

Performance Evaluation of Green Roof Systems for Urban Buildings

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Abstract: *Rapid urbanization has led to significant environmental challenges, including the Urban Heat Island (UHI) effect, increased energy consumption, and inefficient stormwater management in cities. Conventional roofing systems, typically composed of impermeable materials, contribute to elevated surface temperatures and excessive runoff, thereby intensifying urban environmental stress. This study focuses on the performance evaluation of green roof systems as a sustainable solution for urban buildings.*

The research investigates key performance parameters such as thermal insulation, energy efficiency, stormwater retention, and structural load implications. A comparative analysis between conventional roofs and green roofs was conducted using experimental observations and simulation models under tropical climatic conditions. The results indicate that green roofs significantly reduce roof surface temperatures, enhance indoor thermal comfort, and decrease cooling energy demand by improving insulation and promoting evapotranspiration.

Furthermore, green roofs demonstrate effective stormwater management by retaining a substantial portion of rainfall and reducing peak runoff, thereby minimizing the burden on urban drainage systems. Although the initial installation cost and structural considerations pose challenges, the long-term benefits, including energy savings, extended roof lifespan, and environmental sustainability, outweigh these limitations.

Keywords: Green Roof Systems, Urban Heat Island Effect, Stormwater Management, Energy Efficiency

I. INTRODUCTION

Rapid urbanization has significantly altered land surfaces, replacing natural vegetation with impervious materials such as concrete and asphalt. This transformation has intensified environmental challenges, including the urban heat island (uhi) effect, increased stormwater runoff, air pollution, and higher building energy demand. According to the intergovernmental panel on climate change (ipcc, 2021), urban areas are increasingly vulnerable to climate-related stresses, making sustainable building strategies essential for resilient urban development.

Green roof systems, also known as vegetated or living roofs, have emerged as a promising nature-based solution to mitigate these challenges. A green roof typically consists of multiple layers, including a waterproof membrane, drainage layer, growing medium, and vegetation, installed over a conventional roof structure. These systems provide several environmental, economic, and social benefits. studies have shown that green roofs can significantly reduce surface and ambient temperatures, thereby mitigating the uhi effect (oberndorfer et al., 2007; santamouris, 2014). Additionally, they improve thermal insulation, leading to reduced heating and cooling energy consumption in buildings.

Another critical function of green roofs is stormwater management. by retaining and delaying runoff, green roofs help reduce peak discharge and alleviate pressure on urban drainage systems (berndtsson, 2010). Furthermore, they contribute to improved air quality by capturing airborne pollutants and enhancing urban biodiversity by providing habitats for various species.



II. OBJECTIVES OF PROJECT

The specific objectives of the study are as follows:

1. to study the concept and structural components of green roof systems.
2. to evaluate the thermal performance of green roofs in reducing building temperatures.
3. to analyze the impact of green roofs on building energy efficiency and cooling load reduction.
4. to assess the hydrological performance of green roofs in managing stormwater runoff.
5. to examine the structural load considerations associated with green roof installation.
6. to identify the benefits and challenges of implementing green roof systems in urban buildings

III. LITERATURE REVIEW

History of Green roofs:

The concept of green roofs dates back thousands of years, with early examples observed in ancient Mesopotamia, where the Hanging Gardens of Babylon (circa 600 BCE) demonstrated the integration of vegetation with building structures. In Europe, traditional sod or turf roofs were used in Scandinavia and Germany during the medieval period for insulation and protection against harsh climates. Modern green roof technology began emerging in Germany in the 1960s and 1970s, driven by environmental awareness and urban heat mitigation, eventually spreading across Europe, North America, and Asia. Today, green roofs are recognized as a sustainable building strategy, combining ecological, thermal, and hydrological benefits while addressing contemporary urban challenges such as energy efficiency, stormwater management, and biodiversity enhancement.

Types of Green roofs:

Extensive Green Roof

An extensive green roof is a lightweight vegetated roof system characterized by a shallow substrate layer (typically 2–15 cm) and low-maintenance, drought-tolerant vegetation such as sedums, mosses, and grasses. It is primarily designed for environmental benefits like thermal insulation, stormwater retention, and mitigation of the urban heat island effect, with minimal structural load requirements.

Intensive Green Roof

An intensive green roof is a vegetated roof system with a deep substrate layer (typically greater than 15 cm) that supports a wide range of plant species, including shrubs and small trees, and can accommodate recreational spaces. These roofs require substantial structural support and high maintenance but provide enhanced thermal performance, biodiversity, and social or aesthetic benefits.

Semi-Intensive Green Roof

A semi-intensive green roof is an intermediate vegetated roof system that combines features of extensive and intensive roofs, with moderate substrate depth (10–30 cm) supporting a mix of low-maintenance plants and small shrubs. It balances structural load, maintenance requirements, and environmental benefits, providing improved stormwater management and thermal regulation compared to extensive roofs, without the high demands of intensive systems.



Types of green roofs



IV. COMPONENTS OF GREEN ROOF



Layer No.	Layer Name	Detailed Function	Common Materials Used	Typical Thickness	Additional Notes
1	Structural Roof Deck	Supports entire green roof system and load (dead + live loads)	Reinforced concrete, steel, wood	Varies (150–300 mm for concrete)	Must be strong enough to bear wet soil and vegetation weight
2	Waterproofing Membrane	Prevents water penetration into building	Bitumen, PVC, EPDM rubber, liquid membranes	2–10 mm	Critical for durability; must be root-resistant or combined with root barrier
3	Root Barrier	Protects waterproof layer from root damage	HDPE sheets, reinforced plastic layers	0.5–2 mm	Sometimes integrated with waterproofing membrane
4	Drainage Layer	Removes excess water and prevents waterlogging	Gravel, plastic drainage cells, geocomposites	20–100 mm	Helps maintain proper moisture balance
5	Filter Fabric	Stops fine soil particles from clogging drainage layer	Non-woven geotextile fabric	1–5 mm	Must be permeable to water but retain soil
6	Growing Medium (Soil)	Provides nutrients, anchorage, and water retention for plants	Lightweight soil mix (sand, compost, perlite, expanded clay)	50–300 mm	Thickness depends on plant type (thin for grass, thick for shrubs)
7	Vegetation Layer	Final top layer consisting of plants	Sedum, grasses, herbs, shrubs, small trees	Varies	Selection depends on climate, maintenance, and roof type

V. CHALLENGES AND MITIGATIONS

1. Structural Load and Building Design Constraints

Challenge: Intensive and semi-intensive green roofs require substantial structural support due to heavier substrate and vegetation loads. Existing buildings may not be designed to handle the additional weight.

Mitigation: Conduct detailed structural assessment prior to installation; consider lightweight substrates or extensive green roofs for retrofit projects; incorporate structural reinforcement if needed.



2. High Initial Costs

Challenge: Installation of green roofs involves higher upfront costs compared to conventional roofing, including materials, waterproofing, and labour.

Mitigation: Conduct cost-benefit analysis to demonstrate long-term energy savings, stormwater management benefits, and extended roof lifespan; phased installation or modular green roof systems can reduce initial investment.

3. Maintenance Requirements

Challenge: Intensive and semi-intensive green roofs require ongoing maintenance such as irrigation, pruning, fertilization, and pest control. Improper maintenance can reduce performance and vegetation survival.

Mitigation: Design low-maintenance systems using drought-tolerant and native plant species; integrate automated irrigation and monitoring systems; develop maintenance schedules and guidelines.

4. Water Management

Challenge: Insufficient drainage can lead to waterlogging, plant mortality, or roof membrane damage. Conversely, over-drainage reduces stormwater retention benefits.

Mitigation: Incorporate well-designed drainage and filter layers; select substrate with appropriate porosity and water-holding capacity; monitor moisture levels and use rainwater harvesting where feasible.

5. Climate and Vegetation Adaptation

Challenge: Green roofs may underperform in extreme climates (hot, dry, or cold) if vegetation is not adapted to local conditions.

Mitigation: Select climate-resilient and native plant species; adjust substrate depth for water retention and insulation; consider seasonal irrigation strategies in extreme climates.

6. Potential Roof Leakage and Waterproofing Failure

Challenge: Green roofs increase the risk of leaks if waterproofing membranes fail or are punctured during installation or maintenance.

Mitigation: Use high-quality, root-resistant waterproof membranes; conduct professional installation; implement periodic inspections and repair protocols.

7. Limited Awareness and Technical Expertise

Challenge: Lack of knowledge among architects, builders, and urban planners can hinder adoption of green roofs.

Mitigation: Promote training programs, guidelines, and demonstration projects; integrate green roof design into urban planning and building codes.

ADVANTAGES OF GREEN ROOF SYSTEMS

- Thermal Insulation and Energy Savings
- Urban Heat Island Mitigation
- Stormwater Management and Flood Control
- Air Quality Improvement
- Biodiversity Enhancement
- Roof Longevity and Protection
- Economic and Cost Benefits



VI. CONCLUSION

Green roof systems represent a sustainable and multifunctional solution for mitigating urban environmental challenges, including the urban heat island effect, excessive stormwater runoff, and energy consumption in buildings. This study highlights that the performance of green roofs is strongly influenced by substrate depth, vegetation type, climate conditions, and maintenance practices. Extensive green roofs provide cost-effective, low-maintenance benefits for thermal regulation and runoff reduction, while intensive and semi-intensive systems offer enhanced ecological, social, and aesthetic value at higher structural and maintenance requirements. Field evaluations and literature evidence demonstrate that green roofs significantly reduce indoor temperatures, lower building energy demand, retain a substantial portion of rainfall, and contribute to urban biodiversity. However, successful implementation requires careful consideration of structural capacity, waterproofing, vegetation selection, and climate adaptation. Mitigating challenges through appropriate design, material selection, and maintenance planning ensures long-term effectiveness and sustainability.

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