Resistive or Reflective? Suitable Building Materials for Tropical Coastal Areas

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Resistive or Reflective?

Suitable Building Materials for Tropical Coastal Areas

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Abstract: A design shift of houses from traditional to modern is not only driven by personal preferences about modern living and the need for new spaces, but also about the availability and durability of building materials. Changes in building materials, especially on the roof, will modify the thermal conditions in the interior of the building. This study compared the thermal performance of resistive and reflective building materials in tropical coastal areas. An empirical study was carried out to measure external and internal thermal conditions in two vernacular houses located in the coastal area of Central Sulawesi Province, Indonesia. The sample houses were traditional raised floor houses which present two different types of roofing material, namely sago thatch roof (resistive material) and corrugated zinc sheet roof (reflective material). The outcomes indicated that the resistive material has more advantages in controlling the internal conditions than the reflective material. This state is due to its porous material characteristics which can supply a low air temperature to the house and release air humidity to the external environment.

1. INTRODUCTION

Traditional houses are used to provide shelter against critical environmental factors and continued to be developed until they became adapted to the given climate and also reflected the culture of the occupants (Bouillot, 2008; Chandel, Sharma, & Marwah, 2016; Shanthi Priya et al., 2012; Toe & Kubota, 2015). In creating a climate adapted building, the availability of building materials is a crucial factor. Among the many considerations for choosing building materials is durability. Even though traditional houses are widely believed to be responsive to climatic conditions and create a more comfortable internal environment (Chandel, Sharma, & Marwah, 2016; Cofaigh, Olley, & Lewis, 1996; Lee, Han, & Lim, 1996; Shanthi Priya et al., 2012; Zhai & Previtali, 2010), some of them still need occupant adaptation (Fitriaty, Antaryama, & Ekasiwi, 2011; Van et al., 2014; Yermawan, Alfata, & Rumiawati, 2013), and some use envelope materials that have durability issues. In consequence, most of the newly constructed houses in tropical areas are built with preferred modern materials which have a longer life than traditional materials. The shift of materials used in the building envelope and the change in thermal condition in the internal environment, especially on the tropical coastal area are investigated in this paper.

The building envelope is directly in contact with the external ambient conditions. Thus it plays a key role in providing comfortable internal conditions to occupants (Chavez, 2005). In the warm and humid tropics, critical elements of the building envelope which are responsible for overheating in the interior spaces are the roof, and the east and west walls. In this climate, low daily temperature swings make using a large thermal mass to avoid excessive solar heat gain unnecessary. Hence, widely known strategies to provide comfort in internal spaces are to maximise the effect of breeze and to protect the building from direct sunlight (Baker, 1987; Evans, 1980; Moore, 1993). Accordingly, excellent reflective and/or resistive insulation materials are the most suitable for these elements (Szokolay, 2001).

In the coastal region of tropical warm and humid climates, the presence of a large body of water creates a large thermal inertia in the thermal environment. It dramatically reduces both daily and annual temperature variation (Moore, 1993; Shanthi Priya et al., 2012). The breeze in this region has an almost constant direction which can be relied on for cooling. Thus the orientation and building construction are even more imperative to catch the maximum air movement than in inland regions (Koenigsberger et al., 1974). Lightweight porous structures with a lofty roof space and deep overhanging eaves will be beneficial in this region. Therefore, the characteristic of traditional building in tropical warm and humid climate with lightweight structure elevated on the stilts and fully cross-ventilated is appropriate.

Indonesia has the second longest coastline of all countries and traditional buildings on the coast share many similarities. The traditional houses in Labuan Bajo Central Sulawesi Province are one example. The houses are formed on a raised floor construction with single layer plan that stands against the sea and is supported by log pillars (*Figure 1*). The roof is traditionally made of sago thatch material, while the floor and the wall are often made of lumber. Some of the walls are made of plaited bamboo. The envelope of the house is very porous and there are lots of air gaps in its construction. At present, most of the roofs are made of corrugated zinc sheet material. This situation has something to do with durability and availability of the material which generally lasts longer than sago thatch materials, and it is fire proof.

Changing roof materials leads to changes in the thermal conditions inside the house because the roof has been shown to be the most critical element in eliminating solar heat gain (Hernández-Pérez et al., 2014; Kabre, 2010). Corrugated zinc sheet roof (thermal transmittance of 7.14W/m²K) is known to create a higher internal temperature than sago thatch roof (thermal transmittance of 4.42W/m²K), especially when the outdoor temperature reaches its maximum. Corrugated zinc sheet roofing represents a reflective material, and sago thatch roof represents a resistive material in this study. Some studies have demonstrated that reflective material has more advantage in warm conditions (Kolokotroni, Gowreesunker, & Giridharan, 2013; Shanthi Priya et al., 2012; Synnefa, Saliari, & Santamouris, 2012). The use of reflective materials is often treated as a coating layer for outer roof materials and often contains two or more layers of roof. Unfortunately, the application of modern insulated roofs in tropical developing countries has been less popular due to high economic cost. Thus, people tend to choose a single material over layered materials and are unaware of the thermal condition it will cause.

Several studies have analysed climate responsive design strategies of traditional houses in tropical warm and humid climates (Chavez, 2005; Nguyen et al., 2011; Toe & Kubota, 2015). Most of the studies noted the change in roof material but did not discuss the impact of this change to the internal thermal conditions. Considering this problem has an interesting phenomenon in choosing suitable building materials, this study will explore the performance of reflective and resistive materials in the tropical coastal area. The evaluation of actual thermal performance in this research can provide further empirical data and help improve understanding of appropriate design for buildings in tropical warm and humid climates, especially in coastal areas.

Figure 1. Original Construction of Traditional Houses in the Coastal Area of Central Sulawesi, Indonesia

2. METHOD

2.1 Case Study Location

Figure 2. Location of the Case Study (satellite map acquired from Google map, 2016)

The case study area is located at Labuan Bajo Donggala, Central Sulawesi Province of Indonesia (*Figure 2*). The area is in the west part of Palu Gulf at a latitude of 00°39'37.3"- 00°42'31" South, longitude of 119°44'17.6"–119°44'31.9" East, and at an altitude of 0 - 50 meters above sea level. The presence of the gulf and nearby mountains makes the meso-climate of the area a tropical warm and humid climate with a direct effect from sea influences. The area experiences a low range of temperature variation, both during the day and over the year. This condition is caused not only by its position near the equator but also its distance to the sea which has a high thermal capacity. Like most regions in Indonesia, the area has two seasons marked by high and low rainfall periods, sometimes referred to as the wet and dry season.

2.2 Sampled Houses

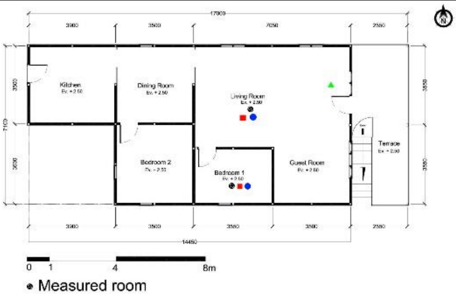
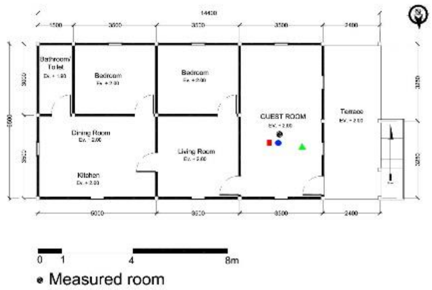
The two sampled houses represent typical traditional houses in coastal areas of Central Sulawesi Province. The houses were chosen purposively by location, long axis orientation, building geometry, building materials and house area. The sampled houses are located in the tidal area where the house pillars will be soaked by the sea water in the afternoon and dry in the morning (*Figure 3*). To minimise confounding factors in the measurements, all the design parameters in both houses were chosen to be more or less the same condition except for roof materials (*Table 1*).

Figure 3. Sample House Location (satellite image acquired from Google map, 2016)

2.3 Measurement of Thermal Condition in Sample Houses

The thermal condition was evaluated by comparing indoor and outdoor thermal condition of the sample houses. A field study was conducted by measuring air temperature, relative humidity, and air velocity. The recorded thermal condition was conducted simultaneously for three days in August 2013 in order to establish temperature and relative humidity trends over a period longer than 24 hours, and to avoid using unrepresentative days for the analysis.

Table *1*. Details of Sampled Houses

	Sample 1 (Reflective Roof)	Sample 2 (Resistive Roof)
Floor Plan		
Exterior and Interior View		
Description	Long axis building oriented to east-west. Floor raised ~2.5 m above the ground, with floor area of 87.5 m^2. The roof is made of corrugated zinc sheet painted glossy light blue colour with ceiling and no insulation. 20mm wood board wall with a glossy brown coating on its exterior wall. 35mm floor made of wood board. Tilt-up windows with framed glass. Ceiling height 2.5m The plan consists of double layer with several rooms, namely living room in the East area, family room in the North area, two bedrooms in the South area, kitchen and dining room with no partition in the West, and terrace in front of the living room and guest room.	Long axis building oriented to east-west Floor raised ~2m above the ground, with floor area of 74 m^2. The roof is made of sago thatch with ceilings and no insulation. Unpainted wall with 20mm thick wood board. Floor made of wood board 20mm thick. Side hung windows made of wood board 20mm thick. Ceiling height 2.5m A double layer plan with several rooms namely a living room in the West area, a bedroom in the South, kitchen which also functions as a dining room in the East, and terrace in front of the living room.

Measurement of air temperature and relative humidity was recorded by employing a Hobo™ data logger (model H08-007-02), at 15-minute intervals for both internal and external spaces. The internal measurement took place in the living room and bedroom at a point located 1 m above the floor. The loggers were carefully placed to avoid direct sunlight throughout the day. Wind speed was recorded by using a Mastech™ anemometer (model MS6252), every hour from 8.00am to 5.00pm at 5 minutes interval, for both internal and external environments.

2.4 Analysis of Thermal Performance

This study uses neutrality temperature to determine the thermal performance of the house. In many studies, thermal neutrality is defined as a thermal condition where people feel neither warm nor cool, but neutral. It is at the middle point of the comfort zone for any given climate, as an average value for many experimental subjects. According to Auliciems, the neutrality temperature is given by the following formula, where the comfort zone range is taken as 5K, 2.5K above and below the neutral temperature approximately (Szokolay, 1987).

$$T_n = 17.6 + 0.31 \times T_0 av \tag{1}$$

Where T_n is thermal neutrality; $T_0 av$ is the average outdoor temperature in given climate.

2.5 Analysis of Building Form and Fabrics

A comparative method was used to analyse the effect of building form and fabric on the internal thermal condition at two sampled houses. According to Evans (1980), basic variables of building form in relation to thermal conditions are surface to volume ratio (SVR), depth of buildings, space between buildings, and ceiling height. Therefore, this study took two types of house as the sample representing almost the same building volume, building depth, and ceiling height, for the purpose of comparing the influence of the building materials on the thermal performance. The chosen samples had different building fabrics especially the roof materials, namely corrugated zinc sheet roof (sample 1) and sago thatch roof (sample 2).

Thermal performance of building form and fabric should be analysed by comparing the modified internal thermal condition to the external thermal condition. Thus, both internal and external discomfort degree hours (Kh) are an important parameter in evaluating building form and fabric effectiveness in modifying indoor thermal condition. Furthermore, occupant comfort duration and building comfort duration are also important parameters in analysing building thermal performance. Accordingly, this study used discomfort degree hours, occupant comfort duration, and building comfort duration to compare building form and fabric of the sample houses. To unify the indicator of building form and the fabrics' thermal performance, this study proposes a new indicator called response effectiveness which is measured in percentage.

Modified internal thermal condition was calculated by the improvement of internal thermal condition compared to the external thermal condition, which can be expressed by the following equation:

$$\boldsymbol{RE = \frac{Kh_o - Kh_i}{Kh_o} \times 100} \tag{2}$$

Where *RE* denotes response effectiveness in percentage; Kh_o denotes outdoor discomfort degree hours; Kh_i express indoor discomfort degree hours.

Indoor comfort duration is assessed by the period of hours where the air temperature is within the range of the comfort zone. In this study, indoor comfort duration was assessed by the period of time when the building is actively used (occupied) and over a period of 24 hours. Comfort duration when the building was actively occupied is later called occupant comfort period (CD_o), and comfort duration for 24-hour period is called building comfort duration (CD_b). Response effectiveness can then be analysed by the percentage of occupant comfort duration and building comfort duration over the period the building is actively occupied (tCD_o) and over the 24-hour period (tCD_b). Thus, the equation can be given as,

$$RE = \frac{CD_{o,b}}{tCD_{o,b}} \times 100 \tag{3}$$

3. RESULT AND DISCUSSION

3.1 Thermal Condition in Sample 1: Reflective Roof

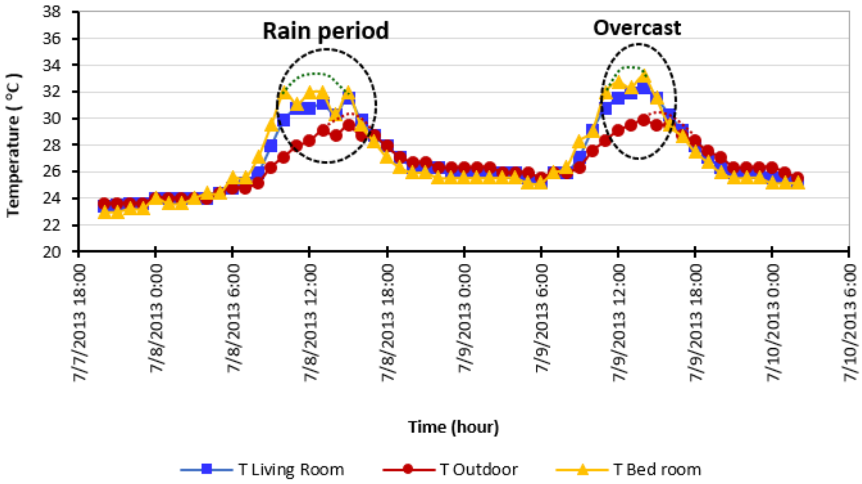


Figure 4. Internal and External Air Temperature over a 3-day Measurement of Sample 1

The internal and external air temperatures over the 3-day measurement at sample 1 can be seen in *Figure 4*. This figure shows that the maximum internal and external temperature was not quite the same over the 2-day measurement. The measurement on day 1 did not show a smooth normal curve. This was mainly caused by the occurrence of rain from 12.00pm to 3.00pm. If the graph is interpolated with an imaginary line, it can be seen that in the absence of rain or cloud, the maximum temperature probably occurred at 1.00pm. In 2-days of measurement it was recorded that the maximum and minimum external temperatures were 29.9 ℃ and 23.6 ℃ respectively, while the maximum internal temperatures were 32.3 ℃ in the living room and 33.2 ℃ in the bedroom, and the minimums were 23.4 ℃ and 23.0 ℃ in the living room and bedroom respectively. Therefore, the internal air temperature was higher than the external air temperature by up to 3.3K in the daytime.

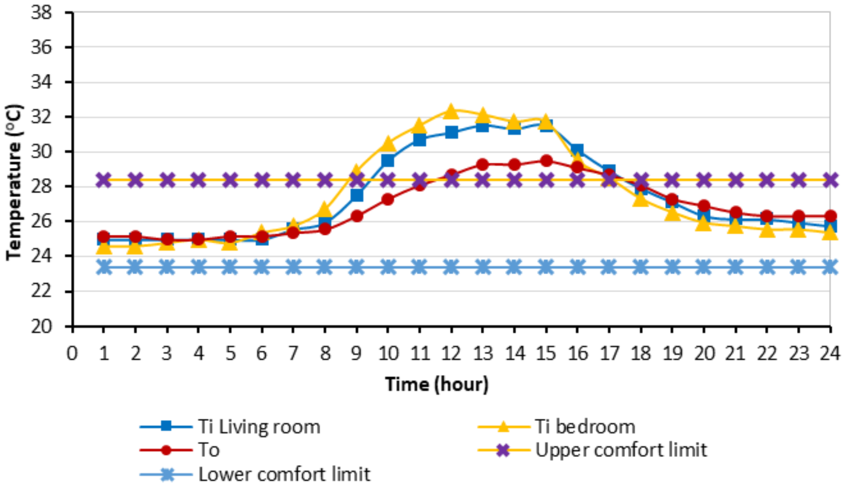


Figure 5. External and Internal Air Temperature against Comfort Zone for Sample 1

By calculating the average temperature (*Figure 5*), the thermal condition in house sample 1 can be analysed. The graphs imply that fluctuations of air temperature inside the building followed the pattern of outdoor temperatures. This condition was to be expected from a building with a lightweight structure. It can be observed that the internal and external maximum temperatures occurred at almost the same time, between 12.00pm to 2.00pm, thus the house did not have a time delay effect meaning that its thermal capacity can be classified as small. This again emphasizes the characteristics of a lightweight building structure.

It can be seen from the recorded internal temperatures that the house experienced overheating during the day. The internal temperatures were above the comfort level from 9.00am till 5.00pm. Underheating did not seem to be a problem in internal spaces as the air temperature never fell below the comfort level line.

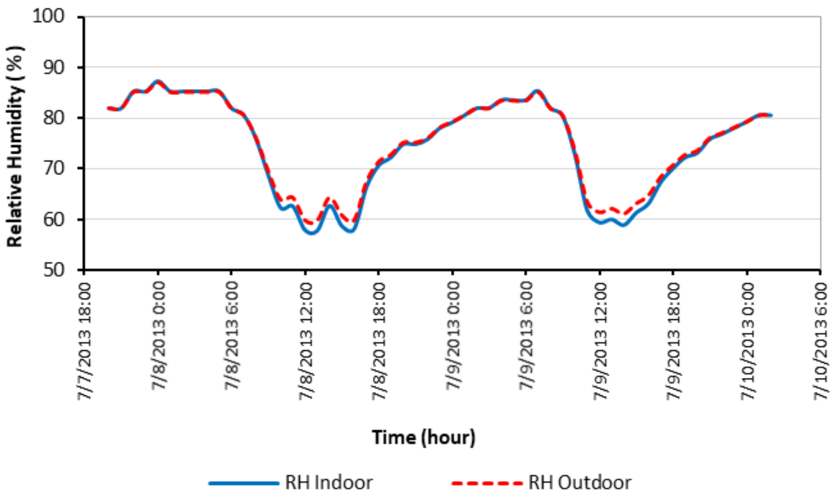


Figure 6. External and Internal Relative Humidity (RH)at Sample 1

Figure 6 shows the internal and the external relative humidity recorded in house sample 1. The internal relative humidity in the house was high and varied between 58 - 87%. The reason for this is due to the high external relative humidity value which ranged from 60 - 87%. The main contributor to this high relative humidity is the sea in front of the house. The highest relative humidity (87%) occurred when temperature fell into the lowest range 23 ℃, whereas the lowest humidity (57%) occurred when temperature reached its highest point 31.5 ℃. According to Givoni (1998) there will be no sensible difference between relative humidities of 30% and 80% in air temperature up to 25 ℃. Therefore, a relative humidity condition in this house will bring minimum effect on thermal comfort, and provision of sufficient air movement will minimize the effect of a high relative humidity value.

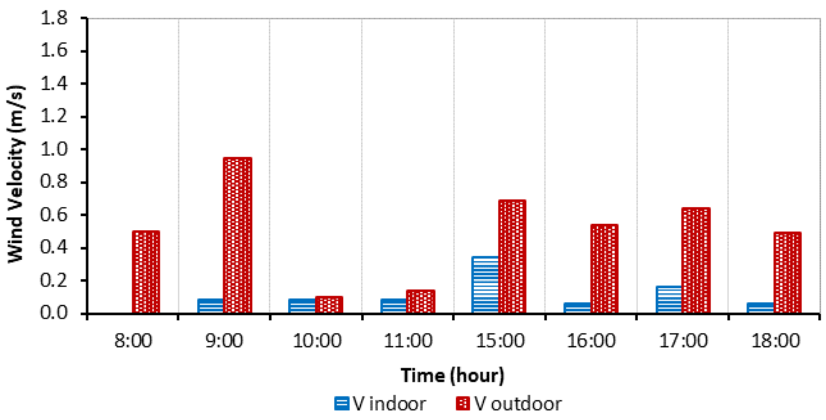


Figure 7. Average External and Internal Air Velocity (V) at Sample 1

The maximum external air velocity was 1.9 m/s which occurred at 5.00pm, while maximum internal air velocity was 1.0 m/s and occurred at 1.00pm (*Figure 7*). The prevailing and secondary wind directions in the measurement period were blowing from the South-East and East (from the sea). Theoretically, air velocity of about 1.1 m/s could facilitate comfort by extending the comfort zone up to 1.5K particularly when the building was overheated. Unfortunately, this was not the case for this house as most of the time air velocity in the internal spaces was 0.0 m/s. One of the main reasons causing this situation was that even though the orientation of the openings where mainly placed on the North and East sides of the house, awnings, and the type of windows can reduce wind speeds by up to 30% (Moore, 1993). In addition, curtains placed inside the windows covered almost 50% of the opening area, which reduced air velocities inside the house.

3.2 Thermal Condition in Sample 2: Resistive Roof

External and internal air temperatures from house sample 2 over the 3-day period were also not a smooth normal curve (*Figure 8*). This was mainly because of the weather conditions: raining and overcast sky lowered the air temperature. In spite of this condition, both external and internal air temperature profiles generally showed good agreement. Hence, the average value could be considered representative for the analysis.

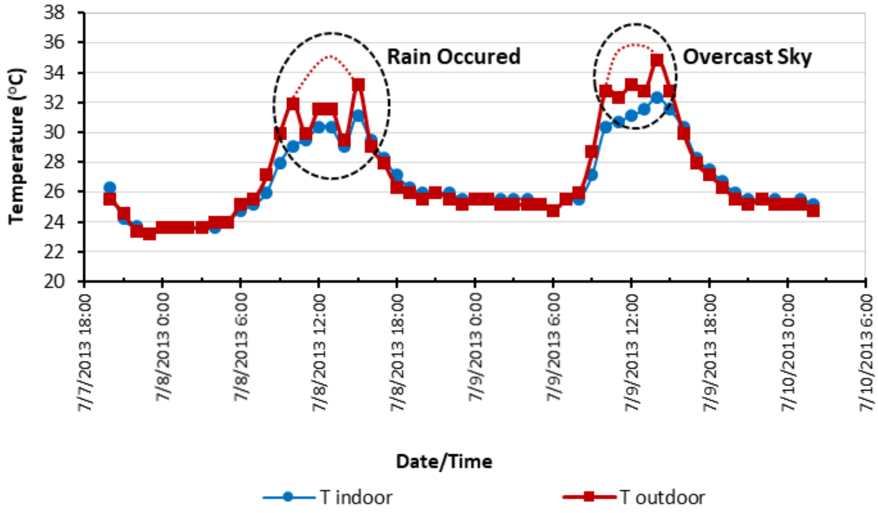


Figure 8. External and Internal Air Temperature (T) over 3-day period of Sample 2

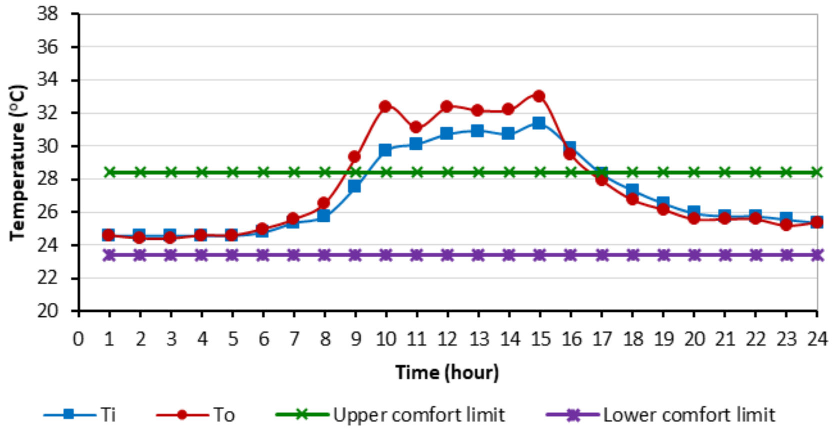


Figure 9. Internal and External Air Temperature against Comfort Zone for Sample 2

To analyze the thermal conditions in house sample 2, the average external and internal temperatures were established as shown in *Figure 9*. The average external air temperature ranged from 24.4 ℃ – 33.0 ℃, whereas the internal air temperatures varied from 24.6 ℃ – 31.3 ℃. Thus, the diurnal temperature ranges were 8.6K and 6.7K respectively for external and internal air temperatures. Therefore the internal air temperature variation was smaller than the external air temperature variation. This means that thermal conditions in the internal space were better than the external condition (i.e. the extremes were lower). The maximum external and internal air temperatures occurred at 3.00pm, whereas both minimum external and internal air temperatures occurred between 2.00am - 3.00am. As for house sample 1, there was no thermal time delay effect in the house. This fact is due to the properties of the house which was made of low thermal capacity fabric (i.e. wooden floor boards and walls, and also sago palm thatch roof).

Profiles of external and internal relative humidity of the 3-day period at house sample 2 are shown in *Figure 9*. The graphic pattern shows that the external and internal relative humidity at this house were almost identical. The maximum and minimum external values were 89% and 58% respectively, while the internal maximum and minimum values were 90% and 56%. These patterns were similar to house sample 1, although the value was higher than in house sample 1. The results again underlined the effect of the sea on humidity at the site.

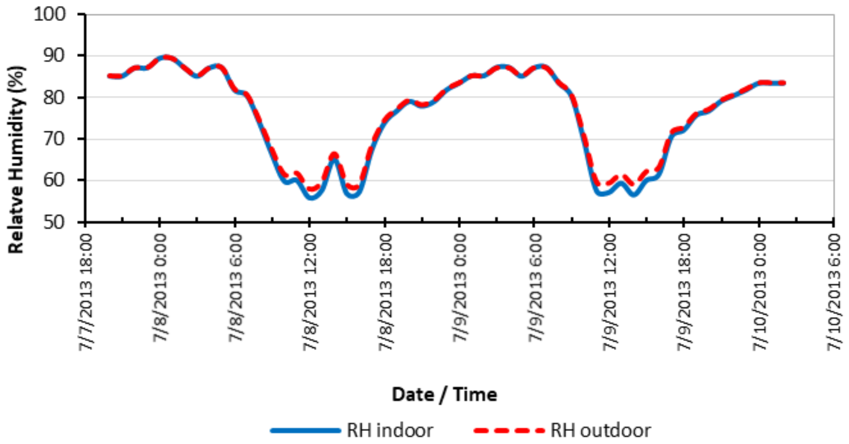


Figure 10. External and Internal Relative Humidity (RH) of Sample 2 House

The largest external air velocities occurred at 3.00pm (2.3 m/s) and at 5.00pm (2.23 m/s). The largest internal air velocities occurred at 8.00am (1.0 m/s), at 12.00pm (0.9 m/s), and at 3.00pm (0.8 m/s). The internal air velocities in house sample 2 were slightly better than those in house sample 1. These conditions were mainly caused by side hung windows, a type which is better than awning windows in not restricting wind velocity compared to side hung windows which can catch 90% of air velocity when placed in the prevailing wind.

The door position in this house was to windward and the opening schedule was from 6.00am till 5.00pm, allowing cool air to enter the internal space from the secondary wind direction (West), but the small area of this opening could not meet the air movement requirement for reducing overheating (1.5 m/s). Most of the openings were placed on the North and South wall with the opening side hung against the windward side, thus wind speed was not optimal for entering the internal spaces.

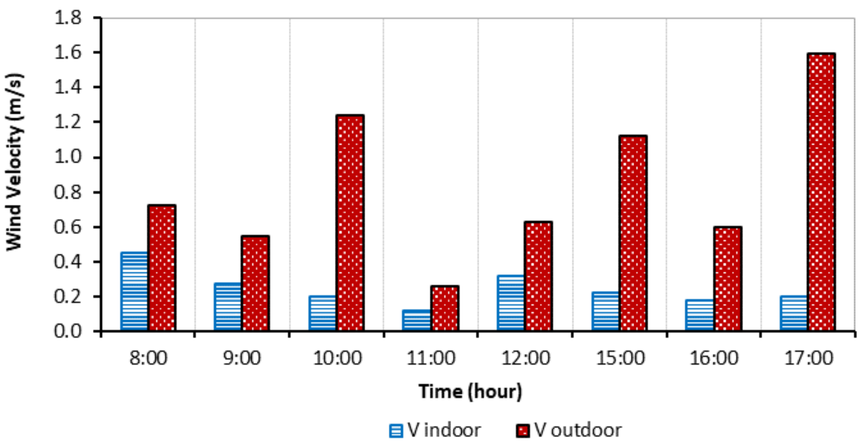


Figure 11. Average External and Internal Wind Velocity (V) of House Sample 2

3.3 Comparison of Thermal Performance in the Sample Houses

The thermal performance of the sample houses was assessed by using degree hours of discomfort and comfort duration for a 24-hour period and the period of occupation. It can be seen from Figure12 that both houses experienced overheating during the daytime, at the same time the outside air temperature was above the comfort level. Thermal discomfort in house sample 1 was for a longer period and higher than that in sample 2.

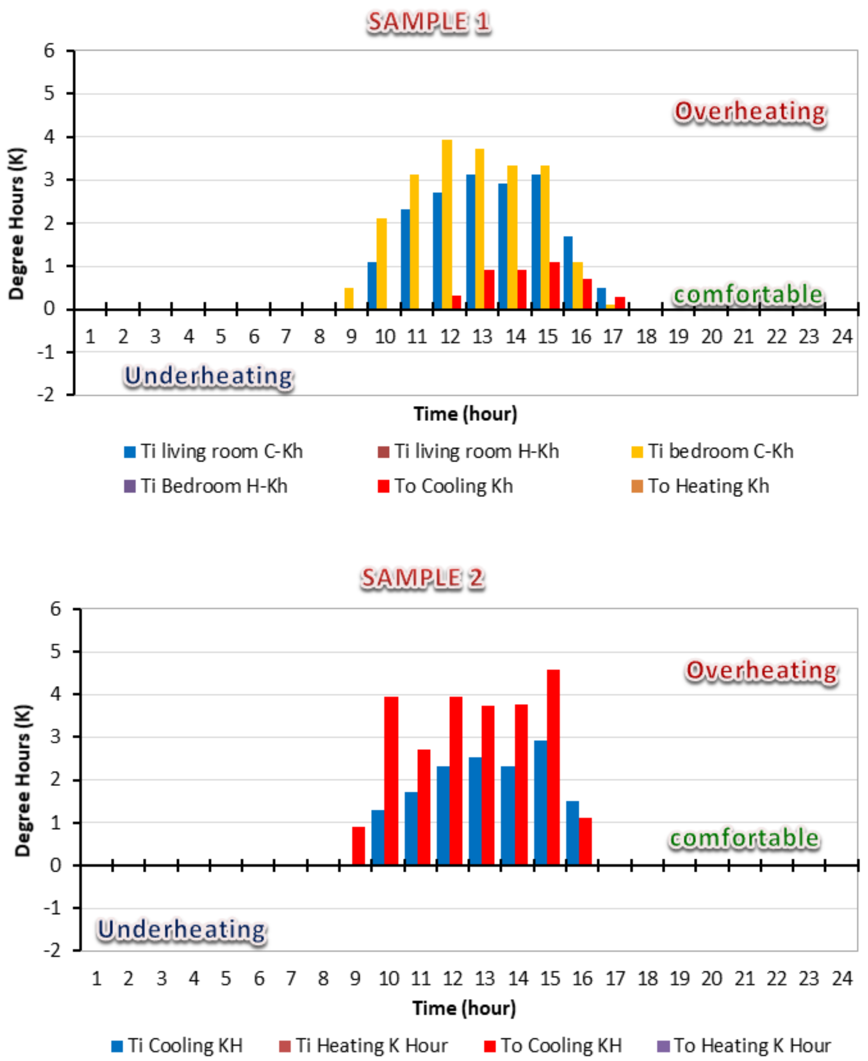


Figure 12. Degree Hours of Discomfort at Sample 1 and Sample 2 Houses

Thermal discomfort degree hours in Sample 1 varied from 0.5K – 3.1K in the living room, and 0.1K – 3.9K in the bedroom, while the outdoor thermal discomfort only varied from 0.3K – 1.1K, with total discomfort degree hours of 17.5K, 21.3K and 4.2K for the living room, bedroom and outdoors respectively. This result implies that internal thermal condition was more dissatisfactory compared to the external thermal condition. This suggests that the building envelope has failed to modify the microclimate into a comfortable interior space. The condition was confirmed by the occupant preference on thermal sensation where the house was unacceptably hot.

In comparison, house sample 2 succeeded in lessening the internal total discomfort degree hours by 10.1K compared to the external total discomfort degree hours (*Figure 13*). Thermal discomfort degree hours in the internal space only varied from 1.3K – 2.9K, while the thermal discomfort degree hours in the external condition varied from 1.1K – 4.6K; the total discomfort degree hours were 14.6K and 24.7K for the internal and external spaces. Hence the thermal condition of the house sample 2 was better than the external thermal condition. This condition was confirmed by the occupant preference on thermal sensation where the thermal condition of the house was acceptable and neutral.

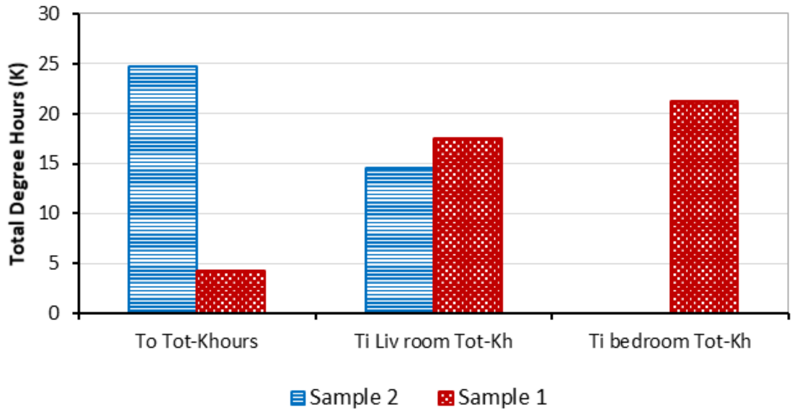


Figure 13. Degree Hours of Discomfort at Sample 1 and Sample 2

3.4 The Influence of Building Form and Fabrics on Thermal Condition

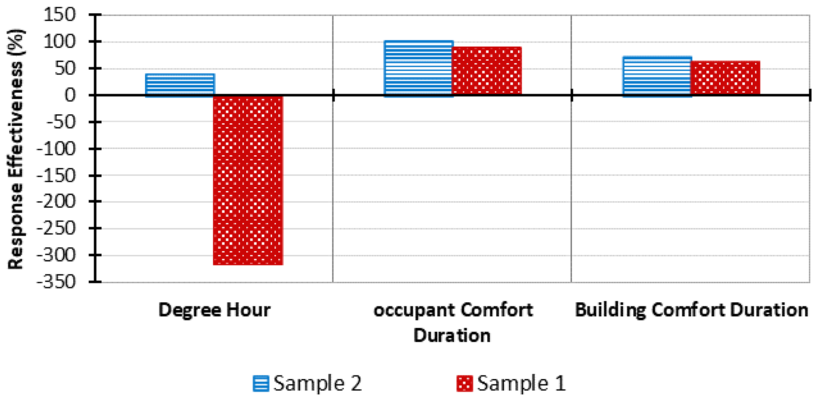


Figure 14. Degree Hours of Discomfort at Sample 1 and Sample 2

The influence of building form was analysed using discomfort degree hours and comfort duration, both in the occupied and unoccupied periods. *Figure 14* shows that in every assessment parameter, sample 2 performed better than sample 1. Sample 2 has 78m ^{2} floor area, 111.25m ^{2} roof area, 88.01m ^{2} wall area, and 4.49m ^{2} of openings; the Surface to Volume ratio (SVR) was 0.85. Meanwhile, sample 1 has 87.5m ^{2}floor area, 153.54m ^{2}roof area, 105.84m ^{2} wall area, and 6.92m ^{2} of openings; the SVR was 0.73. According to Evans (1980), larger volumes will have higher thermal capacities than smaller volumes, hence a small SVR will have a higher thermal capacity than a larger SVR. Thus, in theory, the larger house (sample 1) will have a better thermal response.

Table 2. Parameter Assessment of Building Form and Fabric Effectiveness on Thermal Performance

Parameter	Very Effective	Effective	Quite Effective	Less Effective	Not Effective
Degree Hour	0-29%	30-49%	50-75%	76-89%	90-100%
Comfort Duration	90-100%	76-89%	50-75%	30-49%	0-29%

Table 2 shows a parameter assessment of the response effectiveness of the building form and fabric. The scale is divided into five categories from very effective to not effective. The assessment for the degree hour is in reverse order to that for comfort duration, where the lower the percentage response effectiveness in degree hour parameter, the more effective the building form and fabrics are at modifying the indoor thermal condition. In contrast, the lower the percentage of response effectiveness for the comfort duration parameter, the less effective are the building form and fabric response in modifying indoor thermal conditions. The value of response effectiveness for the degree hour parameter can be shown from a negative value to a positive value. The negative value occurs when the internal thermal condition is modified into a condition worse than the external thermal condition. The higher the negative value is, the worse the response effectiveness of the building form and fabric. However, the scale for degree hour parameter in this study is assessed only between the values of 0% – 100%.

The effectiveness of the sample 2 building design, assessed according to degree hours of discomfort (41%) was classified as effective, whereas the sample 1 design, with degree hours of discomfort of -317% was categorised as ineffective. From the viewpoint of comfort duration, sample 2 with a 100% occupation period was categorised as very effective (*Table 2*), while the building comfort duration (71%) indicated the building design effectiveness was categorized as quite effective. Sample 1, with a comfort duration occupied period of 88% was categorized as effective, and the building comfort duration of 63% was categorized as quite effective.

Based on these assessments of building design effectiveness, sample 1 (larger volume with SVR 0.73) was less effective than sample 2 (smaller volume with SVR 0.85), thus for these two cases the building volume had less influence on the interior thermal condition in tropical coastal conditions. According to Chávez (2005), the building envelope plays an important role in providing comfortable internal conditions for the occupants, which means that the materials comprising the building elements will influence the internal thermal condition.

Both houses are made of essentially the same materials and of the same thickness except for the roof materials, where sample 1 used corrugated zinc sheet material (U-value = 7.14W/m²K) representing a reflective material, and sample 2 applied sago thatch roof material (4.42W/m²K) representing a resistive material. The rate of thermal transmittance in corrugated zinc sheet roofing was twice that of the sago thatch roof, which means that heat transfer to the interior of the house was also faster. However, a reflective material's properties can be altered by surface treatments (Hernández-Pérez et al., 2014). The thermal performance can be modified by changing the surface colour (light – dark), adding a glossy surface, or by using highly reflective materials. Unfortunately, reflective materials, can only reflect heat transmitted by radiative transfer. Thus heat transfer through conduction and convection cannot be avoided. When air velocity in an interior space is not sufficient to release the heat from internal to external spaces, the heat will accumulate inside the house, therefore overheating conditions in the house are difficult to avoid. The reflective material alone then is not sufficient to modify the internal thermal environment into a comfortable condition in the tropical coastal area.

The sago thatch roof in contrast, is formed of many layers of fibrous materials that can function as a resistive insulator and act as an excellent thermal insulator. It resulted in reducing solar radiation transmission from the roof to the internal environment. Therefore, the internal environment tended to have a lower air temperature than the external environment. In addition, the fibrous layers formed by a sago thatch roof can trap water molecules resulting from sea evaporation, thus they can reduce the temperature of the roof by evaporative transfer of heat. Our results suggest that the fibrous or porous materials are more suitable to be applied on the building envelope in the tropical coastal environment.

Thermal conditions in both houses at night was satisfactory. The internal temperature was always in the comfort zone, hence, the lightweight structure with low thermal capacity and porous envelope was very beneficial in the tropical coastal area. The lightweight structure can release heat faster from the building to the external environment, consequently both buildings can be adequately cooled at night.

4. CONCLUSION

The characteristics of a typical tropical coastal climate are marked by little seasonal variations and strong solar radiation with some diffuse radiation from occasional cloud cover. Air temperature ranges from 28 - 32 ℃ during the day and 18 - 24 ℃ at night. The diurnal temperature range both daily and annually is considered low, and seldom exceeds 8 ℃. Humidity varies between 55% and 100%, and high precipitation between 1,250 and 1,800 mm annually. The most suitable structure for this climatic condition is a lightweight structure with low thermal capacity because the daily diurnal temperature range is low. Low thermal capacity is very useful for night thermal comfort as heat is released from the building fabric faster than for a high thermal capacity structure.

Resistive materials performed better than reflective materials in responding to the tropical coastal environment. The insulation formed from layers of sago palm created a fibrous material that can be as good as modern porous materials in thermal resistance. Therefore, heat gain from the roof element can be minimised, and internal air temperature can be maintained lower than the external air temperature especially during the daytime. For a building that is occupied at night time only, reflective materials such as corrugated zinc sheet roofing is acceptable. This material cooled fast at night when a thermally comfortable internal environment could be achieved.

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