The assessment of thermal comfort of sustainable modifying Rumoh Aceh in hot humid climate

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Abstract. The climates of countries in the tropics tend to have high temperatures and humidity, and intense solar insulation. This condition gives the impact of discomfort for humans who are in the building. Implementing a passive cooling strategy can reduce energy use. Traditional architecture is one of the buildings that has been believed to apply natural cooling as a passive cooling design strategy. Based on several previous studies on the application of passive designs to obtain thermal comfort in the room, this study was conducted to assess the thermal comfort of Modifying Rumoh Aceh, which has not been widely studied. This study uses a direct measurement method in the field using an anemometer to measure temperature and airflow velocity. An Infrared-Thermometer Gun is also used to measure the surface temperature of materials (walls, roofs, and floors). Using the Climate Consultant Software to obtain annual climate condition data, Andrew Marsh 3-D Sunpath was also used to assess the orientation of buildings. Measurements were carried out for 3 days on 15 samples of Modifying Rumoh Aceh in Gampong Jawa, Kutaraja sub-district, Banda Aceh. The results obtained indicate an increase in room temperature by 7ºC from the standard comfort temperature based on SNI. The human ability to adapt to the environment can be seen in the perception of the Gampong Jawa community in accepting changes in the thermal environment by 47% with a sense of satisfaction. However, further research is needed to obtain a value for the level of satisfaction of the thermal environment in the tropics area.

1. Introduction
The climates of countries in the tropics tend to have high temperatures and humidity, and intense solar insulation. This condition gives the impact of discomfort for humans who are in the building. Therefore a cooling design is needed for buildings. One of the cooling strategies in buildings is to use passive cooling that can reduce energy use. The implementation of this strategy is mostly carried out by traditional buildings, which are believed to be very responsive to the physical environment to provide thermal comfort for the residents.

The architectural form of traditional houses emerged naturally based on a long process and was built from generation to generation. The implementation process carried out by trial and error has made traditional architecture very responsive to the climate and environment. Various studies that state that traditional buildings are believed to be very responsive to the physical environment to provide thermal comfort for residents have been widely carried out, discussing passive designs used in vernacular buildings to achieve thermal comfort, the use of ventilation to optimize thermal comfort.
The use of ventilation to reset the value of humidity and temperature in the building as a passive cooling system. Improve ventilation performance as an air change feature in the room to achieve thermal comfort [1]-[2]-[3]-[4]-[5]-[6]-[7].

Rumoh Aceh is one form of traditional house architecture that developed in Acehnese society. Until now, we can still find people who defend Rumoh Aceh as their residence. Although many are no longer occupying their homes for various reasons, social and ease of activity. However, Rumoh Aceh is still maintained as a cultural heritage that must be preserved from generation to generation. Rumoh Aceh has various advantages, especially resistance to earthquakes and very comfortable to thermal [8]-[9].

The design concept of Rumoh Aceh is oriented towards north-south and stretching towards east-west. The concept of building orientation is based on the condition of the west wind that blows to avoid high wind pressure on the building. Therefore the side of the building facing East-West is shorter than the North-South side. The application of this orientation concept also supports air circulation paths with openings on the north-south side. While on the East-West side of the building, it has 1 opening on each side. The opening model used is the casement model. Besides that, the walls on the East-West side are covered with translucent carvings. All elements on all sides of the building function as air circulation paths. The air circulation path at Rumoh Aceh is one of the basic principles of passive design. Based on this, Rumoh Aceh can be indicated as one of the buildings that are comfortable with thermal. This statement is reinforced by previous research that examines the potential for thermal comfort in Aceh houses [4].

Based on the design concept that is very responsive to the environment, there is a development of the shape of Rumoh Aceh. This was done by one of the Non-Government Organizations (NGOs) during the emergency response period in Aceh due to the 2004 Tsunami earthquake. Muslim Aid, an NGO, adopted the form of Traditional Aceh Architecture as a Modifying Rumoh Aceh located in the Gp area. Java, Banda Aceh City. Modifying Rumoh Aceh is a stage, using wood materials for structural elements, cold and floors, while the roof uses zinc. The concept of orientation towards Rumoh Aceh cannot be applied to Modifying Rumoh Aceh, which follows road orientation in the Gampong Jawa.

Associated with various studies that assume that traditional houses are comfortable and withstand various existing climatic conditions. Traditional architecture is believed to have such a concept that it can provide thermal comfort. However, tropical climate conditions that tend to get hotter, changes in the surrounding environment, building systems, design materials, and building orientation will change the concept of comfort in traditional architecture. Based on this, it is fascinating to assess the thermal comfort of modifying Rumoh Aceh, which only adopts the shape of traditional Acehnese houses.

2. Materials and methods

2.1. Modifying Rumoh Aceh samples
A total of 15 units of Rumoh Aceh Modifying located in Gampong Jawa, Kutaraja District, were used as research samples. This Modifying Rumoh Aceh is a house assisted by an NGO, Muslim Aid, during the post-earthquake-Tsunami 2004. Muslim Aid tries to modify the principle of the Aceh Traditional House on stilts into the design of a stilt house with a wooden structure made of coconut trees. The wall material uses boards or plywood, and the roof material uses zinc. The construction system used in modifying Rumoh Aceh is a loading and unloading system. The traditional Aceh house construction system chose the stage because the Gampong Jawa area, which is directly adjacent to the Malacca Strait in the north often occurs tidal phenomena.

The overall form of Modifying Rumoh Aceh is as shown in Figure 1 obtained from the field study results. The orientation direction does not follow the concept of the Aceh Traditional House, which faces North-South. The area was reorganized, and the village facilities were repaired due to the aftermath of the 2004 earthquake-Tsunami. The road is an important facility as an evacuation route so
that the orientation of modifying rumoh Aceh follows the direction of the road. Based on the observations, this paper describes some characteristics of each modifying Rumoh Aceh in Gampong Jawa.

The characteristic found in Modifying Rumoh Aceh is the terrace on the front view. In the modifying plan of Rumoh Aceh shown in figure 1, there is a terrace, living room, room (1 unit), and a kitchen. Here are some modifying Rumoh Aceh in Gampong Jawa with different orientation directions and opening models. The house walls are painted in colours determined by each owner to add to the aesthetics of the building. The open space under the house is used as a public space area.

Over time, there have been changes in the basic construction of the building. Changes occur due to the addition of family members so that the need for space increases. Based on observations that have been made in the field, additional space is placed at the bottom of the house (under) and the terrace/veranda, which is closed to be used as a room.

The Modifying Rumoh Aceh found in the Gampong Jawa area is scattered throughout the existing Dusun. There are 5 hamlet areas called Jurong, Jurong Nyak Raden (Dusun 1), Jurong Hamzah Yunus (Dusun 2), Jurong Tuan Dibanda (Dusun 3), Jurong Sad Usman (Dusun 4), and Jurong Tengku Muda (Dusun 5). The sample coding for modifying Rumoh Aceh is shown in the table below based on the shape of the house (Rumoh Panggung, RP), the division of territory in the Gampong (Dusun, DS), and the order of the houses being reviewed. For each sample modifying Rumoh Aceh using the code RPDS1-01 and so forth. The location of this research is in the Gampong Jawa area, Kutaraja sub-district, Banda Aceh. For each location point of the 15 samples modifying Rumoh Aceh, it can be seen from the mapping carried out in the field and tracing through google earth, see Figure 3. The pandemic condition made it a little difficult for researchers to get permission to choose research samples so that the number of samples for each hamlet was unbalanced. Each characteristic of the sample modifying Rumoh Aceh can be seen in Table 1.

**Table 1.** The characteristic of the modifying Rumoh Aceh samples.

| No. | House Code | Orientation | Number of Opening                     | Material    | Roof                     |
|-----|------------|-------------|---------------------------------------|-------------|--------------------------|
| 1.  | RPDS1-01   | West        | 1 north window; 1 west window;         | Wood Board | Metal Roof & bubble foil |
| 2.  | RPDS1-02   | North       | 2 west window; 2 east window;          | Wood Board | Metal Roof & bubble foil |
| 3.  | RPDS1-03   | South       | 2 west window; 2 east window;          | Board Plywood | Metal Roof & bubble foil |
| 4.  | RPDS1-04   | West        | 3 south window; 1 west window;         | Board Plywood | Metal Roof & bubble foil |
| 5.  | RPDS1-06   | South       | 3 north window; 3 west window;         | Wood Board | Metal Roof & bubble foil |
| 6.  | RPDS1-07   | East        | 3 east window; 2 west window.          | Wood Board | Metal Roof & bubble foil |
| 7.  | RPDS2-01   | East        | 1 east window; 1 North window.         | Wood Board | Metal Roof & bubble foil |
| 8.  | RPDS2-02   | South       | 2 north window; 2 south window         | Board Plywood | Metal Roof & bubble foil |
| 9.  | RPDS3-01   | Southwest   | 1 south window; 1 east window; 2 west window | Wood Board | Metal Roof                |
| 10. | RPDS3-02   | North       | 1 southwest window; 3 southeast window | Board Plywood | Metal Roof & bubble foil |
| No. | House Code | Orientation | Number of Opening | Material | Floor | Wall | Roof |
|-----|------------|-------------|-------------------|----------|-------|------|------|
| 11  | RPDS5-01   | East        | 1 north window; 2 west window | Board Plywood | Metal Roof & bubble foil |
| 12  | RPDS5-02   | North       | 1 north window; 1 south window | Wood Board | Metal Roof & bubble foil |
| 13  | RPDS5-03   | Southeast   | 1 north window; 2 east window; 2 west window | Board Plywood | Metal Roof |
| 14  | RPDS5-04   | Southeast   | 3 southeast window; 2 southwest window | Board Plywood | Metal Roof |
| 15  | RPDS5-05   | Southeast   | 1 southeast window; 3 southwest window | Board Plywood | Metal Roof |

**Figure 1.** The plan of modifying Rumoh Aceh.

**Figure 2.** Sample of modifying Rumoh Aceh.

2.2. **Thermal comfort parameters**
Thermal comfort can be defined as the level of satisfaction that a person feels. In this case, the assessment of perceived thermal satisfaction is subjective and influenced by various factors (climate, activity, clothing, and the surrounding environment) by not feeling too hot or not feeling too cold, namely, neutral or comfortable [10]. In hot, humid areas, the thermal comfort factor is influenced by
humidity, temperature, and the intensity of solar radiation. Other factors that affect thermal comfort in traditional buildings are materials, ventilation and openings, floor plans, orientation to sunlight, roof and floor designs, and building environmental arrangements. This factor is related to local wisdom factors that impact the building system described above [11]. Based on the research results above, it is concluded that the application of the concept of local wisdom in traditional architecture still needs further research. Other things are also parameters of thermal comfort, such as surface area, material conductivity. It is necessary to reduce the surface area that can absorb heat energy through convection and radiation [12]. In order to achieve thermal comfort in hot and humid regions, passive cooling is required through ventilation or openings and shading to block solar radiation. A simple thermal performance approach can be achieved through cross ventilation with an orientation facing the existing wind [3]. All of the things mentioned above are thermal performances in traditional buildings that can respond well to climatic conditions.

Based on this, the parameters used to assess thermal comfort in modifying Rumoh Aceh are indoor temperature, material surface temperature, airflow, and humidity. The orientation direction and the location of the opening or ventilation will also be reviewed to improve previous research. The standard of comfort that is the reference based on the Indonesian National Standard (SNI) with the code 14-1993-03: Cool - Comfortable (20.5°C – 22.8 °C); Comfortable - Optimal (22.8 °C – 25.8°C); Warm – Cozy (25.8 °C – 27.2°C).

However, as a basic guideline, thermal comfort for the humid tropics can be achieved with limits of 24°C<T<26 °C, 40%<RH<60%, 0.6m/s<V<1.5 m/s, light and layered clothing, and quiet relaxing activities [13]. The effective temperature is a variable to assess the level of thermal comfort of a room.

2.3. Tool method use
This research method is quantitative. Direct measurements in the field will be carried out using a Digital Anemometer (to measure indoor temperature and wind flow speed) and a Thermometer Gun/Thermorecorder (to measure the surface temperature of the wall, floor, and roof materials).

Measurements in the field were carried out for three days on a total of 15 samples modifying Rumoh Aceh in 3-time intervals (morning, 08.30; noon, 12.30; and afternoon, 4.30). These measurements were carried out on September 16, 21, and 24, 2000, considering the weather and clear air during the rainy season. The Anemometer is placed at the front of the Modifying Rumoh Aceh as high as 1.5 m from the stage floor. This study also uses climate consultant software to obtain the weather conditions of Banda Aceh for one year. The data was obtained in temperature, wind direction, and humidity levels in a year. The Andrewmarsh 3-D sun path software was used to see the shading pattern and the length of time solar radiation on the material's surface. The simulation will be carried out on September 21, where the sun will be right on the equator.

3. Results and discussion

3.1. Thermal comfort assessment
Thermal comfort in Modifying Rumoh Aceh in Gampong Jawa, Banda Aceh city, is reviewed based on characteristics such as the orientation of the building to the sun and wind, the use of appropriate building materials, and the use of architectural and landscape elements.
Figure 3. Measurement Results of indoor air temperature graph (a) and wind speed chart.

Based on the results of air temperature measurements in the room, the hottest occurred during the day. There were fluctuations at several measurement times, but most of them showed the same data; namely, the air temperature during the day increased dramatically and then decreased again at 16.30 WIB. In contrast, the results of wind speed measurements show fluctuations in the magnitude of the measured wind speed from the beginning to the end of the measure.

Table 2. Results of measuring temperature and wind speed.

| No | House Code | Orientation | Result of Measuring | Thermal comfort standard |
|----|------------|-------------|---------------------|--------------------------|
|    |            |             | Temperature (°C)    | Wind Speed (m/det)       |
| 1  | RPDS1-01   | West        | 31,23               | 0,4                      |
| 2  | RPDS1-02   | North       | 31,83               | 0,37                     |
| 3  | RPDS1-03   | South       | 31,13               | 0,47                     |
| 4  | RPDS1-04   | West        | 30,43               | 0,1                      |
| 5  | RPDS1-06   | South       | 32,83               | 0,67                     |
| 6  | RPDS1-07   | East        | 32,87               | 0,8                      |
| 7  | RPDS2-01   | East        | 31,13               | 0,07                     |
| 8  | RPDS2-02   | South       | 31,37               | 0,13                     |
| 9  | RPDS3-01   | Southwest   | 30,57               | 0,2                      |
| No | House Code | Orientation | Result of Measuring | Thermal comfort standard |
|----|------------|-------------|---------------------|--------------------------|
|    |            |             | Temperature (°C)     | Wind Speed (m/s)         |
| 10 | RPDS3-02   | North       | 30.87               | 0.47                     |
| 11 | RPDS5-01   | East        | 31.47               | 0.1                      |
| 12 | RPDS5-02   | North       | 31.57               | 0.23                     |
| 13 | RPDS5-03   | Southeast   | 31.97               | 0.23                     |
| 14 | RPDS5-04   | Southeast   | 32.47               | 0.13                     |
| 15 | RPDS5-05   | Southeast   | 33.23               | 0.17                     |

The house coded RPDS5-05 in Table 2 shows the highest temperature at 33.23°C while wind speed of 0.17 m/s due to the measurement. Based on the standard of thermal comfort, it shows that it does not meet the standard. The orientation direction is towards the southeast, while the wind blows north, west, and east. The placement of the openings is not parallel with the direction of the wind, so the conditions in the room feel uncomfortable. Meanwhile, RPDS1-04, RPDS3-01 and RPDS3-02 showed the lowest room temperature measurement results for each sample, at 30.43 °C; 30.57°C and 30.87 °C with wind speed of 0.1 m/s for each sample; 0.2 m/s and 0.47 m/s. The orientation of the building faces west, southwest, and north. The measurement results for the three modifying Rumoh Aceh RPDS1-04 still do not meet the comfort standard. RPDS3-01 and RPDS3-02 present good thermal performance of indoor airflow and orientation direction that leads to the wind and windows that use the principle of cross ventilation. These facts explain the passive design concept in traditional buildings could be applied to modern buildings by paying attention to openings and cross ventilation orientation and placement.

As explained above, the temperature on the surface of the material also contributes to increasing the indoor temperature. Figure 5 shows the results of the average surface temperature measurement on walls, floors, and roofs.

![Figure 5. Material surface temperature measurement graph wall (a); floor (b) and roof (c).](image-url)
the surface area that receives the most intense sunlight. Countries with hot and humid climate conditions will receive solar heat throughout the year, with an average length of irradiation of 11.59 hours per day. This condition will cause the wall and roof areas to receive and store heat according to the conductivity of the material used. Heat will be released into the building at different times. Shading is a strategy that can be applied to protect the surface area exposed to solar radiation. Table 3 shows the results of the simulation of the performance of the shading pattern for the total sample modifying rumoh Aceh for three measurement times. The wall that is oriented towards North-South will receive a broader shading pattern than the wall with an East-West orientation. The direction of the Southeast-Northwest orientation will receive heat on both sides, namely the east and north in the morning, and the west and north sides will receive heat in the afternoon. Likewise, by modifying Rumoh Aceh with a southwest orientation direction, the east and south sides will receive heat in the morning, and the west sides will receive heat on the west and south sides. Based on this, the shading can be designed as needed so that the shading performance to reduce the incoming heat does not block the light needed in the room. The average surface temperature on RPDS5-05 shows the highest increase in surface temperature for wall and roof surface temperatures, 38.63°C and 38.77°C, see Table 4. The parameters used to assess thermal comfort, orientation direction, surface area, and climatic factors (temperature, humidity, and wind speed) will significantly affect indoor thermal comfort.

Table 3. Shadow performance simulation results.

| No. | House Code | Orientation | Date of Measurement SEPTEMBER 21st, 2020 |
|-----|------------|-------------|----------------------------------------|
| 1.  | RPDS 01-1  | West        | 08.30 AM                               |
| 2.  | RPDS 01-2  | North       | 00.30 PM                               |
| 3.  | RPDS 01-3  | South       | 4.30 PM                                |
| 5.  | RPDS 01-7  | East        |                                        |
| 6.  | RPDS 03-1  | Southwest   |                                        |
Table 4. Average surface temperature measurement results.

| No. | House Code | Average Material Surface Temperature (°C) | Floor (Board) | Wall (Plywood) | Roof (Metal) |
|-----|------------|-------------------------------------------|---------------|----------------|--------------|
| 1.  | RPDS1-01   |                                           | 34,03         | 34,7           | 37,97        |
| 2.  | RPDS1-02   |                                           | 33,73         | 34,6           | 38,8         |
| 3.  | RPDS1-03   |                                           | 33,37         | 35,47          | 37,57        |
| 4.  | RPDS1-04   |                                           | 32,83         | 35,43          | 37,57        |
| 5.  | RPDS1-06   |                                           | 33,03         | 34,2           | 37,53        |
| 6.  | RPDS1-07   |                                           | 35,43         | 35,47          | 45,17        |
| 7.  | RPDS2-01   |                                           | 32,97         | 34,37          | 35,3         |
| 8.  | RPDS2-02   |                                           | 34,9          | 36,63          | 37,77        |
| 9.  | RPDS3-01   |                                           | 32,87         | 36,27          | 37,37        |
| 10. | RPDS3-02   |                                           | 33,43         | 37,27          | 37,13        |
| 11. | RPDS5-01   |                                           | 33,9          | 37,03          | 38,33        |
| 12. | RPDS5-02   |                                           | 34,23         | 35,47          | 37,2         |
| 13. | RPDS5-03   |                                           | 33,63         | 37,93          | 36,93        |
| 14. | RPDS5-04   |                                           | 33,7          | 37,93          | 36,63        |
| 15. | RPDS5-05   |                                           | 35,1          | 38,63          | 38,77        |

3.2. Human respond of thermal comfort

Human satisfaction with the thermal environment conditions and being able to adapt to changing thermal conditions is a fundamental theory of how humans respond to their environment [11]. Related to this, the role of humans becomes vital in assessing thermal comfort in buildings. The perception of human awareness of the thermal environment is the human ability to remember the conditions of the thermal environment and, in the end, can decide on the actions to be taken to achieve thermal satisfaction. To assess the perception of satisfaction of Gampong Jawa residents in considering their thermal conditions. Based on the results of filling out the questionnaire given to the residents of Modifying Rumoh Aceh, 47% answered Neutral, which means they feel comfortable with the Thermal environment. Table 2, which shows the results of temperature and wind speed measurements, shows conditions that do not meet the criteria for thermal comfort standards. This is very contrary to the perception of respondents. The average occupant has lived there for quite a long time, an average of more than five years. Of course, this shows the ability of the occupants to remember the conditions of

Figure 6. Respondent satisfaction level perception data.
the thermal environment to achieve thermal satisfaction

4. Conclusions
Based on the thermal comfort assessment results at Modifying Rumoh Aceh, a new phenomenon was found regarding the thermal comfort standards of Acehnese in general and Gampong Jawa in particular, namely at $30.5^\circ C < T < 33^\circ C$, RH > 70%, $V > 0.47 m/s$. An increase in room temperature with a standard comfort temperature of $7^\circ C$. The increase in the value of room temperature looks very significant. However, changes in the value of thermal comfort can still respond well. Several factors found in the field are the orientation and placement of openings that are not in the direction of the wind. The use of modern materials such as tin roofs also increases heat by releasing heat at certain times. Providing openings and cross ventilation can be used as a passive cooling strategy. Providing a shading device is also the right step to avoid exposure to solar radiation on the wall's surface. However, further research is required to obtain the value satisfaction's level of the thermal environment in the tropics area.

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