Thermal Performance of Traditional House in the Upland Central Celebes of Indonesia

Puteri Fitriaty, I.G.N. Antaryama, and Sri Nastiti N.E.[1]

Abstract —**House presents special problems for design in relation to climate as it accommodates variety of uses over 24-hour period. It is widely known in the tropical countries that traditional houses are more sensitive to the prevailing climate and able to provide comfortable internal environment for the occupants. Tambi as one of traditional houses in upland Central Celebes Indonesia is believed to be thermally comfortable, yet there still no empirical evidence to approve it. Present study conducted empirical studies on typical traditional Tambi houses to evaluate their thermal performance. External and internal climatic conditions were measured in each house and were analysed. Results of the study showed that typical traditional Tambi house are not able to maintain the internal temperature within the comfort range for a preiod of 24-hours. Thermal quality of the house, however, were improving as indicated by internal temperatures which were more satisfactory than the external temperatures.**

Keywords—**thermal performance, traditional tambi house, tropical upland climate**

Abstrak—Rumah dari sudut pandang tertentu dianggap sebagai representasi desain dalam hubungannya dengan kondisi iklim dan berbagai macam penggunaan ruang. Rumah tradisional di negara-negara tropis secara umum dipandang lebih tanggap terhadap iklim setempat serta dapat memberikan lingkungan internal yang nyaman bagi penghuninya. Rumah tradisional Tambi yang berada di dataran tinggi Sulawesi Tengah, Indonesia adalah salah satu contohnya. Meskipun secara empiris belum terbukti, rumah Tambi diyakini memiliki kenyamanan termal yang baik. Penelitian ini dilakukan untuk melihat kinerja termal rumah tradisional Tambi. Melalui studi lapangan, kondisi iklim internal dan eksternal pada setiap rumah direkam dan dianalisa. Hasil penelitian menunjukkan bahwa Rumah Tambi sudah dapat meningkatkan kualitas termal bangunan, namun belum mampu mempertahankan kondisi ruang dalam agar senantiasa nyaman selama periode 24 jam.

Kata Kunci—***kinerja termal, rumah tradisional tambi, iklim dataran tinggi tropis***

I. INTRODUCTION

Traditional house often represented the result of many years or even centuries optimization in relation to resources of materials and labor, the activities carried out within and around the dwellings and also to the local climate as well [1]. That is why there is a general view among the tropical countries, that traditional house is more sensitive to the prevailing climate and undoubtly comfortable. The use of local materials and the harmonization with the local climate and environment are some of the factors which contribute to the distinct architectural identity of every area [2] One of traditional houses which enrich the shape of traditional architecture in Indonesia is Tambi. Tambi is the house belongs to Lore ethnic which lives on west part of south mountain range of Poso regency, Central Celebes Province, Indonesia.The region is known as Napu valley, Behoa (Besoa) valley and Bada valley. The Latitude of the region is $1^{0}06'44"$ - $2^{0}12'53"$ south, the longitude is $120^{0}05'09"$ - $120^{0}52'04"$ east, and the altitude is 1000-1300 m.

The meso-climate of the area is affected by the presence of large mountainous range, making the region of Lore a tropical upland climate. There are small seasonal variations because its position is so close with the equator. The seasons are only marked with more and less rainfall period, which is called wet season and dry season.

Puteri Fitriaty, I. G. N. Antaryama, and Sri Nastiti N. E. are with Department of Architecture, Institut Teknologi Sepuluh Nopember, Surabaya, 60111, Indonesia. Email: puteri_elena@yahoo.com, antaryama@arch.its.ac.id, nastiti@arch.its.ac.id.

Tambi is a raised floor house with a single layer building which is sometimes divided by bamboo mat or wooden plank which covers only one-third wall's chamber. However, sometimes Tambi only consists of one room without partition where different function of room is asigned by different level of floor.

Generally Tambi consists of three main rooms. They are: 1) in the center of the house there is a fireplace (*rapu*) which functions as a kitchen, a heater and as much as lighting, 2) room around the fireplace is a living room (*lobona*) where the occupant spent much of their time, 3) sleeping room called *dasari* which located all around the living room. Some times Tambi also consists of one small room as a prayer room which located in a rear part of *dasari*.

Floor was madeof wood plank varied from 30 mm to 80 mm thick. Wall was made of wood plank varied from 30 mm to 60 mm thick, except for Tambi at Lempe village, which is made from bamboo mat with 5 mm thick. Roof have a steep slopes varied from 57° to 66°, makes it dominate the building form of Tambi. Roof was made of bamboo which has been straightened and arrange layered varied from 50 mm to 60 mm thick.

Unlike the tropical warm and humid climate where buildings are overheated during the day, buildings in tropical upland climate are underheated during the night due to low air temperature. Overheating sometimes occurs at day time and makes the period of discomfort even longer. A study about the traditional round hut house in the tropical upland climate of Zambia indicated that the effect of fabric that has high thermal capacity was largely nullified due to high level of ventilation. That happens because there is a gap between the wall and the roof, and it brings the internal condition suffered from underheating [3]. Therefore the traditional round hut house could not maintain the internal condition on comfort zone frequently for 24-hour period. This can also be true to Tambi, where Tambi has very much air gap between its elements constructions, and is made from a lightweight structure with low thermal capacity.

That fact is contradictory with design principle of building which experiences the tropical upland climate according to [4] where building should be reasonably compact, providing a closed or closeable internal environment, and also thermally heavyweight structure [4]. However field study must be carried in order to analyze the actual thermal performance of Tambi houses in their original habitat.

This paper discusses the results of a field measurement on thermal performance of traditional Tambi houses in tropical upland climate which carried out in three villages at Central Lore subdistrict (Doda, Lempe and Hanggira). These Tambi houses are representation of typical traditional houses at highland of Central Celebes Province. The evaluation of actual thermal performance through this research can provide further improvements and advancement on the topic and appropriate design for buildings in tropical upland climate.

II. Method

Thermal performance of the house (see Figure 1), was assessed by analysing air temperature, mean radiant temperature, relative humidity and air velocity in the house.

Mean radiant temperature can be estimated by combining the result of globe temperature, air temperature and wind speed measurements [5]. If mean radiant temperature are identical, and its pattern was the same as air temperature inside the building (Ti) during the measurement period, then Ti can be used [3].

The relationship between globe temperature (T_g), air temperature (T_a), mean radiant temperature (T_{mrt}) and air velocity (V_a) proposed by Humphrey:

$$T_g = T_a + f_g(T_{mrt} - T_a) \quad (1)$$

$$T_g = T_a + f_g(T_{mrt}) - f_g(T_a) \quad (2)$$

$$T_{mrt} = \frac{T_g - T_a + (f_g \times T_a)}{f_g} \quad (3)$$

The measurements were conducted in March 2011, for five days period and simultaneously in the three houses. Five days were taken in order to establish the trend of the temperature over a period longer than 24 hours, to avoid using an unrepresentative days for analysis. The physical measurements were carried out using air temperature and humidity data logger and anemometer. The air temperature and relative humidity for both internal and external were recorded every 15 minutes. The internal and external air velocity were recorded for three times a day, i.e. morning, noon and afternoon, for 30 minutes with 2 minutes interval.

Measurements were taken in living room (*lobona*) at a point located one meter from the fireplace (*rapu*) and 0.5 meter high from the floor. This due to most of activities in the house is done by sitting on the floor. The loggers were carefully taken care of to avoid direct sunlight throughout the day.

This study uses the neutrality temperature as a base to determine the thermal performance of the houses. In many studies, thermal neutrality is defined as the thermal condition where people neither feel warm nor cool, but neutral [6]. It is in 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 in the following formula, with the range of comfort zone is taken as 5°C with 2,5°C above and below the neutral temperature approximately [7].

$$T_n = 17.6 + 0.31 \times T_0 av \quad (4)$$

III. Results and Discussion

A. *Tambi in Doda Village*

The internal and external air temperatures over five-day measurement at Tambi at Doda village can be seen in Figure 2. The five-day internal and external air temperature data are generally similar, except those of for the second day. By excluding the second day data, average temperatures are established, and shown in Figure 3.

The minimum internal and external air temperature were experienced at 6.00 am with the values of internal temperature was 18.3°C and external temperature was 17.6°C. The maximum air temperature both internal and external occured at 3.00 pm. They were 27.9°C and 27.8°C respectively for the internal and external. These condition implies that fluctuation of air temperature inside the building follows that of outdoors. Since response factor of the building is about 0.83 (i.e. lightweight), the condition such that recorded in the field measurement becomes common among houses of similar type in this village. The lightweight characteristics can also be observed through the internal and external maximum temperatures. From the measurement, it was found that the maximum value were experienced at the same time, that is at 3.00 pm. This again underlined the characteristics of the building which has small thermal capacity, and thus do not have time delay effect.

During the night and morning, the house generally experienced underheating. This can be seen from the recorded internal temperatures, which falls below the comfort zone especially from 8.00 pm till 9.00 am. By contrast, overheating occured for a short period during the afternoon, that was from 2.00 untill 3.00 pm. Since the house was not occupied during the day time, this overheating condition was not considered as a problem for the occupants.

Figure 4 describes internal and the external relative humidity recorded in Tambi house of the Doda village. Due to some errors in the measurement, data recorded on the first day of the measurement was not taken into account. For the analysis data taken on the next four days were used and regarded as representative. From Figure 5 it can be seen (see also the psychrometric chart) that the combination of the temperature and relative humidity at Tambi at Doda village were scattered out of the comfort zone. The figure also shows that for a 24-hour period, the internal relative humidity in the house was above the comfort zone. The reason for this is partly due to the high external relative humidity, and partly linked to the existance of river behind the site, which obviously will have an influences on the humidity around the site.

Considering T_{mrt}, it was found only little difference are recorded between T_{mrt} and Ti (i.e., 3.7K – 3.8K). As indicated by [1], comfortable condition can be achieved if T_{mrt}- T_a (air temperature) difference is not greater than 5K [1]. It can be said then by reffering to Evans' statement that T_{mrt} will less effect on the comfort level if the condition applied. Ti therefore will be suffient indicator for thermal comfort.

The external air velocities ranged from 0.3m/s – 2.7m/s, and reached its maximum value after midday. Air velocity inside the house tend to be lower as compared to that of outdoors. The maximum were recorded about, and the average is 0.3 m/s. Theoretically air velocity of about 1.1m/s could facilitate comfort by extending the comfort zone up to 1.5°C in the afternoon, particularly when the building was overheated. Unfortunately this was not the case for the Tambi house as most of the time the air velocity were only 0.0 m/s. One of the main reason generating this problem was orientation of the openings. Position of the opening were mainly on the north & west sides of the building. It was quite the opposite of the prevailing and secondary wind direction which were from the South-east and East.

B. Tambi in Lempe Village

Figure 6 illustrates results of five-day measurement of internal and external air temperature in Tambi house at Lempe village. LikeTambi at Doda village, air temperature variation in this house was very small, and as that mentioned previously average value can be representative. Figure 7 shows the average internal and external air temperatures. The external air temperature range was 17.3°C – 25.6°C, while the internal air temperature range was 18°C - 27°C. Minimum internal and external air temperatures occurred at 6:00 am, while the maximum were at 2:00 pm. Diurnal temperature ranges were 8.3K and 9K respectively for the external and internal temperatures. There was no time delay effect observed in the house. This due to the fact that its fabric has low thermal capacity (i.e.building response factor was 0.90).

Internal temperatures were generally higher than the external temperatures. In average, the temperature difference was about 2.8K. Most of the time external air temperature were below the comfort range, and around seven hours the temperature were within the comfort range. Internal temperatures more or less followed similar trend to those of external, with an exception temperature at 14.00 to 15.00 which were slightly above the comfort range (i.e., about 0.4 K).

Building orientation, which is elongated towards north-south, can be thought as a factor affecting thermal performance of the house. With such orientation, builiding will receive substatial amount of radiation from the sun. As the building form were largerly determined by roof, this particular building element contribute to the heat accumulation inside the building and thus causing overheating. Overheating also occurred because the position of openings on the building, which were on the west side of the building, did not face the prevailing easterly wind. Because average maximum external wind velocity were relatively low (1.5-2.2 m/s), design of the openings cannot be expected to help cooling the building.

Similar to that observed in Doda village, the difference between T_{mrt} and Ti was less than 5K. This indicates that Ti alone can be used to assess comfort. External air velocity were recorded to be within 0.1 – 3.1m/s, and reached its maximum velocity after midday. Maximum internal air velocity was lower than that of the external (about 1.2m/s), and the average was 0.2 m/s. Eventhough the maximum air velocity is capable of expanding the comfort zone up to 1°C during the afternoon, the fact that calm period predominated (i.e., 0.0m/s) has worsened thermal performance of the building. In this case south openings offerred minimum contribution to the comfort level as this was at the opposite side of the prevailing and secondary wind direction (i.e., from East and West respectively).

Figure 8 describe internal and external relative humidity over five-day period measurement in Tambi house at Lempe village. The graphic pattern shows a small difference. Therefore, average value would be representative to be analyzed. Figure 9 represents the combination of temperature and relative humidity in Tambi at Lempe village which plotted on psychrometric chart in 24-hour period. It clearly shows that the combination was partly out of the comfort zone boundary. Most of the time, the internal relative humidity at Tambi was above the comfort zone. This happens partly because the external relative humidity was above the comfort zone, and it also due to the appearances of the garden trees around site which influence the humidity around the site. When air temperature was less than 25°C, subjects could not experience any difference between relative humidities of 30% and 80% in their subjective sensation (thermal sensation and skin wetness) [8]. Most of the recorded air temperature in Tambi at Lempe Village was below 25°C. By reffering to Givoni's statement It can be concluded that the boundary of thermal comfort for relative humidity can be expanded till 80%.

C. *Tambi in Hanggira Village*

Figure 10 shows the internal and external air temperatures over five-day measurement in Tambi House at Hanggira village. Both of the internal and external air temperature profile shows a good agreement, so the average value would be considered representative for the analysis. Figure 11 illustrates the average external and internal air temperature. The average internal air temperature ranges from18.2°C – 27.8°C, whereas the external ranges from 16.9°C – 27.6°C. The minimum value of external and internal air temperature occurred at 6:00 am, whereas the maximum took place at2:00 pm, therefore there is no time delay effect. Diurnal temperature swing was 10.7K and 9.6K respectively, both for the external and internal, thus the difference was very small. That was mostly influenced by the building fabric which was made of lightweight structure with small thermal capacity (i.e. building response factor was 0.94).

Most of the time, the internal temperature falls below the comfort zone (i.e. from 11.00 pm to 8.00 am). This condition implies that during the night and the morning the house generally experience underheating. On the contrary, overheating occurred for short period right in midday and after which was from 12 pm to 3 pm.

As the other two Tambi houses, the difference between T_{mrt} and Ti was less than 5 K (i.e. 0.6K – 1.8K). Therefore, Ti alone can be used to assess thermal comfort.

Figure 12 describes the result of internal and the external relative humidity over five-day period measurement in Tambi at Hanggira village. The internal and external relative humidity did not differ so much, and the average value would be representative.

The plotted combination value of temperature and the relative humidity at Tambi at Hanggira village were expanded out of the comfort zone boundary for part of the time in 24-hour periode (see Figure 13). Some of the times, the internal relative humidity at Tambi at Hanggira Village was above the comfort zone. It pattern was following the external relative humidity which was also above the comfort zone for certain times. It happens most likely due to the building porosity so that the internal and external relative humidity was very much alike.

The external air velocities ranged from 1.5m/s to 2.9 m/s. It maximum value occurred right after midday. The maximum internal air velocity was 0.5m/s and the average was 0.2 m/s. Theoretically air velocity about 0.5m/s could facilitate comfort by expanded the zone of thermal comfort up to 1°C from its upper limit in midday and after when the building suffered from overheating. Unfortunately that was not the case in Tambi house as most of the time the air velocity were only 0.0 m/s. Therefore overheating condition cannot be avoided. One of the reason behind that was the position of the opening was in the west side of the building. That condition was quite the opposite of the prevailing wind direction which were coming from the east.

Thermal performance of Tambi was assessed by degree hours of discomfort and comfort duration. From degree-hours evaluation of three Tambi Houses showed in Figure 14, it can be concluded that the highest K-hours was conducted at Tambi at Doda village with total K-hours 33.7K and the lowest was in Tambi at Hanggira village with total K-hours 24.9K. The difference is mainly because the influence of internal heat gain (from human activities and fire place), where Tambi at Doda village was measured without any internal heat gain. As for the other two were measured with internal heat gain.

Tambi at Hanggira village was more efficient in overcoming underheating compared to the other two. It was because Tambi at Hanggira village did not have a permanent opening like others. Therefore heat energy from inside the building cannot easily escape from convection by the existence of permanent window. It was also because Tambi at Hanggira village having a higher thermal capacity floor than Tambi at Lempe village which also was measured by internal heat gain.

But Tambi at Hanggira village was not so good in overcoming overheating if compared to others. This happened because the internal temperature was suffered from overheating for 4 hours while external air temperature was suffered only 3 hours with 1,6K higher than external cooling K-hour. Tambi at Doda village was better in overcoming the overheating issue than the other two Tambis. This is mainly because the orientation of Tambi at Doda village was South West – North East and its roof angle is steeper (66°) than the other Tambi (57°), resulting on the sun radiation that never falls vertically through the roof which bring reduction to the heat gaining from sun. The reduction of heat accumulation within the building was also because the existence of permanent opening (permanent window) which help to release some heat from the building to the outside when the external air temperature reached its highest level.

Comfort duration (see Figure 15), is a period where internal building condition was on the comfort zone which ranges from 21.6°C – 26.6°C. Comfort duration was assessed in 24 hour period (building comfort duration) and in period when building was occupied (occupant comfort duration). Tambi house was occupied for 15 hours a day from 5:00 pm in the afternoon till 7:00 am in the morning. This schedule was according to the occupancy pattern in the past where Tambi houses belong.

Comfort duration on Tambi at Doda village for 24-hour period was 8 hour, started from 10:00 am till01:00 pm and 4:00 pm till 7:00 pm. While occupants comfort duration (when the building was occupied) was only 3 hour from 17:00 till19:00. Therefore the percentage of building comfort duration and occupant comfort duration were 33% and 20% respectively.

Comfort duration on Tambi at Lempe village for 24-hour period was 10 hour (42%), started from 10:00 am till 01:00 pm and 4:00 pm till 9:00 pm. While occupants comfort duration (when the building was occupied) was only 5 hour (33%). Comfort duration on Tambi at Hanggira village for 24-hour period was 10 hour (42%), started from 9:00 am till 11:00 pm and 4:00 pm till 10:00 pm. While occupants comfort duration (when the building was occupied) was only 6 hour (35%). From the comfort duration of the three houses, it was Tambi at Hanggira village that had the best performance. That is mainly because Tambi at Hanggira village has the highest building response factor which is 0.94, while the other two only 0.83 for Tambi at Doda village and 0.90 for Tambi at Lempe Village. The performance of Tambi at Hanggira and Tambi at Lempe village did not differ so much, because the response factor was not very much different, and they were both measured with internal heat gain.

From the study, we can know that none of the houses are significantly comfortable. This is due to low insulation level and low thermal capacity of its skin construction. However, people living in naturally ventilated buildings are likely to be more tolerant about their thermal environment. This happened because they have flexibility of their personal and environmental conditions in the form of different adaptation [9]. This case is also be true to people in Tambi houses where they can easily adapted through different value of clothing insulation at 24-hour thermal environment changing (Figure 16). Their clothing insulation varied from 0.34 clo (in the noon and afternoon), 0.76 clo (in the morning and evening), to 1.46 (when sleeping). That makes the range of the comfort zone wider than Auliciems's model (18°C-28°C).

IV. Conclusion

Results of the field measurements indicated that thermal condition in Tambi traditional house could not suffice the 24-hour comfort requirement. As the study showed, the condition is closelly related to materials used in the buildings.Tambi house were conceived of lightweight materials with low thermal capacities, which as previous studies indicated was not recommeded for the tropical upland climate. It was stated that heavyweight structure with high thermal capacity will perform better in this type of climate [3-4].

The present study showed that building form and envelope have limitations in modifying the external condition. As a result, the internal comfortable thermal conditions were only experienced for a certain period of time. The study also indicated that the roof played a significant role in modulating heat so as substantial amount of heat is reduced. By contrast, openings and cracks were found to contribute to the poor performance of the house, especially during the night. In this regard, openings and cracks allowed cool air to flow freely into the internal space and thus caused discomfort.

Internal heat gain was also found to be an important factor in influencing the internal condition of the house. Heat generated inside the building helped to reduce underheating conditions and thermal discomfort. From the occupant standpoint, the study concluded that over the years people of Tambi has developed a mechanism of adaptation through their clothing as a means of increasing thermal comfort under the cold upland climates of Central Celebes.

Figure 1. The study case houses, (a) in Doda village, (b) in Lempe village, (c) in Hanggira village

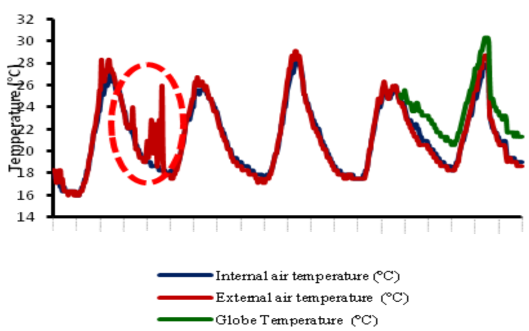

Figure 2. The internal and external air temperature for tambi in Doda village over five days period of measurement

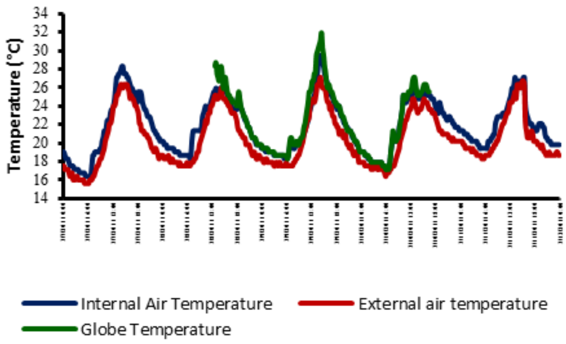

Figure 3. The internal and external air temperature against comfort zone

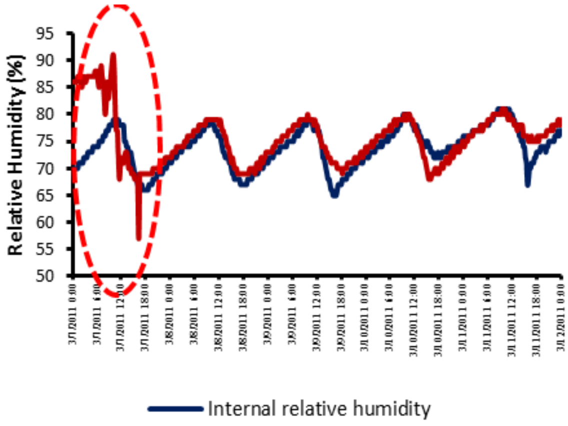

Figure 4. The internal and external relative humidity for tambi in Doda village over five days period of measurement

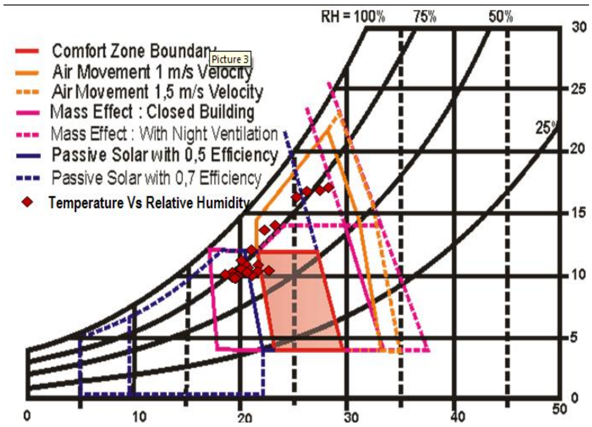

Figure 5. Thermal condition of tambi in Doda village over the 24-hour period on psychrometric chart

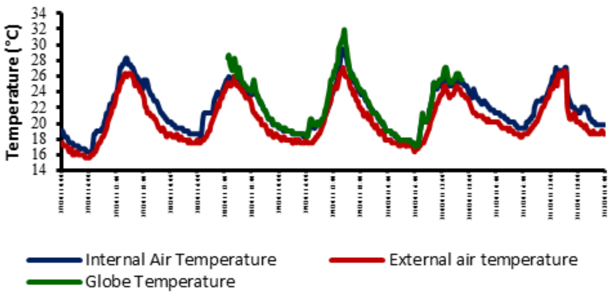

Figure 6. The internal and external air temperature for tambi in Lempe village over five day's period of measurement period

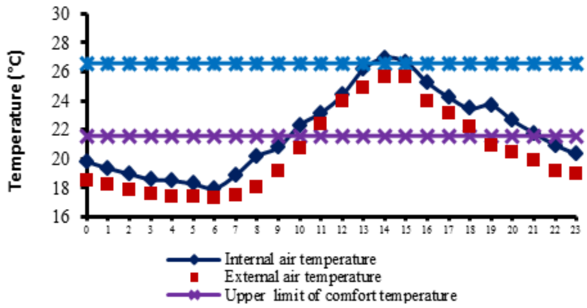

Figure 7. The internal and external air temperature against comfort zone for tambi in Lempe village over the 24-hour

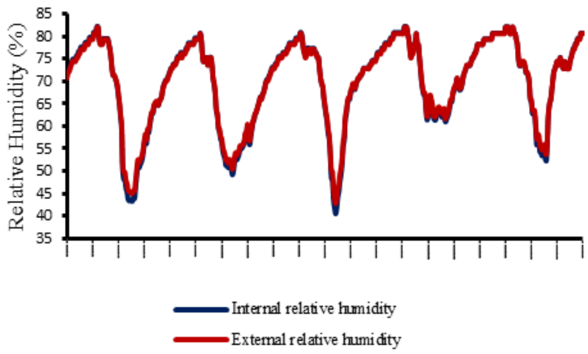

Figure 8. The Internal and External Relative Humidity for tambi in Lempe village over five days period of measurement

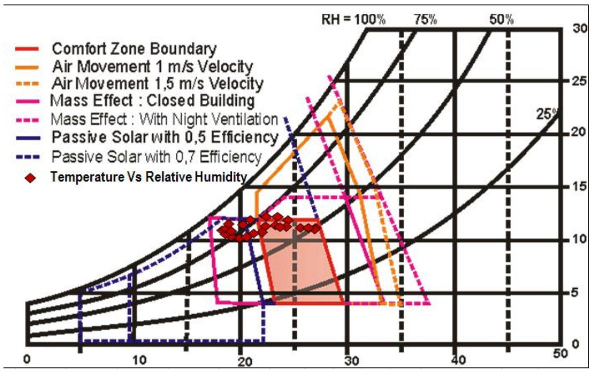

Figure 9. Thermal condition of tambi in Lempe village over 24-hour period

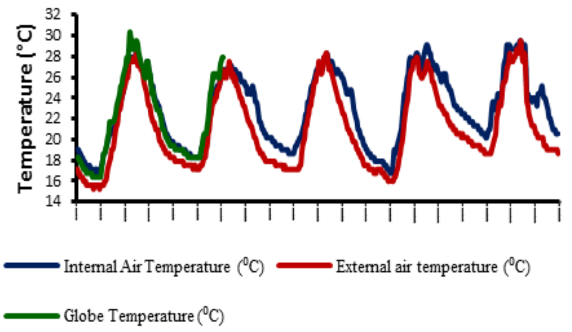

Figure 10. The internal and external air temperature for tambi in Hanggira village over five days period of measurement

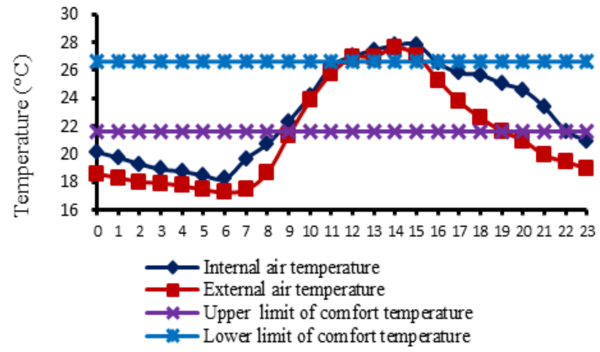

Figure 11. The internal and external air temperature against comfort zone for tambi in Hanggira village over the 24-hour period

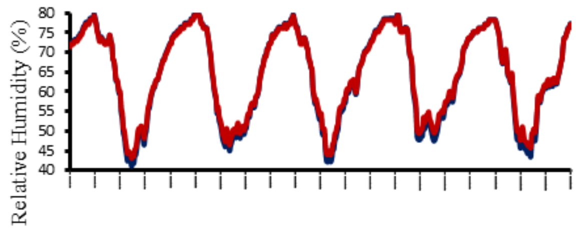

Figure 12. The internal and external relative humidity for tambi in Hanggira village over five days period of measurement.

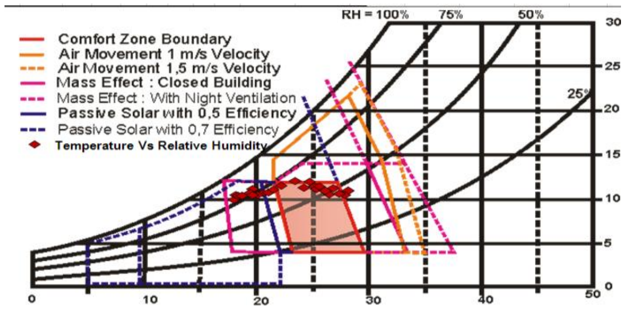

Figure 13. Thermal condition of tambi in Hanggira village over the 24-hour period

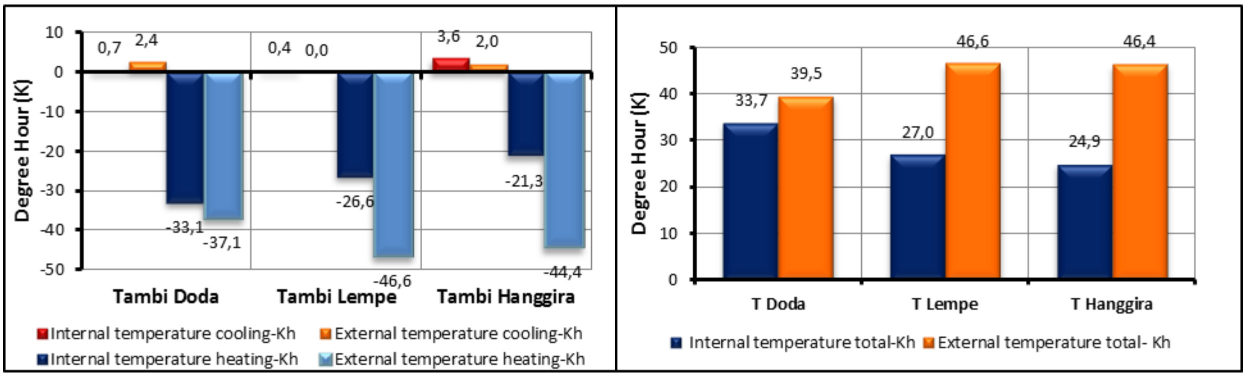

Figure 14. Degree hours of discomfort for Tambi house

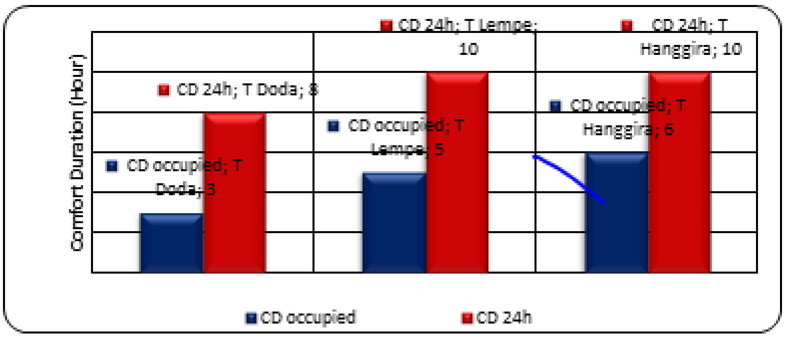

Figure 15. Duration of comfort in Tambi house

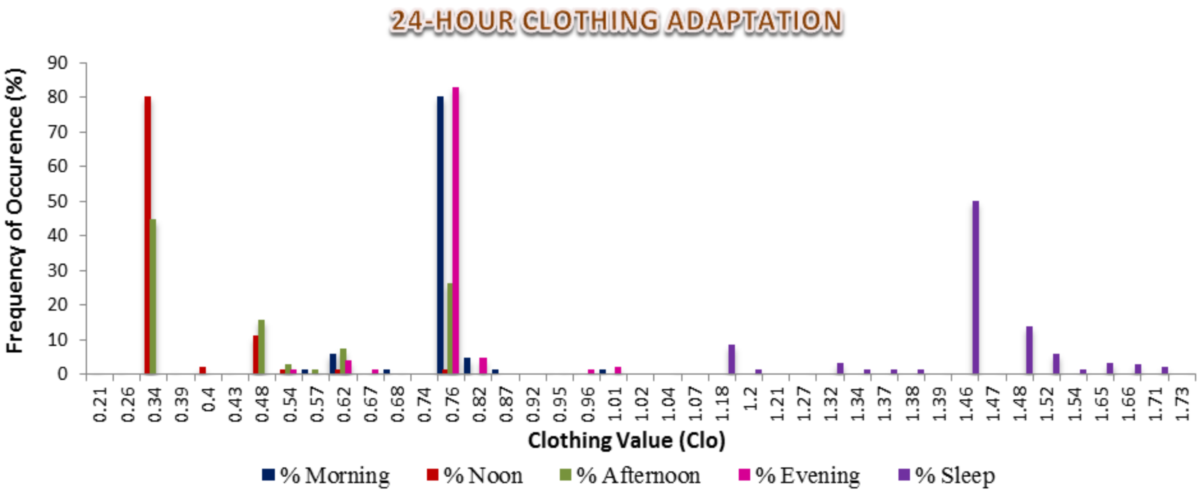

Figure 16. People adaptation around tambi house through their clothing value for 24-hour period

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