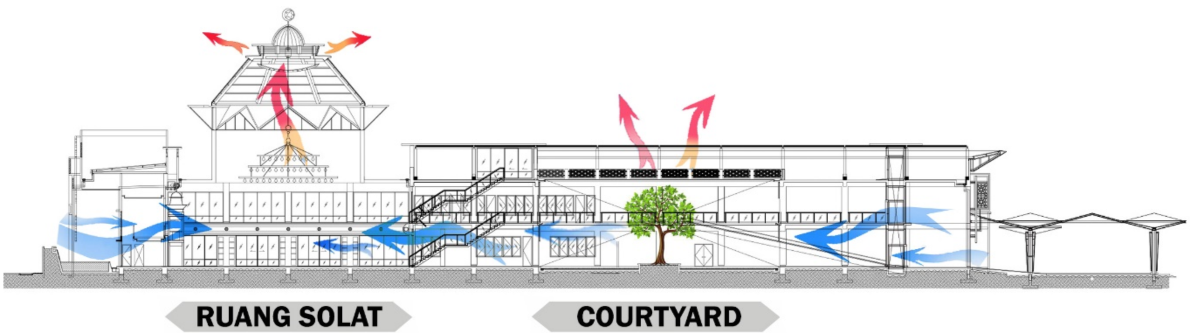

FIGURE 3. Natural ventilation strategy at the *Raja Fi Sabilillah* mosque.
Source: Adapted from (“Masjid Raja Haji Fi Sabilillah, Cyberjaya - Construction Plus Asia,” n.d.)

The green architecture approach at this mosque is complemented by prominent rainwater harvesting funnel roofs, surrounding the mosque front entrance. Harvested rainwater is used for irrigating the landscape and toilet flushing (A. Aziz 2016b). All ablution and toilet fittings are water-saving and limit water wastage. This mosque was constructed with fly-ash reinforced concrete thus, achieved a substantial reduction in the embodied carbon emission.

DISCUSSION

Based on the *Raja Fi Sabilillah* mosque case study, there are a number of steps that need to be taken to improve the existing thermal comfort condition and energy-efficiency of other mosques. Firstly, architects or designers should analyse the location, mosque orientation and effect of neighbouring buildings or landscape on the mosque. Climatic conditions differ between locations and highly contextual. Ambient outdoor temperature and relative humidity varies between urban and rural areas. The macro climate also changes with the elevation of the mosque location with higher wind speeds are observed at higher altitudes in Malaysia. Locations on lake shores and the coastline add an advantage in promoting natural ventilation. Subsequently, they should analyse the existing mosque design, particularly the roof and facades to determine the potential for energy saving thermal comfort measures. The large mosque roof is the main source of heat transfer as Malaysia has a very high exposure to the sun with a very high light insolation between 1,750 kW/m^2/year to 1,850 kW/m^2/year (Haris 2010). Malaysia's cloud formation is inconsistent with intermediate sky condition, allowing more heat penetration (Lim & Heng 2016). The daylight intensity is also very high at 110 k lx with more than 1,000 W/m^2 on clear days (Al-Obaidi, Ismail, & Abdul Rahman 2014)pigment technique (reflective and radiative.

Secondly, architects, engineers or designers should analyse the existing energy use pattern for an extended period to construct an energy usage model. This model is important at configuring responses either through energy management or mosque design enhancements through refurbishments. The consultants could enhance natural ventilation through large openings at low level, and openings at high level on all mosque sides (including the *mihrab* area) to extract spent hot air. The temperature of intake air could be reduced up to 2^{o}C by passing it over water in ponds surrounding the mosque (Tominaga, Sato, & Sadohara, 2015). These ponds should be shaded by projections off the mosque façade, mosque roof or even lush landscaping. Aziz et al. (2022) additionally promoted the use of lush greenery and landscaping to achieve the same result without increasing the humidity. Nonetheless, air passing through lush and shaded landscape and over water bodies would lose some heat before entering the mosque. This technique reduces heat convection into the mosque. Further, LED artificial lights can be decoratively designed as ornaments besides providing ample and desirable indoor lighting at night as demonstrated by Atilgan and Enarun (2018).

Thirdly, the consultants should look into dividing the large expanse of circulation, terrace, and ablution halls with courtyards, air wells and through to allow for natural ventilation as well as daylighting to penetrate through the deep mosque plans. Permeable façade poses less restriction to air movement in and out of the mosque. The façade and roof should be insulated either on the inner side or exterior to significantly reduce heat transmission through conduction as promoted by Brito Filho and Oliveira Santos (2014). They also promoted the use of radiant barrier such as aluminium foil in the roof or metallic roof outer surfaces to effectively reduce heat radiation. Large glazed openings on the façade and in the roof or mosque domes with clear float glass should be replaced with low-emissivity (low-e) glass, double-glazed glass, or clear glass windows with low emissivity to reduce power consumption by up to 4.2%, 3.7%, and 6.6% respectively as cited by Al-Obaidi et al. (2017). Double glazing gives an added advantage of better façade acoustical performance to restrict noise coming in and out of the mosque. They should also enhance the indoor air distribution through the use of high volume low speed (HVLS) fans (Mohamed et al. 2021) or regular ceiling and wall fans for personalized thermal comfort.

CONCLUSION

Many design features at the *Raja Fi Sabilillah* mosque such as permeable façade screens, large operable windows, surrounding terraces around the main prayer hall, and high level openings in the dome are present at many Malaysian mosques. However, each mosque need to be analysed using the three steps discussed above for design weaknesses that lead to poor natural ventilation and daylighting. Refurbishments are needed to improve the situation and reduce carbon emission from energy use.

Besides the passive cooling and other passive solar design approaches, consultants should consider novel technologies to reduce energy use in mosques. These novel technologies are:

1. IoT indoor thermal control (Harsritanto, Nugroho, Dewanta, & Prabowo 2021).
2. Building integrated photovoltaic (BIPV) system (Alquthami & Alaraishy 2021; Elshurafa, Alsubaie, Alabduljabbar, & Al-Hsaien 2019; Haseeb, Al-bayaty, & Abdulkarim 2021; Ibrahim, Ali, & Alqarra 2020).
3. Heat reflecting façade (Ahriz et al. 2021).
4. Green roof installation to regulate heat transfer through the large flat reinforced concrete roof (Rahmat et al. 2018).
5. Heat reflecting paint to reduce heat conduction and radiation through the roof, including existing domes (Nordin & Misni, 2017).

These technologies do consume some energy, but definitely much lower than fully air-conditioning the main prayer halls as implemented at many mosques in Malaysia.

They also ensure thermal comfort among worshippers, and cost-effective mosque maintenance thus, more funds can be allocated for religious and community programs that would strengthen societal spirit and togetherness. In summary, through careful design and planning, the approaches at the *Raja Fi Sabilillah* mosque and the novel technologies mentioned above can be replicated to other mosques in Malaysia for the betterment of the *Ummah*.

Further to this study, a thermal comfort perception, indoor environmental, and energy use measurement study should be conducted to substantiate the *Raja Fi Sabilillah* mosque passive solar design performance and energy efficiency.

ACKNOWLEDGEMENT

The authors would like to thank Universiti Malaya, Politeknik Port Dickson, Malaysia and the Raja Fi Sabilillah mosque management for supporting this research.

DECLARATION OF COMPETING INTEREST

None

REFERENCES

A. Aziz, A. 2016a. Execution of contemporary Islamic architecture through design: the Cyberjaya Green Platinum Mosque Project in Malaysia. *WIT Transactions on the Built Environment 159:* 11–22. DOI:https://doi.org/10.2495/iha160021.

A. Aziz, A. 2016b. Execution of contemporary islamic architecture through the design of the Cyberjaya Green Platinum Mosque Project in Malaysia. *International Seminar on Islam & Green Technology 2016 (i-Green 2016)*. International Institute of Advanced Islamic Studies (IAIS Malaysia).

Ahriz, A., Mesloub, A., Elkhayat, K., Alghaseb, M. A., Abdelhafez, M. H., & Ghosh, A. 2021. Development of a mosque design for a hot, dry climate based on a holistic bioclimatic vision. *Sustainability (Switzerland)13*(11): 1–22. DOI:https://doi.org/10.3390/su13116254.

Al-Obaidi, K. M., Ismail, M. A., Munaaim, M. A. C.& Abdul Rahman, A. M. 2017. Designing an integrated daylighting system for deep-plan spaces in Malaysian low-rise buildings. *Solar Energy 149*(2017):85–101. DOI:https://doi.org/10.1016/j.solener.2017.04.001.

Al-Obaidi, K. M., Ismail, M. & Abdul Rahman, A. M. 2014. Design and performance of a novel innovative roofing system for tropical landed houses. *Energy Conversion and Management 85:* 488–504. DOI:https://doi.org/10.1016/j.enconman.2014.05.101.

Alquthami, T. & Alaraishy, A. 2021. Comprehensive energy and cost evaluation through detailed Auditing and Modeling for Mosque in Saudi Arabia. *International Journal of Applied Engineering Research 16*(9): 778–792.

Aziz, N. S., Ismail, A. S. & Siraj, S. 2022. Responsive design approach towards the Sustainable Mosque Architecture. *IOP Conference Series: Earth and Environmental Science 1022*(1): 012001. DOI:https://doi.org/10.1088/1755-1315/1022/1/012001.

Azmi, N. A. & Kandar, M. Z. 2019. Factors contributing in the design of environmentally sustainable mosques. *Journal of Building Engineering 23*(January):27–37. DOI:https://doi.org/10.1016/j.jobe.2019.01.024.

Brito Filho, J. P. & Santos, T. V. O. 2014. Thermal analysis of roofs with thermal insulation layer and reflective coatings in subtropical and equatorial climate regions in Brazil. *Energy and Buildings 84:* 466–474. DOI:https://doi.org/10.1016/j.enbuild.2014.08.042.

Elshurafa, A. M., Alsubaie, A. M., Alabduljabbar, A. A. & Al-Hsaien, S. A. 2019. Solar PV on mosque rooftops: Results from a pilot study in Saudi Arabia. *Journal of Building Engineering*, *25*(January). DOI:https://doi.org/10.1016/j.jobe.2019.100809.

Erdem Atılgan, L. & Enarun, D. 2018. A case study of lighting Turkish historic mosques using LEDs: Semsi Ahmet Pasha Mosque. *Lighting Research and Technology 50*(6): 894–910. DOI:https://doi.org/10.1177/1477153517698853.

Gunawan, W. & Satwikasari, A. F. 2021. Konsep Arsitektur Surya Pasif pada Bangunan Masjid Raja Haji Fisabilillah di Malaysia. *Jurnal LINEARS 4*(1): 43–49.

Haris, A. 2010. Malaysia's Latest Solar PV Market Development. *Proceedings of Clean Energy Expo Asia*. Singapore.

Harsritanto, B. I. R., Nugroho, S., Dewanta, F. & Prabowo, A. R. 2021. Mosque design strategy for energy and water saving. *Open Engineering 11*(1): 723–733. DOI:https://doi.org/10.1515/eng-2021-0070.

Haseeb, Q. S., Al-bayaty, H. & Abdulkarim, A. H. 2021. Sustainable architecture compatible with renewable energy principles: A Mosque Building as a Case Study. *Periodicals of Engineering and Natural Sciences 9*(2):904–917. DOI:https://doi.org/10.21533/pen.v9i2.1944.

Hussin, A., Haw, L. C. & Salleh, E. 2018. Energy usage and energy saving potential of air conditioning Mosque in Penang Malaysia. *2nd Malaysia University-Industry Green Building Symposium* 69–74.

Ibrahim, A., Ali, H. H. & Alqarra, W. 2020. The effect of installed photovoltaic panels on the aesthetic perception and evaluation of the mosque architectural form in Jordan. *Open House International 45*(4): 449–463. DOI:https://doi.org/10.1108/OHI-07-2020-0085.

Kuala Lumpur Qibla Direction | Qibla Finder. (n.d.). Retrieved August 22, 2022, from https://www.kiblebulma.com/city/kuala-lumpur-qibla-direction.html

Lim, Y. W. & Heng, C. Y. S. 2016. Dynamic internal light shelf for tropical daylighting in high-rise office buildings. *Building and Environment 106:* 155–166. DOI:https://doi.org/10.1016/j.buildenv.2016.06.030.

Masjid Raja Haji Fi Sabilillah, Cyberjaya - Construction Plus Asia. (n.d.). Retrieved August 22, 2022, from https://www.constructionplusasia.com/my/masjid-raja-haji-fi-sabilillah-cyberjaya/.

Mohamed, N. A. S., Shari, Z., Dahlan, N. D. & Idowu, I. A. 2021. Architectural sustainability on the impacts of different air-conditioning operational profiles and temperature setpoints on energy consumption: Comparison between mosques with and without hvls fan in the city center mosques. *Journal of Design and Built Environment 21*(2):18–37. DOI:https://doi.org/10.22452/jdbe.vol21no2.3.

Mohammed, S. B. & Ahmad, S. H. 2012. The Study of air temperature when the sun path direction to Kaábah: with a case study of Al-Malik Khalid Mosque, Malaysia. *International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies 56*(August): 1–18.

Nordin, N. I. & Misni, A. 2017. A comparative study on the Indoor Thermal Performance of New and Old Mosques. *Environment-Behaviour Proceedings Journal 2*(5):23. DOI:https://doi.org/10.21834/e-bpj.v2i5.677.

Rahmat, M. H., Mohkatar, M. H., Abd Wahab, I., Abd Salam, N. N., Abdul Aziz, H. & Abas, N. H. 2018. Assessing the efficiency of green roof technology: A case study of Masjid Kota Iskandar, Nusajaya, Johor. *MATEC Web of Conferences*, *250*. DOI:https://doi.org/10.1051/matecconf/201825006011.

Suhono, Athaya, A. D., Anwari, L. H., Sinaga, F. D. H., Hadaina, S. F. & Novantri, S. O. 2020. Analysis of energy usage in mosques in urban area with tropical climate: Case study in Yogyakarta, Indonesia. *IOP Conference Series: Earth and Environmental Science 599*(1). DOI:https://doi.org/10.1088/1755-1315/599/1/012091.

Tominaga, Y., Sato, Y. & Sadohara, S. 2015. CFD simulations of the effect of evaporative cooling from water bodies in a micro-scale urban environment: Validation and application studies. *Sustainable Cities and Society 19:* 259–270. DOI:https://doi.org/10.1016/j.scs.2015.03.011.