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A COMPREHENSIVE REVIEW OF GREEN ROOFS: ADVANCING SUSTAINABILITY THROUGH BENEFITS

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Abstract
Natural habitat have been extremely thrown into confusion by the increasing outcomes of global warming and urban sprawl, with the building district or appearing as a paramount benefactor—it regards for 40% of yearly power consumption and over 30% of comprehensive greenhouse gas emissions. These discharges are forecasted to shrill higher over the upcoming 20 years due to expeditious urbanization, certainly in appearing sovereign state, except selected sustainable solutions are extracted.
A comprehensive acknowledgement to such issues is provided by extensive green roof systems. In inclusion to make a contribution further hobby, for example decreasing environmental pollutants, decreasing the result of city warmness islands, maintaining electricity, and strengthing urban splendor, Vegetative layers atop homes remodel disregarded urban areas into dynamic inexperienced places. Following structures are vital for dealing with stormwater, making better air circumstance, and lowering electricity charges, which renowned their importance as a basis of sustainable city evolution.
Also, it emphasizes present day design adjustments and innovative trends that improve the overall performance and flexibility of newbie roofs, highlighting their vital role in growing future sustainable towns by means of highlighting their capacity to sell ecological stability, urban sustainability, and weather resilience.

INTRODUCTION

Intensively modifications to the natural environment brought about by climate change have affected ecosystems and human systems all around. Around the globe, this developing crisis has taken front stage as a major cause of worry (Tuma & Pratt, 1982). The growing demand for energy and the thorough use of natural resources—especially in urbanized and industrial sectors—particularly help to contribute to climate change (Ismail, Malek, & Rahman, 2008).

Comprising a significant portion of global resource use, the building industry is among the most important consumers of energy used worldwide. Given their estimated absorption of a significant portion of natural energy, buildings call for creative and environmentally friendly solutions. One such reaction is the incorporation of vegetated roofing systems, occasionally referred to as green roofs, over several kinds of buildings in different climate zones. These systems encourage synergy between artificial and natural surroundings, so supporting environmental sustainability. Particularly extensive green rooftops are a type of green infrastructure meant to control stormwater, improve environmental quality, and offer building thermal insulation (Ghaedi, Ghaedi, & Ghaedi, 2012).

Up to 40% of annual greenhouse gas emissions and about 30% of total energy consumption worldwide come from the built environment. Should suitable policies not be followed, emissions from this industry could possibly double during the next two decades. The rapid expansion of new building in developing nations and the global lack of investment in sustainable infrastructure drive this expected rise (Conference, Built and Countries, 2008).

By turning otherwise underused rooftop areas into useful green areas, green roofs present a sensible and powerful solution. These systems reclaim and improve urban surfaces by layering vegetation over structural rooftops (Ana et al., 2014). Green roof environmental advantages are several. They are mostly responsible for lowering urban temperatures, lowering energy consumption, lowering of greenhouse gas emissions, and enhancement of local air quality. Furthermore, adding visual and ecological value to the built environment, green roofs help offset the urban heat island effect by controlling rooftop and surrounding temperatures (Semaan & Pearce, 2016).

Furthermore, green roofs can be fit for many different kinds of buildings and sites requiring little structural change. Usually, their implementation calls for the integration of a vegetative layer sustained by suitable drainage and waterproofing systems. Apart from helping to reduce environmental damage, these projects support urban greening initiatives, stormwater management, and biodiversity (Sheng et al., 2011). Green rooftops provide essentially a complete plan for improving sustainability, encouraging energy efficiency, and creating better metropolitan ecosystems (Ana et al., 2014).

GREEN ROOF'S BACKGROUND:

Vegetated, or green, roofing systems have roots thousands of years back (Magill, 2011). According to historical records, these systems were first created to lessen the negative effects of the constructed environment on the surroundings. Implementing vegetated roofs atop their institutional buildings, the Romans are among the first people known to have adopted this technique. By the seventeenth century, hanging gardens had attracted Russian interest. This interest changed dramatically in the twentieth century when green roof systems and like landscape ideas started to be embraced in many nations all around (Peck et al., 1999, pp. 11–12).

Built within the courtyards of temple complexes, the ziggurats of ancient Mesopotamia provide one of the first known instances of vegetated roofs (Magill, 2011). Often known as the "land of stepped towers," Babylon is historically linked with terraced buildings covered in shrubs and other plant life. Under the name Babylonia, the earliest identified reference to these gardens comes from almost 290 B.C.E., more than two centuries following their claimed destruction (Magill, 2011).

GREEN ROOFS: A GUIDE TO CLASSIFICATION

Green roofs are can be classified into two main classifications, determined by design, maintenance needs, installation techniques, and intended purposes (Frese, 2016). The two primary categories of green roofs are:

i. Extensive green roofs
ii Intensive green roofs

EXTENSIVE GREEN ROOFS

Extensive green roofs provide distinct structural and ecological attributes that render them appropriate for low maintenance and economical execution. Lin et al. (2013) delineates the defining characteristics of an extended green roof as follows:

a) Minimal maintenance demands render them appropriate for regions with restricted accessibility.
b) Superficial substrate depth, generally varying from 2 to 15 cm.
c) Lightweight construction with a load capability ranging from 60 to 150 kg/m².
d) Cost-effectiveness renders them a viable option for sustainable architecture.
e) Commonly known as "eco-roofs" because of their ecological advantages.
f) Restricted botanical diversity, predominantly accommodating drought-tolerant and low-maintenance species.
g) Vegetation types generally comprise grasses, mosses, and sedums.

h) Additional structural reinforcement is unnecessary, as their lightweight construction reduces the structural requirements on the roof.

This sort of green roof is especially beneficial in situations when financial limitations, inadequate structural capability, or restricted maintenance access are factors to consider.

INTENSIVE GREEN ROOF:

The intensive green roof system stands for the vegetated roofing category most resource-intensive and complicated. Its unique qualities are its structural elements, maintenance needs, and range of flora it can support. Following Ganguly, Chowdhury, and Neogi (2016), the following sets an intense green roof apart: Because of its increased installation costs and high maintenance needs, this more investment-intensive solution is.

a) significant substrate depth minimum of 15 cm or more in soil depth.

b) Requiring strong structural considerations, the weight load falls between 200 and 500 kg/m².

c) It is often used in projects like podium gardens and sky gardens, where the design of lush areas with both aesthetic appeal and practical use is desired.

d) There is great variation in vegetation; a wide range of non-significantly limited plant species abound. helps bigger plants, vegetation, and even small trees to grow, so improving the ecological and aesthetic value.

e) Deeper substrate and heavier load call for more structural support.

f) This raises the structural demands on the roofing system, thus careful engineering and planning are essential in the construction design.

g) Often used in urban projects, intensive green roofs help to incorporate high-performance green areas that support sustainable building performance, increase biodiversity, and improve aesthetics.

CONVENTIONAL CONCERNS REGARDING GREEN ROOF SYSTEMS

Despite the numerous benefits of green roofs, such as improved building insulation, less urban heat island effect, enhanced aesthetics, and superior air quality, several challenges and concerns must be addressed during the design and construction phases (Lin et al., 2013). This outlines these concerns:

Vegetation Management

Extreme temperature conditions on green rooftops can significantly impact plant viability. The enduring success of vegetation relies on the selection of appropriate, climate-resilient plant species (Council, 2007). Typically, in the initial two years, early establishment relies on preliminary irrigation. Upon establishment, maintenance requirements and associated costs typically decrease significantly.

Adaptability in Climate

Green roofs have demonstrated viability across a range of environmental situations, including hot and arid areas. According to Figueroa and Schiler (2009), green roof systems typically require little climate-specific modifications to function efficiently.

Monetary Constraints

Multiple factors influence the cost-effectiveness of green roofs: energy savings, extended roof lifespan, property market value, tax incentives, aesthetic enhancement, and stormwater management benefits. Frese (2016) estimates that green roofs can prolong a roof's lifespan by approximately 20 years by reducing direct exposure of roofing materials to solar radiation. Furthermore, energy demands can be reduced by up to 75% (Figueroa & Schiler, 2009), so contributing to the reduction of long-term operational expenses.

Risk of Water Damage

It is recommended to install a leak detection system to prevent water intrusion and associated structural issues. Deficiencies in waterproofing elements can lead to drainage issues; however, similar to traditional roofing systems, such issues can typically be remedied with minimal disruption.

Property Ownership and Management

Property owners and facility managers must be well informed on the routine maintenance, operational protocols, and long-term management strategies associated with green roof systems. The promotion of continuous education and compliance with best practices ensures the durability and enduring efficacy of the installation (Impact et al., n.d.).

AN APPROACH TO SUSTAINABLE DEVELOPMENT THROUGH GREEN ROOFS

The real worth of land is its sustainability and quality; its economic value is secondary. Maintaining the resilience, energy efficiency, adaptability, and well-maintaining quality of both the natural and built environments is the aim of sustainable development. Still, this basic idea is usually ignored in favor of financial and material advantage.

Essential elements of sustainable building design, vegetated or green rooftops offer a workable solution for the environmental problems related to urban growth. In three key respects—economic, environmental, and social—these systems support sustainability. When well maintained, green roofs provide significant long-term benefits at both the building and community levels (Dadzie, Ding, & Runeson, 2017).

From an environmental perspective, planted roof surfaces lower energy consumption and increase thermal comfort for building occupants. Apart from improving insulation, green roofs have shown to have acoustic benefits. For instance, a green roof with a 4.8-inch substrate layer can help to reduce up to 40 decibels of external noise; increasing the substrate depth to 8 inches will help to reduce roughly 46–50 decibels ('LifeMedGreenRoof Project Green Roof Thermal Performance', n.d.).

BUILDING OF GREEN ROOFS:

Green roofs are made of traditional roofing elements mixed with horticultural materials. Usually arranged in several functional levels, these systems help plants grow while preserving structural integrity and environmental efficiency. Ana et al. (2014) define the following consecutive layers (from bottom to top) of a traditional green roof:

a) Building framework for roofs
b) Membrane waterproofing
c) Roots barrier
d) Defensive layer
e) Stratum for drainage
f) Stratum for filtration
g) Ground
h) Stratum of flora

Framework for Roof Construction:

The basic structure has to be strong enough to support the whole weight of the green roof system, including dynamic loads like maintenance personnel and plant, growth media. A totally moist green roof could weigh more than 80 kg/m². Usually placed on flat or gently sloping surfaces, green rooftops feature a gradient not to exceed 10%. On sloped roof, supplementary stabilizing methods could be required to effectively control drainage layers (Ana et al., 2014).

Non-combustible materials like gravel or stone have to be placed around roof openings and at the base of walls with a view toward fire safety. These materials also limit the spread of fire and help to reduce the risk of igniting brought about by vegetation.

Waterproofing Methodologies

The main layer is the waterproofing membrane, which is indispensable in preventing water intrusion into the underlying construction. Two common waterproofing techniques are:

i) Monolithic membrane sheets
ii) Thermoplastic sheeting

Another method calls for a liquid membrane placed on an inverted roof assembly, with the insulating layer above the waterproofing membrane (Impact et al., n.d.).

Stratum of drainage

This layer helps to remove extra water and maintain enough moisture for the growth of plants. Usually, it consists of a geosynthetic filter cloth preventing fine particles from blocking the drainage system and a permeable drainage mat. Often used materials are recycled polyethylene and coarse gravel, depending on load-bearing capacity and water retention criteria (Ganguly, Chowdhury, & Neogi, 2016).

Surplus and Conveying

Surplus water from saturated media flows into the usual stormwater drain-system. Design of landscaping has to include collecting basins placed at appropriate heights for temporary ponding. Roof drains must include flow restrictors, and overflow water should be guided via roof leaders connected to stormwater outlets.

Surface

Usually combining elements like sand, gravel, crushed brick, organic matter, soil, and fertilizers, the growing substrate consists of Usually ranging from 4 to 15 cm, the depth of the expanding media can help to provide between 8,000 and 170,000 kilos per square meter to the structural stress when fully saturated (Design, 2011). Especially nitrogen and phosphorous, a low-fertilizer mix is advised to lower nutrient runoff (Impact et al., n.d.).

Design of Landscape Architecture

The choice of plant species has to be done in concert with informed botanists and landscape designers. Because of their adaptability and low maintenance, resilient native species like sedum and local grasses are favored by extensive green roof systems. To give plant stability, the root architecture and growth depth have to match the superficiality of the substrate. Plant choice criteria have to consider industry standards, taxonomy, and root sizes (Impact et al., n.d.).

Systems with Modular Components

Pre-planted units grown off-site and then placed on the rooftop to provide quick covering make up modular green rooftops. Their simplicity of removal or repositioning for maintenance makes these systems valuable (Impact et al., n.d.).

ADVANTAGES OF GREEN ROOFING:

For the environment, built buildings, and human health, green roofs offer a wealth of benefits (Mohamed, Lee, & Chang, 2016). Although their efficiency and impact call for more measurement, current studies show significant cost-effective and energy-saving potential. In hot summer months, green roofs help to lower air conditioning reliance; in winter, they help to lower heating needs (Mackey et al., 2018). Vegetation's cooling effects lower indoor temperatures and total energy consumption.

With cooling loads lowered by 15% to 39% generally and up to 58% for the top floor in summer, green roof buildings can significantly save energy. While residential green roofs increase indoor thermal comfort and save energy costs, commercial green roofs are recognized for their outstanding energy efficiency. Two to three story buildings can save between fifteen and twenty-five percent of summer energy consumption (Ganguly, Chowdhury, & Neogi, 2016).

THERMAL CHARACTERISTICS OF SUSTAINABLE ROOFS

Green roofs show several thermal processes improving their energy efficiency:

a) Conduction:

Through solid materials, heat moves from areas of higher to those of lower temperature.

High thermal mass materials—like soil and water—have an impact on a green roof's thermal conductivity.

b) Convection:

Entails heat transfer through liquid or gas movement.

Temperature control can be influenced by water seeping into the drainage layer and air movement over plants.

c) Radiography

Roofing materials either reflect or absorb solar radiation.

Green roofs use vegetation to either deflect or dissipate thermal energy, so reducing radiation.

d) **Evapotranspiration and evaporation**

Water moving from liquid to gas cools surfaces through evaporation.

Through transpiration, plants take up water and release it, so cooling the roof and the surrounding area.

e) Thermal Mass

Materials like water and soil store and emit heat gradually, so controlling indoor temperature.

BENEFITS AND ADVANTAGES OF GREEN ROOFS UNDER DIFFERENT CLIMATIC CONDITIONS

Emphasizing the great global applicability of green roof benefits at the International Conference on Sustainable Design, Engineering and Construction, Semaan and Pearce (2016) Among the benefits of their research were stormwater management, reduction of the Urban Heat Island (UHI) effect, thermal control, more biodiversity, aesthetic enhancement, and longer roof durability.

APPLICATIONS OF GREEN ROOF TECHNOLOGY:

Using case studies from Chicago and New York, Gaffin, Khanbilvardi, and Rosensweig (2012) investigated the operational efficiency of green roof systems over a range of climates. From many climatic zones—including snowy (USA, Canada, Sweden), warm-humid (Greece, France), and equatorial (Singapore, Brazil)—they observed consistent thermal and environmental benefits. The research supports policy-driven implementation for improved results on sustainability (Frese, 2016).

Passive Cooling Strategy: Green Roof

Investigating green roofs as passive cooling systems in tropical regions, Noorazlina Kamarulzaman et al. (2013) Their results matched increasing energy demand with global warming and urban heat island effects. By replacing heat-absorbing surfaces with plants, green rooftops drastically lower cooling loads and improve urban thermal comfort (Mohamed, Lee, & Chang, 2016).

Variations and execution of environmentally friendly roof designs

Green roofs were categorized by Rowe (2011) into:

i) Extensive green roofs with low maintenance and lightweight plants.

ii) Robust systems allowing deeper soil and small shrubs or trees are known as intensive green roofs.

iii) Benefits include less air and noise pollution, better stormwater management, visual improvements, and more biodiversity.

CASE STUDY: ROME GREEN ROOF

Battista et al. investigated the impact of green rooftops in the Flamingo area of Rome during the 71st Italian Thermal Machines Engineering Conference (2016). They showed the decrease of urban heat island intensity by green rooftops using simulation approaches. Reduced soil moisture and evapotranspiration during maximum solar radiation, say at 2 PM, causes temperature control to suffer.

Variations in architectural efficiency

Roslan et al. (2016) found that buildings including green rooftops used 2% less energy—2.6 kWh/day. Performance influences evapotranspiration by means of a complex link with soil water availability.

Thermal Insulation and Economic Efficiency

An empirical study by Tam, Wang, and Le (2016) conducted in Hong Kong found that green rooftops can lower indoor temperatures by as much as 3.4°C. According to the study, green roofs have continuous economic advantages and thermal efficiency.

Evaluation of Performability

When the Leaf Area Index (LAI) is about 4.5, Kumar and Kaushik (2005) found that green roofs can sustain room temperatures at 25.7°C, so producing a daily energy savings of almost 3.02 kWh. In 2009, Theodosiou also recorded a temperature drop from 38°C to 26°C for green roofs, so offering almost 2°C of indoor thermal comfort.

Social and environmental benefits

Particularly in cities, green rooftops help to solve several environmental problems:

a) reducing flood danger

b) Soil depth and precipitation intensity define stormwater retention.

c) Air filtration passing through CO_2 and pollutants sequestration

d) Reducing noise level

e) Natural fauna habitats

f) Individual benefits (e.g., energy conservation, visual enhancement, recreational opportunities) and communal benefits (e.g., less urban heat, increased biodiversity, and enhanced public areas) abound from green rooftops (Rosso et al., 2015).

g) Main advantages of green roofs (Figueroa & Schiler, 2009) for stormwater management

h) Advantages in Visual and Functional Terms

i) Reduction of the Urban Heat Island Phenomenon

j) Reducing Noise pollution

k) Energy Conservation and Thermal Regulation

Aesthetic Advantages of Green Roofs

Depending on the design and view of the green area, one can categorize the aesthetic benefits of green roofs as communal, private, or hybrid. When done well, green rooftops provide necessary visual vegetation in highly populated urban areas, so providing psychological relief and enhancing the urban aesthetic (Design, 2011).

Environmental benefits

Many environmental benefits come from green rooftops, most importantly increasing ecological sustainability. The benefits comprise:

a) Green rooftops improve urban biodiversity by giving small organisms including insects, birds, and other species homes.

b) Green roofs help to retain rainwater, so reducing runoff and relieving strain on urban drainage systems.

c) Rooftop plants help to filter carbon dioxide and pollutants, so cleaning the atmosphere.

Sound Insulation

The strata of vegetation and soil act as acoustic barriers, so reducing outside noise levels (Council, 2007).

Green roofs provide surface cooling by evapotranspiration and vegetation cover, so reducing the heat island effect in urban areas.

Mathematical Benefits

Green roofs have great long-term financial benefits even if their initial capital costs are higher due to additional structural demands and particular installations (Felgueiras, Martins, and Caetano, 2017). These span:

a) Green roofs protect waterproof membranes from UV light and physical damage, so extending the lifetime of the roof.

b) By stabilizing interior temperatures, energy conservation and thermal insulation greatly lower heating and cooling needs and hence lower energy costs.

c) Green roofs improve the market value of a building, raise its green building rating (e.g., LEED, BREEAM), and so strengthen public impression and sustainability credentials.

CONCLUSION

Passive temperature control depends critically on green roofs. While enhancing inside cooling, green roofs help to reduce daytime outdoor heat levels. This effect is especially clear in the afternoon when green rooftops effectively shield the structure from direct solar radiation, so lowering heat absorption through the roof slab.

Green roofs preserve moisture in the substrate, so regulating inside temperatures during bad weather; at night, their thermal mass helps to balance internal and external environments. Green roofs thus help to effectively control thermal transfer, so enhancing the sustainability and comfort of buildings.

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