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# Green roof performance towards the cooling of buildings in tropical climate

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## Abstract

Due to the rapid urbanization, greenery is being rapidly destroyed. Urban Heat Island is one of the major adverse effects of lost flora. Green roof systems can be effectively used to control this issue with a well planned urbanization. Green roof acts positively not only upon the climate of the city and its region but also upon the interior climate of the building beneath it. This will be very useful in the contest of saving energy required for providing thermal comfort for occupants in tropical climatic condition.

This study investigated effects of extensive green roof on cooling of buildings. The main objective of the study was to investigate thermal performance of model buildings due to an extensive green roof. Naturally ventilated building and air conditioned building were represented by a model building "With cross ventilation condition" and "Without cross ventilation condition" respectively. A model building was constructed using flat cement fibre sheets as both roofing material and wall panels. The model building was exposed to direct sunlight throughout the daytime. Roof top was prepared for plant growth. Monitoring of indoor and outdoor temperature has been started in parallel with monitoring of plant growth. The vegetation coverage was quantified by using photographic technique.

It was found that green roofs can be effectively used for the cooling of buildings. When the green coverage is increased the difference in the temperature between the indoor and outdoor also increases. With 77% green coverage, the extensive green roof cools center of the model building with cross ventilation by 1.75°C and that without cross ventilation by 2.0°C.

**Keywords:** urbanization, green roof, thermal comfort

## Introduction

The global population is increasingly concentrated in urban areas and many infrastructures and buildings are required. New developments are often made by destroying greenery. One of the adverse effects of lost flora is formation of Urban Heat Island: the urban area which is significantly warmer than its surrounding rural areas (Jusuf, 2007; Onishi, 2010). Effects of this adverse impact will gradually be increased in future due to unbalance between the infrastructure development and availability of flora.

The term 'Green Roof' refers primarily to "Vegetated surfaces which are installed over man-made structures". They are also referred to as eco-roofs and roof gardens. Green Roofs are more expensive than standard roofing, but they provide a wide range of benefits including thermal comfort. Green roofs provide a measurable psychological benefit to urbanites by adding tangible, accessible natural viewing space for social interaction, recreation, and relaxation (Dunnett and Kingsbury, 2004).

Depending on the plant material, planned usage and required maintenance of green roof, it can be categorized into two main engineering systems: intensive and extensive systems (Dunnett and Kingsbury, 2004). Intensive green roofs are roof gardens and like any garden that provides space for people. They are often accessible to the public and can include garden paths, seating, and other features that make the roof an outdoor room. They require intensive management of a ground level garden which usually is based upon a thick soil or substrate layer and require artificial irrigation. Preferred plants are selected and the roof conditions are created to support them. They are heavy systems and thus can have major structural implications for the building. Extensive green roofs are not usually designed for any recreational or public. They have low management requirements and do not usually require artificial irrigation. 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.

Green roofs are rather new to Sri Lanka. However, in Sri Lanka, the extensive green roof can be easily constructed in buildings because it is a lightweight system. It includes a drainage layer and a high quality impermeable membrane that protects the building structure. In addition, the extensive green roof can be easily maintained as it does not require intensive management and artificial irrigation. It has been reported that extensive green roofs are the preferred option for retrofitting onto existing buildings as the structural capacity of the roof will often not have to be increased (Dunnett and Kingsbury, 2004).

Sri Lanka located close to the equator experiences high humidity throughout the year coupled with low diurnal temperature variations. There is considerable sun shine and high rainfalls during monsoon periods that provide ideal growing condition for vegetation. However, due to the slightly elevated temperature and high humidity, all commercial establishments and homes tends to use air conditioners. Different people attract different temperature settings for comfort. We feel comfortable when our bodies lose heat at the same rate as we produce it. Heat production varies with physical activity and our metabolic rates. Heat loss or heat gain also depends on surface temperatures in the room, air movement. Air temperature implying thermal comfort depends on a lot of factors including surface temperatures in the room and air movement. The use of air conditions for thermal comfort gradually increase due to affordability resulting from improved economic standards and reduced capital cost of air conditioners (Malik, 1996). The demand for air conditioning leads to higher energy bills indirectly increases greenhouse gas emissions from power plants that provide extra energy. So any measure in improving the efficiency or the usage can considerably save on the power bill.

Green roof acts positively not only upon the climate of the city and its region but also upon the interior climate of the building beneath it. This will be very useful in the contest of saving energy required for providing thermal comfort for occupants in tropical climatic condition. However, performance of green roof toward achieving the cooling of buildings in tropical climates is not well known.

The objective of this study is to investigate performance of extensive green roof on cooling of indoor environment of a physical model under varying ventilation conditions. Two ventilation conditions were selected: "With Cross Ventilation Condition" and "Without Cross Ventilation Condition". "With Cross Ventilation Condition" was selected to represent the conditions of building with natural ventilation while "Without Cross Ventilation Condition" was selected to represent air conditioned building.

## Materials and Methods

*Preparation of green roof*

A model building was constructed and a green roof was laid with its standard components: water proofing membrane, water retention layer, growing medium, and vegetation.. A representative Green Roof configuration is shown in Figure 1.

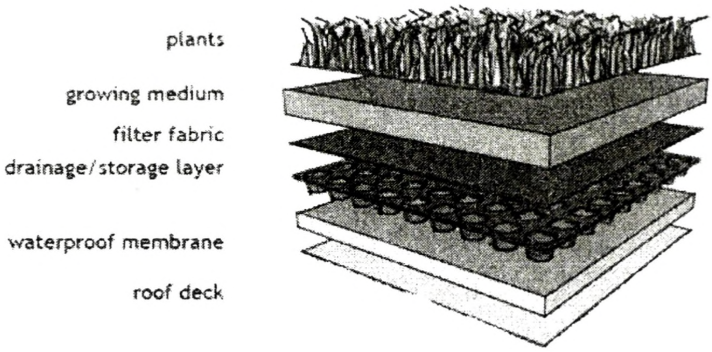
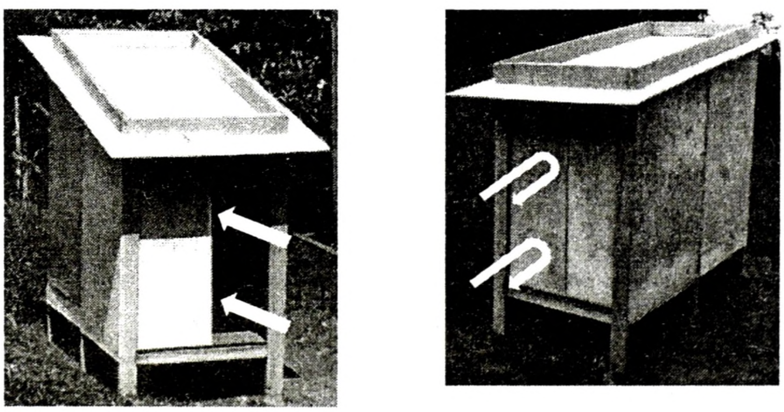



**Figure 1: Green roof layers**

*Construction and monitoring of model building without green roof*

A model building was constructed using flat cement fibre sheets as both roofing material and wall panels. Floor area of the model building was 6 ft x 3 ft, height at front and rear sides were 4 ft and 3 ft, respectively. Sliding doors were provided to front and rear walls to achieve different ventilation conditions: With Cross Ventilation Condition" and "Without Cross Ventilation Condition" (Figure 2). A model building with cross ventilation was obtained by opening the rear and front side doors while a model building without cross ventilation was obtained by closing both doors.

Temperature at the centre of the building, top and bottom of the roof were measured before laying Green Roof layers. Wind condition and climate condition were also recorded corresponding to the temperature measurements.



(a) (b)

**Figure 2: Psysical models (a) With cross ventilation (b) Without cross ventilation**

*Construction and monitoring of model building with green roof*

Water proofing membrane layer was laid within the confinement timber frame on the roof (Figure 3 (a)). Then water retention layer was laid and it was covered with supporting plastic net as shown in Figure 3 (c). On this arrangement, filter membrane was placed and growing media of 3 mm thickness was then prepared. As the vegetation layer, a combination of *Portulaca grandiflora* (Dubai Rose) and *Portulaca pilosa* (Japan Rose) sedum species were planted. These species were selected as they have high drought tolerance (Johnston, 2004). Temperature monitoring has been started in parallel with monitoring of plant growth. To measure temperature, digital thermometer and hygrometer were used. The measurements were taken on a sunny day at the end of April.

Wind condition and climate condition were also recorded corresponding to the temperature measurements.

Surplus temperature was used to quantify the performance of green roof on cooling of the model building and it was calculated as in Equation (1).

***Surplus temperature = Indoor temperature – Outdoor Temperature*** **(1)**

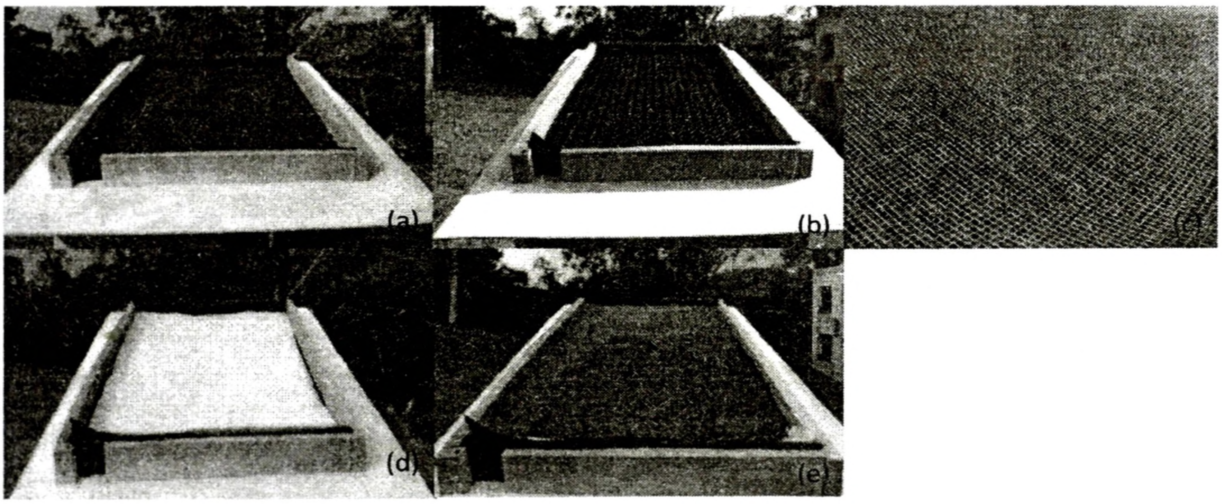



**Figure 3: Construction of green roof: (a) Waterproofing membrane, (b) Water retention layer, (c) Supporting plastic net, (d) Filter membrane, (e) Growing media**

Growth of the plants was monitored and recorded at two weeks intervals. Photographic technique was used to quantify plant coverage. Aerial photographs of a representative portion of green roof were taken using a digital camera as illustrated in Figure 4 (a). The resolution and the focal length were kept unchanged for each image.

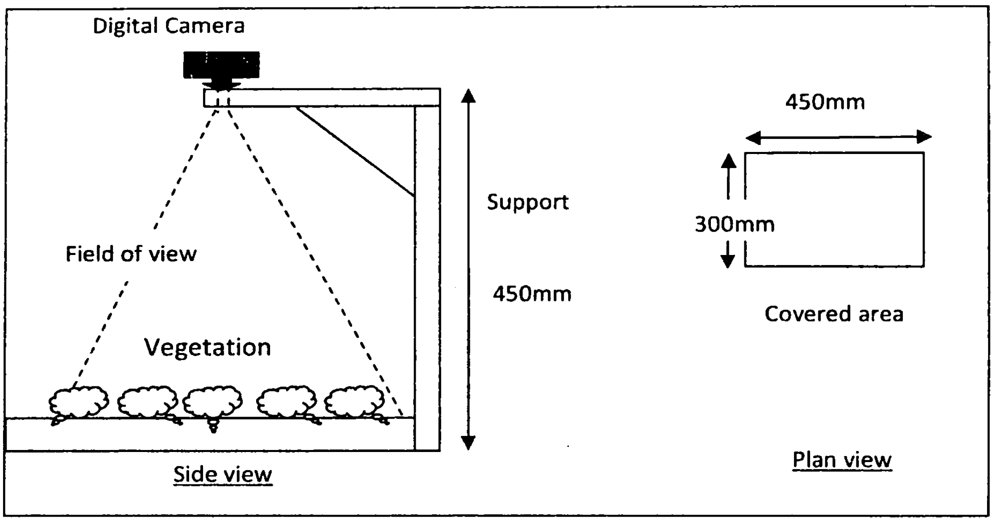



**Figure 4( a): Image recording mechanism**

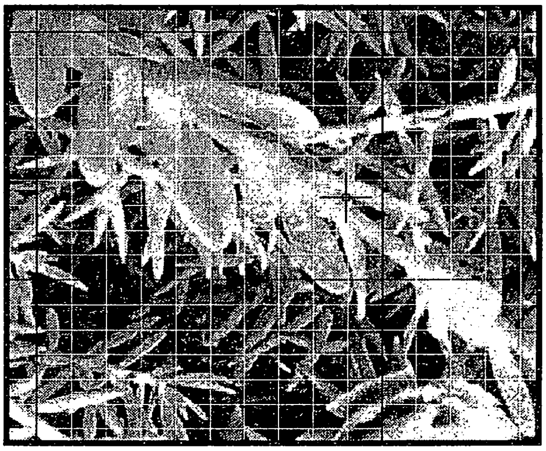


**Figure 4 (b): Part of an image with the grid**

The images were imported into Autodesk Auto CAD software as Raster images against a grid with 4.5 mm horizontal and 3.0 mm vertical spacing. Each small square in the grid covers 4.5 mm × 3.0 mm area of the green roof. The squares covered by the plants were counted manually and the percentage of squares covered by plants was considered as the Green coverage (Figure 4(b)).

## Results

Figure 5 compares the variation of surplus temperature at the centre of the model building without cross ventilation before and after installation of green roof layers. With green roof, measurements were corresponds to plant coverage of 77%. These observations are valid for a typical sunny day with calm wind condition. Without cross ventilation, the indoor temperature was generally high. However, green roof reduces indoor temperature about $1^0C$ during 12:00 noon to 14:00 hrs and the reduction was greater before 12:00 noon and after 14:00 hrs.

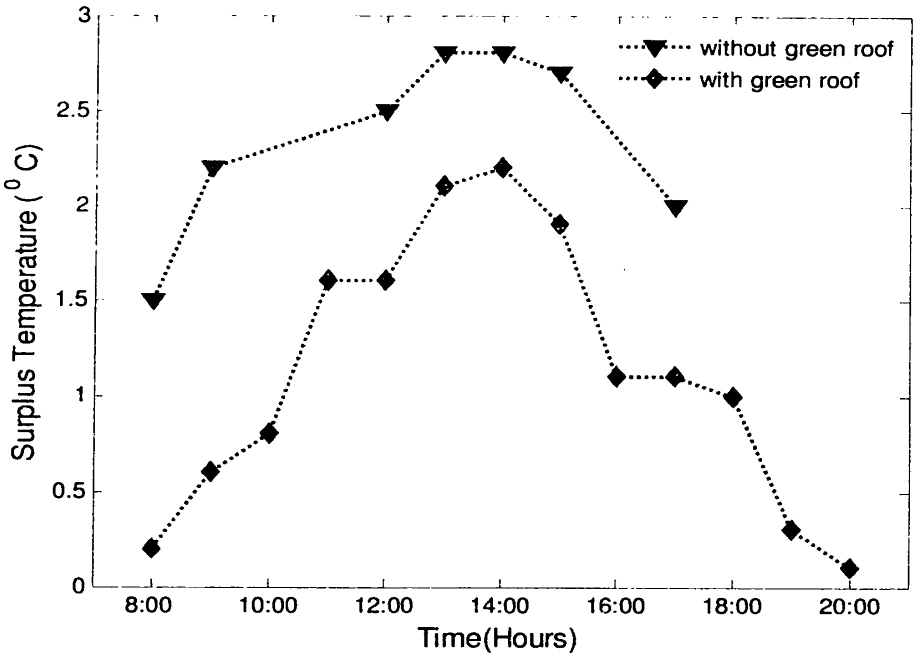



**Figure 5: Surplus temperature at the centre of model building without cross ventilation**

Variation of surplus temperature at the centre of model building with cross ventilation is shown in Figure 6. With cross ventilation, indoor temperature is generally lower than the outdoor temperature. Indoor temperature was further reduced by installation of green roof. During 12:00 noon to 14:00 hr, installation of green roof affected to reduce indoor temperature by $1^0$C and between 10:00 hrs to 12:00 noon, the reduction in indoor temperature is greater than $1^0$C.

Figure 7 shows the variation of surplus temperature at roof bottom of the model building with cross ventilation, before and after installation of green roof layers. Green roof affected to reduce surplus temperature by about 6 $^0$C from 11:00 hrs to 13:00 hrs. Before installation of green roof the maximum surplus temperature was 6.5 $^0$C and that observed at about 13:00, while after installation of the green roof it was 1.5 $^0$C and observed about 16:00 hrs. With the installation of green, there is about three hour time lag to reach the maximum surplus temperature. Similar effect of green roof to time lag of maximum surplus temperature can be observed at the roof bottom without cross ventilation condition (Figure 8). Without cross ventilation condition, the maximum surplus temperature was greater compared to that of cross ventilation condition (Figures 7 and 8). Without cross ventilation condition, the green roof affected to reduce the surplus temperature by about 6 $^0$C and that was observed during 12:00 noon to 14: hrs.

Effect of percentage of Green Coverage on surplus temperature of model building with cross ventilation condition is shown in Figure 9. It can be seen that green roof affected on reduction in surplus temperature at the bottom of the roof and at the centre of model house. With the implementation of green roof layers, there is a significant reduction in temperature at the centre and the roof bottom. Further, the effect of green cover on the surplus temperature is gradually increasing with increasing in green area.

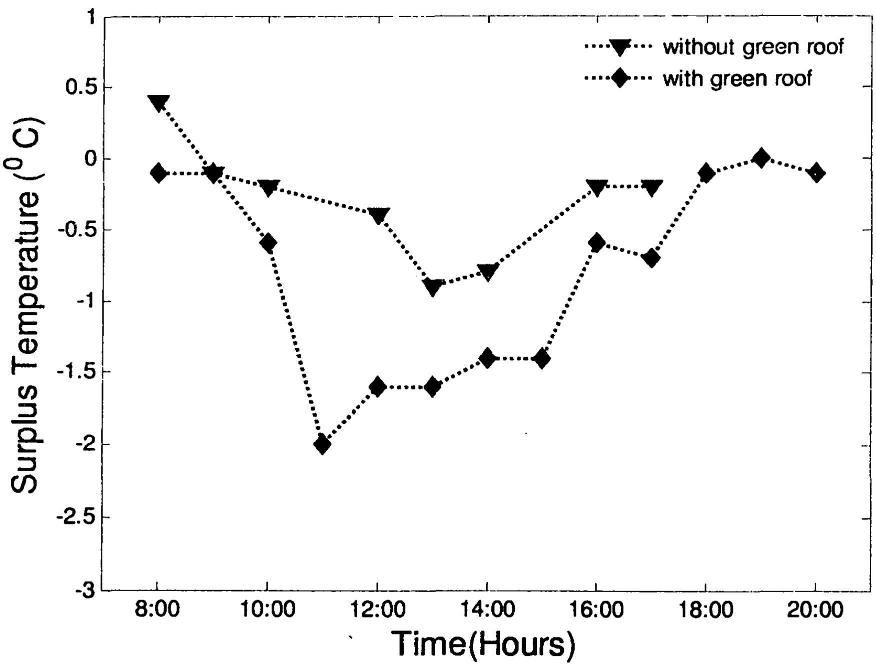



**Figure 6: Surplus temperature at the centre of model house with cross ventilation**

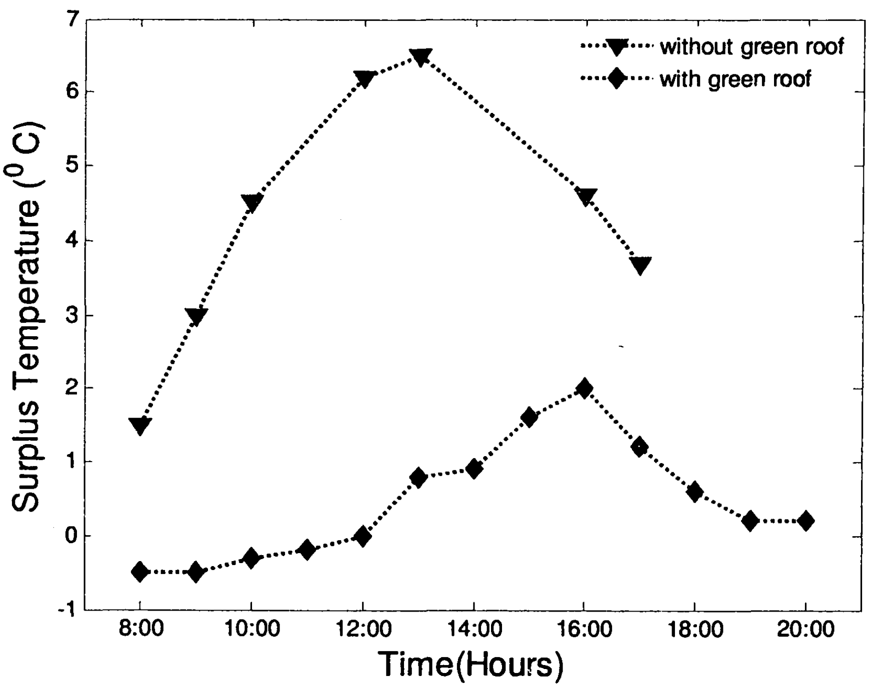



**Figure 7: Variation of Surplus temperature at the roof bottom of model house with cross ventilation**

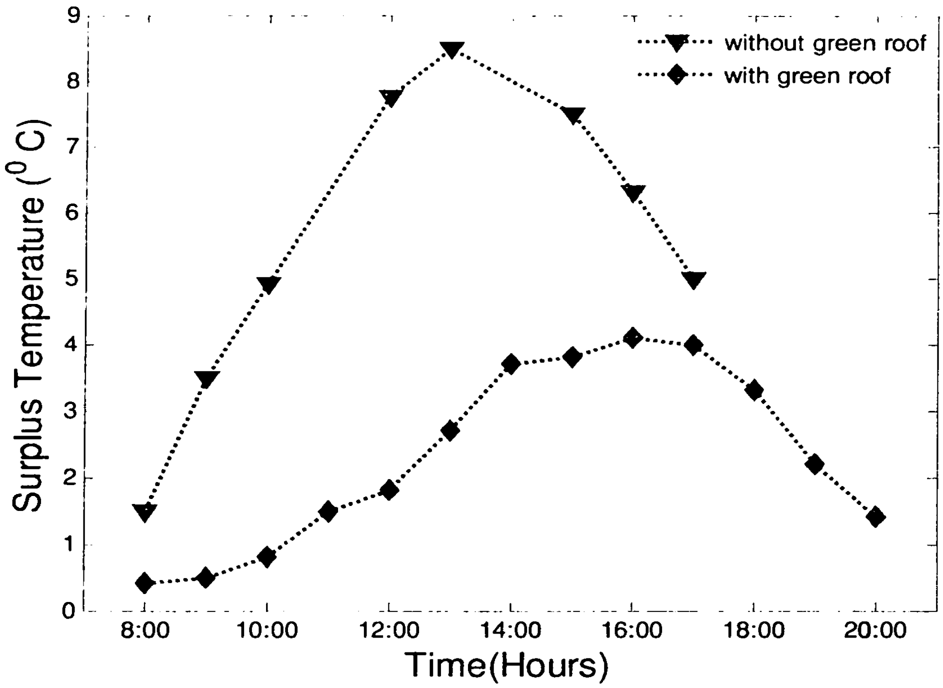



**Figure 8: Variation of surplus temperature at the roof bottom of model house without cross ventilation**

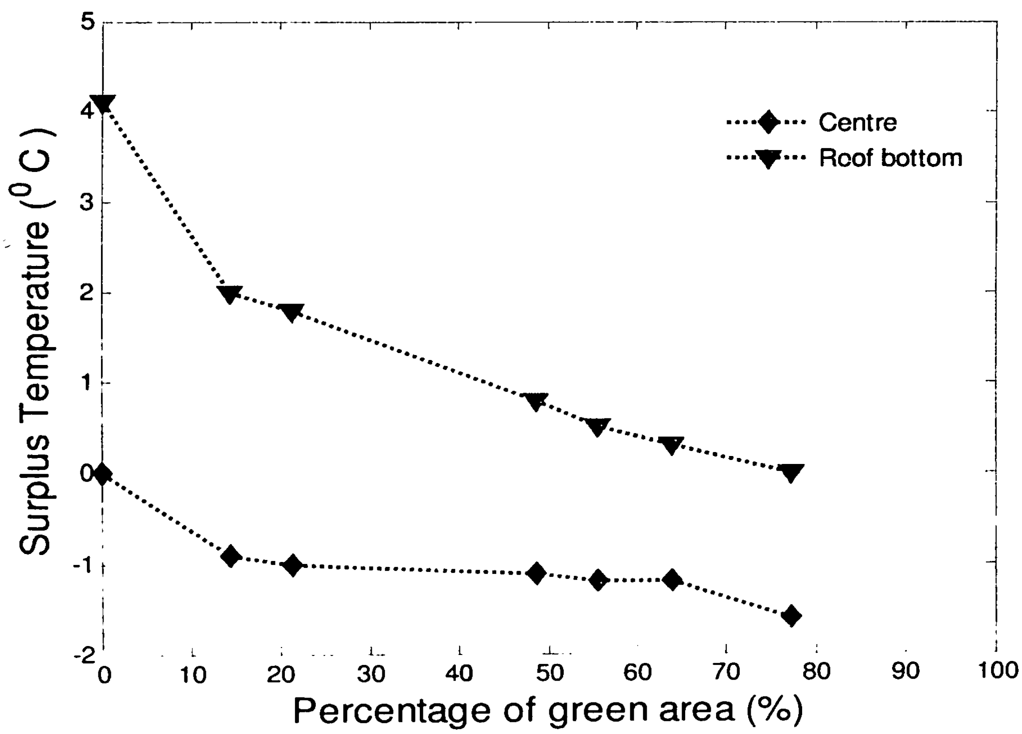



**Figure 9: Effect of percentage of green coverage on surplus temperature under cross ventilation condition**

## Discussion

Green roofs can be effectively used in reducing indoor temperatures under "With cross ventilation condition" as well as "Without cross ventilation condition". Reduction in indoor temperature is greater with "Without cross ventilation" condition compared with "With cross ventilation condition". This may explain that the green roof can be effectively used for air conditioned building where no natural cross ventilation is provided. Reduction in indoor temperature will contribute to reduce the energy consumption for thermal comfort.

There is a considerable time lag between Bare Roof and Green Roof to reach the maximum surplus temperature. This will help for saving the energy consumption in office buildings, where the officers are employing during daytime.

Percentage of vegetation cover has an effect on temperature reduction due to green roof. When green cover increases temperature reduction also increases. To obtain above mentioned temperature reductions, at least 75% green cover should exist. To receive benefits immediately after installation, a modular green roof system can be used. Investigation of the possibility of developing a modular system for current plant type and growing media is recommended for further research.

In the current study, plants glowed with natural weather condition (i.e., no any artificial watering to the plants). As the data were collected in sunny days, current data has not been affected by the water presence in growing media. However, considerable temperature reduction could be expected due to presence of water in the growing media.

## Conclusion

It was found that indoor temperatures of a model building reduce with implementation of extensive green roof systems. When increase the green coverage the difference in the temperature between the indoor and outdoor also increases. With 77% green coverage, the extensive green roof cools centre of the model building with cross ventilation by 1.75°C and that without cross ventilation by 2.0°C implying that the green roofs provide more benefits for cooling of buildings, where air condition are used.

To receive benefits immediately after installation, a modular green roof system can be used.

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