Investigation of Cooling Potential of an Eco Roof on Warm Days

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***Abstract*— The existence of all biota on this earth is challenged by global warming. The indoor and outdoor temperature levels of the buildings are increased due to the rise in ambient temperature. This will cause an increase in total energy consumption of the buildings and the cost of the energy intensive air-conditioning systems. Therefore it is high time to carry out research on sustainable energy with an emphasis on energy conservation. Green roof tops belong to this category which acts as a passive cooling technique that inhibit the solar energy to penetration into the buildings and reduces the cooling load. This paper evaluates the cooling potential and efficiency of green roofs in Indian climate. It is an effort to study the impact of green roofs on energy conservation. Experimental studies proved a reduction of 18% and 23% in indoor air and roof surface temperature of the eco room in comparison with a conventional roof. The efficiency of the green roof to alleviate the daily temperature in Indian climate has been demonstrated.**

***Keywords—* Green roof; cooling potential; Energy conservation**

I. INTRODUCTION

The principle of a green roof is to cover a flat or a low sloped roof with a vegetated substrate. Green roofs are a sustainable technology that could potentially prevent the incoming solar radiation from reaching the building structure below. A green roof consists mainly of five components from bottom to top: a roof support, a roofing membrane (membrane protection and roof barrier), isolation, a drainage layer, a growing media and vegetation. The types of green roofs are usually divided between intensive and extensive. Intensive roofs are deeply soiled and can accommodate a wide range of plants, including, in larger developments, trees. Because of the weight, they require greater support underneath and can incorporate water management systems that can help with recycling. They are a little more labour intensive than other designs. Extensive green roofs have a shallow layer of soil over a bigger area which means they are not suited to all plant types but are ideal for a wider range of roofs because they are lighter and need less structural support. For this reason they are often the type of green roof that is retrofitted to an existing building. They are also lower maintenance than their intensive counterparts [1]. Green spaces in urban environments are increasingly becoming rare due to high building density and urban sprawl. Green roofs could contribute to increasing the total amount of urban green spaces. The effectiveness of green roofs depends greatly on the climate. Green roof technologies and applications are now common practice in North-America and Europe. Although the enhancement of thermal comfort and reduction of cooling demand are considered more effective when the climate is hot and dry, this has yet to be demonstrated in a scientifically quantitative way. In India at present a substantial amount of energy is consumed for cooling buildings due to very high solar radiation throughout much of the year. The primary source of energy in India is from fossil fuel and the majority of the fossil fuel is imported from foreign countries which have affected the total economy of the country. Literature demonstrate that only very few scientific studies have been conducted on the cooling potential and thermal efficiency of green roofs in the Indian climate [2, 13].

Tahir Ayata, et al. (2011) in his laboratory set-up created different environmental conditions to measure sensible heat fluxes to/from a vegetated roof assembly [3]. This experimental setup has been successfully used for different wind velocities (0-3 m/s) to create free and forced convection conditions around green roof tested samples. Furthermore a basic model for calculations of the convective heat transfer at green roof assemblies was developed, which is a modified version of the Newton's cooling law, calibrated and then validated with different sets of data. The study of evaluation of green roof thermal performance in terms of the thermal transmittance coefficient, in real scale and under dynamic conditions was done by Kostriris et al. [4], in 2012. For the study's purposes, five semi-intensive green roof systems were constructed on the roof of an outdoor test cell. The relation between the estimated thermal transmittance and the substrate moisture content was investigated and found to be linear. The green roof systems were also simulated for a single-storey residential building in order to quantify their possible energy savings. The results from the simulation showed that shallow substrates conserve building energy mainly during the summer period of the year. Rock wool and deeper substrates showed significant cooling and thermal insulating features.

A mathematical model of the dynamic thermal behavior of actual green roofs was studied by Barrio et al. [5], 1998. Several parametric sensitivity analyses were carried out to evaluate the cooling potential of green roofs in summer. He formulated the most important design considerations for green roofs. Among them the most important factors were selection of plants with large foliage distributed mainly in horizontal direction and selection of light soils, that reduces the thermal conductivity as well as weight. The main conclusion of these analyses was that green roofs will act as insulation ones, reducing the heat flux through the roof.

II. METHODOLOGY

A. Experimental Set-up

In order to study the effect of green roof on cooling potential, two symmetrical rooms (1.85 m x 1.85m) of different types of roofs were constructed: exposed roof (concrete slab), concrete slab with green roof layer. Experiments were carried out on these roofs allowing paired experiments on both the rooms as shown in figure 1. The experiments were conducted for a duration of 7 days in the month of December, 2015 in southern part of India. The interior walls were insulated with polystyrene foam of 5 cm thickness to stop the heat conduction through the walls and to ensure that the heat flux calculations through roof would not be affected by the large heat flux through the walls.

Fig.1 Experimental Set-up

Polyethylene sheet of 3 mm thickness was used as water proof insulation and as a root barrier. Medium size Gravel of 8 cm thickness layer was used to have proper drain of water. Specially made composite of Coconut rind and Jute matrix was chosen to hold water for a longer time and it acted effectively as a retention medium. Since an extensive green roof with shallow soil structure was selected for this study, a soil depth of 10 cm was adopted. The plant selected was Paspalum Notatum and irrigation was done at regular intervals in the morning. The temperatures were recorded at every 10 minute intervals by a computer assisted automated system.

B. Equipments

- Thermal Image camera (FLUKE) to measure the surface temperature of roofs (Figure 3(a))
- Type T Thermocouples (Type T) for measurement of canopy temperature (Figure 2(b))
- Temperature data logger (PICO) to record the temperature at various points in the green roof and on the concrete slab (Figure 3(b)).

Fig.2. (a) Plants (b) Thermocouple connected to canopy

Fig. 3. (a) Infrared Thermal camera (b) Temperature Data logger

III. RESULTS AND DISCUSSION

C. Indoor Air temperature of standard and eco roof

The room air temperature of the study rooms were measured with the help of thermocouples. Figure.4 and Figure.5 represent the room air temperature profile of green and conventional rooms respectively. It has been observed that the green room air temperature always shows a lower peak in comparison with a conventional room. The temperature peaks of the conventional room were always higher than ambient as it acts as thermal storage layer. It has also been observed that a thermal lag of 1.5 to 2 hours has been observed for green room in comparison with the bare roof. The conventional roof quickly responds to the ambient temperature.

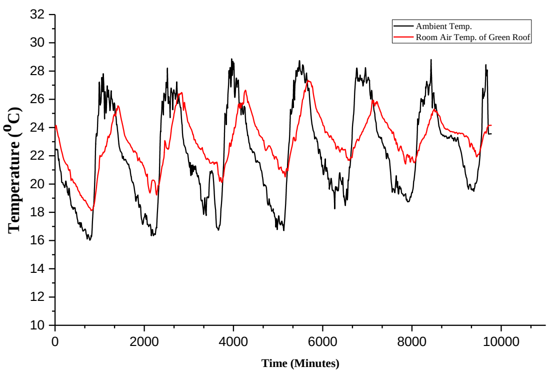

Fig.4. Indoor air Temperature profile of Green room

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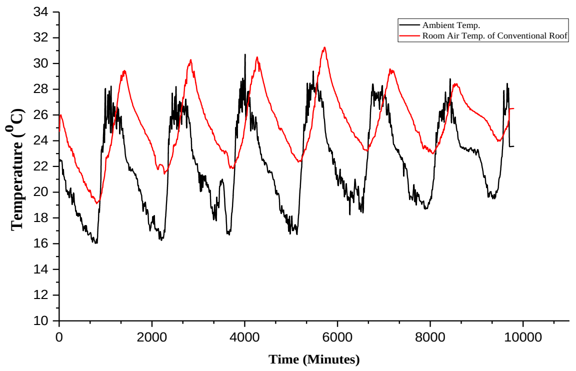

Fig.5. Indoor air Temperature profile of conventional room

The peaks of indoor air temperature profile of the green room were always lower than the ambient while it appeared higher in conventional roof. The main factors for the depression of temperature are due to evapotranspiration and shading of vegetation.

D. Heating gain of the standard roof

Thermocouple fixed at the top face of the roof slabs are used to measure and compare the exterior surface heat gain of conventional roof slabs over green roof. Experimental analysis for a period of 7 days given in Figure.6 showed that the conventional roof top face temperature was higher than the green roof slab with a maximum amount of 4.5ºC. This result establishes the insulating and shading capacity of green roofs.

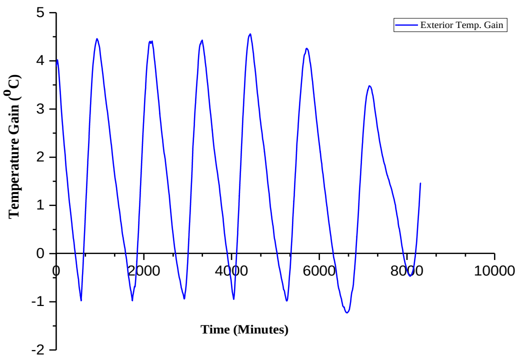

Fig.6. Heating gain of conventional roof over eco roof

E. Bottom Face temperature of the roofs

The bottom roof surface temperature of the roofs was studied by a thermal image camera and the study was conducted on the midafternoon of a warm day of December 2015. The temperature profile obtained from green and conventional roofs are shown in Figure.7 and Figure.8 respectively. It was observed that on a warm day the average temperature of the green and conventional roof slabs were found to be 24.1ºC and 27.4ºC respectively. A depression in temperature profile of green roof has been observed.

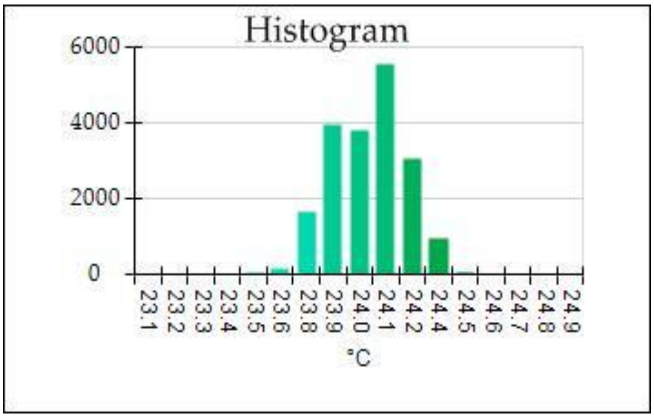

Fig.7. Temperature profile of bottom face of green roof

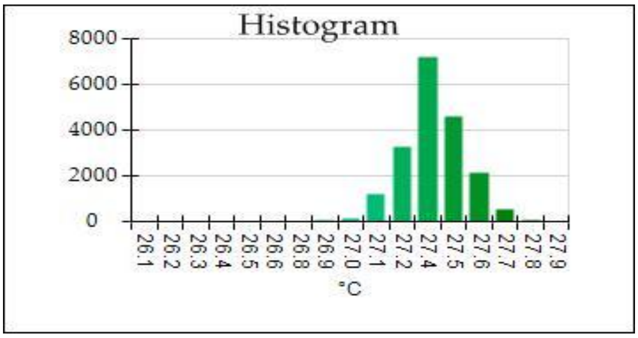

Fig.8. Temperature profile of bottom face of conventional roof

F. Exterior surface temperature of the roofs.

The exterior surface thermal images of the roofs are shown in Figure.9 The temperature profile of exterior surface of green and conventional roofs are shown in Figure.10 and Figure.11 respectively. It shows that the average temperature of the green and conventional roof slabs were 23ºC and 32.3ºC respectively.

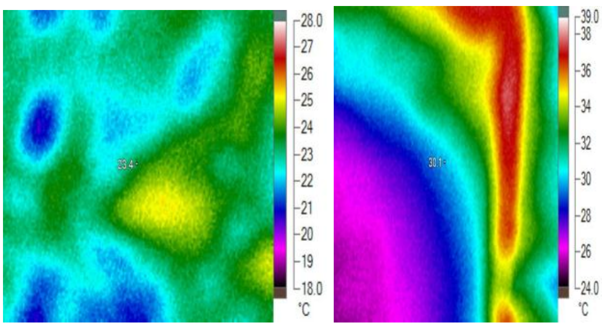

Fig.9. Thermal images (a) Green roof (b) Conventional roof

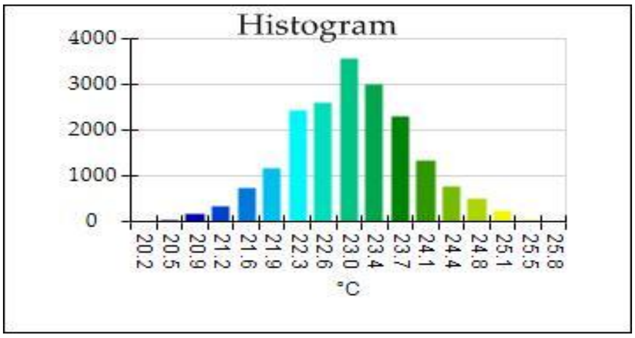

Fig. 10 Temperature profile of top face surface of Green roof slab

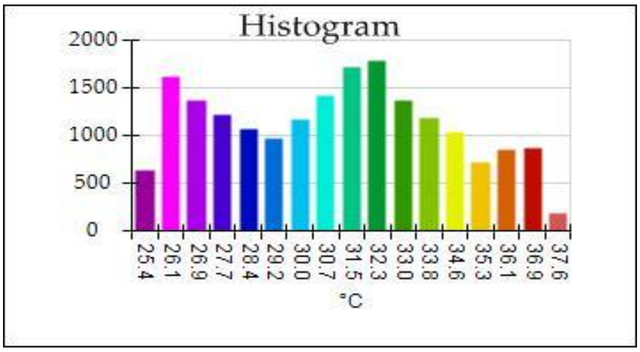

Fig. 11 Temperature profile of top face surface of conventional roof slab

G. Comparison of the room temperatures

Figure 12 shows the temperature profile of conventional and eco-roof indoor air, soil and ambient temperatures. Throughout the experimentation the indoor air temperature of the eco roof was much lower than conventional roof. A maximum difference of 4.5°C has been observed. Depression of the soil temperature was due to presence of moisture content on the surface of the soil. The major factors affect the reduction of eco-roof room temperature are evaporative cooling from soil and plants, transpiration and thermal mass of the green roof layers.

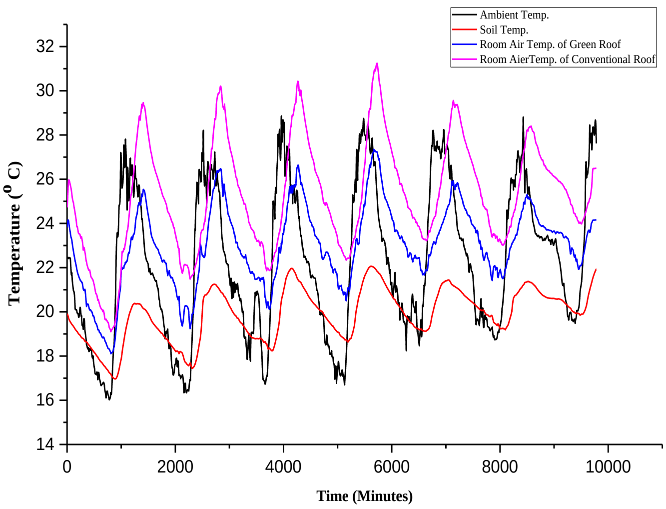

Fig. 12 Temperature profile of eco and conventional room air

IV. CONCLUSIONS

A reduction in heat entering a room underneath a green roof was convincingly demonstrated through the experimental investigation during the warm days. The indoor air and roof surface temperature of the green roof were decreased 18% and 23% in comparison with a conventional roof. The exterior surface heat gain of conventional roof over green roof was observed to be a maximum of 4.5°C. A thermal lag of 1.5 to 2 hours has been observed. It could be inferred that the green roofs are a welcome relief from solar radiation entering the building and providing the thermal comfort conditions in climatic conditions of India.

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