The Effect of Plants on Extensive Green Roofs in Urban Heat Island Mitigation Efforts in Humid Tropical Cities

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Abstract. One of the urban heat island mitigation strategies in reducing urban temperatures in tropical cities is the application of a green roof system. This study compares the reduction in temperature and heat flow rate provided by three types of plants on extensive green roofs (EGR). We demonstrated that a EGR constructed with three types of plants (ground cover, and shrubs) could result in a decrease in temperature relative to the normal roof (NR). The results showed that the base temperature of the EGR of the bush and ground cover was lower than the base temperature of the NR which was 10.2°C on indoor air, 17.8°C on the inside and 19.1°C on the outside. The peak indoor temperature was over 50°C for the NR prototype. In the model with *pennisetum purpureum schamach* as the EGR, the maximum temperature was 40.1°C, while for *portulaca grandiflora* and *tradescantia spathacea* the peaks were 37.6°C and 37.5°C, respectively. This shows that plants with large leaf widths are able to reduce heat greater than plants with small leaf widths.

1. Introduction

The process of urbanization that occurs in urban areas has an influence on the increase in population. This urbanization process results in the conversion of undeveloped land into built-up land which has an impact on microclimate changes where the air temperature in urban areas is higher than the surrounding air temperature [1]. This phenomenon is often called Urban Heat Island (UHI), which is the high concentration of heat in urban areas, so the temperature in cities tends to be hotter than rural areas. Several factors that can trigger the occurrence of UHI in urban areas include the degree of heat of building materials, the height and distance between buildings, and the level of air pollution. During the day these factors can cause more solar energy to be captured, absorbed, and stored on urban surfaces than on rural surfaces. Meanwhile, at night, less energy is released, resulting in higher air temperatures in urban areas. Coupled with less evaporation that causes urban areas to become dry, with reduced coolness.

Around the world, different strategies are formulated to reduce UHI with two approaches namely increasing green area coverage and thermophysical properties, albedo, and emissivity of building envelope materials used in urban areas [2]-[3]. Heat mitigation strategies implemented in tropical climate areas include green infrastructure development, use of shade, modification of urban geometric structures, increase in albedo and use of water bodies. This becomes a study in an effort to reduce heat in tropical climates and identify the most effective heat reduction mitigation measures [4]. The cooling
impact of the application of green infrastructure in urban areas, both in the form of landscapes in the form of trees in road corridors, grass, and city parks as well as the application of green infrastructure on facades and roofs of buildings has been widely carried out in previous studies [5]-[6]-[7]-[8]. The application of a green roof is one of the strategies in the urban heat island mitigation effort because it is able to reduce urban temperatures and building temperatures. Placement of plants on the roof of buildings provides many ecological and economic benefits, including stormwater management, energy conservation, mitigating UHI effects and extending the life of roofing materials, as well as providing an aesthetically better environment [9]. The application of green roofs can reduce the urban heat island effect caused by various pollutants, improve living conditions, beautify the urban environment, and improve the quality of urban ecology [10]-[11]-[12].

Green roofs can be divided into three categories, namely extensive (extensive), semi-intensive (semi-intensive) and intensive (intensive). This category is based on weight, substrate layer thickness, maintenance, cost, plant species and irrigation system [13]. Extensive green roof (EGR) requires a shallow planting medium (soil), the plants used are light ornamental plants and relatively low maintenance costs. EGR is widely used in residential buildings because this green roof system model has a thin structural layer and the survival of vegetation is an important aspect that needs to be considered in relation to the selection of green roofs [14]. Research on green roof vegetation layers has become a hot issue in recent years by using sedum plants in the extensive green roof system (EGR) vegetation layer because of its efficient use of water, tolerance for extreme heat and drought conditions carried out on dry tropical and subtropical climate characteristics [15]-[16]-[17], but not all types of sedum plants used on green roofs are suitable for climatic characteristics in all regions [15]. Selection of plant species according to climatic characteristics can optimize the green roof ecosystem and increase environmental benefits [18].

This experimental study was conducted in Banda Aceh, which has a humid tropical climate by evaluating the extensive green roof of three types of vegetation with different growth forms and biomass structures. The cooling effect of the EGR was investigated with respect to temperature variations across the EGR layer. This study can provide information about the thermal performance of EGR using various types of vegetation and also the thermal performance of NR. This finding can also provide a scientific basis to support the movement to implement extensive green roofs in humid tropical cities as one of the urban heat island mitigation strategies.

2. Materials and methods

2.1. Experiment site

This Extensive Green Roof (EGR) experiment was conducted at the Syiah Kuala University Campus, Banda Aceh City, which is located in a humid tropical climate with latitude and longitude zones of 5°33'27.72"N, 95°19'19.92"E. The weather is dominated by a monsoon macro climate with monthly average temperatures for the wet season months ranging from 25°C to 29°C, and for summer months ranging from 30°C to 39°C. Annual rainfall in the Banda Aceh city area ranges from 1039 to 1907 millimeters. The humidity level in this area is between 70% to 80% [19].

2.2. Prototype model building

The test was carried out by making 3 units of the EGR experimental model in the form of a cubical test room with a size of 600 x 600 x 600 mm and 1 unit of an experimental model in the form of a concrete roof (normal roof / NR) with a size of 600 x 600 x 600 mm [20]. All EGR models with the same green roof system, but different types of plants. The EGR model is made of concrete with a 1% slope of the floor slab towards the drainage pipe with a diameter of 3/4' (Figure 1).
2.3. Plant parameter (plant materials and growth condition)
The types of plants used in EGR are ground cover plants and local shrubs in humid tropical climate conditions that are easy to grow and develop, resistant to heat and wind, resistant to pollution, require little water and fertilizer. Three types of plants are used as a green roof vegetation layer consisting of *Pennisetum purpureum schamach*, *Portulaca grandiflora*, and *Rhoeo discolor*. These three types of plants were chosen with the consideration that these types of plants are easy to grow, develop fast growth, are resistant to heat, and are easily available in the study area. The three types of plants can be seen in Figure 2.

2.4. Experimental design
Measurements were made by placing this EGR and NR test building prototype in direct sunlight and open air. The measurement variable is the response of each prototype model of the green roof building to air temperature, surface temperature, planting media temperature and heat flow. Temperature is measured using a thermocouple sensor connected to a data logger to read and record data during the measurement process and heat flow is also measured using a heat flux sensor attached to the bottom of the concrete plate of the test object. Data recording was carried out in 10 second intervals which lasted for 3 days from 9.00 am to 16.30 pm. Measurements were made in sunny weather conditions with sunlight not covered by clouds. Figure 3 and Table 1 details of measurement items and measurement points.
Figure 3. Extensive green roof layer structure and measurement points for temperature (thermocouple) and heat flow (heat flux sensor).

Table 1. Measurement items and instrument.

| Instrument | Measurement Variable |
|------------|-----------------------|
| Thermocouple (T type, 0.3 mm in diameter) | Ambient air temperature |
| | Surface medium temperature, buried about 0.5 cm in medium surface |
| | Medium temperature, buried in mid of medium |
| | Surface temperature concrete panel (inside and outside), pasted the sensors on the surface using aluminum |
| | Indoor air temperature |
| Heat Sensor (P01e, FluxTreq Instrument) | Heat Flux., pasted the sensors on the surface using aluminum |
| Data logger (GL800, Graphtec Instrument) | Data Acquisition |

3. Results and discussion

3.1. Extensive green roof temperature profile comparison

Based on the measurement results, it can be seen that the maximum indoor air temperature at the EGR for all measurement days is 37.9°C, 36.3°C, and 35.2°C, while at NR it reaches 50.4°C, 47.3°C, and 42.2 °C. There is a temperature difference between EGR and NR of 10.2°C. The maximum external surface NR temperature for all measurement days respectively reached 58.4°C, 54.8°C, and 47.0°C. The concrete surface absorbs solar energy from direct sunlight and is transferred to the space under the roof. There is no significant difference in temperature between the external surface and internal surface on the concrete roof where the variation is less than 1°C. The internal surface temperatures are 57.7°C, 53.9°C, and 46.4°C. On the other hand, the lowest peak temperatures were for external concrete panels (under growing media) of the green roof model, being 35.4°C, 34.1°C, and 33.4°C for all days respectively (Table 2). The green roof layer significantly reduces the heat gained by the concrete panels.
### Table 2. Maximum temperature on extensive green roof and normal roof.

| Temperature         | Normal Roof (°C) | Extensive Green Roof (°C) | Different (°C) |
|---------------------|------------------|---------------------------|----------------|
|                     | Day 1 | Day 2 | Day 3 | Day 1 | Day 2 | Day 3 |        |
| Indoor air          | 50.4  | 47.3  | 42.2  | 37.9  | 36.3  | 35.2  | 10.2   |
| Internal surface    | 57.7  | 53.9  | 46.7  | 36.3  | 34.7  | 34.0  | 17.8   |
| External surface    | 58.4  | 54.8  | 47.0  | 35.4  | 34.1  | 33.4  | 19.1   |

Compared to the NR model, the internal surface temperature of the EGR model is much smaller at its peak with an average temperature difference of 17.8°C. On the other hand, the indoor temperature is higher than the surface temperature of the concrete slab during the day and lower at night. This indicates that the green roof does not transmit heat to the room during the day and releases heat into the room at night. These results indicate that most of the solar energy is absorbed and released back into the environment by the green roof system and only a small amount of solar energy is stored and transmitted into the room.

### 3.2. Thermal performance of extensive green roof

The first stage involves investigating the room temperature and roof surface temperature with and without vegetation. The mechanism of solar radiation heat reduction by EGR is influenced by plant characteristics related to the ability to absorb and transmit heat into the room. In this study, three types of plants were used, namely *Pennisetum purpureum*, *Portulaca grandiflora*, and *Tradescantia spathacea*, as shown in Figure 4, each plant has different characteristics.

![Figure 4. Room temperature on the EGR prototype for various types of plants and room temperature on the NR prototype.](image)

The maximum indoor temperature was over 50°C for the NR prototype. In the EGR model with *Pennisetum purpureum* the maximum temperature is 40.1°C, while for *Portulaca grandiflora* and *Tradescantia spathacea* the peak points are 37.6°C and 37.5°C, respectively. A similar trend was also shown by the surface temperature of the inner panel with the hottest order being NR, EGR with *Pennisetum purpureum*, EGR with *Portulaca grandiflora*, and EGR with *Tradescantia spathacea*. This sequence is consistently shown by other temperature parameters, namely the temperature of the
soil surface (surface of the growing media) and the temperature in the plant media. This shows that the amount of heat radiation received by the roof system is influenced by the type of plant with their respective characteristics. In general, it can be described that the plant layers sequentially from thin to thick are *Pennisetum purpureum*, *Portulaca grandiflora*, and *Tradescantia spathacea* plants. This is in line with the rate of heat gain of each of these models. It can be concluded that the thickness of the plant layer affects the radiation heat resistance of the green roof system. The performance of green roofs significantly reduces heat gain in prototype buildings which is in line with the advantages of using green roofs put forward by various literatures, especially increasing the thermal performance of buildings in tropical climates.

![Figure 5](image1.png)

**Figure 5.** Surface temperature of the inner panel on EGR and NR prototype.

![Figure 6](image2.png)

**Figure 6.** The rate of heat flow through the roof panels into the EGR and NR prototype chambers.

Figure 6 shows the mechanism of heat transfer from the panel surface into the room for each building prototype based on the difference between the surface temperature and the indoor temperature. The temperature difference is directly proportional to the amount of heat transfer that occurs in a unit of time. The difference in panel surface temperature and room temperature where the positive difference during the day only occurs for the NR prototype. In the EGR prototype, the temperature difference is negative during the day. This can be interpreted that there is heat transfer
from the room to the roof panel because the surface temperature of the inner roof panel is lower than the room temperature. At night, the roof panel without plants, the temperature difference decreases rapidly until it reaches a negative value. This indicates that the concrete roof panel has the ability to store little heat. On the other hand, in the green roof system, at night there is a positive trend where the surface temperature of the panels is higher than the room temperature. This is because the planting medium has a better heat storage capacity than concrete. The heat flux is significantly reduced due to the evapotranspiration, shading, protective, photosynthetic and reflective effects of the vegetation layer as well as the insulation, absorption and evaporation effects of the green roof growing media layer.

4. Conclusions
Thermal test results show that the extensive green roof significantly reduces the heat load from solar radiation during the day. Extensive green roofs have a greater heat capacity and will release heat slowly at night, while during the day only a small amount of heat is transferred from the roof into the room, which is favorable conditions for tropical areas with high solar intensity throughout the year. Further studies are still needed for the practical application of roof systems such as inter-panel connection systems, water supply systems, green roof drainage systems, and various other technical aspects.

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