Thermal Performance of Precast Foam Concrete Integrated with Green Roofs System

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Abstract—The increase in urban temperature because of the urban heat island phenomenon affected energy usage for the building sector. Most of the energy usage in the building is for the air conditioning system to achieve thermal comfort. It is necessary to reduce the cooling load by minimizing heat gain to the building so that the air conditioning system uses less energy consumption. Passive design with a green roof system offers a solution to reduce heat gain from solar radiation through the roof. However, only a few buildings have implemented a green roof system in the tropics, especially in Indonesia, and the literature found on this subject is also inadequate. This research studies the thermal performance of precast lightweight foamed concrete as a roof structure integrated with a green roof system through experimental modeling. We constructed two prototype rooms with the precast foam concrete panel as the roof. One prototype uses a green roof and the other without a green roof. We expose the prototypes to an open environment with direct sunlight for 3 days. The air and surface temperatures inside and outside the models were measured continually at the 10-second intervals. The thermal performance of the green roof is evaluated by comparing the thermal responses of the models during the exposure. The results show that the green roofs significantly reduce the heat load from solar radiation during the day.

Keywords: *green roof, extensive, precast foamed concrete, vegetation*

I. INTRODUCTION

Urban temperatures continue to rise due to the phenomenon of urban heat islands (UHI) and the effects of climate change. Researchers have known this phenomenon for almost a century because of higher urban temperatures compared to neighboring suburbs and rural areas [1]. As a result, energy consumption has increased over the past four decades. The International Energy Agency reports that the rise of global energy uses from 1971 to 2014 was around 93%. The building sector is responsible for the largest part of this increase, accounting for 40% of total energy expenditure [2]. Most of the energy usage is for the air conditioning system to lower the indoor air temperature and humidity for thermal comfort. Researchers consider green roofs to be one of the

most appropriate sustainable solutions to resolve the UHI-related issues [2,3,4].

Passive design with a green roof system reduces heat gain from solar radiation through the roof so it can reduce the cooling load for the air conditioning system. Green roofs offer a natural and sustainable way to cover building envelopes with vegetation to bring multiple environmental benefits [4,5,6,7]. Besir and Cuce (2018) state that green roofs and green facades are key solutions to mitigate building-related energy consumption and greenhouse gas emissions. Heat flow through the building roofs in summer reduces by approximately 80% via green roofs [2].

Other important performances of a green roof, particularly in the tropics, are the ability of rainwater detention and retention and reduction in energy consumption [4,8,9,10,11,12]. Tsang and Jim (2011) found that the thermal performance of humid-tropical green roofs is twice more effective than the temperate zones. High rain intensity in the tropics will store high water content in the growing medium of green roof systems [5]. The availability of soil and water affects the heat storage capacity of the green roof. However, the utilization of green roofs in Indonesia is still very minimal, and the literature found in this topic is inadequate. Some reasons for the limited implementation are the expensive construction and maintenance costs. Also, green roofs add more weight to the structural load, which leads to changes in the structural design of columns, beams, and slabs, resulting in a more expensive structural cost [13].

Considering building weight restriction and cost, shallow-substrate extensive green roofs are much more common than deeper intensive roofs [11]. The weight of the extensive green roof is 50–160 kg/m² and substrate depth 5 - 20 cm [2,6,14]. To reduce more structural self-weight, lightweight foamed concrete is a solution. Manufacturing lightweight foam concrete is by introducing air through a proprietary foam process to control concrete density. The density of foamed concrete ranges from 300 to 1800 kg/m³, which is significantly lower than normal concrete (2400 kg/m³). Cement, water, and foam compose foam concrete. The

foamed concrete has the main advantage as roof material because of its low density and low thermal conductivity. The thermal conductivity of foamed concrete ranges of 0.1 - 0.7 W/m.K for a dry density of 600-1600 kg/m³, decreasing according to its density [15,16,17].

This study is an experimental modeling research using foamed concrete panels as roof material integrated with a green roof to determine its thermal behavior. By comparing the variations in the indoor thermal conditions between the model with and without a green, it will show the thermal behavior of the green roof in reducing heat gain from solar radiation energy.

II. MATERIALS AND METHODS

A. Precast Foamed Concrete

Fresh concrete mix pour to the prepared mold to form the precast roof panels. We create the panels in a rectangular shape in a specific form that sets up an area to fill a growing medium for the green roof. The panels use Ø8 mm steel and galvanized welded wire mesh (wire diameter 1.0 mm, opening square 1 inch) for reinforcement, as detailed in Fig.1(a).

Materials used for concrete mix are Portland cement Type-I, foam agent, and water. The foam generator produced foam from the foam agent and a certain volume. Concrete mixture was poured into the mold immediately after preparation to get a target density of 1,400 kg/m³ of fresh concrete. To improve workability, we introduce a small amount of super-plasticizer that does not influence the characteristics of foamed concrete. The composition of foamed concrete mix is calculated based on specific gravity (SG 1.4) and water to cement ratio (w/a 0.4) comprises 1000 kg/m³ of Portland cement, 400 kg/m³ of water, and 282.5 liter/m³ of foam. Three cylindrical specimens (Ø15-30) were molded to characterize the concrete

characteristics in terms of their specific gravity and compressive strength. The curing treatment of the samples was by wet covering method (moist curing) in the shaded area for 28 days before the test.

B. Prototype Model Building

We built two cubical models to represent the indoor spaces beyond the roof as the building models to measure the thermal behavior of the buildings with and without a green roof. The models used L-shaped steel for structural frame and styrofoam board (20 mm in thickness) for the walls and the floors insulation. Styrofoam board provides thermal insulation for the wall and the floor so that the heat flows to/from the room mainly through the top side (foamed concrete panel). Based on this assumption, the heat flow rate value through the roof into the room and the temperature changes will express the thermal performance of each building model.

Fig. 1(b) shows the schematic layers of the green roof system that comprise vegetation layer (plant), substrate (growing medium) layer, soil filter, a drainage layer, root protection layer, waterproof layer, and foamed concrete roof panel. Figure 2 shows the models with the foamed concrete panels on the top part and the styrofoam board as an insulated wall that had been set up for field evaluation. The measurement of thermal parameters took place in 3 days by placing the building prototypes in direct sunlight in the open air. The plant used as the vegetation layer is *portulaca grandiflora*, also known as *ten o'clock flower*, which is a fast-growing and drought-tolerant plant that thrives in dry.

C. Measurements Conditions

The measurement variables include ambient air temperature, surface temperatures, medium temperature, and heat flow. The measurement used thermocouple and heat flux sensors

connected to a data logger. Fig 1(b) and Table 1 summarize the details of measurement items and measurement points.

While exposed to an open ambient environment with direct sunlight, the data logger recorded the data in 10 seconds intervals for 3 day's experiment to observe thermal responses of the models continually. The experiment took place in the inner court of a building where direct sunlight was available during the days. Only the direct sunlight of early morning (until 8:30 am) and late afternoon (from 5:00 pm) did not reach the models. Temperature measurements use thermocouples attached to each layer of the green roof system and on the concrete panel surfaces on both sides, indoor and outdoor, as illustrated on Fig.1(b). The measurement starts from 8:00 am and finishes after 3 days.

III. RESULTS AND DISCUSSION

A. Foam concrete characteristics

Table 1 presents the properties of foamed concrete from three cylindrical specimens made when casting the roof panels. The specific gravity of dry foamed concrete is $1395.85 \pm 15.09 \text{ kg/m}^3$ calculated based on the weight and volume of the specimens. Compressive strength testing was after 28 days of concrete age and the average value was $12.76 \pm 0.55 \text{ MPa}$. This result categorizes the foamed concrete as lightweight moderate-strength concretes (7–14 MPa). Fig. 2 displays the setting of the foamed concrete panel model that had been prepared for the specimen for measuring the performance of the green roof.

TABLE II. COMPRESSIVE TEST RESULT OF CYLINDRICAL SAMPLES

Cylindrical specimen	Specific gravity (Kg/m ³)	Max load (Ton)	Compressive strength (MPa)
Specimen-1	1380.76	23.0	12.76
Specimen -2	1410.94	22.0	12.21
Specimen -3	1395.85	24.0	13.32
Average	1395.85	23.00	12.76
SD	15.09	1.00	0.55

Fig. 3 Temperature profile in 3-day measurement

B. Environmental Conditions

The environmental variable measured was ambient air temperature around the models. Fig 3 illustrates the temperatures in three days measurement, including ambient air temperature, indoor air temperatures, and indoor surface temperatures. Because of instrument limitation, there is no solar intensity data in this experiment. However, the ambient air temperature can considerably represent the environmental condition during the experiments. Data analysis in this experiment only uses data for days with sunny weather. The air temperature will rise when the solar intensity increases. In Fig 3, the indoor temperature rises to respond to the increasing outdoor air temperature.

C. Temperature Profile

Figure 3 illustrates the temperature profile of the roofing system in the three days' experiment. Table 2 compiles the maximum temperatures achieved as peak hours. The external

TABLE III. PEAK TEMPERATURE

temperature	non-green roof			green roof			diff.
	day1	day2	day3	day1	day2	day3	
external surface	58.4	54.8	47	35.4	34.1	33.4	19.1
internal surface	57.7	53.9	46.7	36.3	34.7	34	17.8
indoor air	50.4	47.3	42.2	37.9	36.3	35.2	10.2

Fig. 4 Temperature gradient of the roof in 4-hour interval.

surface of the concrete roof panel without green roof reaches the highest maximum temperatures up to 58.4°C, 54.8°C and 47.0°C for all the days in sequence. The surface absorbed maximum solar energy from direct sunlight and transferred to the chamber beyond the roof. No substantial reduction in temperature for the internal surface, since the variation is less than 1°C. The internal surface conditions are 57.7°C, 53.9°C, and 46.4°C. The smallest peak temperatures are for external concrete panel (under the growing medium) of the green roof model, i.e. 35.4°C, 34.1°C, and 33.4°C for all the days in sequence. The green roof layers reduced the heat stored in the concrete panel.

The internal surface temperature of the green roof model is considerably smaller at peak with 10.2 °C of temperature differences on average compared to the base model. In contrast, the indoor temperature is higher than the surface temperature during the day and lower at midnight. It suggests that the green roof does not transfer heat to the room during the daytime and discharge the heat to the room at night-time. This result reveals that most solar energy is absorbed and released by the green roof system. The green roof system only stores a little of the solar energy and then transmits it into the room. This result conforms with the simulation conducted by Feng et al. (2010) that absorbed solar energy dissipated to surrounding environment by evapotranspiration of soil systems for about 58.4%, and only 1.2% stored by plants and soil, or transferred to the room [20].

D. Temperature Gradient

As described in the preceding section, the green roof layers prevent heat from solar energy so that the indoor temperature appears not to accelerate sharply. Fig. 4 shows the gradient temperature in the layers from the outdoors to the indoor points captured in the 4-hour interval to illustrate the different thermal behavior between the models during heat gain (daytime) and heat loss (night-time) to/from the systems.

The two models show different trends in responding to changing environmental conditions. For the morning time before being exposed to direct sunlight, the green roof system temperature is higher than the base model. As for the green roof model, the surface temperature is still higher than the indoor air temperature, so that there is releasing heat from the roof into the room. For the base model, the indoor air temperature is higher than the surface temperature. After receiving direct solar heat until noon, the air temperature becomes higher than the surface temperature which shows that the heat received indoor is more through the wall than that from the roof. Indoor air transmits the heat to the roof, so the temperature of the internal surface is higher than the external surface of the panel. For the base model, the temperature gradients for 12:00 and 16:00 indicate the accumulation of heat flowing through the roof so that the surface temperature becomes more than 50°C. This also shows that most heat gain flows through the roof, not the wall. This phenomenon might be because the wall insulation was not working perfectly, so that the transmission of heat through the wall still occurs. However, these results show the performance of a green roof in reducing the heat load from solar radiation during the day.

E. Heat Transfer

The tendency of temperature and heat flow changes in response to environmental changes are similar for all three days measurement. Therefore, heat flow analysis only uses the

Fig. 5. Measured heat flow for both green roof and non-green roof model, which is directly proportional to the temperature difference between the surface and indoor air.

measurement results of the second day by considering fewer weather fluctuations. Figure 4 depicts the results of heat flow measurements from the surface of the inside roof panel to indoor air and also shows the temperature difference between the panel surface and the air in the test chamber. Both variables show a similarity in the pattern of change consistently. Figure 5 shows a graph of the relationship between heat flow and temperature differences, which can be written in the following equation:

$$Q = h \cdot \Delta T \quad (1)$$

$$Q = 9.475 \Delta T \quad (2)$$

where Q is the amount of heat flow (W/m^2), h is the heat transfer coefficient ($\text{W/m}^2 \cdot ^\circ\text{C}$), and dT is the temperature difference ($^\circ\text{C}$). Fig.5 shows the relationship of the amount of heat flow to the temperature difference for the green roof model. The heat transfer coefficient is 9.475 $\text{W/m}^2 \cdot ^\circ\text{C}$. This value is a total heat transfer coefficient, which is a combined convective heat transfer coefficient (hc) and radiative heat transfer coefficients (hr).

Fig. 6. The relationship between heat flow and temperature

F. Integration of Precast Foamed Concrete with the Green Roof System

This result shows that the use of a green roof can change the pattern of heat reception in a room. The heat transfer mechanism between buildings that use green roofs and those without green roofs shows the different conditions, both for daytime and nighttime. The green roof has a higher heat capacity and will release heat slowly at night, while for daytime it transfers only a small amount of heat from the roof into the room. This condition is very favorable for tropical regions with high solar intensity throughout the year so that it can save a large amount of energy for the cooling system. Using lightweight foam concrete for roofs is not so common nowadays, one of which is technological constraints. This research offers precast technology to initiate the use of lightweight foam concrete while applying an integrated green roof system. When used without a green roof, with a thickness of only 40mm, foamed concrete could not reduce heat gain even though it has a good heat resistance value. The combination of the use of lightweight foamed concrete and green roof gives the double benefit of reducing construction loads and reducing cooling loads for air conditioning systems.

The strength of foam concrete is the main requirement for its use as a roof structure. Foam concrete with SG 1.2 - 1.8 can produce structural concrete strength with a lighter weight than conventional concrete. Further investigation is still important regarding its strength to a precast roof model integrated with the green roof system. The characteristics of foam concrete and module dimensions of panels are variables that require further study to optimize the use of green roof integrated precast foam concrete.

IV. CONCLUSIONS

Green roofs offer a natural and sustainable way to bring multiple environmental benefits, including improving building energy efficiency. Passive design with a green roof system offers a solution to reduce heat gain from solar radiation through the roof. An extensive green roof system with lightweight foamed concrete as roof material offers a solution for reducing building structural load. This research studied the thermal performance of precast lightweight foamed concrete as a roof structure integrated with a green roof system through experimental modeling. The results show that the green roofs significantly reduce the heat load from solar radiation during the day. Green roofs have a higher heat capacity and will release heat slowly at night, while for daytime it transfers only a small amount of heat from the roof into the room, which is a favorable condition for tropical regions with high solar intensity throughout the year.

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