Negeri Sembilan Malay House Thermal Performance Evaluation towards Sustainable Practice

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Abstract

Traditional Malay House has practices climatic design strategies and getting extinct due to urban development. Consequently, generated urban heat island, causing increased energy consumption for cooling purposes. Therefore, a modern house has an inefficient passive thermal design. Aim: To assess the thermal performance of *Negeri Sembilan* traditional Malay house towards sustainable practice in the tropical environment. Findings: house openings allow cross-ventilation, less strategic house orientation towards the environmental condition and roofing materials contributes discomfort indoor environment, reaching 35ºC during peak hour. This research focuses on improving construction technology for modern architecture to provide a functional indoor environment in a tropical climate.

Keywords: Malay House; Traditional Architecture; Thermal Performance; Tropical; Environment

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1.0 Introduction

Traditional architecture makes use of quite advanced architectural technologies that are well suited to the tropical climate. Naseer (2013) stated that traditional architecture has a high value in terms of the construction process. It has a passive thermal design that is compatible with the local environment as a standard feature. In Malaysia, a traditional Malay house is one of the best examples of traditional architecture that uses climatic design strategies (Toe et al., 2013). This impressive building has emphasized climatic design to provide the residents with the best possible thermal comfort. Previous research has shown that every detail in traditional Malay home architecture, for example, adapts to the surroundings and responds to the physical and climate conditions. Furthermore, lightweight materials (low thermal conductivity materials) were employed to create an outstanding thermal performance in the house's surroundings.

On the other hand, the traditional Malay house underwent significant modifications and faced ongoing threats to its continued existence (Cockrem, 2003). When observing Malaysia's current residential project scenario, Sahabuddin (2016) stated that there is no notion of housing that can equal the "old science" notion of a traditional Malay house. Furthermore, rapid urban expansion has resulted in urban sprawl (Chung et al., 2018) due to population expansion. It has created an Urban Heat Island (UHI) in the metropolis (Ramakreshnan et al., 2018). It has resulted in increased energy use in the residential sector for cooling purposes (Misni, 2017; Lundgren et al., 2013; Cartalis et al., 2001). According to Zin et al. (2012), modern building construction is inefficient in passive thermal design. Toe et al. (2013) discovered that the passive design system in traditional Malay houses is used to achieve thermal comfort in structures. It is because, in comparison to modern homes, it has a more excellent thermal performance. As a result, the primary purpose of this study is to assess the thermal performance of a traditional Malay house in Negeri Sembilan in a tropical environment to build a long-term practice.

2.0 Literature Review

One of the most distinguishing features of traditional architecture is that it is created with a deep awareness and respect for the natural world. Traditional societies had a deep understanding of nature's ways and environmental balance since they relied heavily on nature for most of their resources. The climatic design of the house was expressed in the design with the natural approach found in traditional Malay houses.

The Malays constructed and built the house with these considerations in mind to achieve ideal climatic control. As a result, Malay house architecture is well-suited to the fluctuations of Malaysia's tropical climate. It is far more in keeping with the environment than a modern Western-style brick home (Yuan, 1988). According to prior research, a traditional Malay house has four key thermal quality. They are a traditional Malay village and Compound, built on stilt, walls and openings, and double-slope roof.

2.1 Traditional Malay House Arrangement and Compound

In the linear village area settlement, Malay dwellings are arranged sporadically and haphazardly. The house is set off from other homes and units, with plenty of outdoor space. This accidental design indirectly helps to reduce prevailing winds in coastal areas, where wind speeds are higher than in inland places (Kubota et al., 2012; Sahabuddin, 2012). Furthermore, it ensures that wind velocity in houses in the wind's final route does not significantly decrease (Kamal et al., 2004).

The Malays used observation, sunlight orientation, and religious ceremonies to choose house sites in the past. For religious reasons, traditional Malay buildings are usually oriented to face Kaaba (Mecca) (292.5°, east-west orientation), reducing the area of exposed walls to direct solar radiation throughout the day (Yuan, 1988). In Malay home compounds, crop-bearing trees such as coconut trees and high-branched fruit trees are widely planted. Furthermore, it does not obstruct the passage of wind at the house level. Traditional Malay kampongs have open area complexes that can stimulate social interaction within communities (Sahabuddin, 2012; Yuan, 1988).

2.2 Built on Stilt

The house was built on stilts to provide adequate ventilation and safety. In many ways, the people who live in the house will profit from this concept and approach. The advantages can come from a thermal, functional, or safety standpoint (Sahabuddin et al., 2015). Higher-velocity winds may be caught by the elevated floor, which is higher than the ground (Yuan, 1988), and the floor joist, which has small spaces between the boards, may convey the air to the inside (Hosseini et al., 2014). The raised floor is one solution to the moist ground, which requires more sunlight to dry (Hanafi, 1994). Furthermore, it facilitates cross-ventilating breezes beneath the home while reducing the impact of floods (Amad et al., 2007). Moreover, it is to protect them from potential attacks by wild creatures in their immediate vicinity.

2.3 Openings and Minimal Partitions

The house contains many full-height movable windows designed to be at body level to promote internal ventilation (Kubota et al., 2012; Sahabuddin et al., 2015). The most crucial area for indoor ventilation is at the body level (Kamal et al., 2004). According to Hosseini et al. (2014), windows are frequently constructed with above ventilation lattice in wide openings. Furthermore, inside the house, few partitions generate a sense of openness for the utilitarian spaces. Moreover, Kamal et al. (2004) say that houses with wide-open plans and few interior partitions allow for simple airflow and proper cross ventilation. Talib et al. (2012) and Hosseini et al. (2014) discovered that above ventilation lattice on windows or openings aid increase cross-air ventilation by allowing natural wind into the house. However, Hassan et al. (2010) found that maximal openings on the walls result in significant air intakes outside the house, resulting in poor stack effect performance.

2.4 Double-Slope Roof

A traditional Malay house's roof space is well-ventilated thanks to ventilation joints and panels built into the roof structure (Kamal et al., 2004). The air-ventilated through space below (attic space) permitted by the sloping gable roof pitched effectively cools the dwelling. It's also to keep the warm air out and the cold air (Hosseini et al., 2014). According to Yuan (1988), the attap roof utilized in Malay dwellings is an excellent thermal insulator. This material does not absorb heat and cools quickly when exposed to it. Gable ends (*Tebar Layar*) are another climatically adaptable double-slope roof form. It is part of the ceiling's aesthetic feature and has a variety of motive designs. This component also includes ventilation panels that allow proper air into the roof space while also cooling the house's interior. The gable ends with ventilation in traditional Malay houses and can extend up to 5 to 9 metres in height (Sahabuddin, 2016). The vast roof eaves are also covered with a light and effective thermal insulator made of local palm fronds, which absorbs only a little amount of heat during the day and cools down at night.

3.0 Methodology

The data collection is carried out through the field measurement method. A traditional Malay house in *Kuala Pilah, Negeri Sembilan*, was chosen as the case study. The Malay house located at *Kg. Cheriau, Kuala Pilah, Negeri Sembilan* (Figure 1a & b). *Kuala Pilah* has located 37.9km to the east of Seremban with 2°41'39.5" N Latitude and 102°13'41.9" E Longitude. The owner of the house is Razali bin A. Kadir. The researcher chose this house based on the five-justification. They are the age of the house, house unit, authenticity, compound distribution and cooling equipment.

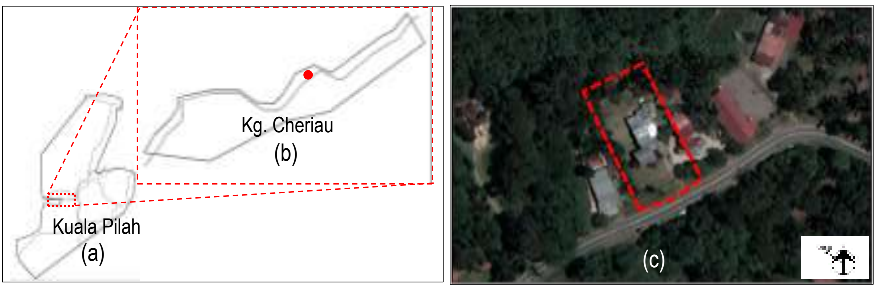
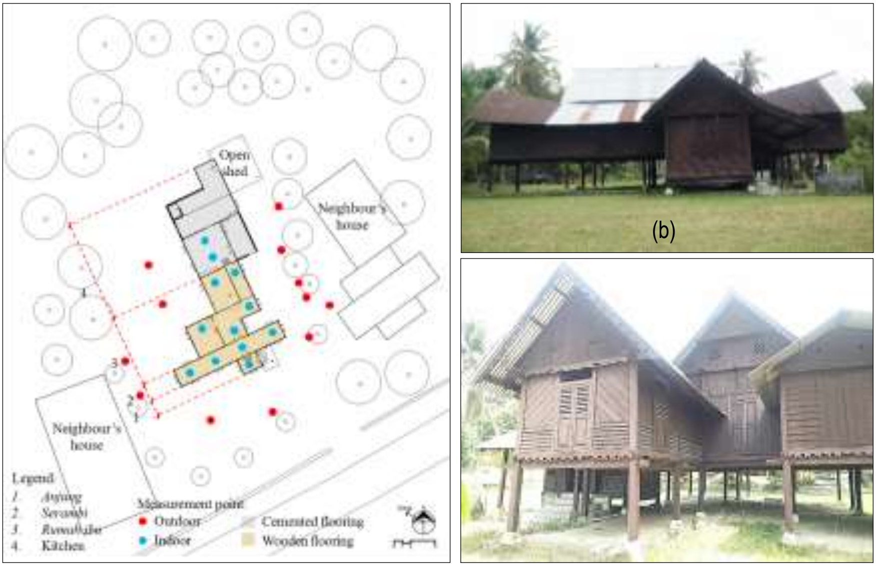


Figure 1 The key plan of *Kuala Pilah, Negeri Sembilan* (a), location of the *Kampung Cheriau, Senaling, Kuala Pilah* (b), and the site plan of the house (c)

With neatly planted greenery and a grassy compound area, the house offers a typical Malaysian rural village. Figure 1c shows the house is oriented to face east-west direction, with the direction of qibla is 293°30'. The house was built over 150 years ago, with a total area of 153.2m^2 (1655.5sqft). It is a detached house. The typology is *Rumah Bumbung Panjang Berserambi dua* and *Beranjung*, and the house form is a long roof. This house is divided into four spatial: *anjung, serambi, rumah ibu*, and a kitchen (Figure 2a). It has a timber structure elevated 1.1m (*serambi* and *rumah ibu*) and 0.5m (*anjung*) above the ground. The brick-and-timber construction in the back of the house was built directly on the ground.

This study has a two-stage fieldwork process: i) observation method and ii) experimental study. Stage (i) is a physical inventory process that collects the following information: house and compound measurements, physical architectural components, building materials used, and mechanical ventilation. Stage (ii) is an experimental study on thermal measurement. The measurement is conducted on 19, 21 and 22 August 2019. In *Negeri Sembilan*, August is projected to have the most consistent rainfall, with an average of 150 to 250mm (Met Malaysia, 2019). The thermal data remains calm, and thus the sky is clear with a medium amount of cloud cover.



(a) (c)

Figure 2 Site plan: The house's spatial division and measurement points inside the house and outdoor area (a), the long roof house form and zinc as a roofing material (b) and full-height timber panel windows and gable end.

The data was gathered in both the interior and outside sections of the house. A point for indoors is 1.1m above the floor level (ASHRAE, 2016) and 1.2m from any wall (CLEAR, 2019). 5m from the home wall and 1.5m above the ground for the outside area (Tcollow, 2014). The data collecting takes place over 12 hours, from 7:00 to 7:30 p.m. Because of the homeowner's privacy, no measurements are taken at night. The data was collected at 30-minute intervals and was only acceptable when the sky was overcast (partly cloudy). There is no survey taken while it is raining or there is a bright sky.

The measuring scale, which refers to ASHRAE, can be identified by the environmental characteristics. Air temperature (degrees Celsius), relative humidity (%), and wind speed (m/s) are the three variables. The data was recorded using an Anemometer 4 in 1 instrument. Indoors, there are 12 points, and outside, there are 12 points. The Canadian index Humidex measures temperature and relative humidity (Hassan et al., 2010). Humidex is a metric that expresses how people react to the combined impacts of hot weather and humidity (CCOHS, 2019). The range is shown on the quantifiable scale (Table 2). The temperature factor's performance at No. 2 is thought to be the best. Furthermore, Rahman (1995) discovered that Malaysia's most comfortable interior temperature is between 25.5 and 28°C, while Misni (2012) defines the comfort zone as 20 to 27°C.

The optimum indoor relative humidity level for RH is between 30 and 60 percent (Table 3). This factor's assessment scale is separated into three degrees of performance, as indicated in Table 2. In terms of wind speed measurement, the Beaufort Scale was used in this study. The Beaufort Scale (Croft, 2019) is a technique for assessing wind strengths, and No. 2 and No. 3 are considered the optimum levels of wind speed performance at 1.6 5.4m/s (Table 4).

The data acquired (observation and thermal measurement) is then compared and evaluated to determine the Malay house's thermal performance.

Table 2 The measurement scale for temperature

Scale	Description	Celsius
0	Cold	Less than 16
1	Cool	16-25.5
2	Comfort	25.5-28
3	Warm	28-32
4	Hot	32-40
5	Extremely hot	Above 40

Table 3 The measurement scale for relative humidity (RH)

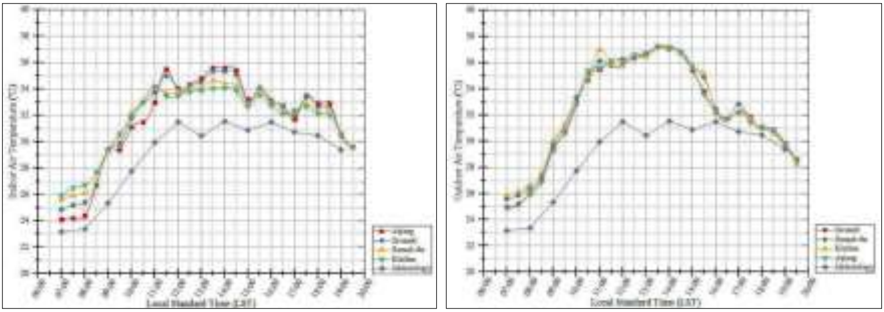
Scale	Description	Percentage (%)
1	Low	Below 30
2	Ideal comfort	30-60
3	High	Above 60

Table 4 The measurement scale for wind speed

Scale	Description	m/s	Condition
0	Calm	< 0.3	Calm smoke rises vertically.
1	Light air	0.3 - 1.5	Wind motion visible in smoke.
2	Light breeze	1.6-3.4	The wind felt on exposed skin. Leaves rustle.
3	Gentle breeze	3.3 – 5.4	Leaves and smaller twigs in constant motion.
4	Moderate breeze	5.5 – 7.9	Dust and unattached paper raised. Small branches begin to move.
5	Fresh breeze	8.0 – 10.7	Branches of a moderate size move. Small trees begin to sway.

4.0 Results

This section describes the measurement of thermal data according to the geographic division of the house: *anjung, serambi, rumah ibu*, and kitchen. Figures 3, 4, and 15 demonstrate the house's thermal data measurements (inside and outdoor).



(a) (b)

Figure 3 Measured indoor (a) and outdoor (b) of air temperature based on the spatial division.

According to figure 3, *anjung* has recorded the lowest indoor temperatures from 7.00-11.00 hour than the other spatial division with the range of differences 0.75-1.43ºC. However, at 11.30 hours, it has recorded a drastically ascend to 34.7ºC, scale No. 4 (Hot). Thus, *anjung* was not in their comfort zone at peak hour (12.30-14.30 hours). In contrast, the kitchen recorded the warmest indoor space between 7.00-11.30 hours with temperature ranging between 25.9-33.45ºC as well as the outdoor temperature.

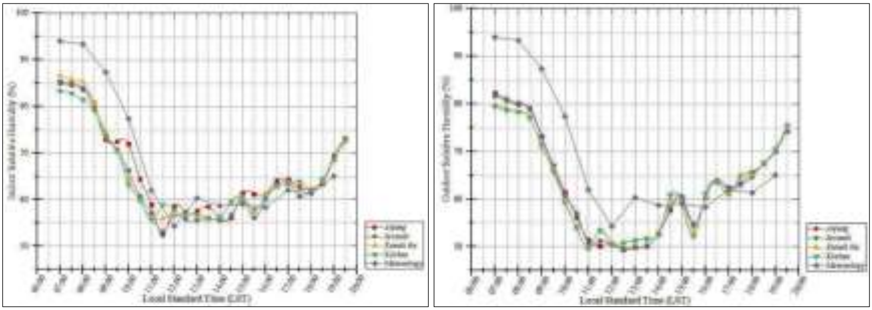
The temperature at *serambi* has the same pattern as *anjung*, where the indoor temperature has recorded a drastically ascend from 11.00-11.30 hours to 34.98ºC. However, the indoor data recorded still lower than anjung with 0.52ºC differences. Meanwhile, *rumah ibu* and kitchen had the same marking range of differences 0.28-0.57ºC. At 14.30-15.00 hours, all of the spatial division recorded a substantial fall of indoor's reading. While at outdoor, it was persist dropped till 16.30 hours. Between 17.00-17.30 hours, the indoor temperature rose while the outdoor temperature run down. The data recorded that indoor or outdoor temperature for all the spatial division declined at 18.30-19.30 hours, the range of differences 1.9-1.15ºC respectively.

Table 5 Average air temperature of the case study

Location	Hour @ Temperature (°C)				
	7.00	10.00	13.30	16.30	19.30
Indoor	25.12	31.71	34.91	32.48	29.61
Outdoor	25.46	33.06	37.17	31.66	28.44

Table 5 shows that the house's indoor temperature has lower temperature during the day than outdoor. In contrast, the outdoor temperature recorded lower than indoor from 16.30 to

19.30 hours. However, most of the time, the house's temperature is above the varieties of comfort level (25.5–28ºC). The data has recorded that the air temperature falls into scale No. 3 and 4. The house recorded the air temperature at warm (28-32ºC) and hot (32-40ºC) level.



(a) (b)

Figure 4 Measured indoor (a) and outdoor (b) of RH based on the spatial division

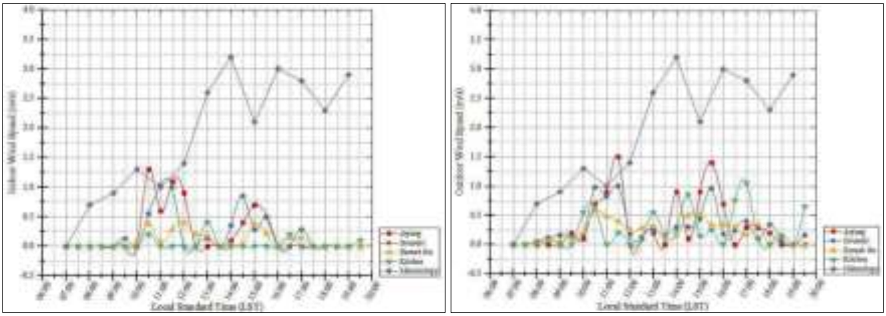
Based on figure 4, at 7.00-9.00 hours, the kitchen has the lowest reading in indoor and outdoor compared to other areas, with the measurement between 82.2-73.15%. But it was above the range of ideal comfort, scale No. 3 (above 60%). At the same time, *rumah ibu* has measured the highest RH rate, ranging between 86.54-74.48%. The range of differences were 0.65-1.58% than other spaces. However, at 11.30 hours, the kitchen has the highest rate of RH than other spaces with a 2.92-6.4% range of differences. This situation also occurs outdoors, where the kitchen and *rumah ibu* have recorded the highest RH with 53.35% and 53.46%, respectively.

The RH in indoor has recorded alignment between peak hour for all the spatial division in data reading. The range of differences that were 0.3-1.47%. But at 13.30 hours, the *anjung* has recorded slightly higher than the other space with 2.6-2.8% differences. However, at 14.00 to 17.00 hours, the data recorded for indoor and outdoor were having the fluctuation situation. From 18.00 to 19.30 hours, the RH recorded increasing gradually for both indoor and outdoor area. The data recorded at rising from 62.13 to 74.85% (scale No. 3-high).

Table 6 Average relative humidity of the case study

Location	Hour @ Temperature (°C)				
	7.00	11.00	14.30	16.30	19.30
Indoor	85.35	56.59	58.22	62.92	72.72
Outdoor	80.43	50.12	59.22	63.68	74.85

According to table 6, the house was only under the range of ideal comfort (30-60%) at 14.30 hours which at peak hour. Most of the time, the houses were at the scale no. 3 (above 60%). The highest RH level was at 7.00 hours in the early morning, and it falls under scale No. 3.



(a) (b)

Figure 5 Measured indoor (a) and outdoor (b) of wind speed based on the spatial division

In Figure 5, the wind speed data recorded indoor and outdoor were below 1.5 m/s, under scale No. 1 (light air) and ranging between 0.04–1.5 m/s. The wind speed often occurs around 9.30 until 17.00 hours indoors. Meanwhile, in the outdoor area, the wind data recorded appears between 8.00 until 19.30 hours. In the early morning (7.00-9.00 hours) and evening, the data recorded indoors at all the spatial division were 0 m/s but still feels the movement of wind flow, and it was under the calm level (<0.3m/s).

Between 10.00-12.00 hours, the wind movement and flow pattern were active in indoor and outdoor areas. At that period, the wind speed rate ranged between 0.08–1.3 m/s in indoor and 0.1-1.5 m/s at outdoor, which is under the scale No. 0 (calm) and 1 (light air). As for the indoor area, *anjung* has recorded the highest rate compared to other spaces, which is 1.3 m/s and followed by serambi with 0.85 m/s.

Table 7 Average wind speed rate of the case study

Location	Hour @ Temperature (°C)				
	7.00	11.00	14.30	16.30	19.30
Indoor	0	0.41	0.32	0.09	0.03
Outdoor	0	0.55	0.44	0.32	0.2

Table 7 shows the average indoor wind speed is at scale No. 0, which is calm wind flow most of the time. At peak hour, the indoor wind speed rate corresponds to the data recorded at the outdoor area. In those hours, the wind speed rate is at a scale No. 1 (light air) where the wind motion is visible in smoke.

5.0 Discussion

This part discusses the relation and influence of the physical aspect on the thermal performance of the house. Thus, the thermal data and physical aspect of the house will be compared and analyzed.

Anjung recorded the highest indoor temperatures at peak hour than the other spatial divisions. This situation happened because zinc material is an excellent heat conductor material. This cause the air temperature to increase. Besides, narrow space and the lower roof are the main reasons for the higher temperature in *anjung*. However, it has recorded the most wind flow. The reading was between scale No. 1 (light air). The wind flow can easily penetrate anjung because the half-height windows with upper ventilation lattice were designed facing the wind flow direction (south to east). In addition, there were fewer trees planted in the lawn compound area. Thus, the wind could freely flow into space without any solid obstacles.

Meanwhile, the indoor air temperature in the *serambi* was slightly lower than *anjung* at noon. The range of differences was 0.2ºC. Because it has plenty of full-height operable windows with upper ventilation lattice, besides it built on stilts, 1.3m above the ground. Furthermore, it was designed with elongated open interior spaces. Thus, these elements aid in ventilating cool air in the interior space without obstacles and practised the cross-ventilation technique. Moreover, the floor joist gap also drives cool airflow into the interior space. However, the wind speed rate was not as high as *anjung*. It has a light air movement, whereas RH level was within comfort level, between 53.1 and 55.21%.

Compared to the *rumah ibu*, even though it was constructed as the middle annexe of the house, the indoor air temperature was cooler than *anjung* and *serambi*. Nevertheless, it is still not under comfort level. The measurement at noon ranged between 33.6 and 34.7ºC. It was lower because *rumah ibu* has ample roof space with the highest roof pitch, about 5.6m. Thus, it helps cool the house by stacking the warm air and executing it through the ventilated gable end roof joist. However, the wind flow reading was lower than in *anjung* and *serambi*. The half-height operable window has allowed wind speed between 0.15 and 0.32m/s, but it was still under comfort level. As for the RH level, the reading was uniformed.

The kitchen has recorded the lowest air temperature (31.9-33.5ºC) from noon until evening compared to the other spatial divisions, but it is still not in comfort level. The kitchen is an ample open space compared to other areas. It has minimal interior partitions. It also has some half-height operable windows with upper ventilation lattice. Hence, these elements assist in circulating the cool air in interior space without any obstacle. Nevertheless, the wind speed measurement was at the lowest rate in contrast to other spatial divisions. Most of the time, it was at 0.01m/s. Meanwhile, RH level was under the range of comfort level.

Therefore, this study's finding shows that the house was not comfortable most of the time. Moreover, the roofing material, zinc, has a fast heat conductor and negatively influences interior thermal performance. After absorbing radiant heat from the sun, the zinc returns the heat to the indoor environment via convection and radiation. The material has caused the air temperature inside the house to increase dramatically. Nevertheless, the Malay house still has practised climatic design strategies to improve indoor thermal performance through passive cooling technique. The open indoor spaces with minimal partition, plenty of operable and large windows, and built-on stilt were practices the cross-ventilation technique. The spacious interior spaces with high roof pitch aid to execute warm air through the ventilated roof. Thus, can practising the stack effect technique. Moreover, strategic placements of vegetation around the house's compound area, together with the correct house orientation, can allow wind to flow into the house without any substantial obstacles freely.

6.0 Conclusion

According to the thermal data collected, the size of floor areas influences thermal performance, size and number of openings, floor and roof height, material utilized, and lawn complex area. The thermal performance of each division of the house was variable. In conclusion, it demonstrates that a study and rediscovery of our indigenous solutions, particularly in construction technology for modern residential building, is highly encouraged to appropriately fine-tuned to satisfy our own socio-economic, cultural, and environmental requirements. The climatic design of the traditional Malay house for residential in the current setting can also be learned from. Although appropriate building materials such as wood and thatch may not be acceptable for high-density living in urban environments, houses built of wood and lightweight construction can be promoted in suburban regions with lower densities. Other examples of good climatic design adapted in modern housing are the Malay house's proper solar radiation and glare controls. Modern dwellings must be adequately oriented to reduce solar heat gain to the structure. The roof should be constructed from low-thermal-capacity materials to control sun radiation. The traditional Malay house's maximization of the passive design system should be adapted to modern house design. As a result, to increase housing quality, housing shortage must be addressed, indirectly supporting sustainable practices.

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