Malaysian Journal of Sustainable Environment
Vol.11.No.1 (2024) 109-126
doi: 10.24191/myse.v11i1.990

SUSTAINABLE MOSQUE DESIGN WITH GREEN ARCHITECTURAL APPROACH: A CASE STUDY OF AL-FURQAN MOSQUE IN BANDA ACEH, INDONESIA

Syahrul Aini[1], Cut Nursaniah[2]*, Irin Caisarina[3] & Abdul Munir[4]
***Corresponding Author**
[1]Master of Architecture Study program, Universitas Syiah Kuala, Banda Aceh, Indonesia
[2,3,4]Architecture and Planning Department, Engineering Faculty, Universitas Syiah Kuala, Banda Aceh, Indonesia

syahrul640@gmail.com, cutnursaniah@usk.ac.id, irincaisarina@usk.ac.id, munirsyadi@usk.ac.id
Received: 04 October 2023
Accepted: 23 November 2023
Published: 31 March 2024

ABSTRACT

The trend of covering intricate ventilation with glass material has caused modern mosques in Banda Aceh to increase carbon emissions, due to electricity consumption for cooling. The current phenomenon is that new mosques are designed with active rather than passive cooling techniques. At the same time, despite being widely promoted within Islam, a sustainable way of life, including water and resource conservation, equitable physical and knowledge access, and community bonding, is not actively promoted and practised by the mosque community. Therefore, this paper conducts a descriptive study on the Al-Furqan Mosque in Banda Aceh, regarding the application of green architectural principles based on Greenship Indonesia. This study aims to reveal the extent to which green and sustainable architectural elements that focus on energy efficiency and conservation have been implemented. This study observed the high amount of renewable energy produced by mosques. Furthermore, energy is saved by using passive cooling and natural lighting. Overall, this case study requires improvements to the design and landscape that lead to a sustainable mosque through an environmentally friendly architectural approach. Even though the design has tried to adapt, it is not optimal.

Keywords: *Green architecture, Sustainable mosque, Passive cooling, Renewable energy*

INTRODUCTION

A mosque is a place of worship for Muslims that accommodates many congregations and holds regular prayer activities. Mosque usage patterns can be predicted based on five prayers per day and the number of worshipers increases and decreases between these prayers (Alquthami & Alaraishy 2021). Once a week, the mosque will be filled to its full capacity during Friday prayers and other religious events, as well as other community gatherings in between prayer times.

Generally, mosque designs have similarities in space requirements, even though they have differences in climate. The design of mosques varies by region due to cultural and geographical factors. However, mosques are generally designed as simple rectangles aligned towards the Qibla (Atmaca, 2019). The humid tropical climate which has two seasons presents challenges in adapting and obtaining thermal comfort when the congregation worships. In hot-humid tropical climate conditions, generally, thermal comfort with natural ventilation systems becomes difficult to obtain. This is because the window openings facing each other are quite far apart, so the airflow in the room is uneven, resulting in turbulence in the closed parts of the walls (Indrayadi, 2011). Apart from that, the orientation factor of the mosque which faces west causes the arrangement of the shafts to be almost parallel to the wind direction from the southwest so that it does not have a big influence on the prevailing wind pattern and speed (Syamsiah & Izzati, 2021). However, this also makes it easier to protect the building from the sun and heat, as the typical monsoon winds and changes in wind direction also provide predictable facade and fenestration protection to the mosque's relatively large space.

A part from climate, openings and material factors, the environment around the courtyard of the mosque will also affect wind movement (Prasetia & Nugrahaini, 2020). The wide yard of the mosque is not necessarily able to provide smooth airflow and a comfortable temperature. In addition, the ground cover material in the form of paving blocks in the surrounding area which is densely filled with buildings creates an air temperature of 25-35 oC (degrees celsius), as well as paving block materials made from a type of cement and buildings around the mosque's courtyard increase the increase in environmental temperature (Satwiko, 2009). Lack of public awareness regarding the benefits of green buildings, financial assistance or government incentives for green building projects, and knowledge about green buildings, are important factors hindering the development of green buildings in Malaysia (Roslee et al., 2022).

Therefore, a green architectural approach, especially natural ventilation and natural lighting for thermal and visual comfort in mosques need to be emphasized. Currently, more and more mosques in Banda Aceh, Indonesia are using central mechanical air conditioning, even though the mosque's room volume is quite large. The current practice of using air conditioners in mosques is a waste and must be corrected because Islam prohibits wastage. Previous research studied mosque energy consumption due to air conditioning, such as that done by Mohamed Kamar et al. (2019) and suggests how to increase energy efficiency while obtaining thermal comfort by using exhaust fans. 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. According to Abdou et al. (2005), the mechanical air conditioning system is the system that uses the most energy in mosque buildings. Energy consumption for air cooling in mosque buildings reaches 73% of the total energy (Budaiwi et al., 2012). One of the causes of high energy use is the influence of the facade envelope design. According to Atmaca (2021) 75% transparent ratio (glass material) of the building envelope causes mechanical system cooling energy consumption to be 13% more, thus requiring a large capacity electrical energy load. One of the right solutions is a passive method that can reduce energy consumption in buildings. Alternative strategies for ventilation methods are needed to provide a satisfactory level of thermal comfort in buildings with large areas such as inside mosques (Chow et al., 2002). Passive strategies for natural ventilation can increase thermal comfort by 40% during the day and 80% at night (Azmi & Ibrahim, 2020). Natural ventilation uses natural forces originating from nearby air currents to push and move air through certain openings such as doors and windows (Elzaidabi, 2009).

LITERATURE REVIEW

Envelope of the Mosque Building

The building envelope is an important role that connects humans with the built environment and the external environment (Askari & Dola, 2009), (Ghaffarian, 2012) and (Johnsen et al., 2015). Thus, the design of the mosque envelope must be functional and refer to representative religious buildings built by Muslims who live mainly in urban areas, even in western countries mosques are often described as Islamic centers, where Muslims gather to engage in congregational worship activities, prayer, weddings, education, and other important activities such as social and cultural (Kahera et al., 2009).

According to Abdel-Aziz and Shuqair (2014), one of the factors that influence facade design is responsive environmental parameters, including orientation, window openings, vertical and horizontal shading devices, type of material and color. To optimize internal comfort conditions while reducing electrical energy requirements, a climate-responsive modification concept that adopts a passive design needs to be implemented. Liping and Hien (2006) agree that the impact of building envelope design is significant on the indoor thermal environment, especially for naturally ventilated buildings.

Generally, materials for mosque envelopes are made from various types of materials such as ferrocement, concrete and Glass Reinforced Concrete and increasing the thickness of the thermal insulation material on building envelopes can contribute positively to energy savings (Atmaca, 2021). Another factor that influences the heat rate process in the building envelope is the dimensions of the building where a smaller building will speed up the heat rate, while a wider building will heat up at a slower rate and cool down more slowly.

Building Cooling Energy in a Tropical Climate

Based on data from the World Green Building Council, it is known that buildings consume 40-50% of energy for construction and operation. According to Karyono (2007), the largest percentage of energy use in buildings is in the operational sector, which is specifically used for heating, cooling and lighting buildings. AC mechanical conditioning systems consume energy between 40% - 70% of the total energy consumption of a building. So mathematically, achieving thermal comfort in buildings consumes 15 to 35% of the total energy sourced from petroleum in a country.

Energy Efficiency in Mosque Building

One design method that is suitable for energy efficiency in mosques in tropical climates is to use a passive design strategy that can reduce the average indoor temperature by 4-6 °C by designing the wall cladding properly (Azmi & Ibrahim, 2020). Furthermore, to improve the thermal performance of buildings, namely by paying attention to the overall performance of all parts of the building envelope starting from walls, roofs, windows and openings that work together and produce a system that is synergistic between elements (Al-Homoud, 2009). Determining a good enclosure design to maximize energy efficiency depends on many specific factors, such as building location, orientation, size, operations, building envelope, electricity, and air conditioning systems. Besides that, the application of building retrofit is also very important to reduce energy consumption.

The design of building openings in the direction of wind incoming and outgoing wind is very important to adapt to a humid tropical climate. The openings will play a role in moving air inside the building, resulting in a change of air from hot to cold and reducing the accumulation of humidity in the room. Ventilation holes should be placed/oriented to face the direction where the main wind direction is towards the building. The larger the size of the ventilation holes and the more there are, the greater the level of ventilation that occurs in the room. The dimensional ratio between inlet and outlet will greatly influence the ventilation process (Mediastika, 2003).

Architecture and Lanscape Elements

The orientation of the mosque building towards East and West cannot be avoided, so free views through windows on this side must be avoided because heat radiation that directly enters the building (through openings/glass) will heat the space and increase the indoor air temperature. Apart from that, the glare effect that appears when the sun's angle is low is also very disturbing. The following are architectural elements that are often used as solar shading devices.

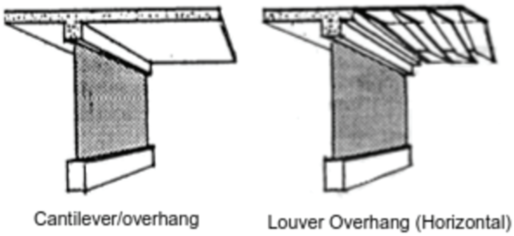

Figure 1. Effective Elements are Used in Building Areas Facing North–South

Source: Egan, (1975)

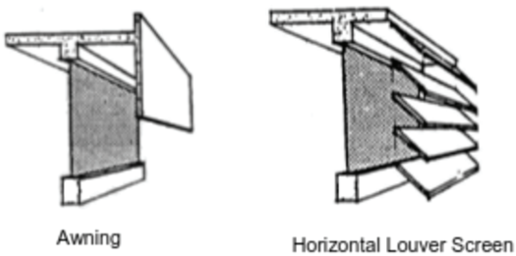

Figure 2. Elements that are Effective for Use on Building Areas Facing East-West (also reduce the glare effect when the sun angle is low)

Source: Egan, (1975)

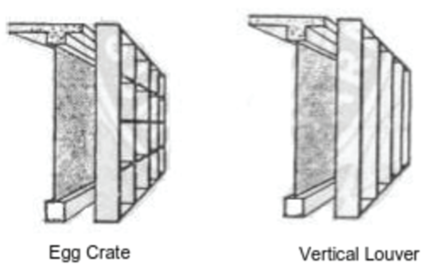

Figure 3. The Most Effective Elements are Used in Building Areas Facing East-West, Function as a 'Windbreak'

Source: Egan, (1975)

Landscape elements such as trees and vegetation can also be used as protection against solar radiation. The presence of trees will directly/indirectly reduce the surrounding air temperature because solar radiation will be absorbed by the leaves for photosynthesis and evaporation. The shading effect by vegetation will prevent heating of the building surface and the ground beneath it.

Trees and plants can be used to regulate airflow into buildings. Inappropriate placement of trees and plants can eliminate the desired cool air, especially during peak heat periods. The proximity of trees to buildings affects natural ventilation in buildings (Egan, 1975).

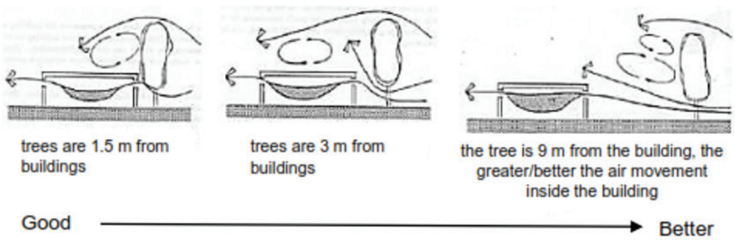

Figure 4. Tree Spacing

Source: Egan, (1975)

METHODOLOGY

The researcher experienced first-hand the indoor environmental conditions of the selected case studies, assessed passive cooling and other passive solar design features, and took notes. Overall, this research is exploratory in nature and was conducted using primary data, namely measuring air temperature, humidity, and airflow velocity inside the mosque. Field observations were carried out with a focus on ventilation shape patterns, dimensions, thickness and facade openings.

Measurements were taken at several points in the mosque with a tripod height of 1.2 m above the floor. The number of measurement points is divided by 5 points based on the interior, central, left-right and rear zones, for the exterior, namely the north, south and east sides. Measurements were carried out at 9.00–17.00 WIB. The measurement time zoning is divided into 3 times, namely starting from morning dhuha time at 9:00-11:00, midday noon time at 12:00-13:00, and evening prayer time at 15:00-17:00. For field measurement data processing, it is displayed in the form of a graphic curve using Excel software, then analyzed at the points that have been measured.

Figure 5. Field Measurements

Source: Authors, (2023)

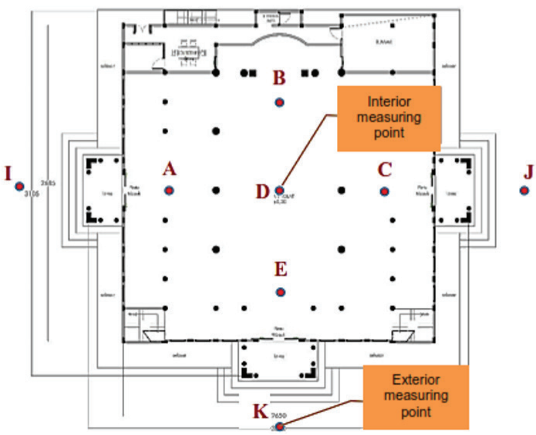

Figure 6. Position of Measurement Points

Source: Authors, (2023)

Object Description

The Al-Furqan Mosque is in the middle of a densely populated residential area, an old village in the middle of the city of Banda Aceh. The roof and walls are white with reinforced concrete and bricks 15 centimeters thick. The material and color cause this building to quickly absorb heat and quickly release heat again. There are various design elements that support the natural ventilation and natural lighting system in this mosque, namely on the facade on the right, left and face of the mosque there are intricate type ornaments called krawangan which also function as ventilation.

Figure 7. Al-Furqan Mosque

Source: Authors, (2023)

The wide intricate areas and doors on three sides of the building are protected by awning-type reinforced concrete designs, thus effectively avoiding glare at low sun angles. The prominent canopy not only protects worshipers from scorching heat and heavy rain but also features Islamic decorative motifs on the floor and walls that match the path of sunlight throughout the day. However, it is more effective if a cantilever or overhang-type canopy is placed on the North and South sides, so it doesn't have to be uniform. The attractive decorative shading enhances the religious feeling and atmosphere inside the mosque. The facade is mostly white to reflect heat. The mosque has large openings protected by decorative permeable reinforced concrete canopies around the mosque.

Figure 8. Daylighting at Al-Furqan Mosque

Source: Authors, (2023)

The design of the Al-Furqan mosque is characterized by a square shape and the application of intricate or krawangan to its facade as an ornament which also functions as a natural ventilation vent. The dimensions of the mosque are square with a length of 32 meters, a width of 31 meters and a height of 20 meters. The total area of the first and second floors is 1043 square meters. Congregational prayer rooms are on the first and second floors with a full capacity of 1434 worshipers. The side walls of the first-floor face north and south, on each side, there is one door and six windows on each side of the side and back walls, and on the second floor on the east, north and south sides there are six windows. The dimensions of each door are 2,65 meters x 3,00 meters. Apart from that, the prayer room is also equipped with 8 wall fan units, 5 standing fan units and 40 ceiling fan units. However, at the time of measurement, all types of fans were not turned on.

At the time of data collection, the wind was flowing from the southwest to the northeast. The environmental conditions of the site also allow the wind to descend and enter the mosque building, because on the site there are no elements or large trees that are very close to the mosque walls. The location of the doors opens in the direction of the wind, namely on the North, South and East facades, thus allowing air movement to enter the room at that time. The occurrence of airflow in the room is very important to achieve thermal comfort in the mosque.

Data results from measurements at the Al-Furqan mosque for one week at several points from interior to exterior with a measuring duration of 3 minutes/each point, and the average temperature value measured was 31.6 degrees celsius indoors, while outside The average room temperature is 33 degrees celsius. Based on the measurement data when compared with the Indonesian national standard, the temperature value is certainly not included in the standard effective temperature category, whereas according to SNI 03-6572 2001, the effective temperature in a room in the warm-comfortable category is 25,8 to 27,1 degrees celsius. Most designers often ignore basic requirements in building design, especially in selecting construction materials that are not suitable for the local climate. Buildings always receive a lot of heat because the wall surface construction does not use environmentally friendly materials that are able to absorb heat during the day (Halim et al., 2022).

Effect of Facade Openings on Indoor Airflow

The graph in Figure 9 shows that the influence of the design of openings in the facade envelope can reduce the airflow velocity in the room. The average value of indoor measurement results is 0,15 meters/second, while the measurement results at certain points as in (A, E) the average airflow speed is 0,28 meters/second. This is due to the influence of door openings on the side of the building so that the airflow rate becomes better. Meanwhile, the measurement data on the exterior looks very different. At measurement points such as (I, J, K) it produces an average speed of 0,62 meters/second, even at certain points it can reach a maximum speed of 2,08 meters/second. This condition can increase the rate of airflow into the room, thereby reducing the temperature inside the mosque.

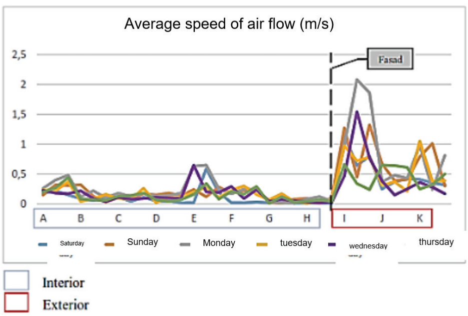

Figure 9. Air Flow Measurement Chart

Source: Authors, (2023)

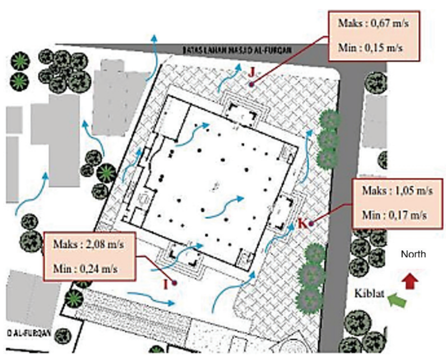

Figure 10. Wind Speed on Mosque Exterior

Source: Authors, (2023)

The occurrence of airflow in the room is very important to achieve thermal comfort in the mosque. Based on the high wind speed outside the building, it is very supportive for the wind to be channeled into the mosque room with a good cross ventilation system design so that a wind speed of 0,25-0,5 meters/second will be obtained and optimal comfort according to SNI with a temperature of 22,8-25,8 degrees celsius.

Cross ventilation appears to have been implemented because it is the most important factor for comfort in the congregational prayer room. The type of ventilation in the form of intricate ornaments, position and openings of doors and windows on the top and bottom sides of the Al-Furqan mosque should be able to increase the cross ventilation effect. However, the ventilation area of the intricate ornaments can be increased, in order to obtain a faster air flow rate in the interior.

The environment around the mosque also influences the rate of airflow entering the building. The Al-Furqan Mosque is located in a densely populated residential area, so it can cause turbulence around the building which contains the movement of air flows whose particles move randomly and unstable at fluctuating speeds that interact with each other.

Figure 11. Illustration of Air Flow in the Mosque Environment
Source: Authors, (2023)

The Influence of Orientation and the Surrounding Environment

The orientation of the building greatly determines the amount of solar radiation that falls on the surface of the facade in different directions. In fact, the Qibla orientation of mosques in Banda Aceh is 22 degrees from west to north. When collecting measuring data, the position of the sun's path is more inclined towards the north, this also greatly influences the amount of radiation received from the sun on the surface of the facade. Based on analysis data taken from Andrewmarsh, the time of exposure to sunlight from 15-20 July was 12 hours 25 minutes with an azimuth angle of 54,12 degrees and an altitude of 61,02 degrees.

The facade design of the Al-Furqan mosque applies a shading system through the reinforced concrete facade which functions as a canopy and the tower walls that jut out. These two elements protect the ventilated walls (intricate) so that the air entering the building tends to be cooler. Almost all day long the entire facade of the mosque building is protected from sunlight, except for the facades in the North (9.30-11.00 WIB) and in the West (13.00-15.00 WIB) which are exposed to sunlight for a limited time.

Based on the discussion above, the design of the Al-Furqan mosque has attempted to adapt to the environmental climate. However, the adaptations carried out are still not optimal. It is proven that thermal comfort has not been achieved in the congregational prayer room. It is possible that the design was not optimal because the ventilation area on the facade was less than optimal and there were no wide trees to shade the building on the site.

In existing conditions, the mosque room already uses several types of fans, to help reduce the room temperature. In fact, pilgrims still complain about the lack of achieving thermal comfort. Therefore, to further improve the quality of thermal comfort, you can install several exhaust fans at a certain height, thereby helping to draw and raise cold air throughout a fairly large room before it turns into hot air. Install exhaust fans as suggested by Mohamed (2019) in the mosques studied in Malaysia.

CONCLUSIONS

The design of the Al-Furqan mosque contains the concept of adaptation to microclimate. However, it is suspected that the field area for implementing the intelligent type ventilation system is still not optimal. It is also recommended to use porous building materials, to redistribute the heat received and the heat generated in the room.

The speed of airflow formed on the exterior and interior of the mosque can be used to reduce high temperatures in the room, by improving the current design. High air temperatures inside mosque buildings can be improved by revising the design, increasing ventilation and improving the exterior environment with vegetation and environmentally friendly materials.

ACKNOWLEDGEMENT

The author would like to thank DRPM and the Institute for Community Service (LPPM) Universitas Syiah Kuala for providing full support for the implementation of the research through a Master's Thesis Research grant.

FUNDING

This Master's Thesis Research Grant is funded by DRPM through the Universitas Syiah Kuala.

AUTHOR CONTRIBUTIONS

All authors contributed to the design of the research, the analysis, and the write-up. The survey, data identification and tabulation were undertaken by the researchers. All authors have read and approved the final manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Abdel-Aziz, D & Shuqair, H.I. (2014). *Amman's Facades Lost between Identity and Veracity; Factors Impacting Facades.* Design, pp. 20-21

Abdou, A.A., Al-Homoud, M.S., and Budaiwi, I. M. (2005). *Mosque Energy Performance, Part I.* Energy Audit and Use Trends Based on the Analysis of Utility Billing Data, 16 (1), pp. 165-184

Al-Homoud, M.S., Abdou, A.A., Budaiwi, I.M. (2009). Assessment of monitored energy use and thermal comfort conditions in mosques in hot-humid climates. *Energy and Buildings, 41*(6), pp. 607-614

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), pp. 778–792

Askari, A.H., & Dola, K.B, (2009). Influence of building façade visual elements on its historical image: Case of Kuala Lumpur city, Malaysia, *Journal of Design and Built Environment,* 5, pp. 49-59

Atmaca, A.B. & ZorerGedik (2019). *Evaluation of mosques in terms of thermal comfort and energy consumption in a temperate-humid climate*

Atmaca, A.B.; ZorerGedik, G.,& Wagner, A, (2021). Determination of Optimum Envelope of Religious Buildings in Terms of Thermal Comfort and Energy Consumption: Mosque Cases. *Energies 14*(20), 6597.

Azmi, N.A., & Ibrahim, S.H. (2020). A comprehensive review on thermal performance and envelope thermal design of mosque buildings, *Building and Environment,* 185, 107305

Badan Standarisasi Nasional (2001). *SNI 03-6572 2001 tentang Tata Cara Perancangan Sistem Ventilasi dan Pengkondisian Udara pada Bangunan Gedung*

Budaiwi, I.M., Abdou, A.A., Al-Homoud, M. S. (2012). Envelope retrofit and air-conditioning operational strategies for reduced energy consumption in mosques in hot climates, *Building Simulation* (2013) 6, pp. 33–50, from doi: 10.1007/s12273-012-0092-5

Chow, W. K., Fung, W. Y., & Wong, L. T. (2002). Preliminary studies on a new method for assessing ventilation in large spaces. *Building and Environment, 37*(2), 145–152. https://doi.org/10.1016/s0360-1323(01)00020-8

Egan, M. David (1975). *Concept in Thermal Comfort.* London: Prentice-Hall International

Elzaidabi, A.A.M. (2009). *Low Energy, Wind Catcher Assisted Indirect-evaporative Cooling System for Building Applications.* Doctoral dissertation, University of Nottingham

Ghaffarian H.A., Berardi U., & Makaremi N. (2012). Intelligent Facades in Low-Energy Buildings. *British Journal of Environmental and Climate Change, 2*(4), pp. 437- 464

Halim, A.Z.A., Talkis, N.A., Ali, W.N.W., & Majid, M.F. (2022). Energy Efficiency in Building an Analysis of K-Value and U-Value Application Through Green Building Material. *Malaysian Journal of Sustainable Environment (MySE), 9* (2). https://doi.org/10.24191/myse.v9i2.18825

Indrayadi. (2011). Aliran Udara Dalam Ruang Masjid Jawa Moderen. Studi Kasus Masjid Babadan Yogyakarta. *Jurnal Vokasi, 7* (2), pp. 156-165

Johnsen, K., & Winther, F.V. (2015). Dynamic Facades, the Smart Way of Meeting the Energy Requirements. *Energy Procedia,* 78, pp. 1568-1573

Kahera, K., Abdulmalik, L., & Anz, C. (2009). *Design Criteria for Mosques and Islamic Centers.* UK: Architectural Press

Karyono, T.H. (2007). *Dari Kenyamanan Termis hingga Pemanasan Bumi: Suatu Tinjauan Arsitektur dan Energi*, pp. 11-12

Liping, W., & Hien, W.N. (2006). The impact of façade designs : orientations, window to wall ratios and shading devices on indoor environment for naturally ventilated residential buildings in Singapore. *PLEA2006 The 23rd Conference on Passive and Low Energy Architecture Geneva Switzerland*, (9), 6-8

Mediastika, C.E. (2003). Uji Manual desain Jendela untuk Mencapai Recommended Ventilation Flow Rotes pada Bangunan Domestik Sederhana. *Jurnal Komposisi,* Universitas Atmajaya, Yogyakarta.

Mohamed Kamar, H., Kamsah, N.B., Ghaleb, F.A., & Idrus Alhamid, M. (2019). Enhacement of Thermal Comfort in a Large Space Building. *Alexandria Engineering Journal, 58* (1) pp. 49-65.

Prasetia, A., & Nugrahaini, F. (2020). *Kenyamanan Termal Pada Masjid Baitul Makmur Pabelan. Seminar Nasional Ilmiah Arsitektur,* pp. 597-600. Surakarta: Prodi Arsitektur Universitas Muhammadiyah Surakarta.

Roslee, N.N., Tharim, A.H.A., Jaffar, N. (2022). Investigation on the Barriers of Green Building Development in Malaysia. *Malaysian Journal of Sustainable Environment (MySE) 9*(2). https://doi.org/10.24191/myse.v9i2.18827.

Satwiko, P. (2009). *Fisika Bangunan.* Yogyakarta: Andi

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). https://doi. org/10.1088/1755-1315/599/1/012091

Syamsiyah, N. R., & Nur Izzati, H. (2021). Strategi Kenyamanan termal Masjid Al-Kautsar Kertonatan, Kartasura, Sukoharjo. *Langkau Betang: Jurnal Arsitektur, 8*(2), 98. https://doi.org/10.26418/lantang.v8i2.45792