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Designing a Sustainable Planting Module for Extensive Green Roofs under the Tropical Climate

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Abstract. Heat from solar radiation contributes to the high energy usage in the tropical climate regions. Extensive green roofs are well known efficient tools for heat insulation. This study designs a module system that is easy to implement and requires low maintenance for the extensive green roofs. The module system combined planting substrates and plants within a planting container which achieves the objectives, namely, light weight, easy shipping, good drainage, UV resistance, high water retention, and air permeability.

Introduction

Green roofs are built for both their aesthetic and functional values. They address two key elements of climate change, namely, the increased frequency of severe rainstorms and associated flooding and the elevated urban temperature and associated atmospheric pollution. However, green roofs are not the only solution, and they work best in combination with other measures. Green roofs prevent the occurrence of flash floods. Carter and Jackson [1] demonstrate that in watershed areas, green roofs significantly reduce the total impervious area and provide additional stormwater storage. Friedman suggests that green roofs can control stormwater, replace green spaces lost to construction, improve air quality, extend the life of roof surfaces, and significantly reduce solar heat gain. Coffman confirms that vegetated roof systems can improve the sustainability of a city, but these systems are reliant on a large number of non-renewable resources for their construction and upkeep. The shallow-substrate eco-roof is the most sustainable (least unsustainable) vegetated roof system compared with the deep-substrate eco-roof and the agricultural roof garden [2]. Most often, green buildings are expected to reduce solar radiation and to minimize the use of air conditioning systems in tropical and subtropical regions [3]. Those with relatively extensive greenery coverage exhibit better thermal performance. Studies have shown that the layered structure of rooftop greeneries can provide a cooling effect [4, 5].

The challenges presented by green roof implementation in Taiwan include heavy solar radiation, distinct wet and dry seasons, and complicated implementation in building completion. Therefore, the present study aims to use the least expensive, the simplest, and the most environment-friendly resource to create the most heat-insulated, water economized, least maintenance and management intensive, and easily implementable solution for the public.

This study intends to design a module system that is easy to implement and requires low maintenance for the extensive green roofs. The module system combined planting substrates and plants within a planting container which achieves the objectives, namely, light weight, easy shipping, good drainage, UV resistance, high water retention, and air permeability. By combining this ideal container will be suitable and sustainable for the extensive green roofs under the tropical climate.

Design Process of Planting Container

Phase One. A prototype was designed as UV resistance. It had spaces for water retention inside and created an air permeability layer for high insulation performance outside the bottom. These prototype planting containers were used to demonstrate that the water retention spaces inside are useful and viable.

Phase Two. During phase one, the assumption that the water retention layers indeed retain water during the rainy season to be supplied to the plants during the drought season was validated. Therefore, a design was proposed to manufacturers with the following requirements: light weight, easy shipping, good drainage, UV resistance, high water retention, and air permeability. After a series of discussions and modifications, the final products were eventually manufactured at the end of year 2009 (Figures 1 and 2). The planting containers have draining holes located 3 cm above the bottom for water retention and an outer air convection layer at the bottom for better insulation. All containers have latches for attachment to one another. The containers were made of UV resistant rubber, instead of plastic, for sustainability.

In most cases, the challenge in designing extensive green roofs lies in the replication of the benefits of green open spaces, while maintaining lightness and affordability. Thus, the new generation of green roofs relies on the combination of the sciences of horticulture, waterproofing, and engineering. The present study attempted to maintain simplicity in designing the extensive green roof system.

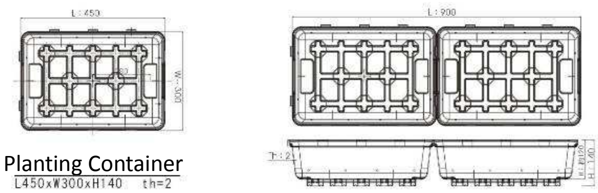

Figure 1 Detail of manufactured planting containers.

Figure 2 Manufactured planting containers with inner water retention spaces (L) and outer air convection layer at the bottom (M), with latches for attachment (R).

Thermal Performance of Module Specimen

The thermal performance of the planting containers was evaluated after they were manufactured. The sintered sludge particles were placed in the containers, and thermocouples (K-type) were placed in close contact with the surface on and under the roof slabs, as well as at the bottom of the containers, to measure accurately the surface temperature outside and indoors. Aside from surface temperature, the air temperature, relative humidity, solar radiation, and precipitation data were also observed as weather conditions from a separate measuring station on the roof. A GRAPHTEC data logger (GL-450AS) was employed to record the data. An interval of 10 min was observed per measurement. Measuring points on the bare rooftop surface and under the roof slab surface were also established for comparison (Figure 3).

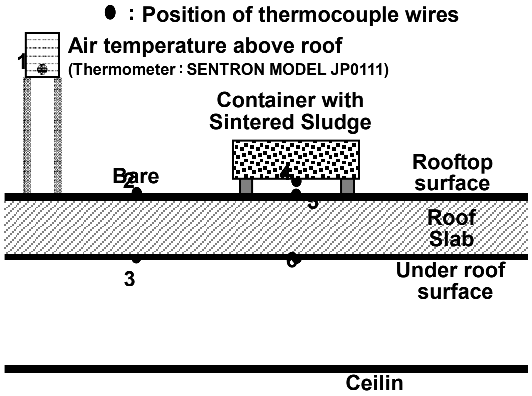

Figure 3 Measuring points for manufactured containers on the bare roof and under the roof slab surface.

Table 1
Temperature comparison between the bare roof and the roof with manufactured containers and sludge particles on/under the roof slab (March 31 to April 5, 2010)

Measure points	Position of thermocouple	Average of temperature(℃)	Range of temperature(℃)	Difference of temperature(℃)	Ratio of amplitude*
1	Air temperature	23.4	18.2 - 31.7	13.5	1.000
2	On the bare roof surface	28.8	19.8 - 48.5	28.7	2.126
3	Under the bare roof surface	27.6	23.8 - 33.2	9.4	0.696
4	Bottom of container	25.1	21.0 - 30.1	9.1	0.674
5	On the roof surface with container	25.4	22.6 - 28.4	5.8	0.430
6	Under the roof surface with container	25.9	23.8 - 28.2	4.4	0.326
	Solar radiation(W/M^2)	109.8	0.0 - 592.0		

Table 1 presents the temperature comparison of the bare roof and the roof having the manufactured containers and sludge particles on and under the roof slab from March 31 to April 5, 2010. The average temperatures in March and April were not extremely high, and midnight was often cold. Nevertheless, the temperatures under the bottom surface of the containers (measure point 4) and on the rooftop surface under the containers (measure point 5) have a significant difference. The differences in temperature were 9.1 °C and 5.8 °C, and the ratios of amplitude were 67.4% and 43.0%, whereas reduction percentages in heat transfer were 68.3% and 79.8%, respectively. These results indicate that the air layer provides good insulation and convection for the roof underneath and mitigates fluctuations in temperature.

Implementation of the Extensive Green Roof Module System

The significant performance of the manufactured planting containers combined with the sintered sludge indicated that such a system was ready for use on some projects to achieve the objective of sustainable green buildings. The first of these projects was the green roof for the Tainan Plant of Delta Electronics Inc. (Figure 4). The second project was the wild roof garden for the Magic School of Green Technology of the National Cheng Kung University. (Figure 5)

A large number of projects followed, and the extensive green roof module system became easier for the contractors and the public to adopt.

Figure 4 Sustainable extensive green roof at Delta Electronics Inc., Tainan Plant, Taiwan.
Photograph credit: Yu-Wei Ho

Figure 5 Sustainable extensive wild roof garden at the Magic School of Green Technology, National Cheng Kung University, Tainan, Taiwan.

Vision in the Future

For purposes of bio-diversity, the planting containers can be used with or without sintered sludge depending on the plants species to be used. However, the use of sintered sludge is recommended because of its good performance and sustainability. The performance of different proportions of sintered sludge and organic substrates were also evaluated. The best combination obtained was 80% sintered sludge with 20% organic substrates, which is suitable for almost all plants species [6]. The weight of a module filled with sintered sludge is less than 10 kg (about 9.6 kg) and will increase up to 20 kg with lush plants. Such features are feasible for the general public to move and implement.

The vision of the present study is to promote the use of the sustainable extensive green roof module system on every rooftop in the future for purposes of heat insulation, biodiversity, urban ecosystem, and wonderful scenery.

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