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Application of extensive green roof systems to mitigate adverse effects due to urbanization in Sri Lanka

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Abstract
Unplanned development, without due regard to the preservation of the environment could lead to degradation of the environment where hydrological, ecological and biological cycles have been badly affected. This affected environment will further deteriorate in future due to unbalance between the built-up areas and availability of flora. Green Roof concept is a better solution to control these issues with a well planed urbanization. This has been proven by many western countries and further researches are in progress to achieve more efficient and effective green roofs. The prime objective of this research is to identify how the affected urban environment can be recovered through the utilization of the Green Roofs for the local conditions. Physical models of green roof and reference roofs have been prepared to study the variation of surface runoff and temperature under the green roofs. Effects of different growing media thicknesses for an extensive green roof and behavior of green roofs under droughts have also been studied. Applicable minimum thickness for an extensive green roof, under the prevailing environmental conditions in Galle has been identified and tested. Life span of extensive green roofs with relevant to the historical drought data has been considered. Surface runoff lag time variations and temperature variations for different conditions of model extensive green roofs have been developed under the results and discussion.

Keywords: Urbanization, GreenRoof

Introduction

Hydrological, ecological and biological cycles have been adversely affected due to urbanization. Increment of heat, air pollution, loss of bio-diversity and flash floods in drainage systems due to increase of surface run-off are some of the major concerns in urbanization. Effects of these adverse impacts will gradually be increased in future due to unbalance between the infrastructure development and availability of flora.

The built environment has been a significant cause of environmental degradation in the previously developed landscape. As public and private interest in restoring the environmental integrity of urban areas continues to increase, new construction practices are being developed that explicitly value beneficial environmental characteristics. One such practice is a green roof. The term 'Green Roof' refers primarily to "vegetated surfaces which are installed over man-made structures' (Figure 1).

Modern green roofs, which are made of manufactured layers deliberately placed over roof to support growing medium and vegetation, are a relatively new phenomenon. They were developed in Germany in the 1960s, and have since spread to many countries in Europe. Today, it is estimated that about 10 percent of all German roof have been "green". The United State has some green roofs, but they are not as common as in Europe. (Herman, R. 2003)

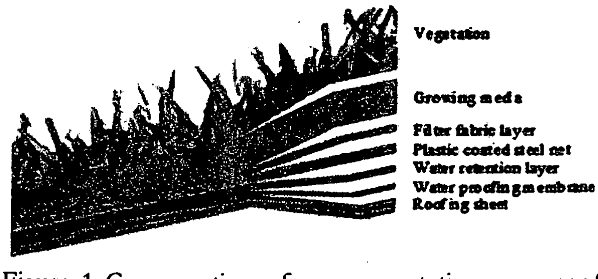


Figure 1 Cross section of a representative green roof system

Extensive green roofs are not usually recreational. They have low management requirements and do not usually require artificial irrigation. Plants are selected that succeed with only minimal modification of the normal roof conditions. Planting styles are usually naturalistic with the objective of establishing a self-sustaining plant community on the roof. Based on a thin layer of soils or substrates, they are lightweight systems with minimal structural implications for the building.

Intensive green roofs are roof gardens and like any garden that provides space for people. They require the intensive management of a ground level garden which usually based upon a thick soil or substrate layer and require artificial irrigation. Preferred plants are selected and the roof conditions created to support them. They are heavy systems and thus can have major structural implications for the building.

The main objective of this research is to investigate the applicability of extensive green roofs to local tropical conditions with identification of essential components of it.

Components for GreenRoofs

Growing Media

When selecting a growing media the following factors have been considered to ensure the quality of growing media.

- The bulk density of growing media should be minimized.
- Water retention capacity should be maximized.
- Soil particles should be light weight and should meet the necessary condition for a green roof
- Heat absorption of growing media should be minimized.

The Michigan University green roof model growing media consisted of 40% heat expanded slate (gradation 3-5 mm), 40% USGA (United State Golf Association) grade sand, 10% Michigan peat, 5% dolomite, 3.33% composted yard waste and 1.67% composted poultry litter by volume. (VanWoert N.D. etal., 2005)

Vegetation

The extensive green roof vegetation should have some special features to obtain the expected outcome from a green roof system. Those special characteristics are as follows (Heinz, W. 1985);

- Plants should have a good drought tolerance and should be light weight.
- Plants should be able to survive for a long period of time without or less maintenance.
- Plants should have very good surface coverage but height of plant should not exceed more than 200mm.
- Roots of plants should not go deep in to the soil but spread over the surface layer.
- Leaves and stems of plants should satisfy the basic function expected from the green roof systems.

From the initial investigation about the availability of suitable plants that are having above characteristics, it is revealed that, a combination of plants can be used for an extensive green roof because such a combination of plant there are some extra advantages such as;

- Growth control of one plant by other.
- Degrading of one plant or its function can generate nutrient for other plant.
- One plant can help to increase survival period of other plant.

Grasses

The water retaining of stems and leaves and the possibility of drought tolerance of the grasses is considerable. Combination of grasses or grasses with other plants (sedum, desmodium) is also fitting with extensive green roof systems requirement.

Axonopus Compresus (blanket grass)

Perennial, tufted, stoloniferous grass often forming loose mats; stolons often long, breached, slender, rooting at nodes; roots fibrous culms laterally compressed, deeply grooved and 20-50 cm long. Leaves are very thin and strongly compressed with ground and having considerable drought tolerant. These are widely naturalized in the humid tropics and subtropics. Widely distributed in Sri Lanka in the low country wet or dry zones, up to medium altitudes (Manidool, C. 1992).

Axonopus Affinis (Carpet grass)

Perennial, tufted grass with ability to produce stollons, often forming loose clumps rather than mats; stolens often long, branched deeply grooved, 20-50 cm long, very leafy. Leaves is very thin and 2-35 cm long These plants have considerable drought tolerance and distributed in tropics. Also widely distributed in Sri Lanka, mainly in the low country wet or dry zone, up to 1200m altitude (*Smith, J. and Valenzuela, H. 2002)*

Sedum species

Sedum species have been the most commonly used plants for green roof systems because, with proper species selection, they can tolerate extreme temperatures, high winds, low fertility and a limited water supply. Combination of sedum is better suited for a green roof systems.

Portulaca pilosa (Japan Rose)

Japan Rose, which have the look of a succulent, with fleshy, torpedo shaped leaves, and perfectly round, reddish stems. The brilliant colors of the blooms range from red through pink, orange and sometimes, yellow. The flowers, which are from 2 - 3 cm in diameter, open during full sun, and close on cloudy days and at night. The plants grow from 5 – 20 cm height. The image below shows two varieties of Japan Rose plants Flowing can be seen under full sun and drought tolerance is higher than grasses, but flowers

Figure 2. Axonopus compresus grass

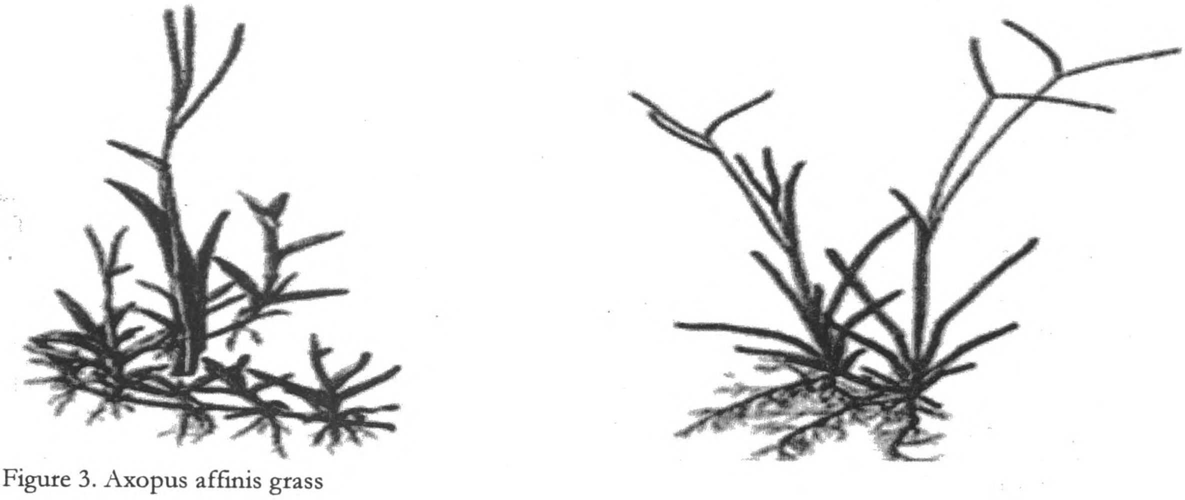


Figure 3. Axopus affinis grass

Figure 4. Japan Rose Plant

Portulaca grandiflora (Dubai Rose)

Dubai Rose reaches about 15 cm tall with a spread of 30.5 cm. The reddish stems and the bright green leaves are thick and soft and juicy. The leaves are cylindrical, about a 2.5 cm, and pointed on the tips. The rose like flowers are about an inch across and come in bright colors like rose pink, red, yellow, white, and orange. This species is also needs full sun to flower and drought tolerance is higher than grasses, but flowers best with regular watering (Christman, S. 2003).

The combination of sedum plants have been selected as the vegetation type for the present application. They have been identified as the best suited plants for the extensive green roof systems with available plants in the region. (Monterusso, M.A., et.al 2004).

Figure 5. Dubai Rose Plat

Methodology

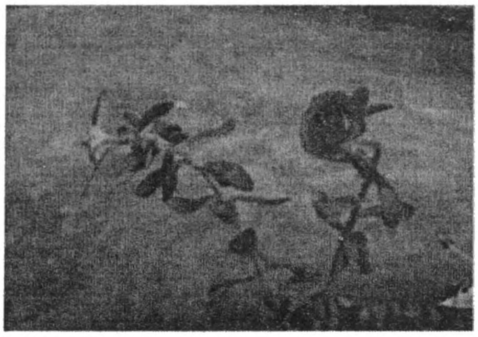
Cement-fiber flat roofing sheet with dimensions of 600 mm x 600 mm has been used for the preparation of the physical models. The model has been protected by a timber outer frame. A water proofing membrane, a water retention layer, plastic reinforcing layer, a filter fabric layer were laid on top of the roofing sheet and finally the growing media of 3cm thickness is laid before planting a combination of two different sedum species as the vegetation layer. The model with green roof system has been given ample time to attain sufficient growth of vegetation before commencement of the monitoring process as near full vegetation coverage will be resulting better outcomes. A reference roof with similar arrangement without green roof layers has also been prepared. Effect of different growing media thickness to plant growth and their survival, variation of surface runoff and roof bottom temperature have been examined.

After vegetation coverage become satisfied, green roof model was allowed to dry out. Then the green roof system is exposed to an artificial rainfall and runoff variation was monitored. Subsequently the green roof system was covered from natural rainfall but exposed to the other prevailing environmental conditions. Then the temperature under the green roof model and the moisture content of growing media was measured until the green roof plants reach to its wilting range.

Observations and analysis

Existing environmental conditions

The daily maximum temperature and daily rainfall data were acquired from the adjust weather station. Figures 7 and 8 illustrate the maximum daily temperature variation and the daily rainfall variation at the study area over monitoring period.



The rainfall and temperature observations from of the study area suggested that the monitoring period is relatively dry with only about 90 mm rainfall for the entire month with lot of non-rainy days and the maximum temperature varies between 32^{0}C -38^{0}C.

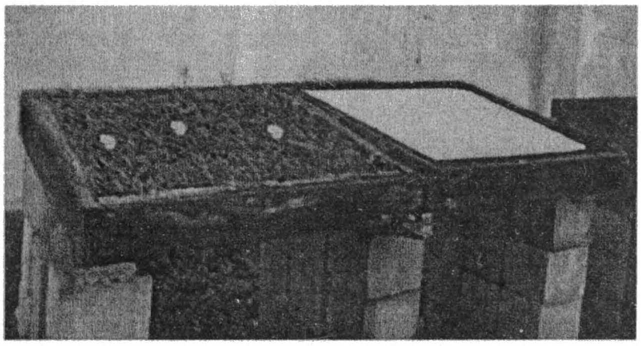


Figure 6. Green roof models

The thermal variation under the roof

Figure 9 illustrates the diurnal temperature variations (on average) over the monitoring period of the green roof system and Figure 10 shows normalize maximum daily temperature variation for the same period.

The Run-off variation due to an artificial Rainfall

Figures 11 and 12 illustrates the instantaneous and cumulative run-off response of the green roof system once exposed to an artificial rain event with high intensity. The idea of introducing such a rain event is to study the response mechanism of the system as high intense rainfall could be a precarious scenario for generation of flash floods.

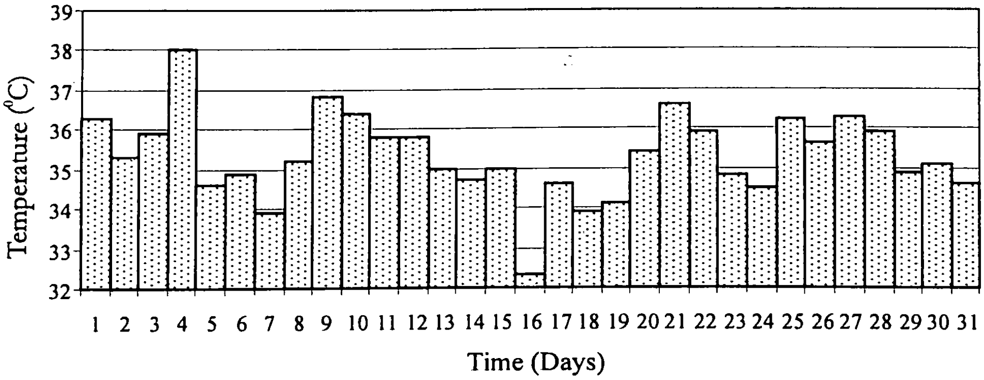


Figure 7. The maximum daily temperature variation (March, 2008)

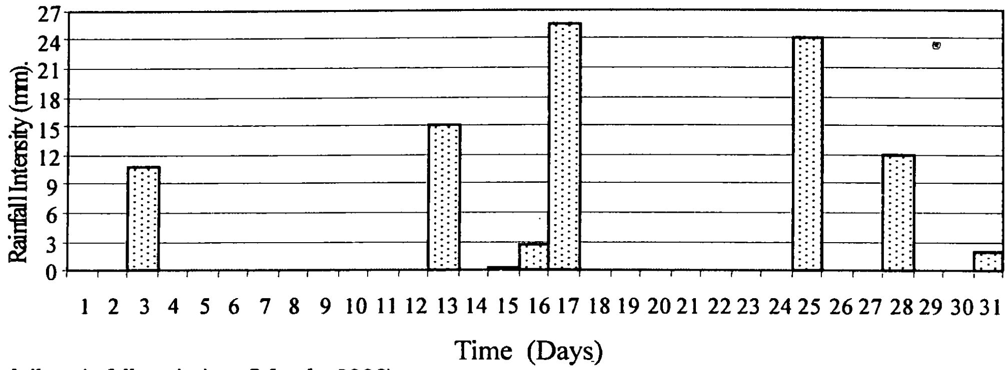


Figure 8. The daily rainfall variation (March, 2008)

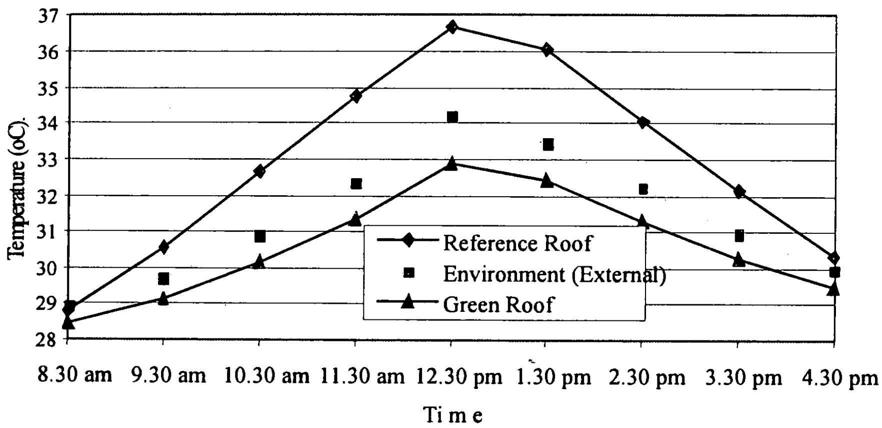


Figure 9. The daily temperature variation (March, 2008)

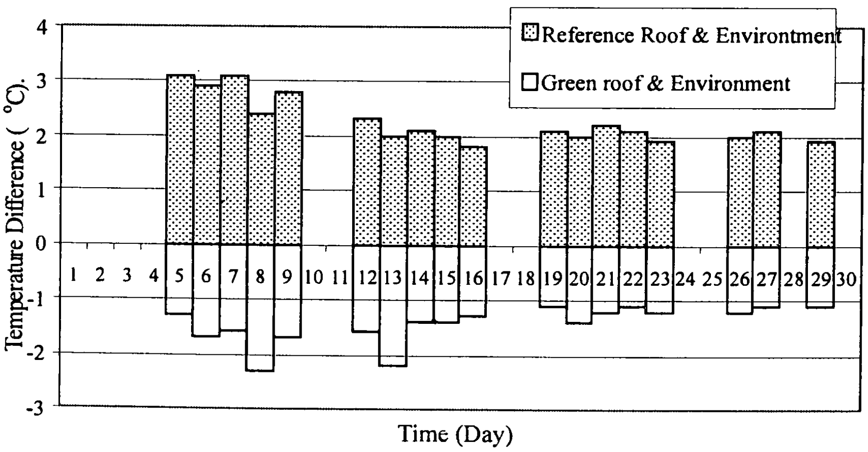


Figure 10. The normalize temperature variation over monitoring period (March, 2008)

The rainfall and temperature observations from of the study area suggested that the monitoring period is relatively dry with only about 90 mm rainfall for the entire month with lot of non-rainy days and the maximum temperature varies between 32°C -38°C.

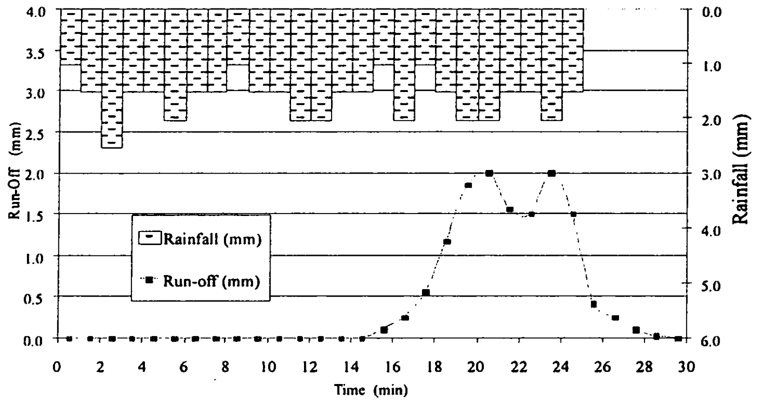


Figure 11. Run-off hydrograph

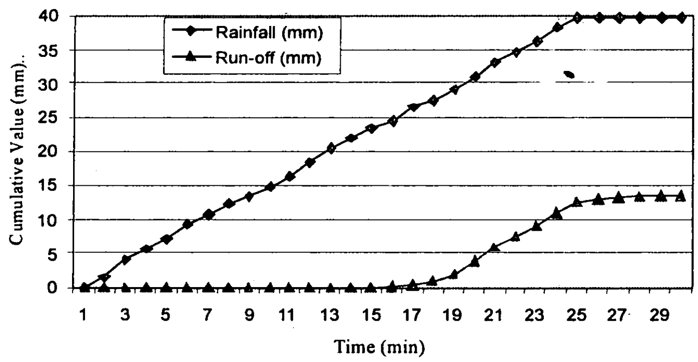


Figure 12 Cumulative Run-off hydrograph

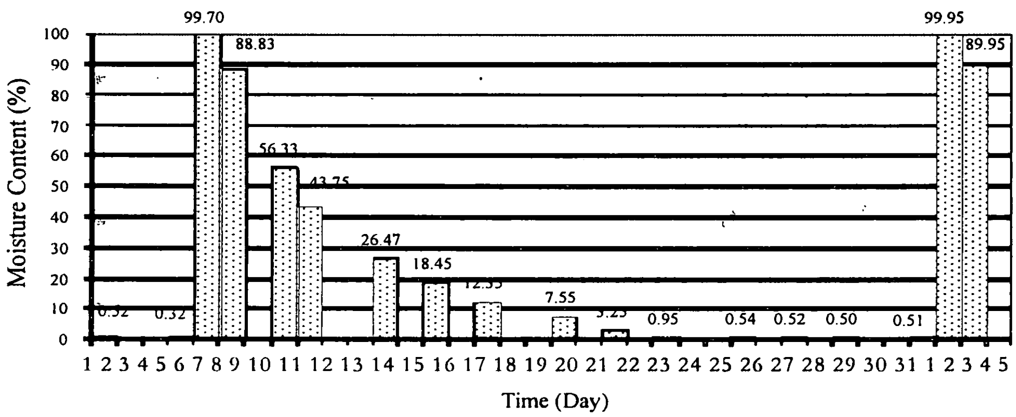


Figure 13 The moisture variation of growing media (March, April 2008)

Figure 13 illustrates the drying up process of growing media over monitoring period after the artificial rain event. The system is exposed to the natural environment except the natural rainfall during this process to expedite the drying. The sedum plant mixture survived during this process of continuous 29 days irrespective of very low availability of moisture within the growing media.

Table 1 illustrates historical drought information for the study area which is extracted from 50 years of historical daily rainfall data (1940-1990)

Table 1: Number of maximum drought period

Drought Period (days)	No of Events	Drought Period (days)	No of Events
18	3	27	1
19	2	28	1
20	3	29	1
21	0	30	0
22	3	31	2
23	0	32	0
24	2	33	1
25	3	34	2
26	0	35 or greater	6

Results and Discussion

Though the results shown here only for the growing media thickness of 30 mm which can retain lot of rain water as high as 30 mm in the green roof system, it is necessary to consider the increased weight to the roof structure as well. As the growing media can absorb very high moisture amount the imposed weight (added due to the green roof system) is as high as the cement fiber roofing sheet cover roof. In other words, due to the green roof system the weight of the roof is nearly doubled. Even though the green roof weight can be reduced by making the growing media shallower, but then the advantages such as drought tolerance and water retention capacity will be affected.

According to the research outputs, it can be concluded that at least 5°C temperature drop could be achieved by introducing the green roof systems. Also by closely observing the diurnal variation under the green roof is always lower than the environmental temperature and it is interesting to investigate the thermal variation with larger roof tops and also during the night time.

There is a considerable time gap between the commencement of the precipitation and the initiating of the surface run-off (lag time). Also the difference between cumulative rainfall and run off is around 25 mm out of total of 40 mm rainfall which means more than half of the rainfall volume is retained within the green roof system. This could be the best achievement in order to control the flash floods that are common in many urban areas around the world.

Conclusions

Identification of locally available sedum vegetation species and their combination that fitted for the extensive green roof system has been the major finding from this research. Furthermore, some benefits of green roof systems which are already identified by previous researches have been investigated for local conditions. The present findings though they were obtained from a small scale model roof, they will be very useful in expansion of this research.

In order to control flash floods, there were numerous attempts in the past by urban storm water researches such as division of flash floods through underground rivers, retention and detention of run off by artificial infiltration facilities and specially made retention areas. However, most of them are very costly and some are not applicable in certain urban areas with high ground water table (coastal cities). The green roof is undoubtedly is a better approach as it has distinct other positive effects such as thermal comfort, reduce green house effect, regain the loss biodiversity in addition to runoff control. However, to achieve all these merits of green roof system, a considerable extent of urban roofs have to be converted to green roof systems. This may be a possibility in urban planning as most of the existing urban roofs are neither capable to bear additional weights nor feasible to retrofit.

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Poster Presentations