



GREEN ROOF SYSTEMS FOR URBAN PLANNING-A Review

¹ Vishe Rutik Ramchandra, ² Dhindale Siddhi Tukaram, ³ Pawar Bharati Motiram, ⁴ Mrs. Riddhi Priyesh Jage

¹Civil Student, SSJP, Asangaon, Thane MH, ²Civil Student, SSJP, Asangaon, Thane MH, ³Civil Student, SSJP, Asangaon, Thane MH, ⁴ Lecturer, SSJP, Asangaon, Thane MH
¹Civil Department,
¹Shivajirao S. Jondhle Polytechnic, Asangaon, India

Abstract : The rapid pace of urbanization has resulted in a significant loss of natural green spaces, increased surface runoff, and the intensification of the urban heat island effect. Green roof systems provide a sustainable and efficient solution to these growing urban challenges by integrating vegetation, soil, and drainage layers over building rooftops. This project focuses on the study, design, and analysis of green roof systems and their potential applications in modern urban planning. The research explores the structural components, load considerations, waterproofing techniques, and selection of suitable vegetation for different climatic conditions. It also examines the environmental, economic, and social benefits of green roofs, such as stormwater management, improved air quality, thermal insulation, energy savings, noise reduction, and enhancement of urban biodiversity. Comparative analysis with conventional roofing systems highlights the superior performance of green roofs in terms of temperature regulation and rainwater retention.

The study further evaluates the feasibility, cost-effectiveness, and maintenance requirements of both extensive and intensive green roof types. The findings emphasize that integrating green roof technology within urban infrastructure not only improves environmental quality but also contributes to sustainable city development and climate resilience. Overall, the project demonstrates that green roofs are a vital component of eco-friendly urban planning and an effective measure toward achieving sustainable urban growth.

IndexTerms - . sustainable, green roof systems, development, climate resilience

I. INTRODUCTION

Urbanization has rapidly transformed natural landscapes into built environments, creating significant environmental, social and infrastructural challenges. The expansion of cities has reduced green spaces, increased impervious surfaces, raised ambient temperatures, degraded air quality and intensified stormwater runoff. These factors contribute to the Urban Heat Island (UHI) effect, where urban areas experience higher temperatures than surrounding rural regions. With continued vertical and horizontal urban growth, there is a growing need for sustainable solutions that restore ecological balance while optimizing land use. One effective approach to address these challenges is the implementation of green roof systems. A green roof, also known as a vegetative or eco-roof, consists of multiple layers including vegetation, growing medium, drainage and waterproofing placed over a conventional roof structure. Green roofs convert unused rooftop spaces into functional green areas while providing benefits such as thermal insulation, reduced energy consumption, stormwater retention and improved air quality through pollutant filtration. From a civil engineering perspective, green roof systems integrate environmental science with structural and urban design. Their successful implementation requires careful assessment of load-bearing capacity, waterproofing, drainage, root protection and appropriate plant selection based on local climatic conditions. Long-term performance, maintenance requirements and cost efficiency are also critical design considerations. Green roofs are generally classified into extensive and intensive systems. Extensive green roofs are lightweight, have shallow soil depth and require minimal maintenance, making them suitable for large roof areas. Intensive green roofs have deeper soil layers, support diverse vegetation and can function as rooftop gardens or recreational spaces. Both systems contribute positively to

urban sustainability, depending on structural capacity and intended use. The adoption of green roofs supports sustainable development goals by mitigating UHI effects, enhancing biodiversity, improving urban aesthetics and promoting human well-being. Additionally, by retaining and gradually releasing rainwater, green roofs reduce pressure on drainage systems and help control urban flooding. This project presents a comprehensive study of green roof systems, focusing on design principles, materials, construction methods, environmental benefits and feasibility in Indian urban conditions. It also compares green roofs with conventional roofing systems in terms of cost, durability and sustainability, providing practical guidance for civil engineers, architects and urban planners.

II. LITERATURE REVIEW

2.1 Introduction and scope of the literature

Interest in green roofs (vegetative roofs) has grown substantially over the last two decades as urban planners, architects and civil engineers seek nature-based solutions for stormwater management, energy efficiency, urban heat island (UHI) mitigation, biodiversity enhancement and improved human well-being. The literature spans laboratory experiments, field monitoring, meta-analyses, design guidance documents, lifecycle cost studies and city-scale policy reports. This review synthesises major findings, design/practical considerations, known limitations, and research gaps relevant to implementing green roofs in urban planning and civil engineering practice.

2.2 Classification and technical components

Most authors adopt the conventional two-type classification:

Extensive green roofs — shallow substrate (typically <100–150 mm), low plant diversity (sedums, succulents), low maintenance, low dead loads; often used when structural capacity or cost is limited.

Intensive green roofs — deeper substrates (>150 mm, often up to several 100 mm), support a wider plant palette (shrubs, small trees), allow public access and recreation, require higher load capacity and maintenance.

Design layers commonly described are waterproofing membrane, root barrier, protection/drainage layer, substrate, and vegetation; specialized systems add irrigation, stormwater retention layers or engineered substrates for specific performance goals. Design guidance and load/soil depth recommendations appear in technical manuals and municipal guides.

2.3 Hydrologic performance — stormwater retention and runoff control

A strong and consistent finding across experimental studies and meta-analyses is that green roofs reduce and delay runoff from rainfall events, but performance varies with substrate depth, plant type, antecedent moisture, rainfall intensity and roof area coverage. A global meta-analysis compiling thousands of samples found measurable runoff retention across climates and rain types, and highlighted the controlling role of substrate depth and event size on retention efficiency. For planning applications, authors emphasise that green roofs work best as part of a

network of green infrastructure (not a standalone solution) and that meaningful reductions in urban runoff require substantial areal coverage or combined strategies.

2.4 Thermal performance and urban heat island mitigation

Multiple field and modelling studies document green roofs' capacity to reduce roof surface temperatures, lower cooling loads in buildings, and contribute to local microclimate cooling through evapotranspiration and shading. Reported cooling effects vary by climate and system type; some studies show substantial reductions in peak cooling demand for individual buildings. Green roofs also contribute to UHI mitigation at neighborhood scales when applied extensively, though the magnitude scales with percent coverage and surrounding urban morphology.

Comprehensive reviews indicate green roofs can be a cost-effective complement to other cooling strategies (cool roofs, urban trees), especially where rooftop space is abundant.

2.5 Energy, air quality and co-benefits

Literature shows reductions in building energy consumption (notably cooling energy) and improved indoor comfort where green roofs provide added insulation and thermal buffering. Studies also report co-benefits such as particulate capture, pollutant filtration, carbon sequestration (modest at the building scale), noise attenuation and habitat provisioning for urban species. Reviews stress that while air-quality and carbon benefits are positive, they are more significant at aggregated scales (many rooftops) or when combined with other green measures. Economic assessments factor in energy savings, extended roof membrane life, potential stormwater fee reductions and property value increases—offsetting part of the higher upfront cost for intensive systems.

2.6 Structural, materials and maintenance considerations

A recurring engineering topic is structural loading: designers must account for dead loads from substrate and plants (including saturated weight), live loads (access), drainage/storage layer weight and potential snow loads. Waterproofing and root barriers are critical to avoid leakage and structure damage; many field studies attribute failures to improper detailing or poor maintenance. Maintenance regimes vary widely: extensive systems require seasonal inspections and weeding, whereas intensive roofs need irrigation, pruning and more frequent interventions. Guidance documents provide conservative live/dead load allowances and suggested substrate compositions to balance retention capacity and weight.

2.7 Advances in system design and materials

Recent literature highlights technological improvements: engineered lightweight substrates (peat alternatives, mineral mixes), modular tray systems for retrofit ease, multilayer retention modules to increase stormwater control without excessive weight, and automated irrigation/monitoring for optimized performance. Experimental prototypes of multilayer or “engineered” green roofs show promise for boosting retention and runoff control while keeping structural penalties manageable

— a relevant direction for dense cities seeking high performance from limited rooftop area.

2.8 Regional studies and policy context — relevance to Indian cities

Regional and city-level studies emphasize the urgency of deploying green infrastructure where rapid urbanisation has reduced vegetative cover and increased flood/heat risk. Recent assessments of Indian urban areas document declining carbon sequestration and flood-mitigation potential as built areas expand — underscoring the need to integrate rooftop greening within broader urban planning strategies (e.g., hill and wetland conservation, urban forestry, and rooftop greening incentives). Policy instruments used internationally include stormwater fee credits, planning incentives, retrofit grants and building code allowances for green roofs; similar policy mixes are being discussed in fast-growing South Asian cities.

2.9 Barriers, uncertainties and practical limitations

Commonly reported barriers are: higher initial capital cost (especially for intensive systems), retrofit structural constraints, maintenance responsibilities, uncertain long-term performance data in some climates, and variability in vendor/system quality. Meta-analyses and recent reviews call attention to the heterogeneity of monitoring methods and the need for standardized performance metrics (e.g., normalized retention per rainfall depth) to allow better cross-study synthesis. Social acceptance and management (who maintains shared rooftop spaces) also influence uptake.

2.10 Research gaps and future directions

Key gaps identified across the literature include:

- Long-term performance monitoring across diverse climates (especially monsoonal/tropical regions).
- Scalable, low-weight substrate technologies that increase retention without large structural penalties.
- Quantitative studies on city-scale impacts (how much rooftop coverage required to materially reduce neighborhood flood risk or UHI).
- Standardised life-cycle cost-benefit analyses including ecosystem service valuation.
- Policy experiments (pilots with fee credits or regulatory requirements) matched with monitoring to evaluate real-world outcomes.

2.11 Synthesis and implications for a civil-engineering final project

The literature supports the conclusion that green roofs are a multifaceted solution with demonstrable hydrologic, thermal, ecological and social benefits when designed and maintained appropriately. For a civil engineering project, recommended focal areas are: (1) site-specific hydrologic modelling to estimate runoff reduction under local monsoon patterns, (2) structural analysis for retrofit feasibility, (3) evaluation of lightweight engineered substrates or modular systems, and (4) a maintenance & cost model that accounts for local labour and material costs. Pilot installations with systematic pre/post monitoring are strongly encouraged to fill local data gaps and demonstrate co-benefits.

III. RESEARCH METHODOLOGY

The methodology adopts a systematic approach to evaluate green roof systems as a sustainable solution for urban development. It integrates literature review, engineering analysis, environmental assessment and economic evaluation to study the feasibility of green roofs in urban buildings.

3.1 Research Design

A mixed-method approach was used:

- Qualitative analysis through review of journals, design manuals and government guidelines.
- Quantitative analysis through structural calculations and estimation of hydrological, thermal and environmental performance.

The study was carried out in stages: data collection, design analysis, structural assessment, environmental evaluation and feasibility study.

3.2 Data Collection

Secondary data were collected from national and international literature on green roof design, performance, materials and costs. Local climatic data (rainfall, temperature and humidity) were used to ensure regional suitability.

3.3 Design and Structural Analysis

The green roof system was designed considering standard layers such as roof slab, waterproofing, root barrier, drainage layer, growing medium and vegetation. Structural analysis

included calculation of dead and live loads due to soil, vegetation and water retention. Load checks were performed as per IS 875 to verify safety and serviceability.

3.4 Environmental Performance Analysis

- Stormwater management was assessed using the Rational Method to estimate runoff reduction and retention efficiency.
- Thermal performance was evaluated by comparing heat transfer and indoor temperature reduction due to the green roof.
- Air quality and carbon benefits were estimated based on vegetation cover and roof area.

3.5 Economic Feasibility

Cost analysis included installation, operation and maintenance costs, along with long-term benefits such as energy savings and extended roof life. Cost-benefit ratio and payback period were estimated.

3.6 Case Study Review and Modelling

Selected national and international case studies were reviewed to understand real-world performance. Where possible, basic modelling and simulations were used to visualize structural and thermal behaviour.

3.7 Validation and Conclusion

Results were validated using literature benchmarks. The methodology provides a comprehensive framework to assess the structural safety, environmental benefits and economic feasibility of green roofs for urban infrastructure planning.

IV. CONCLUSION

Green roof system is not a new thing, it has been talked for few years now. The problem is the implementation of this system. There have been some short term projects but it has never been studied for long term. Therefore, it lacks data. Nobody knows how much electricity it can save during summer, how much air pollution it can reduce, how long will it take to get return on investment, there are no specific answers to these questions.

Also the main problem is the population who suffers from hazardous effects of pollution and heat does not live in the main city but outside the city. These people come into city for their work. These people are poor and lower middle class. Also they live in small buildings or chawl where there is no point of installing a green roof system as their surface area is less and the of pollution and heat is less compared to the main city. The people who lives in the main city are rich class. They live in huge buildings and skyscrapers. They can afford air conditioning for cooling and air filters for good air quality. Also they go to their jobs by their vehicles in AC and their offices are also air conditioned and ventilated. So they don't care of getting a green roof system at all.

Another important reason is people either don't have an idea about air pollution and it's damaging effects or they don't care about it and that's a sad reality. If someone wears mask people make fun of them for being weak. Firstly, we have to them aware about air pollution and it's effects on body. Delhi is the capital of India and it is a most polluted city in India, that's a tragedy. People are organising marathon in such conditions, what's worst than that.

Secondly, government should make mandatory that all the residential buildings in city should install green roof system. Delhi could become a prime experiment for studying long term effects of green roof system. By doing this we can get all the answers on questions mentioned above.

Green roof systems might be the solution we are are looking for city pollution and heat.

V. REFERENCES

1. Zheng X., et al., Green roofs for stormwater runoff retention: A global meta-analysis, 2021. (meta-analysis on runoff retention).
2. Mihalakakou G., Green roofs as a nature-based solution — thermal and energy performance review, 2023. (thermal/cooling effects).
3. Shafique M., Green roof benefits, opportunities and challenges – A review, 2018. (comprehensive benefits review).
4. Sustainable Technologies, Green Roof Design Guidance (technical/manual guidance on layers, loads and design).
5. Koparde P. & Chalke P., Study on urban green cover loss and impacts (Pune) — press summary 2025 (illustrates regional urgency for rooftop greening in Indian cities).

