



# **Thermal Performance of *Setcreasea purpurea* and *Portulaca grandiflora* as a Green Roof Material Applied in a Tropical Climate**

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## **Authors' contributions**

*This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.*

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## **ABSTRACT**

The main objective of this paper is to present results on experimental fields about Green Roofs using two different plant materials such as *Setcreasea purpurea* and *Portulaca grandiflora*. It also describes how Green Roof is constructed in a tropical environment using available sustainable materials with the focus on Succulent plants. A Randomized Complete Design with three replications was used for the study. The main methodological procedure for collection of data was the installation of data loggers in nine (9) experimental test cells for (ten)10 months starting from November and ending August 2016 to record temperature and relative humidity in a time step of 6 (10 minutes). The experimental results shows that Succulent (*Setcreasea purpurea*) plants has the potential to reduce peak indoor temperature as compared to herbaceous plants such as *Portulaca grandiflora*. *Setcreasea purpurea* recorded the lowest temperature throughout the whole year. The study concluded that a reduction in mean temperature is 0.39°C annually ( $P \leq 0.05$ ).

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## 1. INTRODUCTION

A green roof according to Castleton et al. [1], is a layered system comprising of a waterproofing membrane, growing medium and the vegetation layer itself. Green roofs also comprises a roof barrier, drainage layer and where the climate necessitates; an irrigation system. There are two main classifications of green roofs; extensive and intensive. Extensive green roofs have a thin substrate layer with low level planting, typically sedum or lawn, and can be very lightweight in structure. Intensive green roofs have a deeper substrate layer to allow deeper rooting plants such as shrubs and trees to survive. Vijayaraghavan [2] traces this technology of planting vegetation on rooftops to the hanging gardens of Babylon constructed around 500 BC. The natural landscape has been significantly modified as a result of man's activities on earth. Various developmental programmes in the bid to make human life more comfortable have led to diverse activities which is unlikely to come to an end as humans continue to live on earth. Some of the activities includes infrastructural developments such as buildings, roads and others which replaces vegetation with impervious surfaces. The combined effect of the heat absorbing properties of such structures and that of the impervious surfaces results in higher temperatures indoors making it very uncomfortable [3].

The phenomenon of urban heat islands (UHI) refers to the situation where urban air temperatures are higher than their corresponding rural values [4] and this has been widely studied in developed countries. Such studies are however relatively new in Ghana and most likely same with many developing countries. The UHI effects are likely to have caught up with a fast growing city such as the Kumasi Metropolis. Planting of vegetation has been shown to be one of the strategies in mitigating UHI effects [5]. Vegetation plays an important role in the reduction of heat into a space there by enhancing thermal comfort in a space. Vegetative layer of a green roof is defined by several characteristics such as the plant height, leaf area index (LAI), fractional cover, albedo and stomatal resistance [6]. However for roofing purposes unless it is a pre vegetated green roof, the vegetation takes time to develop after being installed. Studies show that green roof with vegetation has more effect on the thermal

performance of a building as compared to green roofs without vegetation [7].

## 2. MATERIALS AND METHODS

### 2.1 Experimental Site

The site (Department of Horticulture-KNUST, Ghana) is in the semi-deciduous forest zone with an elevation of 186 m above sea level (ASL) and a bimodal rainfall distribution. The major rainy season is from late March to mid-July. There is a short dry spell from mid-July to mid-September followed by the minor rainy season from mid-September to mid-November. The mean annual rainfall is 1500 mm. The mean minimum and maximum temperatures are 21°C and 31°C, respectively. The soil at the experimental site is ferric Acrisol.

### 2.2 Experimental Design and Plant Selection for Green Roof

A Randomized Complete Block Design with three replications was used for the study. The plant selected and used as the plant material included *Portulaca grandiflora* (Portlacaceae) and *Setcreasea purpurea*. *Portulaca* (Plates 1, 2) is a low prostrate creeping plant with terele leaves of about 0.15 mm height. This plant was selected because is not fussy about soil and thrives well even in poor soil. Its propagation is simply by division and even with a soil thickness of 50 mm it can survive. It has a leaf area index of 2.39 cm<sup>2</sup>.

*Setcreasea purpurea* a native of Mexico, is a prostrate plant, about 0.3 m high. Its stem and leaves are purple. Its produces violet flowers which are open in the morning and closes in the afternnon. It does well in direct sun light. It has a leaf area index of 3.488 cm<sup>2</sup> (Table 1).

#### 2.2.1 Test cells

##### 2.2.1.1 Location of test cells

The Test cells were constructed at the Department of Horticulture at the Kwame Nkrumah University of Science and Technology. Plate 3 is a map location showing where the experimental test cells are located. To avoid over shadowing on the test cells, they were located at a place where adjacent buildings was not a problem.

**Table 1. Leaf area index of selected plants: Author’s construct**

Name of plant	Leaf area index	Effective leaf area index	Canopy cover
<i>Portulaca</i>	3.79	2.391	0.850
<i>Setcreasea</i>	3.488	3.488	1

- Leaf Area Index (LAI): Total one -sided area of leaf tissue per unit ground area.
- Effective Leaf Area Index (LAI<sub>e</sub>): LAI corrected by the clumping index.
- Canopy Cover: Percentage of ground area covered by the vertical projection of the canopy.
- Clumping Index: Ratio of effective plant or leaf area index to the actual plant or leaf area index [8]



**Plate 1. *Portulaca grandiflora***



**Plate 2. *Setcreasea purpurea***

#### 2.2.1.2 Construction of test cells

The nine test cells were oriented on the north south azimuth. Detail drawings are showed in Plates 4, 5 and 6. The walls for both the control and experimental cells are made of 20 mm thick cement mortar render for both external and internal wall of 150 mm sandcrete block with a

mixture ratio of 1:2:4. The floor of the cells is made of mass concrete (cement, sand and stone) aggregate with a ratio of 1:2:4.

The roof of the control was constructed with 50 mm x 100 mm wooden rafter at 600 mm center to center interval with a wooden purlin size of 50 mm x 75 mm. It was then covered with colourlink

premium aluzin 0.4 mm long span minor red roofing sheet. The experimental cell (Green Roof) was the extensive type of green roof. Its roof construction is made up of 12 mm thick plywood fixed on 50 mm x 100 mm rafters and 50 mm x 75 mm purlin. 0.01 mm back polythene was then fixed on the plywood to act as a waterproof membrane. Also 12 mm size chippings are placed on the waterproof membrane to act as a drainage layer when there

is excess water. A geo textiles material was then fixed on the drainage layer to act as root barrier.

Top soil was obtained from the Department of Horticulture and sieved to remove any debris and stones. Each green roof test cell roof top was filled with 0.15 m<sup>3</sup> of sandy loamy soil. The soil was characterised at the Department of Crop and Soil Science laboratory as within the ferric Acrisol.

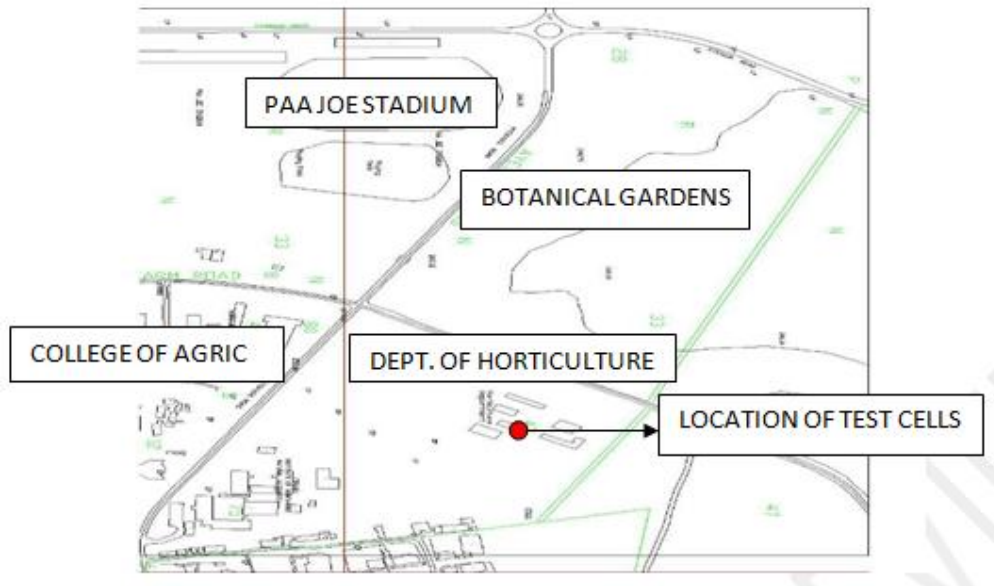


Plate 3. Map of sector of KNUST teaching area

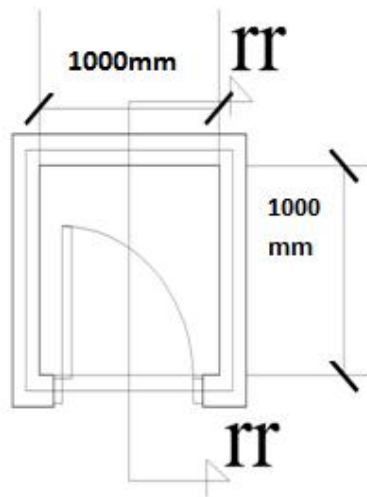


Plate 4. Floor plan (mm)

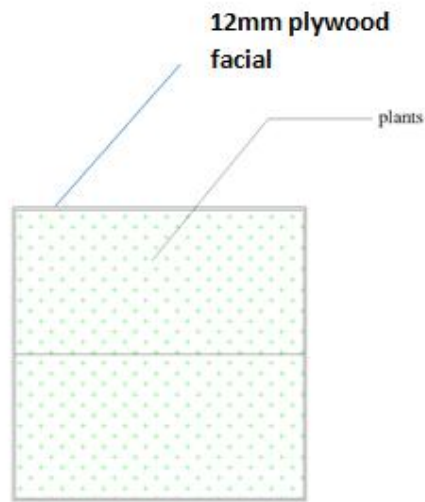


Plate 5. Roof plan (mm)



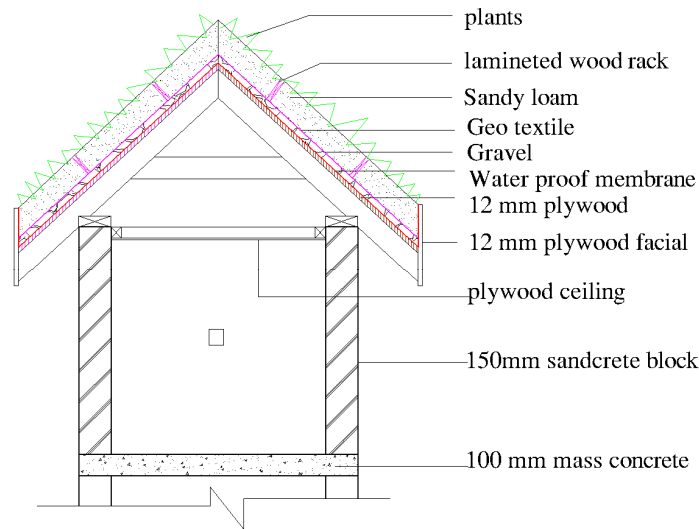


Plate 6. Section r-r

### 3. RESULTS

#### 3.1 Effect of Plant Type on Mean Temperature

For January, there were significant differences ( $P \leq 0.05$ ) between the treatments where the control had the highest temperature and the least was recorded by *Setcreasea*. This observation followed a similar trend to the month of December (Table 2).

#### 3.2 Effect of Plant Type on Mean Relative Humidity

January, February to May, showed significant differences ( $P \leq 0.05$ ) between the treatments where the control had the lowest relative humidity and the highest was recorded by *Setcreasea* for the month of March, April and May. Also, *Portulaca* recorded the highest relative humidity in the month of January and February. From June, July and November there were significant differences ( $P \leq 0.05$ ) between the treatments where the control and *Portulaca* had the lowest relative humidity and the highest was recorded by *Setcreasea* for the month of June to December. Also *Portulaca* recorded the highest relative humidity in the month of December (Table 3).

### 4. DISCUSSION OF RESULTS

Significant differences in indoor temperature of the test cells were indicative of the impact of roofing material on indoor temperature. Aluzinc being a high conducting material allows heat to

be transmitted easily as compared to green roof which is made up of layers of soil and vegetation which has the potential to reduce indoor temperature [9].

In comparing *Setcreasea purpurea* and *Portulaca grandiflora* (Table 2), low temperatures values were recorded by *Setcreasea purpurea*. This reduction in mean temperature is  $0.39^\circ\text{C}$  annually ( $P \leq 0.05$ ).

Vegetative layer of a green roof is defined by several characteristics [7] such as plant height, leaf area index (LAI), fractional cover, albedo and stomatal resistance of the plant [6]. These factors indeed influenced the efficiency of the ground covers used on the test cells. The presence of vegetation on a roof creates a specific microclimate at the site. Hoffman and Henn [10] suggested that the top of the roof have a different microclimate as compared to the grade surrounding the building. This is achieved as a result of the physiological processes the plant goes through by the process of evapotranspiration which increases the humidity around the building.

The sun energy falling on surfaces such as concrete, asphalt or other hard surfaces is radiated back as heat [11]. The characteristics of succulents (*Setcreasea purpurea*) such as coated and waxy leaves help prevent water lost. This also slows air movement out of the surface of the leaves through transpiration. The stomata of *Setcreasea purpurea* because of the waxy leaves opens only at night and absorb carbon dioxide

**Table 2. Effect of plant type on mean temperature from January to December**

Treatments	Measured mean temperature(°C)									
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Nov	Dec
<i>Portulaca</i>	26.82b	26.87b	31.52b	30.83b	30.56b	28.40b	28.40b	26.36b	28.43b	28.93b
<i>Setcresea</i>	26.60c	26.60c	31.36c	30.57c	30.13c	28.15c	28.15c	26.32c	28.33c	28.72c
Control	26.83a	26.82a	31.75a	31.07a	30.86a	28.61a	28.61a	26.59a	28.58a	29.09a
Lsd	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

Key: The shaded brown areas represent dry season and the blue shaded areas represent wet season

**Table 3. Effect of plant type on mean relative humidity from January to December**

Treatments	Measured mean relative humidity									
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Nov	Dec
<i>Portulaca</i>	47.96a	64.03a	71.08b	72.39b	73.33b	73.33b	77.37b	80.14b	80.46c	74.81a
<i>Setcresea</i>	40.50b	62.03b	73.15a	76.28a	76.21a	76.21a	81.38a	83.40a	87.72a	78.21a
Control	38.92c	59.23c	69.94c	71.48c	72.51c	72.52c	76.14c	80.71ab	80.65b	68.55b
Lsd	0.03	0.03	0.03	0.03	0.08	0.03	0.03	2.74	0.03	3.41

Key: The shaded brown areas represent dry season and the blue shaded areas represent wet season

**Table 4. Effect of *Portulaca grandiflora* on energy and temperature savings (Air-condition)**

Treatments	Simulated mean temperature (°c) and energy savings (air condition usage)									
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Nov	Dec
<i>Portulaca</i>	26.82b	26.87b	31.52b	30.83b	30.56b	28.40b	28.40b	26.36b	28.43b	28.93b
Control	26.83a	26.82a	31.75a	31.07a	30.86a	28.61a	28.61a	26.59a	28.58a	29.09a
Difference	0.01	0.05	0.23	0.24	0.3	0.21	0.21	0.23	0.15	0.16
Energy Savings(%)	0.16%	0.8%	3.68%	3.84%	4.8%	3.36%	3.36%	3.68%	2.4%	2.56%

Assumption: For every decrease in internal building air temperature of 0.5°C may reduce electricity use for air-conditioning up to 8% [12]

**Table 5. Effect of *Setcresea purpurea* on energy and temperature savings (Air-condition usage)**

Treatments	Simulated mean temperature (°c) and energy savings(air condition usage)									
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Nov	Dec
<i>Setcresea</i>	26.60c	26.60c	31.36c	30.57c	30.13c	28.15c	28.15c	26.32c	28.33c	28.72c
Control	26.83a	26.82a	31.75a	31.07a	30.86a	28.61a	28.61a	26.59a	28.58a	29.09a
Difference	0.23	0.22	0.39	0.5	0.73	0.46	0.46	0.27	0.25	0.36
Energy savings (%)	3.68%	3.52%	6.24%	8%	7.36%	7.36%	7.36%	4.32%	4%	5.76%

Key: The shaded blue areas indicate the thermal comfort zones from January to December on the table and the yellow represent the possible energy savings

and use it at night. This phenomena helps the plant reduce its metabolism rate, keeping and maintain moist internal tissues. Kim and Lieth [13] studies reveal that during the hot sunny day, since the stomata do not open but opens only at night (crassulacean), much water is not lost through transpiration. This water is stored in the roots making the soil moist.

The above assertion is confirmed by Minke [11] that, of the total light energy that falls on a leaf, 2% is used for photosynthesis, 48% goes through the leaf and stored in the plant water system, 30% is translated into heat by transpiration and 20% is reflected away. *Setcreasea purpurea* due to its inherent characteristics is able to reduce temperature than *Portulaca grandiflora* (Table 2) because of its broad, thicker, waxy nature of leaves and water storing tissues in the plant.

The ability of the plant (*Setcreasea purpurea*) to reduce indoor temperature (Table 2) has the potential to reduce energy consumption in terms of air condition and mechanical ventilators usage (Table 5). Studies by Dunnett and Kingsbury [12], suggested that for a every drop in temperature of about 0.5°C, it leads to energy savings in terms of electricity usage for air conditions of about 8%. Pecks, 1999 also indicated that green roofs have the potential to reduce indoor temperature of about 3°C to 4°C when outdoor temperatures are between 25°C and 30°C. The studies by several authors [12,14] conforms to the reduction of 7% when there is a drop of 0.37°C (Table 5) in mean indoor temperature.

Thermal comfort is defined as the acceptable temperature, humidity and air velocity conditions inside a building [15]. A comfort range of 23°C to 29°C was suggested by Olgay [16]. Ashrae [17] also recommended 23°C to 26°C as the thermal comfort zone for the tropics. From the about studies on thermal comfort, it can be concluded that temperatures and relative humidity recorded by *Setcreasea purpurea* and *Portulaca grandiflora* falls within the thermal comfort zone (Tables 4 and 5) in the month of January, February, June, July, August, November and December. The months March, April and May falls outside the comfort zone and will need mechanical ventilation to make occupants comfortable.

## 5. CONCLUSION

Green Roofs have the potential in reducing peak indoor temperatures in the tropics. The level of

reduction depends on a number of factors such plant material, media used, insulative material and others. The study was limited to the type of plant material and its impact on peak indoor temperature. From the study, it is indicated that *Setcreasea* which belongs to the family of Succulents has the ability to reduce peak indoor temperatures as compared to herbaceous plants such as *portulaca* in the tropics.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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