Investigation of the Thermal Performance of Green Roof on a Mild Warm Climate

Vinod Kumar V*, A.M.Mahalle**

* Department of Mechanical Engineering, Laxminarayan Institute of Technology, RTM Nagpur University, India

(vinodcryo@rediffmail.com, ashishmahalle@ rediffmail.com)

‡Corresponding Author; Vinod Kumar V, Vinod Bhavan, Deveswaram, Kilimanoor.P.O, Thiruvananthapuram, Kerala, India Pin: 695601

Tel: +9960590210

Received: 18.02.2016 Accepted: 23.04.2016

Abstract- Global warming has become a threat of our time. It poses challenges to the existence of all biota on this earth and has made a clear impact on the level of energy and water consumption. No doubt, increase in the ambient temperature increases indoor and outdoor temperature level of the buildings which catalyzes the use of energy and cost intensive mechanical air-conditioning systems. Green roof tops belong to such an idea for cutting down the energy consumption and enhancing the comfort level of commercial and residential buildings. This paper investigated the impact of green roof on thermal performance and cooling potential in mild warm climate of India. It was observed experimentally that compared to the exposed roof, the room air and interior surface temperature of the green roof were reduced by a maximum of 17% and 22% respectively. Heat flux studies show that not only the peaks are lower but also the diurnal heat fluctuation through the green roof assembly is lower than that of the conventional roof in the case of heat in-leak. Further, a thermal lag of around 2 to 3 hours has been observed. The simulated model developed in this study has been closely replicated by the experimental data, thereby efficacy of the model is demonstrated unequivocally.

Keywords Green roof; heat flux; canopy; evapotranspiration; Thermal comfort.

1. Introduction

Onmura et al. [1], in 2001, in his studies in a three story building in Japan, investigated the evaporative cooling effect from roof lawn gardens and it was confirmed that the surface temperature of the roof decreased from 6ºC to 30ºC during day time which was estimated to be a reduction of 50% heat flux. A detailed analysis of the thermal properties and energy performance study through mathematical approach was done by Niachou et al. [2], in 2001. This study was conducted in a hotel situated in Athens, Greece. In his findings the greatest energy savings during a whole year period was 37% for non-insulated buildings, 4% for moderate insulated buildings and 2% in well-insulated buildings. Theodre et al. [3], studied a technique for the inclusion of a model in building energy simulation in 2003. The results were validated by the use of real data taken from an existing construction in the city of Thessaloniki, Greece and a parametric study was performed in order to evaluate the main planted roof characteristics that affect the performance of a planted roof as a passive cooling technique. It was shown that relative humidity is the most important climatic factor which affects the cooling potential of the green roof.

Wong et al, (2003) conducted a field study in a low rise commercial building in Singapore [4]. In his studies a maximum reduction of surface temperature of 30ºC was obtained and the temperature reduction varied on the type of plants and density LAI (Leaf Area Index) of the plants. Thermal performance of green roof installed by the Vicenza Hospital, Italy was studied and analyzed by Lazzarin et al. [5], in 2005. The role of the latent flux of the evapotranspiration was studied and with the soil in almost dry conditions the green roof allows an attenuation of the thermal gain entering the underneath room of about 60% with respect to a traditional roofing with an insulating layer

Evaluation of the cooling potential of green roof with solar thermal shading in India was developed by Kumar, et. al. in 2005 [6]. The model was validated against the experimental data from a similar green roof-top garden in Haryana, India, and in his findings green roof combined with solar thermal shading reduced average indoor air temperature by 5.1ºC, from the average indoor air temperature for the bare roof. The studies [7] have reported that green roofs can reduce summer daily peak surface temperature by 15°C–45 °C and peak air temperature by up to 5°C. Energy demand can be cut by 8%–80% for individual buildings, depending on background climatic conditions and roof insulation levels.

Castleton et al. (2010) reviewed the current literature and highlights the situations in which the greatest building energy savings can be made [8]. Older buildings with poor existing insulation were benefited from a green roof as current building regulations require such high levels of insulation that green roofs are seen to hardly affect annual building energy consumption. As over half of the existing UK building stock was built before any roof insulation was required, it was older buildings that will benefit most from green roofs. The case for retrofitting existing buildings was reviewed and it was found there is strong potential for green roof retrofit in UK.

Green roofs have been investigated as a bioclimatic strategy to improve the energy efficiency of buildings. Parizotto, et al. (2011) studied the green roof thermal performance of an experimental single-family residence in Florianopolis, SC, Brazil [9]. The studies were conducted during the warm and mild warm seasons. In his studies during the warm period, the green roof reduced heat gain by 92–97% in comparison to ceramic and metallic roofs, respectively, and increased the heat dissipation to 49 and 20%. During the cold period, the green roof reduced heat gain by 70 and 84%, and reduced the heat loss by 44 and 52% in comparison to ceramic and metallic roofs, respectively. From the studies it was found that green roof contributes to the thermal benefits and energy efficiency of the building in temperate climate conditions.

An experimental study on the selection of appropriate plants for the green roof was done by Liu et al. (2011).The experiment was done at the top floor of an eight floor building located in Taiwan [10]. The results indicate that the plants from CAM families, Portulacaceae, Crassulaceae and Euphorbiaceae are more droughts tolerant by humans. The results showed that the temperature reduction effects decrease with plant height in the following pattern: 35cm>15cm>10cm. The results also indicate that the plants with green colored leaves are more effective in roof top heat insulation.

A study conducted in University of Lleida, by Gabriel Perez et al. (2011) used recycled rubber from tires as a drainage layer in green roofs instead of porous stone materials [11]. He concluded that the extensive green roofs can be a good tool to save energy during summer in Continental Mediterranean climate, and that the use of rubber crumbs instead of Puzolana as drainage layer material in extensive green roofs is possible, and should not arise any problem for its good operation thereby reducing the consumption of natural materials, which require large amounts of energy in its transformation process to obtain their properties. Moreover it would provide a solution to the problem of waste rubber from the tires.

Permpituck, et. al. 2012 studied the energy consumption performance of roof lawn gardens in Thailand experimentally [12]. He studied the thermal performance by varying the soil depth. In his findings the roof top with a soil depth of 0.10 m could achieve 46.24% less heat transfer than the exposed roof, and the roof top with a soil depth of 0.20 m could achieve 93.96% less heat transfer than the exposed roof.

The thermal benefits of green roofs are unquestionable. The Indoor and roof temperature of a building with green roof experience much lower temperature compared to an exposed bare roof. To analyse the thermal performance, a comparative measurement and experiment were carried out on two symmetrically constructed rooms in Southern part of India. Experimental investigations have been done on these rooms as the objective of this study is to analyse the thermal impacts of green roofs in Indian climate.

2. Materials and Methods

Experiments were carried out on two symmetrical models of each 1.5 m x 1.5 m x 2.2 m with concrete slab of 19 cm thick roofing and hollow brick wall of 15 cm thickness. Two rooms were constructed in such a way that shadows would not cover the walls and block sunlight as shown in Fig.1.

Fig.1. Experimental Set-up (Two symmetrical rooms for the experimentation)

The rooms were identical with one having a plain concrete roof and the other planted with a "Green roof", which consists of typically 5 layers from bottom to top as shown in Table 1.

Table 1. Different layers of Green Roof System

Layer	Thickness	Type
Root Barrier	3 mm	Polyethylene sheet
Drainage Medium	8 cm	Medium Size
Retention Medium	1.3 cm	Composite of
Growing Medium	10 cm	Soil
Plants	2-4 cm	Paspalum Notatum

The interiors were insulated since the ratio of wall area to roof area was quite large and quite unlike an office building or residential building. The insulation was to ensure that the heat flux through roof calculations would not be compromised by an inordinately large heat flux from the walls through solar radiation. The insulation used was polystyrene form of thickness 5 cm (U value of 0.408 W/m^2K). In order to study effect of green roof on cooling potential, two different types of roofs were set: exposed roof (concrete slab), concrete slab with green roof layer. The measurements were made from 17th December 2015 to 24th December 2015. The measurement points made on green roof layer as well as on the conventional roof are shown in Fig.2(a) and Fig.2(b) respectively.

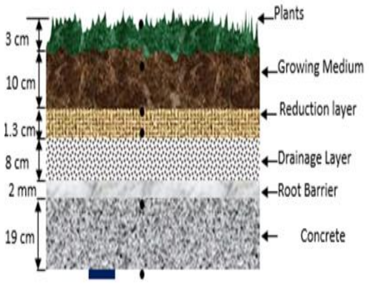

Fig.2(a). Measurement points of Green roofs layers

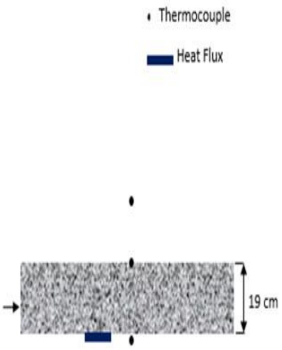

Fig.2(b). Measurement points of conventional

Positioning of the thermocouple used to measure the Green roof plant canopy temperature and the retention medium are shown in Fig.3 and Fig.4 respectively.

Fig.3. Thermocouple fixed on plant canopy

Fig.4. Thermocouple fixed on retention medium

The surface temperature and heat flux data of the indoor and outdoor conditions were recorded. All temperature data were measured at 10 minutes interval and heat flux at 15 minutes interval. Instruments used were listed below:

- Temperature data logger (TC-08) to record the temperature at various points in the green roof and on the concrete slab (Fig.5).
- Thermocouples Type T for measurement of temperature (Fig.6).
- Heat flux data logger (LI19) to record the heat flux in W/m^2 (Fig.7).
- Heat flux sensors (Hukseflux HFP01) for the measurement of heat flux into the rooms (Fig.8).

Fig.5. Temperature data logger

Fig.6. Thermocouple

Fig.7. Heat Flux data logger

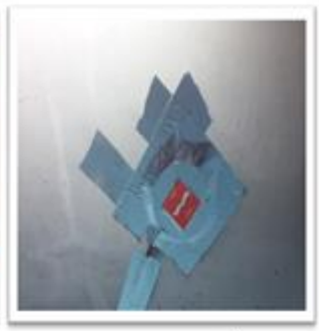

Fig.8. Heat Flux Sensor

3. Simulation Phase

The thermal-energy simulation was carried out in moderately warm days, by taking into account climate boundaries of southern part of India. In order to perform an analysis on the effect of Green Roof on the case study building with respect to other flat roof coverings, Design Builder software (Version 5.00 BETA), with varying the roof coating and insulation characteristics was used. In order to assess Green Roof performance on the two buildings, the dynamic simulation model of the office building was carried out within Energy Plus (U.S. Department of Energy, 2015 Version 8.4) simulation environment with flat roof layout and experimentally measured properties. Firstly, the architectural configuration of the structure was implemented by describing geometry, internal thermal zones, thermo-physical characteristics of the building envelope and its technical elements and materials as shown in Fig.9.

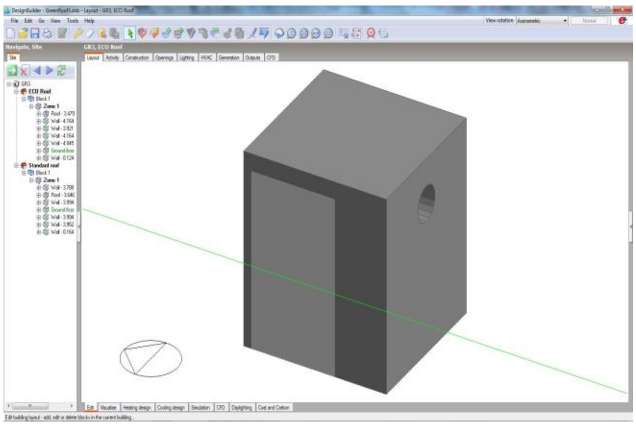

Fig.9. The model building (one of two) created using Design Builder

In order to calculate the heat flux through a green roof, two energy balance equations are simultaneously solved for each time step at the soil (Φ_g) and foliage (Φ_f) level involving soil surface temperature (θ_g) and foliage temperature (θ_f).The energy balance equation at the foliage level [14] is reported in Eq.(1) as:

$$\Phi_f = \sigma_f \left[I_s \left(1 - a_f\right) + \varepsilon_f I_{ir} - \varepsilon_f \sigma \theta_f^4 \right] + \frac{\sigma_f \varepsilon_g \varepsilon_f \sigma}{\varepsilon_f + \varepsilon_g - \varepsilon_f \varepsilon_g} \left(\theta_g^4 - \theta_f^4\right) + H_f + L_f \qquad \text{Eq.(1)}$$

where σ_f is the foliage fraction coverage; I_s is the total solar irradiance; a_f is the shortwave albedo of the foliage layer; ε_f is the foliage emissivity; σ is the Stefan-Boltzman constant; θ_f is the foliage surface temperature; θ_g is the soil surface temperature; I_{ir} is the total infrared irradiance; ε_g is the ground emissivity; H_f is the sensible heat flux and L_f is the latent heat flux. The sensible heat flux (H_f) considers the convective heat exchange between the foliage and the adjacent air while the latent heat flux (L_f) takes into account the heat exchange due to the evaporation at the foliage level as a function of the air and of the stomatal resistance to vapour diffusion. The energy balance equation at the soil level [13, 14] is reported in Eq.(2) as:.

$$\Phi_g = (1 - \sigma_f) \left[I_s \left(1 - a_g\right) + \varepsilon_g I_{ir} - \varepsilon_g \theta_g^4 \right] + \frac{\sigma_f \varepsilon_g \varepsilon_f \sigma}{\varepsilon_f + \varepsilon_g - \varepsilon_f \varepsilon_g} \left(\theta_g^4 - \theta_f^4\right) + H_g + L_g + \lambda_g \frac{\partial \theta_g}{\partial z} \qquad \text{Eq.(2)}$$

Where a_g is the shortwave albedo of the ground; I_{ir} is the total infrared irradiance; σ is the Stefan-Boltzman constant; θ_f is the foliage surface temperature; θ_g is the soil surface temperature; σ_f is the foliage fraction coverage; I_s is the total solar irradiance; H_g is the sensible heat flux of the soil, L_g is the latent heat flux, λ_g is the ground thermal conductivity and z is the depth of the soil. The coupling of the green roof model with the dynamic building thermal one is based on solving the heat balance equation of the indoor air volume with the heat and mass transfer equations through the building envelope. This is achieved by the Energy Plus Simulation engine through the Conduction Transfer function (CTF). In particular, this model takes into account the long and short wavelengths radiation exchanges by the soil and vegetation, effects of vegetation on convective (sensible heat) thermal flow, evapotranspiration (latent heat) through soil and vegetation and heat storage and transfer through the substrate. The model has also the capability to change thermal properties of the growing medium with soil moisture level.

4. Results and Discussions

4.1.Experimental Results(Impact of green Roofs on Temperature Profiles)

The thermal performance of the studied rooms with conventional and green roofs is presented below. The experiment was conducted on warm days from 17/12/2015 to 24/12/2015 for duration of 7 days. Temperature at various points of green roof and conventional roof were measured with the help of Type T thermocouple and the data were recorded at 10 minutes interval by a temperature data logger (TC-08). Heat flux sensors (HFP01) connected at the interior surface of the concrete slabs of the two roofs measure the amount of heat flow through the roofs. Heat flux data were recorded at 15 minutes interval in each room using data logger LI19.

4.1.1.Room Air Temperature

The room with green roof showed lower amplitude temperature profile throughout the experimentation as compared to the conventional roof. On warm days, the room air temperatures (Indoor) for the conventional and green roof in mid after noon (Peak temperature) reached 31.5ºC and 27.1ºC respectively and the variation of its temperature profile is shown in Fig.10. The minimum room air temperature of green roof was found to be 18.11ºC. The peaks of the room air temperature of green roofs are always lower than the conventional roof through out the experimentation with a maximum diffrerence of 4.4ºC. It has been observed that the reduction of room air temperature in green roof is because of two factors, namely (1) the thermal mass of green roof and (2) the evapo-transpiration which allows the green roof to cool itself and surroundings.

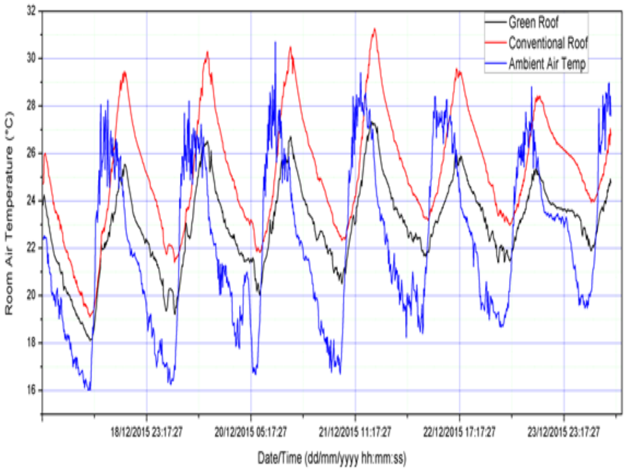

Fig.10. Room air temperature of conventional and green roofs

4.1.2.Interior Surface Temperature of the Green Roof

The thermocouples (Type T) fixed at the interior surface of the concrete slabs of the two roofs (Conventional and Green) are used to compare the interior temperature of the roofs. The peak temperatures of the interior surface of the concrete slab of conventional and green roofs were 28.53ºC and 22.39ºC respectively. The temperature profile of the interior surface of the concrete slab is shown in Fig.11. The maximum heat gain of conventional roof over green roof was found to be 6.14ºC. The interior surace temperature of the green roof shows a damped temperature profile through out the experiment. The result suggest that the green roof temperature reduced significantly because of the presence of vegetation and soil layer. Evapotranspiration and thermal mass of the green roofs are the main contibuting factors for the reduction of roof temperature.

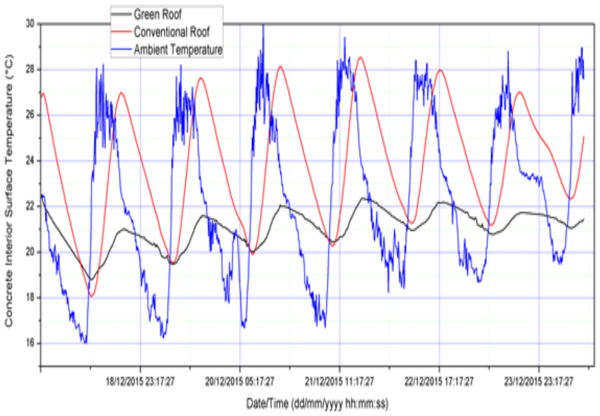

Fig.11. Interior surface temperature of green roof and conventional roof

4.1.3.Soil Temperature of the Green Roof

The temperature profile of the soil is shown in Fig.12. A damped temperature profile is obtained for the soil temperature throughout the experiment. On warm days soil is colder than the ambient temperature and this effect is mainly due to solar insulation of the foliage and evapotranspiration. It indicates that the room air and roof temperature of the green roof reduced significantly because of the presence of soil layer.

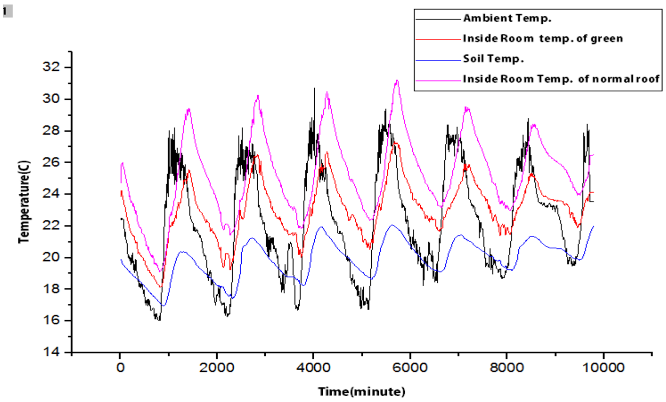

Fig.12. Soil Temperature of green roof

4.2 Description of Impact of Green Roofs on Heat Flux Measurements

Heat flux sensors (HFP01) connected at the interior surface of the concrete slabs of the two roofs measure the amount of heat flow through the roofs. Heat flux data were recorded at 15 minutes interval using a data logger LI19. Fig.13. displays the heat transfer history for 6 days. The heat flux showed lower peaks for green roofs compared to conventional roofs as shown in figure. From graph, it is evident that not only are the peaks lower but also the diurnal (daily) heat fluctuation through the green roof assembly is lower than that of the plain roof in the case of heat in-leak. It was noted that the predominant reason for the lower heat fluctuation is due to the thermal insulation capacity of the green roofs. A thermal lag of around 2 to 3 hours has been observed. This would reflect on the energy costs for air conditioning, since the green roof assembly peaks at an hour when the cooling/heating are not in peak demand and so the costs are lower.

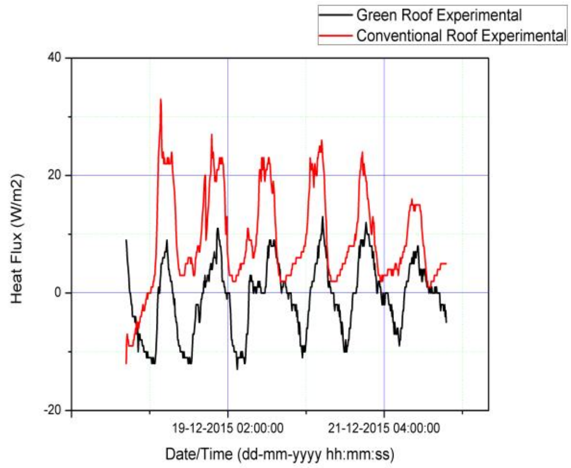

Fig.13. Heat flux Studies

4.3 Simulation Results

The simulated results of green and conventional rooms using energy plus shows a close agreement with the experimental results. Fig.14 depicts the drop in temperature in the green roof as an average of 4°C in the experimental data, whereas the simulation shows a slightly lesser difference of 3.1°C degrees. It is also worth noting that the green roof temperatures are offset from the conventional roof temperature trends by a sizeable time difference. In other words, the green roof warms up slowly and cools down slowly as compared to the conventional roof.

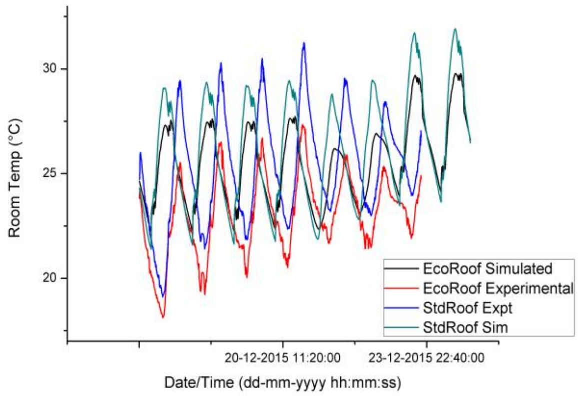

Fig.14. Experimental and Simulated values of room air temperature of conventional and green roof

Plant canopy temperatures shown in Fig.15 are a very close match in both experimental and simulated datasets. This is because the canopy temperature swings very closely mirror the ambient dry bulb temperature swings. It is found that the temperature of plant canopy as modelled is always at least 0.7°C higher than the measured data.

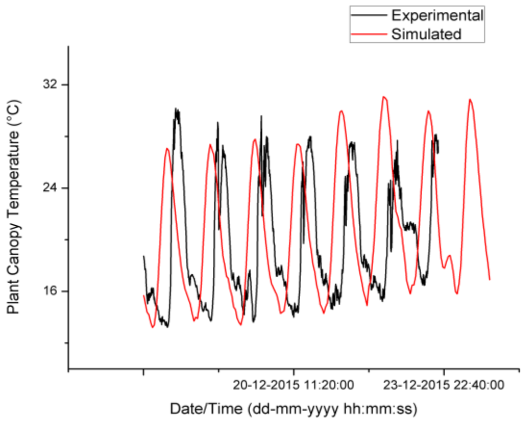

Fig.15. Experimental and Simulated values of plant canopy temperature

The validated model was used to create parametric studies for soil depth. Soil depths of 10cm, 20cm, 30cm and 40cm were simulated to plot the room temperature variations across a period of one week; the temperatures being logged automatically every 10 minutes. Deeper soil gave better insulation and lowered the temperatures in the room. The temperature swings were also flattened out for higher depths of soil. Here the soil was acting as a thermal reservoir, heating up more gradually during the day and cooling down at night more gradually. The Fig.16 shows the effect of soil depths of the green roof upon the temperature swings inside the room.

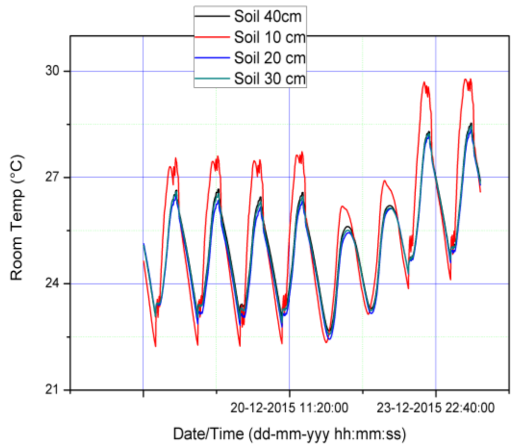

Fig. (16). Parametric study: Effect of soil depth on room temperature in a green roof.

5.Conclusions

This paper investigates the thermal behaviour of an extensive green roof on mild warm climate of India. It is convincingly demonstrated that the green roofs can greatly affect the room air temperature and interior and exterior surface temperature of the roofs on warm days. Temperatures in the two rooms are shown to be different by a large margin. Compared to a bare roof, the room air temperature of a green roof was reduced by a maximum of 4.4°C and the roof surface temperature was reduced by a maximum of 22%. A maximum heating gain of 6.1°C has been observed for the conventional roofs over the green roofs. The heat flux studies show that the heat transfer is reduced to a large extent (by 50%) on an average for experimental data. The heat flow swings are also considerably dampened and smoothed out. A thermal lag of 2 to 3 hours has been observed. The thermal performance of green roof model is presented with extensive set of validation with experimental data for room air temperature and plant canopy temperature. Parametric study shows that, to be effective, the soil depth needs to be more than 10 cm. In the study, it was found that the 20 cm, 30 cm, and 40cm (soil depth) roofs were all successful in bringing down the temperature of the room to more or less the same extent. It could be inferred that in hot climate (like the southern part of India), green roofs are a welcome relief from scorching solar radiation by contributing to human comfort as well as minimizing air conditioning expenses.

References

[1]S.Onmura, M. Matsumoto, S.Hokoi, Study on evaporative cooling effect of roof lawn gardens, Energy and Buildings, Vol 33, pp.653-666, 2001

[2]A.Niachou, K Papakonstantinou, M Santamouris, A. Tsangrassoulis, G.Mihalakakou, Analysis of green roof thermal properties and investigation of its energy potential, Energy and buildings vol 33, pp 719-729, 2001

[3]Theodore G. Theodosiou, Summer period analysis of the performance of a planted roof as a passive cooling technique, Energy and Buildings,Vol.35, pp 909–917, 2003

[4]N.H Wong, D.B.K Cheong, H. Yan, J.Soh, C.L. Ong. A.Sia, The effect of rooftop garden on energy consumption of a commercial building in Singapore, Energy and Buildings Vol.35, pp.353-364, 2003

[5]M. Lazzarin, Francesco Castellotti, Filippo Busato, Experimental measurements and numerical modeling of a green roof, Energy and Buildings Vol. 37, pp 1260-1267, 2005

[6]Rakesh Kumar, S.C Kaushik, performance evaluation of green roofs and solar shading for thermal protection of buildings, Buildings and Environment, Vol.40, pp.1505-1511, 2005

[7]Raji, B.; Tenpieric, M.J.; Dobbelsteen, A.V.D. The impacts of greening systems on building energy performance: A literature review. Renew. Sustain. Energy Rev. 2015, 45, 610–623

[8]H.F. Castleton, V. Stovin, S.B.M. Beck, J.B. Davison, Green roofs; building energy savings and the potential for retrofit, Energy and Buildings vol. 42, 1582-1591, 2010

[9]S.Parizotto, R. Lamberts, Investigation of green roof thermal performance in temperate climate: A case study of an experimental building in Florianopolis city, Southern Brazil, Energy and Buildings vol.43, pp 1712-1722, 2011

[10]T.C.Liu, G.S Shyu, W.T Fang, S-Y Liu, B.Y.Cheng, Drought tolerance and thermal effect measurement for plants suitable for extensive green roof planting in humid subtropical climates, Energy and buildings, 2011.

[11]Gabriel Perez, Lidia Rincon, Anna Vila, Josep M. Gonzalez, Luisa F. Cabeza , Green vertical systems for buildings as passive systems for energy savings, Applied Energy Vol.88, 4854-4859, 2011

[12] Sittipong Permpituck, Pichai namprakai, the energy consumption of roof lawns in Thailand, Renewable energy, Vol. 40, pp.98-103, 2012.

[13]D.J. Sailor, M. Hagos, An updated and expanded set of thermal property data for green roof growing media, Energy and buildings vol 43, pp 2298-2303, 2011

[14]Elena Palomo Del Barrio, Analysis of green roofs cooling potential in buildings, Energy and buildings vol. 27, pp 179-193, 1998