The analysis of thermal performance of vernacular building envelopes in tropical highlands using Ecotect

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Abstract. Climate change affects all areas, including those with low temperature. Wonosobo belongs to highland areas with low temperature. The thermal performance of buildings is influenced by micro-environment climate so that the climate change will affect the thermal performance of buildings. Vernacular buildings are believed to be able to make the occupants comfortable. The vernacular buildings in tropical highlands have either exposed stone walls or wooden walls. The present research seeks to analyze the thermal performance of building envelopes with wooden walls and exposed stone walls in highland areas. Simulation method using the Ecotect software was applied. There are 12 building models with a variety of roofing and flooring were selected. The results of the simulation indicate that the difference between indoor and outdoor temperatures of one model and other models is not significant. Warm temperature mostly occurs in houses with exposed stone walls. Highland areas need much warmth so that cold temperature will not disturb occupants.

1. Introduction

Global warming has become a never-ending issue. Global warming creates climate change. In many areas, climate change creates building discomfort. In the field of architecture, global warming is related to excessive energy use in the process of either artificial cooling or heating. Many experts have tried to conduct some research to find out a comfortable building without air coolers or room heaters [1]. Thermal comfort created by buildings is called the thermal performance of buildings. The thermal performance of buildings is closely related to climate conditions of a region. In a region with relatively hot temperature required air coolers, meanwhile in a region with cold temperature need room heaters. Energy saving becomes the key point in the analysis of thermal performance [2].

Thermal performance measurement is done in several variables, one of which is solar radiation [3]. Building protectors, in particular, can be applied to deal with solar radiation if the main building envelopes cannot hold the heat of the solar radiation. The building envelopes directly exposed to solar radiation include building walls and roofs. In addition to the solar radiation, another variable used for the analysis of the building performance is room temperature [4]. Indoor temperature can be compared to outdoor temperature to gain air temperature differences. A good thermal performance will make the indoor temperature fit occupants’ comfort standards.
The analysis of thermal performance can be done through either field research or experimental research. Some studies have combined both types of research to result in a comprehensive analysis. Many simulation instruments can be applied in the analysis. One of the instruments is Ecotect software. The Ecotect software was used in many researches on thermal performance to analyze the thermal performance of buildings. The Ecotect belongs to Building Information Modeling (BIM) which is currently being developed [5].

A simulation using Ecotect was applied in research carried out in India to process architecture designs resulting in optimal architecture designs in term of thermal [6]. The same simulation was done in research conducted in China. A discussion on thermal analysis is connected to such factors of energy saving as building orientation, natural lighting, and natural ventilation conditions [7]. Natural lighting may have both positive and negative effects on health, productivity, and room user satisfaction. In addition to the positive effects resulted from the research on thermal performance, materials have become the main discussion in realizing sustainable buildings. The research also attempts to find out sustainable and energy-saving materials [8]. The thermal performance measurement using simulation will generate a residential model which fits a region.

Indonesia has two regions with different climates: lowlands and highlands. In highland areas, abuilding which can make the occupants feel warm is required. Highlands have a sufficiently low temperature of about 20°C on average. At a certain time, the temperature can reach -4°C. Low temperatures cause humans to get cold and finally lead to discomfort. A house as a shelter is needed to deal with uncomfortable temperatures. The present research seeks to measure the thermal performance of house models in highlands to find out the house models which fit the highland climate.

Table 1. House models

| Number of model | Walls             | Roofing               | Flooring            |
|-----------------|-------------------|-----------------------|---------------------|
| 01              | Wooden            | Zinc                  | Lean concrete       |
| 02              | Wooden            | Zinc                  | Soil                |
| 03              | Wooden            | Zinc                  | Ceramic tiles       |
| 04              | Wooden            | Sago leaf thatched    | Lean concrete       |
| 05              | Wooden            | Sago leaf thatched    | Soil                |
| 06              | Wooden            | Sago leaf thatched    | Ceramic tiles       |
| 07              | Exposed stone     | Zinc                  | Lean concrete       |
| 08              | Exposed stone     | Zinc                  | Soil                |
| 09              | Exposed stone     | Zinc                  | Ceramic tiles       |
| 10              | Exposed stone     | Sago leaf thatched    | Lean concrete       |
| 11              | Exposed stone     | Sago leaf thatched    | Soil                |
| 12              | Exposed stone     | Sago leaf thatched    | Ceramic tiles       |

2. Method
Simulation method using Ecotect was applied in the research. The research on building performance or architectural designs emphasizes the integrated and comprehensive optimization of a building. The Ecotect has become a reliable architecture modeling simulation software. The performance effectiveness of the Ecotect has been proved to be able to present the analysis of the building performance used as reference material of the building performance [9]. The analysis of the Ecotect was carried out by making building modeling. Such modeling has been commonly carried out including to analyze carbon emissions and energy saving [10].

The research involved 12 building models with a variety of roofing and floorings, as well as wooden walls and exposed stone walls. The models can be seen in table 1. They were determined based on the field research on vernacular houses in highlands of Dieng, Wonosobo, Central Java. The field research demonstrated various building envelopes according to wooden walls and exposed stone walls.
3. Results and discussion

Data processing using Ecotect software focuses on data of outdoor temperatures, indoor temperatures, as well as Mean Radiant Temperature (MRT). The Ecotect indicates the results in graphs which show both outdoor and indoor temperatures and the figure of MRT distribution for each model. The graph of outdoor and indoor temperature differences can be seen in the first graph. Color gradation indicates MRT difference of 2°C. The MRT results of the 12 models are dominated by blue and purple colors, meaning that the air temperature ranges between about 20–26°C (figure 1).

![Figure 1. The results of data processing using Ecotect, a) the indoor temperature data processing, b) the MRT (Mean Radiant Temperature) data processing](image)

The results of the indoor temperature data processing point out two result groups (figure 2). The first group shows a graph with the sufficiently extreme change, while the second group demonstrates a sufficiently sloping graph. The first group includes house models 01-06 with wooden walls and a variety of roofing and floorings. Meanwhile, the second group involves house models 07-12 with exposed stone walls. A variety of roofing and floorings do not lead to far different indoor air temperature. At 12pm–7am, the first group showed the simulation result: indoor temperature of about 22°C. At 6am–11am, the indoor temperature increased approaching 27°C. At 11am–4pm, the temperature remained 27°C. At 4–7pm, the temperature seemed to decrease from 27°C to 20°C. At 7am–11pm, the air temperature became 20°C.

The second group does not indicate a significant change in temperature. At 12pm–7am constant increase of temperature by 22–23°C was found. At 7–12am, the temperature seemed to increase from 23 to 24°C. At 12am–9pm, the air temperature decreased from 24°C to approaching 21°C. At 9pm–11pm, the air temperature seemed to be stable (about 21°C). The house models with wooden walls and those with exposed stone walls have different roles. The house models with wooden walls have a significant difference in the change of temperature in each hour. The wooden house model has a maximum air temperature approaching 27°C. The difference in the change of indoor air temperature of the exposed stone house model is not significant. The exposed stone house model has a maximum air temperature of about 25°C and minimum air temperature of 22°C. Meanwhile, the wooden house model has a minimum temperature of about 21°C. The difference in the minimum air temperature is about 1°C.

At minimum air temperature condition, the exposed stone houses will be more comfortable since the temperature of 22°C approaches comfortable temperature for humans. A comfortable temperature for humans in cold areas is 24°C [11]. In the afternoon, wooden houses get hotter than exposed stone ones since the air temperature reaches 27°C. In stone houses, the temperature in the afternoon reaches about 25°C. At this condition, the air temperature in exposed stone houses approaches a comfortable temperature. Regarding the human comfortable temperature, the exposed stone houses have an average air temperature approaching comfortable temperature instead of wooden houses.
Figure 2. Indoor air temperatures in twelve house models

The analysis of building performance using air temperature will be completed with the analysis of MRT (Mean Radiant Temperature). The MRT is the average temperature of solar radiation. Tropical areas are areas with sufficiently intensive sunlight so that the analysis of MRT is required. The results of the analysis using Ecotect are not far different from those of the analysis of indoor air temperature. In the group of wooden house models, the MRT of model 01, the house model with zinc roofing and lean concrete flooring, is different. The MRT seems to be between the first group and the second group.

The difference of the MRT and the indoor air temperature is below 1°C. The MRT of houses with wooden walls and those with exposed stone walls have the same characteristics as the indoor air temperature. At certain hours such as 7 am and 6 pm, the fluctuations in MRT occurred in house models 02, 06, and 12. House model 02 is a house with wooden walls, zinc roofing, and soil flooring, house model 06 is a house with wooden walls, sago leaf thatched roofing, and ceramic tile flooring, while house model 12 is a house with exposed stone walls, Sago leaf thatched roofing, and soil flooring. House models 02 and 12 are houses with soil flooring which tends to be moist, and therefore the MRT is possibly influenced by the moisture. The wooden walls can store warmth, which enables the MRT to fluctuate. The house model 06 has Sago leaf thatched roofing and ceramic tile flooring. The combination of wood, sago leaf, and ceramic tiles lead to fluctuations in the MRT since the two materials (wood and sago leaf) are materials which can cause fluctuations in solar heat.

The results of the MRT regarding human comfort prove that houses with exposed stone walls are more comfortable than houses with wooden walls. Less sunlight in highlands will make the houses cold. The building orientation will also exert an influence on thermal performance. The results of the building orientation are not discussed in the article since the discussion focuses on the performance of building materials. The materials of building envelopes influence the thermal performance of buildings [12].
The results of the research are in accordance with other research in which the Ecotect was applied for the analysis of building envelope performance. Walls and roofs are architectural elements which exert an influence on the thermal performance of buildings. The recommendation on walls and roofs has become the way to save energy [13]. Wood and exposed stones are eco-friendly materials. The ecological aspects have become significant in energy saving. The eco-friendliness can be seen from the use of materials from surrounding environments, contributing to the reduction of global warming effects [14]. The use of eco-friendly elements will give comfort to the occupants and confirm the vernacularism of architectural design. Vernacular as a local architecture domain will make local culture or tradition global [15]. Buildings with local walls will make difference the indoor temperature [16].

4. Conclusion
Research using simulation has a benefit: being unaffected by extreme environmental conditions. In addition, the research also has an economic value. Simulation using the Ecotect results in accountable models. The present research reveals a comfortable house model in term of occupants’ comfort: a house with exposed stone walls and a variety of roofing and floorings. The results on a variety of roofing and floorings are not far different, and therefore such variety can be applied in highlands. Finding variations in building envelope will reduce the effects of climate change on buildings. Climate change which is affecting all regions greatly affects the inconvenience of buildings. Residents will feel the thermal comfort despite climate change.
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