Conference Paper

Review of Thermal Comfort in Warm Humid Climate for Traditional Architecture in Indonesia

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Abstract

This review discusses the thermal performance of traditional buildings in Indonesia. It is intended to see the impact of the traditional architectural design and its thermal comfort in the warm humid climate of Indonesia. The literature review was taken from 16 articles which cover Sumatra, Java, Kalimantan, Sulawesi, and the Nusa Tenggara region. The articles were classified into tropical climates (Af), monsoon tropics (Am) and savanna (Af) groups to identify which architectural elements in traditional buildings contributes to thermal comfort. Based on simulation and measurement in the field, it is found that the roof contributes to changes in temperature in the building.

Keywords: Thermal Comfort, Traditional Architecture, Tropical-humid Climate

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1. Introduction

Based on climate conditions, Indonesia is a country with a humid tropical climate, meaning that the temperature in Indonesia is warm but very humid. When referring to Koppen's classification, the majority of the Indonesian archipelago is influenced by the moderate maritime climate which further differentiated into three: without dry season, with dry summer, and with eternal ice. Almost all regions in Indonesia are classified into medium moderate maritime climate without a dry season. An exception applies for East Java, Bali, West Nusa Tenggara, and East Nusa Tenggara which have a moderate marine climate with dry summer.

In recent years much research has been carried out to evaluate thermal comfort in traditional buildings in Indonesia. Several variables have been included to see the impact on temperature, humidity and wind speed within the building. These variables include the width of the topography, the orientation of the building, the envelope of the building and material. Such research is important in order to preserve traditional buildings and enhance its thermal performance through design in accordance with Indonesian climate.

Traditional buildings in Indonesia contain different traditional values and cannot be separated from the concept of green buildings or green environments. That concept means that the construction of traditional buildings is adapted to the environment, climate, culture and social conditions [1]. The use of the passive design in traditional buildings can be used as a reference to achieve thermal comfort because it has better performance compared to modern buildings [3-4]. Traditional buildings in tropical areas are considered to be more sensitive to a climate to provide a comfortable internal environment for residents [5]. The comfortable range is influenced by building design factors which include: material, structure, and construction in traditional houses. Scarcity of local building materials and the development of the industrialization of building materials have resulted in a decreased traditional architecture performance [6].

Physically, traditional buildings in Indonesia have a typical high roof, a light envelope of buildings from the construction of wood, windows and wide eaves, and bright colors on the walls to anticipate these climatic conditions. It causes traditional architecture to survive until now, although some traditional buildings have changed.

2. Research Method

The literature examined in this study focus on thermal comfort in traditional buildings in Indonesia published in academic magazines from 2000 to 2017. The paper criteria are as follows (1) The location of the study is in Indonesia, (2) Findings related to thermal comfort in traditional buildings; and (3) Articles published/published in national/international accredited journals. The selected literature are then evaluated based on the parameters of the purpose of this review.

3. Literature Review

3.1. Tropical climate

According to Koppen in Indonesia, there are types of climate namely tropical rainforest climate (Af), savanna climate (Aw), and tropical monsoon climate (Am). The climate of tropical rainforests and tropical monsoon climates is found in areas of western and northern Indonesia such as West Java, Sumatra, Kalimantan, and North Sulawesi. The savanna climate is found in Indonesia, which is close to the Australian continent such as the areas in Nusa Tenggara, Aru Islands, and Irian Jaya South Coast.

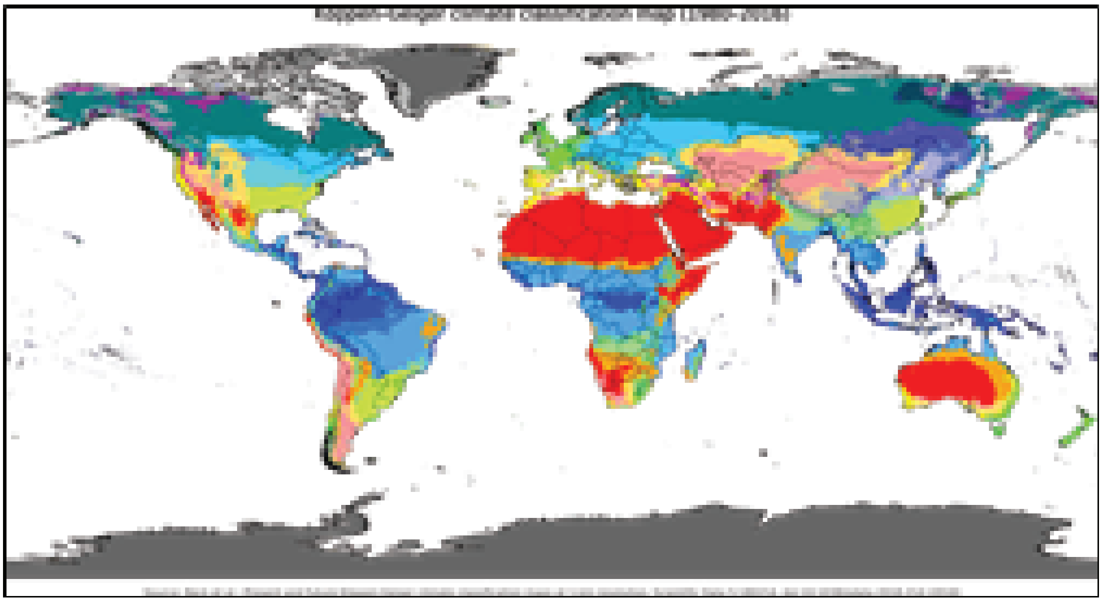


Figure 1: The Climate Classification System proposed by Köppen.

3.2. Tropical climate

The humid tropical climate is a tropical climate with an average daily air temperature of around 28∘C, where in general the outside air temperature tends to be at the upper limit of the human thermal comfort threshold or even above the thermal comfort threshold [12].

Thermal comfort is a condition that expresses satisfaction with the thermal environment. According to Fanger [7], comfort is based on psychological phenomena compared to being based on physical (environmental) conditions. Climate variables that can affect good thermal conditions are air temperature (∘C), air humidity (%), and air movement (m/sec) [8-10].

According to Karyono [12], the humid tropical climate itself is characterized by various characteristics, namely relatively high air humidity (can reach rates above 90%), relatively high air temperature, high intensity of solar radiation and high intensity of rainfall. Climate factors are very influential on human physical comfort, especially the thermal comfort aspects.

3.3. The traditional architecture in Indonesia

According to Hermawan [6], forms are more influenced by microclimate conditions (lowland heat with high temperatures or high land with low temperatures). Traditional architecture can be distinguished anatomically into three main components, namely roof, wall, and floor (including the stage mast). These three components have different functions. The roof consists of the main components of the roof cover, roof truss, and ornaments. The wall consists of massive walls and openings in the form of doors or windows. Meanwhile, the legs consist of floors, columns, and foundations. The shape of the form includes material, structural and construction aspects.

The use of building material in traditional houses are dominated by local materials obtained from the surrounding environment and less industrial materials. Natural building materials that are widely used are wood, both for structural components such as beams and columns and non-structural components such as walls, doors, and floors. Traditional architectural classification based on climate zones, as follows:

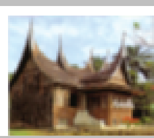
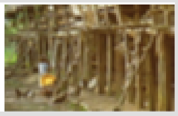
3.4. Architecture traditional element and thermal comfort

Environmental conditioning in buildings architecturally can be done by considering building placement based on sun and wind orientation, utilization of architectural and landscape elements and the use of building materials in accordance with the character of the humid hot tropical climate.

In traditional buildings, there are several variables of building envelopes (roofs, walls, doors/windows, floors, and ornaments) that respond to climate conditions both in form and function. The roof is a building component that is very important for tropical climates which have high rainfall and solar radiation throughout the year.

The primary function of the roof is to provide protection against the main buildings, namely the body of the building, and some parts of the foot. Walls are physical boundaries between outer space and inner space which function as protection from external environmental conditions including climate conditions. The type of walls strongly influences indoor thermal comfort in traditional buildings. Traditional house floors usually have a distance from the ground. One of them is caused by hygiene considerations and durability of building materials. Houses are generally on stilts and have a fairly high range from the ground, allowing the movement of air into the room through the cracks of the floor as well as the air from inside the building to come out through the gap.

Table 1: Traditional Architectural Classification Based on Climate Zones.

1. TROPICAL RAIN FOREST CLIMATE			
NO	REGION	CHARACTERISTICS	ARCHITECTURAL TYPOLOGY
1.	Sumatra	Tropical rainforests have a tropical climate type where there is no dry season - all months have an average rainfall value of at least 60 mm. In tropical rainforests, the dry season is abridged, and rainfall is usually heavy throughout the year. One day in the equatorial climate can be very similar to the next day, while changes in temperature between day and night may be more significant than changes in the average temperature during the year.	 
2.	Kalimantan		 
3.	Papua		

2. TROPICAL MONSOON CLIMATE			
NO	REGION	CHARACTERISTICS	ARCHITECTURAL TYPOLOGY
1.	West Java	In essence, the tropical monsoon climate tends to see more rainfall than the tropical savanna climate or has fewer dry seasons. Besides, the tropical monsoon climate tends to see less temperature variation during the year than the tropical savanna climate. This climate has the driest month which almost always occurs at or immediately after the "winter" solstice for the equator.	 
2.	Central Java		
3.	South Sulawesi		

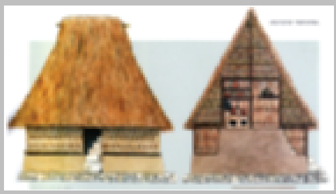
3. TROPICAL WET AND DRY (SAVANA) CLIMATE			
NO	REGION	CHARACTERISTICS	ARCHITECTURAL TYPOLOGY
1.	NTB	This latter fact is directly in contrast to the tropical monsoon climate, where the driest month gets less than 60 mm of rainfall, but has more than 100 rainfall - [total annual rainfall {mm}/25]. The tropical savanna climate tends to get less rainfall than the tropical monsoon climate or more clearly the dry season. In tropical savannah climates, the dry season can be severe, and often drought conditions last for one year. The tropical savanna climate often displays tree-lined grasslands, not dense forests. The existence of tall and wide grasslands (called "savannas") causes climate Aw which is often referred to as "tropical savanna."	
2.	NTT		

Table 2: Architecture Traditional Element and Thermal Comfort.

No	REGION	ILLUSTRATION	TRADITIONAL VALUE	THERMAL COMFORT VALUE
			Roof	
1	Sumatra		Roofs have the value of recognition and submission to TYME (usually for putting heirlooms)	- Materials used such as fibers can reduce heat - Forms add value in air movement
2	Jawa		The place to communicate with spirits	Materials used such as fibers can reduce heat
3	Kalimantan		Symbol of grandeur, nobility, and heroism	- The material used can withstand strong winds - The angle of slope on the roof used so that heat is not trapped in the building
4	Sulawesi		- Describes trust in God - Symbolizes the social status of its inhabitants	A wide roof with openings in response to the tropical climate

No	REGION	ILLUSTRATION	TRADITIONAL VALUE	THERMAL COMFORT VALUE
5	NTT		The place to communicate with spirits	Materials used such as fibers can reduce heat
		Wall (body)		
1	Sumatra, Jawa, Kali-mantan, Sulawesi, NTT		Some traditional values that can be taken from the walls (bodies) of traditional houses in Indonesia are: - ornaments and carvings located on the body of the building have meaning - In the body of the building is divided into several inner spaces that describe the position / social status of a person.	In traditional houses in Indonesia, walls function in providing protection against heat and rain. The presence of openings in the wall helps the air circulation system so that residents feel more comfortable.
		Foundation (foot)		
1.	Sumatra, Jawa, Kali-mantan, Sulawesi, NTT		An elevated foundation means the level of social status of its inhabitants	Elevated pillars have several advantages including: - overcoming mud and flooding during the rainy season - As under-floor ventilation during hot weather.

4. Results and Discussion

The availability of natural resource for building materials largely determines building technology. Traditionally, the roof symbolizes the identity of the occupants in it. As the main architectural form, the importance of the roof is underlined by the need to take shelter from the hot sun and rain. Besides, the shape of the stage in residence is considered capable of answering the problem of comfort in the building.

Table 3: Review of Traditional Architecture on Achieving Thermal Comfort.

No	Title of article with year	Element architecture discussed	Region	Achievement of thermal comfort (Ta/RH/v or index)	Illustration
1	Investigation of Indonesian Traditional Houses through CFD Simulation (2017)	Wall (building body)	Lampung (Sumatra), Jawa, Toraja (Sulawesi)	In traditional houses in Lampung and Java wind speeds range from 0.16-0.25 m / s. while in Toraja it varies more between 0.024-0.17 m / s.	Dimensions, types of openings and direction of openings and the height of the floor can influence the flow of air into the dwelling.
2	Analysis of Thermal and Aerodynamic Performance in Toba Batak Traditional Houses Using Digital Simulation and Field Measurement (2016)	Roofs and openings on the walls of the building	Batak Toba	reference upper limit temperature thermal comfort which is 29 ° C.	Arches on the roof can affect the behavior of the wind towards the building
3	Expression of Tropical Climatic Forms of Archipelago Traditional Architecture in Regionalism (2017)	Roof	the islands of Sumatra, Java, Kalimantan, Sulawesi, Bali, NTT, NTB, Papua	Is research using qualitative descriptive methods	Roofs of traditional houses have a dominant role in adapting to the climate, in the form of roof steepness.
4	Tropical-Humid Architecture in Natural Ventilation Efficient Point of View A Reference of Traditional Architecture in Indonesia (2000)	Roof	Java	Using a comparison method for thermal comfort in traditional buildings on the island of Java	The shape and construction of the roof can affect building temperature.
5	Effect of Traditional Building Roof Forms in Central Java for Increased Comfort (2007)	Roof	Java	The Joglo House and the Holy House roof are in the Comfortable to Warm area. While the other three houses are within the limits of Warm - Too hot (Thermal comfort according to P.O Fanger)	roof formation that has no circulation the air inside the roof contributes heat to the space below, which affects comfort thermal

No	Title of article with year	Element architecture discussed	Region	Achievement of thermal comfort (Ta/RH/v or index)	Illustration
6	Heat Removal Using The Hollow Roof In the Javanese House (2016)	The material on the roof	Java	Reducing the average air temperature from a value of 27.7˚C, up to a value of 27.2 ˚C	Material and roof openings can affect airflow so that it can provide comfort for residents in the building
7	Thermal Performance of Traditional House in the Upland Central Celebes of Indonesia (2011)	Tambi traditional house (roof, walls, and foundation)	Celebes (Sulawesi)	Being in a comfortable condition, but does not last within 24 hours	The shape of the building, building envelopes, and direction of openings provide a role in providing thermal comfort in the building
8	Thermal Comfort in Traditional Toraja Residential Buildings (2012)	Comparison of Tongkonan bamboo roof and tongkonan zinc roof	Toraja	Tongkonan bamboo roofs are in optimum comfort conditions at temperatures while the humidity is felt less comfortable when compared to zinc roof	The material used on the roof can affect the temperature and humidity in the building
9	Thermal Comfort in Riverfront Houses "Case Study of the Kahayan River Edge House in Palangka Raya City (2014)	Comparison of riverside houses and stilt houses (all building elements)	Kalimantan	PMV index 2.9-3. PPD Index by 43%-55% indicating discomfort.	Climate factors, building design, physical physiology, and occupational psychology were able to influence the perception of thermal comfort felt in buildings.
10	Thermal Performance of Traditional Houses in Uma Kbubu (2012)	Uma Khubu	NTB	The temperature is neutral ie 24.6°C in the rainy season and 27.6°C in the spring season	The roof is a building envelope element that plays a significant role in thermal conditioning in Uma Kbubu, while the wall has no significant effect
11	Thermal Characteristics of Uma Lengge in Mbawa Village West Nusa Tenggara (2013)	Uma Lengge	NTB	Uma Lengge is able to warm the room 0.1°C in the rainy season and is 0.8°C lower in the dry season than the outdoor temperature.	Imperata as a roof material can influence the temperature changes in the building

No	Title of article with year	Element architecture discussed	Region	Achievement of thermal comfort (Ta/RH/v or index)	Illustration
12	Adaptive Thermal Comfort in Sao Pu'u Traditional Houses in Wogo Village, East Nusa Tenggara (2012)	Traditional Sa'o Pu'u house	NTT	the neutral temperature in the rainy season is 27.1°, while in the dry season the neutral temperature is 24.9°C.	Climate factors, building design, physical physiology, and occupational psychology were able to influence the perception of thermal comfort felt in buildings.
13	Preliminary study on the Thermal Environment of the Flores's Vernacular house for Development Tropical Responsive Design (2011)	Traditional house in Bena and Wogo	NTT	Air humidity is 80% higher / hour in a day	Sun shading is considered important compared to openings in buildings, especially in areas with low temperatures such as Bena and Wogo.
14	A Thermal Assessment of the Traditional House In Flores, Indonesia (2012)				
15	Thermal Performance of Niang Houses in Moist Tropical Plateau in Manggarai District (2016)	Niang's house	NTT	The U-value of the floor and roof elements is large (3.20 W / K) and has a short lag time (0.30 hours)	the floor and roof are the most critical elements of heat release.
16	Thermal Performance at Sao Ria Traditional Houses in Ngalupolo And Nggela Villages East Nusa Tenggara Province (NTT) (2012)	Traditional Sao Ria house	NTT	Comfortable temperature range of 24-28 °C,	the performance of buildings in Sao Ria indicates that the indoor temperature is warmer in the rainy season and vice versa

4.1. Sumatra

Suhendri's research [14] in Lampung traditional houses was a study to investigate natural ventilation strategies in traditional buildings in the area. This study uses a CFD (Computational Fluid Dynamics) simulation without regard to other variables such as the surrounding environment. Wind speeds in buildings ranging from 0.16-0.25 m / s are considered to be still in the comfort range for wind speed. However, it was found that the slope of the roof, window position, and type of openings are variables that affect the flow of air entering the building and potentially create discomfort if the wind speed outside the building is slightly higher.

Another study was conducted by Prasetyo [16] to measure thermal performance in traditional Toba Batak buildings in a relatively flat topographic area. Measurements were made using the Meteonorm, Ecotect and CFD simulations where the results showed had a similarity of 80% results when compared to the standard maximum thermal comfort temperature of 29°C. Besides, according to Hermawan [6] in the "Tropic Climate Form of Traditional Architecture Architecture's Expression in Regionalism" explained that the shape of the roof dominates traditional houses on the island of Sumatra by incorporating decorative elements into identities while functioning as a form of climate adaptation. The existence of a foot/stage pole is seen lifting the building clearly.

4.2. Java

Looking at the problems in the humid tropics in Indonesia and the efficiency of natural ventilation in architecture, Prianto [17] compared traditional buildings, colonial and contemporary buildings on Java. His research concluded that the shape and construction of the roof could affect the temperature of the building as it influences the air flow can remove heat in the building.

According to Sanjaya [18], in his research in the houses of Trajumas Village, the Doro Gepak Village House, Limasan House, and Joglo House, it was known that roof formations that did not have air circulation inside the roof contributed heat to space below. In the four houses studied using tools or software calculations, it can be seen that the air temperature ranges from 36-38 degrees Celsius. The use of roof cover material such as asphalt shingles and terracotta tile provide a comfort range, since the absence of air movement inside the roof. The heat in the roof cavity then affects space under the roof. However, according to Pranoto [13], the traditional Javanese buildings he studied used a CFD program, revealing that the geometry and hollow roof forms in buildings influenced air movement inside and outside the building. Openings in the roof area can provide a cooling effect of 0.55 degrees Celsius and reduce the average air temperature from a value of 27.7 ℃ to 27.2 ℃.

4.3. Sulawesi

Traditional buildings in Sulawesi are generally high class, with open/windowed walls and terraces. The shape of the roof protects the building and has the function of forming space. The roof space also functions to drain air. Comparison of the shape of the roof, walls, and ponds tend to be balanced [6].

In Fitriaty's [5] study of the thermal performance of Tambi traditional buildings in the highlands, it was suggested that the thermal conditions of the building could not meet 24-hour comfort needs. This is because the building materials used as building envelopes are lightweight materials with low thermal capacity. The roof plays an important role in heat modulation so that the amount of heat is substantially reduced. But the openings and cracks found in the building allow cold air to flow and affect the internal conditions of the building. However, the clothes worn are considered as a factor that helps residents to get thermal comfort in the building.

In other traditional buildings in North Toraja Regency (Tongkonan), it was found that there was a significant difference between the original roofing bamboo and the non-authentic roof covering material especially those in high-lying areas. In Tongkonan with zinc roofing material, the temperature conditions are quite high while Tongkonan with bamboo roofing material is quite high in humidity [19].

4.4. Kalimantan

Traditional buildings in Kalimantan tend to have the same anatomy as traditional buildings in Sumatra, consisting of roofs, bodies (walls) and legs (under). The shape of the roof does not dominate which functions to protect radiation and drain rainwater and part of the roof functions to drain air [6].

According to a study conducted by Bua'Toding [20] in a stilt house (rumah lanting) house in Palangkaraya, Central Kalimantan, there were no differences in the conditions of effective temperature in the morning to night. The comfortable perception based on PMV and PPD analysis occurred at 7:00am to 8:00 pm. The peak condition occurred at 13:00, where the PMV index is 2.9-3 and PPD index of 43% -55% agrees to feel uncomfortable. From the calculation of the PMV index, a comparison with the results of the questionnaire was conducted, where the results of the PMV index calculation were warmer or more than one scale from the results of the questionnaire.

4.5. West Nusa Tenggara and East Nusa Tenggara

Traditional Balinese settlements, NTT, NTB are influenced by dry hot climates. Therefore settlements tend to be in valleys and hills. Houses are generally low-lying (not under) and terraced [6].

One of the traditional buildings in West Nusa Tenggara Province is Uma Lengge which can be found in Mbawa Village. Uma Lengge has the structure and construction of a stage building with prism-shaped roof components. Roof cover material used in buildings is reeds that can either reduce or increase room temperature. Where the temperature in the room can rise by 0.1-0.8 degrees Celsius under conditions of low external temperature and reduce the room temperature by 0.6 -1.8 degrees Celsius in conditions of high outside temperatures. The ability of reeds to deliver heat is influenced by surface properties, wind speed and surface temperature [21].

According to I. K. D. Suwantara [22] in his research at Sa'o Ria, Ende, East Nusa Tenggara, it was known that Sao Ria's traditional buildings were more comfortable to feel in the dry season with a comfortable temperature range of 24-28 degrees Celsius. The lag time of building envelope materials ranges from 3-7 hours. The building envelope is the most influential roof and wall in reducing temperature and humidity in the area located on this coastline. Reeds as a material on the roof can reduce heat for 3 hours, while the boards and bamboo pads on the wall can reduce heat for 3-7 hours.

Not much different from the research conducted in Timor Tengah Utara District at Uma Kbubu. Based on the research conducted by Nugrahaeni [1], the traditional Uma Kbubu building has good thermal performance in the rainy season or dry season. The ability of the building to condition the air, especially the role of the roof on Uma Kbubu as the main element of the building envelope has a significant effect on the thermal performance of the building. Roofs of reeds are able to withstand heat from inside the room (in the rainy season) and hold heat from outside into the building (during the dry season). The wall at Uma Kbubu has no significant effect on the thermal performance of the building. Even though it has high humidity in the room, the occupants' thermal response is below neutral (AMV). This shows that Uma Kbubu is able to create a neutral thermal environment to cool and comfortable for occupants.

Other research in Flores, East Nusa Tenggara is a traditional house in the mountainous areas of Wogo and Bena.. In both of these buildings, double facades in the form of bamboo (outside) and wood (inside) are applied in response to climate in the region. Roof material (reeds) provides a good effect for air circulation that occurs in residential areas, especially when the fireplace is turned on in the house [23-24]. According to I. K.

Suwantara [22], the adaptive response of residents of the house of Sao Pu'u in Wogo Village, NTT to the neutrality in the rainy season was higher by 27.1 degrees Celsius compared to the dry season of 24.9 degrees Celsius; Preference temperature in the rainy season is higher by 23.9 degrees Celsius compared to the dry season of 23.4 degrees Celsius; the average acceptance in the rainy season is higher by 23.3 degrees Celsius compared to the dry season at 21.1 degrees Celsius to the operative temperature. This temperature comparison shows the adaptive response of the occupants to want lower temperatures both in the rainy and dry seasons.

Another variety of traditional house is Rumah Niang which is located in the highlands of Manggarai district, East Nusa Tenggara. The peculiarity of this building is a circular plan and a cone-shaped roof. According to Alfred [25], the building elements at Rumah Niang have not been able to provide adequate thermal comfort at night until morning, where building conditions tend to experience underheating for a considerable period. This is influenced by the value of U-value which is relatively large and a short time lag so that it cannot hold and store heat longer. A single layer building shape cannot help slowing the heat out even though the orientation of the building is right north-south.

5. Conclusions

Conclusions that can be drawn from this study are as follows:

- Roof is the variable that most contributes to thermal comfort in buildings both in the tropical rainy climate (Af), monsoon tropical (Am) and savanna (Af). This can be seen from the use of materials, shapes and sizes.
- The temperature conditions at occupancy using bamboo/wood material are quite low compared to occupancy using other materials as building skin. In addition, the crack or density of material in the building can also affect the comfort of the building.
- Adaptation is another factor for residents to get thermal comfort. This is not only indicated by the clotting factors that are worn but habits/behavior that influence perceptions of the comfort felt by residents in the building.

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