A preliminary Study on The Use of PET Bottle Waste as The Green Roof Drainage Layer for Thermal Insulator

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Abstract. The phenomenon of urban heat island (UHI) and global warming are significant issues now in relation to sustainable urban development. The application of green roofs is an intention to weaken the impact of UHI by reducing heat gain on the building surface that is emitted to the environment. In addition, green roofs also reduce heat transmission from solar radiation received by the roof to the indoor. Utilization of plastic bottle waste from PET (Polyethylene Terephthalate) will cut down the weight of the green roof system, which also develops the heat resistance value of the roof. This research is an initial study that suggests a green roof application that is more environmentally friendly with the principle of reusing PET waste as a sustainable building material to increase thermal resistant of the system. The analysis concentrates on describing the thermal behavior of the green roof system with the inclusion of PET bottles as a drainage layer. The investigation was carried out by preparing a cubical model of 60cm x 60 cm x 60 cm with a green roof system. Thermal performances were assessed by measuring the temperature of each layer of the green roof using thermocouple wire. The environmental variables measured were solar intensity, ambient air temperature, and air humidity, where the sensors placed close to the models. This analysis demonstrates the influences of green roofs in reducing solar radiation heat. Even though the decreasing of room temperature between the models was not significantly different, this initial results show that, by introducing PET, still display a further performance in reducing heat gain from solar radiation. However, it is necessary to adjust the evaluation models. Heat accumulation in room raised the indoor temperature to be higher than the roof temperature, so that the behavior of the green roof with the purpose of PET is not obviously distinguishable. A trial model with ventilation opening will release heat from enclosed space and it could evaluate clearly the rate of heat flow from the roof.

1. Introduction
Development in urban areas causes many environmental problems, one of which is an increase in urban heat island phenomenon. Increasing urban temperatures has a direct effect on the energy and environmental sustainability of cities [1]. High urban temperatures increase building energy consumption for the air conditioning system. We need efforts to reduce heat gain in buildings through passive designs, one of which is the application of a green roof system. Using the green roof system
prevents solar radiation transmission into the room so that it can save energy significantly up to 50% compared to ordinary roofs [2]-[3]-[4]-[5]. Implementing green roofs is a concept of sustainable buildings, energy efficient and friendly structure the environment to the standard low carbon building. Besides that, it is also interesting in terms of architectural aspects and aesthetics [6]-[7]. More than an aesthetic function, green roofs provide greater benefits to buildings by reducing heat flow through evapotranspiration, roof shading, and increasing roof insulation and thermal mass, reducing energy requirements for the cooling system [8]. The application of green roofs can reduce the temperature in residential buildings [9]. The disadvantage of a green roof system is the added load on the building structure system. Previous studies developed the precast foam concrete as a roof component to reduce the load on the roof, also increases thermal resistance due to low conductivity value [10]-[11]. Introducing the lightweight material into the roofing system is an alternative to reduce more weight of the green roof system. Incorporating PET bottle waste into green roof system solves overcome load problem in the system. It will reduce the weight of the building and increase the heat resistance value of the roof. Empty PET bottles with airtight conditions can be an insulator because air has a small value of heat conductivity. Its use in the green roof system can also be an alternative material for the drainage layer. This is also to overcome the availability of a drainage layer that is not widely available in the market.

This research offers the development of green roof technology that is more environmentally friendly with the principle of reuse of PET waste as a sustainable building material. This can reduce the environmental impact of the waste PET bottles that are widely used today and reduce the carbon emissions as energy-efficient buildings. The application of PET waste as a building material has been widely used, among others, for walls that show increased thermal performance and are considered as environmentally friendly and sustainable materials [12]-[13]-[14]-[15]-[16].

Incorporating waste PET bottles as the layer of the green roof system provides a lightweight green roof system with good heat resistance because of the air content in the bottles, resulting in energy efficient building components for the tropics. So far, it has not found the use of PET waste as a layer on green roof components in the literature. This study provides information about the basic characteristics of the thermal behavior of green roofs with the addition of waste PET bottles, which can reduce heat gain in the room.

2. Materials and methods

2.1. Material

This study is an experimental research on a laboratory scale by making and testing a prototype model of a green roof system using PET bottle waste. We built three prototype models to analyze the thermal performance of the green roof with PET bottle waste with the ordinary roofing system. The three models are a model without a green roof, a regular green roof model, and a green roof model with PET bottles. This research focuses on identifying the thermal performance of the green roof system by incorporating the empty PET bottles. The dimensions of the model are 60cm x 60cm x 60cm by forming the room under the roof as an indoor environment.

The roof material for the test model was the precast foam concrete panels with its specific gravity (SG) of 1.4. Figure 1a shows the shape of a square panel measuring 60cm x 60cm with a panel thickness of 4cm. This model uses a panel with a depth of 10 cm as a green roof by filling the planting media and PET as a drainage layer. Figure 1b shows the details of the green roof section and measurement points of temperature. The cavities between the rows of PET bottles can serve as a drainage layer for the green roof.
2.2. Experimental setting

Three cube-shaped test room models to represent the indoor space were built to simulate the thermal performance of a green roof prototype with foam concrete panels as the roof structure. The prototype uses L-shaped steel for the structural frame and Styrofoam boards (30 mm thick) for the walls and floor insulation. Styrofoam board becomes a thermal insulator for walls and floors so heat flows to/from the dominant room through the top side (foam concrete panels with green roof system). Based on this assumption, the value of the heat flow rate through the roof into the room and temperature changes will describe the thermal behavior of each building model. The prototype construction of the test room is as shown in Figure 2. The type of plant used as a green roof vegetation layer is zoysia japonica grass plant with the consideration that this type of plant is easy to grow, develops fast growth, is resistant to heat, and is easily available in the environment around the research site.

2.3. Data Acquisition

Measurements lasted for 3 days by placing the test building model in direct sunlight in the open air. The main parameter measured is the response of each prototype model to external environmental conditions, especially heat from solar radiation (solar power). temperature changes in each model show the performance of the test model. The comparison of the responses of the three test models is how the roof's ability of each model inhibits the flow of heat into the space. We measured temperature...
using a thermocouple sensor connected to a data logger to read and record data during the
measurement process. Measurement duration is for 3 days, with data recording every 1 minute. Figure
1b shows the position of the measuring point for each temperature sensor and Table 1 shows the
instrument and its variables.

| Table 1. Measurement items and instrument. |
|-------------------------------------------|
| Item                                      | Instrument                                      |
| Surface temperature concrete panel        | Thermocouple (T type, 0.3 mm in diameter)       |
| (inside and outside)                      |                                                |
| Ambient air temperature                   |                                                |
| Indoor air temperature                    |                                                |
| Medium temperature b                      |                                                |
| Data Acquisition                          | Data logger (GL800, Graphtec Instrument)        |
| Solar Radiation                           | Solar Power Meter                               |

\^ a pasted the sensors on the surface using aluminium tape
\^ b pasted in the middle of the growing medium

3. Results and discussion

3.1. Environmental Conditions

The environmental variables measured were solar power, ambient air temperature, and air humidity,
where the sensors placed close to the models as shown in Figure 2. Air temperature fluctuates
according to the intensity of sunlight. Likewise, with the relative humidity, which depends on the air
temperature, when the air temperature is high, the relative humidity drops. Fluctuations occur due to
weather that turn cloudy at certain times. The measurement results of the three variables in Figure 3
are the data obtain from the measurement results 3-day recording with a data-logger. Figure 3 also
shows the results of smoothing with the 15 points simple moving average method. The relative
humidity date was missing on the first day of measurement.

The peak conditions for solar radiation occur between 12:00 and 14:00, while the peak temperature
occurs around 15:00. There is a lag time between the maximum intensity of sunlight and the maximum
air temperature of about 1 hour. Solar radiation hit the test model at around 9:00 am, because the
model was placed in the inner court of a building, so the east side of the roof blocked it. Likewise, in
the afternoon, the test model only received sunlight until around 5:00 pm because the west side roof
blocked it. However, this condition does not affect the substance of this study, as it exposed the test
model to direct sunlight for approximately 8 hours, including time of maximum radiation intensity at
midday. For detail analysis of the thermal responses of the model to the environmental condition, the
second day data are used because of less fluctuation compared to that of the first and the third day,
particularly at the midday with maximum solar radiation 990 W/m² based on moving average data and
maximum air temperature 39.2 °C.
Figure 3. Measured value of solar radiation, ambient air temperature, and relative humidity during the 3-day experiment.

3.2. Green roof thermal performance

Figure 4 illustrates the temperature profile of the roofing system in the three models of experiment. The external and internal surface of the concrete roof panel without green roof reached the highest maximum temperatures up to 62.4°C and 63.2°C, respectively. Meanwhile, the maximum surface temperature of the outer concrete panel for the green roof model with and without PET bottle were 41.5°C and 41.7 °C, respectively. The temperature different between the model with and without green roof system was about 20°C. 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. Surface of the green roof system absorbed solar energy from direct sunlight before it transferred to the chamber beyond the roof. No substantial reduction in temperature for the internal surface compare to the external for green roof models, where the variation was less than 1 °C.

Figure 4. Temperature profile on components of green roof layers [Model-A], green roof with PET [Model-B] and without green roof [Model-C]
Maximum air temperature also showed a significant difference between the model with and without a green roof, namely 42.3 °C for the green roof model (model-A) and 53.5 °C for the model without a green roof (model-C). 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].

3.3. Green roof temperature profile
The performance of a green roof can be evaluated based on the response of each component of the green roof layer as a temperature variable to changes in environmental conditions, especially due to direct solar radiation on the roof system. The temperature profile in each test model can describe how the green roof system can reduce heat caused by radiation heat exposure to the roof area. Figures 4 illustrates the temperature profile of each type of roof in response to conditions without solar radiation at night and with maximum solar radiation heat during the day between 12:00 to 14:00.

3.4. Thermal respond of the green roof with PET bottle
The temperature difference that occurs because of the addition/replacement of the drainage layer with used PET bottles does not show an obvious difference in indoor temperature. Possibly because of thermal accumulation problems that occur with the wall and floor insulator system in this model. The other components of the green roof showed a difference with the addition of a drainage layer from PET bottle, especially on soil medium. Using PET bottles with a diameter of 6 cm causes the difference in the thickness of the growing media to be thinner, so the ability of the media to store heat becomes smaller. This can be seen in the temperature profile in Figure 4, where at night, the temperature of the growing media becomes smaller because it released faster heat than in thick media. Further testing will be carried out with a ventilated model, so it is hoped that we can see it more clearly on changes in indoor air temperature as an indicator of the thermal performance of green roofs.

![Temperature difference between the inner roof surface and the indoor air.](image)

Figure 5. The temperature difference between the inner roof surface and the indoor air.

The rate of heat flow through the roof can be seen as heat transfer from the inner surface of the roof into the room. Figure 5 shows the temperature difference between the inner surface and the indoor temperature for 24 hours. The convection heat transfer coefficient can be considered the same between
the three models where the model is set with the same surface and the same room conditions, so that the temperature difference can be seen as a difference in the heat flow rate. The biggest difference occurs when the presence of solar radiation heat in the model. Models without a green roof transfer heat quickly into the room with a temperature difference of more than 10°C at the maximum radiation intensity. In contrast to the model with a green roof, the temperature difference shows a negative value, which means there is heat transfer from the room to the roof surface. This happens because the indoor air temperature is higher than the roof surface temperature.

![Figure 6. Time different from maximum outdoor and indoor temperature as time-lag for each model.](image)

3.5. Time lag
The maximum temperature difference variable between outside and inside the room, showed by the time-lag, indicates the roof thermal performance. Figure 6 shows the lag time that occurs for the 3 models. Comparing all the models, it shows that there is a difference in lag time between models with a green roof and without a green roof, which is almost 2 times. Using PET on green roofs does not show extending the lag time. This is also in line with the indoor temperature indicator, where the difference is also insignificant.

4. Conclusions
The application of green roofs is an effort to reduce the impact of UHI by reducing heat on the building surface that is radiated to the environment. Utilization of plastic bottle waste from PET (Polyethylene Terephthalate) will reduce the weight of the green roof system, which also increases the heat resistance value of the roof. The initial results of incorporating PET bottle to the green roof system show a better thermal performance compared to that of the ordinary slab roofs. Thermal performance with the addition of PET bottles can also reduce the heat flow rate of the green roof, even though the difference is not significant when compared to those without PET. These results show the superiority of green roofs in reducing solar radiation heat. However, the difference in heat flow from the roof on the two models cannot be clearly read due to the accumulation of heat in the enclosed space so that the indoor air temperature is higher than the roof surface temperature. It is necessary to develop a test model with openings (ventilated) so that hot air can escape and heat transfer from the inner roof surface into the space can occur. The types and sizes of bottles also have not varied, so they cannot describe the effect of using PET bottles as thermal insulation. The research will continue by modifying the model by providing a ventilation system to reduce heat accumulation in the room and varying the type and size of PET as an insulator.
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