

# The Influence of Extensive Green Roofs on Roof Thermal Performance in Batu Pahat Climate



Mohd Norfekry Md. Yacob, Hartini Kasmin, Mohd. Khairul Adam Mohd. Kori, Wan Afnizan Wan Mohamed, Siti Nazahiyah Rahmat and Mohd. Shalahuddin Adnan

**Abstract** Climate change has increased global temperatures. When air temperature rises, it affects the condition of urban areas and creates discomfort among inhabitants of buildings. A potential sustainable approach to overcome the global warming issue is to implement green roof technology. This study aims to determine the effect of green roofs on roof thermal performance and to identify the best plant species which has the potential to lower temperatures. This study also determined the U-value, R-value, k-value and heat-flux parameters that constitute the thermal behaviour of green roofs. Three identical small-scale roof houses were constructed with one non-vegetated roof house as a control while the other two vegetated roof houses were planted with *Portulaca G.* and *Alternanthera P.*, respectively. Surface roof temperatures were collected from both inside and outside the roof of each house. Results show that the average differences in temperature inside the building between the control roof and the green roof were 0.02 °C and 0.22 °C for *Portulaca G.* and *Alternanthera P.*, respectively. Meanwhile, the average differences in temperature on the control roof and the green roof were 1.12 °C and 2.84 °C for *Portulaca G.* and *Alternanthera P.*, respectively. The heat flux value of *Alternanthera P.* roof is 3.15 w/m<sup>2</sup> better than *Portulaca G.* roof at 7.72 w/m<sup>2</sup>. This concludes that the roof with *Alternanthera P.* reduces heat that travels through the roof layer better than *Portulaca G.*

**Keywords** Green roof · Roof thermal behaviour · Climate changes · Thermal conductivity

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M. N. Md. Yacob · H. Kasmin (✉) · Mohd. K. A. Mohd. Kori · W. A. W. Mohamed · S. N. Rahmat · Mohd. S. Adnan  
Micropollutant Research Centre, Jabatan Kejuruteraan Air Dan Persekitaran,  
Fakulti Kejuruteraan Air dan Persekitaran, Universiti Tun Hussein Onn Malaysia,  
86400 Parit Raja, Batu Pahat, Johor, Malaysia  
e-mail: [hartini@uthm.edu.my](mailto:hartini@uthm.edu.my)

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## 1 Introduction

Roofs are one of the building elements most exposed to the sun as well as solar radiation [9]. Surface temperatures that rise above the ambient air temperature are a function of surface solar absorptance while surface temperatures that drop below ambient air temperature at night reflect the effect of radiative cooling such as a net heat loss by long-wave radiation to the night sky [30]. Urbanization has led to numerous global warming and climate change issues [20–22, 27] due to the increasing development of housing, buildings and town areas which also leads to increasing roof exposure to heat. At the same time, green areas such as forests that absorb more humidity are decreasing due to urbanization [8, 17]. Green roofs are widely known to have great potential in providing sustainable use of natural resources to reduce heat in urban areas [7, 12, 16, 29]. The presence of plants, soil and water generates different thermal properties in green roofs compared to conventional roofs [5]. Previous studies have shown the reduction of roof temperatures or heat transferred by focusing on each green roof layer and the soil media [14, 24], vegetation [3, 15, 19] and both of soil and vegetation [11]. A study by Issa et al. [14] generated the best net heat flux for a vegetated roof using two different soil media types, namely sand roof and silt clay roof at 4.7 W/m<sup>2</sup> and 7.8 W/m<sup>2</sup>, respectively. Their study used the experimental roof to record temperature data of 8 roof layers of a green roof system using thermocouples. In order to determine the thermal properties inside the composite roof material, they used a Dual-Needle Heat-Pulse sensor which employs the following transient conduction heat transfer equation [14]:

$$\rho c_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x} \left( k \frac{\partial T}{\partial x} \right) \quad (1)$$

where  $\rho$  is the material's average density and  $c_p$  is the material's specific heat. They measured the energy of the top soil layer using Fourier's Law.

Furthermore, Sandoval et al. [24] used the energy conservation equation to measure heat flow in a porous medium, taking into consideration the theory of fluid together with heat transport as follows:

$$C_p \frac{\partial T}{\partial t} + L_0 \frac{\partial \theta_v}{\partial z} = \frac{\partial}{\partial z} \left[ \lambda(\theta) \frac{\partial T}{\partial z} \right] - C_w q_1 \frac{\partial T}{\partial z} - L_0 \frac{\partial q_v}{\partial z} - C_v \frac{\partial}{\partial z} [q_v T] \quad (2)$$

where  $T$  is temperature;  $q_1$  is liquid flux density and  $q_v$  is vapor flux density;  $C_w$ ,  $C_p$  and  $C_v$  are the volumetric heat capacities of liquid water, moist soil and water vapour, respectively;  $\lambda(\theta)$  is soil apparent thermal conductivity and  $L_0$  is volumetric latent heat of vaporisation [24]. However, these studies [3, 5, 15, 19] only monitor temperature differences using different devices for continuous temperature monitoring. Three major thermal parameters which are the R-value (the thermal resistance value), the U-value (conduction heat transfer coefficient) and the k-value

(the thermal conductivity coefficient) need to be determined. The thermal properties of the green roof will then be evaluated based on temperature fluctuations and variation in heat fluxes. Therefore, following the simplest method used by previous studies, this paper examines the thermal performance of green roofs in Batu Pahat.

## 2 Materials and Methods

### 2.1 Experimental Setup and Instruments

This preliminary experiment was conducted at the Research Center for Soft Soil (RECESS), UTHM. Three identical small-scale houses were constructed using plywood material that represents the test model (Fig. 1a). Plywood is a common material used by researchers to make test models for their experiments [6, 10, 25]. The flat roof houses (at 10° slope for irrigation) were labelled as Roof A, Roof B and Roof C. The size and materials of the models should be considered as important parameters in the small-scale test. In some situations, a cubic model is used as a module for experiment. The plywood module used was 100 cm × 100 cm × 100 cm for the study thermal performance of green roofs and vertical greenery [10]. In two experiments formed and described by Binabid [6], the plywood test cell modules measured 122 cm × 122 cm × 122 cm. Test box samples by Schumann [25] had gable roof forms and they measured 175 cm × 150 cm × 100 cm. One of the experiments by Tobassom [28] used plywood models measuring 80 cm × 80 cm × 140 cm. The experiment focused more on vertical greenery systems and urban areas. Due to budget limitations, this experiment focused more on the effect of the roof's thermal on high rise buildings. The size of small-scale roof houses built was 80 cm (L) × 80 cm (W) × 140 cm (H) (Figs. 1a and 2). Roof A which was used as the control roof represents a conventional roof, also known as a non-vegetated roof. Meanwhile, Roof B and Roof C were vegetated roofs planted with a layer of *Portulaca grandiflora* (Japanese rose), also known as *Portulaca G.* and *Alternanthera paronychioides*, also known as *Alternanthera P.*, respectively. Each plant species was planted in a medium size polybag with compost soil as its medium. Retrofitting an existing bare roof with a simple green roof system might be advantageous due to its simple installation and portability [2]. Therefore, this study emphasises on the use of potted plants on rooftops in order to investigate thermal performance. All the plants were left to grow for a few weeks to ensure that they provide better shade for the roof with strong root grips. The selection of vegetation to be planted on the roofs depends on their flowering period and type of substrate these particular plants need [26].

All these three small-scale roof houses were then subjected to actual climatic conditions which include direct sunlight, wind and local rainfalls. Six units of basic USB Hygrometer data loggers (Fig. 1b) were used to collect data on temperature and humidity at intervals of 10 min due to budget restrictions. Two logger units



**Fig. 1** a Small-scale roof houses, b USB hygrometer data logger

were placed at each house to monitor both the outdoor (on the roof) and indoor (under the roof) temperatures of the roof surfaces (Fig. 2). The accuracy of surface temperatures recorded by USB Hygrometer data loggers is  $\pm 0.25$  °C between 0 and 50 °C and the measuring range is between  $-40$  and 105 °C. Although this study was conducted under a restricted budget, the use of simple instruments may still generate useful data which can be used in the future as a database.

## 2.2 *Analysing Thermal Performance*

Materials which have heat transference at low rates and high rates are known as insulators and conductors, respectively [13]. Three main thermal parameters which are normally used to measure green roofs as insulators are the R-value (the thermal resistance value), the U-value (conduction heat transfer coefficient) and the k-value (the thermal conductivity coefficient). Conduction occurs when heat is transferred between two different surfaces of a solid material with temperature difference whereas convection occurs when heat is transferred due to flowing liquid or gas [5]. Thermal conductivity is the heat transfer rate through a unit thickness of specific material per unit surface per unit temperature difference [4]. The presence of

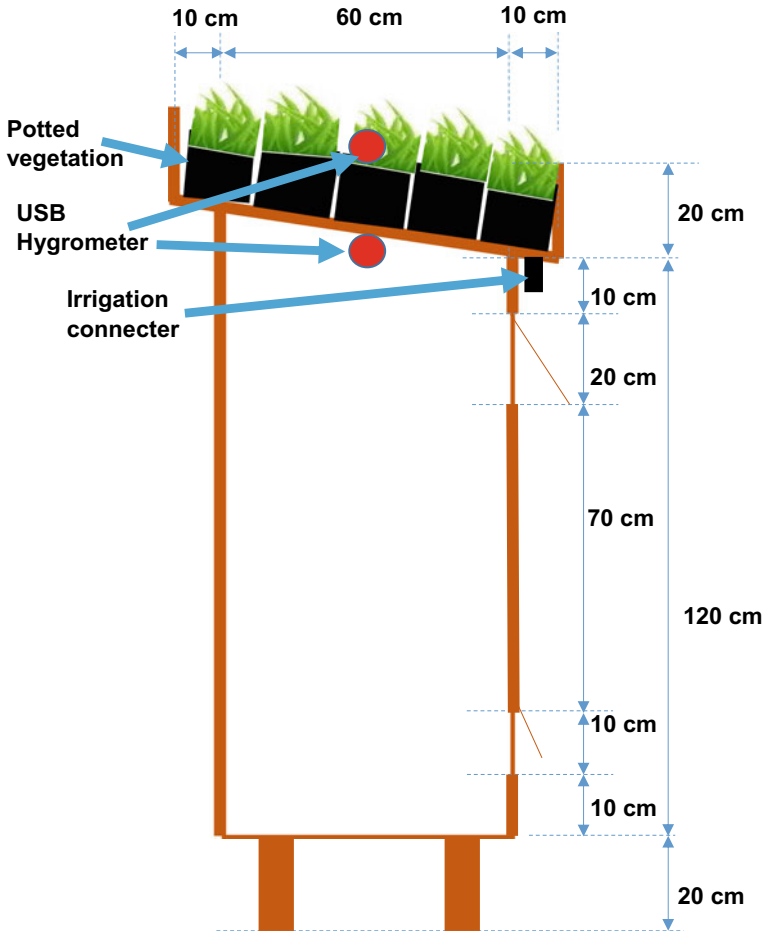


Fig. 2 The diagram of the housing system and the location of USB hygrometer data loggers

temperature difference is the basic requirement of heat transfer. Heat flux,  $q$ , is the heat transfer rate  $Q$  per unit area  $A$  and the average heat flux on a surface [5]. Heat flux comprises of the material and its temperature and the material's depth, where  $\Delta T$  is the temperature difference. A low heat flux means that there is less heat moving through the layer [5].

$$Q = \frac{\Delta T}{R} \quad (\text{W/m}^2) \tag{3}$$

According to Bahrami [4], heat transfer rate is the conduction that moves through the thickness of plane wall,  $\Delta x = L$  of its surface area,  $A$ ; over the

temperature difference between these two wall surfaces,  $\Delta T = T_2 - T_1$ ; such as the following:

$$\text{rate of heat transfer} \propto \frac{(\text{surface area})(\text{temperature difference})}{\text{thickness}} \quad (4)$$

$$Q = kA \frac{\Delta T}{\Delta x} \quad (\text{W}) \quad (5)$$

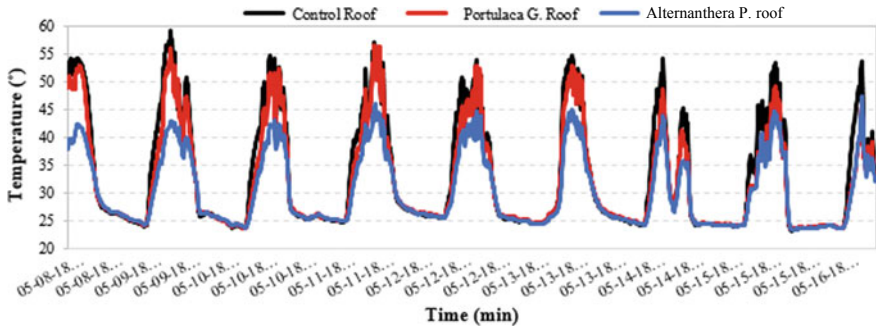
where  $k$  is the constant proportionality for material thermal conductivity. The higher the thermal conductivity, the greater the heat transfer. Thus, the thermal conductivity of a roof can be affected if the top of a roof is constructed with a layer of soil and plants as insulation. Previous studies about the  $k$ -values of green roof soil are limited. However, the  $k$ -value is normally based on the types and thickness of soils. The  $R$ -value (thermal resistance) is a measure of the opposition to heat transfer offered by a particular component surface of walls [18]. Green roof soil is predicted to provide better thermal insulation due to higher thermal resistance. Thermal resistance for the material is measured as follows:

$$R = L/k \quad (6)$$

where  $R$  is the thermal resistance of the material ( $\text{m}^2 \text{ K/W}$ ),  $L$  is the thickness of the material ( $\text{m}$ ) and  $k$  is the thermal conductivity of the material ( $\text{W/mK}$ ).  $U$ -value (thermal transmittance) is a measure of the overall rate of heat transfer through a particular wall surface [18]. The  $R$ -value (thermal resistance) normally represents the heat flow through soil. Heat flow for green roofs usually occurs from the outer surface of a green roof to the inner surface of the roof. The  $U$ -value ( $\text{W/m}^2 \text{ K}$ ) is measured as the following:

$$U = 1/R \quad (7)$$

All the  $U$ -values,  $R$ -values and  $k$ -values are determined based on soil moisture. The moisture presence could increase the thermal conductivity of soil ( $k$ -value) since water is a better conductor than air in voids whereas the  $R$ -value of soil should decrease [5]. However, when the soil is moist, evaporative cooling will be enhanced. In this study, the  $k$ -value refers to that of previous studies. Similar types of substrates and the thickness of extensive green roofs should be considered. By considering the moisture of the substrate of 33% due to the frequency of watering, the  $k$ -value used for this study is  $0.3 \text{ w/mK}$  [23] with green roof substrate used as the guideline.



**Fig. 3** Temperature fluctuation on the roof surface (outdoor) for all roof treatment types for a week

### 3 Results and Discussion

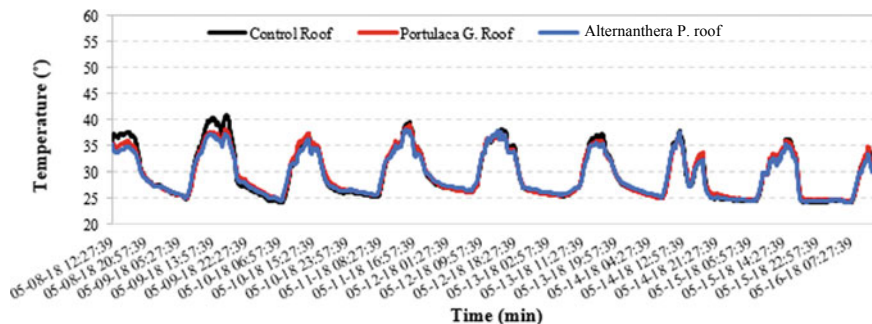
#### 3.1 Temperature Results of Roof Surface (Outdoor)

In this preliminary analysis, the experiments were only conducted for a week. Monitoring with a data interval of 10 min started from 8/5/2018 until 15/5/2018 using USB Hygrometer data loggers. Figure 3 shows the temperature results for outdoor measurements located at the rooftop of all the roof treatment types for a week. There were no drastic changes in temperature in a week. It reaches its peak temperature at 57.8 °C on 9/5/2018 where peak hours were between 12 p.m and 3 p.m.

A reduction in average temperature of 2.84 °C was recorded by the *Alternanthera P.* roof compared to the control roofs in a week. Meanwhile, the *Portulaca G.* roof had a reduction of 1.12 °C in average temperature. The average temperatures of the control roof, the *Portulaca G.* roof and the *Alternanthera P.* roof were 33.21 °C, 32.09 °C, and 30.37 °C, respectively. The highest value of 59 °C was obtained by the control roof. Meanwhile, the highest temperatures obtained by the *Portulaca G.* roof and the *Alternanthera P.* roof were 56.4 °C and 47.3 °C, respectively. In addition, the lowest values obtained in a week for the control roof, the *Portulaca G.* roof and the *Alternanthera P.* roof were 23.3 °C, 23.6 °C and 23.4 °C, respectively.

#### 3.2 Temperature Results Under Roof Surface (Indoor)

Figure 4 shows the temperature results from indoor measurements in a week for all the 3 roof houses. The values ranged between 47 and 23.4 °C for the indoor temperatures. This indicates that the presence of plants on the roof may reduce temperatures inside buildings. However, the outdoor temperatures still rose



**Fig. 4** Temperature fluctuation under the roof surface (indoor) for all roof treatment types for a week

everyday from 11 a.m. to 6 p.m. The temperatures later dropped at 6 p.m. The indoor average temperature results of the control roof, the *Portulaca G.* roof and the *Alternanthera P.* roof were 29.5 °C, 29.53 °C and 29.33 °C, respectively. The highest temperature observed on 9/5/2018 for indoor measurements was around 47 °C compared to the outdoor temperature of 59 °C which translate to a difference of 12 °C. On 9/5/2018, both the indoor and outdoor temperatures of control roofs were the highest compared to other roof types. The *Portulaca G.* roof had a similar outdoor temperature as the control roof, but it was 2 °C lower in terms indoor temperature compared to the control roof.

The *Alternanthera P.* roof had a reduction in temperature of 2.84 °C compared to the control roof in a week. Meanwhile, the *Portulaca G.* roof had a 1.12 °C reduction in temperature. The average temperatures of the control roof, the *Portulaca G.* roof and the *Alternanthera P.* roof were 33.21 °C, 32.09 °C and 30.37 °C, respectively. The highest value of 59 °C was obtained during the week by the control roof. Meanwhile, the highest values obtained by the *Portulaca G.* roof and the *Alternanthera P.* roof were 56.4 °C and 47.3 °C, respectively. In addition, the lowest values obtained during the week for the control roof, the *Portulaca G.* roof and the *Alternanthera P.* roof were 23.3 °C, 23.6 °C and 23.4 °C, respectively.

### 3.3 Temperature Differences Between the Inner and Outer Roof Surfaces for *Portulaca G.* and *Alternanthera P.*

Figure 5 shows the results obtained for temperature difference between the indoor roof surface and the outdoor roof surface for *Portulaca G.* The average temperature difference between indoor and outdoor roof surfaces for *Portulaca G.* was 2.55 °C.

Figure 6 shows the results obtained for the temperature difference between the indoor roof surface and the outdoor roof surface for *Alternanthera P.* The average temperature difference between the indoor surface and the outdoor surface for



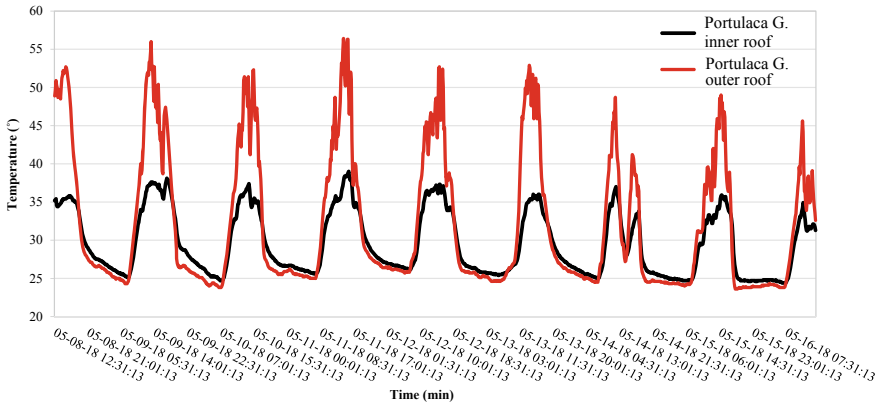


Fig. 5 Temperature differences between inner and outer roof surfaces of *Portulaca G.* for a week

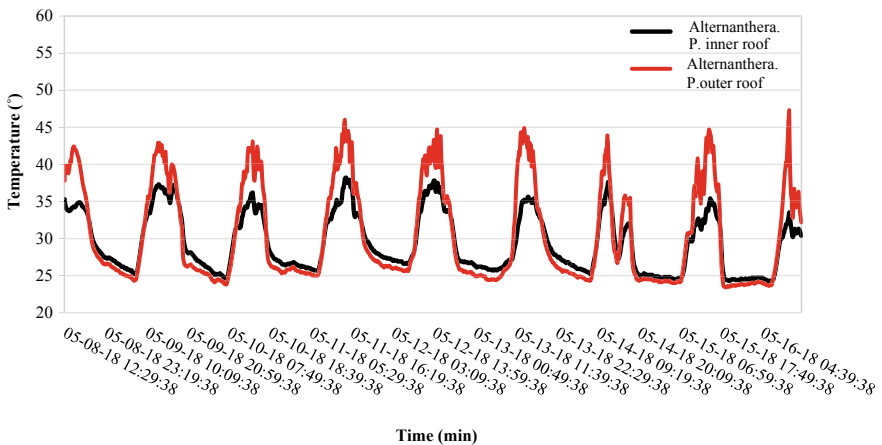


Fig. 6 Temperature differences between inner and outer roof surfaces of *Alternanthera P.* for a week

Table 1 The heat flux for the control roof and different green roof plants

Layer	Thickness layer (m)	K-value (W/mK)	R-value (m <sup>2</sup> K/W)	U-value = 1/R total (W/m <sup>2</sup> K)	ΔT (°C)	Heat flux q <sub>m</sub> = ΔT/R (W/m <sup>2</sup> )	Energy loss = q <sub>m</sub> × t <sub>m</sub> (MJ)
Plywood (control roof)	0.015	0.138	0.0001	10000	1.01	10100	6.9 × 10 <sup>9</sup>
<i>Portulaca G.</i> roof	0.100	0.300	0.3300	3.03	2.55	7.72	5.3 × 10 <sup>6</sup>
<i>Alternanthera P.</i> roof	0.100	0.300	0.3300	3.03	1.04	3.15	2.2 × 10 <sup>6</sup>

*Alternanthera P.* was 1.04 °C. This result shows that the heat conductivity of the *Alternanthera P.* roof is slightly less than that of the *Portulaca G.* roof.

Table 1 indicates the thermal conductivity of plywood at 0.138 W/mK [1] with a soil cover for *Portulaca G.* roof and *Alternanthera P.* roof at 0.30 W/mK [23] when

the moisture content of soil of 33% is taken into consideration. The heat flux values for *Portulaca G.* and *Alternanthera P.* were  $7.72 \text{ W/m}^2$  and  $3.15 \text{ W/m}^2$ , respectively. It shows that *Alternanthera P.* has a better heat flux than *Portulaca G.* This may be due to the physical characteristics of each vegetation.

## 4 Conclusions

From the results, the temperature reduction of small-scale green roof houses for all roof treatment does not show any major difference as the temperature difference recorded ranged between  $1.0$  and  $3.0 \text{ }^\circ\text{C}$  for both indoor and outdoor temperatures. Furthermore, the temperature difference between indoor and outdoor roof surfaces also recorded a similar range between  $1.0$  and  $3.0 \text{ }^\circ\text{C}$  for both vegetated roofs. This may be due to the size of the small scale houses where the wall temperature may affect the indoor temperature performance. Wall insulation should be taken into consideration for future experiments. Meteorological parameters can potentially influence the results and should be monitored in future studies. It is also suggested that vegetation with better shade, bigger leaves or shrubs may provide more temperature reduction. The thickness of the soil medium without polybags should be also considered as polybags might absorb more heat than normal rectangular boxes.

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