Enhancing Indoor Thermal Comfort Through Passive Design Strategies in a Hot-Humid Climate: A Case Study of Anjung Kelana, Malaysia

Zanariah Kasim[1]*, Azman Zainal Md. Nor[2], Thanousorn Vongpraseuth[3] and Badariah Daud[1]

[1]Department of Civil Engineering,
Politeknik Port Dickson,
KM.14 Jalan Pantai, 71050 Si Rusa, Port Dickson, Negeri Sembilan, Malaysia.

[2]Principal, Arkitek Azman Zainal,
No 17A, Jalan Tengku Ampuan Zabedah J9J, Seksyen 9,
40100 Shah Alam, Selangor, Malaysia.

[3]Faculty of Architecture,
National University of Laos,
P.O. Box 7322, Vientiane 0117, Laos.

*Corresponding Author's Email: zanariah@polipd.edu.my

Article History: Received 13 July 2024; Revised 21 November 2024; Accepted 26 November 2024

Abstract

In hot-humid climates, using air conditioning to achieve comfort is often considered the most convenient solution. However, relying on air conditioning for comfort is unhealthy and detrimental to the environment. This study aimed to assess the effectiveness of passive design strategies in enhancing indoor thermal comfort in hot-humid climates. Field data were collected from eight internal spaces within the Anjung Kelana residence in Port Dickson, Malaysia: Serambi, Anjung, Kitchen, Stairwell, Bedroom 1, Bedroom 2, Bath 1, and Bath 2. Three microclimate parameters i) air temperature (Ta), ii) wind velocity (v), and iii) relative humidity (RH) were measured to evaluate indoor comfort levels. The collected data were analysed and compared across different spaces and parameter values. The results highlight the positive impact of passive design strategies on indoor thermal comfort. These findings can provide valuable guidance for architects and building designers in selecting suitable passive design strategies to improve indoor comfort in hot-humid climates.

Keywords: Air Temperature, Hot-Humid Climate, Indoor Thermal Comfort, Passive Design Strategies, Relative Humidity

1.0 Introduction

In hot-humid climate, resorting to air conditioning to be comfortable is more expedient. The temperature in Malaysia ranges from 23°C to 38°C and the humidity is between 67% to 95%. Relying on air conditioning to achieve the desired comfort levels is unhealthy and harms the natural environment [1]. This seems to have become the norm in the high-technology lifestyle of today. The passive approach should be the default mode; the first action to achieve comfort levels in this climate. Passive design principles should be incorporated during the design stage, relying on mechanical systems as secondary and supporting strategies. Studies have proven by applying proper passive design strategies at the early design stage, a high building performance can be achieved [2], [3], [4]. R. Ergun and A. Bekleyen [5] stated that passive cooling techniques expel indoor heat to the outside or prevent outdoor heat from entering the interior. It is also said to be able to create low-energy buildings that are less dependent on mechanical energy [6], and the effects just like smart home control to set the indoor thermal comfort for the inhabitants [7].

Researchers worldwide have adopted various passive design strategies to counteract the impacts of climate change [8], [9], [10], [11], [12]. M. Sanz-Mas et al [13] studied the effects of passive cooling strategies in school buildings in Barcelona on human thermal comfort and highlighted that the passive design benefits for student's comfort and well-being in Mediterranean climates. Another study by Y. Zhao et al. [14] investigated passive design strategies to improve student thermal comfort in a hot-humid subtropical monsoon climate. The studies focus on semi-outdoor environments including courtyards and overhead spaces of an academic building, Guangzhou University of China. In another study A. Kaihoul et al. [15] studied the role of passive strategies inspired by traditional architecture in the hot-dry climate of Algeria, they successfully proved that the indoor air temperature is between 30.1°C and 35.4°C, even though the outdoor air temperature is 47°C. The studies above have proven the effectiveness of passive design on energy consumption and thermal comfort in buildings.

In hot-humid climates, among the studies on passive design strategies, Sheng Liu et al. [2] examined the effectiveness of passive design strategies for residential buildings in Hong Kong under the context of future climate change. Solar protection strategies were found to be the most effective way to improve building performance. Similarly, S. Mirrahimi et al. [8] ranked the effectiveness of the effect of building envelopes on energy consumption and thermal performance of high-rise buildings in Malaysia. This is supported by Aimi Zulkarnain et al. [16] suggested that control building shading devices are considered one of the major solutions to achieve the optimum balance of thermal daylighting. In Thailand, Nafisa Bhikhoo et al. [11] indicated that the roof material and the presence of a balcony have the greatest influence on indoor thermal comfort. In Malaysia, R. Daghigh [17] conducted a review of the available literature on the thermal comfort and ventilation of offices, classrooms and residential buildings, and found that proper ventilation and healthy indoor air quality have a great influence on the sensation of thermal comfort via occupants of buildings. With the field measurements of the effect of building orientation in Penang, Malaysia, N. M. Al-Tamimi et al. [18] investigated the solar radiation absorptance of exterior walls, varied area ratio of glazed window to wall and the effect of natural ventilation on the thermal performance of residential buildings and found that the east windows have a more obvious effect on increasing indoor air temperature than west windows, that is applicable for ventilated or unventilated rooms. Based on the above studies, it was found that studies on the effects of passive design on buildings or wooden houses are rarely conducted, therefore the objective of this study is to investigate the effectiveness of passive design strategies in influencing indoor thermal comfort in hot-humid climate environments, a case study of a wooden house.

2.0 Methodology

M. Frontczak & P. Wargocki [19] study how different factors influence human comfort in an indoor air environment. Three factors were studied namely thermal comfort, visual and acoustic, as well as air quality. Thermal comfort has become the first choice of respondents, in determining comfort in indoor air environments [20]. It refers to the personal subjective psychological condition an individual experiences in each environment, which can be objectively assessed based on certain factors to predict how the majority of occupants feel [1]. According to W. Cui et al. [21], there is an effect of air temperature on thermal comfort, motivation, performance and their relationship. Five different temperatures: 22°C, 24°C, 26°C, 29°C, 32°C were tested in the study. It has been proven that the learning effect was greatly affected by temperature.

Based on the author's experience in designing and building more than 30 buildings in hot-humid climates, Ar. Azman Zainal has concluded that the idea of comfort in this type of climate is shade, cool, dry, spacious and breezy as listed in Figure 1. Shade is achieved by cutting out glare and preventing direct penetration of sunlight into the living spaces. As a result, internal surfaces and air do not get heated up by direct heat and heat waves or radiation. Protection from rain and being dry is naturally a comfort factor. Spaciousness, apart from impacting us psychologically, also means that there is a larger volume of air to heat up and heated air would be confined at higher levels, further away from our body. With good cross ventilation, this heated air would regularly be flushed out thus lowering the temperature and moderating the humidity.

Figure 1: The idea of comfort in the hot-humid tropical climate

This study was conducted to investigate the effectiveness of passive design strategies in influencing indoor thermal comfort in hot-humid climate environments, a case study of a wooden house. The study measured 3 variables: Air temperature (Ta), Wind velocity (v) and Relative humidity (RH). These were selected based on previous studies [15], [22], [23]. This is a descriptive study to measure the effects of passive design strategies in 8 areas of internal spaces of a three-storey bungalow house named Anjung Kelana. It is a modern Malay house prototype. The design appeals extensively to the rugged, natural beauty of timber. Timber is the main material used throughout the building. The Anjung Kelana is located (Lat. 02.5°N, Long.101°E) in Port Dickson Malaysia which experiences hot and humid temperatures throughout the year. The daily air temperatures from a low of 24°C at night and up to 38°C at noon time.

2.1 Case Study and Measurement Period

The study focuses on 8 internal spaces of Anjung Kelana to assess the influence of passive design strategies on indoor thermal comfort. These 8 internal spaces are Serambi, Kitchen, Bedroom 1, Bedroom 2, Bath 1, Bath 2, Stairwell, and Anjung (refer to Figure 2). The Field measurements were performed during the hottest part of the day (12:00 to 15:00) on November 1, 2023 [24]. Air Temperature (Ta), Wind Velocity (v) and Relative Humidity (RH) were measured repeatedly 3 times at each point to obtain an average reading. This was done in similar studies in Singapore and Malaysia that required outdoor temperature measurements at different locations [25], [26].

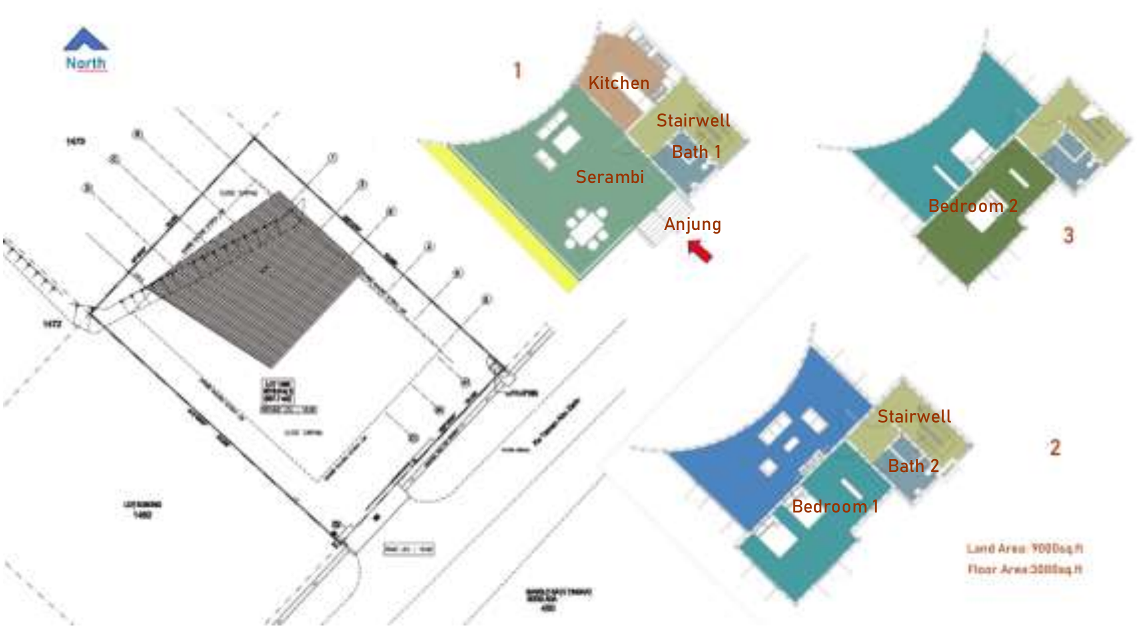

Figure 2: Plan of Anjung Kelana and the 8 internal areas

2.2 Field Measurement Equipment and Procedure of the Case Study

Measurements for each area were conducted by two trained research assistants, who took readings of air temperature (Ta), wind velocity (v), and relative humidity (RH) at a minimum of three points in each area. To record these parameters, three portable instruments—Testo 925, Testo 425, and Testo 625—were used to measure air temperature, wind velocity, and relative humidity, respectively. As noted by Hwang et al. [25], these instruments are well-suited for the task due to their quick response times, compact size, and accuracy, which comply with ISO 9001:2008 standards and the specifications of the German Federal Institute of Physics and Technology.

3.0 Results and Discussion

The data analysis highlighted important findings related to the passive design strategies tested for indoor thermal comfort. The results for air temperature (Ta), wind velocity (v), and relative humidity (RH) indicated significant variations across the eight internal areas of Anjung Kelana.

3.1 Air Temperature (Ta)

Figure 3 presents the air temperature (Ta) data for all eight internal areas of Anjung Kelana. The air temperature varies between 30.1°C and 30.5°C, with an average of 30.36°C. In comparison, the external temperature (outside the house compound) is 31.7°C. The difference in average air temperature between the eight internal areas and the outside temperature is 1.34°C. According to [8], the thermal comfort zone for indoor environments in Malaysia falls between 25°C and 31°C.

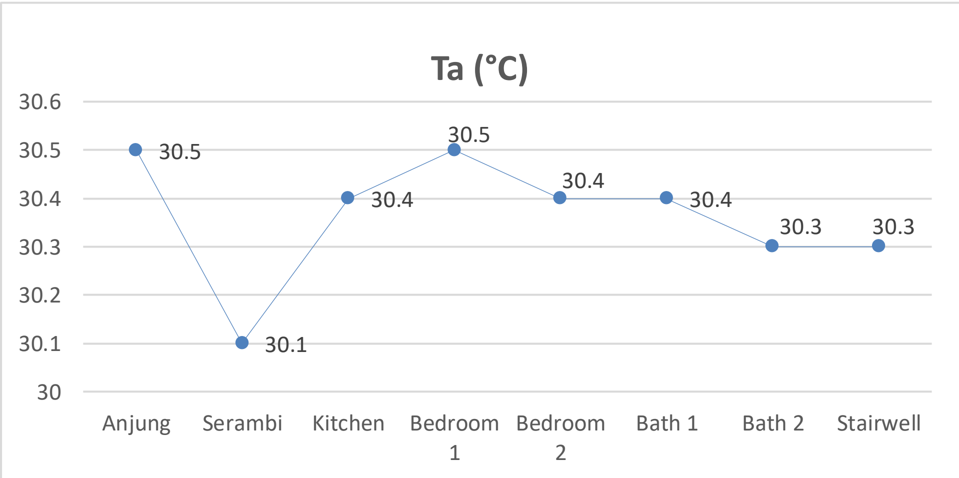

Figure 3: Air temperature (Ta) of 8 areas in Anjung Kelana

3.2 Wind Velocity (v)

The comfort range for airspeed is between 1.2 m/s and 2.0 m/s [12]. The wind velocity outside the house compound is 1.21 m/s. Figure 4 illustrates the wind velocity (v) across the eight areas of Anjung Kelana.

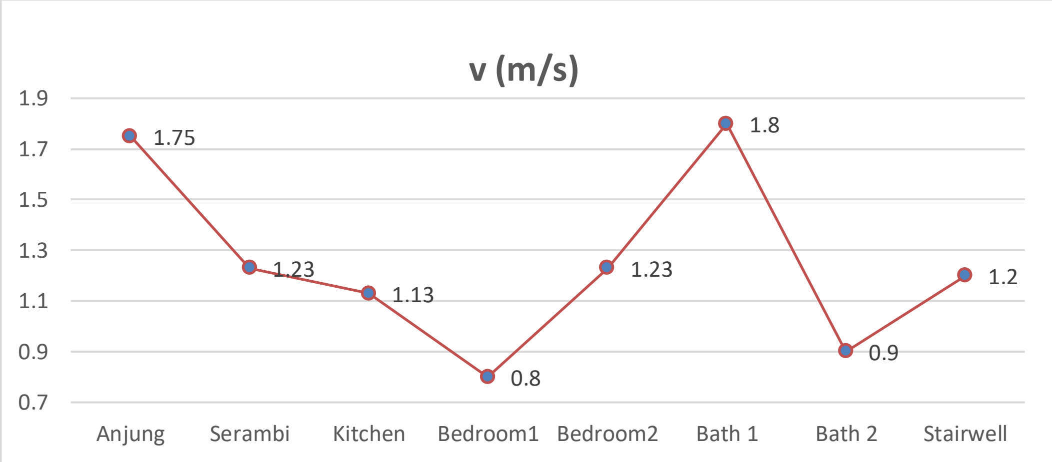

Figure 4: Wind velocity (v) of 8 areas in Anjung Kelana

Bath 1 has the highest average wind velocity at 1.8 m/s, followed by Anjung with 1.75 m/s. The lowest average is found in Bedroom 1. Serambi and Bedroom 2 exhibit similar wind velocities, both around 1.23 m/s, while the Stairwell has a value of 1.2 m/s. The Kitchen shows a wind velocity of 1.13 m/s, followed by Bath 2 with 0.9 m/s. Of all the areas measured, five (Bath 1, Anjung, Serambi, Bedroom 2, and Stairwell) fall within the comfort range for wind velocity.

3.3 Relative Humidity (RH)

The graph in Figure 5, clearly indicates the highest RH occurred in Bath 2 (73%) and the lowest is 66.9% in Kitchen. Note that the relative humidity outside (house compound) is 66.7%. These results indicate that 8 internal areas of Anjung Kelana are within the comfort zone of RH. According to Zhou et al. [27], the comfort zone of RH is between 40%-90%. Kitchen, Anjung, Serambi, Bath 1, Bedroom 2, Bedroom 1, Stairwell and Bath 2 in ascending order.

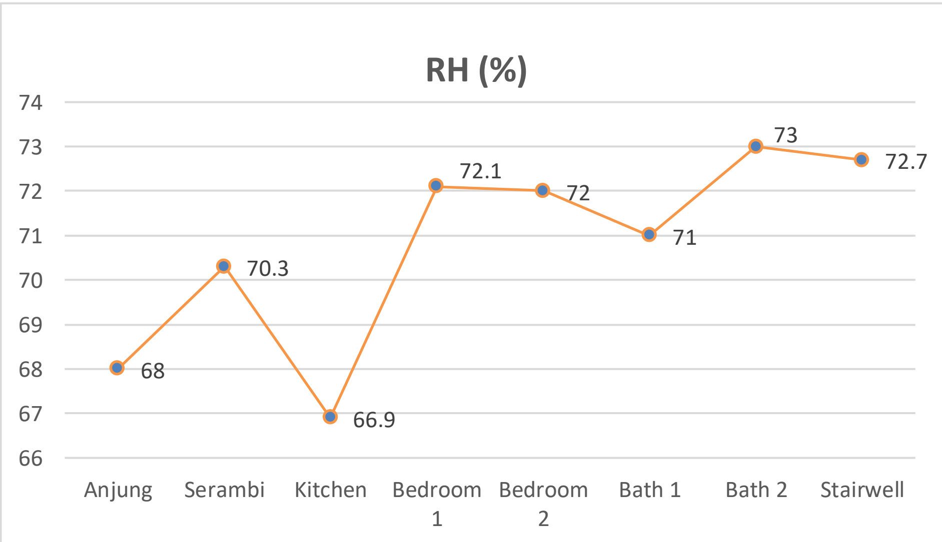

Figure 5: Relative humidity (RH) of 8 areas in Anjung Kelana

3.4 Effect of Passive Design Strategies on Indoor Thermal Comfort

This study examines the impact of passive design strategies on indoor thermal comfort in hot-humid environments. The significance of passive design in enhancing internal thermal comfort is evident from the results presented earlier. The areas were ranked according to air temperature as follows: i) Serambi, ii) Bath 2/Stairwell, iii) Kitchen/Bedroom 2/Bath 1, and iv) Anjung/Bedroom 1. There is a difference between Serambi and kitchen, where Serambi provides more comfort to the user than the Kitchen. Serambi gives better comfort to users due to a wider opening area when compared to the Kitchen, where Serambi has less wall area as shown in Figure 6. Wider cross ventilation provides more thermal comfort for the user in this situation. However, the air temperature at Anjung is higher than at Serambi due to the exposure to the outdoor environment as illustrated in Figure 7. The results of air temperature, wind velocity, and humidity for all 8 areas that have been studied are within the comfort zone. The results indicate the effects of the passive design strategies of Anjung Kelana on indoor thermal comfort in a hot-humid climate. For example, wind velocity (v) values in Bath 1, represent good ventilation in the area resulting from the passive design. Other evidence that shows the passive design plays a role in creating a comfortable internal temperature in Anjung Kelana is cross ventilation reduces heat and humidity in Anjung Kelana. Likewise with horizontal and vertical shading (Bedrooms), self-shading wall (Kitchen) creates comfort as illustrated in Figure 8 and Figure 9.

Figure 6: The Serambi area in Anjung Kelana

Figure 7: The Anjung area of Anjung Kelana

Large overhangs for rain and sun shading are also passive designs found in Anjung Kelana (Figure 10). In designing the building, the architect had to place openings in the East-West orientation that led to a beautiful view, Figure 10 and Figure 11 explain how Anjung Kelana overcomes this problem. Figure 12 shows the solar penetration study of Anjung Kelana. In general, the results of this study suggest that passive design strategies can help create thermal comfort in the building. This finding is supported by M. Hu et al. [28], a systematic review of the effectiveness of passive cooling strategies for residential buildings. Furthermore, results indicate that the cross ventilation, horizontal and vertical shading, self-shading wall and large overhang are among the passive designs used. This is supported by a previous study by A. Zulkarnain et al. [16] suggesting that shading devices are considered one of the major solutions to reach indoor thermal comfort and are key determinants for future architectural and urban design [29]. In other words, passive design strategies enhance indoor thermal comfort as reported by F. Garde et al. [30] and [18].

Figure 8: The bedroom area of Anjung Kelana

Figure 9: Passive design strategies of Anjung Kelana

Figure 10: Large overhang of Anjung Kelana

Figure 11: Wing wall of Anjung Kelana

Figure 12: Solar penetration study of Anjung Kelana

4.0 Conclusion

The study concluded that passive design strategies: cross ventilation, shading devices, large overhangs, and sun-path consideration affect the air temperature, wind velocity and humidity of the 8 internal areas of Anjung Kelana. It has succeeded in creating indoor thermal comfort in Anjung Kelana's house. The results demonstrate the effectiveness of passive design strategies in enhancing indoor thermal comfort. Further research, incorporating feedback from building occupants, is recommended to understand better the strategic implications of the impact in hot-humid climates. These findings can provide valuable insights for architects and building designers in selecting suitable passive design approaches to improve indoor comfort in a hot-humid climate.

Acknowledgement

The authors would like to express their gratitude for the cooperation and support from Ar. Azman Zainal, the owner and designer of the Anjung Kelana.

Author Contributions

Z. Kasim: Conceptualization, Methodology, Software, Writing-Original Draft Preparation; **A.Z. Md. Nor**: Data Curation, Validation, Writing-Reviewing, Supervision; **T. Vongpraseuth**: Content-Reviewing, Technical Content; **B. Daud**: Software, Writing-Reviewing and Editing.

Conflicts of Interest

The manuscript has not been published elsewhere and is not under consideration by other journals. All authors have approved the review, agree with its submission, and declare no conflict of interest in the manuscript.

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