PERFORMANCE OF GROUNDCOVER ON SURFACE TEMPERATURE REDUCTION IN THE APPLICATION OF THE EXTENSIVE GREEN ROOF

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ABSTRACT

Malaysia's climate is struggling with unusually hot and dry weather from February to May 2016. Temperatures soared to the limits of a new record. One of the solutions is by having green roof to reduce the heat transfer in urban microclimate and buildings. Thus, the evaluation of potential plants in this study is to understand their performance in surface temperature reduction. In this study, the field measurements was carried out with ten types of groundcover and one exposed soil and one selected concrete flooring on three clear days. The measurement is taken from 8 AM to 6 PM and recorded at one-hour interval using an infrared thermometer. This study was done to compare the surface temperature of green roof and exposed bare roof within the same outdoor ambient environment. The result from this study indicates that Eremochloa ophiuroides and Rhoeo spathacea are suitable for planting in extensive rooftop system. Eremochloa ophiuroides and Rhoeo spathacea significantly provide the value of the average percentage of surface temperature reduction which was 18.9% and 18.8% respectively. Thus, it is recommended that both species are suitable for extensive roof planting. This knowledge can be applied by professionals in landscape architecture, horticulture, urban planning and design to provide better rooftop planting material in tropical urban environments.

Keywords: groundcover, turfgrass, surface temperature, extensive green roof, Axonopus, Cynodon dactylon, Digitaria didactyla, Eremochloa ophiuroides, Paspalum vaginatum, Zoysia japonica, Stenotaphrum secundatum, Sansevieria trifasciata 'Golden hahnii', Zephranthes candida, Rhoeo spathacea

1. INTRODUCTION

Green roofs have converted from a horticultural use to a flourishing growth industry because the environmental benefits of green roofs are now beyond dispute. Green roofs provide ecosystem facilities in cities; mitigate urban heat island effect (Mustapa & Yusop, 2006), improved urban biodiversity; improved run-off water management; and balancing of building temperature (Arabi & Khodabakhshi, 2014).

Malaysia is a developing country. The government is putting an effort in creating a green and beautiful environment. The high concentration of buildings in Malaysia has resulted in many environmental issues, such as the urban heat island effect, the flash flood on 21th May 2016 in Kuala Lumpur (Joash, 2016). The greening of buildings is essentially one of the ecological measures. Government incorporated landscaped rooftop gardens and other forms of Skyrise greenery in our urban landscapes. Green roof can reduce the effect of urban heat island and global warming in urban areas through the process of transpiration and humidify dry air (Mustapa & Yusop, 2006). This process provides a better climate for the occupants of adjacent apartments and buildings.

From February to May 2016, Malaysia has struggled with unusually hot and dry weather which has been brought on by the current El Nino (Joash, 2016). Temperatures soared to the limits of a new record. Temperatures in Malaysia soared above 37°C on 11th April 2016, prompting more than 250 schools to close. Kedah and Perlis recorded temperatures as high as 39.2°C. This unusual hot and dry weather local authorities to order schools in the states of Kedah and Perlis to shut temporarily. The decision was made to protect the health of around 100,000 pupils (Bernama, 2016). The country's capital, Kuala Lumpur, rarely sees highs vary beyond 32°C or 33°C throughout the entire year. Chuping, Perlis recorded an unusually high temperature on 20th March 2016 at 39.5°C.

Plant species of turfgrass and groundcover roofs have to survive drought, intense wind exposure, solar radiation, low nutrient supply, extreme temperatures, and limited root area (MacIvor & Lundholm, 2011). Groundcover is a popular solution for rooftop because it's low maintenance, aesthetically pleasing and fast growing, which minimizes the spread of weeds (Jing, 2014). Turf cools itself and its surroundings by the evapotranspiration process. Each grass blade acts as an evaporative cooler (McNitt, 2005). For this reason, turfgrass is also a popular choice for extensive rooftop system. This study is to testing new plants and adding planting list suitability for extensive green roof if possible.

Modern roof greening has two main types, extensive and intensive. Extensive roofs have a thin soil layer and feature succulent plants like sedums that can survive in harsh conditions. Extensive roofs require little maintenance once they are established, and are generally cost effective. Extensive Green Roofs are well suited to roofs with little load bearing capacity. The costs are lower and suitable for less demanding and low growing plant communities (MacIvor & Lundholm, 2011).

Since Malaysia is in this region hot-humid climate all the year round, it is particularly important to develop rooftop system to reduce the temperature (Bulbir, 2016). Extensive green roof application act as a passive cooling method in Malaysia (Zain-Ahmed, 2008). This paper presents field measurement in temperature which compare the cooling effect the green roof to the original exposed roof. These findings lead to a discussion on the potential of temperature reduction by applying extensive green roof.

The goal of this research is to study the surface temperature reduction performances of groundcovers on the concrete roof slab. In achieving this goal, there are two strategic objectives. It is to measure the reduction of surface temperature of groundcover in compare to a bare concrete slab. Besides, it is to compare types of groundcover in surface temperature reduction performances

Thus, two research questions were generated on how much reduction of surface temperature made by groundcovers in compare to concrete slab? Which type of groundcover performs better in reducing surface temperature?

2. MATERIALS AND METHODS

This study was carried out on the concrete ground slab at nursery Universiti Putra Malaysia, Serdang, Selangor, Malaysia due to absence of shade and not influence by any structural (building) shadow.

There were some limitations in this study, it is hard to get flat roof with no shade in this study. Green roof planting experiment needs an open roof and without any shades to act as control. Therefore, the concrete slab at nursery was being chosen to carry out the study. Next, due to the plant limitations and the sources available in this study, the planter boxes with 30cm X 40cm X 11cm in size were used. Plants were arranged properly, the layout shows in Figure 1A.

(A)

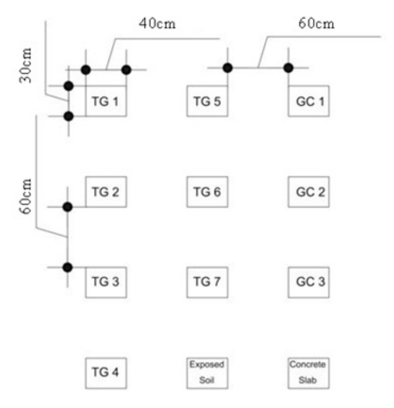

Figure 1 A: Arrangement of plant layout

Planter box was used in this research because it was easy to maintain, cost effective to construct, easy for drainage of rain water and had the lesser effect on the roof surface. Since the cost of construction of the actual green roof construction cost was higher than the planter box green roof, planter box green roof was used for this study.

In this study, the field measurements carried out with ten types of groundcover and one exposed soil and one selected concrete flooring on three clear and sunny days which are not cloudy. The measurement is taken from 8 AM to 6 PM. This was done to compare the surface temperature of green roof and open roof within the same condition of the outdoor ambient environment. The field measurements were measured using the infrared thermometer. The surface temperature was recorded at one hour interval. The data will be average for every hour to obtain the hourly values. The selected groundcover and turfgrass species shown in Table 1.

Table 1: Selected groundcover and turfgrass species

Sample	Scientific Name	Common Name
TG1	*Axonopus*	Cowgrass
TG2	*Cynodon dactylon*	Bermuda Grass
TG3	*Digitaria didactyla*	Serangoon Grass
TG4	*Eremochloa ophiuroides*	Centipede Grass
TG5	*Paspalum vaginatum*	Seashore Paspalum
TG6	*Zoysia japonica*	Japanese Lawngrass
TG7	*Stenotaphrum secundatum*	St.Augustine Grass Buffalo Grass
GC1	*Sansevieria trifasciata 'Golden hahnii'*	Golden Bird Nest Sansevieria
GC2	*Zephyranthes candida*	White Fair Lily
GC3	*Rhoeo spathacea*	*Oyster Plant*
Exposed Bare Soil		

Planter boxes with plants and exposed bare soil were arranged on the concrete flooring as shown in Figure 1B. Two pieces of bricks were placed below the planter boxes with six pieces of 12.5 mm of draining holes at the bottom. The gap between the planter box and concrete slab was for irrigation purposes. The distance from one planter box to another was 60 cm. The planter box was divided into four zones (A, B, C and D) to obtain the average (Jim, 2014) by ropes while concrete slab was divided by using tape in Figure 1C.

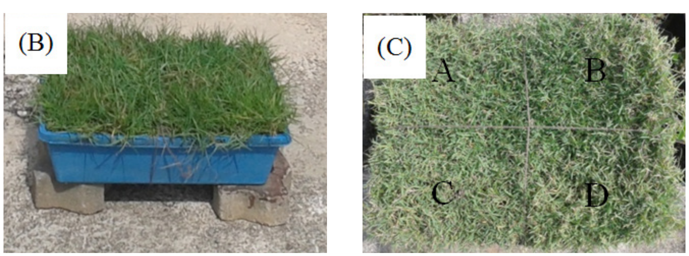

Figure 1: (B) Arrangement of planter box; (C) Four zones of plants A, B, C and D.

The measurements were carried out at 6th, 7th and 11th April 2016 with one hour interval (from 8 AM to 6 PM). The data was averaged for every hour to obtain the hourly readings. The field measurements were obtained using the Fluke 561 Infrared Thermometer at the height of 60 cm from plants (attached to a wood stick to standardize the measurement of distance).

3. RESULTS AND DISCUSSION

Relationship between Surface temperature and Time Frame

According to Figure 2 and Table 2 below, the exposed concrete slab act as a control in this study and exemplifies the average surface temperature scenario on flat concrete roofs that were common in Malaysia. Exposed concrete slab showed the highest surface temperature among all. The temperature rose from of 31.3°C at 8 AM to 44.8°C at 12 PM. Therefore the surface temperature rose quickly at the rate of 3.38°C per hour. The effect of the heated concrete floor surface on surface temperature occurs with a delay of about 3 hours after peak radiation at noon. The daily surface temperature pattern follows an extended bell shape, peaking at 47.5°C at 3 PM. Therefore the temperature rose constantly at the rate of 0.8°C per hour. The surface temperature drops rapidly from 47.5°C at 3 PM to 38.6°C at 6 PM. Therefore it cools down very rapidly at the rate of 3.2°C per hours.

At 8 AM, the moderate surface temperature was achieved by *C. dactylon* (TG2) and *Z. japonica* (TG6) at 28.9°C. *Z. japonica* (TG6) continue create the moderate temperature at 12 PM and 3 PM, 37.3°C and 39.4°C. At 6 PM, *C. dactylon* (TG2) showed the moderate surface temperature which was 31.8°C.

Z. candida (GC2) showed the lowest surface temperature, 28.0°C among all at 8 AM. During the early morning, groundcover develops a better canopy temperature inversion (CTI) than turfgrass. *E. ophiuroides* (TG4) showed the lowest at 12 PM which was 35.5°C. At 3 PM, *D. didactyla* (TG3) and *E. ophiuroides* (TG4) created the lowest surface temperature which was at 37.5°C while *D. didactyla* (TG3) shows the lowest surface temperature 30.7°C at 6 PM.

The exposed soil surface temperature began to rise quickly from 28.8°C to 40.5°C at 12 PM and reached the maximum of 47.5°C at 3 PM. It drops slowly to 33.8°C at 6 PM.

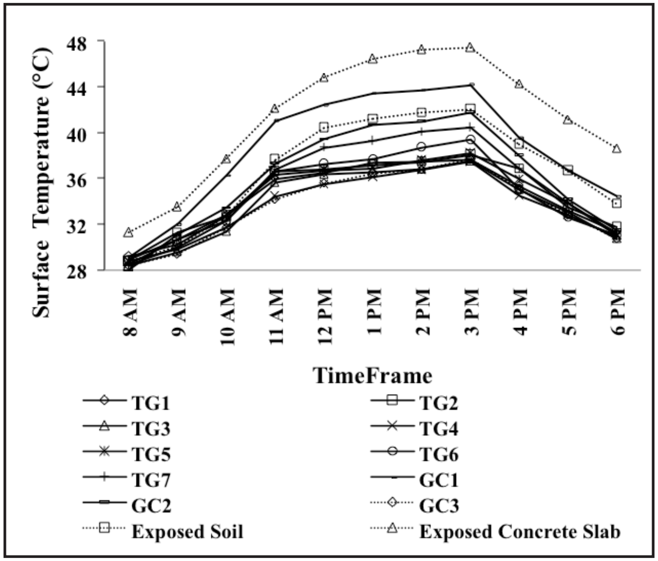

Figure 2 : Relationship between surface temperature and time frame for turf grasses, groundcovers, exposed soil and exposed concrete slab.

Note: TG1, *Axonopus;* TG2, *Cynodon dactylon;* TG3, *Digitaria didactyla;* TG4, *Eremochloa ophiuroides;* TG5, *Paspalum vaginatum;* TG6, *Zoysia japonica;* TG7, *Stenotaphrum secundatum;* GC1, *Sansevieria trifasciata 'Golden hahnii';* GC2, *Zephranthes candida;* GC3, *Rhoeo spathacea*

Table 2: Relationship between surface temperature and time frame

Sample	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM
TG1	29.2	31.2	33.5	36.0	36.9	37.4	37.5	37.7	35.4	33.2	31.3
TG2	28.9	31.3	32.7	36.7	36.8	37.2	37.5	38.1	36.9	33.5	31.8
TG3	28.4	29.6	31.4	35.6	36.4	36.6	36.8	37.5	35.0	33.1	30.7
TG4	28.6	29.9	31.7	34.4	35.5	[illegible]	36.7	37.3	34.3	32.8	31.0
TG5	28.5	30.6	32.9	36.4	36.7	36.9	37.6	38.2	36.0	33.9	31.0
TG6	28.9	30.7	32.3	36.6	37.3	37.7	38.7	39.1	[illegible]	32.6	31.1
TG7	28.5	30.0	32.3	36.8	38.7	39.3	40.1	40.5	36.9	33.8	31.2
GC1	29.1	32.0	36.3	[illegible]	42.4	43.4	43.7	44.2	39.6	36.7	34.4
GC2	28.0	31.1	33.4	37.3	39.4	40.7	41.0	41.8	38.0	34.2	31.3
GC3	28.4	29.5	[illegible]	34.2	35.6	36.3	36.8	37.7	[illegible]	32.8	30.8
Exposed Soil	28.6	30.2	32.7	37.7	40.5	[illegible]	41.8	42.1	39.0	36.7	33.8
Exposed Concrete Slab	31.3	33.6	37.7	[illegible]	44.8	46.5	47.3	47.5	44.3	41.1	38.6

The turfgrass can provide better cooling to the green roof with compare to groundcover or exposed soil roof. Turfgrass demonstrates more air cooling than groundcover and exposed soil. During the day, grass develops a miniature suspended temperature inversion (STI) (Dimoudi & Nikolopoulou, 2003). Grass has the simplest biomass structure, but it was more able to create passive air cooling. The grass plot has notably warmer soil than the groundcover plots. The daytime temperature-height gradient was more gradual than groundcover.

The daytime heating–cooling processes of groundcovers occur later than turfgrass; falling behind slightly in the morning warming and more in the afternoon cooling. In other words, it takes more time to warm the air and even more to cool it afterward. (Herrington, 1978; Akbari and Taha, 1992). Compared with the control or concrete floor the short delay in afternoon cooling was evident. Moreover, both the warming and cooling rates were faster than turfgrass (Akbari et al., 1992).

Relationship between average percentage of surface temperature reduction and groundcover samples

According to Figure 3 and Table 3, E. ophiuroides (TG4) create the highest value of an average percentage of surface temperature reduction among all which was 18.9%. This second highest value was followed by R. spathacea (GC3), 18.8% and D. didactyla (TG3), 18.4%. The turfgrass was more effective than groundcover in surface temperature reduction. Despite simple biomass structure, turfgrass cooled air more effectively than groundcover. Grass demonstrates more air cooling than groundcover and exposed soil (Dafis, 2001). During the day turfgrass cooled daytime near-ground air so as to develop a miniature suspended temperature inversion (STI).

S. trifasciata (GC1) create the lowest value of an average percentage of surface temperatre reduction, which was 7.0% only. This groundcover was less effective than other groundcovers in cooling itself because has more coverage of leaves. The plant temperature undergoes higher surface temperature because of the top denser coverage heat up more easily through irradiance and reach a higher temperature than others (Dunnett & Kingsbury, 2004).

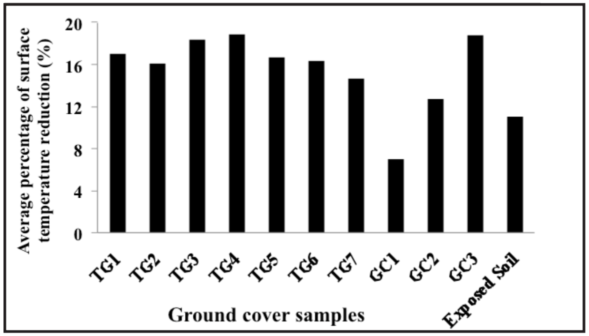

Figure 3 : Relationship between average percentage of surface temperature reduction and ground cover samples

Note: TG1, *Axonopus;* TG2, *Cynodon dactylon;* TG3, *Digitaria didactyla;* TG4, *Eremochloa ophiuroides;* TG5, *Paspalum vaginatum;* TG6, *Zoysia japonica;* TG7, *Stenotaphrum secundatum;* GC1, *Sansevieria trifasciata 'Golden hahnii';* GC2, *Zephranthes candida;* GC3, *Rhoeo spathacea*

Table 3: Relationship between average percentage of surface temperature reduction and groundcover samples

Groundcover Samples	Average Percentage of Surface Temperature Reduction (%)
TG1	17.0
TG2	16.1
TG3	18.4
TG4	18.9
TG5	16.7
TG6	16.4
TG7	14.7
GC1	7.0
GC2	12.8
GC3	18.8
Exposed Soil	11.1

Performance of Turfgrass in Surface Temperature Reduction

According to Figure 4 and Table 4 below, the reduction of surface temperature for turfgrass was obtained by comparing with the concrete which act as control in this study. At 8 AM, the highest reduction of surface temperature was achieved by *D. didactyla* (TG3) with 2.9°C while at 12 PM was created by *E. ophiuroides* (TG4) with 9.3°C. This reduction of surface temperature was followed by *D. didactyla* (TG3) and *E. ophiuroides* (TG4) with 10°C at 3 PM. The highest surface temperature reduction at 6 PM was achieved by *D. didactyla* (TG3) with 7.9°C. This showed that *D. didactyla* (TG3) and *E. ophiuroides* (TG4) works efficiently in reducing the surface temperature. Daytime thermal suppression due to latent heat extraction by active evaporation and transpiration from the grass field was more effective than the concrete floor, bare soil and groundcover.

Axonopus spp (TG1) showed the lowest performance in reduction at 8 AM and 6 PM with 2.1°C and 7.3°C. At 12 PM and 3 PM, *S. secundatum* (TG7) created the lowest reduction of surface tempertaure, 6.1°C and 7°C. *Axonopus spp* (TG1) and *S. secundatum* (TG7) showed the low performance in reducing the surface tempertaure of concrete slab. *Axonopus spp* (TG1) has the simplest biomass and can warm the near-ground air and surface temperature of the concrete slab than other turfgrass in the morning (MacIvor & Lundholm, 2011).

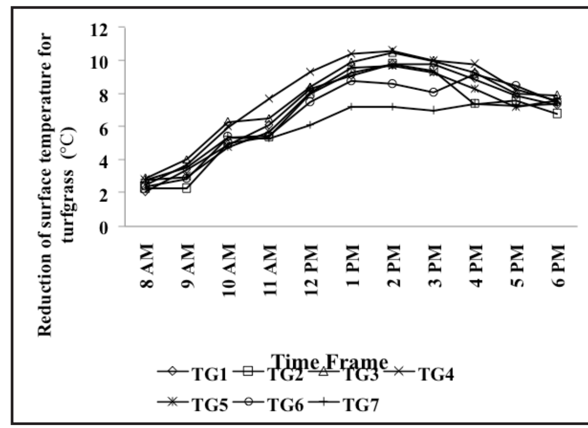

Figure 4 : Performance of Turfgrass in Surface Temperature Reduction

Note: TG1, *Axonopus;* TG2, *Cynodon dactylon;* TG3, *Digitaria didactyla;* TG4, *Eremochloa ophiuroides;* TG5, *Paspalum vaginatum;* TG6, *Zoysia japonica;* TG7, *Stenotaphrum secundatum;*

Table 4: Performance of turfgrass in surface temperature reduction

Sample	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM
TG1	2.1	3.4	4.9	6.1	8.3	9.1	9.8	9.8	8.9	7.9	7.3
TG2	2.4	2.3	5.0	5.4	8.0	9.3	9.8	9.4	7.4	7.6	6.8
TG3	2.9	4.0	6.3	6.5	8.4	9.9	10.5	10	9.3	8.0	7.9
TG4	2.5	3.7	6.0	7.7	9.3	10.4	10.6	10	9.8	8.3	7.6
TG5	2.8	3.0	4.8	5.7	8.1	9.6	9.7	9.3	8.3	7.2	7.6
TG6	2.4	2.9	5.4	5.5	7.5	8.8	8.6	8.1	9.2	8.5	7.5
TG7	2.8	3.6	5.4	5.3	6.1	7.2	7.2	7.0	7.4	7.3	7.4

Performance of Groundcover and Exposed Soil in Surface Temperature Reduction

Z. candida (GC2) perform well in reducing the surface tempertaure at 8 AM. It reduced 3.3°C of the concrete slab. *R. spathacea* (GC3) successfully reduced 9.2°C, 9.8°C and 7.8°C of concrete slab at 12 PM, 3 PM and 6 PM.

S. trifasciata (GC1) showed the lowest surface temperature reduction at 8 AM, 12 PM, 3PM and 6 PM, which was 2.2°C, 2.4°C, 3.3°C and 4.2°C. This groundcover was less effective than other groundcovers in cooling itself because it has more coverage of leaves. The plant temperature undergoes higher surface temperature because the top of denser coverage heat up more easily through irradiance and reach a higher temperature than others. The perennial herbaceous groundcover forms a dense and multiple-layered mat of living stems resting on the soil to support a surficial layer of foliage (Snodgrass & Snodgrass, 2006). The three-dimensional scaffold framework of living biomass on the soil surface with relatively more tissue moisture content creates a reservoir of thermal capacity. It takes more energy to raise the temperature of the groundcover than the simple ground-hugging turfgrass cover. Once warmed, it takes a longer time for them to cool down. The heat energy stored in the living tissues also pushes the maximum temperature to a relatively high level (White & Snodgrass, 2003).

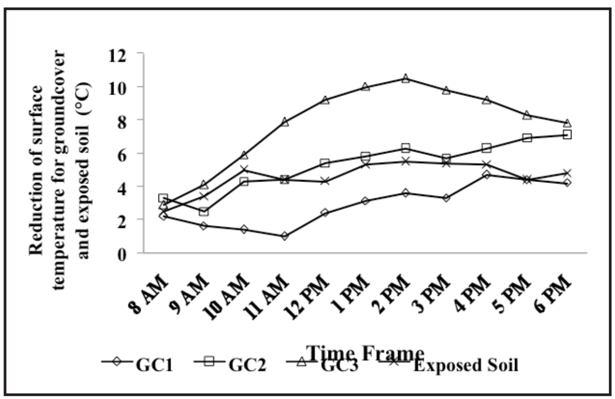

Figure 5 : Performance of Groundcover and Exposed Soil in Surface Temperature Reduction

Note: GC1, *Sansevieria trifasciata 'Golden hahnii';* GC2, *Zephranthes candida;* GC3, *Rhoeo spathacea*

Table 5: Performance of groundcover and exposed soil in surface temperature reduction

Tray	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM
GC1	2.2	1.6	1.4	1.0	2.4	3.1	3.6	3.3	4.7	4.4	4.2
GC2	3.3	2.5	4.3	4.4	5.4	5.8	6.3	5.7	6.3	6.9	7.1
GC3	2.9	4.1	5.9	7.9	9.2	10.0	10.5	9.8	9.2	8.3	7.8
Exposed Soil	2.5	3.4	5.0	4.4	4.3	5.3	5.5	5.4	5.3	4.4	4.8

4. CONCLUSIONS

This paper set out to illustrate the effectiveness of groundcovers and exposed soil in reducing surface temperature improving in hot, humid regions. This study has shown that turfgrass demonstrates better air cooling effect than groundcover and exposed soil. *E. ophiuroides* (TG4) is the suggested turfgrass to be applied in the green roof to reduce the surface temperature of building roof as create the highest value of average percentage of surface temperature reduction among all which was 18.9%. It is recommended that *R. spathacea* (GC3) as groundcover to be planted at building roof since it was significantly reduced the surface temperature of concrete slab to 18.8%.

The finding proved that *E. ophiuroides* (TG4) and *R. spathacea* (GC3) are the new planting material that suitable for extensive green roof. These two plants are recommended especially for green roof landscape that concern of microclimate moderation and building temperature modification. It is also recommended that the performance will be greater if arranged in clusters. The performance could provide better shading quality, suitable to moderate urban perforce and contribute to landscape architecture industry. In sum, the study suggests that *E. ophiuroides* (TG4) and *R. spathacea* (GC3) are two types of planting materials that suitable for planting in extensive rooftop system. This knowledge can be applied by professionals in landscape architecture, horticulture, urban planning and design to provide better rooftop system in tropical urban environments.

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