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Review on A Comprehensive Study on Various Roofs for Thermal Comfort

Aashish Jadhav[1], Pratik Salunkhe[2], Adhiraj Patil[3], K. S. Redekar[4], Prof. K.S. Redekar[5]
Department of Civil Engineering
D Y Patil Technical Campus, Talsande, Maharashtra, India

Abstract*: Green roofs have gained attention as sustainable solutions to urban environmental challenges. This comprehensive study delves into the multifaceted aspects of green roofs, including their environmental, economic, and social impacts. The research design incorporated data collection from diverse sites and rigorous analysis to provide a holistic perspective. The study reveals that green roofs exhibit promising benefits in terms of temperature regulation, energy efficiency, stormwater management, and biodiversity promotion. Economic analysis indicates long-term cost savings and ecological advantages, while the social and cultural dimensions shed light on the positive influence on human well-being. This research also delves into policy and regulation aspects, highlighting the importance of supportive measures for wider green roof adoption. Through case studies, practical insights are shared, emphasizing the real-world potential of green roofs. In conclusion, this study recommends the integration of green roofs in urban planning, emphasizing the need for informed decision-making and policy frameworks to unlock the full potential of green roofs in creating sustainable and resilient cities Green roofs have been heralded as a "sustainable building practice" in cities throughout the world as one response to mounting environmental stresses. A range of stressors plus erosion of aesthet-ics and human well being in urban areas have initiated policies and practices often with incentives to develop green infrastructure such as green roofs. They provide a suite of public and private benefits most of which map onto services generally provided by the ecosys-tem. Green roof development imbeds in environmental design pro-cesses and is constrained by both human and environmental factors. As relatively small, simple, anthropogenic ecosystems, green roofs relate to several existing conceptual and applied ecological ideas. Understanding and applying from ecology and ecosystem studies, ecological engineering, managed ecosystems, construction ecology, urban ecology, landscape ecology, restoration ecology, reconcilia-tion ecology, soil ecology and community ecology show green roof ecosystems can be created to cycle energy and nutrients. Further-more, green roofs can be constructed to model an ecosystem and may provide a setting for testing ecological concepts. This book takes an ecosystems approach to describing a large number of inter-actions on green roofs placing them in the total human ecosystem.*

Keywords: Green roofs

I. INTRODUCTION

Green roofs, often referred to as vegetated or eco-roofs, represent a sustainable and innovative approach to urban architecture and environmental design. They have gained significant attention in recent years due to their potential to address pressing challenges such as urban heat islands, stormwater management, energy efficiency, and biodiversity conservation. This comprehensive study seeks to explore the multifaceted world of green roofs, examining their history, benefits, construction techniques, and environmental impacts.

In an era marked by increasing urbanization and climate change, the implementation of green roofs offers a promising avenue for mitigating the adverse effects of urban development. This study aims to shed light on the various facets of green roofs, from their historical roots to their modern applications, with a focus on their role in promoting environmental sustainability and enhancing the quality of urban living.

As cities continue to expand and grapple with the consequences of climate change, understanding the potential of green roofs becomes imperative. Through an in-depth examination of their design, functionality, and ecological contributions, this study aims to provide a comprehensive foundation for both researchers and practitioners in the field of sustainable urban development.

A green roof or living roof is a roof of a building that is partially or completely covered with vegetation and a growing medium, planted over a waterproofing membrane. It may also include additional layers such as a root barrier and drainage and irrigation systems. Container gardens on roofs, where plants are maintained in pots, are not generally considered to be true green roofs, although this is debated. Rooftop ponds are another form of green roofs which are used to treat greywater. Vegetation, soil, drainage layer, roof barrier and irrigation system constitute green roof.

Green roofs serve several purposes for a building, such as absorbing rainwater, providing insulation, creating a habitat for wildlife, increasing benevolence, and decreasing stress of the people around the roof by providing a more aesthetically pleasing landscape, and helping to lower urban air temperatures and mitigate the heat island effect.

Green roofs are suitable for retrofit or redevelopment projects as well as new buildings and can be installed on small garages or larger industrial, commercial and municipal buildings. They effectively use the natural functions of plants to filter water and treat air in urban and suburban landscapes. There are two types of green roof: intensive roofs, which are thicker, with a minimum depth of 12.8 cm (5+1⁄16 in), and can support a wider variety of plants but are heavier and require more maintenance, and extensive roofs, which are shallow, ranging in depth from 2 to 12.7 cm (13⁄16 to 5 in), lighter than intensive green roofs, and require minimal maintenance.

II. METHODOLOGY

2.1 Normal Slab

In construction, a "normal slab" typically refers to a standard concrete slab used in various applications such as building foundations, floors, or flat roofs. It's usually of a standard thickness and strength suitable for the intended purpose of the structure. The dimensions and specifications of a normal slab can vary depending on factors such as building codes, structural requirements, and the specific use of the slab within the construction project.

A normal slab, also known as a conventional slab, is a concrete slab that is reinforced with steel mesh to distribute the load and prevent cracking.

2.2 White Coated Slab

A "white coated slab" could refer to a specific type of surface treatment applied to a concrete slab or other construction material.

White Coating for Protection: The slab might be coated with a white material for protection against weathering, stains, or other environmental factors. This coating could be a paint, sealant, or specialized coating designed to provide durability and resistance to damage.

2.3 : Slab with Green Roof (Artificial Lawn) :

Artificial turf or Artificial lawn is a surface of synthetic fibers made to look like natural grass, used in sports arenas, residential lawns and commercial applications that traditionally use grass. It is much more durable than grass and easily maintained without irrigation or trimming, although periodic cleaning is required.

It is covered on slab surface to increase the thermal insulation.

2.4 : Sandwich Panel :

Sandwich panels are composite materials used in construction for creating walls, roofs, and floors. They are composed of three layers: a core material sandwiched between two outer skins or facings. The core material is usually lightweight and provides insulation properties, while the outer skins offer structural support and protection.

2.5 : Mangalore Tiles :

Mangalore tiles (also Mangalorean tiles) are a type of roof tile native to the city of Mangalore, India. Mangalore tiles are said to provide excellent ventilation especially during summer and are widely considered aesthetically pleasing.

2.6 : Galvanized Steel Sheet :

Galvanized sheet is a steel sheet that has received a specific treatment consisting of hot galvanizing. As such, The steel is immersed in a zinc crucible, so that the sheets are fully covered with this metal. Sometimes, depending on the specific sheet, the immersion may have been carried out in a zinc-iron alloy.

2.7 : Aluminium Sandwich Panel :

Aluminium Sandwich Panel are composite material manufactured by using material like aluminium sheet and wood shavings. They are composed of three layers: a core material of wood shavings sandwiched between two outer skins of aluminium sheets.

III. LITERATURE REVIEW

1. Vegetation -

1.1. Native, non-native and invasive plant-

There are debates about using native plants on green roofs around the world (Currie and Bass, 2010). In Peck (2008)'s the book of award winning green roof designs, 45% of the award winning green roofs used native plants. Another book written by Cantor (2008) also recorded 59% of the green roofs used native plants. It shows the significance of using native plants on green roofs. Moreover, non-profit organizations, including the Ladybird Johnson Wildflower Center and the Peggy Notebaert Nature Museum in the United States, governmental organizations, namely the city of Toronto's Green Roof Pilot Program, and even commercial organizations, for example Rana Creek in the United States, also promoted the use of native plants on green roofs (Butler et al., 2012). Butler et al. (2012) also summarized the common reasons for choosing native plants in ground-level. First, Environmental Protection Agency (EPA) in the United States (2012) claimed that native plants were already adapted to the local conditions; once they are established, they do not need watering, fertilizers or pesticides. Native plants can help restore the healthy ecosystem by attracting various animals, birds and butterflies (EPA, 2012). Currie and Bass (2010) also wrote that native plants have the potential to replicate local native species communities as well as benefit the ecology. In Alberta, Clark and MacArthur (2007) held a research of a semi-intensive green roof, which had a native mixed prairie community. They found that there was more biomass, in particular spiders and various species; they also found that the biodiversity in the semi-intensive roof was greater than an non-native extensive green roof (Clark and MacArthur, 2007).

Yet there are concerns about promoting native plants planting on green roofs. First, Sam Benvie (mentioned in Clark and MacArthur, 2007) suggested that native plant community can be threatened by other rare species and invasive species, so the cost of maintaining a native plant community on a green roof can be increased and challenging. Moreover, Dunnett (2006) stated the concern of whether the seeds of native plants from non-local source, i.e. local nursery, can survive during the establishment. Dunnett (2006) suggested rather than using seeds from other areas, using local plants as source of seeds. Dunevitz Texler and Lane (2007) cited reasons not to plant rare species or native plants because rare species or native plants, which are already in fragile populations, would be impacted by altering genes from similar plants. In addition to rare species, they often had various habitat requirements, so the process of planting and establishing could be unsuccessful in long term (Dunevitz Texler and Lane, 2007).

Opinions toward the use of native species on green roofs remain mixed. Butler et al. (2012) had also summarized different opinions toward their use. Quantitative data from 14 papers had been published regarding the rates of growth and survival of native plants on green roofs under different conditions. The data are summarized and shown in Table 1 (Butler et al., 2012). Nonetheless, unsuccessful establishment of native plants will influence the green roof performance, i.e. esthetics. Green roof performance will then influence the long-term acceptance by the public (Maclvor and Lundholm, 2011).

1.2. Drought tolerant and solar radiation tolerant

As mentioned above, green roof performance will influence the long-term acceptance by the public (Maclvor and Lundholm, 2011). Thus, choosing appropriate plants is important. This section summarized different researches about vegetation's performance as drought tolerant and solar radiation tolerant.

Sedum is often regarded as an ideal choice for planting on green roofs because of its properties (Van Woert et al., 2005). *Sedum* are succulents and regarded as crassulacean acid metabolism (CAM) plants in which the stomata opens in nighttime to allow carbon dioxide to enter and closes in daytime to avoid water loss from transpiration (Ting, 1985). Not only *Sedum* have such ability, but families of *Portulacaceae*, *Crassulaceae* and *Euphorbiaceae* are also CAM plants which can survive for a long period of time without watering (Liu et al., 2012). The research conducted by Farrell et al. (2012) showed that CAM plants, *Sedum pachyphyllum*, *Sedum spurium* and *Sedum clavatum* survived for about 113 days without watering, depending on the soil types. *S. spurium* was recorded to have a lower drought tolerance with only 19% of survival rate, under a low water regime of watering every 3 weeks (Nagase and Dunnett, 2010). Additionally, the report conducted by Liu et al. (2012) indicated that the temperature reduction effect increases with plant height: 10 cm < 15 cm < 35 cm. It was proved that even plants with high drought tolerance can help in regulating the temperature.

Besides drought tolerance, solar radiation tolerance is also considered because most of the roofs are exposed to high solar radiation. Some plants are not favorable for strong sunlight while some are capable of withstanding it, e.g. *Parthenocissus quinquefolia* requires a site receiving less than three hours of direct sunlight (Fairfax County, 2007). On the contrary, some roofs might be shaded by nearby objects, for example buildings. According to the experiment conducted by Getter and Rowe (2006), *Sedum kamtschaticum*, *S. spurium* and *Allium cernuum* are good candidates for shaded locations; while *Sedum acre*, *Sedum album* and *Talinum calycinum* are suitable for both shaded and sunny locations on green roof.

1.3. Albedo effect -

It is well known that there is a negative correlation between albedo effect and surface temperature: the greater the albedo, the lower the surface temperature. Gaffin et al. (2006) conducted a research comparing surface radiation reflectivity (albedo) of white roofs and green roofs. White paint recorded an albedo of 0.8 on average, but it is difficult to maintain high albedos on white surfaces without regular washing. It recorded an albedo decrease of 0.15 in a year (Gaffin et al., 2006). On the contrary, green roofs recorded an equivalent albedo of 0.7–0.85 (Gaffin et al., 2006). Gaffin et al. (2006) also made a comparison of temperatures of the subsurface (the conventional rooftop level) and the green roof surface. It is indicated that the subsurface temperature was significantly lower than the green roof surface temperature; it is because the green layer insulated heat (Gaffin et al., 2006).

This proves that green roofs can reduce the thermal loading.Moreover, albedo increases with higher peak cover and biomass on the green roof. A planted module of Maclvor and Lundholm (2011) reflected on average 0.22 of incoming solar radiation whereas growing medium only reflected 0.17 as control in the entire study period, from May to October. Lundholm et al. (2010) also reported that the average albedo of a conventional rooftop over the same period (from May to October) is only 0.066. By comparing the two sets of data, it was found that the best performing species from Maclvor and Lundholm (2011) increased the albedo effect by 22.2% over the growing medium alone and more than 200% of albedo effect over the conventional rooftop.

BlanusaHYPERLINK "https://www.sciencedirect.com/science/article/pii/S2212609014000211" et al. (2013) demonstrated that plants provide a cooling effect by transpiration of water through stomata and direct shading, as mentioned above. *Stachys* had a higher ability in regulating its own temperature and leaving its leaves cool (Blanusa et al., 2013). It had the lowest surface temperature even with limited soil moisture and closing stomata. One of the experiments compared the leaves with hairs trimmed indicating that hairs on the leaves of *Stachys* reduced the amount of infra-red radiation from leaf, thus making the leaves cooler. Such cooling mechanism may be due to the light hair color or its reflectivity of incoming irradiance, thus it provided higher albedo and avoided direct heat stress. Nevertheless, available moisture and water transpiring through *Stachys*' leaves strongly altered its air cooling ability (Blanusa et al., 2013).

Surface temperature was mainly related to solar radiation reflectivity (albedo). Solar radiation reflectivity is influenced by species richness and biomass variability, where greater biomass led to greater solar radiation reflectivity (Lundholm et al., 2010). Thus the thermal loadings in the daytime are decreased; the discomfort underneath the roof will be alleviated (Maclvor and Lundholm, 2011, Blanusa et al., 2013).

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2. Environmental benefits –

2.1. Enriching biodiversity in urban area -

Green roofs in urban and suburban areas act as green corridor, which are the stepping stones for wildlife to enter the nearby habitats (Kim, 2004). They can connect the fragmented habitats with each other so as to promote the urban biodiversity (Kim, 2004). A total number of 30 species or even more of organisms were observed in the green roof (Fountain and Hopkin, 2004, Schrader and Boning, 2006). Species like *Isotoma viridis* and *Parisotoma notabilis* were observed and they are classified as cosmopolitan pioneer in urban soils (Dunger et al., 2004, Fountain and Hopkin, 2004). The distributions of organisms in soil were diverged from young and old roofs (Schrader and Boning, 2006). Schrader and Boning (2006) revealed that there are three factors contributing to the biodiversity in the green roof. First is the type of growing substrate; second is the process of soil formation during the maturation of substrate; and the last is the increasing biological activity as well as increasing organic matter from dead leaves or organisms. Nonetheless, it is suggested that green roof could not be a justification for destroying the natural nor replace the nature.

2.2. Cooling performance on the building and surroundings -

The cooling performance of the green roof depends on the plant species chosen (Maclvor and Lundholm, 2011, Blanusa et al., 2013). Green roofs cool down the temperature because of the direct coverage of plants and the opening of stomata that allows transpiration during daytime (Santamouris, 2012). The textures of leaf surface and albedo effect also take place. The vegetation stores the heat and cools down the air (Santamouris, 2012). The daily maximum temperature on the vegetated rooftops was reduced and dampens diurnal temperature fluctuations. Researches in US indicated that vegetated rooftops decreased the peak temperature from 0.5 K to 3.5 K; along with dropping of temperature, the albedo increased from 0.05 up to 0.61 (Santamouris, 2012). Susca et al. (2011) compared the albedos of the white-painted roof and green roof, its influence toward the surface temperatures, and the energy consumption for controlling the indoor temperature below the green roofs. The white and green roofs substituted the black-painted roof and reduced the energy consumption. Moreover, a green roof rather than a white roof can further reduce the energy saving from 40% to 110%.

2.3. Managing runoff quantity -

First of all, the definition of water retention means the water storage capacity of a green roof. Green roof characteristics including the growing medium and the drainage layer influence the water retention capacity as well as the runoff dynamics (Banting et al., 2005). In between different types of vegetation in extensive green roofs, their water retention ability varied from 40% to 60% of total rainfall. Water retention for semi-intensive and intensive green roofs depends on area coverage (Banting et al., 2005). The size of rain event as well as the rain intensity affects the water retention. Green roofs retained all small rain events that were less than 10 mm. The retention of green roofs differed from 88% to 26% when the rain events were 12 mm. Such retention was depended on the substrate and the type of drainage (Simmons et al., 2008). The peak discharge of small storms from vegetated roof was lower than that from conventional roof; however, such effect was reduced for larger storms. On a vegetated roof, 57% of peaks were delayed up to 10 min comparing with a conventional roof (Carter and Rasmussen, 2006). According to DeNardo et al. (2005), the rainfall intensity reduced from 4.3 mm/h to average green roof runoff rate of 2.4 mm/h. Therefore, green roofs reduced the peak intensities.

Age of green roof also affects the storm water discharge (Getter et al., 2007). By comparing the organic matter content and physical properties of soil after five years of time, the organic matter content was increased from 2% to 4% and the pore space was also increased from 41% to 82%. Along with these two factors, the water holding capacity also increased from 17% to 67% (Getter et al., 2007). However, the vegetation plays a minor role in water retention when comparing with the substrate. Van Woert et al. (2005) proved that roofs with media alone retained 50.4% of rainfall while vegetated roofs retained 60.6%. On the contrary, Maclvor and Lundholm (2011) showed that some plant species can evapo-transpire more water, so they create more space for water storage capacity of media. In addition, warmer seasons lead to higher evapo-transpiration, thus the water storage regenerates faster. There were seasonal variations toward the runoff reduction (Bengtsson et al., 2005). During September to February, the runoff reduction was 34% while during the period between March and August, the runoff reduction was 67%. The slope has impacts on water retention too. The lower the slope, the higher the water retention on the green roofs (Villarreal and Bengtsson, 2005).

IV. CONCLUSION

In this paper, various aspects of green roofs have been discussed highlighting the green roof benefits. Literature review clearly suggests that various researchers working on the lines of the common goal of achieving benefits from green roofs are successful to a greater extent. Literature suggests that research on green roofs is restricted to only a few countries [8], which advocates that there is a wide scope of studies and research in the area of green roofs. Research is needed on the effect of green roofs on achieving human comfort and energy conservation. A green roof can be implemented in various parts of the globe with different geographical backgrounds and diverse climatic conditions.

In this paper, an effort was made to understand the know- how of green roofs and their benefits. From the study, it is apparent that future research and development is impertinent and green roof could be used widely as an integrated part of nature in buildings. In the long run, it will prove very beneficial for better human comfort, social, economic and sustainable development.

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