TOWARDS GREENER CITIES; INVESTIGATING THE POTENTIALS OF VERTICAL GREENING IN TROPICS AS A DESIGN APPROACH TO CREATE SUSTAINABLE URBAN ENVIRONMENTS

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Abstract

The rapid population acceleration and urbanization pressurize the need of more living places leading to considerably high artificial constructed structures and comparatively less vegetation. Vertical greening is identified and implemented as an interesting integration in improving urban environmental quality and life standards. Energy saving, influencing biodiversity, noise attenuation and many more benefits are associated with the vertical greening. In Sri Lankan context the practice of vertical greening is still at an initial stage and the knowledge on the system is very limited. The paper presents the results of experimental design conducted to identify plant performance to select a plant species for vertical greening in local context. Twelve plant species were selected for the study. Plant health was rated for all plants using a 3 point scale. 1 = thriving, 2 = alive, but with signs of pest, disease or other stresses, 3 = dead. Plant height and leaf area were measured along with visual assessments of plant development stages and pest/disease incidence. Temperature reduction was measured for selected species. Inter-species variations were identified using one-way ANOVA followed by Tukey's pairwise comparison. In terms of actual performance, Roheo spathacea, Axonopus compressus, Ophiopogon japonicus, Axonopus fissifolius displayed the greatest survival and coverage on an extensive green wall. Highest LAI obtained from Roheo spathacea (3.99) followed by Axonopus compressus (0.99) over the trial period.

Keywords: vertical greening, plant physiological parameters, leaf area index, Mean temperature difference.

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Introduction

Over the past years, transformation has overtaken our urban environments in a rapid pace. With the globalization and population growth, urbanization trends has attracted higher number of people to towns and cities causing very high population densities and space scarcity. The world population is predicted to reach 9.8 billion 2050 (PRB, 2017). Expansion of cities has resulted in increasing urban population with more focus on materialistic needs and less on environment. The rapid population acceleration and urbanization pressurize the need of more living places leading to considerably high artificial constructed structures and comparatively less vegetation. The high building densities and the vegetation scarcity in our surroundings demonstrate this rapid transformation. Transformation of urban forms has altered the land surface as well due to concentration of materials that retain heat and create impervious surfaces. Growth of tall buildings on the other hand multiplies the surfaces that absorb solar radiation and reradiate heat creating Urban Heat Islands. Urban context further acts as sinks and emitters of numerous contaminants which are resultants of human induced activities. Poor urban air quality, escalated heat island phenomena will inevitably be the collective impacts of global warming and urbanization leading to magnify the negative outcomes such as thermal discomfort, high energy demand for cooling and numerous health issues. Therefore, it is a vital need to find solutions which enables people and cities to adapt such crisis situations and to take migratory steps in coming years. Internationally this has become a much discussed topic where many researches are being conducted in finding better implementation strategies and recommendations.

Vegetation is identified as the best solution to overcome the effects of urban heat islands, air pollution and global warming. Absorption of CO_2 and various air pollutants in varying amounts, cooling effect of evapotranspiration and shading stand out from numerous benefits of trees. Thus, greenery in urban context is vital in balancing the environmental quality and air quality.Yet the rapid deforestation and less greenery in new urban development has reduced the efficiency of favorable impact of vegetation whereas ever increasing building population causes numerous issues related to global warming, health issues and etc. Number of present researches investigate the potentials of greenery as a UHI mitigation strategy recommending increment of greenery to enhance urban outdoor thermal comfort conditions.

In the context of sustainability vertical greening has come into practice with its identified benefits on environment and in improving favourable thermal performance of building. Vertical greening offer the benefit of improving the urban environmental conditions by promoting air quality, reducing heat island effect and etc. thus promoting the wellbeing of occupants. Moreover the concept of vertical greening offers the opportunity to restore the greenery lost due to man-made constructions while recreating the link of man and nature. Among the diverse benefits of vertical greening air quality improvement, regeneration of bio diversity and mitigation of heat island effect become prior considerations. However, vertical greening systems are not fully recognized yet, for the environmental benefits and energy-saving opportunities in the buildings, due to inadequacy of data to quantify and evaluate the real sustainability of these (Perini & Ottele, 2014).

Evolution of vertical greening and the existing situation

Using the cooling potential and thermal capacity of vegetation in moderating indoor environments is not a new concept. Since past vegetation has been used in different means such as in court yards and green envelops in different parts of the world. Earliest example for green facades have been found from Mediterranean region about 2000 years ago whereas Tigris and

Euphrates civilization claims for initial development of roof gardens as per the historical evidence. In Northern Europe number of examples for green envelops have been found which dated back to 18-19th century (Kohler 2008; Dunnet, 2008).

Over the years, researchers, architects and engineers have given considerable interest on the external perimeter design of buildings with the concerns for energy efficiency, aesthetic appearance and sustainable design (Hyde et al, 2013). Building façade is a main component of the building envelop that separates the building interior from the outside (Ibrahim, Hayman & Hyde, 2010). Thus it has a greater potential of being the climatic filter to take only the favourable impacts from the outside. Double skin envelop is identified as a better option in terms of climatic filter to maintain comfortable indoors (Rajapaksha et al, 2015).

Green roofs and living walls offer very significant social, environmental and economic benefits such as reducing urban heat island effects, energy needs and related Carbon dioxide emissions (e.g. from air conditioning), improve citizens' wellbeing and productivity (aesthetic and voice control), and providing habitat for microbes and large organisms (Wim, 2006). By altering urban environments with vegetation mainly Green facades and living walls, metropolises will become more livable, cooler and quieter (Perkins and Joyce, 2012).With these benefits the market for green walls is growing rapidly. The task is to develop wall systems which durable and cost-effective for commercial applications, residential towers and prefabricated structures. High density plantings can be supported by integrating, modular living walls with the building envelope and maintain intensively (Perkins and Joyce, 2012).

Vegetation cover of the green facades system is made by climbing plants or cascading groundcover. Normally, in green facades climbers are rooted at the base in the ground or in plant boxes, and fixed to the wall at a certain height, Otherwise on rooftops as a falling green cascade (Flatbud, 2017). Although green facades require less intensive maintenance and protection than living walls it has lower plant density and diversity (Perini and Rosasco, 2013).
Most of the living walls are complex structures that comprise with a supportive structures with different attachments. An impermeable aid is necessary to separate the living wall from the building with the purpose of avoiding problems related with moisture. An irrigation system is necessary for irrigation and fertigation as well (Mazzali *et al.*, 2013).

When considering the panels system there are existent option of planting in-situ. once the structure is attached to the wall or using pre-vegetated panels that are planted, before attached to the vertical structure (Charoenkit and Yiemwattana, 2016).To grow plants on the vertical green systems it can use both organic and inorganic substrates (soilless or hydroponics) along with mineral nutrients. So the resources used to build structures of the vertical systems are greatly variable and can support a great variety of plant species. Initially living walls were built using epiphytic plant growing in the tropical forests. with the time, it has found that wide variety of plants possibly will adapt and raise properly on a vertical living walls (Kosaka *et al.*, 2013).Epiphytes , lithophytes (Growing on other plants and on rocks by deriving nutrition from atmosphere) Ferns, succulents, shrubs, and herbaceous or climbing plants are the different types of plants that can be used for living walls (Weerakkody *et al.*, 2017).

Species selection for the living walls shouldn't be constructed merely on esthetic concerns, but should be based on several aspects such as cultivation system, conditions of the microclimatic , and sun exposure) (Mazzali *et al.*, 2013).Plant species of the Living walls are greatly differ according to the location and microclimate of the site such as height sun exposure and wind exposure, as well as height. The use of vegetation to increase the quality of the building surroundings has become a major factor when designing modern buildings that not only demand aesthetic effects but also provide means of ecological services such as water filtration, natural air cooling and other environmental issues (Pérez *et al.*, 2017).

However, living walls gives more benefits than green facades such as chances to use a broader variations of species, letting them for complex and more esthetic designs , swiftly gaining a full coverage of the wall after setting up of the system and dropping noise insulation and temperature (Koyama *et al.*, 2013).Most published articles generally focus on the benefits and impacts of vegetation on urban climates and buildings, with emphasis on roof gardens rather than vertical greening systems(Wong *et al.*, 2010).

Research context of vertical greening

A large number of researches has been done in different parts in the world to evaluate the environmental benefits of vertical greening focusing on different aspects such as heat reduction, dust control, noise and air pollution control and etc. Using vegetation to improve a building's microclimate has long been investigated by a number of researchers. The comparative study conducted by Parker (1987) on energy consumption profile of a United States residential building before and after introducing plants adjacent to the building indicated potential cooling energy savings of up to 60% during warm summer days could be achieved. Existing research studies implies that in evaluating the performance of vertical green systems in terms of minimizing heat gain, energy saving, mitigating noise and air pollution and etc. type of vertical green system, plant type, and maintenance must be considered. Such variations in vertical greening systems cause deviations of the effectiveness in each type (Perez et al, 2011).

When considering the functional aspects such vertical greening systems require complex design approach considering the above variables. Characteristics of vertical greening systems, materials used and etc. determines the influence of the system in terms of performance either positively or negatively in terms of improving building envelop behavior, moderating the outdoor climatic conditions and the life cycle of the system itself. (Perini & Ottele, 2014). Research suggests that larger green covers have the potential of storing heat and reducing surface heating (Tam et al., 2015). Vertical greening concept is well-known in European region whereas recent trends in Asian countries too signifies a more attention on vertical greening applications. Vertical greening benefits diverse from building performance improvement to numerous environmental benefits (Ibraheem et al., 2017; Köhler, 2008; Safikhani et al., 2014).

Though various researches are being done all over the world to investigate the vertical greening systems, their benefits and performance analysis as well as innovations in vertical greening, in Sri Lanka vertical greening is still at an initial stage and the knowledge on the system is very limited. No proper study has been done to identify the existing vertical greening types, characteristics and the reasons for implementing vertical greening. The work aims at investigating the existing vertical greening systems of Sri Lankan context along with the plant selection, watering systems, maintenance details related to vertical greening.

Materials and methodology

The work is a part of an ongoing research which aims at developing a vertical green panel as a sustainable design approach. The work intends to investigate the background theories and practical situations to create a platform for the vertical green panel development. The present study is to envisage the potential utilization of selected media for the growth of different plant species to utilize in vertical green walls to assess its cooling effect with the objectives of selecting best suitable plant types for selected medium on vertical green wall panels, investigating the different plant physiological parameters (Leaf Area Index, average leaf dimensions, plant growth rates) of the plants and evaluate the cooling effect of the green walls. Method of the research involved an experimental design and an on-site investigation. Twelve plant species were selected to be tested and three replicates of each type was tested and compared. Experimental site was Department of civil engineering faculty of Engineering. University of Moratuwa.Sample panels were created and the saplings of selected plant types were planted and maintained under controlled conditions till the plants achieve their optimum height. Then the panels were tested for their performance in terms of thermal benefits, survival ability and etc. A west facing wall exposed to direct sunlight was selected to fix the panels for the on-site investigation.

Fabrication of green panels

Modular green wall system was selected to be followed which consists of self-contained units that can be assembled and planted ex situ and later install on the wall vertically. Each module represents a repetition, all modules have the same growth medium and protective layer, only different planting plant between the modules. Green wall panels were prepared by using timber (60*30 cm). Thickness of each panel is 1 ½ inch. Two coating of the Multilac wood care sealer was applied with thinner solvent to improve the water resistant thus durability. To increase the stability, each panel was divided into two parts by adding one barrier across the panel horizontally. Several holes at the bottom of wooden structure was prepared to facilitate to drainage water.

Selection of growing media

Coir fiber was used as Growing media because of its light weight, high water holding capacity and its binding ability. To be a productive growing medium, it should own a good physical structure with the ability to obtain a successful balance between water and air in the medium during and after irrigation. Coir fiber layer was fixed to the panels by using wire mesh. Thickness of the substrate layer not exceeds 1 inch (2.5 cm) thick.

Selectionof plant types

Plant species were selected based on its growth form and the growing medium with the assumption that these species would be best suited to the extensive green wall environment: shallow soil, high winds, intermittent flooding and drought, and absence of tree cover (Cameron, Taylor and Emmett, 2014). Also several plant types that are already used in vertical greening systems in local context too were investigated.

Irrigation

Horizontal panels were irrigated twice a week early morning (9.00 am) by sprayers manually until the growth medium become wet. But applying too much water was avoided in early stages of the plant and was taken care to avoid moisture loss and retain enough heat.0.5 liter water was applied to each 60 *30 cm panel.After one month period of time the panels were hand-watered as required to maintain plant health, with 0.5 l of water slowly from the top of each module.

Fertilizer application

Nutrient supply is not needed until true leaves appear. Until this time only clean water was applied. However, as the leaves unfolded, the nutrient supply gradually began because the growing medium contains very little plant nutrients. Nutrient solution was prepared by dissolving 0.5 g of Albert's mixture in 500ml of water for each panel and applied twice per week.

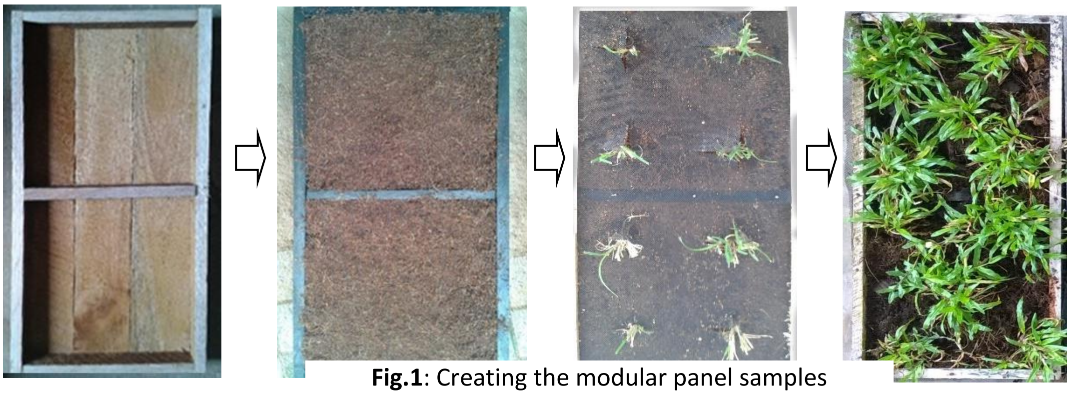

Fig.1: Creating the modular panel samples

The Albert mixture is used as a water-soluble production line for drip irrigation and foliar spraying. These formulas cover a wide range of nutritional ratios and are balanced with high nitrate nitrogen content, are chlorine free and dissolve instantly. The Albert solution is the foundation of a successful fertilization program due to the enrichment of basic chelated micronutrients with its premium ingredients and balanced ingredients.

Limitations

With the time constraints study was limited to selected twelve plant species and based on literature and practical applications the growth media and nutrient supply were selected. The investigation was limited to the plant performance of prevailing climate conditions of the investigated time period.

Experimental design

Experimental design was Completely Randomized Design (CRD) with 3 replicates from each plant species. The twelve plant species (treatments) were placed in panels. Each panel (replicates) held eight plants of each species.

Data collection

Monthly plant evaluations was conducted for two months. Plant health was rated for all plants using a 3-point scale of:

1 = thriving
2 = alive, but with signs of pest, disease or other stresses
3 = dead.

Plant height was measured along with visual assessments of plant development stages (flowering and seed set) and pest/disease incidence.Leaf length and width were measured from plant species that have linear leaves and broad leaves area was measured by using graph paper method during the study period.Canopy temperature for each species, substrate surface temperature and ambient air temperature (20 cm above canopy level) were measured for day time on a clear day using a data logger GL 820 midi.

Data analysis

Data was analyzed by using Minitab and SAS software package (ANNOVA).Vegetation coverage and temperature data were subjected to analysis of variance using a general linear model (SAS statistical analysis software, version 9.2). Separate analyses were conducted for each evaluation time. Where significant differences ($P< 0.05$) were found to be exist between species, a Tukey's studentised range multiple comparison test was performed.

Results and discussion

Plant survival rate varied significantly between each species (Figure 2). Health of the plants for these species also consistently high, with only minor bacteria blight spots observed during late October. Vegetal survival rate over the trial period was hieghest inRhoeo spathacea species whereas Axonopus compressus, Ophiopogon japonicas, Portulaca grandiflora, Axonopus fissifoliu andElusine indica too showed a high survival ability. Tectaria spp and Desmodium triflorum displayed a decline from 100% in September to 33% and 62% respectively. Centella asiatica displayed comparatively slow growing rate and were not capable to survive in this environment. Begonia spp did not show any significant growth rate. Even though Dieffenbachia spp did not survived in the vertical environment, it has indicated that 100 % survival rate in the horizontal environment over the trial period.

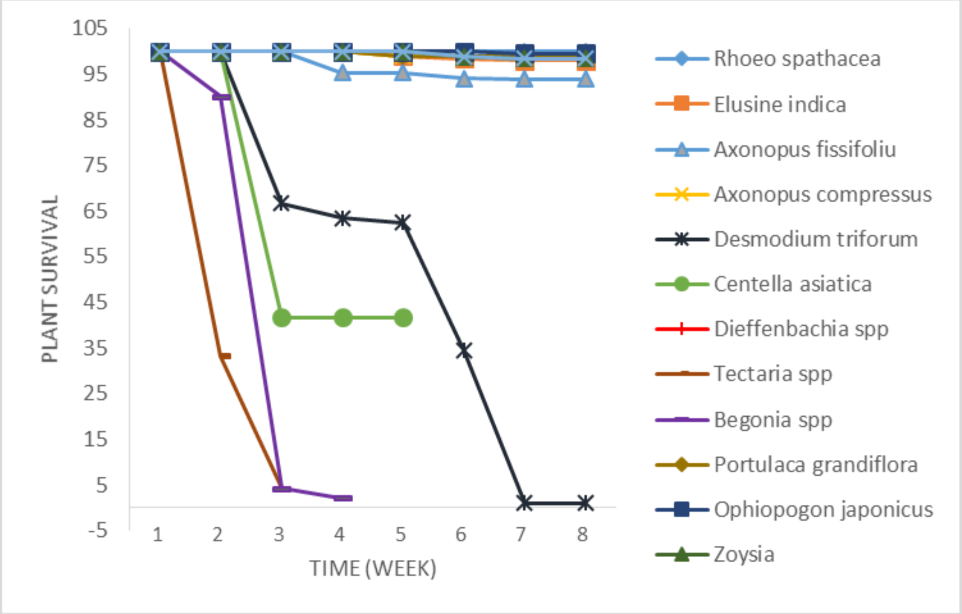

Fig. 2: plant survival rates during the trial period

Plant growth rates differed significantly among species. Dieffenbachia spp revealed vital growth both in terms of plant height (Figure 2) and LAI (Figure 3). One month after transplanting, panels were kept vertically. *Dieffenbachia spp* produced tall stems that have a tendency to grow downward and across the vertical green wall panels. This weakness of the *Dieffenbachia spp* stems restricted outer growth of the plant and therefore the capability of the plant to successfully grow in the vertical environment. And also the stems and the leaves were fragile and liable to breaking with the high growing rate of the shrub. This is a problem in circumstances where green wall vegetation is presented to mechanical unsettling influence such as high wind velocities, human handling (Perkins and Joyce, 2012).*Tectaria spp* also displayed the most rapid growing as to plant height (Figure 3). But it was not survived in the panel as the medium thickness is very low (1 inch). Plants of *Rhoeo spathacea* displayed the highest rates of spread and outer growth from the Vertical panel surface.

The dense canopy of variegated foliage also make *Rhoeo spathacea* an attractive choice for green walls. Most of the other trial species such as Axonopus compressus, Ophiopogon japonicus, Zoysia, *Elusine indica* reached heights between 10 and 15 cm. This is an ideal height range for an extensive green walls, as per short plants have a tendency to be less likely to wind damage and maintenance capability (Snodgrass and Snodgrass, 2006). *Desmodium triforum, Centella asiatica, Begonia spp*did not survived in the green wall panels within the study period.

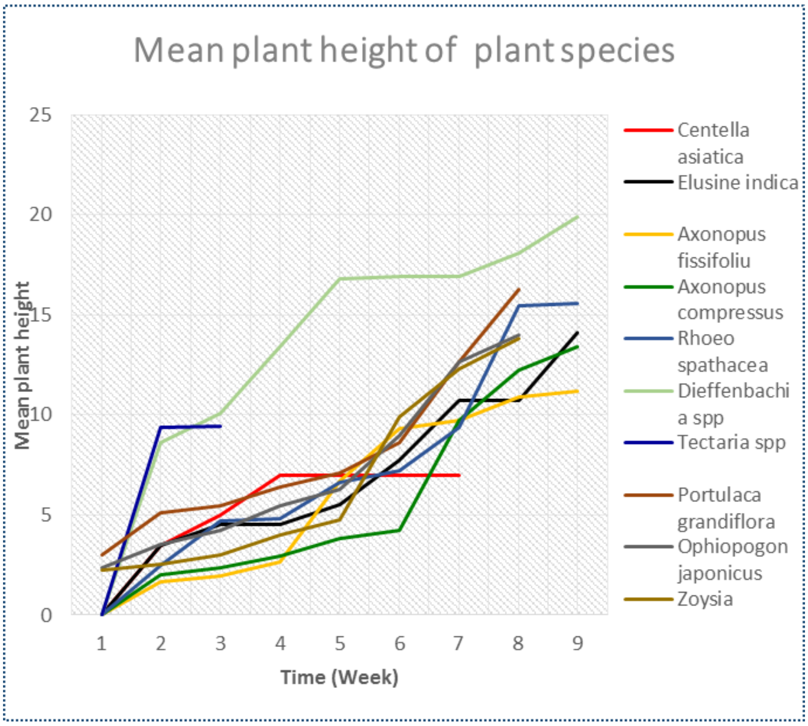

Fig. 3: Mean plant height of the plant species

Green wall thermal performance

Plant species that showed the best growth performances were selected to the initial study of thermal performances of green wall plants. Selected plant species were *Rhoeo spathacea, Axonopus compressus, Portulaca grandiflora, Ophiopogon japonicas and Elusine indica*.

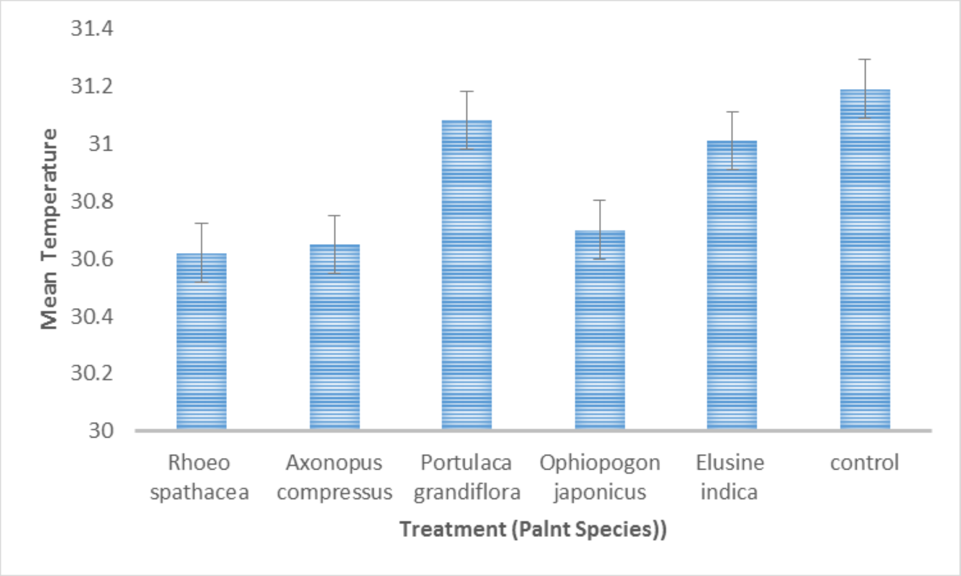

Fig 4: Mean air temperature 20 cm away from the panel surface level.

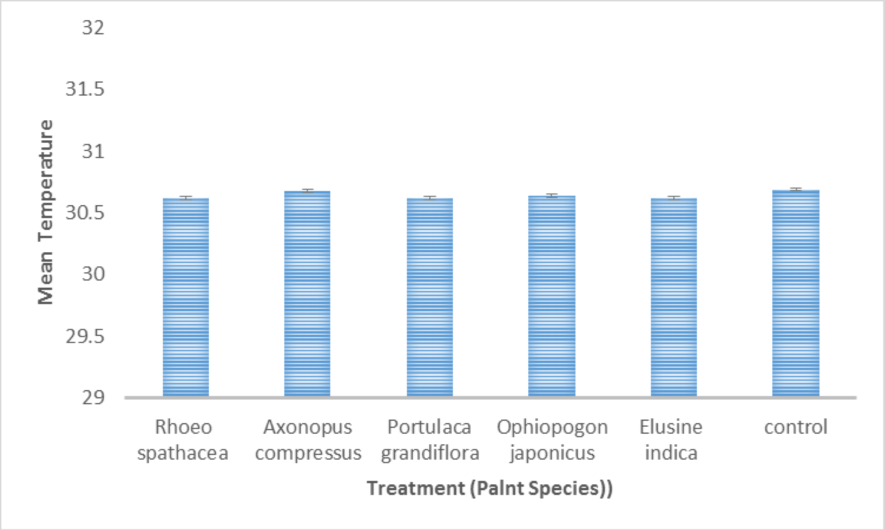

Fig 5: Mean temperature of the substrate surface

According to Cameron (2014) *Jasminum officinale* and *Lonicera* spp showed greater potential for total cooling as it has thicker canopy when considered on a per leaf area basis and leaf orientation. The size of the leaf blades and the morphology can affect other thermal aspects of the green walls (John & Unsworth, 2008; Raji et al., 2015). The rate of convection and conduction of heat from the leaf surface increases as the size of the leaf reduces (Tilly et al., 2014). Therefore, the cooling effect of *Axonopus compressus* was greater than *Rhoeo spathacea* though it has smaller leaves.

During the study, the highest temperature reduction was recorded by the plants which have high foliage density. According to Wong et al. (2010) higher cooling effect can be gained by having a higher foliage density and different vegetation colours.Furthermore, in an experiment conducted in Maryland, the green façade reduced the average temperature of the façades by

7.1 ° C during the summer and reduced the wall temperature by 14° C compared to the exposed walls surface. Another study in Hong Kong predicted a maximum decrease of 8.4°C in an urban canyon if both building roofs and walls were enclosed by plants. According to Cameron (2014), a maximum temperature reduction of 20.8 ^{0}C in exterior wall and 7.7 ^{0}C in interior wall has been shown by a living wall system in China. The average temperature of the air layer between the wall and vegetation were 3.1 ^{0}C cooler than ambient air.Studies in Japan have recorded the following maximum cooling variations between each species were 11.3 ^{0}C *Ipomoea tricolor*, 7.9 ^{0}C *Canavalia gladiata*, 6.6 ^{0}C *Pueraria lobata*, 4.1 ^{0}C *Momordica charantia* and 3.7 ^{0}C *Apios Americana* as maximum cooling variations between each species (Azkorra et al., 2015).

Mean temperatures of the panel back side recorded at different time intervals for a period of 24 hours were significantly different. Highest Temperature reduction was recorded by the green wall panel with *Axonopus compressus* when compared with the other species and the control (*Fig6*).It is assumed that the degree of temperature reduction was influenced by the density and the consequent shading effect of the leaves. Furthermore, interactions between leaf areas, geometry of leaf, color of the leaf and other microclimatic parameters such as solar radiation too result in differences in the cooling efficiency.

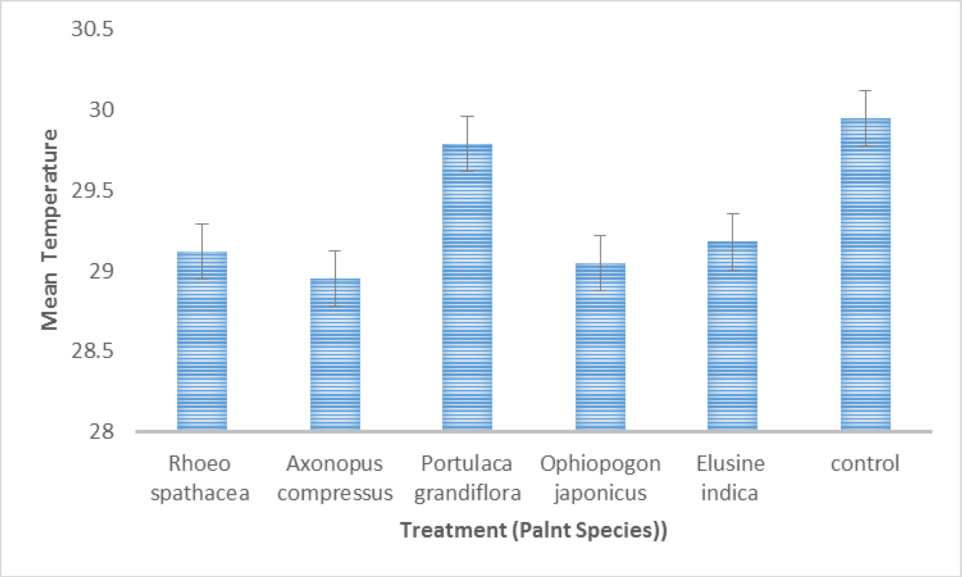

Fig 6: Mean temperature of the backside of the panel.

Conclusion and further studies

In terms of actual performance, *Roheo spathacea, Axonopus compressus andElusine indica*showed highest rate of survival and coverage on the vertical green wall. *Desmodium triflorum, Centella asiatica, Axonopus compressus, Dieffenbachiae spp, Tectaria spp,* and *Bigonia spp* have declining survival rates in the vertical green walls. Growth rates of *Roheo spathacea, and Axonopus compressus and Elusine indica* were higher than the expected and they achieved full coverage within 12 weeks of transplanting. Through this study it could also be concluded that the temperature of the wall surface can be decreased by covering walls with vegetation. The study reveals in selecting the plant species for vertical greening apart from aesthetics the survival rate and their thermal performance must be considered to achieve the maximum potentials of the vertical greening systems.

The studies need to be conducted for longer terms exposing the plants to year-round climate conditions to further investigate their actual performance throughout the year. Moreover studies on a broader range of plant species, substrate preparations and irrigation management is mandatory to assess for long-term usage in green infrastructure for Sri Lanka. It is necessary to determine the sustainability of green wall plants and media in a tropical context, both with and without supplementary irrigation.

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