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The Assessment of Thermal Comfort Performance in Bamboo Ecotourism Infrastructure in the Tropical Climate of Malaysia

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Abstract: - Ecotourism has become a growing trend, offering a platform for raising awareness of environmental issues in the tourism industry. One of the principles of ecotourism is relying on environmentally friendly infrastructure to prevent environmental degradation. The shift towards ecotourism has highlighted the significance of sustainable practice and infrastructure design in tourism. Bamboo is gradually renowned due to its role in carbon sequestration, bringing hope to the natural environment despite the slow acceptance by society. Assessing the thermal comfort performance takes on added value in the context of encouraging bamboo utilization for sustainable practice. As bamboo gains recognition for its potential in environmental protection, its thermal comfort attributes could encourage its adoption in future infrastructure. Hence, this study examines the thermal comfort performance in bamboo buildings in Malaysia using various design approaches in the same microclimate. Fieldwork was conducted to analyze the indoor and outdoor temperatures in three different chalets in Tadom Hill Resort, Banting, namely Gendui Chalet, Semantan Chalet, and Hakka Village. Generally, findings concluded that the indoor temperatures are higher than the indoor thermal conditions indicated in Malaysia Standard, MS1525:2007. Findings also indicate that the maximum temperature reduction is 2.4°C, 4.1°C, and 4.6°C for Gendui Chalet, Semantan Chalet, and Hakka Village, respectively. Ultimately, this study seeks to emphasize the feasibility of bamboo as a likely option for building construction, developing, and improving the ecotourism destinations in Malaysia.

Keywords: Bamboo, Ecotourism, Sustainable practice, Thermal comfort

I. INTRODUCTION

The tourist industry has become a significant contributor to the country's economy. Tourist arrivals contributed around RM 86.1 billion to the national economy in 2019 and continued to increase after the pandemic gradually subsided [1]. However, as much as the tourism industry grows and provides local economic benefits, it may lead to environmental degradation, resource depletion, and cultural disruption to fulfill the demand in the industry [2].

Bamboo is a versatile and environmentally friendly material, gaining attention for its potential to mitigate environmental degradation [3]. The ecotourism sector offers a setting to highlight bamboo's exceptional versatility as a green material in line with sustainable tourism practices. The common misconception of Bamboo is its use is just for traditional construction and temporary shelter. However, Bamboo has become a notable local building material, with 154 species of bamboo collection used for building, crafts, and other daily products in Indonesia [4]. It brings opportunities for the locals in Malaysia to explore the use of Bamboo in

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creating an ambitious architectural look in creative ways, attracting people to the beauty of the natural building material.

To emphasize bamboo's contribution to sustainable tourism practices this study evaluates the thermal comfort performance of bamboo infrastructure to encourage the utilization of bamboo as building material. The finding of the research contributes to the design strategies for the construction of bamboo-based buildings that ensure the thermal comfort of the user.

II. BAMBOO IN MALAYSIA

There are common bamboo and rare bamboo [5]. Common bamboos include Gigantochloa scortechninii that spreads into disturbed lowland areas like logged-over forests, especially at Ulu Langat, Kanching, Ulu Gombak (Selangor), the Slim and Grik areas (Perak), the Bentong-Raub area and the Bukit Tinggi area (Pahang), and the Nami, Pedu, and Baling areas (Kedah). Moreover, other common bamboos such as Dendrocalamus pendulus, and Schizostachyum grande usually appear more on the hillsides.

III. BAMBOO AS AN ENVIRONMENTALLY-FRIENDLY MATERIAL

Bamboo has been known for its fast growth rate compared to other plants and has become a potential substitute for wood in the building industry for its higher regeneration ability. It also produces 35% more oxygen and absorbs four times more carbon, providing more clean air. However, in the building construction industry, the main advantage of Bamboo is that Bamboo has a high tensile strength compared to steel due to its fibers that run axially. Besides their strength, lightweight, and elasticity, Bamboo can resist fire up to 400 °C because of its silicate acid and water content, which are safe for the environment and human health [6]. Bamboo has a natural lifespan of two years and can live up to seven years if kept under shade. Additionally, the flexibility of Bamboo allows the architects to design creatively from rigid to organic forms of building that could capture people's eyes to the beauty of nature. With their natural characteristics as eco-friendly building materials, they could reduce the carbon footprint caused by the construction industry.

IV. THERMAL COMFORT FOR BUILDING IN THE TROPICAL CLIMATE

According to MS 1525, the recommended outdoor design conditions for dry bulb temperature are 33.3˚C and 27.2˚C for wet bulb temperature. Dry bulb temperature refers to the ambient temperature unaffected by air moisture measured by the regular thermometer. Wet bulb temperature determines how much water vapor the atmosphere can hold under the current weather [7]. Meanwhile, the recommended indoor condition for dry bulb temperatures ranges from 23˚C to 26˚C. The minimum dry bulb temperature recommended is 23˚C at 50% to 70% design relative humidity. The air movement within the building is expected to be between 0.15 and 0.5 m/s with a maximum allowable airspeed of 0.70m/s.

Table 1 Indoor Air Condition of a Space for Comfort Cooling.

Design dry bulb temperature	23 ℃ – 26 ℃
Min dry bulb temperature	22 ℃
Design relative humidity	55 % – 70 %
Air movement	0.15m/s–0.50m/s
Max air movement	0.7 m/s

V. METHODOLOGY

There is a numerous prominent bamboo infrastructure in Malaysia. They are categorized into different typologies such as resort, place of worship, demonstrative structure, bridge, and public reaction. However, Tadom Hills Resort, Banting Selangor was selected based on the following criteria:

a. Function as ecotourism purpose.

b. Have various types of building configurations to study.

c. Due to their proximity to one another, all of the chosen case studies shared the same microclimate.

Tadom Hill Resort consists of various typologies of buildings such as chalets, huts, and public recreation. It consists of five types of Bamboo chalets with variations in design layout. It was one of the best bamboo tourism spots to study for different building configurations and design strategies that influence thermal comfort performance. Three chalets namely the Gendui chalet, Semantan chalet, and Hakka Village were chosen based on the application of the following considerations:

a. Similar size and occupancy of each chalet. Three chalets chosen can cater to about four to five people with an area ranging from 20 sqm to 30 sqm.

b. Different building configurations to analyze factors that influence thermal performance in terms of passive design planning.

c. All chalets are in good condition and still function well to be easily accessible, making it easier for the researcher to access the chalet from time to time.

(a) (b) (c)

Fig.1. Gendui (a), Semantan Chalet (b), Hakka Village(c)

The instruments used in the study are a data logger for relative humidity and air temperature measurement, an anemometer to measure air velocity, a distance meter for size and volume measurement, and an infrared thermometer to measure the radiant temperature on the internal and external sides of the wall. The field measurement activity was conducted on 15th May 2023 (Monday) and 20th May 2023 (Monday) to collect the mean radiant temperature and air velocity data. Meanwhile, a data logger was placed and remained in place for a week to collect data on air temperature and humidity.

Table 2 Location of Data Logger for Each Chalet.

	Gendui Chalet	Semantan Chalet	Hakka Village
Location A	Outdoor		
Location B	Internal wall exposed to sunlight	Shared open corridor	Wall facing courtyard
Location C	Internal wall with no direct sun exposure	Internal wall exposed to sunlight	Internal wall exposed to sunlight
Location D	-	Internal wall with no direct sun exposure	Internal wall with no direct sun exposure

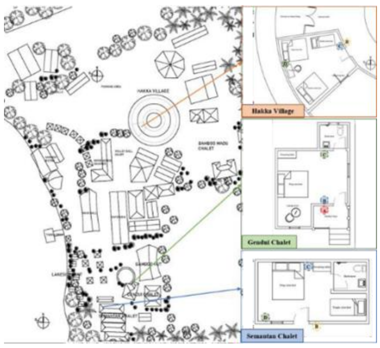

Fig 2. The Location of the Data Logger.

An infrared thermometer to measure the radiant temperature on the internal and external sides of the wall. Figure 3,4,5 indicates the radiant temperature taken for each side of the wall with A facing south, B facing east, C facing north, and D facing west. The data acquired is then compared and evaluated to determine the bamboo's thermal comfort.

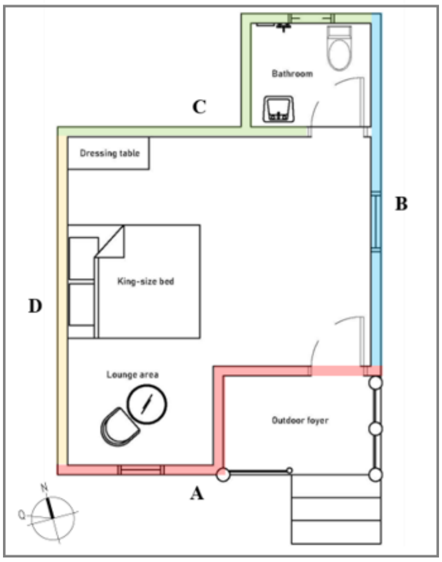

Fig.3. Wall indication for Radiant Temperature Measurement for Gendui Chalet.

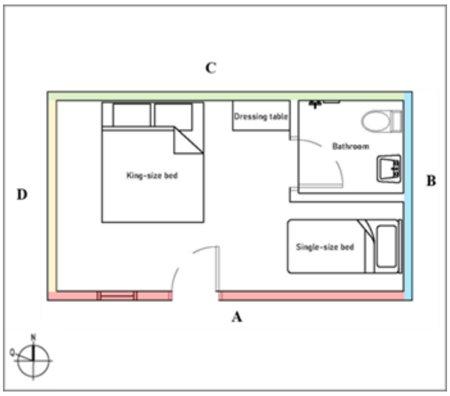

Fig.4. Wall indication for Radiant Temperature Measurement for Semantan Chalet.

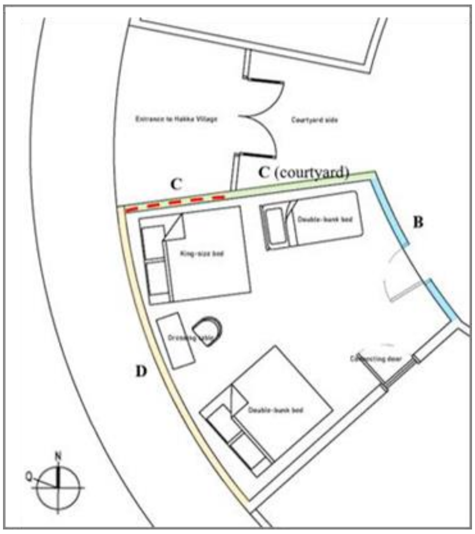

Fig.5. Wall indication for Radiant Temperature Measurement for Semantan Chalet.

VI. RESULT AND DISCUSSION

Four climatic parameters determine the desired level of thermal comfort: 1) air temperature, 2) radiant temperature,

3) relative humidity, and 4) air velocity. Hence, the field measurement assists in understanding and analyzing the parameters affecting thermal comfort performances in the three case studies. The result from the field measurement was evaluated and used to compare the thermal comfort performance of the ecotourism infrastructure with design strategies implemented in each building.

a) Gendui Chalet

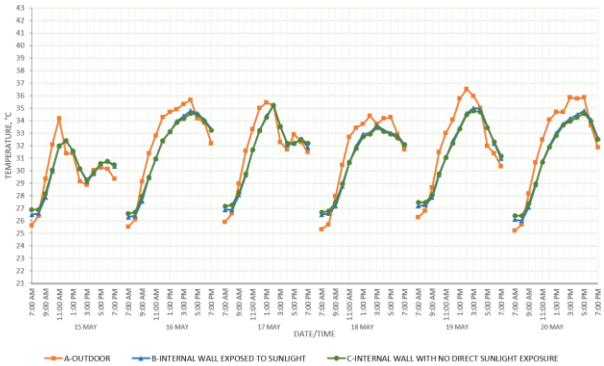

Fig. 6. Indoor and Outdoor Temperature of Gendui Chalet.

Fig. 6 indicates indoor and outdoor air temperature data for five days in the Gendui chalet. It shows a typical pattern where it records a lower temperature in the morning and reaches its peak at noon. The outdoor temperature gradually increases when the sun rises and reaches the maximum temperature of 36.5°C at 2 p.m. on 19 May. The graph shows that the outdoor temperature has affected the temperature for both interior sides of the wall. At one point, when it is 3 p.m., the data obtained shows a negative value for the temperature reduction for each day, indicating the outside was cooler than the inside of the chalet. This might be because the interior was heating up, and it took time to reduce the temperature. In contrast, the outdoor temperature was influenced by the air velocity and humidity that helped to reduce the temperature.

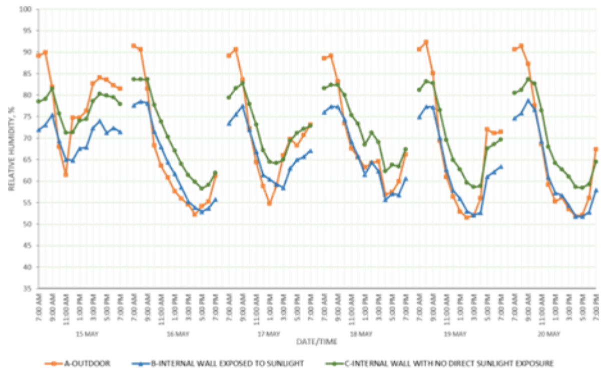

Fig.7. Indoor and Outdoor Relative Humidity of Gendui Chalet.

Fig.7 shows the decreasing pattern of relative humidity readings recorded for the outdoor and indoor Gendui chalet. The reading started with the highest relative humidity in the morning due to the presence of dew and moisture, along with the minimal sun exposure. Subsequently, it decreases as the temperature rises, resulting in lower relative humidity recorded. The highest relative humidity recorded is in the outdoor environment, with an average of 90%.

b) Semantan Chalet

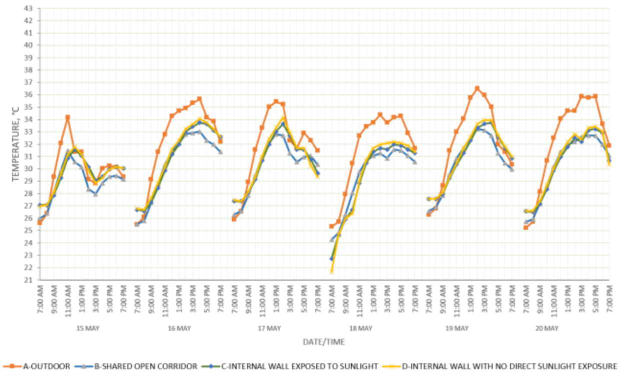

Fig.8. Indoor and Outdoor Temperature of Semantan Chalet.

The outdoor temperature shows a significant difference between the other three readings. The outdoor temperature ranges between 25.2°C and 36°C, while the shared open corridor temperature ranges between 24.3°C and 33.2 °C. Generally, the shared open corridor highlights a slightly lower reading than the temperature of the interior. This may be influenced by the presence of wind and shaded from the direct sunlight shown in Fig.9.

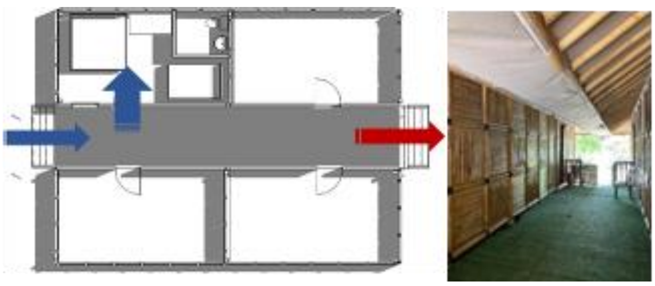

Fig.9. Air movement in an open shared corridor.

The temperature range of the internal wall exposed to sunlight recorded is between 22.7°C and 33.7°C. Noted that compared to the Gendui chalet, the Semantan chalet recorded maximum temperature reduction reached 3.9 at 11 am, with 32.7°C and 28.9°C for outdoor and internal walls exposed to sunlight, respectively. This suggests that the indoor temperature of the Semantan chalet is slightly cooler than the outdoor air temperature.

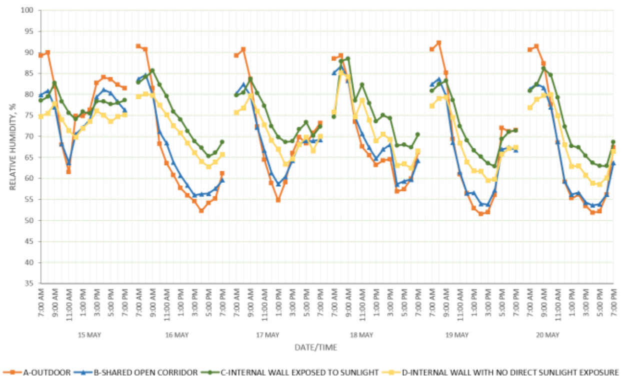

Fig.10. Indoor and Outdoor Relative Humidity of Semantan Chalet

Fig.10 depicts the relative humidity pattern for the Semantan chalet, which shows the typical pattern with higher relative humidity in the morning and gradually decreasing after 10 a.m. Most days show a similar pattern when the relative humidity rises again after 6 p.m. except on 15 May when there is higher humidity in the afternoon. It highlights the inverse correlation between temperature and humidity relationship, where higher air temperature results in lower relative humidity for outdoor and indoor spaces. However, internal walls exposed to sunlight have higher readings compared to others. This may be because it was facing the playground that blocked the prevailing wind from the north direction.

c) Hakka Village

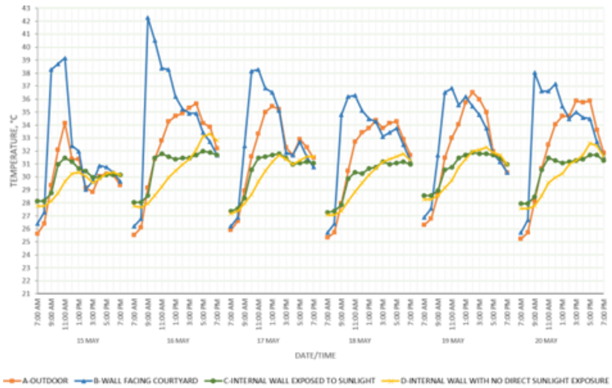

Fig.11. Indoor and Outdoor Temperature of Hakka Village.

Hakka Village shows a prominent pattern for the wall-facing courtyard, increasing rapidly from below 30°C to more than 35°C from 8 a.m. to 10 a.m. Then it starts to drop from 11 a.m. until 7 p.m. This is because the wall facing the courtyard was exposed to the direct sun rises on the east (Fig.12) compared to the outdoor temperature facing the south (Fig.2 Location A).

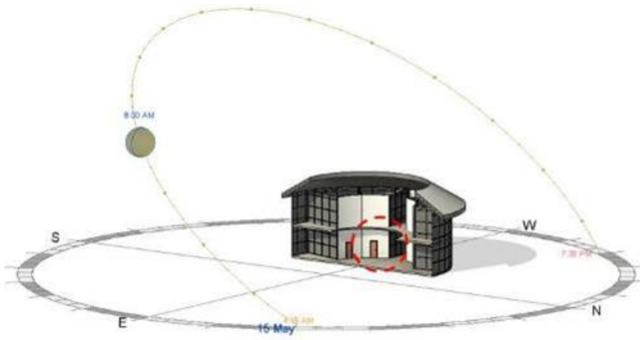

Fig.12. Wall facing east exposed to direct sunlight

Meanwhile, the indoor air temperature shows a consistent and gradual rising temperature from the morning until evening. The highest air temperature recorded for the outdoor wall-facing courtyard is 42.3°C at 9 a.m. The indoor temperature recorded simultaneously is 28.6°C for the internal wall exposed to sunlight and 28.0°C for the interior wall with no direct sunlight exposure.

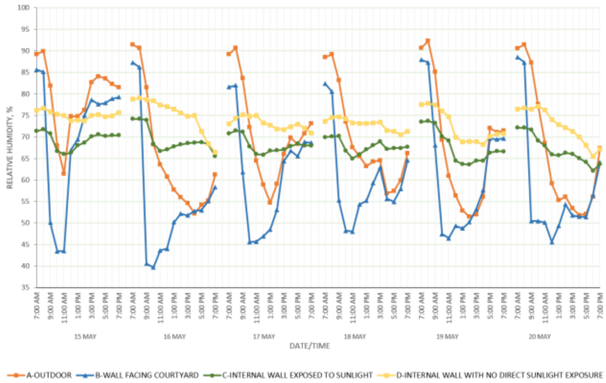

Fig.13 Indoor and Outdoor Relative Humidity of Hakka Village.

Fig. 13 illustrates Hakka village's graph pattern for outdoor and indoor relative humidity. The outdoor and wall-facing courtyard relative humidity started with a higher percentage of above 85% and reached its lowest of 40% at 10 a.m. due to exposure to sunlight on the east wall. In comparison, the internal wall exposed to sunlight and the internal wall with no direct sunlight show a consistent pattern of relative humidity throughout the day.

Table 3 Overall Minimum and Maximum Data for the Chalet

	A OUTDOOR	Gendui chalet		Semantan chalet			Hakka village		
		B	C	B	C	D	B	C	D
Min. temperature (°C)	25.2	26.0	26.4	24.3	22.7	21.7	25.7	27.3	27.1
Max. temperature (°C)	36.5	35.2	35.2	33.2	33.7	34.2	42.3	32.0	33.3
Min. Relative Humidity (%)	51.5	51.8	58.3	53.6	62.9	58.6	39.7	62.2	65.5
Max. Relative Humidity (%)	92.3	78.8	83.7	86.7	88.5	85.1	88.5	74.2	79.1

Table 3 emphasizes the overall minimum and maximum data for the three chalets. Generally, after analyzing the thermal comfort performances, the three chalets shared substantial similarities. However, subtle variations in design strategies have produced different thermal outcomes affecting thermal comfort performance. The findings conclude the average outdoor temperature for bamboo buildings is 31.2°C while indoor air temperature is 29.6°C.

Generally, the highest indoor temperature of 35.2°C was obtained in Gendui Chalet, while the highest outdoor temperature was 42.3°C in Hakka Village at 9 a.m. These outcomes are influenced by the design strategy that could affect the thermal comfort performance. It gives information on the thermal comfort performance of the existing bamboo building.

Air velocity

The wind flow pattern is generally light and inconsistent with uniform intermittent differences [8]. The average air velocity inside the chalet is 1.2 m/s when the fan is turned on and 0 m/s with no mechanical ventilation. However, outdoor air velocity affects indoor air velocity as the opening allows natural ventilation to pass through the building.

The average indoor and outdoor air velocity for Gendui chalet is 0.68 m/s and 0.75 m/s, respectively. Thus, making the difference between the two is 0.07 m/s. Similar to the Gendui chalet, the indoor air velocity was recorded at 1.2 m/s with the fan on. However, the Semantan chalet has the higher air velocity recorded outdoors, 1.5 m/s at noon. Comparatively, Hakka village has a lower indoor air velocity reading than other chalets as it relies on the courtyard to allow the wind into the building. The average air velocity for Hakka village is 0.73 m/s indoors and 0.93 m/s outdoors, resulting in a difference of 0.2 m/s.

Overall, the air velocity analysis shows inconsistent air velocity for all three chalets, influencing the indoor air velocity when there is an opening.

Mean Radiant Temperature

The mean radiant Temperature for the three chalets highlights the importance of shading devices and building orientation. It depicts the radiant heat transfer process through the overall average surface temperature in a particular space. It emphasizes the radiant energy emitted or absorbed from the nearby surfaces that influence the occupant's perception of thermal comfort. Radiant energy will be released from the external wall if it becomes hotter due to sun exposure and later will be absorbed by the interior surfaces and heat a room.

Generally, the outdoor mean radiant temperature has a typical pattern with lower temperatures in the morning and gradually decreasing until 7 p.m., except the wall facing east has a higher temperature at noon due to sunrise, and the wall facing west is hotter than other walls in the afternoon due to sunset.

Additionally, for Gendui Chalet, the wall facing the south side begins with a higher temperature of 36.2°C at 10 a.m., and by referring to the previous literature review, this is because during this month, the sun travels southerly and has an impact on the facade on the south to receive more solar heat gain (Fig.14).

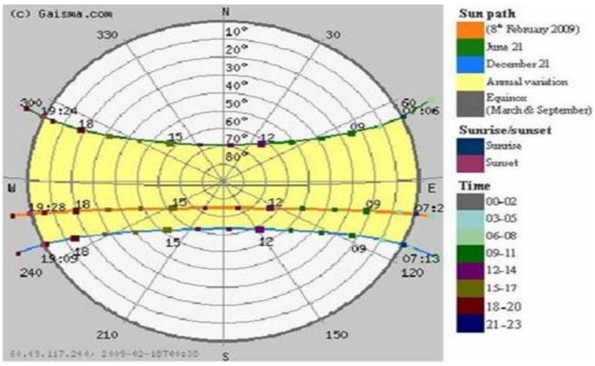

Fig. 14. Sun Path Diagram for Kuala Lumpur, Malaysia.

Olgyay Bioclimatic Chart

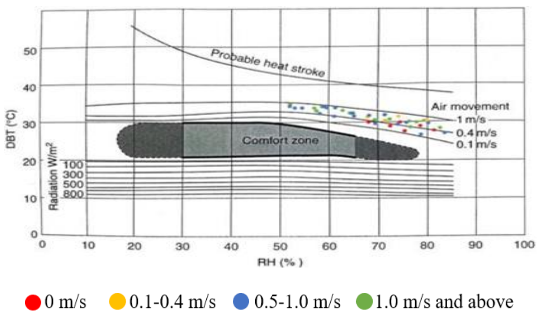

Fig. 15. Thermal Comfort Condition for Gendui Chalet.

The chart illustrates points in the hot and humid zone. The red dots indicate during that particular time, such as at 2 p.m., the humidity reached 74.44% with the air temperature of 30.2°C, but the air velocity was 0 m/s. Thus, to achieve user comfort, the wind needed should be in the range of 0.1 to 0.4 m/s. In correlation to the MS1525, the ideal temperature for hot and humid climates is between 20°C and 26°C, with air velocity ranging from 0.05m/s to 0.5m/s. However, since tropical climates usually have higher mean temperatures, a higher air velocity is needed to achieve a comfortable level [9].

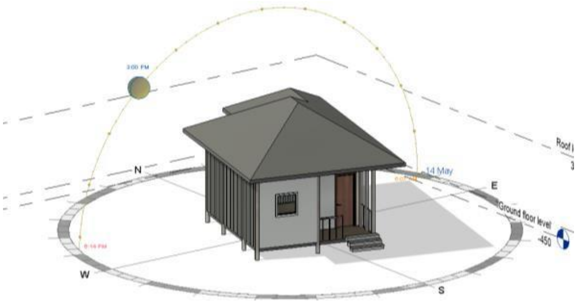

Fig.16. The stand-alone Gendui Chalet.

Consequently, he suggested the maximum limit for air movement in this climate is 1.5 m/s and less. Most of the dots are in the range of 0.5 to 1.0 m/s, illustrating the Gendui chalet is in its comfort zone most of the time except for six dots that require air movement at a particular time as the wind flow is inconsistent. The findings suggest that even though the stand-alone building (Fig.16) can allow natural ventilation to enter from all sides, the design still depends on mechanical ventilation to maintain a consistent level of thermal comfort inside the chalet.

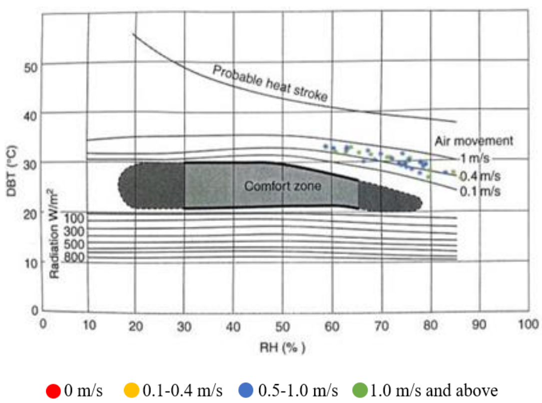

Fig. 17. Thermal Comfort Condition for Semantan Chalet.

The chart depicts the Olgyay Chart for Semantan Chalet. Compared to the Gendui chalet, the Semantan chalet has no red and yellow dots requiring certain air movement to achieve thermal comfort. It shows that all the intersecting points of temperature and humidity plotted are in the range of comfort conditions with the presence of wind ranging from

0.5 to 1.0 m/s.

Notably, the dry bulb temperature and relative humidity of Semantan Chalet highlight sufficient and consistent wind flow within the chalet. It may be influenced by the open shared corridor that allows natural ventilation most of the time. The shared corridor was also shaded from the direct sunlight through the roof connected to the adjacent building. The finding suggests to include design strategies that reduce heat gain through natural ventilation and shading devices.

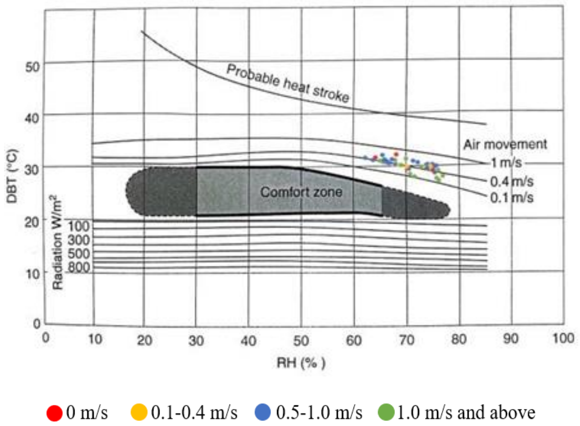

Fig. 18. Thermal Comfort Condition for Hakka Village.

The chart illustrates the distribution of Hakka Village's air temperature and relative humidity intersect. The data shows the temperature range of 26.8°C to 32.6°C while relative humidity ranges from 62.2% to 77.2%. These four red dots at 3 p.m. and 5 p.m. required wind flow to achieve thermal comfort. Hakka Village relies on the exhaust fan to remove air or odors from indoor spaces, drawing in fresh air from outdoor areas.

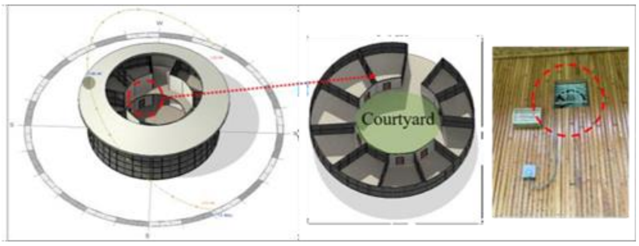

Fig. 19. Enclosed space relies on an exhaust fan for natural ventilation.

Most of the time, the chalet depends on the air conditioning system to cool the surrounding temperature and create comfortable conditions for the users. This is because the space is enclosed with bamboo, without windows for natural ventilation and lighting, and dependent on a door to allow wind flow (Fig. 19). The building layout is also crucial, as the wind can only come from the courtyard to all the rooms. Hence, most room relies on mechanical devices to lower the temperature and regulate moisture levels.

In conclusion. the findings suggested that Semantan Chalet has effectively applied most of the design strategies to achieve thermal comfort for the user. Hence, there are some techniques for building layout and strategy to allow optimum thermal comfort performance for the bamboo infrastructure. Based on the overall findings and analysis, the recommendations for design strategies are as follows:

a) The utilization of the abundance type of bamboo which is G. scortechinii (Buluh Semantan), the most useful bamboo.

b) North-South orientation prevents the shorter part of the building from receiving as much heat from the sun's rays on the east and west sides.

c) Open share corridor allows natural lighting to come in without blocking the air movement and shaded from the solar heat gain.

d) Built on the concrete stump to avoid pest and insects that reside in the soil that causes damage to the bamboo building structure.

e) An open roof structure allows warm air to escape from the building.

f) The courtyard allows natural lighting but is needed to avoid direct sun exposure that could heat up the wall and raise the temperature.

CONCLUSION

Overall indoor temperatures for bamboo buildings are found to be higher than the recommended indoor condition of MS1525:2007. The average indoor temperature for Bamboo buildings is 29.6°C, slightly falling outside the recommended comfort condition range between 23°C-26°C. The highest indoor temperature of 35.2°C was obtained in Gendui Chalet at 2 p.m. and recorded the lowest temperature of 26°C at 8

a.m. Semantan Chalet indoor temperature ranges from 21.7°C to 34.2°C while the Hakka village temperature ranges from 27.1°C to 33.3°C.

Although Semantan chalet's highest temperature reaches 34.2°C, the mechanical ventilation system can effectively reduce it with minimal energy consumption to achieve thermal comfort. It is also one of the chalets that recorded the maximum temperature reduction of 4.1°C. Besides, referring to the Semantan chalet's Olgyay Bioclimatic Chart, all the temperatures recorded are in a comfort zone because sufficient air velocity helps to achieve thermal comfort through the open shared corridor that allows natural ventilation to pass through the building. Hence, the Semantan chalet offers valuable design strategies to be adopted to ensure comfort to the occupant.

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