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COMPARATIVE STUDY ON THE THERMAL ENVIRONMENTAL RESPONSES OF INDIGENOUS BAMBOO AND MODERN BRICK HOUSES IN HOT-HUMID CLIMATE OF MALAYSIA

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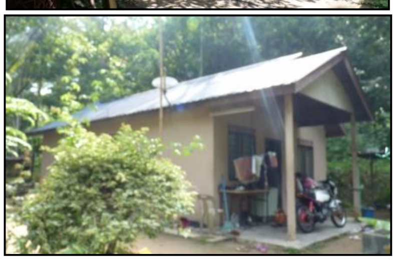
Graphical abstract



Abstract

Vernacular houses using indigenous building materials have shown to be a good strategy for sustainable energy consumption without compensating the occupant's indoor thermal comfort. Bamboo has been identified as the most used building material for vernacular houses in South-East Asia region. However, very little investigation has been conducted to study the passive performance of a bamboo house in maintaining indoor thermal comfort. This study compares the indoor microclimate conditions using thermal comfort Predicted Mean Vote and Predicted Percentage of Dissatisfied models (PMV-PPD) developed by American Society Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) between indigenous bamboo house (H1) and modern brick house (H2) at a village located in the Ulu Gombak Forest Reserve, Selangor. Observations on environmental factors and predicted thermal comfort satisfaction level between day and night times were also taken into consideration. The findings suggest that the use of bamboo plus other vernacular house design features such as raising a house on stilts, located on hilly site and providing air permeability in H1 can lead to a thermally comfortable indoor environment, particularly during night time.

Keywords: Passive cooling, indigenous bamboo house, concrete house, PMV-PPD, outdoor and indoor temperature time lag, thermal comfort

Abstrak

Rumah vernakular yang menggunakan bahan binaan asli terbukti merupakan strategi yang baik untuk penggunaan tenaga mapan tanpa mengabaikan keselesaan terma dalaman penghuninya. Buluh telah dikenal pasti sebagai bahan binaan yang selalu digunakan untuk pembinaan rumah vernakular di rantau Asia Tenggara. Walaubagaimanapun, masih kurang kajian yang dilaksanakan untuk mengkaji prestasi pasif sesebuah rumah buluh dalam mengekalkan keselesaan terma dalaman. Penyelidikan ini membandingkan keadaan mikroklimat dalaman menggunakan model *keselesaan terma Predicted Mean Vote* dan *Predicted Percentage of Dissatisfied (PMV-PPD) oleh* American Society Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) di antara rumah buluh asli (H1) dan rumah bata moden (H2) di sebuah kampung yang terletak di Hutan Rizab Ulu Gombak, Selangor. Pencerapan terhadap faktor persekitaran dan ramalan tahap kepuasan keselesaan terma di antara waktu siang dan malam turut dipertimbangkan. Hasil dapatan mencadangkan penggunaan buluh beserta dengan ciri lain rumah vernakular seperti mempunyai kolong, terletak di kawasan berbukit dan membenarkan pengaliran udara yang terdapat pada H1 akan membawa kepada persekitaran terma dalaman yang selesa terutamanya pada waktu malam.

Kata kunci: Pendinginan pasif; rumah buluh asli; rumah konkrit; PMV-PPD; lag masa suhu luaran dan dalaman; keselesaan terma

1.0 INTRODUCTION

Studies conducted on passive environmental control methods and techniques from vernacular buildings worldwide acknowledge the contribution of local craftsmen in building livable and sustainable structures that respond to the surrounding microclimate with minimal to none energy dependence [1-4]. The majority of these studies have increased the attention on the significant impact of local materials on the thermal performance, environmental responsiveness and cost efficiency of buildings. This economic approach to energy consumption by using indigenous material in buildings not only meets occupants' thermal comfort but also provides a more sustainable living environment [5-7]. Among the wide range of these indigenous materials, this study concentrates on bamboos which grow naturally in many parts of the world including South-East Asia and have more than 1000 species. The key characteristics of bamboos are their rapid growth, great strength, flexibility and successful adaptations [8]. Several studies introduced bamboo as a rapidly renewable material and an environmentally benign solution for integration in green buildings [9, 10]. Likewise, other studies reported that bamboo-structure buildings consume less energy and emit less carbon in comparison with concrete-structure buildings [11]. In the tropical region of East-Asia, bamboo can be seen widely used as structural support and building materials in vernacular buildings, as observed in some vernacular kampong houses in Malaysia [7, 12, 13].

Observing the rapid urban growth in Malaysia, the vernacular kampong houses have been largely replaced by modern residential projects. These vernacular houses have evolved over time to meet the needs of the local people while responding to the local characteristics of the microclimatic conditions. Nevertheless, with the rapid urban expansion, many of their vernacular values embodying major environmental and social benefits are lost [14]. In Peninsular Malaysia, houses made out of bamboo can be widely found in the *Orang Asli* community. The use of bamboo is associated with its fast growth rate and low maintenance characteristics. Moreover, these simple vernacular bamboo houses were made to respond to the hot-humid rainforest climate of Malaysia. Although bamboo houses are sustainable in their construction method, their passive performance through traditional techniques for the purpose of maintaining thermal comfort has not yet been fully examined.

This study compared the indoor microclimate and PMV-PPD calculation between *Orang Asli* bamboo house (H1) and modern brick house (H2) in Ulu Gombak. Due to warm air temperature, low air velocity, high relative humidity and intensified solar radiation detected at the selected site, the study also focused on finding the significant differences between thermal comfort conditions during day time and night time for both measured houses.

2.0 METHODOLOGY

2.1 Geographic and Microclimate Descriptions of the Selected Site

Malaysia is a South-East Asian country encompassing a tropical area near to the equator with hot-humid bioclimatic conditions and heavy tropical rains and intensified solar radiations. The study was carried out at Kampung Batu 16 near the Ulu Gombak Forest Reserve in the state of Selangor in Peninsular Malaysia (03° 22' N, 101° 47' E). The Ulu Gombak Forest Reserve is a secondary forest located at 152.9 m above sea level. The forest reserve receives an annual rainfall of 2500 mm. Based on weather data collected since 2006 until 2011, the temperature recorded here is between 22°C (minimum) to 33°C (maximum) with an average of 25°C. The relative humidity level is between 84% and 93%. The high relative humidity level is resulted from frequent rainfall that occurs at this particular site. The dry bulb temperature and relative humidity data were collected from the closest weather station at Tapak Semaian Lentang (03°22' N, 101°53' E) i.e., 11km from the selected site (Malaysian Meteorological Department). Hourly mean surface wind speed were obtained from FELDA Kampong Sertik station (3° 30'N, 102° 2'E; mean sea level = 70m) which was 31.4km from the selected site (Malaysian Meteorological Department).

Kampung Batu 16, a village occupied mainly by the *Orang Asli* Temuan tribe was selected as the site for the field measurement. Twelve modern brick houses were provided by the government under the Hard-core Poor Development Programme or *Program Pembangunan Rakyat Termiskin* (PPRT) housing scheme. The settlement layout observed in Kampung Batu 16 is typical of an *Orang Asli* hamlet where the houses are dispersed along a hillside next to a small river as described by Michael Bier in the Encyclopaedia of Vernacular Architecture of the World (1997) [13]. Figure 1 shows the settlement layout and location of the two measured houses.

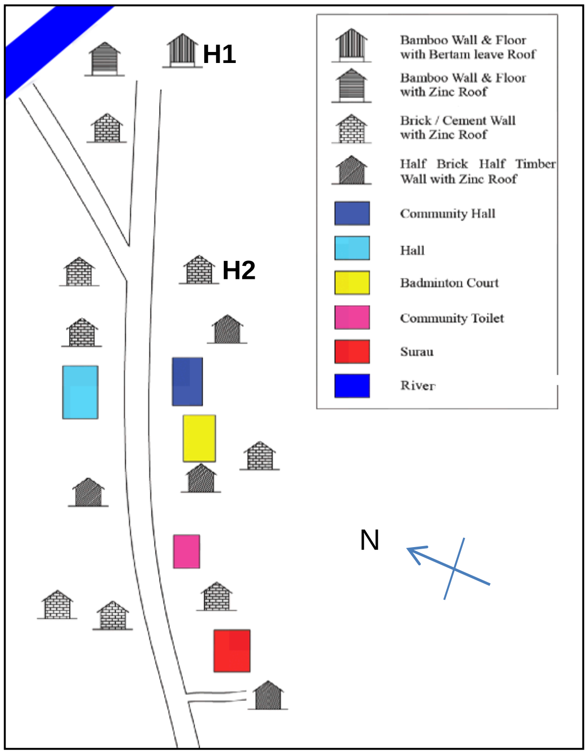


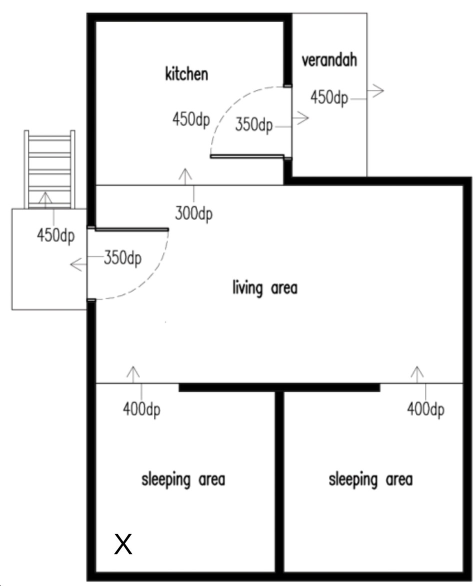
Figure 1 Settlement layout and location of H1 and H2 in Kampung Batu 16, Ulu Gombak

The selected *Orang Asli* bamboo house (H1) for the study was located next to a small river (Figure 1). The built up area is around 50 m^2. The bamboo walls had a thickness of 5mm and based on a research by Kiran et. al. [15] on thermal conductivity of bamboo mat board it can be suggested that bamboo walls' density and thermal conductivity in H1 were 0.77 gm/cm^3 and 0.12 W/mK, respectively. Its living area was raised 2.25m above the ground. Sleeping areas were raised 0.4 m higher than the living area, while the kitchen was the lowest covered area in the H1. The main building material and structure for this house was bamboo except for the roof, in which the owner decided to use corrugated zinc finish instead of organic material such as *nipah* thatch (Figure 2). There was no ceiling and gable end installed in order to allow for passive cooling. H1 was not supplied with electricity. The OHM Delta instrument was installed in the location marked as 'X' in Figure 2.

The selected modern concrete house (H2) was built using concrete structural framing and brick infill for its walls (Figure 3). The overall built up area for H2 was 90m^2 and installed with 0.6m x 1.1m adjustable aluminium louver windows. The walls of H2 consisted of 110mm thick plastered brick wall with a material density and thermal conductivity of 1.76 gm/cm^3 and 0.81 W/m K, respectively. Similar to H1, H2's roof is also assembled with corrugated zinc finish and without any ceiling. The living area, kitchen and three bedrooms were installed with ceiling fans and electric lights. The OHM Delta instrument was installed in the location marked as 'X' in Figure 3.

a)

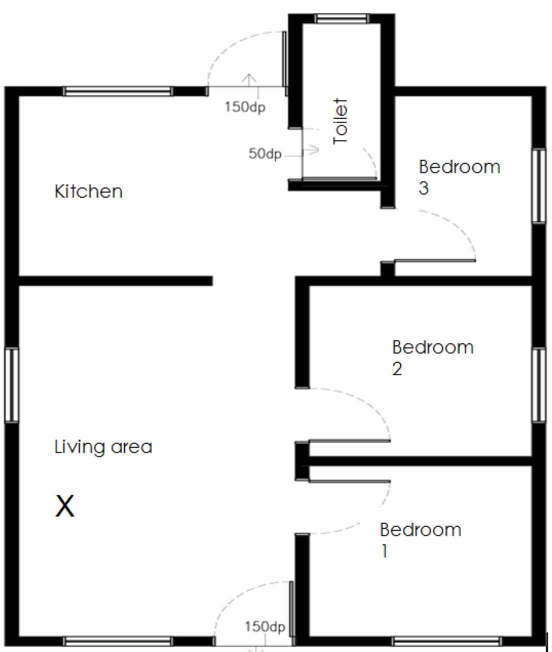
b)



c)

Figure 2 (a) Selected *Orang Asli* bamboo house in Kampung Batu 16, Gombak, (b) exposed roof structure in H1and (c) its floor layout, 'X' marks the location of OHM Delta instrument a)

b)



c)

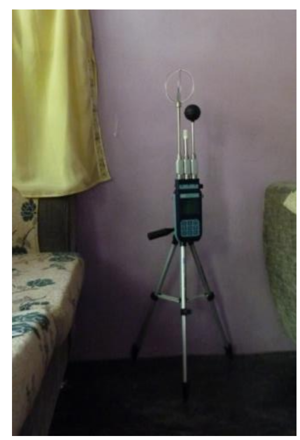
Figure 3 (a) PPRT modern concrete house in Kampung Batu 16, Gombak, (b) exposed roof structure in H2 and (c) its floor layout, 'X' marks the location of OHM Delta Instrument

2.2 Research Procedure

Continuous microclimate monitoring for a period of four days starting from 14 to 17 April 2011 were recorded simultaneously in both H1 and H2. In H1, no electric fan was available and the doors were left shut for security reasons. It was unoccupied at the time of the field measurement. On the contrary, H2 was always occupied, windows were operable and the fans were switched on almost the entire day.

Micrometeorological sensors were selected in accordance with the specifications outlined in ASHRAE Handbook of Fundamentals. The OHM Delta Thermal Microclimate HD32.2 was used to log four basic environmental parameters known to influence thermal comfort namely, air temperature, relative humidity, globe temperature and wind speed. The temperature probes resolution is 0.1°C. Occupant's clo value and metabolic rate were preset at 0.3 (clothing ensemble: sleeveless shirt, short pants and bare-footed) and 1.0 (represents metabolic rate while sedentary), respectively. Readings were logged every 15 minutes for a period of four days. Both OHM Delta instruments were calibrated prior to the actual field measurement. The instrument's probes in H1 and H2 were positioned to be at the same height as the chest of an occupant while sitting namely, 0.6 m (i.e.: siting on the floor) and 1.0 m (i.e.: sitting on a chair), respectively (Figure 4). Instruments were positioned close to the walls in order to avoid occupants from bumping into them and were the only locations agreed by the heads of both houses.

a) OHM Delta data logger located in H1



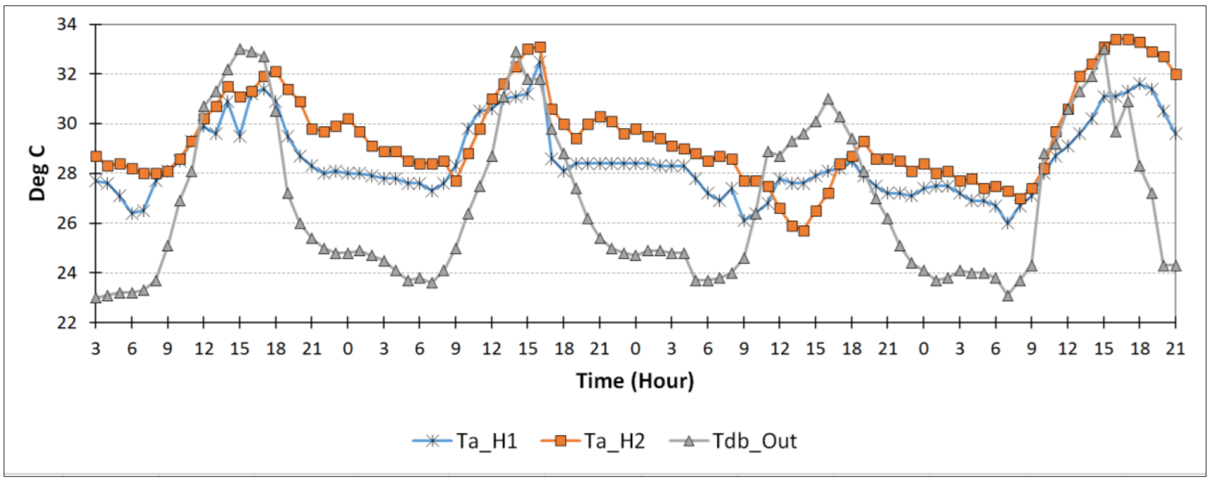
b) OHM Delta data logger located in H2

Figure 4 Location of OHM Delta data loggers in H1 and H2

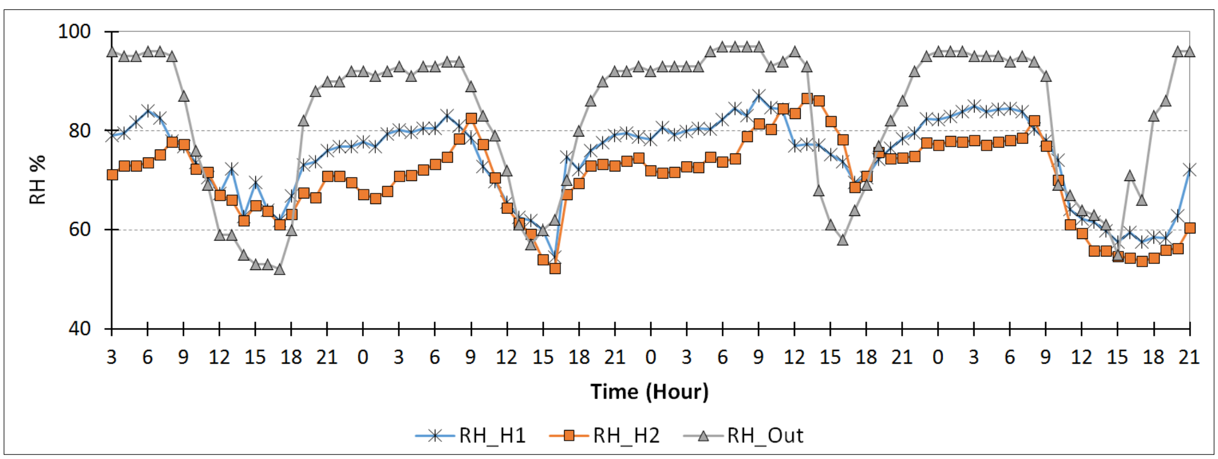
Descriptive statistical outcomes were provided to show the mean operative temperature and PMV-PPD values for both houses during day and night times. ANOVA One-way Test was used to analyse the PMV mean differences between both houses. Chi-square test was generated to identify significant differences of PMV between day and night times for both H1 and H2. Cross tabulation calculation from the chi-square test was used to depict the distribution of thermal sensation votes throughout the PMV scale.

3.0 RESULTS AND DISCUSSION

Field measurements were conducted starting from 14 to 17 April 2011. There were sunny days throughout the field measurement except for 16 April (4th day). On the latter day, an outburst of rain during the daytime was observed from 12 p.m. to 6 p.m. Hourly air temperature, relative humidity and air velocity for H1 and H2 is shown in Figure 5. It is suggested that the outdoor temperature has a diurnal variation of 10°C i.e., from 23°C to 33°C in Ulu Gombak (Figure 5a). The indoor temperature varied from 26°C to 31°C for H1 and from 26°C to 33°C for H2. Air temperature variations suggest H1 is approximately 2°C cooler than H2 when compared with the maximum outdoor temperature. High outdoor relative humidity percentage of more than 90% is due to the location of the weather station that is located in a tropical rain forest (Figure 5b). Low relative humidity evidenced in H2 was resulted by its warmer indoor temperature in comparison to H1. The air velocity in H2 was quite low (i.e., mean = <0.2m/s) in comparison to air velocity recorded in H1 (i.e., mean = 0.3 m/s), despite the regular usage of fans in the former house (Figure 5c).



a)



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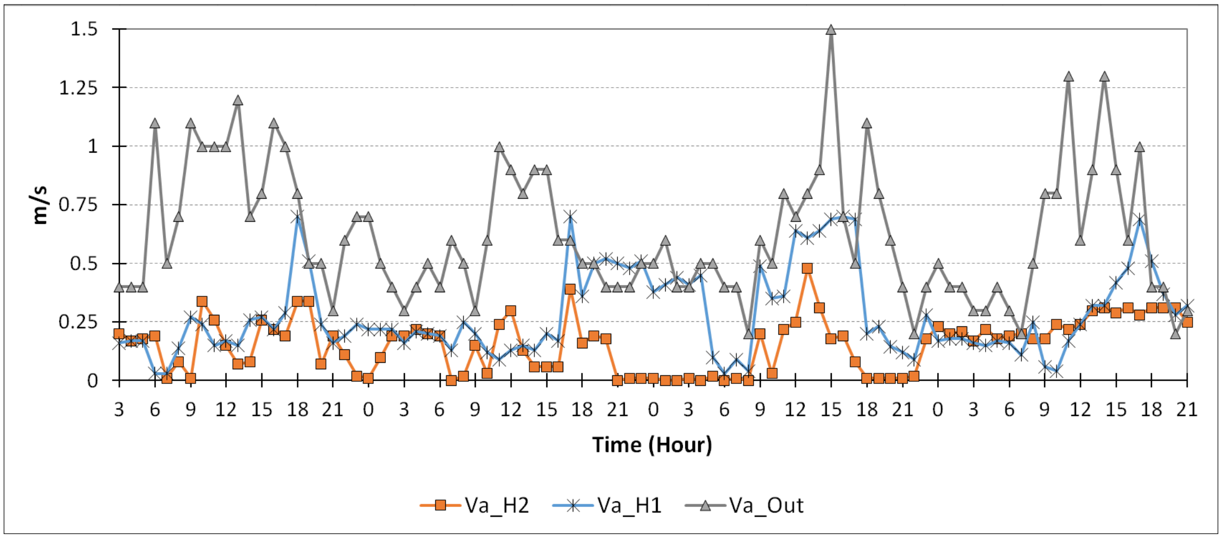
c) 

Figure 5 Air temperature (Ta) for H1 & H2; (b) Relative humidity (RH) for H1 & H2; and (c) Air flow (Va) for H1 & H2 - monitored from 14 - 17 April 2011

Table 1 exhibits the environmental parameters measured during daytime (6 a.m. - 6 p.m.) and night time (7 p.m. - 5 a.m.). It is observed that H1 indoor temperature during night time is 1°C cooler than its indoor temperature during day time. However, no temperature difference was detected in H2 between day and night time.

Table 1 Environmental parameters during the field measurement

		(6 a.m. – 6 p.m.)		(7 p.m. – 5 a.m.)	
		Mean	**S.D**	**Mean**	**S.D**
H1	Ta (°C)	28.80	±1.8	28.09	±0.9
	Tg (°C)	29.02	±2.1	27.96	±1.0
	RH (%)	72.18	±9.1	78.10	±5.1
	Va (m/s)	0.29	±0.2	0.27	±0.1
H2	Ta (°C)	29.52	±2.2	29.37	±1.3
	Tg (°C)	29.35	±2.2	29.13	±1.3
	RH (%)	70.08	±9.9	71.68	±5.3
	Va (m/s)	0.18	±0.1	0.13	±0.1
Outdoor	Ta (°C)	28.04	±3.4	24.91	±1.2
	RH (%)	75.79	±15.7	91.69	±4.4
	Va (m/s)	0.76	±0.3	0.44	±0.1

PMV/ PPD analysis based on Fanger's comfort theory [16-18] was performed for both buildings. Clo value of 0.3 (i.e., sleeveless shirt with short pants including underwear) and MET value of 1 (i.e., sedentary) were assumed for the analysis. In H1, the PMV value ranges from -1.2 to 2 and the corresponding PPD values are 5% and 75%, while in H2 the PMV value ranges from -1.4 to 2.7 and the corresponding PPD values are 5% and 98% (Figures 6 and 7a & b). It can be noted that PMV-PPD analyses suggest that the indoor of H1 is cooler especially during night time and thus is predicted to have lesser percentage of dissatisfaction than H2. Overall, PMV calculated that in H1, the highest vote value of slightly warm (+1) is to be expected from 1 p.m. until 4 p.m. In H2, the highest PMV value (i.e., close to warm vote or +2) occurred from 3 p.m. to 6 p.m. (Figure 6).

Moreover, the current finding is in agreement with many other thermal comfort studies in naturally ventilated building in hot-humid climate countries that found occupants can be thermally comfortable within the optimum comfort temperature range of 28-30°C [19-22]. Despite accepting the temperature range as thermally acceptable, occupants living in naturally ventilated buildings in hot-humid climate conditions have to employ many efforts such as using fan, opening windows, changing clothing and etc. in order to feel thermally comfortable.

From these observations, it can be concluded that the two houses resulted in different air temperature time lag between the outdoor and indoor conditions during the afternoon (i.e., 3 p.m. to 6 p.m.). Moreover, suggesting that H2 is warmer than H1 during the particular time range with mean PMV values that differ significantly at p<0.01 level using ANOVA one-way test.

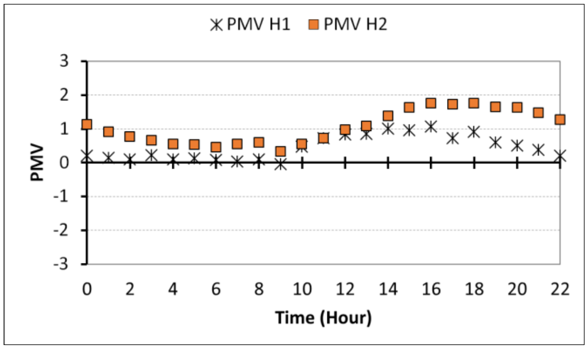
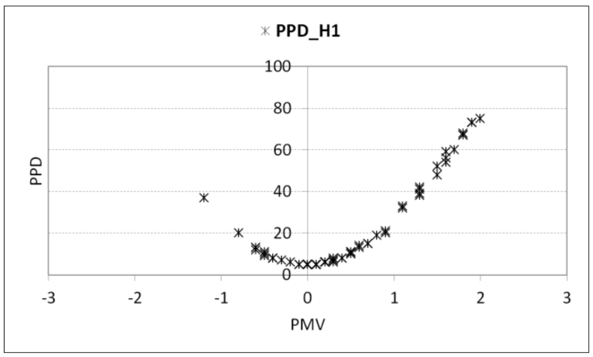
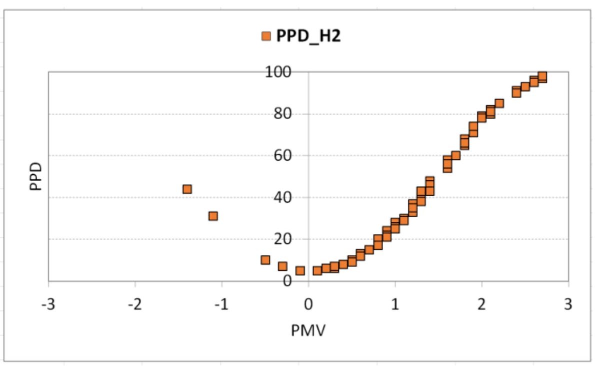


Figure 6 Mean PMV vs. time for H1 and H2



(a)



(b)

Figure 7 Averaged PMV vs. PPD for (a) H1 and (b) H2 for all four days

Means of operative temperature, PMV and PPD for H1 and H2 between day and night times are shown in Table 2. The findings suggest that higher level of thermal comfort is observed during night time in H1 (PPD = 9%) in comparison to H2 (PPD = 33%). The particular conditions were attributed to lower air temperature but higher air velocity in H1 during night time. Operative temperature for H2 was found to have no significant difference with H1 throughout the day. However, readings in H1 decreased to be lower than H2, suggesting that heavier thermal mass (i.e., brick) in the tropics resulted in a warmer indoor condition than a bamboo house. The temperature of the outside air remains almost the same throughout the day and night; H2 cannot cool off sufficiently at night time, due to its high thermal capacity compared to H1. The findings have been corroborated in numerous studies in tropical housing [7, 22-25]

Table 2 Operative temperatures and mean between H1 and H2 at different time of a day

		Mean	**S.D**
Day time (6 a.m. - 6 p.m.)	T op. H1	28.8	±1.8
	PMV H1	0.6	±0.9
	PPD H1	28%	
	T op. H2	29.5	±2.2
	PMV H2	1.0	±1.0
	PPD H2	39%	
Night time (7 p.m. - 5 a.m.)	T op. H1	28.1	±0.9
	PMV H1	0.2	±0.4
	PPD H1	9%	
	T op. H2	29.3	±1.3
	PMV H2	1.1	±0.6
	PPD H2	33%	

Analyses using Chi square tests suggest that the PMV during night time for both H1 and H2 differ significantly at the 0.01 level (2-tailed) (Table 3). A high number of thermal comfort neutrality is shown in H1 indicating that its occupant can be assumed to feel neither warm nor cold during night time. On the other hand, in H2, it is predicted that an occupant can feel slightly warm throughout the night. No statistical difference was detected for both houses during the day, despite higher outdoor airflow of 0.76 m/s observed (Table 1).

Table 3 Results of Chi-square tests

	PMV							***p* value**
	-3	-2	-1	0	1	2	3	
Day time (6 a.m. - 6 p.m.)								
H1	0	0	8	16	14	13	1	
H2	0	0	3	12	20	11	6	0.077
Night time (7 p.m. - 5 a.m.)								
H1	0	0	0	32	6	1	0	
H2	0	0	0	7	24	7	1	0.007

The results of this study suggest that H1 has a lower night time variation of the indoor temperature in comparison with H2. Findings suggest that concrete walls as found in H2 can deter heat loss during the night due to higher thermal mass property compared to H1. Both houses were installed with corrugated zinc roof but only H2 windows were operable during nigh time. In H1, design characteristics such as the permeability property of bamboo as building material, built on stilts and on gradient slope areas allows more airflow into the house and enable heat to escape via the gable end, hence works better to lose heat especially during night time.

In order to perform passive cooling strategy in hot-humid environment, building materials for houses need to have less thermal mass to result in shorter time lag between outdoor and indoor air temperature [1, 26]. Slightly cooler PMV in H1 can be predicted to be in association with H1's better passive cooling performance especially during the night compared to H2. It can be suggested that H2's greater material density and thermal conductivity compared to H1 contributed to its longer time lag in releasing heat. Moreover, it was observed that the outdoor air flow, particularly during the night has no influence in reducing the interior ambient temperature of the measured houses.

4.0 CONCLUSION

This study investigated the passive cooling method of two different houses with two different building material usages, namely, bamboo and brick. It is suggested that vernacular architecture approach by using bamboo for the wall and floor system of a house may provide an alternative to night cooling strategy. The study demonstrates that building material has an important role in order to create a thermally tolerable indoor environment for hot-humid climate condition. Passive control method in an environment with limited wind velocity and high relative humidity is proven to be quite challenging in this particular climate region.

For future research, it can be recommended that PMV-PPD and passive cooling performance for houses with organic indigenous roof finish material such as bamboo in hot-humid climate environment should be investigated. More researches are needed to identify thermal characteristics of organic indigenous building materials particularly the walls and floors under actual hot-humid climate conditions.

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