Assessment of indoor thermal environment of Aceh house based on WBGT index

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Abstract. Thermal comfort is one of the standard assessments of building thermal environment. Air movement is an important parameter for in a naturally ventilated to achieve thermal comfort by accelerating the evaporative cooling process on the human body. Aceh House has a standard of thermal comfort with a vernacular architecture with a natural ventilation system. This vernacular architectural building has a fairly high harmonization of the environment because it has undergone a process of adaptation. In this study, observations were made at the Original House (OH), the Adaptive Reuse House (ARH), and the Aceh Modified House (AMH). By using the method of assessing changes in environmental comfort, using Wet Bulb Temperature Index (WBGT) method, the minimum and maximum temperature ranges are 25°C and 30°C. In the WBGT thermal rating, AMH has the higher thermal and is followed by ARH and OH respectively. Thus, OH has lower thermal compared to other Aceh houses.

1. Introduction

Aceh House is local wisdom in the form of traditional houses that have been used by the Acehnese for generations. This building is in the form of a stage with several round wooden pillars that function as structural columns totaling 16 pieces arranged in a straight line. Aceh House shows high compatibility and is adaptive to the environment through a long process. The thermal comfort of Aceh House is assessed because traditional buildings or vernacular buildings are theoretically said to have adapted to the environment.

This building was erected on a wooden pillar 3 meters high to avoid attacks by wild animals and flooding. The orientation of Aceh House always faces east and west, because it adjusts to the Qiblat direction and also to avoid the movement of storm winds. The roof of Aceh House is made of thatch leaves which are woven by the community themselves to circulate air movement in Aceh House. At
Aceh House there are several ornaments in the form of carvings on the walls and "Tulak Angen" as aesthetic elements and also function as natural ventilation [1]. Aceh House is the result of local technology in the form of traditions that have been owned by the Acehnese for generations. The construction process is carried out by the community together, so as to create Aceh House which is in accordance with local climatic conditions, but now Aceh House has rarely been used as a residence and has been converted into a museum, cafe, etc. The thermal evaluation of Rumah Aceh was carried out to see the effect of the thermal changes of Rumah Aceh on the field conditions due to changes. Some changes that occurred in the modified house, namely the use of leaf roofing material turned into metal, the use of ceilings so that there is no more “tulak angen” that makes air circulation hampered, and the loss of carvings on the walls so that there is no natural ventilation. In OH "tulak angen" still has a cavity as a place for air to pass, while in ARH and AMH there is no cavity anymore.

Figure 1. Tulak Angen on (a) OH; (b) ARH; and (c) AMH.

Thermal is the heat generated by solar radiation as long waves that are felt by humans. Indoor thermal conditions are influenced by air temperature, air movement, radiation temperature, and humidity. To determine the level of thermal comfort in a building, it is necessary to carry out a thermal assessment.

Thermal comfort is strongly influenced by human activities, type of clothing, temperature, humidity, air pressure and air movement [2]. Indoor thermal comfort has become the basis for the development of international indoor environmental standards in new and old buildings [3]-[4]. For example, ARHRAE 55 [5] Standard for “Thermal Environmental Conditions for Human Occupancy”, combines environmental and personal factors in indoor areas to ensure conditions of thermal comfort that are acceptable to most occupants. In addition, when the area is mechanically conditioned, the Fanger model, which is proposed in this standard, is widely used at the international level [5]. The ISO 7730 standard for “Ergonomics” of the thermal environment” [6], provides an analytical determination and interpretation of thermal comfort, while EN 16798-1:2019 for “Energy performance of buildings—Ventilation for buildings—Part” 1: Indoor environmental input parameters for design and energy performance assessment of buildings addressing indoor air quality, thermal environment, lighting and acoustics” [7], determining the design criteria, evaluation, and parameters involved in thermal comfort and indoor air quality for buildings. While human comfort/discomfort, morbidity, and mortality are highly temperature-dependent, other climatic variables such as specific humidity, wind speed, and solar radiation are also significant factors [8]-[9]. Various bio- theoretical indices have been used to assess the human perception of temperature, or thermal comfort, and the resulting thermal stress. They are based on a combination of temperature, humidity, wind speed, and possibly other variables [8]-[10]. Several relatively simpler indices have been used in analyzing heatwave changes under global warming conditions [11]-[12].

Thermal comfort is analyzed with the WBGT index because this index is recommended by the International Standards Organization (ISO 7243) [13] for the assessment of the hot environment [14], it is also a thermo-physiological index that is widely used to measure individual heat stress under direct sunlight. [8]-[15] and WBGT account for several variables directly.

Wet Bulb Globe Temperature (WBGT) is an index of a measurement method for hot temperature performance that requires measurements of Natural Wet-Bulb Temperature (Tnw), Dry Temperature (Td), and Globe Temperature (Tg). This index has been used as a global standard and is applied to control pressure heat in many work environments [16]. WBGT is widely used by the United States
National Weather Service and the United States Military to identify heat stress levels [17]. In addition, it is also used as an ISO standard that outlines screening methods to evaluate the presence of heat stress among workers exposed to environmental heat [6]. Heat stress evaluation can be carried out to ensure thermal comfort in buildings by measuring environmental parameters. [18] The development of the thermal comfort index has been carried out long ago to obtain an index that accurately describes the heat stress level of the room [19]-[20].

Thermal comfort is one of the priority factors in a dwelling with the method and limitations of air temperature that affects thermal comfort by using the Temperature Effective (TE). The measurement methods used in this study based on SNI (Standar Nasional Indonesia) standards set by BSN (National Standardization Agency) and applicable in the territory of the Unitary State of the Republic of Indonesia. [21] states the thermal comfort area in buildings conditioned for Indonesians, namely:
- Cool comfortable, TE (20.8-22.8) °C Humidity (Rh) 50%
- Optimal comfort, TE (22.8-25.8) °C. Humidity (Rh) 70%
- Warm comfortable, TE (25.8-27.1°C). Humidity (Rh) 60%
- Warm comfortable threshold with TE > 27.1°C.

Analysis with the PMV index is carried out so that researchers can determine thermal comfort based on the psychological parameters of building users. This analysis uses software CBE Thermal Comfort [22] PMV (Predicted Mean Vote) is a scale to indicate cold or warm feelings felt by humans. The PMV value determines the range of temperature sensation felt by the user to the surrounding environment. The PMV scale is -3 (very cold), -2 (cold), -1 (cool), 0 (neutral), +1 (warm), +2 (hot), and +3 (very hot). The zero value is thermal neutrality, not thermal comfort. [23].

2. Material and Methods
The Wet-bulb globe temperature index (WBGT) is a method of measuring the performance of the influence of air temperature, humidity, wind speed and radiation. The index is used to determine the level of exposure to heat and thermal comfort in the room.

Aceh House's assessment is based on the WBGT index. The assessment process begins with the selection of case studies and locations, the first measurement was taken at Original House (OH), the second measurement was at Adaptive Reuse House (ARH), and the last measurement was at Aceh Modified House (AMH). The assessment was carried out at room temperature and user the Aceh House case study. The research is in two different locations in Aceh, one of which is in the tourist village of Lubuk Sukon which is the tourist village of Aceh House. coordinates 5° 29’ 45.3” N and at longitude 95° 22’ 37.1” E, and the second location is on Jalan Sultan Mahmudsyah No.10, Peuniti, Kecamatan Baiturrahman, Banda Aceh City, Aceh. Coordinates 5° 32’ 55.5” N 95° 19’ 16.0” E, then data collection on physical and psychological variables of the thermal comfort of Aceh House is carried out in case studies at the research location. Measurements were carried out at 6 measuring points in 3 main rooms of Aceh House, namely the front, middle and back rooms.
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Figure 2. Measurement points of (a) OH; (b) ARH; and (c) AMH.

The object is selected with the same orientation, namely east-west, has 3 main rooms, namely the front, middle and back porches with wooden wall materials. OH is an Acehnese house that is closest to traditional houses in the past, the wall material of the house is wood and the roof material is thatch leave with lots of carvings on the walls of the room as natural ventilation and still has "Tulak Angen". ARH is a house after OH which is closer to traditional houses in the past, with the wall material of the house is wood and the roof material is thatch leave with lots of carvings on the walls of the room as natural ventilation, but this house no longer has "Tulak Angen". AMH is a house that has undergone many changes, such as metal roofing material and the loss of carvings and " Tulak Angen" in the house. The material that has not changed from this house is the wall material of wood.

Data were collected by measuring the physical variables of thermal comfort and filling out questionnaires by users of Aceh House Museum and Lubuk Sukon Village. To collect data on the physical variables of thermal comfort, the researchers used two tools for measuring data in the field, namely the Anemometer to measure air velocity and the Heat Stress WBGT Meter to measure air temperature and humidity. Radiation temperature data is obtained by calculating the radiation temperature formula. Psychological variable data was obtained by filling out questionnaires in the field, the questionnaire aims to obtain thermal comfort data based on the sensitivity of Aceh House users. The results of the measurement data and questionnaires were then analyzed using the WBGT index with a comparison of SNI and PMV.

3. Results and Discussion
The results of the research are thermal comfort parameters by measuring the Anemometer and Heat Stress WBGT Meter in the form of measuring humidity Rh (%) and air temperature Ta (°C), wind speed Va (m/s) and the calculation results of Radiation Temperature Tr (°C). The results of the measurement of physical parameters of thermal comfort will be analyzed with SNI standards then PMV analysis using physical and psychological parameters of metabolism, clothing from the questionnaire.
Table 1. Measurement results of OH, ARH, and AMH.

| Hour | OH (°C) | TR (°C) | VA (m/s) | RH (%) | OH (°C) | TR (°C) | VA (m/s) | RH (%) | OH (°C) | TR (°C) | VA (m/s) | RH (%) |
|------|---------|---------|----------|--------|---------|---------|----------|--------|---------|---------|----------|--------|
| 8    | 26,5    | 26,5    | 0,1      | 90,7   | 26,7    | 0,7     | 100      | 26,7   | 26,8    | 0,1     | 100      |
| 9    | 28,5    | 28,5    | 0,1      | 80,3   | 29,8    | 0,3     | 91,6     | 28,8   | 28,9    | 0,1     | 100      |
| 10   | 29,8    | 29,2    | 0,2      | 76,6   | 31,5    | 0,2     | 81,5     | 31,6   | 31,7    | 0       | 87,4     |
| 11   | 31,4    | 29,0    | 0,3      | 70,7   | 32,1    | 0,3     | 75,3     | 32,5   | 32,6    | 0       | 79,4     |
| 12   | 32,5    | 29,1    | 0,3      | 64,0   | 32,8    | 0,1     | 74,7     | 32,8   | 32,9    | 0       | 83,1     |
| 13   | 33,0    | 29,5    | 0,3      | 61,6   | 32,9    | 0,1     | 76,8     | 33,7   | 33,9    | 0       | 77,6     |
| 14   | 32,9    | 29,4    | 0,3      | 67,4   | 32,7    | 0,3     | 80,0     | 35,0   | 35,2    | 0       | 72,8     |
| 15   | 31,4    | 29,0    | 0,2      | 71,8   | 32,5    | 0,1     | 79,2     | 34,3   | 34,3    | 0       | 76,8     |
| 16   | 29,8    | 28,1    | 0,1      | 80,0   | 32,9    | 0,2     | 73,7     | 33,2   | 33,3    | 0       | 81,6     |
| 17   | 29,0    | 28,0    | 0,1      | 82,4   | 32,8    | 0,2     | 79,0     | 32,7   | 32,7    | 0       | 84,0     |
| 18   | 29,1    | 28,2    | 0,1      | 82,5   | 32,1    | 0,1     | 80,0     | 31,9   | 31,9    | 0       | 85,9     |

Average 30,3 27,0 0,2 75,3 31,7 29,7 0,4 81,1 32,1 32,2 0,0 84,4

Note: RH = relative humidity; Ta = air temperature V = velocity; Tr = radiation temperature.

The three measurement comparison results OH, ARH, and AMH experienced an increase in temperature during the day and began to experience a decrease in temperature in the afternoon, the air temperature in the morning started from 26°C and began to increase in temperature during the day with a temperature of The highest air temperature occurred at AMH at 14:00 WIB with an air temperature of 35°C. At OH the air temperature decreased during the day at 15:00 WIB this was caused by cloudiness at the research location, and the other measurements were taken when the weather was sunny at the site.

Figure 3. Comparison (a) Ta (°C); (b) TR (°C); (c) RH (%); (d) VA (m/s) of OH, ARH, and AMH.
The measurement results of the three houses showed the highest $T_a$, $T_r$, and $R_h$ in AMH followed by ARH and OH. $V_a$ measurements were not very stable at ARH, at OH there was an increase in the afternoon from morning and decreased in the afternoon, while AMH did not occur in air movement in the room.

In figure 2 (a) temperature of the highest air temperature occurred at AMH at 14.00 WIB with an air temperature of 35°C. In figure 2 (b) temperature of the highest radiation occurred at AMH at 14:00 with a radiation temperature of 35.2°C. In figure 2 (c) OH experienced a periodic decrease in humidity where during the day the lowest humidity occurred at 13:00 WIB and began to experience an increase in humidity. In figure 2 (d) OH the wind speed experienced a periodic increase in wind speed from morning to noon, during the day the air speed was stable and decreased in the afternoon, ARH experienced unstable air speed throughout the day and at the peak of the wind speed at 15:00 WIB because it was cloudy at the research location and at AMH there was no wind speed throughout the day.

### 3.1. SNI analysis

Based on the SNI standard, the OH is categorized as warm and comfortable, while ARH and AMH are categorized as warm and comfortable, the threshold with measurement results $>27.1°C$ which means the thermal comfort of the two case studies declared uncomfortable.

| Hour | OH       | ARH               | AMH               |
|------|----------|-------------------|-------------------|
|      | TE(°C)   | Sensation         | TE(°C)            | Sensation         |
| 8    | 25.7     | Warm Comfortable. | 26.8              | Warm Comfortable. |
| 9    | 26.8     | Warm Comfortable. | 29.4              | Warm Comfortable, Threshold. |
| 10   | 27.0     | Warm Comfortable. | 30.2              | Warm Comfortable, Threshold. |
| 11   | 27.1     | Warm Comfortable. | 30.4              | Warm Comfortable, Threshold. |
| 12   | 26.8     | Warm Comfortable. | 31.0              | Warm Comfortable, Threshold. |
| 13   | 27.0     | Warm Comfortable. | 31.2              | Warm Comfortable, Threshold. |
| 14   | 27.9     | Warm Comfortable, Threshold. | 31.4 | Warm Comfortable, Threshold. |
| 15   | 27.4     | Warm Comfortable, Threshold. | 31.1 | Warm Comfortable, Threshold. |
| 16   | 27.3     | Warm Comfortable, Threshold. | 31.1 | Warm Comfortable, Threshold. |
| 17   | 27.2     | Warm Comfortable, Threshold. | 30.3 | Warm Comfortable, Threshold. |
| 18   | 27.4     | Warm Comfortable, Threshold. | 30.7 | Warm Comfortable, Threshold. |
| Average | 27.1 | Warm Comfortable. | 30.3 | Warm Comfortable, Threshold. |

### 3.2. PMV index analysis

The results of the PMV comparison show that the three Aceh House case studies are uncomfortable with OH Slightly warm, ARH warm, and AMH Hot sensations. This shows that although the three comparative studies are uncomfortable, there is a significant difference between ARH, ARH, and AMH. Where AMH is far from thermal comfort.
Table 3. Analysis PMV of OH, ARH, and AMH.

| Input   | OH   | ARH  | AMH  |
|---------|------|------|------|
| Ta (°C) | 30,3 | 31,7 | 32,1 |
| Tr (°C) | 27   | 31,9 | 32,5 |
| Va (m/s)| 0,2  | 0,4  | 0    |
| RH (%)  | 75,3 | 77,6 | 84,4 |
| Met     | 1    | 1    | 1    |
| Clo     | 0,5  | 0,6  | 0,8  |

| Output  | PMV  | PPD (%) | Sensation | SET (°C) | Dry-bulb (°C) | Cooling effect (°C) |
|---------|------|---------|-----------|----------|---------------|---------------------|
| Compliance | x    | x       | x         |          |               |                     |
| PMV     | 1,06 | 1,93    | 2,97      |          |               |                     |
| PPD (%) | 29   | 74      | 99        |          |               |                     |
| Sensation | Slightly Warm | Warm | Hot   |          |               |                     |
| SET (°C) | 29,2 | 32,8    | 37,5      |          |               |                     |
| Dry-bulb (°C) | 29,8 | 30      | 32,1      |          |               |                     |
| Cooling effect (°C) | 0,5  | 1,7     | 0         |          |               |                     |

Figure 4. PMV chart of OH, ARH, and AMH.

4. Conclusion
Based on the analysis of SNI standards, it can be concluded that the thermal comfort based on the OH standard has a comfortable warm sensation which means the building is categorized as thermally comfortable, while ARH and AMH have a comfortable warm sensation, a threshold which means the building is categorized as thermally uncomfortable with an average effective temperature of 6°C higher than OH.
Based on the PMV index, it can be concluded that the thermal comfort of the three comparative studies is stated to be uncomfortable with OH having a Slightly warm sensation, while ARH has a warm sensation and AMH has a hot sensation which means the three buildings thermally uncomfortable.

The results of the measurements of the 3 case studies can be seen that the room temperature AMH is much hotter than the other two comparative studies, this can be caused by changes/modifications in the Aceh House building, both modifications to the roof material from thatch leaves to metal as well as changes in the carvings on the walls. which functioned as natural ventilation in the building which resulted in the absence of access to wind/air velocity in the building and the use of ceilings so that there is no more “tulak angen” that makes air circulation hampered.

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