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Temperature performance and thermal comfort study in vernacular houses in East Nusa Tenggara, Indonesia

Tri Harso Karyono [1)], I Ketut Suwantara [2)], Rini Nugrahaeni[2)], Iwan Suprijanto[2)], Robert Vale[3)]

[1)] School of Architecture, Tarumanagara University, Indonesia
E-mail: tkaryono15@gmail.com; t_karyono@yahoo.com
[2)]Research Centre for Building and Settlement , Ministry of Public Works, Denpasar, Bali, Indonesia,
E-mail: lokatekkimdenpasar@yahoo.com
[3)]School of Architecture, Victoria University of Wellington, New Zealand,
E-mail: Robert.Vale@vuw.ac.nz

Abstract
More than 350 different ethnic groups inhabit Indonesia. Many of them are still maintaining their own local traditions and cultures, and some are still living in their own vernacular houses. About 80% of Indonesian region is rural, minimising urbanisation process like conserving these vernacular houses is one of the appropriate way to achieve sustainability. Vernacular houses are built by local communities, using local materials which are available in their surrounding environments. Some are wondering whether these kinds of buildings are thermally comfortable. Recent study has been made in three different vernacular houses namely Uma Lengge, Sao Ria and Uma Kbubu in three locations in the Province of East Nusa Tenggara, Indonesia. This study was an attempt to see whether these houses, which were built without any scientific basis, are thermally uncomfortable i.e. not too warm for the inhabitants. This paper discusses the study and draws some conclusions from it.
Keywords: vernacular houses, indoor climate, outdoor climate, thermal comfort, thermal performance

1. Introduction
Most of the vernacular houses in Indonesia are still being used by people of vernacular ethnic communities. There are spread out from the north tip of Sumatera Island in the west part of Indonesia to West Papua in the east part of Indonesia. Vernacular houses are built by local ethnic communities, using local materials like bamboos, wood, branches, leaves and other parts of trees. These kinds of materials are available in their surrounding environments. Vernacular houses tend to be built wisely by local people in the safe locations, away from natural disaster sources like landslides and away from wild animals. These houses have been proven to be able to withstand from natural disasters like earthquakes and vulcanic eruptions for many decades. No report has been made that any people lives in the vernacular houses was killed by landslides or by wild animals, like tigers, komodos, crocodiles or snakes.

Vernacular people tend to live in a modest way and many of them have no electricity in their houses. They use wood and leaves as fuel for cooking and use coconut oil for the lanterns to light the rooms. Most of them are animists who believe that things like trees, rivers, lakes, etc., have spirits and they must be protected. Vernacular people tend to stick to their ancestors' wisdoms to protect their natural

environments and live naturally. Houses were built by using materials found in their immediate environment.

In Indonesia, most of modern societies look vernacular societies as backward and their houses as old fashion. Although some who admire these houses were then just copying them to build similar shapes of buildings in urban areas but for different function other than dwellings. A number of such buildings like restaurants, museums, retails, etc in some Indonesia towns are resembled the roofs of some vernacular houses, although these buildings are usually not naturally ventilated like the original vernacular houses. People tend to wonder that vernacular houses which are inhabitted by vernacular people are thermally comfortable.

Vernacular communities built their vernacular houses without any drawings since they have memorized traditionally the plan, the form and the structure of the houses from generation to generation.

Fig. 1 Locations of the selected Vernacular houses

Source: http://www.dimensionsguide.com/wp-content/uploads/2009/12/Indonesia.gif

This study was conducted in two seasons: the rainy season in April and the dry season in July 2011. In most areas of Indonesia, during the rainy season outdoor temperatures are likely to be lower than in the dry season. The crucial condition may occure in the dry season where occupants may feel too warm since the ambient temperatures tend to be higher. This study is to examine whether occupants will feel thermally comfortable in both seasons in vernacular houses. Three different vernacular houses in three locations, namely Uma Lengge in the island of Sumbawa, Sao Ria in the island of Flores and Uma Kbubu in the island of Timor (West Timor) in the Province of East Nusatenggara, Indonesia, were taken as samples for the study.

1.1. Background of Study

Vernacular houses are built without drawings, with no scientific base like the requirement of areas of windows and openings. The houses are built by implementing traditional technology and also using unfabricated local materials. In this kind of situation a question rises whether the dwellings are thermally comfortable. Building

thermal performance and occupants' thermal comfort are becoming matters of interest and concern.

To answer these questions, a field study has been conducted in three different vernacular houses in three locations in the Province of East Nusa Tenggara, Indonesia (see Fig. 1). The three different houses were chosen as they are situated relatively close together in a particular region with a similar climate. Although the three different houses are built by different societies which have no contact between each other, the houses are in fact have some similarities in their forms and shapes, and also are built using more-or-less similar building materials. Since many vernacular houses are located in remote areas and not easy to reach, the selected houses were chosen by considering the accessability for them to be reached and to be measured.

1.2. Aims of Study

The study aims firstly to measure the thermal performance of the house, to see how indoor climatic parameters like air temperature, etc, are affected by the outdoor conditions and secondly to see whether the selected vernacular houses are thermally comfortable within the two different seasons.

2. Methods

Two types of data were collected in this study. The first type of data consisted of climatic parameters inside and outside the houses. This data is to be used to examine how the houses performed thermally against the ambient climates. Due to some limitations, this data was only able to be collected during the rainy seasons in March, not in the dry season. The second data, which was collected during the rainy and the dry seasons, consisted of thermal votes of the occupants, in which occupants were given thermal vote questionnaires to be filled in. This data was used to see whether people who live in these selected vernacular houses would be comfortable during both the rainy and the dry seasons.

Figure 2. QUESTemp-34

Climatic parameters inside and outside the houses, i.e. air temperatures and humidity, were measured continously every hour during 24 hours by using QUESTemp-34 digital equipment. Air movement was measured by Kanomax A031 digital equipment. During the measurement period equipment was put on a small wooden table 1m above floor surfaces. Whereas the thermal comfort study was conducted in a number of the houses, the thermal performance studies were conducted only in one house for any type of the vernacular houses.

Since people living in the vernacular houses are having different activities within a day, thermal votes, based on the seven-point scale: cold (-3), cool (-2), slightly cool (-1), neutral (0), slightly warm (+1), warm (+2) and hot (+3), were distributed amongst the occupants in their houses at any time depending on their time availabilities. Thermal votes were not used to find out occupants' neutral temperature,

but rather used to see whether occupants would feel uncomfortable (too warm) inside the houses. Since subjects' thermal measurements were taken at different times from morning to evening, the results may not well represent the whole thermal conditions inside the houses. Subjects who were available in the morning may vote neutral or below since the temperatures were quite low. On the other hand subjects who were available in the afternoon may vote above neutral when air temperature reached its imaximum level. However, along with comfort votes, air temperature and relative humidity were also measured at the same time so the range of indoor temperature and relative humidity were expected to represent indoor thermal environment during the time that subjects' thermal votes were taken.

3. Data and Discussion

Data were collected in three selected vernacular houses: one each in Uma Lengge in the village of Mbawa in the island of Sumbawa, Sao Ria in the village of Ngalupolo in the island of Flores and Uma Kbubu in the village of Maslete in the island of Timor (West Timor).

3.1. Uma Lengge in the Village of Mbawa, Sumbawa Island

The vernacular house of Uma Lengge is located in the village of Mbawa at the altitude of 600-700m above sea level in the island of Sumbawa. The Mbojo ethnic community occupies these houses. The house is a stilt house and consists of three floors. Each floor area is between 2.5m x 2.5m and 3.5m x 3.5m or about 18.5 m^2, and is usually occupied by two persons so per person the floor area is about 9.25 m^2.

Fig. 3. Vernacular house of Uma Lengge in the island of Sumbawa,

Fig. 4. Stilt house, with the lowest floor for receiving guests

Fig. 5. Interior of Uma Lengge house and the rice barn in upper left

The lowest floor is a space without walls, used for semi public activities like receiving guests, the middle floor is for sleeping area and kitchen, and the top floor (or mezzanine) is a rice barn. The house is constructed from jackfruit, areca nut and kapok woods, while the roofs are constructed of bamboo and covered by dried grass or rice straw.

3.1.1. Thermal performance of the house

A climatic parameters measurement of the Uma Lengge vernacular house was carried out in April 2011. This measurement aimed to see the thermal performance of the house in a given climatic condition. Based on the 24 hour measurements, maximum indoor temperature was 25.4^{o}C, which occurred between 13.00 and 14.00 pm accompanied by RH of 76%. The minimum indoor temperature was 20.6^{o}C which occurred at 6.00 am with RH of 92%. The mean indoor temperature was 22.4^{o}C and the mean RH was 88.1%. The maximum outdoor temperature was 28.1^{o}C which

occurred at 14.00 pm with RH of 61%. The minimum outdoor temperature was 20.7 which occurred at 6.00 am. The average outdoor temperature was 23.5^{o}C with the average RH of 84.3%. Indoor air movements were measured between 0 and 0.8m/s while the outdoor air movements were between 0 and 1.6 m/s.

3.1.2. Occupants' thermal comfort

Occupants' thermal responses were taken twice, during the rainy and the dry seasons. In the rainy season measurements were taken in April 2011. Subjects' thermal votes were taken along with air temperature and relative humidity measurements. During the measurement, the mean indoor air temperature was 25.5^{o}C, with maximum of 27.5^{o}C and minimum of 24.4^{o}C and STD of 0.9^{o}C. The mean of RH was 92.7%, with maximum of 99% and minimum of 82% and STD of 5.9%. There were 23 subjects participating in this study in which 17 subjects were males and six were females, aged between 22 and 100. There were six subjects who voted cold, four subjects who voted cool, four subjects who voted slightly cool, five subjects who voted neutral, one subject who voted warm and three subjects who voted hot. Subjects' mean vote was -0.83 (between neutral and slightly cool).

In the dry season thermal comfort votes were taken in July 2011. Thermal comfort votes were distributed amongst 37 subjects in which 25 were males and 12 females. Subjects were between 13 and 80 years old. Six subjects voted cold, 18 subjects voted cool, nine subjects voted slightly cool, one subject voted neutral and three subjects voted slightly warm. Subjects' mean vote was -1.62 (between slightly cool and cool).

3.2. Sao Ria in the Village of Ngalupolo, Flores Island

The vernacular house of Sao Ria is in the village of Ngalupo in the island of Flores. This vernacular house is located at the altitude of 34m above sea level. The Ende ethnic community occupies these houses.

Fig.6. Vernacular house of Sao Ria in the island of Flores, Indonesia

Fig.7. Interior of the house, the lower floor

Fig.8. Roof structure mainly from bamboo and covered with dried grass

The house is a stilt house and consists of two floors. Each floor area is about 103 m^2 and is usually occupied by ten persons or 10.4 m^2 per person. The lower floor is used as a multi functional room for sleeping and other activities. The upper floor is a barn. The house is constructed from coconut wood and bamboo. Some parts of the walls and the floor are made from woven bamboo while the roof is covered by dried grass or rice straw.

3.2.1. Thermal performance of the house

A climatic parameters measurement of a Sao Ria vernacular house was carried out in April 2011. This measurement aimed to see the thermal performance of the house in a given climatic condition. Data collected from the measurements shows that maximum indoor temperature was 30.2^{o}C reached at 10.15 am and minimum indoor temperature was 24.9^{o}C which took place at 6.15. The maximum outdoor temperature was 32.2^{o}C which occurred at 12.00 noon, and the minimum was 24.3^{o}C which happened at 4.14 am. The average indoor temperature was 27.2^{o}C or about 0.1^{o}C lower than the average outdoor temperature (27.3^{o}C). The indoor average RH was 81.2%, with maximum of 88% and minimum of 66%. The outdoor average RH was 80.2%, with maximum of 88% and the minimum of 59%. The range of air movements inside the house were between 0 and 0.5m/s, while the outdoor air movements were between 0 and 2.5m/s.

3.2.2. Occupants' thermal comfort

Occupants' thermal responses were taken twice, during the rainy and dry seasons. In the rainy season measurements were taken in April 2011. Subjects' thermal votes were taken along with air temperature and relative humidity measurements. The mean indoor air temperature was 28.6^{o}C, with maximum of 30.9^{o}C and minimum of 25.8^{o}C and STD of 1.52^{o}C. The mean of RH was 78.1%, with maximum of 87% and minimum of 66% and STD of 5.5%. In these climatic conditions, 28 subjects were asked to give their thermal votes. They were 18 males and 10 females with the range of age between 16 and 71 years old, and the average of 34.5 years old. Three subjects voted cold, 17 subjects voted cool, two subjects voted slightly cool, two subjects voted neutral, one subject voted slightly warm and three subjects voted hot. Subjects' mean vote was -1.25 (between slightly cool and cool).

In the dry season thermal comfort votes were taken in July 2011. Subjects' thermal votes were taken along with air temperature and relative humidity measurements. The mean of indoor air temperature was 27.4^{o}C, with maximum of 30.5^{o}C and minimum of 23.9^{o}C and STD of 1.24^{o}C. The mean of RH was 76.2%, with maximum of 84% and minimum of 65% and STD of 4.5%. Ther were 23 subjects involved in this study in which 11 were males and 12 were females. They were between 22 and 87 years of age. Subjects' thermal votes were distributed as follows: six subjects voted cold, seven subjects voted cool, two subjects voted slightly cool, seven subjects voted neutral and one subject voted slightly warm. Subjects' mean vote was - 1.4 (between slightly cool and cool).

3.3. Uma Kbubu in the village of Maslete, Timor Island

The vernacular house of Uma Kbubu is in the village of Maslete in the island of Timor (West Timor). The village is located at the altitude of 371m above sea level. The Atoni ethnic community occupies these houses. The house is a house on the ground and consists of two floors. Each floor area is about 25m^2 and usually occupied by two persons or 12.5 m^2 per person. The ground floor is used as a multi functional room for sleeping and other activities. The upper floor is a barn. The house is constructed of red wood, pine wood and bamboo, and the roof is covered by dried grass or rice straw.

Fig. 7. Vernacular house of Uma Kbubu in the island of Timor (West Timor), Indonesia

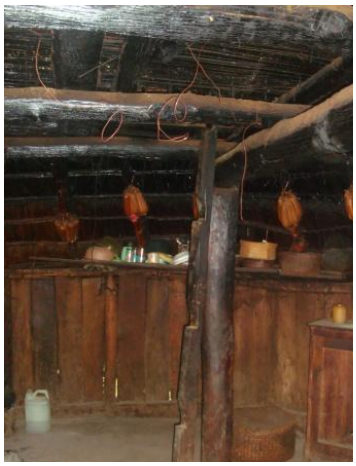

Fig. 8. Interior of Uma Kbubu vernacular house

3.3.1. Thermal performance of the house

A climatic parameters measurement of one of the Uma Kbubu vernacular houses was carried out in April 2011. The measurement aimed to see the thermal performance of the house in a given climatic condition. Data collected from the measurement shows that maximum indoor temperature in the house was 27.3^{o}C and it was reached at 13.00am. The minimum indoor temperature was 24.5^{o}C which took place at 3.00am. The maximum outdoor temperature was 27.2^{o}C occurred at 15.00pm, and the minimum was 24.0^{o}C happened at 6.00am.

The indoor average RH was 86.6%, with a maximum of 91% and a minimum of 81%. The outdoor average RH was 87.0%, with a maximum of 92% and a minimum of 87%. The range of air movements inside the house were between 0 and 0.4m/s, while the outdoor air movements were between 0 and 1.8m/s.

3.3.2. Occupants' thermal comfort

In the rainy season measurements were taken in April 2011. Subjects' thermal votes were taken along with air temperature and relative humidity measurements. The mean of indoor air temperature was 25.5^{o}C, with maximum of 27.5^{o}C, minimum of 24.4^{o}C and STD of 0.9^{o}C. The mean of RH was 92.7%, with maximum of 99% and minimum of 82% and STD of 5.9%. There were 27 subjects consisting of 17 males and 10 females involved in this study, aged between 25 and 82 years of age. Ten subjects voted cold, six subjects voted cool, two subjects voted slightly cool, three subjects voted neutral, two subjects voted slightly warm and four subjects voted warm. Subjects' mean vote was -1.33 (between slightly cool and cool).

In the dry season measurements were taken in July 2011. Subjects' thermal votes were taken along with air temperature and relative humidity measurements. The mean of indoor air temperature was 26.2^{o}C, with maximum of 28.9^{o}C, minimum of 23.4^{o}C and STD of 1.92^{o}C. The mean of RH was 69.9%, with maximum of 87% and minimum of 55% and STD of 10.8%. There were 32 subjects involved in the study. Subjects consisted of 22 males and 10 females, aged between 16 and 82 years old. Ten subjects voted cold, five subjects voted cool, six subjects voted slightly cool, seven subjects voted neutral, one subject voted slightly warm, one subject voted warm and two subjects voted hot. Subjects' mean vote was -1.16 (between slightly cool and cool).

4. Discussion

4.1. Thermal performances of the vernacular houses

Table 1 shows a comparison between indoor and outdoor climatic parameters (air temperature, relative humidity and air movement) in the three selected vernacular houses.

Table 1. Comparison between indoor and outdoor climatic parameters in the selected vernacular houses

	AIR TEMPERATURE (°C)						HUMIDITY (%)						AIR MOVEMENT (M/S)			
	INDOOR			OUTDOOR			INDOOR			OUTDOOR			INDOOR		OUTDOOR	
March 2011	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Min	Max	Min
 **UMA LENGGE**	25.4	**22.4**	20.6	28.1	**23.5**	20.7	92	**88.1**	76	89	**84.3**	61	0.8	0	1.6	0
 **SAO RIA**	30.2	**27.2**	24.9	32.2	**27.3**	24.3	88	**81.2**	66	88	**80.2**	59	0.5	0	2.5	0
 **UMA KEBUBU**	27.3	**25.5**	24.5	27.2	**25.7**	24.0	91	**86**	81	92	**87**	87	0.4	0	1.8	0
MEAN	27.6	25.0	23.3	29.2	25.5	23	90.3	85.1	74.3	89.6	83.8	69	0.6	0	1.97	0

Although the mean indoor relative humidity was about 1.3% higher than the mean outdoor, the average indoor temperatures in all the selected houses were about 0.5^{o}C lower than the average of the outdoors. In Uma Lengge, the average indoor temperature was 22.4^{o}C or about 1.1.^{o}C lower than the outdoor (23.5^{o}C). In Sao Ria, the average indoor temperature was 27.2^{o}C or about 0.1.^{o}C lower than the outdoor (27.3^{o}C). In Uma Kbubu, the average indoor temperature was 25.5^{o}C, and it was 0.2^{o}C lower the the average outdoor temperature (25.7^{o}C). This shows that even in houses which are not being designed according to the modern approach, without drawings, no scientific basis and using simple building materials the indoor climates were correctly fitted to the outdoor climate.

In all the selected houses roofs help to protect the indoor environment from being overheated. The shape and materials of the roof both protect from direct sun radiation entering the house and minimize the heat transfer from outside into the inside of the house. It seems that dried grass may help to reflect and absorb the heat from outside therefore the indoor temperature is maintained close to that of the outdoors. In addition, even without any windows, the houses can be naturally ventilated because of the use of porous materials like woven bamboo, dried grass and rice straw as the building envelope.

4.2. Thermal comfort measurement of occupants in the vernacular houses

Table 2 shows subject's thermal sensations during both rainy and dry seasons in the selected vernacular houses. It can be seen from the Table that in any season and in any type

of the houses subjects' mean votes were below neutral. This means that on average subjects did not have the feeling of being too warm.

Table 2 Subjects' thermal sensations during rainy and dry seasons in the selected vernacular houses

			 UMA LENGGE		 SAO RIA		 UMA KEBUBU	
			RAINY April 2011	**DRY July 2011**	**RAINY April 2011**	**DRY July 2011**	**RAINY April 2011**	**DRY July 2011**
INDOOR CLIMATIC PARAMETERS	AIR TEMPERATURE	Max	27.5	28.9	30.9	30.5	27.5	28.9
		Mean	25.5	26.2	28.6	27.4	25.5	26.2
		Min	24.4	23.4	25.8	23.9	24.4	23.4
	HUMIDITY	Max	99	87	87	84	99	87
		Mean	92.7	70.1	78.1	76	92.7	69.9
		Min	82	55	66	65	82	55
COMFORT VOTES	HOT	+3	3	0	3	0	0	2
	WARM	+2	1	0	0	0	4	1
	SLIGHTLY WARM	+1	0	3	1	1	2	1
	NEUTRAL	0	5	1	2	7	3	7
	SLIGHTLY COOL	-1	4	9	2	2	2	6
	COOL	-2	4	18	17	7	6	5
	COLD	-3	6	6	3	6	10	10
	NO SUBJECTS		23	37	28	23	27	32
	MEAN VOTES		**-0.83**	**-1.62**	**-1.25**	**-1.4**	**-1.33**	**-1.16**

In the Uma Lengge vernacular houses, subjects' mean votes in the rainy and dry seasons were -0.83 (between neutral and slightly cool) and -1.62 (between slightly cool and cool) respectively. In the Sao Ria vernacular houses, subjects' mean votes were -1.25 (between slightly cool and cool) in the rainy season and -1.4 (between slightly cool and cool) in the dry season. In Uma Kbubu, subjects' mean vote was -1.33 (between slightly cool and cool) in the rainy season and -1.16 (between slightly cool and cool) in the dry season.

A thermal comfort study done by Karyono in Bandung, Indonesia in 2007 (Karyono, 2008) shows that the maximum number of subjects would reach thermally comfortable conditions at air temperature of 24.7^{o}C. Considering that subjects' clothing value in that study was about 0.6 clo (average tropical clothing value) and they were conducting light activities (1 met), subjects would still be comfortable in the range of air temperatures between 23.0^{o}C and 26.5^{o}C.

Since Bandung's altitude is about 700m above sea level which is more or less similar to the altitude where the Uma Lengge houses are located (600-700m above sea level), the thermal environment of both locations can be considered comparable. Within the air temperature of between 24.4^{o}C and 27.5^{o}C in the rainy season and 23.4^{o}C and 28.9^{o}C in the dry season, which was quite close to Bandung's comfort range, the Uma Lengge subjects' mean vote was -0.83 in the rainy season and and -1.62 in the dry season.

From Table 1 it can be seen that the range of indoor air movements between 0 and 0.8m/s in Uma Lengge, 0 and 0.5m/s in Sao Ria and 0 and 0.4m/s in Uma Kbubu may help occupants to feel below neutral. In tropical countries being slightly cool or cool is better than being too warm since thicker clothes could easily help people to feel warmer.

Even though there is no extensive study done yet in Indonesia to investigate thermal performance in modern houses, in fact it is difficult to find any modern house in the big towns of Indonesia which is not air conditioned. Almost all modern houses have air conditioners. This is a good indicator that most of these houses must not be thermally comfortable without this kind of mechanical system.

A thermal study done by Sari, et al (2010) in ten types of post Tsunami house in Banda Aceh, Indonesia, and a study by Karyono (2010) in post earthquake shelters in Jogja, Indonesia, showed that the modern houses which were designed and built by reputable national and international building companies were too warm for the occupants. In these houses, indoor temperatures were just too high to be comfortable. In Banda Aceh, the mean indoor temperature of the houses was higher than 32^{o}C and the maximum temperature could reach higher than 38^{o}C. A thermal comfort study done by Karyono in non air conditioned houses in the city of Semarang in Indonesia in 2001 (Karyono, 2002), shows that, based on the seven-point scale, the mean vote of 60 respondents living in 60 houses was +1.43 (between slightly warm and warm). This was a good indicator that most of the houses were not thermally comfortable.

While many modern houses and buildings in many Indonesian towns are extremely warm without air conditioners because the indoor temperatures exceed the outdoors, these vernacular houses were perfectly satisfactory without any mechanical systems. The study also shows that the houses could maintain slightly lower indoor temperatures than the outdoors. This may prove that both the design of the houses and the use of building materials were entirely appropriate as ways to respond to the local climate.

Questioning whether these kinds of houses can be built in such urban setting, the answer would probably no. Strickly speaking, vernacular houses are unlikely to be appropriate to be built in urban areas. This is due to the fact that these houses are built purposely to accommodate people with a distinctive tradition, not for everyone with various cultural backgrounds like people live in urban areas. Vernacular houses are built to adjust to their surroundings climates, considering to the availability of local materials and bonded with local beliefs and traditions. It is difficult to find such appropriate building materials in the urban areas for these kind of houses. Also, it is certainly difficult to ask modern people in urban areas to follow the way of life of vernacular society, as the basic requirements to establish vernacular houses.

4. Conclusions and Recommendations

The Indonesian vernacular house is one of many which is in danger of disappearing if there is no effort made to save this unique human creation. As many are wondering whether these kinds of houses might not comfortable to be occupied (Karyono, 2002), the study shows that occupants living in these houses were not feeling warm or even hot. On average, subjects voted that they felt between slightly cool and cool.

Although the mean indoor relative humidity was slightly higher than the mean outdoor RH, the study showed that on average occupants felt below neutral both in the rainy season and in the dry season.

Further study may be conducted in more houses and in more different types of vernacular houses in Indonesia to assess whether vernacular houses are still acceptable to be occupied in terms of thermal comfort

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