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 were 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. Setcresea purpurea recorded the lowest temperature throughout the whole year. The study concluded that a reduction in mean temperature is 0.39 °C annually (P≤0.05).

Key words: Thermal performance, Green Roofs and Tropical Climate.

1.0 Introduction

A green roof according to [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. [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 has 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].
2.0 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 186m 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 1500mm. 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 (Portulacaceae) and Setcreasea purpurea. Portulaca is a low prostrate creeping plant with terele leaves of about 0.15mm 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 50mm it can survive. It has a leaf area index of 2.39cm².

Setcreasea purpurea a native of Mexico, is a prostrate plant, about 0.3m high. Its stem and leaves are purple. Its produces violet flowers which are open in the morning and closes in the afternoon. It does well in direct sun light. It has a leaf area index of 3.488cm².

Plate 1: Portulaca Grandiflora
Table 1: Leaf Area Index of Plants. Authors' construct.

<table>
<thead>
<tr>
<th>Name of Plant Cover</th>
<th>Leaf Area Index (LAI)</th>
<th>Effective Leaf Area Index (LAI_e)</th>
<th>Canopy Cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portulaca</td>
<td>3.79</td>
<td>2.391</td>
<td>0.850</td>
</tr>
<tr>
<td>Setcresea</td>
<td>3.488</td>
<td>3.488</td>
<td>1</td>
</tr>
</tbody>
</table>

- Leaf Area Index (LAI): Total one-sided area of leaf tissue per unit ground area.
- Effective Leaf Area Index (LAI_e): 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]
2.20 Test cells

2.2.1 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.

Plate 3: Map of sector of KNUST teaching area.

2.2.2 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 20mm thick cement mortar render for both external and internal wall of 150mm sandcrete block with a mixture ratio of 1:2:4. The floor of the cells are made of mass concrete (cement, sand and stone) aggregate with a ratio of 1:2:4.

The roof of the control was constructed with 50mm x 100mm wooden rafter at 600mm center to center interval with a wooden purlin size of 50mm x 75mm. It was then covered with colourlink premium aluzin 0.4mm 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 12mm thick plywood fixed on 50mm x 100mm rafters and 50mm x 75mm purlin. 0.01mm back polythene was then fixed on the plywood to act as a waterproof membrane. Also 12mm size chippings is 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 0.15m³ of sandy loamy soil. The soil was characterised at the Department of Crop and Soil Science laboratory as within the ferric Acrisol.

Plate 4: Floor plan

Plate 5: Roof plan
Plate 6: Section r-r

- plants
- laminated wood rafter
- Sandy loam
- Geo textile
- Gravel
- Waterproof membrane
- 12 mm plywood
- 12 mm plywood facial
- Plywood ceiling
- 150mm sandcrete block
- 100 mm mass concrete
3.0 Results

3.1 Effect of plant type on mean temperature
For January, there were significant differences (P≤0.05) between the treatments where the control had the highest temperature and the least was recorded by Setcresea. 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≤0.05) between the treatments where the control had the lowest relative humidity and the highest was recorded by Setcresea 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≤0.05) between the treatments where the control and Portulaca had the lowest relative humidity and the highest was recorded by Setcresea for the month of June to December. Also Portulaca recorded the highest relative humidity in the month of December (Table 3).

<table>
<thead>
<tr>
<th>MEASURED MEAN TEMPERATURE( °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TREATMENTS</strong></td>
</tr>
<tr>
<td><strong>JAN</strong></td>
</tr>
<tr>
<td>Portulaca</td>
</tr>
<tr>
<td>Setcresea</td>
</tr>
<tr>
<td>Control</td>
</tr>
<tr>
<td>Lsd</td>
</tr>
</tbody>
</table>

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

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.

<table>
<thead>
<tr>
<th>TREATMENTS</th>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
<th>NOV</th>
<th>DEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portulaca</td>
<td>47.96a</td>
<td>64.03a</td>
<td>71.08b</td>
<td>72.39b</td>
<td>73.33b</td>
<td>73.33b</td>
<td>77.37b</td>
<td>80.14b</td>
<td>80.46c</td>
<td>74.81a</td>
</tr>
<tr>
<td>Setcresea</td>
<td>40.50b</td>
<td>62.03b</td>
<td>73.15a</td>
<td>76.28a</td>
<td>76.21a</td>
<td>76.21a</td>
<td>81.38a</td>
<td>83.40a</td>
<td>87.72a</td>
<td>78.21a</td>
</tr>
<tr>
<td>Control</td>
<td>38.92c</td>
<td>59.23c</td>
<td>69.94c</td>
<td>71.48c</td>
<td>72.51c</td>
<td>72.52c</td>
<td>76.14c</td>
<td>80.71ab</td>
<td>80.65b</td>
<td>68.55b</td>
</tr>
<tr>
<td>Lsd</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.08</td>
<td>0.03</td>
<td>0.03</td>
<td>2.74</td>
<td>0.03</td>
<td>3.41</td>
</tr>
</tbody>
</table>

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)

Assumption

For every decrease in internal building air temperature of 0.5°C may reduce electricity use for air-conditioning up to 8% [9]

<table>
<thead>
<tr>
<th>TREATMENTS</th>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
<th>NOV</th>
<th>DEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portulaca</td>
<td>26.82b</td>
<td>26.87b</td>
<td>31.52b</td>
<td>30.83b</td>
<td>30.56b</td>
<td>28.40b</td>
<td>28.40b</td>
<td>26.36b</td>
<td>28.43b</td>
<td>28.93b</td>
</tr>
<tr>
<td>Control</td>
<td>26.83a</td>
<td>26.82a</td>
<td>31.75a</td>
<td>31.07a</td>
<td>30.86a</td>
<td>28.61a</td>
<td>28.61a</td>
<td>26.59a</td>
<td>28.58a</td>
<td>29.09a</td>
</tr>
<tr>
<td>Difference</td>
<td>0.01</td>
<td>0.05</td>
<td>0.23</td>
<td>0.24</td>
<td>0.3</td>
<td>0.21</td>
<td>0.21</td>
<td>0.23</td>
<td>0.15</td>
<td>0.16</td>
</tr>
<tr>
<td>Energy Savings(%)</td>
<td>0.16%</td>
<td>0.8%</td>
<td>3.68%</td>
<td>3.84%</td>
<td>4.8%</td>
<td>3.36%</td>
<td>3.36%</td>
<td>3.68%</td>
<td>2.4%</td>
<td>2.56%</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>TREATMENTS</th>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
<th>NOV</th>
<th>DEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setcresea</td>
<td>26.60c</td>
<td>26.60c</td>
<td>31.36c</td>
<td>30.57c</td>
<td>30.13c</td>
<td>28.15c</td>
<td>28.15c</td>
<td>26.32c</td>
<td>28.33c</td>
<td>28.72c</td>
</tr>
<tr>
<td>Control</td>
<td>26.83a</td>
<td>26.82a</td>
<td>31.75a</td>
<td>31.07a</td>
<td>30.86a</td>
<td>28.61a</td>
<td>28.61a</td>
<td>26.59a</td>
<td>28.58a</td>
<td>29.09a</td>
</tr>
<tr>
<td>Difference</td>
<td>0.23</td>
<td>0.22</td>
<td>0.39</td>
<td>0.5</td>
<td>0.73</td>
<td>0.46</td>
<td>0.46</td>
<td>0.27</td>
<td>0.25</td>
<td>0.36</td>
</tr>
<tr>
<td>Energy</td>
<td>3.68%</td>
<td>3.52%</td>
<td>6.24%</td>
<td>8%</td>
<td>7.36%</td>
<td>7.36%</td>
<td>7.36%</td>
<td>4.32%</td>
<td>4%</td>
<td>5.76%</td>
</tr>
</tbody>
</table>

4.0 Discussions 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 [10].

In comparing Setcresea purpurea and Portulaca grandiflora (Table 2), low temperatures values were recorded by Setcresea purpurea. This reduction in mean temperature is 0.39 °C annually (P≤0.05). Vegetative layer of a green roof is defined by several characteristics (Olivieri et al., 2013) [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. [11] 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 [12]. The characteristics of succulents (Setcresea 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 Setcresea purpurea because of the waxy leaves opens only at night and absorb carbon dioxide and use it at night. This phenomena helps the plant reduce its metabolism rate, keeping and maintain moist internal tissues. [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 [12] 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. This explains why Setcresea purpurea is able to reduce temperature than Portulaca grandiflora (Table 2) because of its broad and thicker leaves, waxy nature of leaves and water storing tissues in the plant.

The ability of the plant (Setcresea 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 [9], suggested that for 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) [9] and [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 [16]. [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 Setcresea purpurea and Portulaca grandiflora falls within the thermal comfort zone (Table 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.

5.0 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 Setcrecea 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.

REFERENCES


