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Research paper

Improving Indoor Thermal Comfort on a Slant-Roofed Building with Layered Materials

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Abstract

Indonesia is geographically located along the equator with climatic characteristics of rainfall, relatively high humidity and sunlight intensity. Under these climatic conditions, we should consider to design suitable building with optimized thermal comfort. The room temperature—as the main variable for such comfort—is mainly caused by the heat from sunlight retained by the roof that in turn warm up the air underneath. The hot air must be removed to achieve comfortable room temperature. Using building mockups, this experiment researchs the effect of rooftop-covering materials layered as a good insulator against heat. The method used is to compare between the sloping roof building models using clay tile rooftop as reference models and building models using a slanted roof and a combination of layered aluminum foil and coir fiber rooftop. The application of layered roofing materials (aluminum foil and coir fiber) proved to be more effective in improving indoor comfort compared with a tile roof material commonly used in buildings in Indonesia..

Keywords: *indoor thermal comfort, slant-roofed, layered material, coir fiber, bioarchitecture*

1. Introduction

Global Warming has become the most discussed and heard phrase in the past years as the phrase represents catastrophic possibilities for any lives on the Earth. It is not merely a hype anymore, following the livelihood of mankind that has changed from agrarian into the industrialized mass production and now into the fast world of digital technology.

Not just the livelihood, the geomorphology of the Earth has changed drastically as well, for instance: forests have been cleared out for agriculture, while agriculture sites have been covered with housings, offices, malls, and so forth—all of which have created contemporary urbanization all around the world. It is safe to say that the physical changes on the surface of the Earth have eventually been affecting local climate where the changes occur, as well as globally affecting other regions—from which the term ‘global climate change’ come to being. Local, regional, and global climate changes have altered climate parameters, one of which is rapidly rising air temperature. There have been simultaneous increase in air temperature in average that certainly deteriorate the quality of life for all living creatures on one hand, and increase the difficulty to provide a building with indoor thermal comfort for its inhabitants.

Surabaya, with its tropical climate with high level of humidity, has an average thermal mass at 68% above thermal comfort limit (overheating) for building inhabitants, and only 32% below the limit. It shows that air temperature inside always exceeds air temperature outside, while the air temperature outside surpasses thermal comfort zone for human beings which means the air temperature inside is even worse in terms of thermal comfort.

Rooftops play a significant role in developing interior temperature due to its function as the largest protector against the radiation of the Sun, as suggested “A roof is the most essential part of a building. People have lived without walls but never without roofs” (Rury, 2015). Altering rooftop materials is one of possible efforts to provide indoor thermal comfort. The material itself is a main determinant here, as it must have sufficient isolation that could resist heat, cold, water (raindrops) and noise. Its durability should be able to prevent transformation or decomposition from weather changes, and to be deprived of constant maintenance. While the nature of the material should have fire retardation with sufficiently light weight to sustain acceptable elevated position. The most widely used materials include clay tiles, concrete slabs, coir fiber (dried palm leaves), corrugated/flat tin roofs, asbestos, and composite plastic (polycarbonate and polypropylene). In this research, some of these materials are arranged in layers and tested to determine the best insulator from possible combinations.

The use of coir fiber as a rooftop layer is supported by its elasticity, hardness, water-proofness, and indigestibility for decomposing organisms. The field study and research that were conducted for six month have indicated that certain layering of coir fiber can provide effective protection against termites, preventing wooden poles from decomposition by an absolute termite extermination rate of 100%. A rope from coir fiber can last for thousands of years, as suggested by an archeological finding of decaying wooden stakes bound by the rope that is still solid and strong. Certain exposure to radioactive rays also can enhance coir fiber to withstand nuclear radiation, as the mass fraction of its fibers affects the absorbtion coefficient toward radiation, and at 40% fraction the coefficient is higher than aluminum

(Suriadi, 2011). Coir fiber or Arenga pinnata Merr has volumetric mass density of 1.136 gram/cm3. It consists of 8.90% water, 51.54% cellulose, 15.88% hemicellulose, 43.09% lignin, and 2.54% ash. The cellulose part of coir fiber can absorb noise (Suriadi, 2011). Therefore, it was concluded that coir fiber fibers with its solidity and ability to reflect radiation were assumed to be able to reflect the heat of sunlight and to reduce outside noise as well. Coir fiber as a rooftop material has separate strain of fibers that needs to be complemented by plastic sheets underneath to prevent raindrops from seeping in (Suriadi, 2011).

Thermal comfort is a cognitive condition of satisfactory thermal environment, where the inhabitant of a building perceive convenient air temperature (Karyono, 2001). It correlates with the surrounding nature but is still manageable by architecture (Snyder,1989). Meanwhile, the occupant has reached thermal comfort when he or she does not need to lower or raise air temperature in the room/building, where comfort zone is a zone in which the occupant can reduce the energy expended to adapt with his or her surrounding (Olgyay, 1973).

2. Materials and Methods

This research utilized a quantitative method to seek the best possible thermal comfort from modifying rooftop materials and their layerings, and an experimental research strategy of daily temperature measurement inside building mockups for six days.

The variables used in this research were referred from the literature study in relation to the research problem and purpose. This research is intended to seek for rooftop material solutions that can favorably affect air temperature and thermal comfort inside a building. Hence, the free variable of this research is rooftop materials which include aluminum foil and coir fiber, while its bound variables are limited to air temperature and humidity. Data collection is needed to support thermal comfort testing. Data utilized as variables in this research include climatic data from BMKG and the air temperature and humidity measurements taken on the field.

2.1. Mockup Study with Clay Tile Rooftop

The measurement was conducted on two mockups that have similar base area of 40 cm2—from 80 cm length and 50 cm width—with 40 cm height, oriented toward west and east to obtain the longest exposure to sunlight, equipped with Hygrometer and Anemometer. The first mockup was covered with clay tile rooftop. The wall was built with 7 cm thickness from bricks and cement, while the floor used 30 x 30 cm ceramic tiles. The clay tiles for rooftop were of the standard size of 32.5 cm x 23.5 cm with 1 cm thickness, as shown below.

Fig.1: Building mockup with clay tile rooftop

2.2. Mockup Study with Multi-Layered Materials

The second building mockup to be studied was built with similar specifications and sizes but blanketted with multi-layered materials, including: net wire for the base layer, covered with aluminum foil, followed by white fiberglass mat, and coir fiber layer on top of them all. This rooftop modification/alteration can be seen on Figure 4.2. below.

Fig. 2: Mockup study with multi-layered rooftop

Data analysis was conducted when the field study has provided the result of measurement over the course of six days. The quality analysis of rooftop materials was intended to explore the potential of each material as a suitable insulator in creating indoor thermal comfort. In this case, a comparison between multi-layered rooftop comprising of net wire, aluminum foil, fiberglass mat, and coir fiber with a standard rooftop of clay tile covering that is commonly used in the country.

3. Results and Analysis

Based on the measurement on the field, this research aims to figure out and to compare the capability of each rooftop in creating indoor thermal comfort. An initial calculation was needed to obtain a reference point for determining daily thermal comfort in a Psychometric chart in order to analyze the comfort zone that has been developed.

The formula for the calculation (Szokolay, 1987):

Average outdoor temperature

Tn: 17.6 + (0.31 x Tav)

Tn: Chart : 50% RH Curve

Tn – 2 : L

Tn + 2 : U

SET Lines

0.025 x (L – 14) = X

0.025 x (U – 14)= Y

Upper limit AH a g/kg

Lower limit AH b g/kg

L + (a x X)

Y + (b x Y)

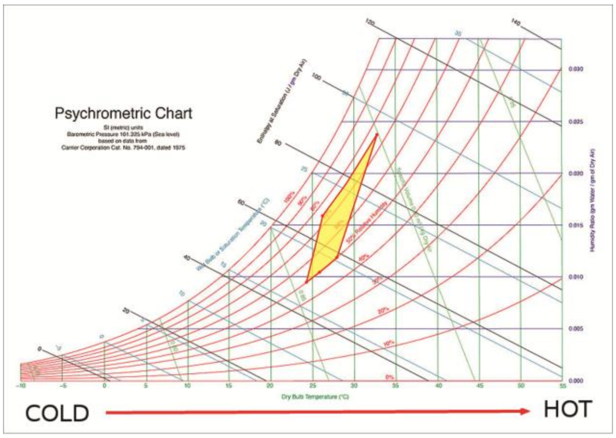

Fig. 3: Psychrometric chart 1st day, December 10th, 2014

Figure 3 shows that comfortable room temperature was obtained at the range of 24.27°C – 32.9°C and humidity level of 50% - 74.11%. The measurement on the field has resulted the periods of thermal comfort inside the mockup with clay tile rooftop occurred from 08.00 to 11.00 and from 13.00 to 16.00, while the coir fiber rooftop obtained thermal comfort from 06.00 to 09.00 and from 13.00 to 16.00, which means coir fiber rooftop can provide longer thermal comfort period than clay tile rooftop.

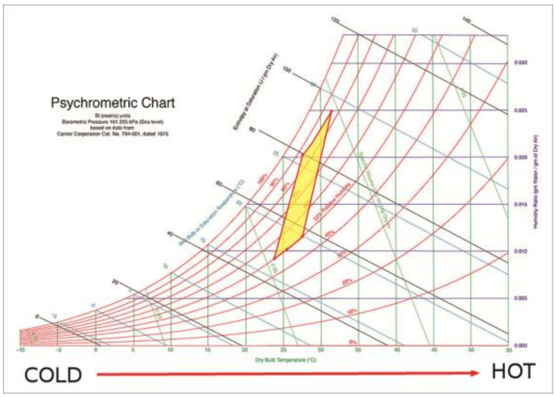

Fig. 4: Psychrometric chart 2nd day, December 11th, 2014

The figure above shows that indoor thermal comfort occurred at the room temperature of 23.68°C – 31.78°C and humidity of 50% – 87.16%. The field study on the second day showed the mockup with clay tile rooftop, thermal comfort occurred at 06.00, 08.00 – 11.00, and 13.00, while the coir fiber rooftop at 06.00 – 08.00 and 15.00 – 16.00 wib, which means thermal comfort on multi-layered rooftop has longer period than clay tile rooftop.

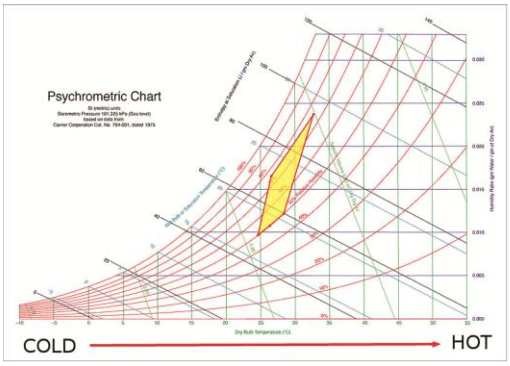

Fig. 5: Psychrometric chart 3rd day, 12 December 2014

Based on the figure above, thermal comfort occurred at room temperature of 24.43°C – 32.93°C and humidity of 50% – 75.79%. The field study on the third day showed that thermal comfort occurred inside the clay tile mockup at 09.00 – 11.00 and 15.00 –17.00, while inside the coir fiber mockup occurred at 09.00 – 17.00, which means, once again, the coir fiber rooftop can provide longer period of thermal comfort than the clay tile one.

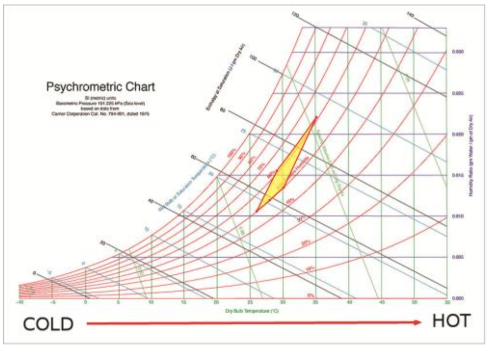

Fig. 6: Psychrometric chart 4th day, December 13th, 2014

The figure above shows that indoor thermal comfort occurred at the room temperature of 26.05°C – 35.43°C and humidity of 50% – 61%. The field study showed no thermal comfort inside the mockup with clay tile rooftop on the fourth day, while the coir fiber rooftop only provided thermal comfort at 11.00.

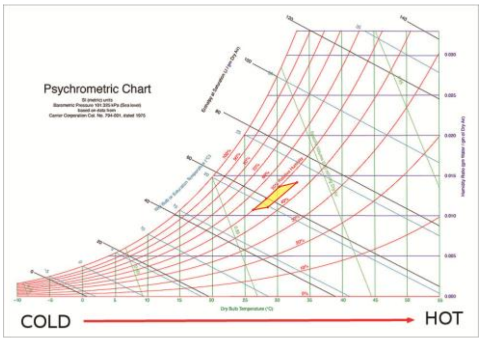

Fig. 7: Psychrometric chart 5th day, December 14 th, 2014

Figure 7 shows that comfortable room temperature was obtained at the range of 26.33°C – 34.02°C and humidity level of 46.33% – 50%. On the fifith day, the measurement on the field has resulted the periods of thermal comfort inside the mockup with clay tile rooftop did not occur, while the coir fiber rooftop only obtained thermal comfort 14.00.

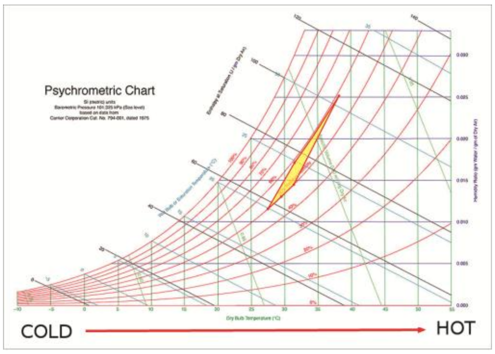

Fig. 8: Psychrometric chart 6th day, 15 December 2014

Based on the figure above, thermal comfort occurred at room temperature of 27.63°C – 38.09°C and humidity of 50% – 59.83%. The field study on the sixth day showed that thermal comfort occurred inside the clay tile mockup at 09.00, 12.00, and 13.00, while inside the coir fiber mockup only occurred at 09.00.

4. Conclusion

This study aimed at finding better rooftop materials and layers in providing indoor thermal comfort between clay tile and coir fiber and aluminum foil. It concludes that:

1. Data shows that coir fiber and aluminum foil materials can provide longer thermal comfort zone inside a building mockup compared to clay tiles, which means multi-layered materials have proven to be more effective in creating comfortable room temperature.

2. Multi-layered rooftop can obtain longer period of thermal comfort compared to clay tile rooftop, which means modifying rooftop materials can produce indoor thermal comfort better than standard use of clay tiles.

3. The amount of measurement days should be extended to further develop possible correlations between each variable, as well as the necessity of better arrangement of multi-layered materials in order to cover rooftop more evenly.

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