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Thermal Performance of Green Roof in Residential Buildings of Kathmandu Valley

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Abstract
Green roof technology is one of the energy-saving measures to reduce thermal loads, thereby maintaining a comfortable indoor air temperature. This paper aims to study and evaluate the thermal performance of green roof technology in residential buildings in the Kathmandu Valley. The study continues to analyze the detailed field data collected to identify the summer indoor thermal environment in relation to the outdoor thermal environment. The study also compared the thermal performance of green roofs with the conventional RCC roofs in residential buildings of the Kathmandu Valley. The potential indoor thermal comfort that could be achieved by in-built of different green roof technology in residential buildings has been studied and analyzed. From this study, it was found that among different kinds of green roof technologies, intensive green roof performs better than any other types of green roofs in terms of thermal comfort. The conclusion of the research is that, by the in- built of intensive green roof in building, there was a significant reduction of indoor air temperature by 2.4°C compared to conventional RCC roofing system during summer. Hence, the thermal performance of the green roof technology, which is adapted to change the thermal environment in various ways to achieve thermal comfort, is superior to the thermal performance of contemporary RCC roofing system.

Keywords
Green roof, environment, residential buildings, Kathmandu valley, thermal performance, indoor comfort

1. Introduction

1.1 Overview of the study

Sustainable development requires appropriate adjustments to green building design technologies in terms of regulations and technologies, which will have a significant impact on national energy demand and the environment. Through simple design and adaptation of green buildings, the lowest level of comfort can be obtained at a limited cost [1]. Recently, the concept of green infrastructure has been defined as a set of artificial elements that provide multiple functions of environmental protection on an architectural scale [2]. In this context, roof greening is one of the most innovative solutions in the green building construction system. Traditionally, the greening system in buildings is mainly for aesthetic reasons, but today, its need is also reasonable for various ecological and economic reasons, such as energy saving, improvement of urban climate, biodiversity, durability of building materials, etc. There are many studies on the implementation of vegetation in building envelopes in different environments, such as reducing urban heat islands, energy aspects, energy and economic evaluation, building thermal performance, thermal protection, managing thermal energy, environmental life cycle assessment and air conditioning energy consumption worldwide. In present scenario, green roof technology is becoming more and more popular in major cities around the world to alleviate environmental problems. Green roofs can reduce the near-surface temperature by 0.4°C to 1.3°C, such that the average temperature in areas with more vegetation and less vegetation can differ by 2°C [3]. Green roof technology has quickly become one of the energy-saving measures to reduce heating and cooling loads, thereby maintaining a comfortable indoor temperature. It has many environmental, aesthetic and social benefits. In developed countries, this technology has become part of urban development strategy, and the government encourages people by providing financial incentives

[4]. Although this green roof technology has been widely deployed in many parts of the world, its adoption in the Kathmandu Valley has been slow. In Nepal, green roofs are being developed and practiced in the form of roof top gardening which is commonly named as ”Kaushi Kheti”. Some builders have added green roofs to hotels and accommodations in the Kathmandu Valley for aesthetic purposes. This system is important for the Kathmandu Valley, because the core area is composed of high-rise buildings and the open vegetation terrain are minimal. Green roofs, also known as green roofs, living roofs, and roof gardens, are flat or sloped roofs designed to support vegetation [5]. As shown in table 1 below, green roofs have been categorized into three groups of intensive, semi-intensive and extensive roofs. Intensive green roof is thicker and heavier and can grow under a wider range of vegetation, while extensive green roof is light in weight, low in capital cost and low in plant diversity whereas, semi-dense green roofs require deeper layers of soil, but the benefits depend on the type of planting available.

1.2 Previous studies of green roof in international context

Many international researches on green roof have been carried out in international context. Most of the researches were conducted in urban areas and residential buildings. Most of the research methods consist of simulation model ENVI-met [6], field measurement [7], GIS software, and local meteorological data’s [8], field data [9] etc. All the international researches as mentioned below were carried out in the region of warm and temperate climate. The authors of [7] investigated the thermal performance of green roof in warm and temperate climate of Florianopolis city, Southern Brazil. The study was performed in an experimental residential building of 124 m2 area having three different types of roofs (i.e., ceramic roof, metallic roof and green roof). The study concluded that, during warm week, the indoor air temperature of a bedroom below green roof was 0.5°C-1°C lower than other rooms whereas, the green roof surface temperature was lower than the outside air temperature with a maximum difference of 2°C. Whereas during cold period, the indoor comfort conditions of bedroom with green roof were identical to that of other rooms except that, the indoor air temperature of bedroom with green roof stays 1°C higher than that of other rooms when the peak temperature is lower. The rate of decrease in the external surface temperature in winter is very similar to the rate of decrease in summer. The authors of [8], assessed the potential benefits of green roofs by collecting data from the Pennsylvania State University Center in New York having warm and temperate climate. In this study, the simulation conducted by the roof energy balance model confirmed that, the indoor air temperature of green roof buildings was 2°C lower during the day, whereas it was 0.3°C higher at night, since the roof greening can reduce roof surface temperature between 0.4°C and 1.3°C. Similarly, the study conducted by [9], in New York city to find the positive effects of vegetation in both urban and building scale validated that, in between most and least vegetated areas, there is an average temperature difference of 2°C. According to [10], in residential buildings, green roof can reduce the average indoor air temperature by up to 2°C compared to conventional roofing system. Similarly, a regional temperate climate simulation model developed by [6] predicts that, when fifty percentage of Toronto’s roofs are green, the temperature will drop by 2°C and 3°C.

1.3 Objectives of the study

This study has following objectives:

1. To compare and contrast the thermal performance of green roof against conventional RCC roofing system in the buildings by field measurement.

2. To evaluate the thermal performance of green roof technologies depending upon the different types of green roof.

2. Methodology

2.1 Investigated area

The study area is modern residential buildings located in Kathmandu valley. This research adopts post positivism paradigm. In order to fulfill the objective, the present paper has adopted both the qualitative and quantitative research. As a part of qualitative research, the thermal performance of green roof technologies was studied through literature. Likewise, the quantitative method was carried out intensively in field. Purposive sampling was done for selection of reference buildings. For data collection, field measurement was performed. Field measurements include recording the indoor air temperature and external roof surface temperature at various points in each of the reference building. The evaluation of

Table 1: Different types of green roof

	Extensive roof	Semi intensive	Intensive roof
Plant options	Sedum, moss, perennial, grass	Perennial, moss, grass,flowers, shrubs	Sedum, shrubs, trees
Soil depth	2” to 6”	6” to 8”	8”-30”
Weighs	60 to 150 kg/m2	120 to 200 kg/m2	180-500 kg/m2
System build-up height	60-200mm	120-250mm	150-400mm
First cost	Low	Medium	High
Maintenance	Minimal	Routine	Routine

thermal environment of buildings contains field data, sample analysis, followed by discussion. The SPSS software was used to perform statistical evaluation on all data collected on site. This article conducts a detailed study on three randomly selected residential houses to evaluate the thermal environment by measuring temperature data.

2.2 Climate of Kathmandu valley

Kathmandu Valley lies in the hilly area of Nepal, located between 27°32’13” and 27°49’10” north latitude and 85°11’31” and 85°31’38” east and at an average elevation is about 1300 meters [11]. The climate of Kathmandu has three different seasons, namely cool and dry, hot and dry and warm and humid seasons. The November to march are identified as cool and dry season whereas, coldest months are in December, January and February, while May and June are dry and hot, and June to August is warm and wet [12]. The subtropical and warm-temperate climate prevails in Kathmandu valley with maximum 35.6°C temperature in summer while a temperature range of 2°C-20°C in winter [11]. The average annual rainfall is about 1300 mm, the relative humidity is a bit high, but the daytime value will drop, varying between 36% and 100%, and is highly dependent on the ambient temperature [13]. Regarding the climate of Kathmandu, the comfort zone is between 22.8°C-27.8°C in summer and 18.5°C-23.5°C in winter [14]. The prevailing wind direction in the valley is west wind, with an average wind speed of 0.6 m/s and average sunshine duration is 6.3 hours, varying from 3.3 hours to 8.4 hours [13].

2.3 Description of instrument and measuring period

The thermal monitoring of the reference residential buildings was performed by using the air temperature measuring instrument, data logger. As per hygrometer manufacturer in Nepal, the accuracy and resolution of instrument data logger is ±0.5 °C, ±3% RH and 0.1°C, 0.1% RH respectively. The air temperatures of three reference buildings were measured by using data logger for continuous ten days starting from 17th July to 26th July, 2078 in summer. Internal thermal monitoring of reference buildings was done using four air temperature measurement points in each building as shown in figure 3, 4 and 9 respectively. The two points were the indoor measuring points located on two rooms each below the green roof and the conventional RCC roof respectively. The indoor measurement points were 150 cm above each floor level. The remaining two points were the outdoor measurement points, located in lower and upper terraces of each building having RCC roof and green roof respectively. The outdoor measurement points were nearly 30 cm above the roof slab level. All data were measured three times a day by using data logger manually.Whereas all thermal data’s were measured at 7am, 12 pm and 7am every day. Care was taken to avoid direct sunlight on the data logger throughout the day. The measured data were calibrated. There were nearly 360 temperature data collected in four points of three houses in 10 days.

2.4 Investigated buildings

Thermal behavior analysis of 3 residential buildings having 3 different kinds of green roofing technologies such as: intensive green roof, extensive green roof and building with rooftop farming were performed. Each building consists of upper and lower terrace, each having RCC roof and respective green roof. These buildings were ventilated naturally.

1. Case 1 building with intensive green roof:

This residential building is located in Kuleshwor-14. The building is north-west oriented and frame structure, having a floor area of 89.96m2. This building consists of intensive green roof in first floor terrace at an area of 36.23m2 facing south. The intensive green roof of 0.457m thickness consists of

0.005m water proof membrane above 0.127m concrete RCC slab. The waterproof membrane is layered by 0.003m plastic sheet as protection layer. It consists of 0.04m drainage layer above plastic sheet followed by 0.127m gravel layer and 0.282m soil layer above. Vegetation's are grown in the soil layer. This resident building consists of annual plant like garden flowers and vegetables on the soil layer.

Figure 1: Case 1 building with intensive green roof

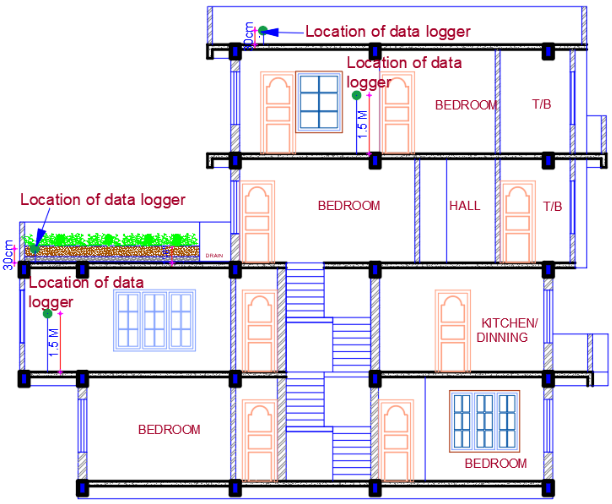

Figure 2: Building section of case 1 building with locations of data logger in indoor and outdoor of building for air temperature measurement.

2. Case 2 building with extensive green roof:

This residential building is located in Guitole-8. This building is east oriented and frame structure, having a floor area of 90.97m2. This building consists of extensive green roof in fifth floor terrace at an area of 25.86m2 facing south. The extensive green roof of 0.152m thickness consists of 0.005m water proof membrane above 0.127m concrete RCC slab followed by 0.003m waterproof membrane and 0.144m soil layer above it. Vegetation's are grown in the soil layer. This resident building consists of perennial plant like turf grasses on the soil layer.

Figure 3: Case 2 building with extensive green roof

Figure 4: Building section of case 2 building with locations of data logger in indoor and outdoor of building for air temperature measurement.

3. Case 3 building with rooftop farming:

This residential building is located in Dallu-13. This building is south-west oriented and frame structure, having a floor area of 46.2m2. This building consists of rooftop farming in fourth floor terrace at an area of 16.28m2 facing south.

Figure 5: Case 3 building with roof top farming roof

3. Results and Discussion

3.1 Evaluation of thermal behavior of green roof by field measurement

3.1.1 Indoor and outdoor air temperature of reference buildings

Case 1 Building with intensive green roof:

In order to compare the thermal behavior of each of the green roof with conventional RCC roofing system within the same building, indoor and outdoor air temperature of upper and lower terrace having RCC roof and specific green roof in each of the buildings respectively, were recorded, compared and analysed. The results in table 2 below shows that, for the indoor and outdoor air temperature measurement of room with intensive green roof, the minimum indoor and outdoor air temperature recorded was 21°C and 22°C respectively at 7am. The same building recorded the maximum indoor and outdoor air temperature of 26.1°C and 30.2°C at 12pm. So, this building records the indoor and outdoor air temperature difference by around 1°C in 7am and it recorded air temperature difference of around 1°C-4°C at 12pm. Subsequently, in the same building, for the indoor and outdoor air temperature measurement of room with RCC slab, the minimum indoor and outdoor air temperature recorded was 23.3°C and 23°C respectively at 7am. The same building recorded the maximum indoor and outdoor air temperature of 28.1°C and 30.9°C at 12pm. So, it shows that there was 0.3°C air temperature difference between indoor and outdoor at 7 am whereas, there was 1°C-2°C air temperature difference around 12 pm.

Case 2 building with extensive green roof:

The results in table 3 below shows that, for indoor and outdoor air temperature of room with extensive green roof, the minimum indoor and outdoor air temperature

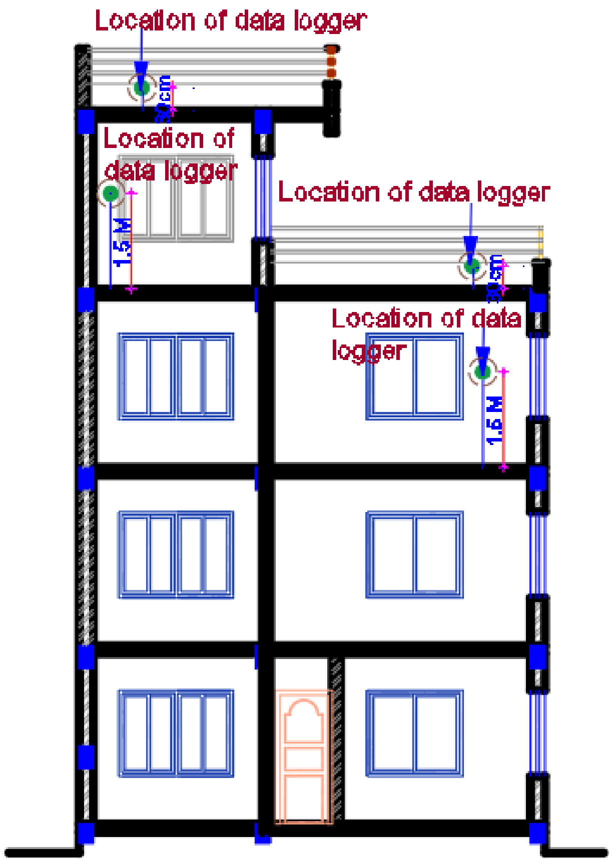

Figure 6: Building section of case 3 building with locations of data logger in indoor and outdoor of building for air temperature measurement.

recorded was 21.5°C and 22.4°C respectively at 7am. The same building recorded the maximum indoor and outdoor air temperature of 29.8°C and 32.9°C at 12pm. So, the records show, there was 0.9°C air temperature difference between the indoor and outdoor air temperature in 7am and whereas, it recorded air temperature difference of around 3°C at 12pm. Subsequently, in the same building, for the indoor and outdoor air temperature of room with RCC slab, the minimum indoor and outdoor air temperature recorded was 21.5°C and 21°C respectively at 7am. The same building recorded the maximum indoor and outdoor air temperature of 31.5°C and 30.2°C at 12pm. So, it shows that, there was 0.5°C air temperature difference between indoor and outdoor at 7 am whereas, there was 1.3°C air temperature difference around 12 pm.

Case 3 building with rooftop farming:

The results in table 4 below shows that, for the indoor and outdoor air temperature of room with rooftop farming roof, the minimum indoor and outdoor air

Table 2: Indoor and outdoor air temperature of case 1 building

Types of roofs	Minimun air temp. recorded (7am) in deg. celcius			Maximum air temp. recorded (12pm) in deg. celcius		
	Indoor	Outdoor	Temperature difference	Indoor	Outdoor	Temperature difference
Intensive green roof	21	22	1	26.1	30.2	1-4
RCC roof	23.3	23	0.3	28.1	30.9	1-2

Table 3: Indoor and outdoor air temperature of case 2 building

Types of roofs	Minimun air temp. recorded (7am) in deg. celcius			Maximum air temp. recorded (12pm) in deg. celcius		
	Indoor	Outdoor	Temperature difference	Indoor	Outdoor	Temperature difference
Extensive green roof	21.5	22.4	0.9	29.8	32.9	3
RCC roof	21.5	21	0.5	31.5	30.2	1.3

temperature recorded was 23°C and 22°C respectively at 7am. The same building recorded the maximum indoor and outdoor air temperature of 30.9°C and 31.8°C at 12pm. So, the records show, there was 1°C air temperature difference between the indoor and outdoor air temperature in 7am and it shows that there is 0.9°C air temperature difference between indoor and outdoor at 12 pm. Subsequently, in the same building, for the indoor and outdoor air temperature of room with RCC slab, the minimum indoor and outdoor air temperature recorded was 22°C and 21°C respectively at 7am. The same building recorded the maximum indoor and outdoor air temperature of 31.9°C and 30.6°C at 12pm. So, it shows that there was 1°C and 1.3°C air temperature difference between indoor and outdoor at 7 am and 12 pm respectively.

3.1.2 Comparison of indoor air temperature of green roof surfaces with RCC roof surface

The figure 7 below shows that, for case 1 building, the mean indoor air temperature of room below intensive green roof was 23.3°C whereas, the mean indoor air temperature of room below RCC roof within same building was 25.6°C. Hence, there was an indoor air temperature reduction of 2.3°C in the room below intensive green roof compared to the room below RCC roof. Similarly, for case 2 building, the mean indoor air temperature of room below extensive green roof was 24.5°C whereas, the mean indoor air temperature of room below RCC roof within same building was 26.07°C. Hence, there was an indoor air temperature reduction of 1.6°C in room below the intensive green roof compared to the room below RCC roof. Finally, for case 3 building, the mean indoor air temperature of room below rooftop farming was 25.8°C whereas, the mean indoor air temperature of room below RCC roof within same building was 26.7°C. Hence, there was an indoor air temperature reduction of 0.9°C in room below rooftop farming compared to room below RCC roof.

3.1.3 Comparison of outdoor air temperature of green roof surfaces with RCC roof surface

As shown in figure 8 below, in case 1 building, the mean outdoor air temperature of intensive green roof was 25.7°C whereas the mean outdoor air temperature of RCC roof within the same building was 26.3°C. This shows that, the intensive green roof cooled the outdoor air temperature by 0.6°C compared to RCC roof. Similarly, in case 2 building, the mean outdoor air temperature of extensive green roof was 26.09°C whereas the mean outdoor air temperature of RCC roof within the same building was 26.7°C. This shows that, the extensive green roof cooled the outdoor air temperature by 0.6°C compared to RCC roof surface. Whereas, in case 3 building, the mean outdoor air temperature of roof top farming roof was 26.6°C whereas the mean outdoor air temperature of RCC roof surface within the same building was 27°C. This show that, the roof top farming roof cooled the outdoor air temperature by 0.4°C compared to RCC roof surface.

3.1.4 Comparison of mean indoor and mean outdoor air temperature of green roofs with conventional RCC roofs.

The figure 9 below shows that, in case 1 building with intensive green roof, the mean indoor air temperature of room below intensive green roof was 23.3°C when the mean outdoor air temperature of intensive green roof was nearly 25.7°C and mean indoor air temperature of room below RCC roof within the same building was 25.6°C when the mean outdoor air temperature of RCC roof was 26.3°C. This result shows that, the room below intensive green roof was 2.4°C cooler than the room below RCC roof. The figure 10 below shows that, in case 2 building with extensive green roof, the mean indoor air temperature

Table 4: Indoor and outdoor air temperature of case 3 building

Types of roofs	Minimun air temp. recorded (7am) in deg. celcius			Maximum air temp. recorded (12pm) in deg. celcius		
	Indoor	Outdoor	Temperature difference	Indoor	Outdoor	Temperature difference
Rooftop farming roof	23	22	1	30.9	31.8	0.9
RCC roof	22	21	1	31.9	30.6	1.3

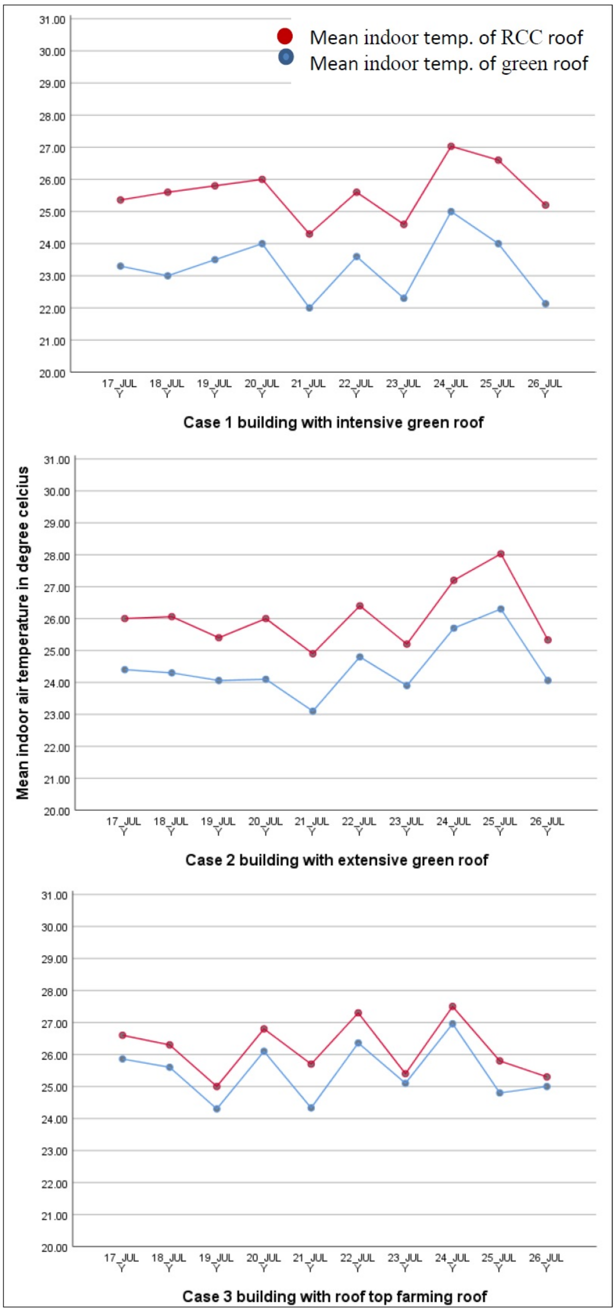

Figure 7: Comparison of mean indoor air temperature of green roof with RCC roof.

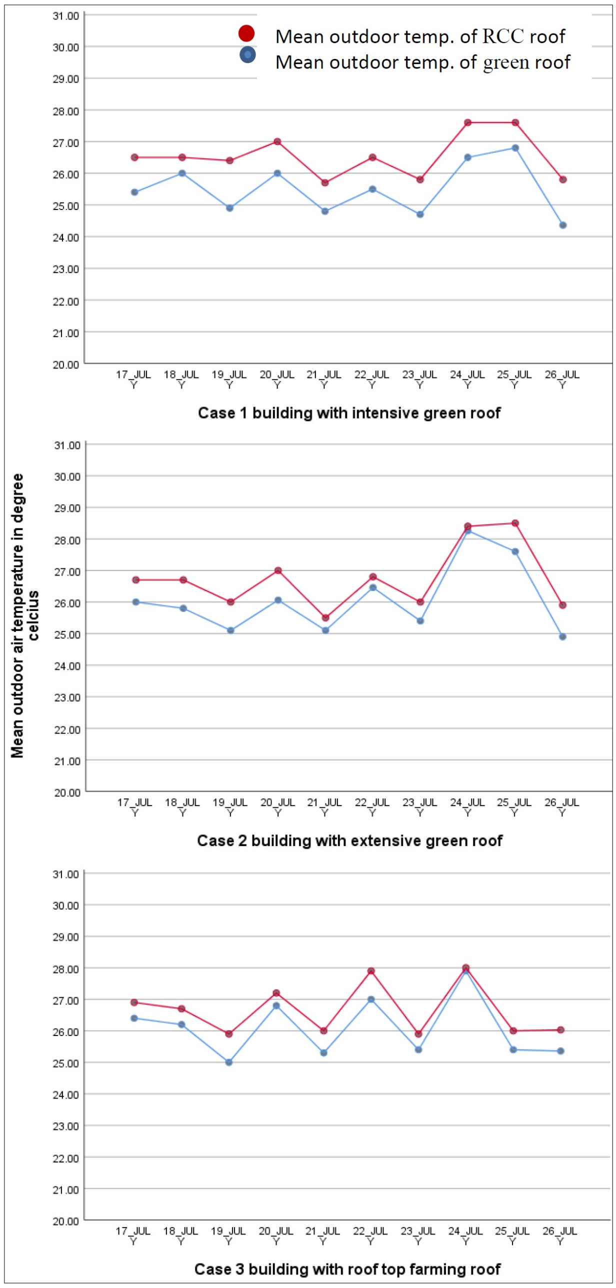

Figure 8: Comparison of mean outdoor air temperature of green roof with RCC roof.

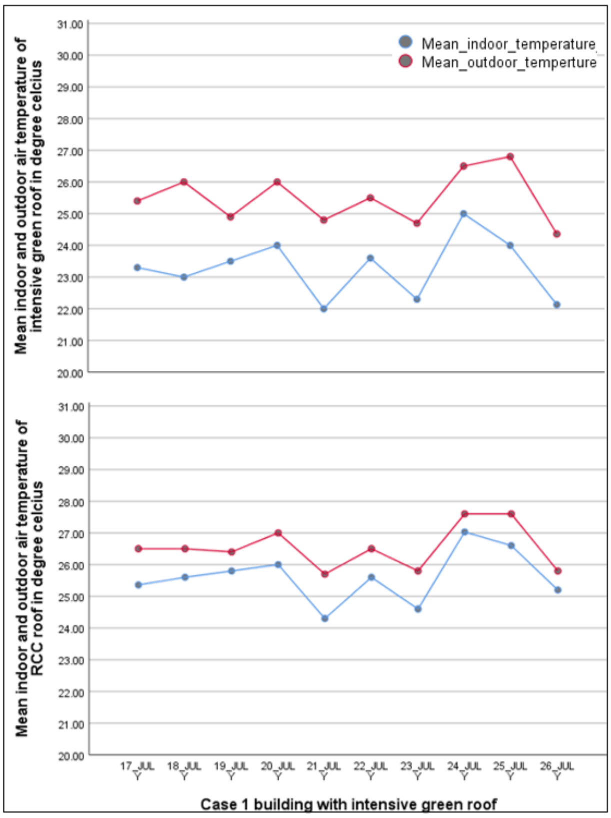

Figure 9: Comparison of mean indoor and mean outdoor air temperature of case 1 building.

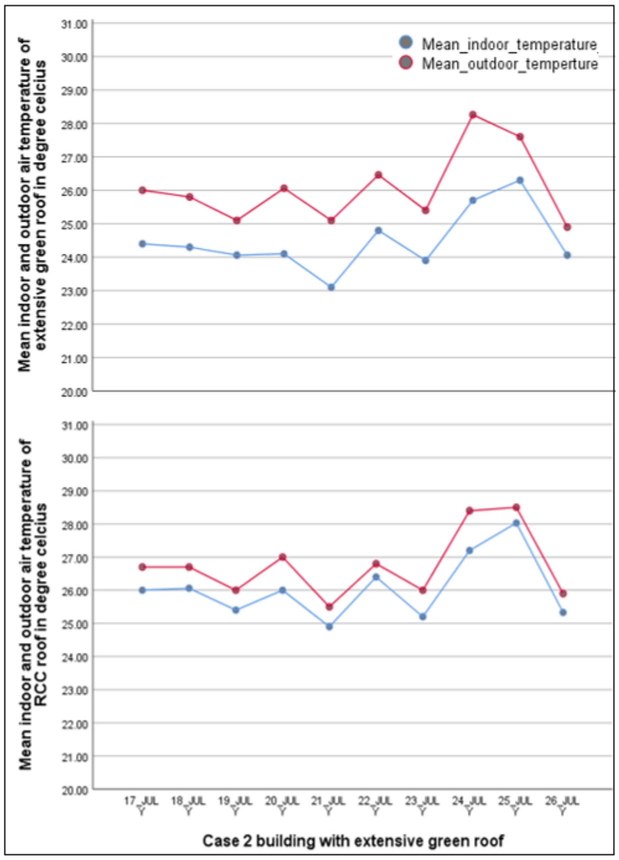

Figure 10: Comparison of mean indoor and mean outdoor air temperature of case 2 building.

of room below extensive green roof was 24.5°C when the mean outdoor air temperature of extensive green roof surface was nearly 26.09°C and within the same building, the mean indoor air temperature of room below the RCC roof was 26.07°C when mean outdoor air temperature of RCC roof was 26.7°C. This result shows that, the room below extensive green roof was 1.6°C cooler than room below RCC roof. Similarly, the figure 11 below shows that, in case 3 building with rooftop farming roof, the mean indoor air temperature of room below rooftop farming roof was 25.8°C when the mean outdoor air temperature of roof top farming roof was nearly 26.6°C and within the same building, the mean indoor air temperature of room below RCC roof was 26.7°C when the mean outdoor air temperature of RCC roof was 27°C. This result shows that, the room below roof top farming roof was 0.8°C cooler than room below RCC roof.

4. Conclusion

From various international research study on green roof, it is confirmed that, the indoor air temperature with vegetated roof surfaces were on average 0.5°C-1°C [7] and 2°C [10] cooler than non-vegetated surfaces. And outdoor air temperature of green roof roofs was cooler by 0.4°C-1.3°C [8]. Now comparing these results with the findings of this project study, the indoor air temperature stays cooler by 2.4°C, 1.6°C and 0.8°C in case of intensive, extensive and rooftop farming roof respectively compared to RCC roof. Similarly, the outdoor air temperature of green roof cools down by 0.6°C in case of intensive and extensive roof and 0.4°C in case of rooftop farming roof compared to RCC roof. Hence, comparing these results of project study with the international findings, the temperature difference of about 0.3°C at minimum temperature range and temperature difference of 0.4°C at maximum temperature range was found at indoor air measurement. Also, the temperature difference of 0.7°C at maximum temperature range was found in outdoor air measurement comparing the results of this project study with international findings. Hence, it is concluded that, the green roof technology provides best indoor thermal comfort compared to conventional RCC roofing system during summer. In terms of green roofing technique, the thermal performance of intensive green roof is found better

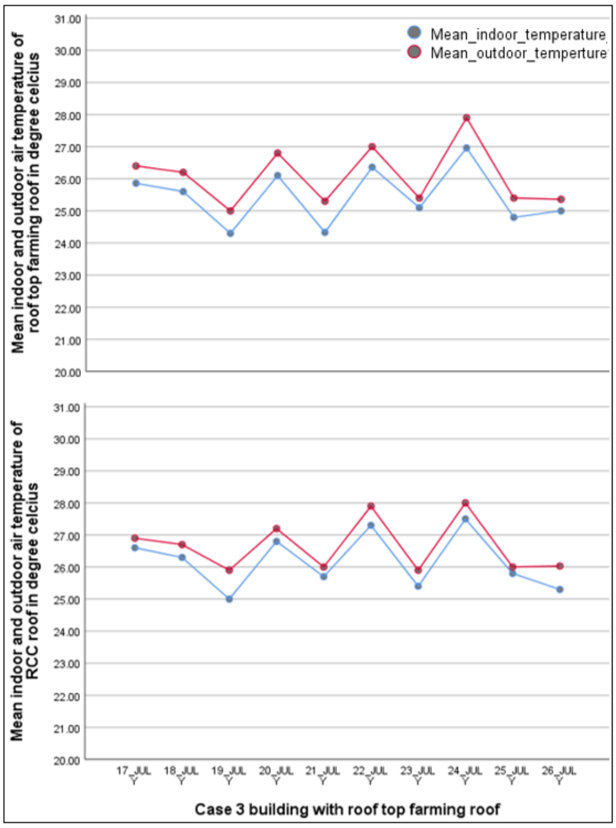

Figure 11: Comparison of mean indoor and mean outdoor air temperature of case 3 building.

than extensive green roof and rooftop farming.

Green roof can play a significant role in enhancing indoor thermal comfort. This research could help professionals and policy makers understand the importance of green roofs in improving the energy efficiency of buildings. Some recommendation on further studies are, since the above study have done research on thermal performance of roof greening in summer season only, green roof can perform differently depending upon the different seasons. Also the addition of insulating material can further enhance the thermal performance of the green roof.

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