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THERMAL PERFORMANCE ANALYSIS OF AFFORDABLE HOUSE IN THE EQUATORIAL COASTAL AREA OF THE TROPICS

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Abstract
Affordable housing subsidised by the government in Indonesia often poses many problems, including an uncomfortable internal environment that leads to the massive use of mechanical ventilation. Designing an affordable house undoubtedly faces challenges due to the very small building lots, while it should provide many spatial needs and functions for the occupants' daily activities. Because of limited funding provided by the government, affordable house design is often based only on basic needs, thus scarcely considering thermal comfort for the occupants. This study evaluates the thermal performance of affordable houses built for the 2018 great earthquake, tsunami, and liquefaction victims in Palu's coastal area. Field measurements were conducted in an affordable housing complex, and a sample house was selected, representing a raised floor house design prototype. External and internal climate conditions were recorded for nine days to establish the hourly thermal trend. Hobo Onset H21 microclimate stations were used to record external climate conditions, whereas Onset Hobo U12-012 T-RH-Light was employed to record internal thermal conditions. The result showed that the thermal condition in the sample house was intolerably hot. The main cause of these conditions is the design of the roof and building envelope. The selected materials with a high U-value also worsen the thermal conditions in the sample house.

Keywords: Affordable House, Thermal Performance, Tropical Coastal Area, Raised Floor Construction

INTRODUCTION

It has been widely known that affordable housing especially in Indonesia, will unlikely provide a thermally comfortable internal living environment for the occupants. It mainly prioritised the maximum quantity of units possible by the given land area (Kumar et al., 2023). With very small building lots, the challenges in providing a thermally comfortable interior are very tantalising. This study evaluates the thermal performance of affordable houses in the tropical equatorial climate of Palu coastal area, Indonesia. The design is adapted to the local vernacular strategies, formed a raised floor construction and was specially built for the great earthquake, tsunami and liquefaction victims on 28 September 2018. This study contributed by providing empirical evidence of affordable housing thermal performance in the tropical coastal area of Indonesia. Additionally, this research suggested new ways of improving the thermal performance of affordable houses by modifying the building envelope constructions (Ariani & Zulhawati, 2023).

Thermal performance of buildings is considered to have a vital role in the quality of internal living environments (Pessoa, Guimarães, Lucas, & Simões, 2021) and directly influence domestic energy consumption (Krelling et al., 2023). Hence, design parameters of building thermal performance are always counted in the energy standards and regulations related to building codes. The related design parameters include the form and shape of buildings, their materials, fenestration, and ventilation (Szokolay, 1987). Thus, in addition to building forms, the building's envelope and roof are the main contributors in creating a thermally comfortable living environment (Fitriaty, Antaryama, & Ekasiwi, 2011; Fitriaty, Basri, Alam, & Bassaleng, 2020).

Natural ventilation is frequently utilised as a passive design strategy for residential buildings to achieve thermal comfort in the interior (Liping & Hien, 2007; Parisi, Kubota, & Surahman, 2021). However, using natural ventilation is sensitive to outdoor air quality, especially in tropical warm and humid areas, regarding several issues such as a higher outdoor air temperature, dust, and other polluted air contaminants. Moreover, disturbance by insects in tropical climates also became a major consideration for occupants in employing natural ventilation, especially those that carried endemic diseases such as mosquitos and flies. Therefore, the windows are often found closed even in the daytime when the maximum air temperature occurs, which makes a well design naturally ventilated buildings to be wasted, leading to mechanical ventilation.

With these related issues, an evaluation of thermal performance is needed to provide a design recommendation that improves thermal comfort and provides a healthy internal environment for affordable houses in tropical areas. A sample of houses is highlighted in this study, representing ten affordable houses that were initially built as a raised floor construction. The houses were built using RISA technology developed by the Ministry of Public Works and People Housing (PUPR) (Ministry of Public Works and People Housing, 2016).

RESEARCH METHOD

This study was conducted by field measurement on a free-running affordable house located in the coastal area of Palu, Indonesia. It is situated at the latitude of 00°47′53.8″ South and longitude of 119°52′39.2″ East, altitude ± 15 meters from the sea level and 320 meters from the coastal line (Figure 1).

Figure 1. Study location, ARKOM Mamboro Huntap permanent residence

Object and sample of study

The object of the study is the typical affordable housing in ARKOM Mamboro housing. They are constructed using RISHA concrete panels developed by the Ministry of Public Works and People Housing (PUPR) for instantly built housing. The houses were built for the victims of the great earthquake, tsunami and liquefaction disaster that happened on 28 September 2018 in Palu City. They were initially built into two types of floor construction: raised floor construction (stilt-house) and non-raised floor construction, categorised as a small, simple house with one bedroom, kitchen, family room, living room and toilet. The houses were designed as detached houses with a distance of 3.5 meters between their outer walls. All of raised floor houses oriented to East North East - West South West, while most of non-raised floor houses oriented to North-South.

Figure 2. Sample House

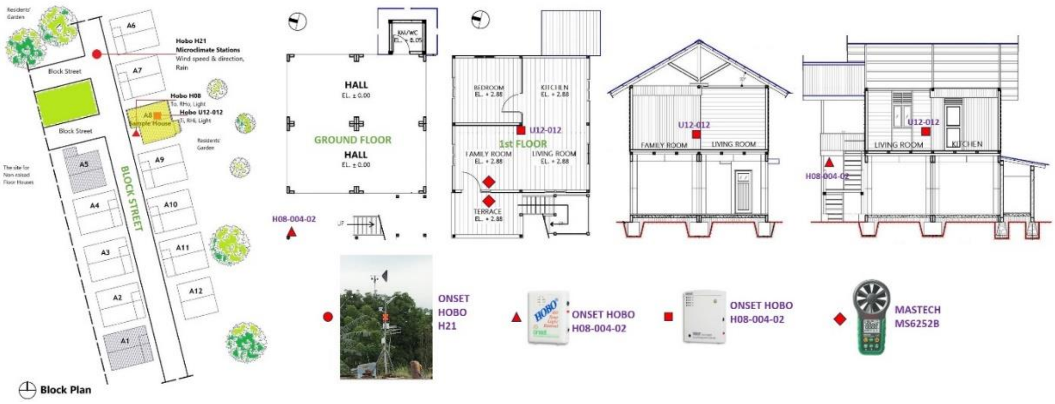

Figure 3. Point of measurement

The sample house is a raised floor construction with its front oriented to the West-south-west facing the sea (Figure 2). The building has openings on all sides of the wall with a 36m² area on the first floor and an additional 36m² open hall on the ground floor for multifunction activities. The house form was adapted from the local vernacular house of the Kaili ethnic (To-Kaili), forming a gable roof with a 30° roof slope in response to the heavy rain that seasonally occurred. The roof materials made of corrugated zinc are placed on the wooden roof structure. The walls are made of wooden board with 2 cm thickness while the floor is made of wood board with 3 cm thickness. There is no ceiling in the measured house, and it is the same with all houses in the study site.

Field study measurement

The field measurement was conducted to record internal and external thermal conditions measured simultaneously (Merchant, Chow, & Wu, 1995). Hobo microclimate stations H21 and H08 were used to measure external climate conditions. Meanwhile, Hobo U12-012 was utilised to measure internal thermal conditions (Figure 3). The climate elements included in the measurement are air temperature, relative humidity, light intensity, wind speed and direction, and rain. External air temperature and relative humidity sensors were carefully placed in the shaded area so the measurement excluded sol-air temperature, while the light sensor was intended to measure diffuse sunlight instead of direct sunlight.

The internal air temperature, relative humidity and light intensity sensor was placed in the middle of the family room and living room at 50 cm height from the floor because the activity in the building interior is more often in the sitting position directly on the floor, especially in the first floor (Fitriaty et al., 2011). The climatic data was set to be recorded in a time interval of 15 minutes for ten days in June to observe the daily climatic variations. Two

Mastech MS6252B digital anemometers were used to measure wind speed in 1 meter outside and inside the building opening.

Thermal Performance analysis

A building's thermal performance is generally evaluated through climate-responsive design (Lawal & Ojo, 2011). Therefore, thermal performance is evaluated by comparing outdoor and indoor thermal environments. The parameters used in the evaluation were air temperature, relative humidity, lighting intensity and air movement. The temperature neutrality is utilised for objective analysis of the interior thermal conditions. It represents a neutral state of thermal condition where most people will feel neither cool nor warm. It is at the middle point of the comfort zone for any given climate. The temperature neutral is expressed by the following equation (Szokolay, 1987, 2014):

$$T_n = 17.6 + 0.31 \times T_o av \qquad (1)$$

Where T_n denotes neutrality temperature, and $T_o av$ represents the average outdoor air temperature of the given month. The comfort zone for the air temperature parameter can be plotted by extending the neutrality temperature to ± 3 degC. An adaptive model proposed by Auliciems is also used to asses interior thermal conditions where thermal discomfort is considered in the calculation of thermal comfort temperature (T_{co}) by mean indoor air temperature (T_i) and mean monthly outdoor air temperature (T_m) (Feriadi & Wong, 2004).

$$T_{co} = 0.48T_i + 0.14T_m + 9.22$$

RESULT AND DISCUSSION

External vs internal thermal conditions

The measurement result of air temperature and relative humidity reveals that the interior of sample houses follows the trend of exterior thermal conditions (Figures 4a and 4b). The result of eight measurement days showed good agreement in each measured day. Thus, each day can be a typical day representing all measured days for the purpose of analysis (Figure 4d). The air temperature in the indoor environment ranged between 23.1 and 34.6°C with an average air temperature of 27.8°C while outdoor air temperature varied from 23.2 to 35.3°C with a 27.7°C average temperature. Most of the time, building interiors have a higher air temperature of up to 1.3 degC (Figure 4c), which implies that the sample house is made of lightweight constructions where the internal thermal condition is vividly reflected the external thermal condition.

In evaluating thermal performance of the sample house, temperature neutral and comfort temperature were used. The calculation on thermal neutrality (Eq 1) and comfort temperature (Eq 2) based on the measured days are 25.97°C and 26.06°C, respectively. By using six degC thermal comfort range the comfort zone can be superimposed by the range of 22.97°C - 28.97°C or by 23.06°C - 29.06°C. The thermal zone resulting from the two equations is basically the same. The range of 23.06°C - 29.06°C resulting from the comfort temperature equation is preferred in this study because tropical people are more resistant to the heat environment than the cool environment, especially those who live in a free-running building (Feriadi & Wong, 2004). Based on the comfort zone calculated before, it is shown that the internal and external environment experiences overheating in the daytime with total cooling K-hours up to 150.2K for indoors and 164K for outdoors during eight days of measurement. Only when the sky condition was overcast or raining for the whole day, the building interior did not suffer from overheating. The indoor air temperature was improved by building design by only 13.8K, which is considered insignificant in modifying the outdoor thermal environment for occupant thermal comfort.

Unlike air temperature, which directly affects occupants thermal comfort, relative humidity indirectly affects thermal comfort. However, this parameter is not to be ignored because it influences thermal comfort when the air temperature is more than 25°C. The average relative humidity for indoor and outdoor were 73% and 66%. Whilst the range of indoor relative humidity was 51% - 90%, and the range of the outdoors was 39% - 87% (Figures 4a and 4b). It is to be expected from the warm and humid tropical climate that the highest relative humidity occurred in the morning when the air temperature was at its lowest, which applies to this study. Therefore, the higher humidity did not really affect the thermal comfort because there will be a very minimal difference between relative humidities of 30% and 80% in air temperature up to 25°C (Givoni, 1998). A higher relative humidity of up to 90% in the sample house is due to the presence of the sea, where the study site was located approximately 320 meters from the coastal line. Thus, the microclimate in the study site is more or less affected by the sea as the largest water body.

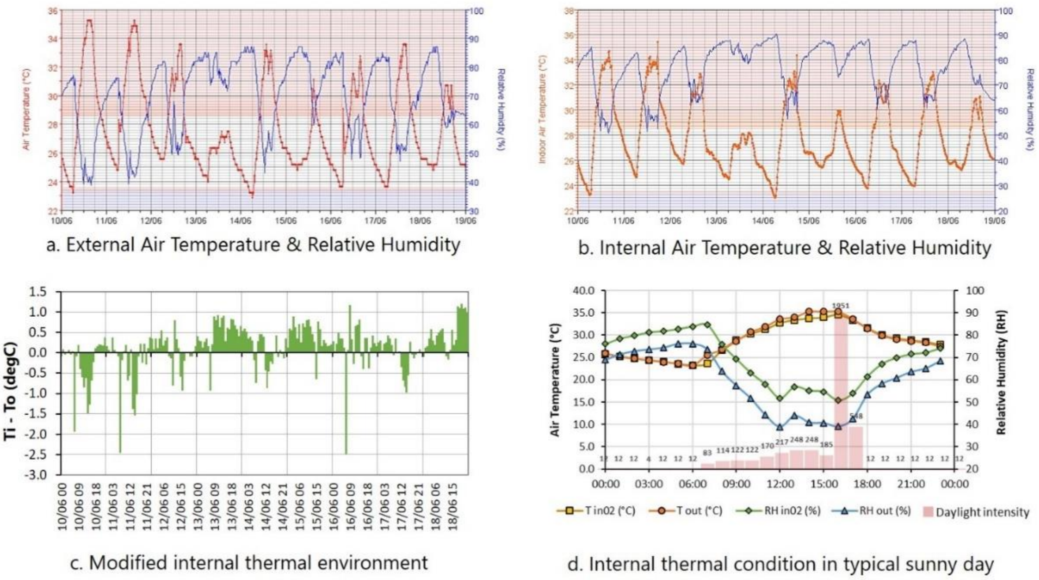

Figure 4. External and internal air temperature and relative humidity

Daylight intensity is also measured in the house interior. It was done because the sunlight not only introduces light fractions but also brings along heat waves through its direct beam. The range of light intensity recorded in the outdoors is between 22 – 8902 lux, with an average value of 2261 lux (Figure 5). Meanwhile, the indoor light intensity at the measurement point ranges from 4 lux to 3292 lux with an average value of 186 lux. Apparently, direct sunlight will penetrate the family room and the living room through the west openings. It can be seen from the much higher internal light intensity recorded on the sunny and partly cloudy day from 4:45 pm to 5:15 pm. This situation more or less introduced more heat gain from the direct sunlight beam. When there is obstruction from the cloud in the afternoon, the daylight intensities are never more than 410 lux. This result highlighted previous research that the west openings should be protected from direct sunlight by utilising appropriate shading devices.

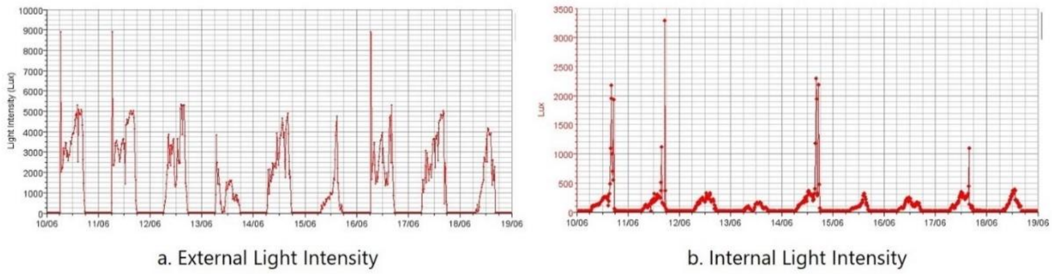

Figure 5. External and internal light intensity

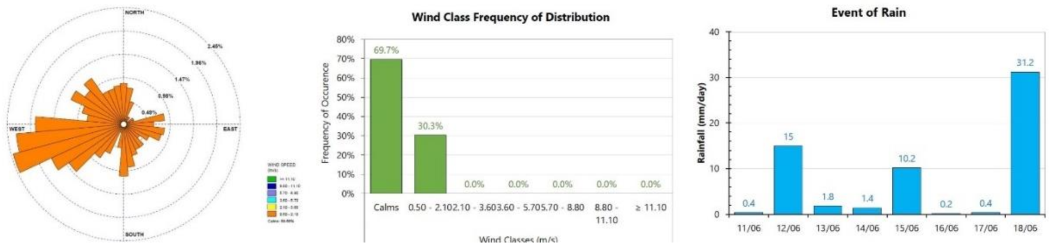

Figure 6. Result of wind speed direction and rain

The outdoor wind speeds recorded during the measurement period were 69.7% calm and 30.3% in the range of 0.5 – 2.10 m/s (Figure 6). The prevailing wind direction is from the west-south-west (WSW), with the secondary wind direction distributed in every direction. Hence, strategies to accelerate and utilise wind are imperative to provide a comfortable living environment. Air velocity of 0.5m/s – 1.5m/s is required to minimise the effect of high air temperature and relative humidity (Fitriaty et al., 2020). Unfortunately, air movement in the sample house is mostly calm, following the trend of outdoor wind speed. Useful air velocity occurred in the afternoon when the air temperature was the highest; hence, it has the potential to be controlled for evaporative cooling. The air velocity measurements recorded in the house interior ranged between 0.142 m/s and 1.564 m/s (Figure 7).

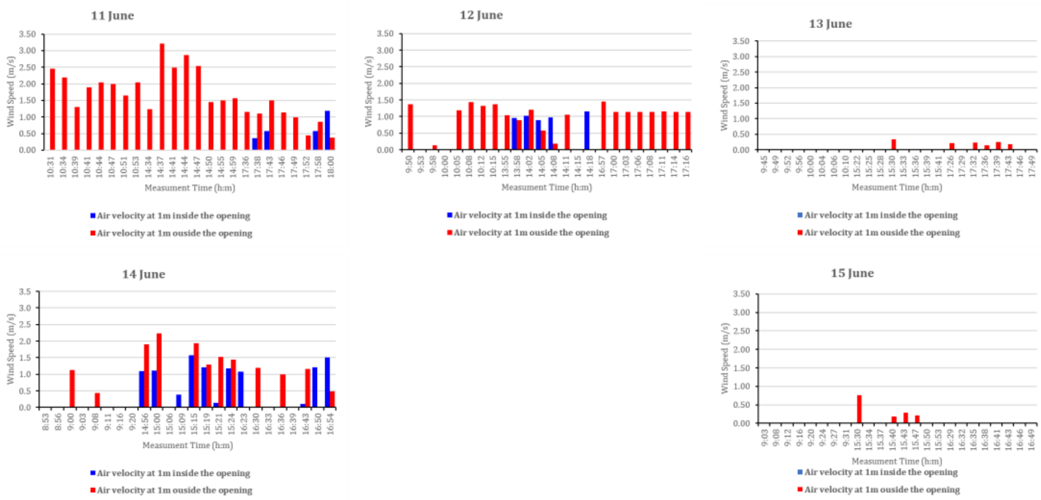

Figure 7. Air velocities at 1 meter outside and inside the opening

Analysis of house form and fabric on building thermal performance

Affordable housing in the HUNTAP Mamboro complex was designed with raised floor construction inspired by the traditional house of Sulawesi, mainly affected by Sauraja and Tinja Kanjai. It is a final product involving many stakeholders such as the local government, PUPR Ministry, public figures, volunteers from ARKOM Indonesia Foundation, and the house owner itself.

Sauraja and *Tinja Kanjai* are two of the traditional houses of Kaili Ethnic (ToKaili), which are spread along the Palu valley. *Sauraja* is designated for aristocratic families and those with high nobility in the ToKaili social stratification system. Meanwhile, *Tinja Kanjai* was designated for the commoner class society. According to the house plan, the affordable house in Mamboro is closely similar to *Tinja Kanjai* type of house.

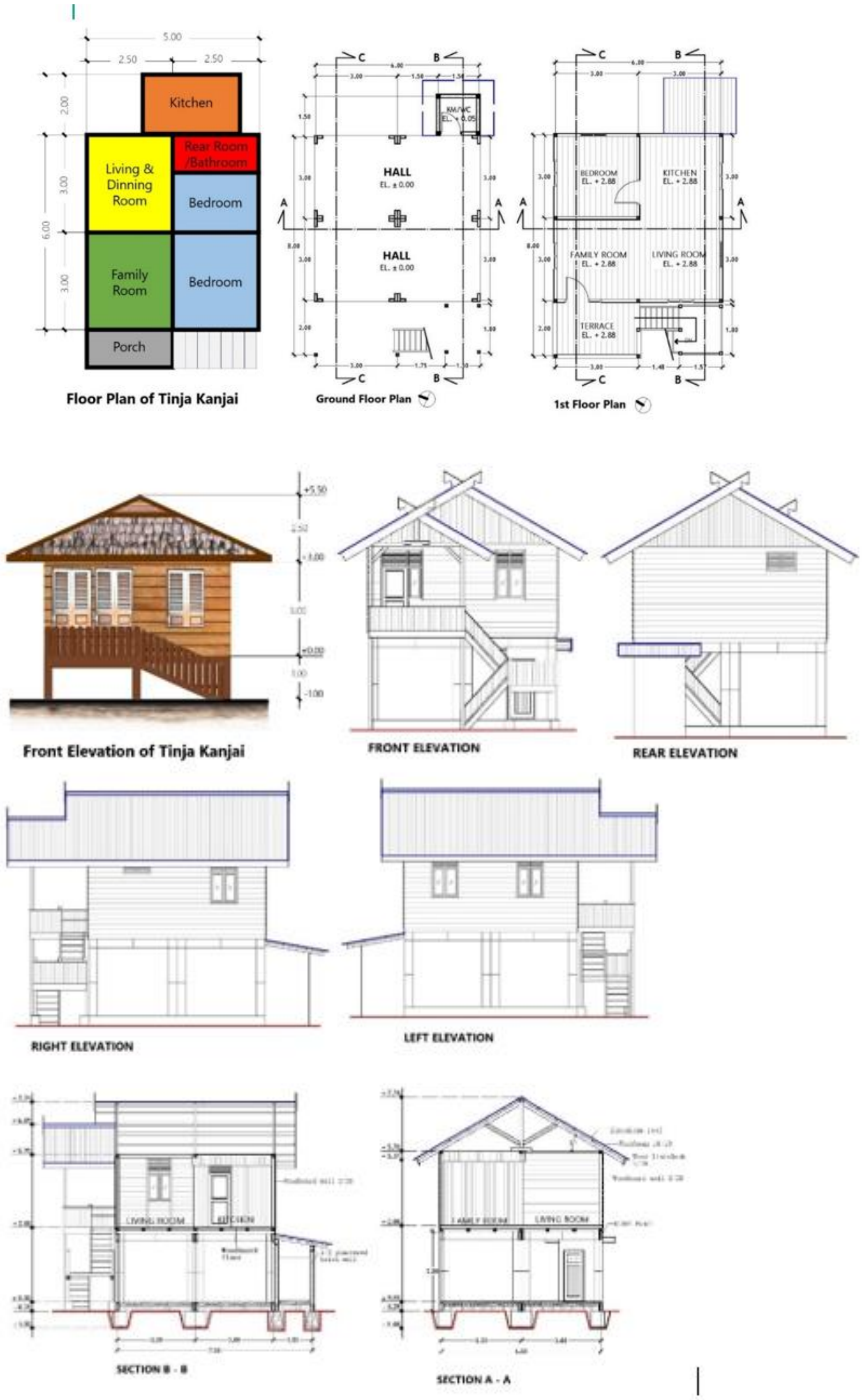

Figure 8. Comparisson of *Tinja Kanjai* traditional house and affrodable house of Huntap Mamboro

Figure 9. Perspective View of Huntap Mamboro House

It is generally accepted that traditional houses are considered to be environmentally responsive architecture. Because it is built based on many years of experience and inherited from generation to generation, the house design transformed from traditional house principles should be climatically responsive. Thus, it can provide a comfortable internal living environment. Unfortunately, the houses in Huntap Mamboro did not portray this phenomenon. According to the field measurements, the building interior suffers from overheating during the daytime up to 5 degC from the range of temperature comfort zone. This result indicated that the indoor environment was intolerably hot without adequate air velocities for physiological cooling or in the absence of mechanical ventilation. This result highlighted that the design transformation from *Tinja Kanjai* not really succesfull.

The failure of design elements by Huntap Mamboro is due to several issues. Firstly, the roof materials that should be made of resistive materials with adequate thickness (i.e. sago thatch roof) are replaced by a reflective roof matesrial made of corrugated zinc roof. These two materials have a totally different thermal behavior, which affects indoor thermal comfort. The second is related to attic design. While *Tinja Kanjai* formed an attic with a cross ventilation system, Huntap Mamboro's house design keeps the hot air in the attic and keep warming the indoor environment by not providing ceilings for thermal barrier and attic openings to encourage natural cross ventilation. The third issue is the opening design. The *Tinja Kanjai* design provides a side-hung window with louvres type of windows. Thus, when the window is open, the incoming air volume will be accepted through its opening for almost 90%. Hence, the possibility of creating a natural cross ventilation for physiological cooling is higher than the Huntap Mamboro house with top-hung windows that only accept 30% of wind flow through its glass framed windows.

CONCLUSION

The affordable house of Huntap Mamboro cannot provide a comfortable indoor environment, especially in the daytime. This result was affected by its design elements that have the limitation of modifying the internal environment to be more comfortable in the daytime. However, this house is thermally comfortable at night. Thus, the Huntap Mamboro house design is suitable for the night occupancy pattern house. However, for 24-hour occupancy patterns, the house design should be modified related to its roof materials, attic ventilation, ceiling, and opening for cross ventilation purposes.

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