Civil Engineering and Architecture 11(6): 3642-3650, 2023 http://www.hrpub.org
DOI: 10.13189/cea.2023.110630

Suitability of the Bioclimatic Architectural Design Concept and the Achievement of Thermal Comfort in the Building (Case Study of Baitul Musyahadah Mosque in Banda Aceh City)

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Received May 14, 2023; Revised August 10, 2023; Accepted September 8, 2023

Cite This Paper in the Following Citation Styles

(a): *[1] Mirza Fuady, Rizal Munadi, M. Andrian Kevin , "Suitability of the Bioclimatic Architectural Design Concept and the Achievement of Thermal Comfort in the Building (Case Study of Baitul Musyahadah Mosque in Banda Aceh City)," Civil Engineering and Architecture, Vol. 11, No. 6, pp. 3642 - 3650, 2023. DOI: 10.13189/cea.2023.110630.*

(b): *Mirza Fuady, Rizal Munadi, M. Andrian Kevin (2023). Suitability of the Bioclimatic Architectural Design Concept and the Achievement of Thermal Comfort in the Building (Case Study of Baitul Musyahadah Mosque in Banda Aceh City). Civil Engineering and Architecture, 11(6), 3642 - 3650. DOI: 10.13189/cea.2023.110630.*

Abstract Several mosques in Banda Aceh city have developed an artificial air conditioning system employing a cooling unit in the form of an air conditioner in order to create thermal comfort conditions for worshipers. The mosque's initial plan called for it to be open, but its closure was brought about by the adoption of this artificial air conditioning system. This reveals a flaw in the building's original design. Ideally, a climate-responsive bioclimatic architectural design strategy can be used to ameliorate this problem. One of the large mosques in Banda Aceh city that still use a natural cooling system is Baitul Musyahadah mosque. This study was done to find out suitability of the bioclimatic architectural design concept and the achievement of thermal comfort in the interior area Baitul Musyahadah Mosque. Data for this study were gathered through observation and interviews, using qualitative methodologies. The findings indicated that the majority of attendees believed the mosque's interior area to be warm and expected more air conditioning amenities. The results of the questionnaire on thermal comfort perception are generally consistent with the measurement results, which were based on the air temperature conditions in the mosque at the time it was not deemed to be at its most comfortable, but fell into the warm or hot comfortable category.

Keywords Bioclimatic Architecture, Climate-Responsive, Masjid Kupiah Meukeutop, Passive Cooling, Thermal Comfort Perception

1. Introduction

The Indonesian humid tropical climate, which includes Banda Aceh city, has a variety of natural potentials for a tropical climate marked by high levels of solar radiation intensity, relatively high air temperature and humidity, low wind speeds, and gloomy skies [1]. The inherent potential of the tropical environment can endure virtually the entire year, which might make it difficult to achieve thermal comfort inside the building [2].

A number of mosques in Banda Aceh city have moved to implement a closed interior conditioning system by depending on an artificial air conditioning system utilizing air conditioners (AC) in order to ensure ideal thermal comfort to support congregational activities. Both large mosques with many worshipers and tiny mosques with fewer congregations, such Meunasah or Mushalla, experienced these changes.

It is true that the use of a mechanical ventilation system, particularly air conditioning in general, can make worshipers feel more at ease while doing activities in the mosque. However, when considering energy use, the adoption of an artificial ventilation system will have an impact on the rise in energy consumption and electricity costs. Additionally, as buildings become more reliant on air conditioning, more Chloro Fluoro Carbon (CFC) gas will be released into the atmosphere, which can harm the ozone layer and have a negative influence on the ecosystem [3].

Buildings in humid tropical settings should not rely on artificial ventilation systems, claims Arifin [4]. This can be accomplished by using several strategies, such as the application of suitable apertures and ventilation in an effort to supply natural air and lower room temperature. To achieve thermal comfort, it is necessary to arrange for an adequate amount of openings and ventilation when designing buildings in tropical climates.

One of the key factors in creating comfortable circumstances for users during indoor activities is thermal comfort in a structure. Most of the new and old mosques in Banda Aceh city have converted to establishing an air conditioning system for interior areas inside the mosque in order to achieve thermal comfort conditions for worshipers.

Due to the usage of an artificial cooling system in the form of air conditioning, the mosque's original open design changed into a closed one. The mosque's design changes made to improve thermal comfort point to a flaw in the structure's construction. Applying a building design with a climate-responsive bioclimatic architecture strategy is the ideal way to ameliorate this condition.

Masjid Kupiah Meukeutop, also known as Baitul Musyahadah Mosque (see Figure 1), is one of the main mosques in Banda Aceh City that continues to use an open-plan design and natural ventilation. The mosque's courtyard is fairly spacious, and the building itself has numerous apertures.

Figure 1. View of Baitul Musyahadah Mosque

The natural ability of the Baitul Musyahadah mosque regulates thermal comfort using passive cooling techniques. This study aims to find out suitability of the bioclimatic architectural design concept and the achievement of thermal comfort in the interior area of Baitul Musyahadah Mosque.

2. Literature Review

Olgyay invented the term bioclimatic design to describe a way for matching local climate factors in order to achieve human comfort [5]. According to Watson, bioclimatic design is a way of designing buildings and landscapes that takes into account the local climate [6]. The goal of bioclimatic design in architecture is to create building designs that are both climate-responsive and energy-efficient. [7] Also the purpose of bioclimatic design is to take advantage of local bioclimatic conditions in order to enhance both the natural and built environments. [8].

The design of buildings is aligned with the fields of climatology, human physiology, and building physics in the notion of bioclimatic architecture. The idea of bioclimatic architecture, according to Rahmadiah [9], is an art of building design by planning and executing suitable architectural elements to assist energy savings and pay attention to the local environment in order to solve problems that frequently emerge. In contrast, bioclimatic architecture, as defined by Tumimomor [10], is a style of contemporary architecture that not only adapts to the local environment but also fosters strength, tranquility, and harmony that are relevant to the setting of the building type being created.

The response and focus of the international community on the problem of thermal comfort for building occupants are related to the issue of rising global warming, and this has led to numerous thermal research on various types of structures. The term thermal comfort refers to a state of mind that expresses satisfaction with the thermal conditions present in the environment, according to ASHRAE Standard 55-1992, one of the international standards published by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers [11].

From this explanation, it can be concluded that a group of Indonesian people and a group of European people will get the same level of comfort if they are placed in the same room, carry out the same activities and wear the same clothes [12]. The American standard, too, states that it is not much different from the International Standard, ISO [13], which was almost entirely inspired by Fanger's thinking with the theory of heat balance [14].

According to Cahyaningrum [15], the bioclimatic approach's general design concepts include: (a) energy conservation; (b) consideration of the local climate; (c) environmental friendliness; d) adapting to the building's site characteristics, and e) providing comfort features for the building's occupants. The five bioclimatic architectural design concepts can be broken down into three fundamental ones: energy conservation, climatic responsiveness, and environmental friendliness, in an effort to increase user comfort.

According to Karyono [16], given the rising use of air conditioning in buildings nowadays, one problem for architects and building designers is essentially figuring out how to maximize thermal comfort through natural air conditioning optimization in order to create a comfort index that compares temperature, thermal performance, and level of comfort. Thermal comfort can be understood as a state of mind and feeling toward stimulation by hot or cold temperatures received from an environmental condition both inside and outside the building [17].

The existence of openings generally as a medium for capturing and allowing wind or airflow into the building, so that the process of changing air from the outside and inside the building could happen naturally, is one of the most crucial design elements in seeking passive building thermal comfort, according to Latifah [18].

Building orientation, prevailing wind evaluation, wall thickness, material and color definition, shading circumstances, roof structure, natural ventilation window, and so on are all dependent on specific climate definitions. Bioclimatic architecture can increase both indoor thermal comfort and building energy performance [19].

Thermal insulation of mosque envelopes can significantly improve thermal comfort conditions. The height of the air supply outlets should be as low as feasible to give thermal comfort while consuming as little energy as possible. The mosque must be comfortable and quiet, and visitors must be able to leave with a sense of calm and peace [20]. Thermal comfort levels for the various prayer hours can also be increased by at least 40% to 80% when better wall design is combined with the operation of mechanical fans. [21]. Similarly, placing multiple exhaust fans on the west side wall of the prayer hall can greatly increase the thermal comfort inside the main prayer hall [22].

The procedures for designing ventilation and air conditioning systems in buildings, Indonesian National Standard Number 03-6572-2001, served as the foundation for the development of the standard criteria for the thermal comfort of the human body in the tropics [23], which are displayed in the following table:

Table 1. Comfort Temperature Criteria based on SNI 03-6572-2001

Sensation	Effective Temperature
Cool comfortable	20,5 ºC – 22,8 ºC
Comfortable Optimal	22,8 ºC – 25,8 ºC
Comfortable Warm	25,8 ºC – 27,1 ºC

3. Method

The Baitul Musyahadah Mosque, which is situated at Teuku Umar Street, Gampong Geuceu Kayee Jato, Banda Raya district, Banda Aceh city, was the site of this study (see Figure 2). The Baitul Musyahadah Mosque was chosen as the study site and subject because it falls under the category of a large mosque in Banda Aceh city and has not yet been fitted with air conditioning facilities. Up until now, open indoor air conditioning has been maintained by using natural ventilation.

Figure 2. Baitul Musyahadah Mosque is situated on Teuku Umar Street in Banda Aceh City

This study processes the data from the measurement of the thermal comfort of the mosque's interior space (see Figure 3) using a quantitative approach. Thermohygrometers, Hot Wire Anemometers, and Infrared Thermometers were used to collect data on air temperature, humidity, and wind speed at Baitul Musyahadah Mosque. Thermohygrometers measured air temperature and humidity as well as air temperature, while Hot Wire Anemometers measured wind speed and air temperature. Additionally, Baitul Musyahadah Mosque worshippers were given a thermal comfort perception questionnaire as part of the research data collection process.

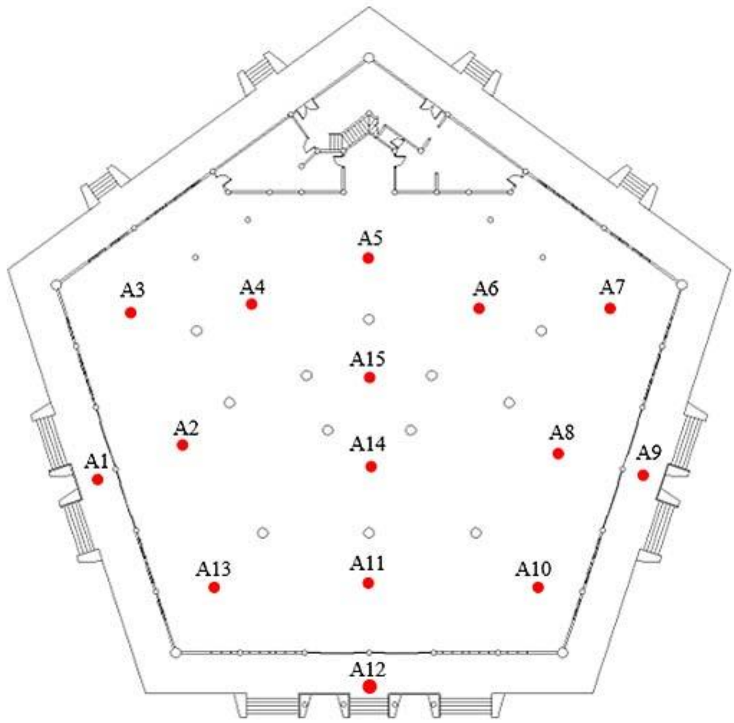

Figure 3. Point of measurement on the mosque plan

From the morning before midday until Asr in the afternoon, three days' worth of temperature, humidity, and wind speed readings were made. The measurement period was chosen in accordance with references from multiple earlier studies which claim that buildings in hot and humid tropical regions experience their peak heat around noon, when most residents or users of the space frequently express discomfort from the heat.

A thermal comfort perception questionnaire was given to a number of worshipers present in the mosque at the time of the zuhr, and after in an effort to complete the validation of the thermal comfort measurement. Perception is the capacity for feeling and making judgments through a variety of senses, such as hearing, smelling, tasting, and others. Therefore, the assessment of others' judgments of their level of thermal comfort is done in order to learn how they perceive themselves as regular users or worshipers of the mosque.

4. Results and Discussion

4.1. The Current State of Banda Aceh City's Baitul Musyahadah Mosque

One of the large mosques in the Banda Raya District in Banda Aceh city is the Baitul Musyahadah Mosque, which was started in 1989 and finished in 1993. Ali Hasjmy, one of Acehnese thinkers of note, was the one who first proposed building this mosque. Because of the distinctiveness of the Kupiah Meukeutop dome (see Figure 4), the Baitul Musyahadah Mosque is quite well known.

According to the structure's architecture, this mosque has two stories and a pentagon-shaped layout. The mosque features many repeating windows that open on practically every side, giving it the illusion of a modern tropical building with a plain appearance. The Baitul Musyahadah mosque design incorporates wide openings, roofs with sufficient inclination angles, ceilings, and plenty of shade around the building, all of which are design elements Sukawi [24] mentions as being typical of buildings in tropical climates.

Figure 4. The environment outside of the Baitul Musyahadah Mosque, which features a Kupiah Meukeutop dome

This mosque stands out from other mosque designs in general because of its distinctive dome. This mosque's dome design is particularly notable since it is formed like the kupiah meukeutop, a traditional cap worn in Aceh. The mosque on Teuku Umar street is also referred to as Masjid Kupiah Meukeutop or Masjid Teuku Umar by locals of Banda Aceh city.

Given that it is a closed-plan structure without air conditioning (AC), the Baitul Musyahadah mosque is one of the main mosque structures in Banda Aceh city that has not yet experienced indoor cooling. This mosque's daily air conditioning system uses natural air conditioning (see Figure 5).

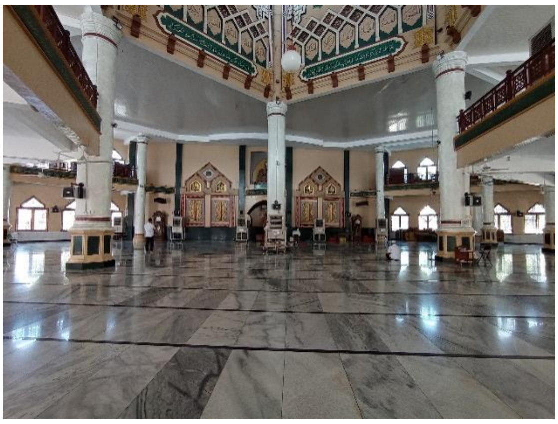

Figure 5. Baitul Musyahadah Mosque's inner space has a certain atmosphere

This enormous mosque is 1500 square meters in size and can accommodate up to 3000 worshippers. One factor that could support cross-ventilation in the form of natural air exchange in the mosque's interior space is the number of openings in the form of windows and doors on various sides of the mosque's walls. Additionally, the mosque's interior spaces benefit from natural lighting due to the quantity of openings. This mosque, however, has a sizable parking lot that is around 2500 m^2, allowing for the parking of numerous automobiles and motorcycles. The mosque's courtyard serves as a green area with a variety of plants that provide shade.

Given the potential that the mosque holds, it will be able to passively support the thermal comfort of the mosque by influencing the interior space of the mosque building to the movement of free air outside the building. This is unquestionably different from the situation in which buildings are situated on a small plot of ground and are in close proximity to one another, obstructing the free flow of air.

4.2. The Bioclimatic Architectural Design Concept in Baitul Musyahadah

Building orientation, spatial planning and transitional arrangements, building envelope, passive shading, openings, building materials, and landscape are among the outcomes of the investigation of applying the concept of bioclimatic architectural design to the Baitul Musyahadah Mosque.

The recommended building orientation for tropical climate zones, according to Yeang [25], is extended to the east and west with openings to the north and south. However, this is not consistent with the allotment conditions for the design of mosque buildings because Muslim worship buildings have guidelines to adapt to conditions that point towards the Qibla, so mosque buildings, particularly in the geographical area of Aceh, have a main orientation that tends to face the west.

Under the current conditions, the front half of the Baitul Musyahadah mosque building on the west side cannot avoid being exposed to more sunlight and heat than parts of the building on the other side. Aside from the west side, the existing state of the mosque with a pentagonal shape can also influence the building envelope on each side of the opposite direction in receiving varying intensities of solar radiation.

The findings of three days of wind speed measurements show that the primary wind direction at the Baitul Musyahadah mosque tends to emanate from the east side. This is evidenced by greater average wind speed readings at measurement locations A11 and A12, which are near the east side of the mosque, when compared to measurement points on the north and south sides. While measurement locations A8 and A9 are close to the north side door, A1 and A2 are close to the south side door and exhibit a similar average difference in wind speed.

The floor plan of this mosque is essentially in the shape of a pentagon. The existing spatial plan in the design of the Baitul Musyahadah mosque building can be divided into two areas, namely (a) the service area, which includes the office area of the mosque's prosperity board and other supporting rooms, and the rest is (b) the area of the prayer hall, which consists of two floors.

Most of the solar radiation is received by the covering of the walls of the mosque building and the many glass window openings and ventilation. It's not just walls that can receive and distribute heat to the interior. Likewise, the glass material acts as an intermediary medium for the entry of solar heat radiation into the building, thereby influencing the heating of the interior space.

The existing condition of the mosque, which has a number of window openings and upper ventilation made of glass but is not balanced with sufficient canopies, is inconsistent with Sukawi [24], who states that in areas with a humid tropical climate, it is recommended that buildings be able to protect the building envelope from direct sunlight radiation, which tends to spread heat into the room, so it is often a problem in increasing room temperature.

Because of the dynamic conditions of wind flow, it is difficult to feel the wind in a consistent manner. Similarly, the current existing natural ventilation system has an issue with the passage of wind in the mosque's interior that is not realized or cannot be felt. Regarding the mosque building's design, which employs an open inner space and numerous apertures, this demonstrates that there are still flaws, particularly in the distribution of wind uniformly throughout the structure.

The uneven distribution of airflow in the room is caused, among other things, by the distance between the windows that face each other, the direction of the window opening, which inhibits the pressure in and out of the air so that it does not move freely in the room, so that in the end the weak air velocity is unable to form an airflow pattern.

The dominating Effective Temperature (ET) is obtained with best comfortable sensation based on the results of ET calculations at many positions next to the door opening. This is also influenced by wind speed, much of which cannot be measured but may be felt to provide a pleasant sensation to the body. The design of the trellis door at the mosque is regarded as excellent as an aperture that allows the process of changing air in the room to continue, and it has a significant impact on the comfort of the temperature, humidity, and air ventilation in this mosque.

Even though it has an opening design that has the potential to support thermal comfort, the presence of many openings in the form of windows does not function optimally, especially in terms of supporting the achievement of thermal comfort for the spaces inside the mosque, based on the existing conditions in the mosque during the three days of measurement. This is because many of the shutters on both the first and second floors are not fully open.

Natural marble measuring 120 x 60 cm is the main floor covering material related to the Baitul Musyahadah mosque construction. Apart from its texture and pattern, which creates a luxurious and majestic impression, marble floor material has several advantages that support the thermal comfort of space, such as (a) having pores that can absorb and store cold air from free air, and (b) being durable, including against hot weather, which can affect the comfort of the congregation as users of space in the mosque.

The usage of concrete in the form of paving blocks dominates the mosque's scenery over greening with plants. Because landscape features are exterior elements that are directly exposed to solar radiation, the quality of the courtyard landscape can also affect the thermal comfort characteristics of the building's indoor and outdoor spaces. Despite its huge yard, the boundaries beyond the mosque site are extremely congested, as it is surrounded by multiple housing estates, shops, and retail centers.

4.3. The Findings of the Baitul Musyahadah Mosque's Thermal Comfort Measurement

The Baitul Musyahadah Mosque served as the site for the gathering of research data, and each preset point's thermal comfort was measured there. In this study, thermal comfort is evaluated by measuring air temperature, relative humidity (RH), and wind speed in naturally ventilated buildings. Measurement equipment is positioned approximately 1.1 meters above the ground floor. The measurement spans three time periods, from 09.00 AM to 3.30 PM.

Three categories: (a) optimal comfort, (b) warm comfortable, and (c) not comfortable, can be determined based on the Effective Temperature, or ET calculation results at each measurement point on the first and second floors that have been obtained for three days of measurement.

In accordance with SNI 03-6572-2001, which is applicable to all temperature measurements but one of which is significantly influenced by wind speed, the results of the computation of ET can be classed. The wind has a hard time stabilizing when the wind flow is dynamic. In truth, there are a number of requirements, among them the inability to detect wind movement, for measuring temperature at specific spots using instruments.

The air humidity conditions and the presence or absence of wind speed, which may be detected by the hot wire anemometer at each measuring point during measurement, have a significant impact on the findings of the acquired ET calculations, which leads to a range of ET values.

Based on the temperature measurement time and subsequent ET calculations at each measurement point 63 times per day, warm comfortable conditions predominated in the building on the first day 24 times, followed by ideal comfortable conditions 22 times, and uncomfortable conditions 16 times. The dominant ET was then attained on the second day under ideal pleasant conditions 31 times, warm comfortable conditions 16 times, and uncomfortable conditions 8 times. On the third day, the dominant ET was measured in warm, comfortable conditions up to 25 times, in ideal, comfortable conditions 21 times, and in uncomfortable conditions 17 times.

When compared to the ET conditions in the interior space between the first and second floors, the first floor has the most of the ideal comfortable condition and the most of the uncomfortable condition. The highest ET conditions in the building reached 30.1^{o}C on the third day of the third session, according to the overall ET calculation for the three days of measurement. The lowest ET temperature inside the building was 23.4^{o}C, while the average ET temperature inside the building was 26.5^{o}C, which is considered pleasant and comfortable.

The average ET outside the building, which doesn't move much, is 26.5^{o}C, and the average ET within the building is 26.3^{o}C. When the building is in its best condition, the ET inside is higher than the ET outside; the highest ET inside is 27.8^{o}C, while the highest ET outdoors is 26.5^{o}C. The lowest ET inside the building is 24.5^{o}C, which is lower than the highest ET outside the building, which reaches 26.5^{o}C.

According to the mosque's plan, which includes a large amount of interior space, one of which is created by voids that extend from the first floor to a height below the dome. A void space with a sufficiently high depth is an advantage in terms of supporting stack effect ventilation, which promotes thermal comfort. In a process known as stack effect ventilation, warm or hot air molecules weaken and experience a gap between the molecules, making the air density lighter and easier to breathe (see Figure 6). This happens as a result of an increase in room air temperature, which exerts a buoyant force on the air molecules. raised up.

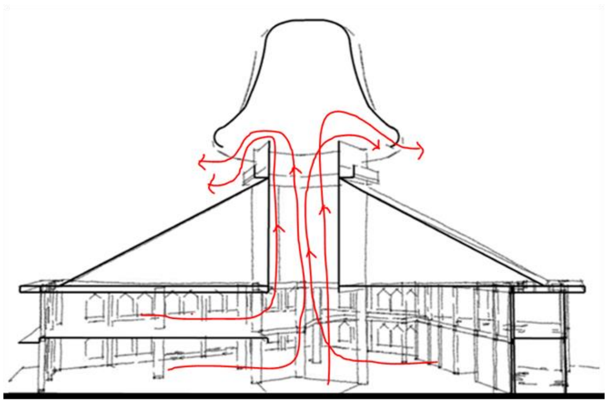

Figure 6. An example of how the top aperture in the Baitul Musyahadah Mosque structure might allow hot air to escape

In terms of the measurement results, the ET calculation results at the measuring point related to the void in the middle of the room, more specifically under the void, give rise to the dominant sensation of optimal comfort, with the lowest temperature reaching 24.0°C during the day and the highest temperature that can be reached being 27.7°C in the afternoon.

This is in keeping with Arifin [4] and Karyono [16] opinions, according to which building designs with vents at the top of the structure may cause heated air within to rise, resulting in airflow inside the structure during times of high wind speeds. It frequently draws heated steam to the building's upper apertures.

4.4. The Perception of Thermal Comfort

In the study 100 respondents took part, 60 of them were men and 40 were women worshipers who were recruited by handing out questionnaires at Baitul Musyahadah Mosque. At midday, the timing for questionnaire distribution will be decided. The assessment of the thermal comfort perception scale indicators for this study was very comfortable (3), comfortable (2), slightly comfortable (1), neutral (0), slightly uncomfortable (-1), uncomfortable (-2), and very uncomfortable (-3), (see Table 2).

Table 2. The thermal comfort perception inside the mosque

3	2	1	0	-1	-2	-3
-	5%	8%	13%	36%	31%	7%

According to a total of 74% of respondents, the Baitul Musyahadah Mosque's overall thermal comfort levels are currently on the uncomfortable side of the scale, with specifics of the perception acquisition including slightly uncomfortable at 36%, uncomfortable at 31%, and very uncomfortable at 7%. 13% of respondents chose the remaining neutral options, and 13% chose the answers that would result in a comfortable situation. In terms of the intended thermal comfort conditions within the mosque, 94% chose the answer option that declared a desire for enhanced comfort, with answers that were significantly more comfortable by 42%, more comfortable by 37%, and slightly more comfortable by 15%.

According to 88% of respondents, the air temperature within the mosque is currently included on the heat scale, with specifics of the perceptual gain including hot (41%), slightly hot (37%), and extremely hot (10%) at the top of the scale. All responders who were asked what air temperature they would want to have in the mosque selected the response option that stated they would like the temperature to drop significantly.

When asked how frequently the sense of wind flow is consciously perceived and impacts comfort, 49% of respondents selected the option for a neutral response. Additionally, 71% of respondents reported feeling a modest wind speed, which is consistent with the idea that this can alter how long it takes for respondents to notice the presence of wind in the mosque. The majority of the responders who were in the majority wanted the wind flow sensation inside the mosque to be enhanced, namely by adding more wind that could be felt and enjoyed while inside the mosque.

The current mosque trellis door is considered by the majority of responders to be the most important opening element in terms of the flow of air into and out of the structure. By asking about the current state of the openings in the mosque, it was discovered that, in contrast to trellis doors, the presence of window openings causes respondents to hesitate when answering whether or not the effect is related to air entering smoothly, so the dominant response is the neutral option by 39%.

The majority of respondents stated that the current evaluation of cooling facilities was inadequate. 90% of the congregation expressed their agreement with the statement that the air conditioning facilities in the mosque are now significant, if not extremely significant.

5. Conclusions

The principle of spatial planning and transition space is the most appropriate as a reference from the study of bioclimatic architectural principles, out of a number of bioclimatic architectural principles that were applied to the design of the Baitul Musyahadah Mosque in accordance with the achievement of passive thermal comfort. Despite efforts to incorporate bioclimatic architectural concepts through design features, some principles in this mosque are still not completely adequate and not the best for passively supporting thermal comfort.

The final average effective temperature condition at the Baitul Musyahadah mosque is categorized into the warm pleasant level based on the findings of the measurements and computations. The dominant state is still relatively comfortable, as indicated by the warm comfortable condition, which is the lowest range from the standard thermal comfort limit. However, the warm comfortable sensation obtained differs from the optimal comfortable sensation.

The results of the questionnaire on thermal comfort perception are generally consistent with the measurement results, which were based on the air temperature conditions in the mosque at the time it was not deemed to be at its most comfortable, but falls into the warm or hot comfortable category. As a result of the generally weak wind speed and the warm, comfortable conditions that were found, it is challenging to notice the wind's presence and how it specifically affects comfort. Most respondents report feeling on the slightly hot side of things. This is in line with the opinion of the majority of respondents that it is crucial that cooling equipment facilities are always on because the perceived thermal comfort is not yet at its best.

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