Influence of Roofing Material on Indoor Thermal Comfort of Bamboo House

Thet Su Hlaing and Shoichi Kojima

***Abstract*—In built environment, there is renewed interest towards the local building material, which is cost-effective, environmental-friendly, and best suited to the local climate. In this framework, the study will be emphasized the impact of local roofing materials on indoor thermal comfort of Bamboo house in a warm and humid region of Myanmar. In practice, Bamboo houses with different roofing materials were monitored with seven sensor points at outdoor and indoor to observe its thermal performance. By regarding microclimate conditions, the performance of different roofing materials on the indoor environment will be analyzed by statistical analysis based on the thermal comfort index. The result shows indigenous roofing material has less thermal conductivity impact on indoor thermal comfort than the other roofing materials. Moreover, the double roof, which is made of a combined layer of Dani and GI sheet, keeps the room with moderate thermal comfort for almost the whole day. The result of this study will propose suitable roofing material of Bamboo House and the required period to operate an air-conditioner with an extensive explanation to lead the reduction of Energy Consumption in further.**

***Index Terms*—Bamboo vernacular house, indoor thermal comfort, local roofing material, tropical region.**

I. INTRODUCTION

The growing desire for improving the indoor thermal environment with moderate energy consumption is becoming an emerging issue by challenging today's climate changes, sick building syndromes, and high energy consumption. The rise of necessity in finding strategies that can reduce Greenhouse Gas (GHG) emission while preserving proper indoor thermal comfort, become a priority all over the world [1]. According to 1998-2017 records, global warming has been prominently increased worldwide and which also has an impact on climate change. According to the record, Myanmar has been ranked third out of 183 countries, most affected by extreme weather and long-term climate risk index [2]. As urban microclimate change directly influences indoor thermal comfort and building energy consumption, consideration should be taken for designing buildings [3]. In response to climatic characteristics, traditional vernacular houses are predominantly dependent on natural ventilation and passive cooling for thermal comfort. Normally, the weather of tropical climate countries is mostly high in humidity, high temperature, and intense solar radiation [4]. Thus, the choice of building material should be the right decision to suit a microclimate. Local building material, which is eco-friendly and cost-effective become popular lately.

Traditional buildings have been constructed with locally available materials like stone, wood, mud, and lime. In recent years, both construction technique and material has been developed by using such as cement, glass, and steel. In this era, these materials have replaced most of the local materials due to the high durability, low maintenance, low likelihood of corrosion and decay, and ease of construction of the former. On the other hand, modern construction materials are also energy-intensive and eco-destructive [5]. Thus, the local building materials were being interested as a renaissance.

This paper reviews the natural ventilation techniques used to achieve thermal comfort by comparing three types of Bamboo vernacular houses, representing three types of roofing material contexts. It analyzes how the use of indigenous materials, layout, and building orientation can provide thermal comfort with natural ventilation in a vernacular house. The main target of this study is to suggest building material guidelines that can keep optimal indoor thermal comfort in vernacular houses by aiming to reduce the air conditioner operation period.

II. FACTORS AFFECTING ON INDOOR THERMAL COMFORT

A. Thermal Comfort

Various factors influence the thermal comfort of the building, including building orientation, building space usage, ventilation, integration of passive and modern energy-saving technologies, and the thermophysical properties of the building materials. Thermal comfort is influenced by six parameters: activity, clothing, air movement, radiant temperature, air temperature, and relative humidity [6]. Moreover, building envelope performance is also essential in maintaining thermal comfort. It performs not only as a separator from the external environment but also as a protection from climatic elements affecting the building directly [7]. Building envelopes that lack ventilation has the heat trapped in the building that could further worsen the thermal comfort of the occupants. The ventilation is an important attribute in enhancing thermal comfort, with or without the use of advanced building materials.

The several strategies approach to improve poor indoor thermal conditions include applying a low absorption roof coating, providing ceiling insulation, fixing sunshade at the building's exterior surfaces, and nighttime ventilation [8]. The thermal performance of a vernacular house is better than that of the modern house [9]. The advanced building material has higher thermal conductivities and diffusivities than some conventional materials used in a vernacular house, which will

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increase heat transfer that does not favor thermal comfort or energy-saving [5]. Thus, the improvisation of conventional materials should be done by modifying and adopting a better composition to integrate technology for future energy needs.

B. Relation between Building Material and Indoor Condition

The properties of building materials act as building envelopes by resisting the external temperature and humidity, mostly influenced by indoor thermal comfort. The materials having lower thermal conductivity, thermal diffusivity, and absorptivity has the properties of less temperature swing on the inside surface of the walls compared to the materials with high thermal conductivity [10].

Materials that transfer minimum heat from outside to inside viz., certain kinds of glass materials, wood may be chosen for walls, ceilings, and windows for a cool interior. Heat transfer from buildings occurs through the building envelope, windows, and ceilings. Mutual radiation between the ceiling and the wall affects the indoor temperature and, subsequently, the thermal comfort of the occupants. The excessive heat transferred through the roof inside the building is one of the main causes of thermal discomfort in warm, humid zones.

The characteristic of the materials used should be selected depending on the building's usage and the weather conditions to achieve optimal thermal comfort. The use of materials that are abundantly available locally has its pros and cons in today's constructed environment, including issues with the load-bearing capacity and durability of these materials. However, a wide range of conventional and local materials was used as thermal conductivity, which is suitable for optimal thermal comfort [8].

C. Climatic Condition and Thermal Comfort

Thermal comfort can be achieved by designing the building to suit the local climatic conditions. For example, in hot regions, to prevent the discomfort of which will affect the infiltration of the hot outdoor air, buildings were constructed with low ventilation. In warm and humid tropical regions, the ventilation in the indoor space should be maintained with wide building openings such as (windows and doors) facing the predominant wind direction. In contrast, the thermal mass of the building was low to avoid evening discomfort from the stored heat. In dry regions, the buildings were constructed with a high thermal mass to reduce the temperature fluctuation of the indoor space as the outdoor air temperature is high. In solar-intensive regions, the dome structured roofs were used to reduce the solar heat gain, as they provide self-shading and reduce the surface area to volume ratio [5].

III. Research Background Study of Myanmar

A. Origins of Site Area

In this paper, a site study was conducted in Dala, Yangon, Myanmar. The Republic of the Union of Myanmar, formerly known as Burma, which is one of the Southeast Asia countries, is bordered by Bangladesh and India to its northwest, China to its northeast, Laos and Thailand to its east and southeast, and the Andaman Sea and the Bay of Bengal to its south and southwest. Yangon was the capital city of the Republic of the Union of Myanmar from 1948 to 2006, and nowadays, it is the main central commercial city in Myanmar [11]. As Yangon is the central commercial district, it has become the main growing city in Fig. 1. The growth of the population in Yangon is also dramatically increasing for 30 years ago, with the increasing population year by year to approximately 6.2 million populations in 2017.

Fig. 1. Yangon City 2017 (Source - Yangon Information).

By 2040, the city is expected to become a megacity with 10 million inhabitants, according to the Yangon Vision 2040 [12]. It is suggested that the increasing population can lead to a high demand for energy consumption in Yangon. Many researchers nowadays are aiming to solve the issue with a green and energy-saving method [13]. There are seven townships in the Yangon CBD area, and Dala is one of the townships located on the southern bank of Yangon River. It is a suburban area developing into an urban standard of living according to the urbanization of the city. Hence, within a few years it is estimated that, most traditional houses in that area can be vanished by replacing with contemporary buildings as the connection bridge between the Yangon downtown area and Dala township is under the process in Fig. 2 [14].(Times, 2018).

Fig. 2. Construction of new bridge between Dala and Yangon (Source - Yangon Expansion).

B. Climate Condition

Yangon lies at 27m above sea level and has a tropical climate. In winter, there is much less rainfall than in summer. The microclimate of the site area is classified as a Tropical savanna climate (Aw) with dry-winter characteristics of average monthly precipitation by the Koppen-Geiger system [15]. The average annual temperature in Dala is 27.3°C, and the rainfall averages 2374 mm. April is the hottest month of the year, which averages around 30.4°C. In January, the average temperature is 24.9 °C, the lowest average temperature of the whole year. The driest month is January with 3 mm of rain. Most precipitation falls in August, with an average of 512 mm [16]. Investigation of thermal comfort in three types of Bamboo Vernacular House was conducted in March during summertime in Myanmar. The target area is often affected by natural disasters such as flooding because of heavy rain and close to the river.

C. Myanmar Vernacular Houses

Depending on the characteristic of the major ethnicities residing in the country, there are eight Myanmar vernacular houses. Each house shows its significant culture and symbolic structures based on the topography, local availability, and climatology of each region. Depending on the environment and region, all Myanmar races inclusive of Bamar, Mon, Shan, and Inn-thar, commonly used the indigenous building materials for their houses. Among them, the traditional house of the Bamar ethnic group, Bamar Traditional House, can be found in the tropical region, especially in the lower part of Myanmar.

Bamar Traditional House can be classified into two types, such as Wooden House and Bamboo House, based on the building material used. In this study, Bamboo House will be selected as a survey house to analyze the roofing material used and its effect on indoor thermal comfort. The original type of Bamboo House becoming evolves into two other new types of houses with different roofing materials shown in Table I, as the decade changes to be adaptable with weather variability. Three types of Bamboo House as in Fig. 3. (a,b,c) with different roofing materials are as follows;

Type 1 = Bamboo House with Dani Roof
Type 2 = Bamboo House with GI Sheet Roof
Type 3 = Bamboo House with Double Roof (Dani+GI)

(a) (b) (c)

Fig. 3. Types of Bamboo House in Tropical Region, Myanmar. (a) Bamboo House with Dani roof; (b) Bamboo House with GI Roof; (c) Bamboo House with Double Roof (Dani + GI).

D. Building Material made with Indigenous Materials

1) Wood Material

Wood and timber are widely used in windows, doors, beam, column, walling, and flooring, also known to be good thermal insulators. The thermal properties of wood are functions of moisture content, and the type of wood as wood is a hygroscopic material [17]. Wood products such as fiberboard and hardboard panels made from fibers have thermal conductivity value less than solid wood due to a large number of air spaces in the fiber-based panel [18]. Wood has a higher heat capacity (1.6-3 kJ/kg.K) and relatively low density compared with other building materials such as glass, rubber, plastic, concrete, brick. Moreover, it is suitable to use as thermal insulators due to its low thermal conductivity. There are eleven types of wood species, which are the selected suitable timbers for the construction of houses in Myanmar. Depending on the species of the wood, the duration and quality of the wood are different. The most typical used durable timbers in Myanmar are Teak, Pyinkado, Padauk, Thitya, and Ingyin. Timber such as Inn, Kanyin, Aukchinza, and Thabye are popularly using though not much durable.

2) Bamboo Material

Bamboo occurs in huge quantities in most of the forests in Myanmar. Natural Bamboo is widely used as an indigenous building material for flooring, walling, roofing, binding cordages, and even beams, columns, rafters, and fence, among other things. The flattened bamboo wall thickness is normally 7-9 mm that are commonly used in local building construction. The specific heat of bamboo varies from 1.08 to 2.29 kJ/kg.K. According to existing substantial mechanical studies, bamboo can support the application in load bearing structure, however owing to lack of hygrothermal properties, bamboo is not regarded as an independent material. For walling in the Bamboo house, Bamboo was crushed and woven into a square shape, or split bamboo nailed into the grid, as shown in Fig. 4. Different species of Bamboo can be found in classification with the duration of material and their uses. There are seven species of Bamboo for constructing material, and Tin-wa is mostly used in the studied area as it is particularly suited for split Bamboo and used for walling [19].

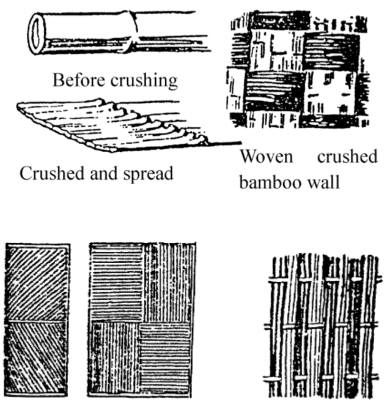


Fig. 4. Woven Crushed Bamboo Wall (Source - JAABE May 2003).

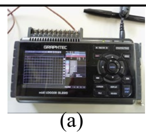
3) Dani Roofing Material (Nypa plam)

Nypa palm is a good source of palm sugar, and its matured leaves are suitable roofing materials. Dani leaf blades are folded onto the tiny split bamboo sticks. Each Dani byit is about 120cm to 137cm long, sometimes 180cm long and about 30cm wide, as shown in Fig. 5. For roofing, Dani byit is used by overlapping with 23cm intervals [19]. They are tied with a bamboo strip onto the common rafters. Dani roofing should not be kept less than 25 degrees' gradient. More than other indigenous local roofing materials such as Thatch roofing and Taung-htan Roofing, Dani Roofing can withstand heavy rain and mostly used in heavy rainfall areas. It is durable and lasts for 2 to 4 years.

TABLE I: OUTLINE OF SURVEY HOUSES

		Type 1	Type 2	Type 3
Type of House		Bamboo House with Dani Roof	Bamboo House with GI sheet Roof	Bamboo House with Double Roof (*Dani* + GI)
Building Age		1 year	1 year	1 year
Total Floor Area		2.1 m × 3.6 m	2.1 m × 3.6 m	2.1 m × 3.6 m
Building Material	Roof	*Dani* (palm leave)	GI Sheet	Dani + GI sheet
	Wall	Woven Crushed Bamboo	Woven Crushed Bamboo	Woven Crushed Bamboo
	Floor	Wood	Wood	Wood
Room Function		Bed space, Living space	Bed space, Living space	Bed space, Living space
Building Height		3 m	3 m	3 m
Building Façade Orientation		North Orientation	North Orientation	North Orientation
Measurement Duration		3 days	3 days	3 days

TABLE II: PARAMETERS AND MEASURING EQUIPMENT

	Parameter	Measuring Devices	Device Photo	
Indoor Measurement	Air Temperature Globe Temperature Humidity Wind Velocity Surface Temperature	GL220 Data logger (a) Black Ping Pong ball with Wire Sensor T&D TR-72Ui Thermo recorder (b) AM-14SD Hot Wire Anemometer (c) IR-TE Infrared Thermometer	 (a)	 (b)
Outdoor Measurement	Air Temperature Globe Temperature Humidity Wind Velocity Solar Radiation	GL220 Data logger Black Ping Pong ball with Wire Sensor T&D TR-72Ui Thermo recorder AM-14SD Hot wire anemometer ML-020VM Pyranometer (d)	 (c)	 (d)

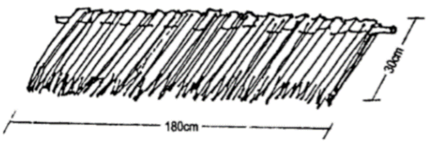


Fig. 5. Dani Roofing (Source - JAABE May 2003).

IV. RESEARCH METHODOLOGY

A. Scope of the Study

Indoor Thermal Environment related to thermal comfort in Bamboo House is monitored 24 hours continuously for three days in every three types of bamboo houses, as shown in Table I. The measurement data result is analyzed from the parameters as indoor and outdoor temperature (T), relative humidity (RH), wind speed (V), globe temperature (Tg), Mean Radiant Temperature (MRT) and Solar radiation. Based on these results, Standard Effective Temperature (SET*) is evaluated with statistical calculation. Two types of comparison explain as the most proper indoor thermal comfort house and design guidelines of indigenous roofing material. Measurement was conducted in the second hottest month (March) in Myanmar. During the measurement time, no air conditioner is operated. With Natural-Ventilation, windows and doors are controlled for opening and closing in accordance with the periods depending on the residents' behavior.

B. Monitoring Plan

The measurement sensor points are set according to ASHRAE Standard 55, 2013; six sensor points for the indoor thermal comfort measurement and one sensor point at the outdoor, as shown in Table II. The temperature sensors are set at 0.6 m and 1.1 m above the floor for seated occupants and standing occupants, respectively. At the middle pole of the house, three sensors are set at 0.6m, 1.1m and the other is set near the roof to know the temperature diffusion from the roof to the room. Humidity sensors are also set at every sensor pole in both indoor and outdoor.

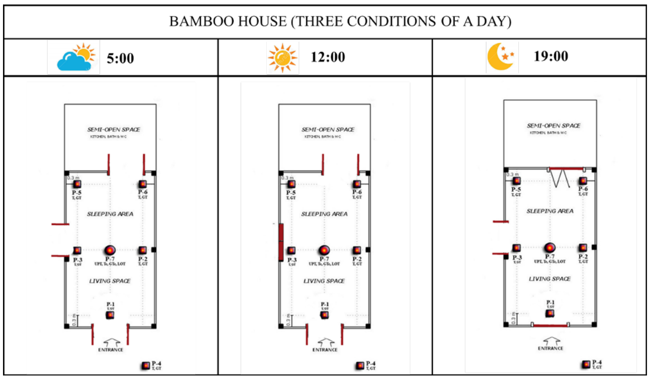


Fig. 6. Set-up Conditions of Natural Ventilation in Bamboo House.

Wind velocity measurement is set at the center of the house and the outdoor of the house. The surface temperature of the house is detected by using infrared thermometer and thermo camera. Surface temperature of the building materials changes can be known from the thermo photography. By observing the behavior of the occupants in the studied area, there are three room conditions as shown in Fig. 6 set in the early morning, afternoon, and night as below.

Condition 1: Both window and door open (At 5 AM)

Condition 2: Half window close and door open (At Noon)

Condition 3: Half window open and all doors close (At 7 PM)

C. Comparison Method

In this study, two types of comparison will be done to analyze the statistical result from the measurement survey. In the first comparison, the two days with the common outdoor weather condition in each type of Bamboo house will be selected in the measurement days. Moreover, three sensor points are set at the front, middle and back part of the house as shown in Fig. 7, the data collected from these three parts will be the base data to analyze temperature fluctuation every hour of a day. This comparison will refer to define which period of a day exit within the comfort zone set by ASHRAE standard while some period is outside of it. In this way, the suggestion of the period which needs to operate AC can be given.

In the second comparison, the data from the sensor point, which set nearest to the roofing will be selected to analyze each temperature fluctuation in each hour. Three types of Bamboo Vernacular houses with different roofing material will make a comparison of roofing material's influence on the indoor thermal comfort of the house. Then, the result will be the suggestion of reasonable roofing material guidelines of Bamboo Vernacular house.

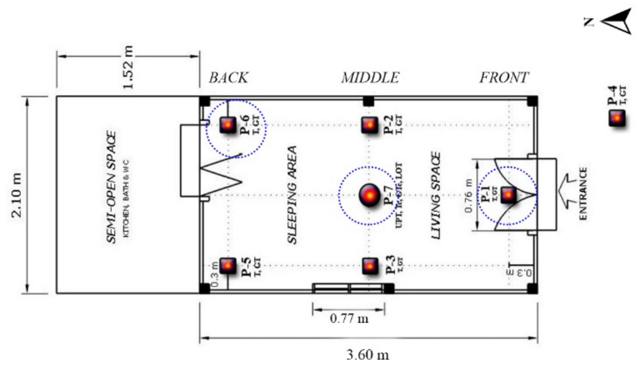


Fig.7. Sensor point Layout plan of Bamboo House.

V. Result and Discussion

A. Comparison of Hourly Peak Uncomfortable Period

The graph explains the indoor thermal comfort index determined by SET* in each type of house. The horizontal axis represents hourly for two days, while the vertical axis is the temperature range of SET*. The graph is vertically divided into two periods such as daytime and nighttime in each day, while the horizontal dotted lines provide the degree of thermal comfort zone set by ASHRAE Standard 2015 as follows.

22.2°C – 25.6°C	Comfortable, Acceptable
25.6°C – 30.0°C	Slightly warm, Slightly unacceptable
30.0°C – 34.5°C	Warm, Uncomfortable

1) Bamboo Vernacular House (Dani)

As shown in Fig. 8, most of the nighttime in two days receive comfortable conditions though the daytime is getting slightly warm from morning 10 am to till the evening. Through the detailed analysis, it can be found that in the daytime, especially from 11:00 to 18:00, the indoor environment of the room reaches the point of the warm and uncomfortable zone. Moreover, this happens the same on the next day on the exact period. Among the three parts of the house, the front part of the house gets uncomfortable than the other two parts. For the Bamboo Vernacular house, it is suggested that the air conditioner should operate on the critical uncomfortable time from 12:00 to 16:00 interval.

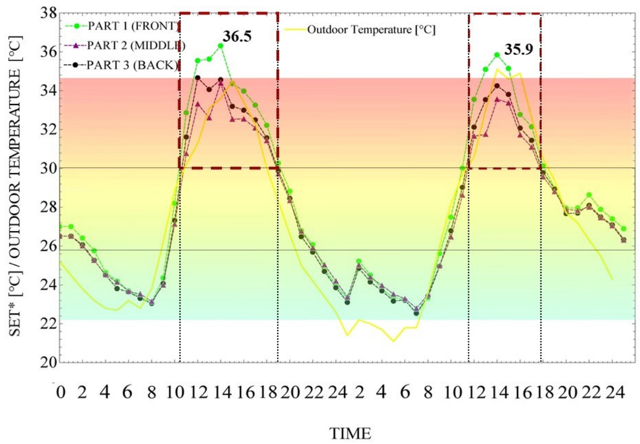


Fig. 8. Comparison of three points Indoor Condition in Bamboo House (Dani).

2) Bamboo Vernacular House (GI)

In Bamboo House with GI roofing, as shown in Fig. 9, unlike the other types of houses, even in the nighttime of each day, the comfort condition is within the slightly uncomfortable zone, which ranges from SET* temperature 26°C to 30°C. Moreover, in the daytime from 10:00 to 18:00, the house is within an uncomfortable zone ranging between SET* temperature 30.0°C – 34.5°C, and at the peak sunshine hour from 12:00 to 16:00, it exceeded the SET* temperature of 36°C, which will make occupants feel a little bit uncomfortable. It can be suggested that GI sheet roofing absorbs and store the heat in the daytime and release heat back into the indoor in the nighttime. In this case, the air conditioner supply is necessary for almost the whole period of the daytime.

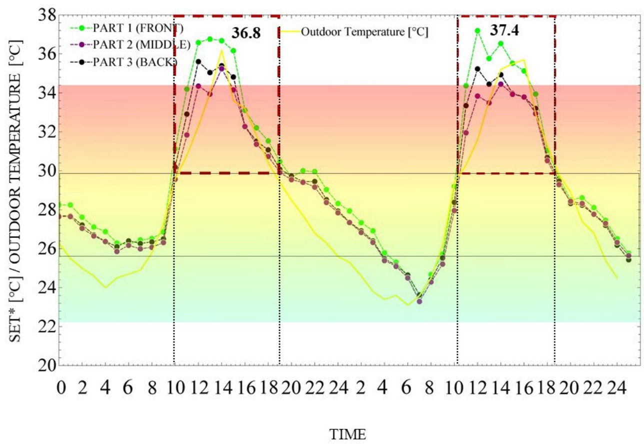


Fig. 9. Comparison of three points Indoor Condition in Bamboo House (GI).

3) Bamboo Vernacular House (Dani+GI)

In this type of house, there is not much thermal comfort fluctuation between daytime and nighttime. According to the Fig. 10, it can be assumed that the room keeps the comfort range with the minimum 22°C to the maximum 34°C. The critical uncomfortable condition happens in the daytime from 11:00 to 18:00 though which temperature is somehow bearable for occupants in the house.

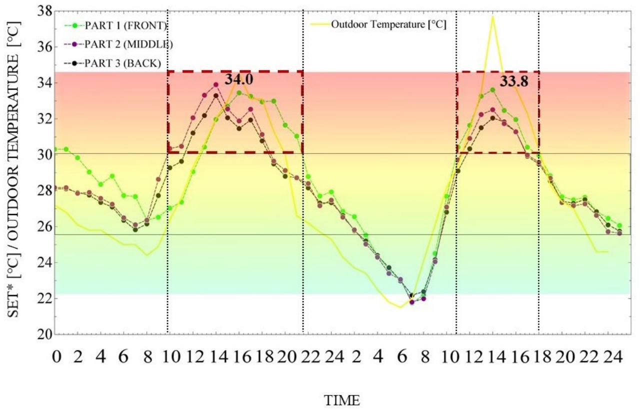


Fig. 10. Comparison of three points Indoor Condition in Bamboo House (Dani+GI).

B. *Comparison of Roofing Material Impact on Indoor Thermal Comfort*

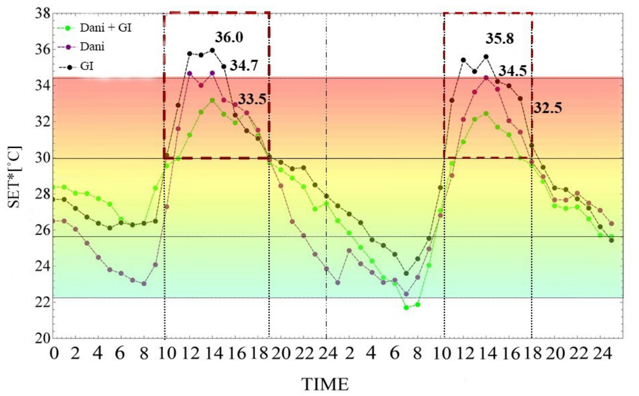


Fig. 11. Comparison of Roofing Material in Three Types of Bamboo House.

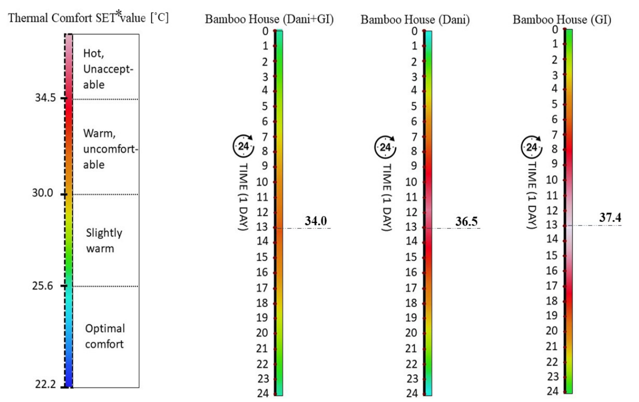


Fig. 12. Comparison of Thermal Comfort in Three Types of Bamboo House.

This analysis is to compare the roofing materials of three types of Bamboo House. As shown in Fig. 11, there are almost similar conditions in the nighttime of three houses. However, differences can be found in the day critical time. All the houses achieve an uncomfortable period from 11:00 to 18:00, as shown in Fig. 12. At that period, Bamboo house with GI roof hit the highest record 36°C while the Bamboo with a Double roof maintains the SET* temperature within 32°C. For two days of analysis, both days show the same result of each house. Thus, it can be suggested that the Bamboo House with a double roof can keep the room cool for almost the whole day.

VI. Conclusion

This paper presents the Bamboo Vernacular house in Myanmar with a natural ventilation system focusing on indoor thermal comfort performance using indigenous roofing material. The paper compared the impacts of roofing materials on indoor thermal environments of the Bamboo house by evaluating the SET* standard. According to the above results, Bamboo House, which roofing is made of two layers such as Dani and GI sheet, keep the optimal thermal comfort in the comfort range of 25.6°C to 32°C for the whole day with only natural ventilation. The double roof function in the hot and humid region, the outer layer GI sheet, plays the role of protection from heavy rain, and the Dani layer prevents the diffusion of heat into the room from the roof. Further studies are necessary to develop the indigenous material and be able to use it in a contemporary building by addressing the optimal thermal comfort and energy efficiency.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Thet Su Hlaing, conducted the research based on the measurement data and analyzed data by statistical calculation. Shoichi Kojima, who is the supervisor of Thet Su Hlaing checked the analyzed data and guided the way to approach the purpose of the research. With the guidance, Thet Su Hlaing finished writing the paper. After revising for three times, all authors had approved the final version.

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