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The Investigation of Green Roof, Roof Pond and Water Spray over the Roof Cooling Potential on Single Storey Residential Building in the Indian Climate

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Abstract*—the phenomenon of global warming or climate change has led to many environmental issues including increasing atmospheric temperatures, increased greenhouse gaseous emissions and increased indoor discomfort. Studies have shown that bringing nature to the roof using passive cooling roof treatments may give positive impact in mitigating the effects of global warming potential and in increasing thermal comfort conditions inside buildings. In this study cooling potential of green roof, roof pond and direct evaporative roof spray as passive cooling roof treatments were conducted on a case study building in Indian climate. The results of the study shows that green roof is one of the effective cooling technique from both thermal comfort and environmental impact point of view in Indian climate. The average indoor temperature achieved underneath the green roof treated room is 28.9^{0}C and the average relative humidity levels also in the thermal comfort conditions range compared to roof pond and evaporative water spray over the roof passive treatments.

***Keywords*— global warming, cooling potential, green roof, direct evaporative roof spray, roof pond, thermal comfort.**

I. INTRODUCTION

Thermal comfort describes the human satisfactory perception of the thermal environment. Thermal comfort is more than just pleasant conditions. Thermal discomfort occurs when the thermal environment does not meet the requirements of the human body. If the thermal environment does not meet expectations, occupants of the building will try to influence the thermal environment does not meet expectations, occupants of a building will try to influence the thermal environment to make it do so with use of mechanical cooling units like air conditioners. This condition lead to the widespread of air conditioning in residential and commercial constructions. But use of air conditioning is make the environment even hotter due to its contribution to global warming.

Global warming lead to climatic changes in which the world experiences rising temperatures and sea levels, changes in precipitation and severe droughts and floods.The warmer temperature outside the buildings will affect the indoor temperature and thermal comfort inside the buildings. When the outside atmosphere temperature increases, occupants inside the buildings will experience increase in indoor discomfort and this situation will lead to a higher electricity demand for mechanical cooling devices and increased energy consumption in buildings. These affects lead to move towards Passive or natural and low energy consumption cooling are the most preferred cooling techniques used to minimise the solar radiation and heat gain through the building exterior surfaces.

Passive cooling systems is used to encompass the wide range of design techniques that can be employed in a building to cool the building without the use of mechanical cooling systems. Some of these systems function on their own after they are installed and do not need any further input from the occupants of the building other than the occasional maintenance.Passive cooling systems are proven to be effective and can contribute in reduce the energy consumption of buildings. Passive cooling is a natural way of cooling homes, using an approach to building design that controls the heat entering into the structure and encourages its heat dissipation. Passive cooling techniques reduce the room internal and external heat gains with the use of shadings, green roof, radiative cooling, etc.

Green roofs are means the roofs that support vegetation [1]. It is also known as eco-roof, living roof, planted roof or vegetated roof which uses plants to improve roof performance [2]. According to Werthmann [1] green roof consists of growing medium, drainage layer, root barrier, planted over a roof with protective membrane layer. According to Dunnett [3] and Werthmann [1], extensive green roof have lower thickness compared to intensive roof. The maximum substrate depth of extensive green roof is 15 cm. Extensive roof requires 2 to 15 cm of substrate depth for minimal maintenance. Green roof can extend the life of a roof by securing its roof membrane with series of layers and secure it from the solar irradiation ultraviolet rays (Snodgrass [4]). According to Williams et al. [5] extensive green roofs are more common due to their lower capital cost, lesser weight, and lower layer depth and usually they require minimum maintenance and does not require any extra roof structural adjustments to install.

An open roof pond is usually constructed on a flat concrete roof, was always exposed to the ambient atmosphere [6]. Yannas et al [6] reviewed the depth of open roof pond and suggested that Minimum water depth recommended for open roof pond is 30 cm. Givoni [7] studies under hot and dry climatic conditions of Atascasdero, shown that inside air temperature of a building with roof pond is about 8^0C lower than that of the conventional building without roof pond. Vorster and Dobson [8] conducted a studies are conducted to find performance of open roof pond without spray under the hot and humid climatic conditions. The maximum temperature of indoor air in test room was reduced from 33.97 to 28.41^0C after it was installed with roof pond. Sodha, Singh [9] examined performance of a Cool-poll system under hot climatic conditions of New Delhi, India. When maximum indoor temperature of the control room (without any treatment) was about 40^0c, maximum indoor temperature of the room with Cool-pool was about 35.4^0C.

Tiwari et al. [10] and Srivastava et al. [11] conducted studies on the performance of evaporative cooling systems on the roof and concluded that evaporative cooling is an effective method. Giabaklou and Ballinger [12] have examined the performance of a passive direct evaporative cooling system. The front faces of a building are provided with water wetting surfaces by guiding filaments, water flows from the top to bottom to wet the exterior filament surface. The fresh incoming air gets cooled by passing through wetted surfaces and goes inside the building. Such cooling is found to decreases the temperature of fresh incoming air by 9.8^0C. Qinglin Meng et al. [13] made a theoretical analysis of evaporative cooling effect of porous medium with moisture content and validated with an experiment and concluded that for low rise buildings with large roof area, cooling load was reduced by 25%.

II.EXPERIMENTAL METHODOLOGY

A. Case Study Building

The study was conducted on the flat roof of a single storey residential building with attached rooms in the anantapur. This single storey residential building was constructed of brickwork and exposed to full sunlight during the day. The attached rooms of the building are constructed with a concrete flat roof and located near the college campus was selected to be the test room for this study. These rooms are attached to one another and isolated from the surrounding buildings. These rooms are of north-south orientation and seems to experience solar radiation during the daytime hours due to full sun exposure. Every room measuring 3.04m x 2.75m x 3.04m consists of a door and a window on one side of the brick wall. The four rooms have same orientation and are exposed to similar conditions. In this research, outdoor and indoor environments i.e. outdoor and indoor air temperatures, and indoor humidity were measured to evaluate the thermal performance of the room underneath the roof. The temperature and humidity measurements were conducted on the each room with different roof treatments namely bare roof, green roof (using potted plants), roof pond and water spray over the roof. 3 days' measurements for each roof were conducted on different days with the measurements of the bare roof acting as control for this study.

B. Methodology adopted for the research

In this research, the cooling potential of the three passive cooling methods are tested on a single storey residential building. These methods are tested on a flat roof by following methodology.

Extensive green roof construction method

Extensive green roofs are green roofs that are not meant for recreational use, but are intended to be ecological. Extensive green roofs have a narrow range of plant spices limited to pulses, herbs, low growing grasses, mosses etc. Extensive green roof consists of multiple layers and they are arranged in a proper manner. The layers of extensive green roof from bottom to top are Roof deck, water proofing, Protection layer, Drainage layer, Root preamble filter layer, growing medium. Water proofing layer is placed at the bottom of the extensive green roof layers. Main purpose of placing this layer at bottom is to avoid the damage to the roof and building. The growing medium used for the extensive roof construction is light weight soil and also it depends upon the strength of the roof used for green roof construction.

Figure 1. Green roof on roof of case study building

The maximum depth of substrate of extensive green roof medium is 15 cm. In this research study extensive green roof substrate thickness 12 cm is tested to provide comfort inside the building and daily 20 litres of water was poured on green roof to grow vegetated plants.

Open roof pond

An open roof pond is usually supported by a flat concrete roof, is always exposed to the ambient environment. Minimum water depth required for open roof pond is 30 cm. during day time hours the heat gained from solar irradiation is absorbed and stored into the water before getting into the room. This feature of water delays the indoor peak temperature appearance. This heat is gets into the room in late afternoon's hours when the ambient temperature is already cooler making it easier to achieve thermal comfort.

Fig 2. Roof pond construction on roof of case study building

The depth water in maintained in the roof pond for this research study is 30 cm. The water in roof pond goes on continuously evaporating by absorbing the heat, so we need maintain the level of water to avoid less cooling effec*ts.*

Water spray over roof

Water spray over the roof is on of direct evaporative cooling technique to cool the roof. In this passive cooling technique water is poured over the roof with the help of the sprayers arranged over the roof and water circuiting pump. Based on the amount of water available the pouring process is done in certain intervals of time. The amount of water poured is directly linked with the temperature of the roof. The water poured over the roof gets evaporated by absorbing the solar radiation fall on the roof reduces the heat gain of the roof. By using this process roof gets cooled fast, but the amount of water consumption is higher.

Fig.3 Water sprayer's arrangement on roof of case study building

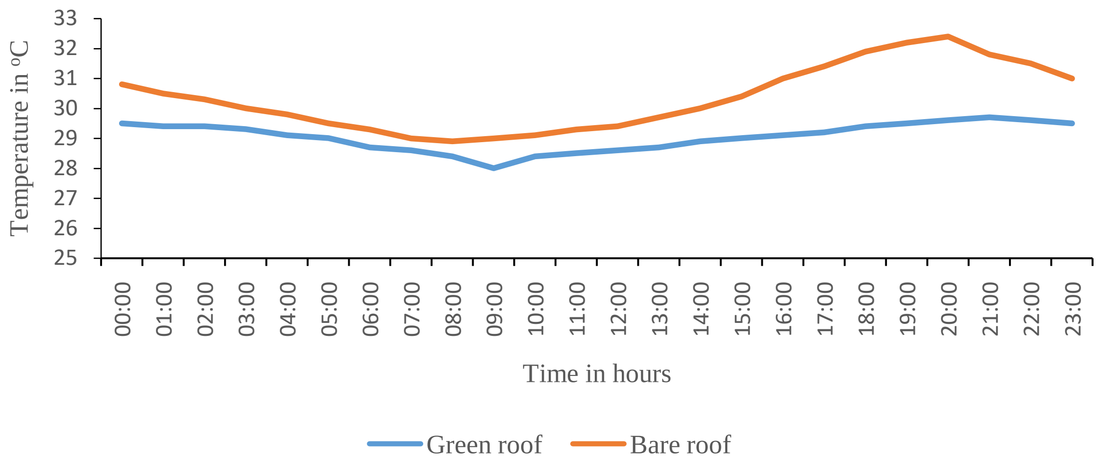
In this research based on the climatic conditions, 40 litres water is poured 5 times per a day during daytime in the interval of 2 hours.

The measurement

The measurements of indoor and outdoor microclimates of test room with different types of roof treatments were conducted on consecutively three days. In this research temperature of the outdoor air and indoor air temperatures and relative are measured. The instrument digital temperature and humidity indicator used for the measurement of temperature and relative humidity in indoor and outdoor environments of case study building. The indoor air temperature of the rooms and outdoor air temperature of the rooms and relative humidity inside the rooms measured for every one hour throughout the day. This process of measurement is taken for 3days and average of the measurements is taken for the research purpose. All readings were taken with windows and doors of the four rooms closed.

III RESULTS

The measured values of indoor air temperature, and relative humidity are plotted into graphs as below.



Graph 1: Comparison of average indoor air temperatures between green roof, and bare roof for three day's reading

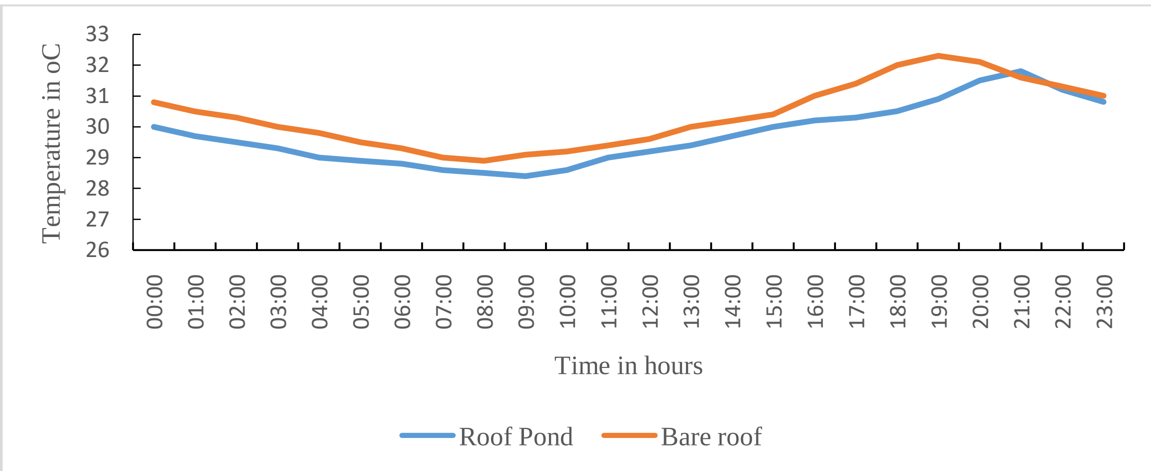
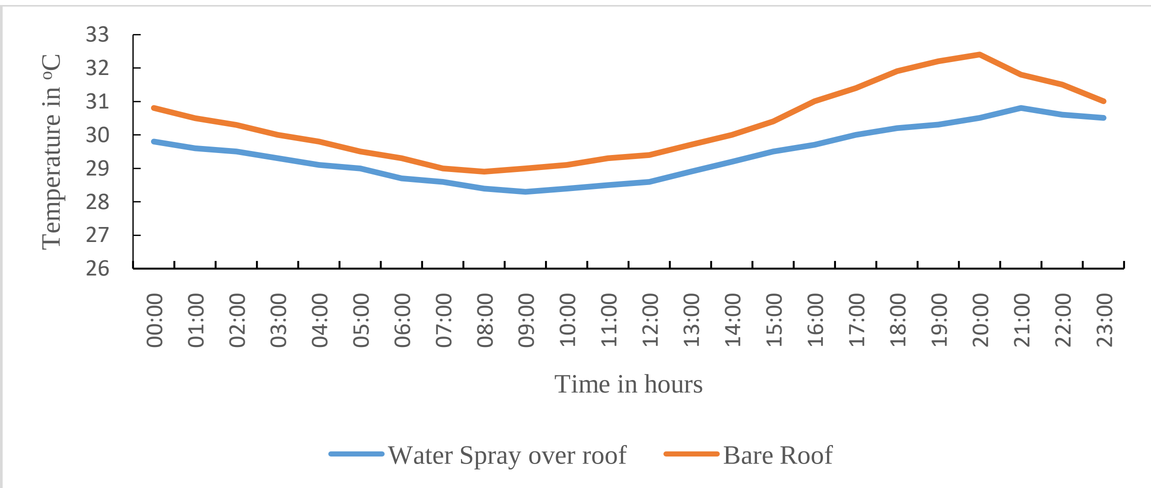
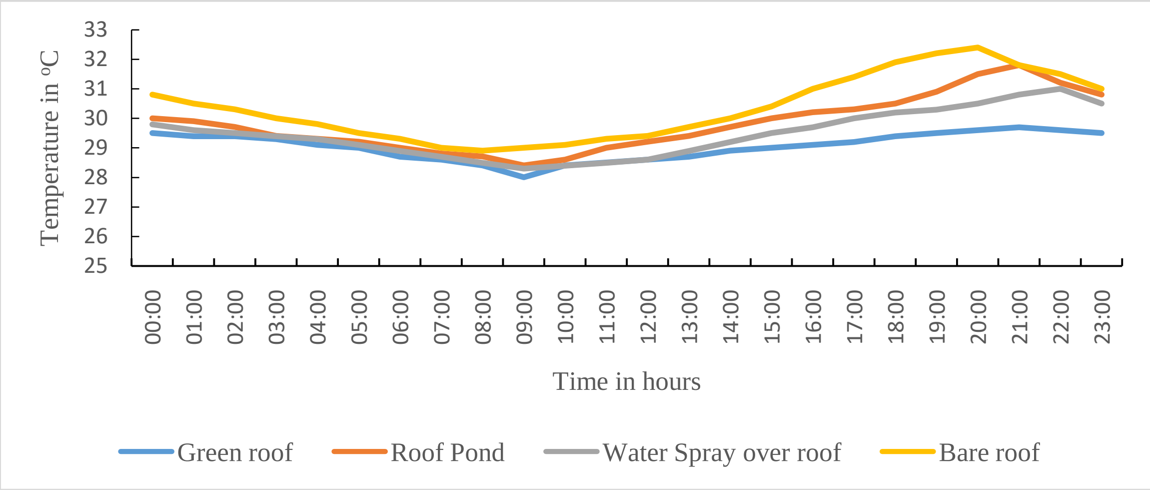


Fig 2: Comparison of average indoor air temperatures between roof pond and bare roof for three day's reading



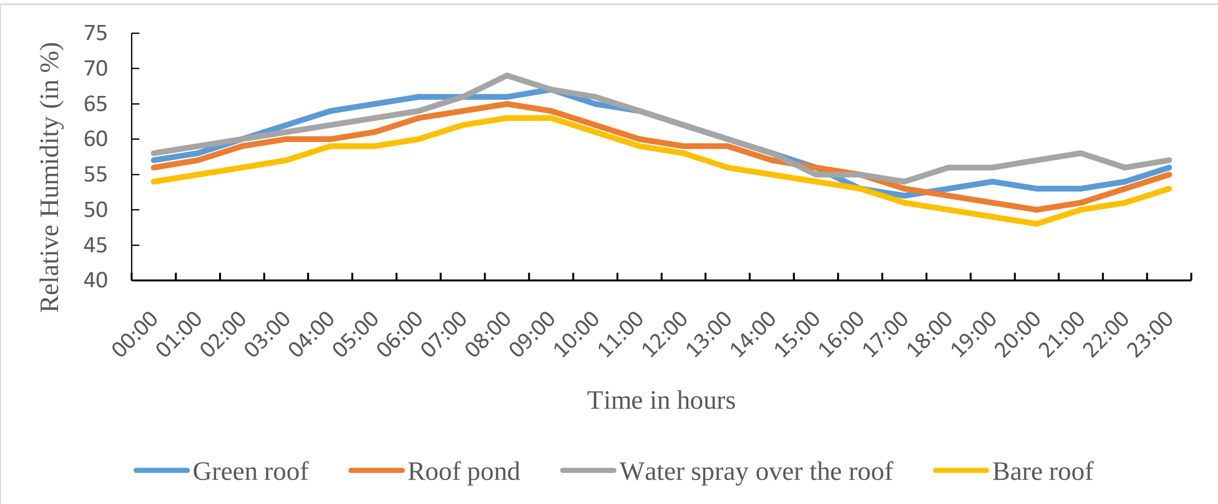
Graph 3: Comparison of average indoor air temperatures between water spray over roof, and bare roof for three day's reading



Graph 4: Comparison of average indoor air temperatures between green roof, roof pond, water spray over roof, and bare roof for three day's reading

Graph. 4 shows the average three days' reading of indoor air temperatures for all four types of roof. Again, the graph demonstrated a lower value for green roof's indoor air temperature in comparison with bare roof at all times during the day. The highest average temperature difference between bare roof and green roof during daytime hours was recorded at 2.7^{0}C at 7 o'clock in the in the evening. During the measurement period, the plants on the green roof were watered once a day to ensure their survival. The watering of plants on the green roof was carried out at 8 o'clock in the morning for every day. Hence, the indoor air temperature recorded during these hours (which can be seen on the graph) was the lowest. The average indoor temperature range from 28^{0}C to 29.7^{0}C was observed in the room underneath the green roof whereas, temperature ranges from 28.4^{0}C to 31.8^{0}C, 28.3^{0}C to 30.8^{0}C, and 28.9^{0}C to 32.4^{0}C were observed underneath the roof pond, water spray over roof and bare roof respectively. The minimum and maximum temperature differences of 0.1^{0}C and 2.2^{0}C were observed in the experiment at 9.00 o'clock in the morning and 7.00pm in the evening underneath bare roof and green roof. Meanwhile, the highest temperature difference between green roof and roof pond was recorded at 1.9^{0}C at 9 o'clock in the evening. The average indoor air temperature for all roofs started to increase from 10am in the morning until 8pm in the evening and after that starts to gradually decrease. This was because the roof started to absorb heat during daytime hours and slowly released the heat stored during night time.

In order to evaluate the cooling potential of green roof, roof pond, water spray over the roof, and bare roof, the indoor air temperature of those roofs were examined



Graph 5: Comparison of average indoor relative humidity values between all roofs for three day's reading

Indoor relative humidity is inversely proportional to indoor air temperature in which higher temperature results in lower relative humidity. Graph 5 shows the average indoor relative humidity pattern for all types of roof. Average indoor relative humidity of bare roof was lower than the other type of three roofs at all times especially during late afternoon hours due to higher indoor temperatures. The difference in average indoor relative humidity is shown in graph 5. The indoor relative humidity patterns are proportional to average indoor temperature recorded for all roofs.

IV. CONCLUSION

Green roof has proven promising technique in reducing indoor air temperature and providing positive environmental impact to buildings. Experiments have been conducted to study the effect of three such passive cooling techniques viz. 1.green roof, 2. Roof pond, and 3. Water spray over the roof. Experiments were carried out during 7^{th} to 10^{th} June 2018. Among the three techniques adopted green roof prove to be effective. An average temperature drop of 1.30C, 0.570C, and 0.960C is observed in case of green roof, roof pond, and water spray over the roof as compared to bare roof.

Indoor relative humidity is inversely proportional to indoor air temperature in which higher temperature results in lower relative humidity. Average indoor relative humidity of bare roof was lower than the other type of three roofs at all times. The indoor relative humidity underneath the green roof present in the range of 52% to 67%.

From the data analysis and obtained results, concluded that Green roof is one of the efficient passive cooling technique to reduce the indoor temperature compared to bare roof, roof pond and water spray over roof passive cooling techniques.

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