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The Evaluation on Thermal Performance of *Rumah Negeri Sembilan Berserambi Dua dan Beranjung*

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ABSTRACT

Traditional Malay house, a passive design architecture, is believed to have more effective thermal performance than modern residential houses through climatic design strategies. Unfortunately, the Malay house has experienced numerous changes and is confronted with constant dangers due to present-day science and innovation. Thus, this study aimed at evaluating the thermal performance of *rumah* Negeri Sembilan *berserambi dua* dan *beranjung* for sustainable practice in the tropical environment. The method used was fieldwork: observation and thermal measurement. Comparing the suggested comfort level by ASHRAE 55 and ICOP, 20% percent of the total data is falls within the thermal comfort range suggested. However, the house is considered in comfort environment between 25-27ºC, which is only in the early morning. As for the wind flow, each house division recorded different readings. However, it was still within the comfort level range, i.e., between 0.12-1.25m/s, while the RH level was 50-60%. Therefore, the primary findings elaborate that the Malay house construction has five factors that directly influence the house's thermal performance. These include floor areas, openings, floor and roof heights, materials, open compound areas, and building setting. This study aspires to provide useful insights regarding the effectiveness of practices in the climatic design strategies of a traditional Malay house. Thus, its contribute to the scientific discussions on sustainable practices in modern residential design which aligned with the Twelfth Malaysia Plan (RMK12) Theme 3.

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1. Introduction

Passive design strategies take advantage of natural energy opportunities, to maintain thermal comfort in a building. In order to achieve and maintain thermal comfort, climatic design strategies are practiced. The strategies are about the appropriate building orientation and design, the properties of building materials, the local climate, and landscaping (Gulpınar Sekban and Düzgüneş, 2021; Jamaludin et al., 2021; Marro, 2018; Altan et al., 2016; Misni, 2015). These design strategies aim to produce an effective indoor thermal performance by capitalizing on prevailing winds and promoting indoor natural cross ventilation. Besides, they are also intended to avoid direct solar radiation in the interior spaces while ensuring natural daylight in the building. The strategies of this design are substantially practiced in vernacular architecture (Shaeri et al., 2018; Rapoport, 1969).

Understanding the climatic adaptations of the vernacular architecture requires understanding the climatic and environmental conditions of the houses's location. As a tropical country, Malaysia's climate can be classified as hot and humid. Its high temperature and humidity characterize it. Air temperature averages should be between 28 and 32°C with small annual and diurnal ranges. According to MetMalaysia (2021), humidity is high throughout the year, with an average of about 75% or more. Consequently, direct solar radiation is filtered with heavy clouds covering the high-water vapor content in the air. The winds are generally of low-variable speed, but strong winds can occur with the rains. Rainfall is also high throughout the year averaging from 2500 to 3000mm annually. To achieve optimal climatic control, the traditional houses are designed appropriately to suit specifically the vagaries of the tropical climate of Malaysia. They are appreciably suited to the local climate.

1.1 Climatic Design Strategy of Malay House

In Malaysia, these design strategies were developed and applied in traditional houses such as traditional Malay houses (TMH). According to Johari and Said (2021), Malay houses are among the best traditional houses that practice climatic design strategies. TMH is believed to have the right harmony with the environment by being responsive to the surrounding physical environment (Yaa'cob et al., 2021; Toe and Kubota, 2014; Toe and Kubota, 2013; Huang and Liu, 2010). It is known for its distinctive characteristics of the climatic design that give a positive response to the thermal condition.

The main element of its thermal qualities is raising the house floors on posts above the ground using low thermal conductivity materials, such as timber. Secondly, it has plentiful windows and ventilation lattices while possessing minimal partitions in open interior spaces to provide cross ventilation. Another element is the high or steeply sloping roof with ventilated *tebar layar* and *lubang angin* that promote cross ventilation. In contrast, the low wall of the house is to control direct solar radiation. Lastly, the houses are randomly arranged in the village area, strategically planting vegetation to allow wind paths (Kumar and Sharma, 2021; Misni, 2016; Kubota and Toe, 2012).

Research on the evaluation of the thermal performance of TMH in Malaysia has been widely done. Full-lenght operable windows allow maximum air from outside into the interior spaces, producing indoor cross-ventilation but poor performance in the stack effect (Hassan and Ramli, 2010). Meanwhile, Mohd Nawayai et al. (2020), Roslan et al. (2015), Abd Wahab and Ismail (2014) have proven that houses being raised on stilts with floor joist and having *lubang angin* as well as steeply sloping roofs with ventilated gable ends do contribute to encouraging air movement into the buildings. Besides, shady trees without bushy shrubs in huge lawn areas give less obstruction in allowing maximal cross-air ventilation and reducing direct solar radiation (Misni, 2016; Misni, 2015; Abd Wahab and Ismail, 2014; Toe and Kubota, 2013). Hence, these have proved that the Malay house is an intelligent building design as it depends entirely on natural resources and is built responding to local climatic conditions' needs.

1.2 Neglection of Traditional Construction Technology

Unfortunately, the Malay house is experiencing numerous changes and is confronted with constant dangers to its proceeded presence. Policymakers, analysts, and experts' inclination toward present-day science and innovation has led to the disregard and decay of its technologies and cultural forms. In addition, proper local building materials and design principles of the TMH forms are being supplanted by advanced impacts (Husen and Mohamed, 2021; Lim, 2010). As a result, the intelligent traditional construction techniques of the Malay house are being brought down and deserted.

Subsequently, house forms ought to alter to fit the changing needs of the users. Progressive changes within the Malay house forms are troublesome and improper since such changes are frequently forced from external sources and are missed by the local communities. Consequently, these changes are often insignificant and neglect local and socio-economic, social, and environmental conditions (Manurung et al., 2022; Lim, 2010). Sahabuddin (2016) stressed that when observing Malaysia's current housing project scenario, practically no housing concept can match traditional Malay houses' 'ancient science' concept.

1.3 Thermal Performance Evaluation

Therefore, this study highlighted research about evaluating the thermal performance of *rumah Negeri Sembilan berserambi dua dan beranjung* for sustainable practice in the tropical environment. According to previous studies, there is a lack of experimental studies done on thermal performance evaluation that engages the TMH which have curved roof structure and elongated floor plan. Roof with height angle design would give a positive effect as the incident solar radiation angle reaches zero degrees, reducing the solar radiation's penetration to the house (Ramly and Hussain, 2006). Furthermore, a shallow floor plan is more efficient because it facilitates more airflow inside the structure, practising the cross-ventilation technique (Yüksek and Karadayi, 2017). Correspondingly, previous studies' inference shows that most experimental studies on thermal performance have been keen on the basic design of *bumbung panjang*, *bumbung limas*, and Malay houses without the open passageway (Johari and Said, 2021; Saad et al., 2019; Toe and Kubota, 2013; Hassan and Ramli, 2010).

In this study context, evaluating is defined by using quantitative and qualitative techniques that can be used to assess the indoor thermal performance of the house. Moreover, the thermal performance of a building refers to the process of modeling the energy transfers between a building and the surroundings (Rathore et al., 2022; Nordin and Misni, 2017; Joseph et al., 2015; Misni, 2015). This study aspires to provide helpful insight regarding the effectiveness of practices in the climatic design strategies of a TMH. The findings will contribute to the scientific discussion on this subject towards a sustainable approach to modern residential design and the technology used. Besides, it is also aligned with the Twelfth Malaysia Plan (RMK12) Theme 3, where Malaysia aims to be a carbon-neutral country by advancing green growth and enhancing energy sustainability as early as 2050.

2. Methodology

In this study, two phases of the fieldwork were used. The first phase is the pre-survey case study, and the next phase is the data collection, as illustrated in Figure 1.

2.1 Phase 1

A pre-survey case study was applied to identify the potential case study. This process is required to obtain the case study material that fulfilled the criteria set. A purposive sampling method was applied to discover, understand, and gain insights at this research stage.

2.1.1 Type of House

Bumbung panjang (long roof) is Malaysia's most typical house form and has been chosen as the case study's house form. *Rumah bumbung panjang* in Negeri Sembilan have curved roof structure and elongated floor plan. Abdul Wahab and Bahauddin (2019), and Ismail et al. (2016) mentioned that the roof structure design is differ from other states due to evolve of a cultural migration movement by the people of Minangkabau. There are several typologies of the house and *rumah Negeri Sembilan berserambi dua dan beranjung* (RBDB) was chosen as the case study. This typology has curved roof structure slightly at the left and right, has *bumbung cerun bertingkat* (double-slope roof) between the roof of the *rumah ibu* and *serambi,* and the *tebar layar* (gable ends) at both ends of the roof (Ismail et al., 2016; Yaakub, 1996). Commonly, *rumah Negeri Sembilan* with *anjung* are for the houses of traditional chiefs and dignitaries (Ismail et al., 2014), others have different sizes and architectural styles and this can be clearly seen in the *serambi* (Ismail et al., 2017).

Furthermore, to identify the appropriate potential of case study, there are five justifications of house criterias were adopted as a guideline (Table 1); age of the house, house unit, authenticity, compound distribution, and cooling equipment. The criterias were obtained based on the analytical review of previous studies and documentation (Abdul Wahab and Bahauddin, 2019; Ismail et al., 2017; Ismail et al., 2016; Sahabuddin and Gonzalez-Longo, 2015; Kubota and Toe, 2012; Feilden, 2003).

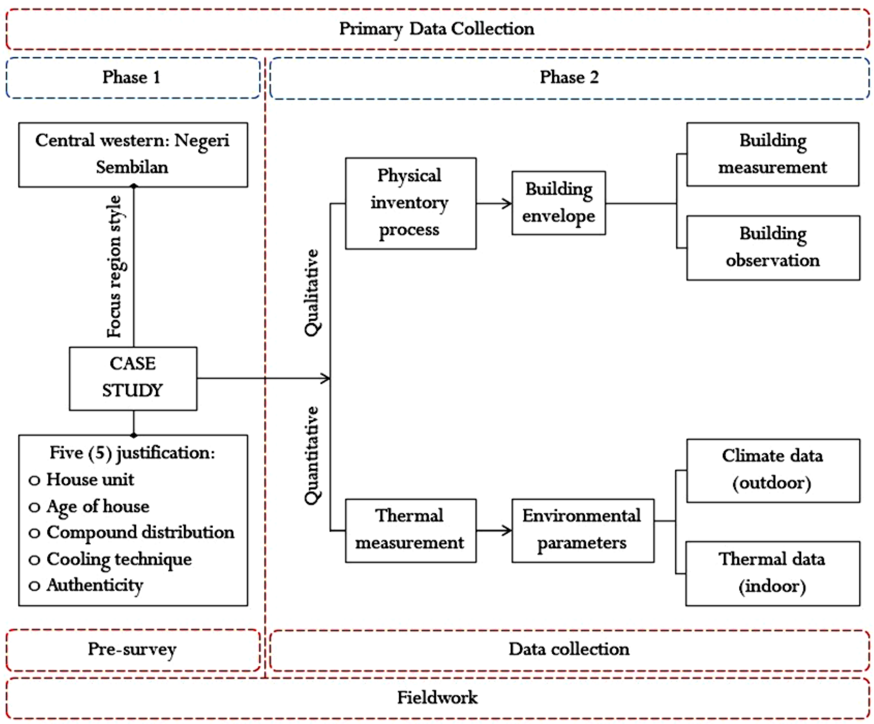


Figure 1 Fieldwork flowchart

Table 1 Case Study House Selection Criteria

Items	Authentic elements
House unit	Single-family house of traditional Malay house
Age of house	Approximately a 100 years old
Compound distribution	Malay house compound (front, sides, and back yard)
Building cooling control	Natural ventilation
Authenticity	Physical requirement elements (minor modification): o Use local low thermal capacity materials of building envelopes (wall/floor/roof)

	○ Elevated from the ground (built on stilt) ○ The large opening of the window and other openings ○ Original landscaping/edible/native plants in the surrounding compound ○ Strategic orientation of the house

2.1.2 Study Location

The selected study location for the RBDB typology was in Kuala Pilah, Negeri Sembilan. Kuala Pilah is located 37.9km to the east of Seremban. The study location was identified by reviewing previous studies for instance, Abidin et al. (2018), Abdul Latif and Kosman (2017), Sulaiman (2016), Ismail et al. (2016), Ismail et al. (2014), Chen et al. (2008) as well as the database from Center for the Study of the Built Environment in the Malay World (KALAM). Another relevance of selecting this specific location was due to the opportunity to access the house's thermal performance. In addition, the house also fulfills the essential requirement stated in Table 1.

2.2 Phase 2

A fieldwork study was carried out through observation and thermal measurements of the selected case study.

2.2.1 Data Collection

The primary data collection in this study used mixed methods; qualitative and quantitative. The first is qualitative via on-site physical observation and measurement which is called as on-site physical inventory process. This process requires collecting information regarding the following details: measurement of the house and compound with the layout respectively, physical architectural elements, building materials used, and mechanical ventilation system utilized in the house. The second was quantitative, thermal performance measurement. The data collection was conducted in August 2021 as this is the month when the most stable rainfall at an average of 150 to 250mm which expected in Negeri Sembilan, according to the Meteorology Department of Malaysia. Thus, the thermal data would be calm, and the sky is clear with medium cloud cover.

The thermal data collection was conducted in the interior spaces and exterior areas of the house. The indoor data acquisition point are about 1.1m above the floor level (ASHRAE, 2017) and 1.2m distance from any wall (CLEAR, 2019). In contrast, the outdoor area measurements are not less than a one-meter distance from the wall of the house and about 1.5m above the ground levels (Collow, 2020). There were 12 selected data acquisition points both indoor and outdoor (Figure 3). The data recorded were within 12 hours, from 07.00 until 19.30, with 30 minutes intervals over three days. No measurement was carried out at nighttime due to the owner's privacy.

In conjunction, other rationale the measurement taken only in daytime because it is the peak time where heat exists due to the presence of the sun. Therefore, it is reasonable in evaluating the influence of house design on the degree of regulation of indoor thermal performance. The data were only taken during the overcast sky (partly cloudy) condition, which is a typical type of sky condition in the tropical climate of Malaysia (MetMalaysia, 2021). No survey was conducted in rainy and clear sky condition. It is because the scope of this study was only to evaluate the thermal performance during the ordinary climate of Malaysia.

2.2.2 Environmental parameter and the comfort zone

Three specific environmental parameters were taken to measure thermal performance: air temperature, relative humidity (RH), and wind speed. The measurable scale for temperature is Celsius (°C), RH in percentage (%), and wind speed in meters per second (m/s) (ASHRAE, 2017). All parameters were measured using Delta OHM HD32.3 Data logger. The validation of climate data, including hourly temperature, relative humidity, wind direction and speed, and solar radiation, was obtained from the nearest meteorology station, Kuala Pilah Station and Hospital Seremban.

In order to identify and verify thermal performance and comfort zone of the house, the comfort zone recommended by ASHRAE Standard 55 (ASHRAE, 2017) and the Industry Code of Practice (ICOP) on Indoor Air Quality (IAQ) 2010 in the psychrometric chart (Figure 2) is used as a reference. Whereas the Malaysian Standard Energy Efficiency and Use of Renewable Energy (MS 2680:2017) (Table 2) is the measurable scale for the wind speed.

Sookchaiya et al. (2010) stated that the comfort zone by ASHRAE 55 in the psychrometric chart is the standard used worldwide. However, it can have a little different value because the climate type in any country worldwide varies with their comfort levels. Thus, their comfort zone has not been defined though. Based on the standard illustration in Figure 2, the comfort zone recommended by ASHRAE 55 is represented in the blue zone. The indoor temperature at the comfort level was supposed to be between 19 and 27ºC. Moreover, ASHRAE 55 suggests that the RH level should be between 30-80%.

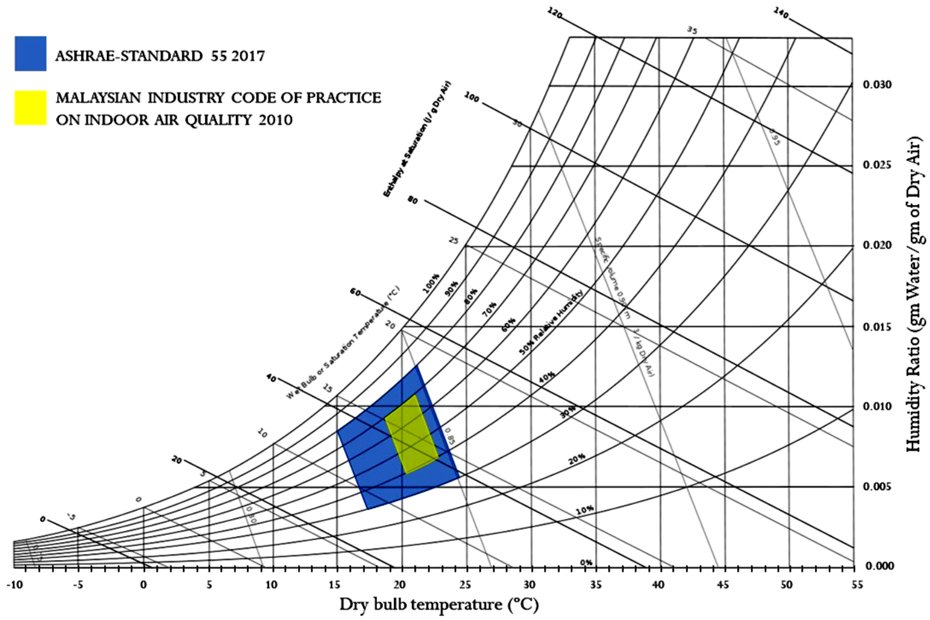


Figure 2 The thermal comfort zone in the standard psychrometric chart
(Modified from ASHRAE standard 55 and Malaysian Industry Code of Practice (ICOP) on Indoor Air Quality (IAQ) 2010)

Table 2 The Measurement Scale for Wind Speed based on the MS 2680:2017

Scale	Unit (m/s)	Description	Occupant sensation
1	≤ 0.25	○ Smoke (from a cigarette) indicates movement	○ Unnoticed, except at low air temperatures
2	0.25 - 0.5	○ Flame from a candle flicker	○ Feels fresh at comfortable temperatures but draughty at cool temperatures
3	0.5 - 1.0	○ Loose papers may be moved. Equivalent to ○ walking speed	○ Generally pleasant when comfortable or warm but causing constant awareness of air movement.
4	1.0 - 1.5	○ Too fast for deskwork with loose papers	○ Acceptable in warm conditions but can be from slightly to uncomfortably draughty
5	> 1.5	○ Equivalent to a fast-walking speed	○ Acceptable only in very hot and humid conditions when no other relief is available. Requires corrective measures if comfort and productivity are to be maintained

However, the Industry Code of Practice (ICOP) on Indoor Air Quality (IAQ) 2010 (yellow zone) proposed that indoor thermal comfort in Malaysia is slightly different from the ASHRAE 55. The recommended indoor thermal comfort should be at 23-26ºC, while the RH is between 40-70%. As for the wind speed, ASHRAE considered efficient indoor wind speed performance is between 0.1 and 0.8m/s. According to MS 2680:2017 (Table 2), the wind speed scale recommended by ASHRAE 55 is 1 to 3. Compared to the ICOP on Indoor Air Quality (IAQ) 2010, the suggested appropriate indoor wind speed is 0.15-0.50m/s on scales 1 and 2.

Nevertheless, the Beaufort Scale, a system for estimating wind strengths advises that the best wind speed performance level should be 1.6-5.4m/s. If the wind speed measurement is below 1.5m/s, the interior condition might be less convenient due to stagnant air and low wind flow to evacuate warm air to the outdoor. Compared to ASHARE 55 and ICOP on Indoor Air Quality (IAQ) 2010, it is shown that the Beaufort Scale prefers more significant air movement to provide a pleasant indoor environment for the occupant.

3. Results and Discussions

3.1 Case study

A RBDB located at Kampung Cheriau, Senaling, Kuala Pilah, with 2°41'39.5"N Latitude, 102°13'41.9" E Longitude, and an elevation around 114m above sea level was chosen as the case study. The house owner is Mr. Razali A. Kadir, and it was inherited from his late grandfather. Four occupants are living in the house. The age of the house is around 153 years with a total built-up area of 152.62m^2, and the outdoor lawn compound area is 604.71m^2.

The house has possess the criterias as in Table 1. The pedestal fans as mechanical ventilation equipment were only used when there are feasts or events. Figure 3 illustrates the orientation of the house and data acquisition point at indoor outdoor area. The front of the house is facing southeast, while the main entrance is oriented to face northeast. In addition, the bedroom is in the southwest direction, and the kitchen is facing northwest. Whereas the main direction of qibla is 293° 30'.

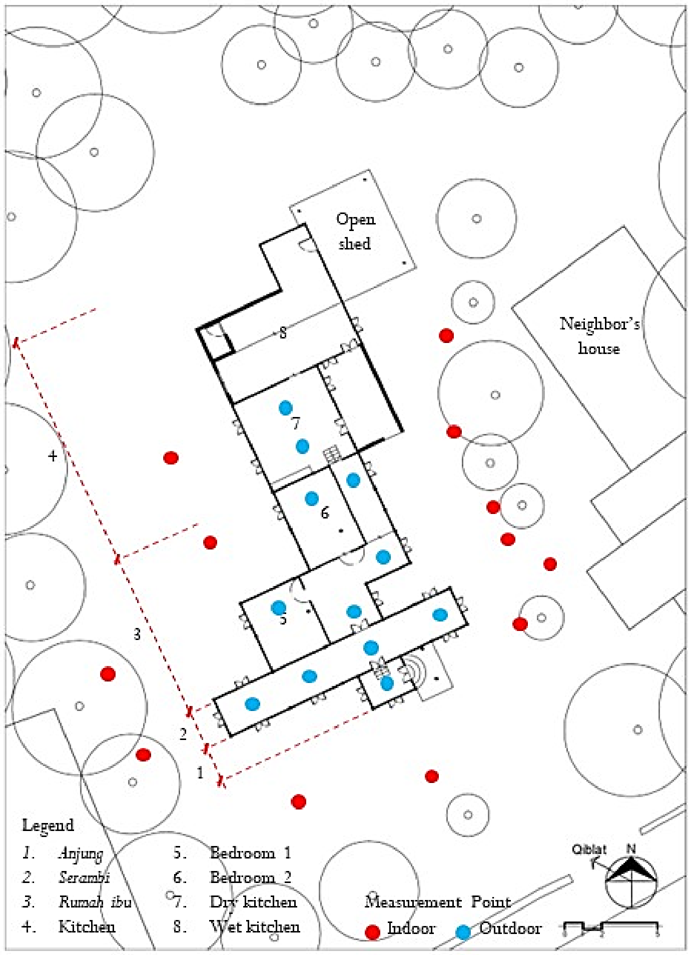
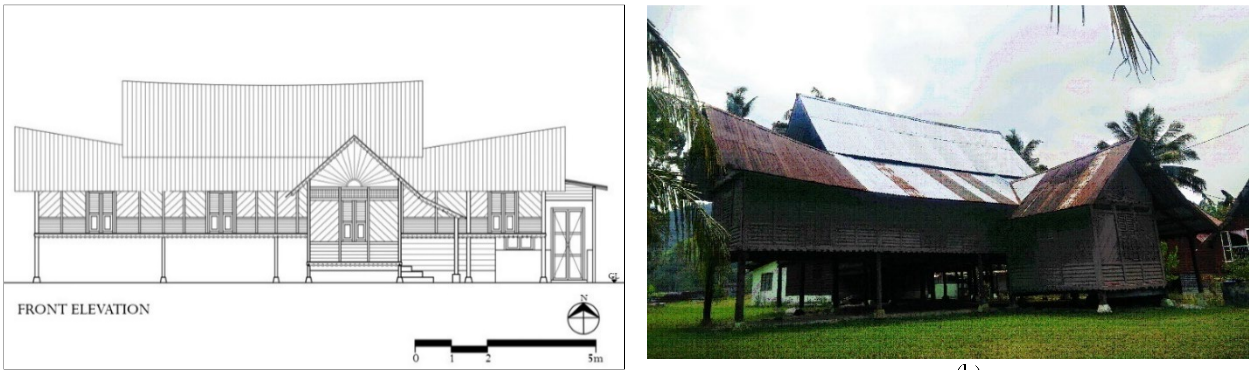


Figure 3 The house's spatial division and the location of measurement points inside the house and outdoor area

3.2 Physical Inventory Data

The roof design has curved roof structure slightly at the left and right, and *tebar layar* at both ends, as shown in Figure 4a. The house was designed with *bumbung cerun bertingkat* between the roof of the *rumah ibu* and *serambi*. This indicates that the house has ample roof space with the highest roof pitch at *rumah ibu* which reaches about 5.6m. In addition, the roof has ventilated gable end features. The original roof material has been replace to zinc sheet (Figure 4b) and was designed without a ceiling. The case study has four spatial divisions: *anjung*, *serambi*, *rumah ibu,* and kitchen. The house was built on stilts which is only at the front part of the house. It has a timber structure elevated about 1.2m (*serambi*) *and 1.*35 (*rumah ibu*) above the ground. Moreover, the *anjung* is elevated above the ground by about 0.5m. While the rear parts of the house were built using a brick-and-timber structure directly on the ground; kitchen and toilet. The house has undergone some modifications and extensions of space. The wet kitchen and open shed are the areas that have been extended from the actual space.

Rumah ibu is the largest area with 53.9m^2 (compared to the other front part) followed by *serambi*, 29.3m^2. In comparison, *anjung* is the compact among the spatial division, which is 4.6m^2. The house was constructed using timber material. The floor and roof joist, as well as gable ends with ventilation lattice are examples of passive ventilation devices in house construction (Figures 5). Besides, the house has plenty of full-lenght operable windows at body level. Moreover, the house was also fabricated with ventilated *kepala tingkap pagar musang* and *lubang angin*. Besides, the windows came with wooden louvers paneling. As for the floor finishes, the house uses a rubber mat in Bedroom 1, dry and wet kitchen, while the other spaces are not covered with any finishes. Thus, indirectly, it has many passive ventilation devices that convey natural airflow into the house.



(a) (b)

Figure 4 The front elevation (a), and the roofing material which is using zinc

(a) (b)

Figure 5 Plenty of full-length operable windows at the body level, ventilated *kepala tangkap, pagar musang* and *lubang angin* (a), and the ventilated gables end and f full-length wooden panel operable windows with louvers paneling (b)

3.3 Thermal data

The average thermal (indoor and outdoor) were recorded according to the spatial divisions; *anjung*, *serambi*, *rumah ibu,* dry kitchen and outdoor area. The instrument's setup and the house's thermal data measurements are presented in Figure 6 and Figure 7.

Based on the overall measurement, most of the time, the indoor air temperature ranged between 30.2 and 35.7°C which were not under comfort level. The house was only under a comfort level between 07.00 and 09.00 hours which is refer to the psychrometric chart. The temperature ascended from early morning until late noon, with the solar radiation pattern recorded at 2.75 MJ/m^{-2} at 14.30 hours. This situation happened due to the material used in upper part (roof), which is zinc. The roof is exposed to heat caused by high solar radiation and high emissivity levels. The roof accumulates heat, cause the indoor air temperature arised. The RH reading was within the comfort level range (73.2-74.8%) between 09.00 and 19.30 hours. While wind speed data recorded were also within the acceptable range which is between 0.12 and 1.25m/s (Scale 1 to 4) and it is acceptable in warm conditions.

Anjung recorded the highest indoor temperatures at peak hours (11.30-14.00 hours) than the other spatial divisions. It ranged between 35.3 and 35.5°C, which was not in a comfortable environment. While, RH level is maintained at the comfort level during the peak hour and the reading was between 52.5 and 57.7%. As for the wind speed reading, it recorded the most wind flow. The reading was between 0.38 and 1.26m/s (Scale of 2 to 4). However, from early morning until early noon, this area measured the lowest temperature. Other than the zinc roofing driving the increases in temperature, compact space along with *anjung* which was not built elevated above the ground same level as the *serambi* were also part of it. As a result, the warm air is trapped due to compact space even though it receives most wind flow because it cannot smoothly circulate to the adjacent space, *serambi*. Wind flow can easily penetrate into the *anjung* because the half-length operable windows with louvers paneling and ventilated *kepala tingkap* were designed facing the wind flow direction (south to east). In addition, there were fewer trees planted in the lawn front yard. Hence, the wind can freely glide into the space without any obstructions.

(a) (b)

Figure 6 The setup of the instrument (a), and the Delta OHM HD32.3 Data logger (b)

Meanwhile, the indoor air temperature in the *serambi* was slightly lower than *anjung* at noon but still not in comfort level. The range of differences was 0.2ºC, despite that, the wind speed rate was not as high as *anjung*. It has a light air movement. The reading was within the range of 0.13-1.2m/s (scale 1 to 4). Meanwhile, RH level was within comfort level, between 53.1 and 55.21%. Despite of using the same roofing material, this thermal performance ensued as *serambi* has plenty of full-lenght operable windows with louvers paneling, ventilated *kepala tingkap*, *pagar musang* and *tebar layar* at both ends of the roof. Besides, it was built elevated 1.2m above the ground level. The raised floor built higher than the ground can obtained and enabled higher-velocity winds to pass through, added with elongated open plans without any partition across the space, thus providing a cross-ventilation technique. The maximal wall openings outturn in significant air intakes outside the house aided to dispense warm air into the outdoor area. Despite that it resulting to poor stack effect performance. Furthermore, the floor joist, which creates small gaps between the planks, might help to circulate air throughout the space. While the ventilated *tebar layar* and roof joist were also fabricated to perforate the warm air. Other than that, *serambi* is designed with low roof overhang, minimizes the glare from the sun and the amount of direct sunlight entering the house.

Compared to the *rumah ibu*, even though it was constructed as the middle annex of the house, the indoor air temperature was cooler than *anjung,* and *serambi* but still not under comfort level. The measurement at noon ranged between 33.6 and 34.7ºC. The range of differences was between 0.8 and 1.6ºC. However, the wind flow reading was lower than in *anjung,* and *serambi*, between 0.15 and 0.32m/s (scale 1 and 2). As for the RH level, the reading was uniformed. The range of differences was 0.1%. Eventhough the roofing material is zinc, the thermal reading was lower because *rumah ibu* is designed with *bumbung cerun bertingkat* this means it has ample roof space and the highest roof pitch is about 5.6m. Therefore, the space below the roof helps effectively cool the house by stacking the warm air and executing it through the ventilated *tebar layar* and roof joist. As for the low wind flow rate, despite of having the largest area with 53.9m^2 among *anjung,* and *serambi, rumah ibu* was not designed as open floor plan. It has few walls to enclose the bedroom 1 and 2. In addition, this spatial division was built with operable windows without louvers paneling, ventilated *kepala tingkap*, and *pagar musang*. This characteristic resulting in degenerate the wind circulation in the space as well as reduce the speed rate.

The kitchen has recorded the lowest air temperature from noon until evening compared to the other spatial divisions. The measurement ranged between 31.9-33.5ºC, but it is still not within the range of comfort level. The kitchen has ample open space compared to other areas with minimal interior partitions. It also has some half-lenght operable windows with ventilated *kepala tingkap.* Hence, these elements assist in circulating the cool air in interior space without any obstacle. Furthermore, it is also can allow easy passage of warm air discharge from the area. Nevertheless, the wind speed measurement was at the lowest rate in contrast to other spatial divisions. The highest reading was 0.32m/s (scale 2), and most of the time, it was at 0.01m/s. Meanwhile, the RH level was under the range of comfort level. The reading ranged from 55.2 to 55.8%.

To deduce, in the evening (17.30-18.30 hours), all the spaces seems to have a contrary reading where there are significant air temperature differences in comparing to outdoor weather data. It shows that the indoor temperature is higher compared to outdoor data. The same thing also applies to the wind speed reading. There are barely reading at indoor area for all the spaces eventhough outdoor wind speed rate within the scale 1 and 2. This proves that wind movement is essential to cool the interior of the house.

3.3.1 Comfort zone of the case study

To identify and verify the house's thermal performance and comfort zone, the average lowest and highest air temperature, as well as the RH, are illustrated in the psychrometric chart (Figure 8). The orange zone in the psychrometric chart indicates the case study's thermal performance. Comparing the suggested comfort level by ASHRAE 55 and ICOP to the house's thermal performance, it stipulate that the indoor environment is not at the comfort level most of the time. It is only about 20% percent of the total data is falls within the thermal comfort range suggested by ASHRAE 55 and ICOP. The comfort condition was only can be experienced in the early morning in all spatial divisions.

Therefore, the factors that influence the thermal environment of the house are identified. Replacing original roof material to zinc sheet give the significant influence towards thermal performance where it has generate a warmer indoor environment. In relation to that, it also reducing the effectiveness passive cooling strategy. The zinc sheet has a fast heat conductor, after receiving radiant heat from the sun, the zinc releases the heat into indoor spaces by employing convection and radiation. This has caused the indoor air temperature increase dramatically. Nevertheless, this Malay house still practices several other climate design strategies to regulate the indoor thermal performance.

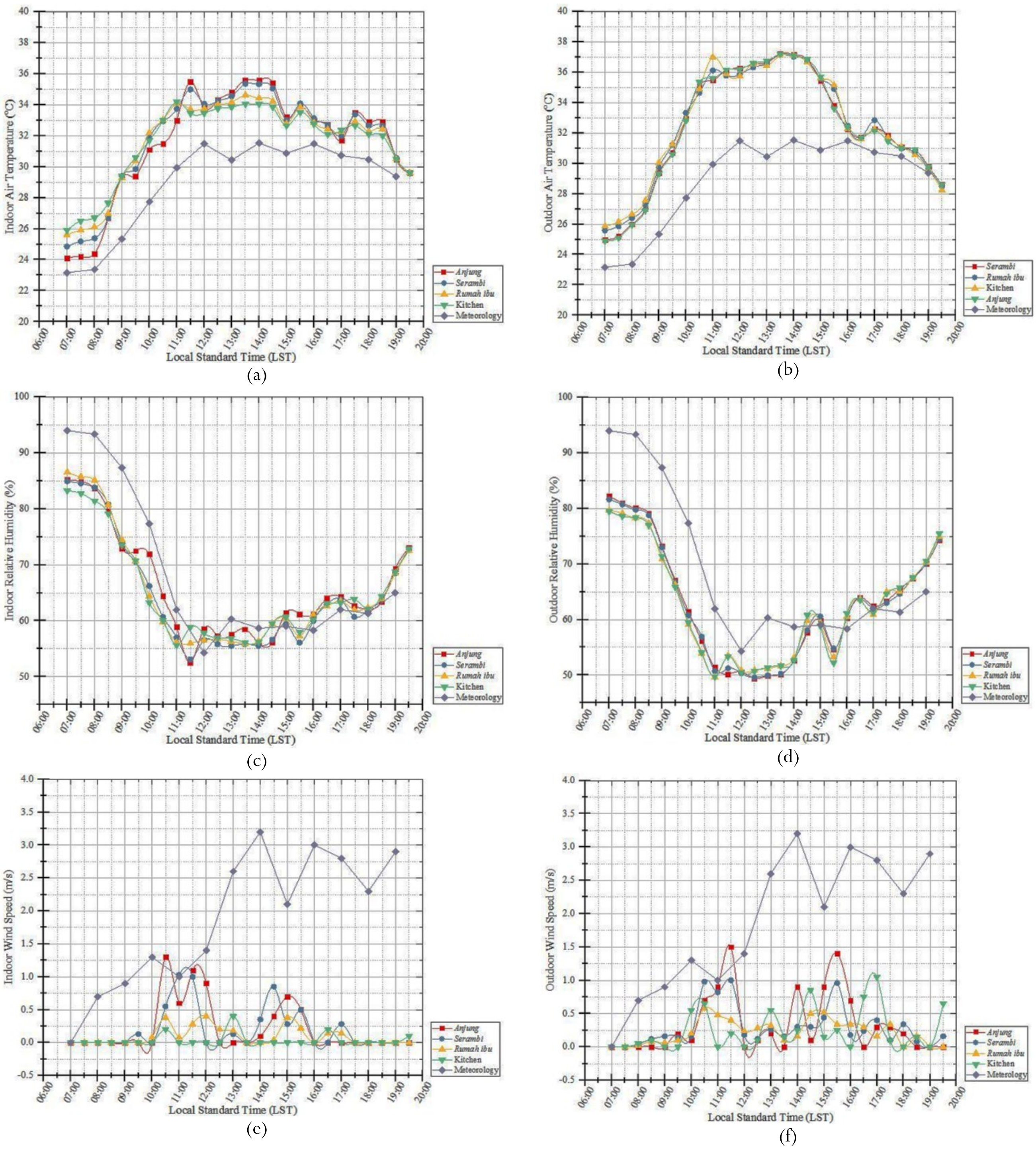


Figure 7 The house's thermal data measurements

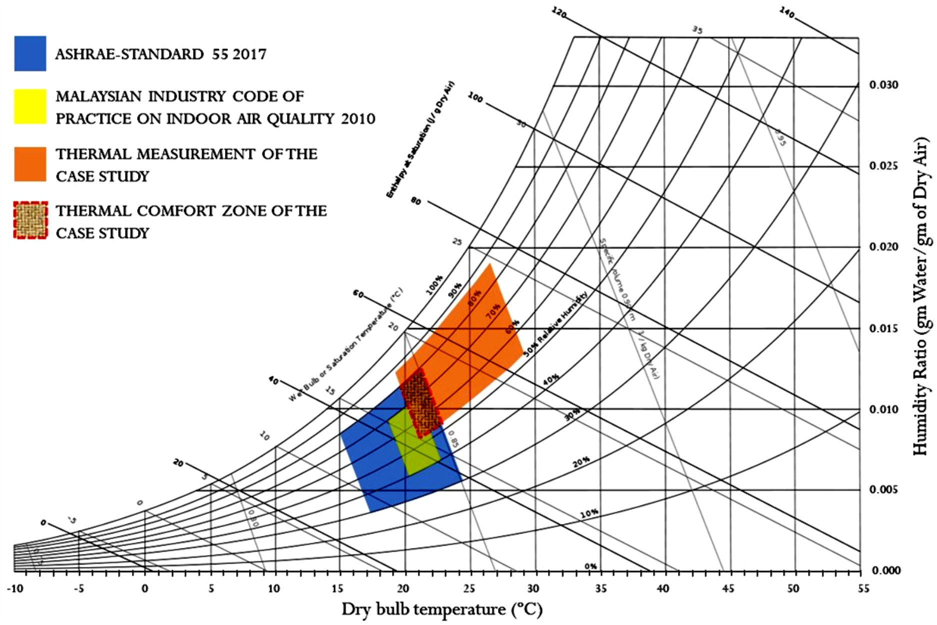


Figure 8 The comfort zone of the case study

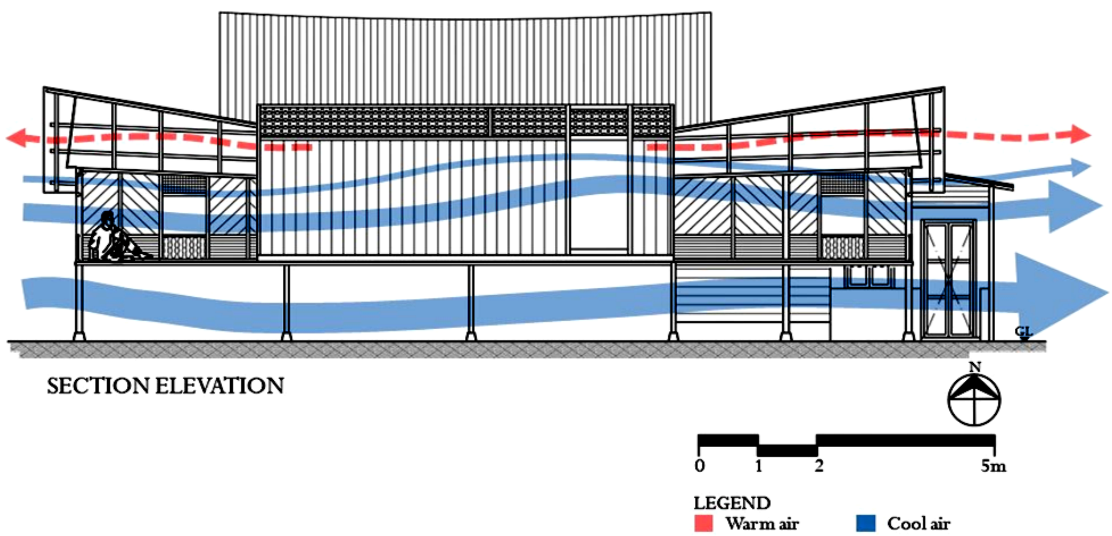


Figure 9 The passive ventilation through the opening such as windows and *tebar layar*

Elongated open plans without any partition across the space with plenty of operable and large size windows as well as built on stilt were practices, providing cross-ventilation technique (Figure 9). At the same time, *bumbung cerun bertingkat* which has ample roof space, aid the space below the roof to effectively cool the house by practicing the stack effect technique, the warm air were execute through the ventilated *tebar layar* and roof joist. Moreover, in order to encourage wind flow easily penetrate into indoor space, operable windows with louvers paneling, ventilated *kepala tingkap, pagar musang* as well as *lubang angin* were designed strategically facing the wind flow direction. Other than that, there were fewer trees planted in the yard. The plant is in strategic placements around the house's compound area, thus the wind can freely into the space without any obstructions.

4. Conclusion

This study has demonstrated the essential strategies that existed in TMH, technically. The passive and climatic design strategies in TMH have a lot to offer to develop building construction, especially in the tropical country of Malaysia to attain a degree of passive control, thus providing comfortable conditions. It can be deduced that there are five features of RBDB typology construction that directly influence thermal performance which lead to indoor thermal comfort. They are size of the space, opening, floor and roof heights, materials, open compound area, and building settings. Nonetheless, the percentage of thermal comfort is too low compared to suggested by ASHRAE 55 and ICOP, showing that it is not significant enough to be the reference for modern housing.

The primary aspect that generates this eventuate is the replacement of the original roofing material with zinc sheet. As suggestion, the zinc sheet can be replace with the ceramic roof tiles. It is because the ceramic material would provide better indoor thermal performance by reduce heat transmitted. This material could decreases up to 60% or less than asphalt shingles of heat which transmit from the ceramic tiles roofing into the ceiling (Miller et al., 2007). In addition, another elements that should be considered as part of the passive design strategies is the roof color. The majority of roof tiles in Malaysia are dark in color, which means that it absorbs more heat (Roslan et al., 2015). However, having natural ventilation devices has to assist to lessen the warmer indoor environment and occupants overcome the situation.

Therefore, to ought a justifiable finding, statistical adaptive (SA) models should be applied and recommended in further thermal comfort assessment. SA model is the advanced study to acknowledge thermal comfort based on particular environmental conditions. The findings from these models emphasize the value of post-occupancy data. Other than only evaluating the occupant's comfort level by measuring the indoor environment and verifying the result through the standards, the occupant's perception is also needed to enhance the understanding of the indoor environment. This survey will help verify and identify which thermal condition gives adequate performance to the occupants. In addition, adaptive comfort standard (ACS), an alternative adaptive model by ASHRAE 55 is advised to use for determining and analyzing permissible thermal conditions in occupant-controlled naturally conditioned spaces or natural ventilation (NV) buildings.

Additionally, to apprehend the different strategies which influence the indoor thermal pattern of the tested house, scientific evidence through computer simulation is suggested. The simulation should be graphically intelligiblly illustrated through the use of any software, such as computational fluid dynamic (CFD). Besides, the experiment could identify the best strategy to achieve thermal comfort for the tested house. Through this study can aspires to provide useful insights into effective climatic design strategies in a TMH. The findings will contribute to the scientific discussions on this subject towards sustainable practices in modern residential. Therefore, it is possible to reinvent the housing design process as long as people in this industry can cooperate to achieve the goal of sustainable housing and respond well to the local tropical climate. This is crucial to ensure that modern house designs for Malaysians are of good quality and fulfill the people's expectations of sustainable housing. Thus, it is aligned with the Twelfth Malaysia Plan (RMK12) Theme 3, where Malaysia aims to be a carbon-neutral country by advancing green growth and enhancing energy sustainability as early as 2050. Apart from it, the intelligent traditional construction techniques of the Malay house can be preserved and prolonged.

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