Thermal evaluation for exposed stone house with quantitative and qualitative approach in mountainous area, Wonosobo, Indonesia

Hermawan Hermawan 1*, Eddy Prianto 2
1* Architecture Department, Faculty of Engineering and Computer Science, Qur’anic Science University, Wonosobo, Indonesia
2 Department of Architecture, Faculty of Engineering, Univeritas Diponegoro, Semarang, Indonesia

E-mails: hermawanarsit@gmail.com

Abstract. A building can be considered as having a good thermal performance if it can make the occupant comfortable. Thermal comfort can be seen from the occupant’s respond toward the architectural elements and the environment, such as lighting, the room crowding, air temperature, humidity, oxygen level, and occupant’s behaviours. The objective of this research is to analyse the thermal performance of four different orientation houses in mountainous area. The research was conducted on the four expose stone houses with four different orientations in the slope of Sindoro Mountain which has relative cool temperature, about 26°C. The measurement of the elements above was done quantitatively and qualitatively for 24 hours. The results are as follows. First, the most comfortable house is west-orientation house. Second, based on the quantitative and qualitative observation, there is no significant difference (±5 %). Third, the occupant’s behaviours (caring and genen) also become factors influencing occupant’s comfort.

Keywords: orientation, thermal performance, occupant’s behaviours, qualitative, quantitative

1. Introduction

In architecture, research in thermal and performance comfort has a close relation. Thermal comfort is the expression of occupants’ satisfaction related to the building thermal. Thermal performance is the ability of building in managing thermal environment. Both of them should be integrated to make a thermal condition so the occupants can do activities in their house well. Thermal comfort related to the occupants’ feeling is known as active thermal. Basically, researches in active thermal use the qualitative approach, and building thermal (passive thermal) use the quantitative one. However, people can also use quantitative or mixed approach to know active thermal, and use qualitative or mixed one to know passive thermal.

Most of thermal comfort measurements are based on PMV (Predicted Mean Vote) and PPD (Predicted Precented Dissatisfied) theory. Although the theory of adaptive thermal comfort has been developed, it still cannot be separated from PMV and PPD theory. Adaptive thermal comfort is based on three main things: Thermal Comfort Vote (CV), Preference vote (PV), and Thermal Acceptance and Neutrality. Adaptive thermal comfort can also predict thermal comfort through statistic tests [1]. Occupants’ adaptation is a factor influencing the building’s thermal comfort. Adaptation is an important factor in adaptive thermal comfort. Adaptive thermal comfort also refers to the people’s perception toward hope and choice related to comfort. Adaptive thermal comfort orientate to
occupants’ comfort, while thermal comfort related to the building is known as passive thermal comfort.

Passive thermal comfort can be known by analysing the building envelope. It is considered as an important aspect in creating passive thermal comfort. Design of building envelope must be adaptive and interactive to be able to respond climate surrounding the building. Design of building envelope has relation to aspects of the building’s facade in controlling solar radiation. One method to improve the performance of building envelope is simulation. One of the simulations is CAD (Computer Aided Design). It can also save energy [2].

There are a lot of building’s cover researches related to energy saving. Researchers in Malaysia conclude that energy waste of buildings reaches 19% of total energy waste. The temperature in Malaysia’s buildings is 25–30 [3]. In addition to temperature, there are some climate factors related to building envelope: temperature, humidity, wind speed, rain, and solar radiation [4]. Design of building envelope which is influenced by climate variables will influence the energy consumption [5]. Materials of building envelope also influence the thermal comfort. Materials of building envelope also influence the thermal comfort. The previous researches have shown that building envelope made of stone and exposed stone have different result related to thermal comfort in the coastal areas [6]. In addition, houses with wooden wall have different thermal comfort if the location have different climate [7]. The part of building has a big role for achieving building thermal performance including balcony and windows [8]. Optimized design of windows can make a good thermal performance [9].

Heat is the greatest factor influencing the building envelope. Heat is closely related to solar radiation, and orientation of building has big impact in creating thermal comfort for the occupants. Thermal comfort of the occupants and buildings should be researched at the same time. Aspects of occupants and building can be observed quantitatively and qualitatively. Qualitative approach should be focused by the researchers so when they conduct research related to thermal comfort, they can mix both quantitative and qualitative method.

In architecture, it needs to see qualitative and quantitative aspect of the elements. Elements which can create thermal comfort are lighting, air temperature, air humidity, room level of oxygen, room tightness, and occupant’s behaviours. Researches which see thermal comfort from qualitative and quantitative aspects was done in Peru. It analysed the building elements qualitatively and analysed the thermal quantitatively. It was done in a city which has height 3200 meters. The result shows that the occupant feels uncomfortable when the elements and design of buildings did not meet the requirement of good buildings [11].

Indonesia is located in a tropical area with warm and humid climate. It also has low and high land. The high land has cold temperature but there is still sun light. The people sometimes feel cold and they create a traditional heater. The heater is in form of stove using wood fuel which produces smoke. For long term it makes the house condition unhealthy because the occupants feel breathless. The characteristics of housing in high land are that the walls are made of wood, stone, brick, and bamboo. However, people begin to leave stone-walled house and replace by modern one although sometimes it is not appropriate. Some researches showed that traditional houses could adapt to the local climate [12]. Therefore, it needs to know the characteristics of stone-wall traditional house in facing climate so it can find the strategies to get thermal comfort. Research objectives are to analyse thermal performance of exposed stone-walled houses in mountainous area, to analyse thermal receipt of the occupant of exposed stone-walled houses in mountainous area and to analyse characteristics of exposed stone-walled house which meet thermal comfort.

2. Methodology

The research was done in houses with river stone wall and four different orientations. They are located Gunung Alang Village in Sindoro slope and Tambi Village, Kejajar District, Wonosobo. The research used four climate variables and two personal variables. The climate variables were air temperature, solar radiation temperature average, wind speed and humidity. The personal variables were clothes and occupant’s activities. Occupant’s responds were ranked using ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineer) which covers seven indicators: very hot, hot, warm, comfortable, cool, cold, and very cold. The result was displayed in form of graphs and pictures. Analysis was conducted by calculating average, maximum and minimum data. The difference of climate variables between outside and inside room would be known. From the
occupants side, their respond toward micro environment condition was analyzed. Graph analysis was used to the quantitative approach. Habit and occupant’s response used qualitative approach. Analysis related to buildings condition and elements was linked to graph and interview results. The research findings were building strategy to create thermal comfort in tropical high lands.

![Indonesia and Wonosobo Map](source: Google Maps); b) Location of sample research; c) Type of research sample

One research which used quantitative and qualitative approach was thermal evaluation in historical building. This research used decision support system (DSS). DSS can be used as a solution to determine the criteria of buildings renovation. The elements of criteria were determined by using Graphical Analysis for Interactive Aid (GAIA) and DEPHI. The result is the suggestion to make a policy to reduce energy consumption on masonry buildings. Some data used here were building information and climate zone, building facade plan, organization, building volume, construction method, building aperture, and energy consumption. The research data were collected by measurement (quantitative) and interview (qualitative). Measurement was done to know the levels of energy consumption and investment cost, and interview was done to know the risk of the loss of historical aesthetic features and spoilage fabric [13].

3. Results and Discussions
Descriptive discussions are combined with graph and three-dimensional pictures. People’s job and habits, as well as culture in building a house are also analyzed here. The measurements of house elements related to thermal performance discussed are lighting, air movement, room crowding, and house environment. The discussion on climate variables is linked to energy saving, so the strategies of a house to save energy would be known.

The main job of people in Gunung Alang is tobacco farmers. It influences the design of their house rooms. Their house consists of wide living room for keeping tobacco crops, bed rooms, bath room, kitchen, and family room for watching TV. The roof is covered by zinc. The walls are made of stone or wood, these materials are easy to get in the surroundings. In constructing their house, people still keep the ancestor culture tightly. For example, it is forbidden to build houses facing or opposing mountain since it can cause negative atmosphere, and it is bad for the occupants. Therefore most of houses face to north or south although there are also people who don’t believe.

The process of house building is started by collecting stones or woods. People collect stones from the river under the village by breaking the giant stones into small sizes. Then they put the stones on the main road and carry them to village by car. When materials to build foundation and wall are adequate, the people plant banana trees on the location in which the houses will be built. After the trees are forty days old, people start to build foundation and wall. In building house, people employ masons and get aid from their neighbors. In the process of setting nok (munggah molo), people hold a ceremony to show their thanks to God and hope to get salvation and prosperity. They put rice, corn, and red white flag as symbols of wealth and prosperity which will cover the house. Some people also put Raja banana as the symbols that the house will be strong and doesn’t need many renovations. The flag symbolizes independence and red fabric also functions to repel pests that can attack wood on the roof structure.
3.1. Natural Lighting

The observed house have different orientations: north, south, west, and east. It creates a difference in getting sun light. The house of Subardi’s, orienting north, gets sun light from the front windows and western side of the house. There is no room which can get sun light continuously. The living room and family room more often get sun light from western windows.

The house of Dipon’s has east orientation. Sun light comes through the front side and hole in the bath room which has function as the entrance of rain. The other sides are challenged by neighbour’s houses. Meanwhile in the Supardi’s house, sun light can enter freely since it faces north and the windows are 180 x 80 cm and main door is 220 x 200. In the west side, there is 120 x 60 cm² window. The sun light can enter the living room but the light is not dazzling. According to the occupant, the lighting in Mubasir’s house is good enough to do activities. It has two windows; 180 x 120 cm² and 60 x 40 cm² and one main door, 200 x 220 cm².

Of the four houses, most of natural lighting just can illuminate the main room (living/family rooms). Other rooms such as kitchen, bath room and bed rooms don’t get adequate natural lighting and need artificial lighting. One house has roof because the wall is so close to the neighbor’s houses.

![Figure 2 Natural lighting analysis, a) Darto’s house, b) Dipon’s house](image-url)
3.2. Natural Wind Movement

Wind movement determines the comfort of inside rooms. In the tropical areas the wind blows fast enough. Wind from valley and mountain blow from east to west and enter Darto’s house through side windows. In this house, the wind enters through living room, then family room, and kitchen at last. Bed rooms don’t get wind movement directly. West wooden window, 70 x 120 cm², opens at 06.00–17.00. The wall of Darto’s house is higher than the neighbors so that the wind can enter easily. Meanwhile wind movement at Dipon’s house is challenged by neighbor’s house. Wind moves to living room and family room through front ventilation and windows. Bed rooms don’t have ventilation so that they don’t get wind movement.

The absence of the ceiling in the Supardi’s house makes the wind enter through the roof but cannot come inside the rooms. The wind also enters through side windows. Basir’s house whose west orientation makes the wind enters the house fast but stopped at living room and storage. Ventilation in the kitchen, 60 x 40 cm², is not closed tightly, closed by wire net only and makes the wind enter the house fastly. In the Supardi’s and Mubasir’s house, at 11.00 am and 3.00 pm, the wind blow fast, 7.3 m/s, and causes rumble when the wind hits pine trees located behind the house.
3.3. Room Crowding

Air volume in a room is influenced by the crowd of the room. The crowd can be known from the content of the house and the volume of the room. In Darto’s house, the most crowded room is at the room number 2. It is only 2.5 x 2 m but it contains 1.8 x 2 m bed, cupboard, and a television. On the contrary, the less crowded room is living room containing chairs, tables, big cupboard, small cupboard, TV set, and sound system. The width is 24 m.

In Supardi’s house, the crowded situation happens at the living room, 6.5 x 9.5 m², containing long chair, tables, and sound system. The furniture is made of wood and it should make the room warm. However, there is no sun light entering the room and makes it cold.

In the family room of Dipon’s house, there are some furnitures, such as chairs, cupboard, aquarium, television and table. Here the family members usually meet and there is enough sun light. It
makes the room warm and comfortable for the occupants. The most crowded room is family room, 3 x 2 m². In this room, there is big wooden cupboard for television. In the Mubasir’s house, the most crowded room is bedroom. It contains big bed, big wooden cupboard, television table and the television. Actually these furniture can make the room hot, however the absence of window which can function as entrance for the wind make the room cold.

![Figure 6 Room crowding, a)Darto’s house, b)Dipon’s house](image)

![Figure 7 Room crowding, a)Supardi’s house, b)Mubasir’s house](image)

3.4. Patterns of Occupants’ behaviours

Natural lighting, air movement, and room tightness have a close relationship to the patterns of occupants’ behaviors. The three factors influence the thermal comfort. A research in China showed that patterns of occupants’ behaviors have close relation to the reach of thermal comfort. Courtyards and shade spaces influence the thermal comfort of the occupants [14]. In addition, individual and social environment also influence occupant’s perception to thermal comfort. Individual environments are gender, age group, exposure to sun, level of activity and clothing insulation, skin color, while social environments cover position, companionship and cultural background [15]. Both factors are relevant with the research which has been done. Pattern of occupant behaviors in this research is to do natural warming by making fire and sitting near it (genen) at night and sitting under the sun light in the morning (karing). Both activities influence the reach of thermal comfort. In addition, people have sustainable concept in building house. They take stone from the river little by little. It protects the nature from damage.

3.5. Oxygen Level, Temperature and Humidity

By measuring the oxygen level, it can be known that the family room which contains the lowest level of oxygen is Supardi’s. The level is 5.1°C at 12.00 am. It happens because of the location and the width of the room, 3 x 2 m², and the less effectiveness in using windows in west side. The windows are blocked by the cupboard from inside and there are many fire woods outside the windows so the air is difficult to enter.
Each kitchen observed has both traditional stove, which uses fire wood, and gas stove. Both stoves are used for cooking and heating body, geni. The highest level of the temperature is in Mubasir’s house. In the afternoon the temperature reaches 28.6 °C and the humidity is 48%. Although each kitchen has similarity in function and the temperature, Mubasir’s is warmer than others because there are windows in the north side and transparent zinc on the roof so that the sun light is easy to enter the kitchen. The roof is also lower than others so that the heat is easy to spread and makes the temperature increase.

Figure 8 Result of Oxygen measurement in living room

Figure 9 a)Result of air temperature (Ta) in kitchen, b)Result of relative humidity (RH) in kitchen
The four houses which become the objects of research have same characteristics; there is no ventilation and the ceiling is made of board, bamboo or thick fabric which functions to slow the warm air up. The difference is that Supardi’s has glass window. The lowest level of temperature is in Dipon’s house, 15°C and 2°C. It may be influenced by the bedrooms location which is in the west side and directly linked with the neighbor’s wall so that the air in the room becomes humid. In addition, the solar radiation is so little because it only gets sun light from 09.00 am–02.00 pm and after that it will be blocked by neighbor’s roof.

![Graph of temperature and humidity over time](image)

Figure 10 Result of bed room measurement’s air temperature (Ta), b)Result of relative humidity (RH) in the bedroom

Temperature is one factor in thermal comfort both in hot and cold areas. Research in China showed that temperature became the parameter to see thermal comfort in cold areas. It shows that average temperature in living room is 13.5°C and in the bed rooms is 12.7°C. These conditions make the occupant feel uncomfortable and need artificial heating [16]. In addition, air humidity and CO₂ level influence the occupants’ thermal comfort. Research in Singapore used variables of temperature, air humidity, humidity and CO₂ level to know thermal comfort in the house, restaurant, and work places. The result shows that those three variables can predict thermal comfort of the occupant [17]. Both researches confirmed that temperature, air humidity and CO₂ level can be a basic to measure thermal comfort. In my research, CO₂ was replaced by O₂ by argument that the freshness of the air in the house is related to O₂ and there is no much smoke which can make the occupant in danger.

4. Conclusions

Some people’s belief that the houses should not face or opposite to the mountain is something which can be explained scientifically. It is due to the fast mountain wind which will make the house temperature cold. The Raja banana trees planted on the location of building is believed to make the materials durable because they can reduce pest which attacks the materials. The people also believe that on the roof frames red white flag should be put. The red color can avoid beetles eating wood because the red color dazzles battles. The local people use traditional equipment to collect stones and it will not destroy nature.

House orientation, ventilation, shape and size have effect on lighting and air condition. Room crowding and the furniture placement influence the amount of entering. Comparison between the room size and the number of furniture influence the amount of fresh oxygen. The great amount of oxygen will create thermal comfort for the occupants. Vegetation surrounding the house will provide oxygen and protect it from the wind. Adaptive strategies which are done accidentally are proper house orientation karing (heating body under the sun light) and genen (heating body near traditional stove and boiling water for tea or coffee)

References

[1] E. Kuchen, Variable Thermal Comfort Index for Indoor Work Space in Office Buildings: A Study in Germany, Open Journal of Civil Engineering, 2016, 6, 670-684.
[2] Cherif Ben bacha, F. Bourbia, Effect of kinetic façades on energy efficiency in office buildings - hot dry climates, 11th Conference on Advanced Building Skins, pp.458-468.

[3] Seyedehzahra Mirrahimi, Mohd Farid Mohamed, Lim Chin Haw, Nik Lukman Nik Ibrahim, Wardah Fatimah Mohammad Yusoff, Ardalan Aflaki, The effect of building envelope on the thermal comfort and energy saving for high-rise buildings in hot–humid climate Renewable and Sustainable Energy Reviews 53 (2016) 1508–1519.

[4] Sadineni SB, Madala S, Boehm RF. Passive building energy savings: a review of building envelope components. Renew Sustain Energy Rev 2011;15 (8) : 3617–31.

[5] Al-Saadi S, Budaiwi I. Performance-based envelope design for residential buildings in hot climates. In: Proceedings of building simulation; 2007.

[6] Hermawan, Prianto, E., Setyowati, E., (2015), The difference of thermal performance between houses with wooden walls and exposed brick walls in tropical coasts, Procedia Environmental Sciences (23) 168 – 174.

[7] Hermawan, Prianto, E., Setyowati, E., (2015). Thermal comfort of wood-wall house in coastal and mountainous region in tropical area. Procedia Engineering 125 725 – 731.

[8] Prianto, E & Depecker, P. (2003). Optimization of architectural design elements in tropical humid region with thermal comfort approach. Energy and Buildings 35, 273-280.

[9] Prianto, E & Depecker, P. (2002). Characteristic of airflow as the effect of balcony, opening design and internal division on indoor velocity: A case study of traditional dwelling in urban living quarter in tropical humid region. Energi and Buildings, Volume 34, Issue 4, 401-409.

[10] Chan K, Chow W. Energy impact of commercial-building envelopes in the sub-tropical climate. App Energy 1998; 60 (1) : 21–39.

[11] Houmam MELIANI, Jacques TELLER, Shady ATTIA, Architectural and environmental housing typology analysis in Huamachuco, Peru, PLEA2016 Los Angeles – 32nd International Conference on Passive and Low Energy Architecture Cities, Buildings, People: Towards Regenerative Environments, 11-13 July, 2016.

[12] Prianto, E., Bonneaud, F., Depecker, P., Peneaud, J-P. (2000). Tropical-Humid Architecture in Natural Ventilation Efficient Point of View-A Reference of Traditional Architecture in Indonesia. International Journal on Architectural Science, 80-95.

[13] Seddiki, M., Anouche, K., Bennadji, A., & Boateng, P. (2016). A multi-criteria group decision-making method for the thermal renovation of masonry buildings: The case of Algeria. Energy and Buildings, 129, 471–483. http://doi.org/10.1016/j.enbuild.2016.08.023.

[14] Haiyan Yan, Liu Yang, Wuxing Zheng, Wenfang He, Daoyi Li, Analysis of behaviour patterns and thermal responses to a hot–arid climate in rural China, Journal of Thermal Biology 59 (2016) 92–102.

[15] Salman Shoooshtarian and Ian Ridley, The effect of individual and social environments on the users thermalperceptions of educational urban precincts, Sustainable Cities and Society 26 (2016) 119–133.

[16] Borong Lin, Zhe Wang, Yanchen Liu, Yingxin Zhu, Qin Ouyang, Investigation of winter indoor thermal environment and heating demand of urban residential buildings in China's hot summer - Cold winter climate region, Building and Environment 101 (2016) 9-18.

[17] Toby C.T. Cheung, Stefano Schiavo, Elliott T. Gall, Ming Jin, William W Nazaroff, Longitudinal assessment of thermal and perceived air quality acceptability in relation to temperature, humidity, and CO2 exposure in Singapore, Building and Environment 115 (2017) 80-90.