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Evaluating the Impact of Green Roofs on Buildings

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Abstract.

A green roof is a smart ecosystem built on a roof that helps improve the urban environment. They provide natural insulation, which significantly reduces the energy required to heat and cool buildings. Green roofs also absorb carbon dioxide through photosynthesis and evapotranspiration, helping reduce greenhouse gas concentrations. They improve air quality by trapping pollutants such as particulate matter (PM2.5, PM10), ozone (O3), and nitrogen oxides (NO2), thus making cities cleaner and healthier. In addition, green roofs effectively manage rainwater, reducing the risk of flooding and filtering pollutants from runoff. They improve water absorption and retention, which helps keep water clean and reduces the load on drainage systems. Green roofs also support urban wildlife by creating habitats for plants and animals, which contributes to ecological sustainability. For the public, green roofs offer peaceful, beautiful outdoor spaces in busy cities, helping reduce noise pollution and improve mental health. The review includes a variety of models and experiments that study the performance of green roofs, including how factors such as crop cover and soil depth affect their efficiency. The book also discusses environmental benefits, such as improving air quality, reducing carbon emissions, and managing rainwater. In addition, life cycle assessments show that green roofs are environmentally friendly throughout their lifetime, from manufacture to disposal. Overall, green roofs are practical solutions that save energy, improve urban air and water quality, support biodiversity, and make cities more livable.

Keywords: Air quality improvement, energy saving, green roof, pollutants, reduction.

1. Introduction

Urban sustainability has become one of the biggest challenges in recent decades, driven by climate change, human activity, and increasing urbanization (Shafique, Kim, & Rafiq, 2018). Negative impacts of these processes include global warming, air pollution, stratospheric ozone depletion, the urban heat island effect (UHI), excessive noise, and declining biodiversity, all of which severely affect human mental, psychological, and physical health (Susca, Gaffin, & Dell'Osso, 2011). To address these issues, a variety of sustainability-oriented approaches have been designed and implemented, including the construction of energy-efficient buildings, the use of renewable energy sources, the mitigation of air and water pollution, and the expansion of green spaces and green infrastructure (Liu et al., 2021; Shafique, Kim, & Rafiq, 2018).

One of the most prominent nature-based solutions is green roofs, an artificial ecosystem designed and implemented to improve urban sustainability (Shafique, Kim, & Rafiq, 2018). Green roofs offer a variety of benefits, such as reducing heating and cooling energy use, reducing air pollutants through particle deposition, controlling runoff and water contaminants, promoting biodiversity, and providing aesthetic and health benefits (Mutani & Todeschi, 2020). This advantage makes green roofs a multifunctional solution that transforms previously underutilized roof space into areas with ecological, social, and economic value (Cook & Larsen, 2021).

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In this context, green roof research and assessment include thermal performance modeling, experimental studies, and evaluation of environmental benefits—including air pollution reduction, carbon sequestration, rainwater management, and urban noise mitigation (Espinosa-Paredes et al., 2020). This approach supports urban sustainability and resilience to climate change while emphasizing the role of green ecosystems in creating healthier, more sustainable urban environments (Van Middelem et al., 2022; Liu et al., 2021).

2. Method

The research methods used in the studies summarized in the references reviewed in this study include modeling, experimental, and bibliographic review approaches (Cook & Larsen, 2021; Van Middelem et al., 2022).

2.1 Modeling Approach

Many studies use thermal performance models, including energy balance models, transmission coefficient calculations, and data-driven models such as Artificial Neural Networks (ANNs) (Espinosa-Paredes et al., 2020). These models simulate the thermal behavior of green roofs, evaluate key parameters that affect their performance, and predict energy savings and environmental impacts (Ismail, Samad, & Rahman, 2011).

2.2 Experimental Approach

Some studies conduct direct field measurements, such as monitoring temperature drops, air quality, and rainwater management, by collecting empirical data from green roof systems of varying configurations and scales (Ramasubramanian et al., 2021).

2.3 Life Cycle Assessment (LCA)

Many studies conduct comprehensive environmental analyses covering raw materials, production processes, construction, use, and end-of-life of green roofing products to thoroughly evaluate their ecological impact (Van Middelem et al., 2022; Cook & Larsen, 2021).

3. Results and Discussion

The results and discussions of the study on green roofs reflect several important aspects:

3.1 Environmental Impact and Life Cycle

LCA studies show that the main contributors to environmental impacts are the material extraction, manufacturing, and construction phases, particularly for materials such as polymers and cement. The use of materials such as polyester and cement significantly affects climate change and resource consumption (Van Middelem et al., 2022). However, the use of materials such as hydroponic mineral wool can reduce impacts during the operational phase, thereby supporting sustainability benefits (Cook & Larsen, 2021).

3.2 Energy Efficiency and Thermal Performance

Experimental testing and simulation models show that green roofs can significantly reduce heating and cooling loads in buildings (Mutani & Todeschi, 2020). For example, decreases in indoor temperature of 21.4–21.8% and energy savings of 37-48% have been reported, highlighting the energy efficiency of these systems (Ismail, Samad, & Rahman, 2011). Parameters such as *the Leaf Area Index* (LAI) are critical for improving thermal performance, with higher LAIs increasing shading and evapotranspiration, thereby reducing temperature fluctuations and energy requirements (Espinosa-Paredes et al., 2020).

3.3 Thermal and Economic Benefits

Parametric studies and energy analysis show that certain configurations of green roof systems can significantly increase energy savings (Mutani & Todeschi, 2020**).** Adjustment of parameters such as soil layer thickness, insulation, and vegetation density can improve system performance and reduce operational costs (Ismail, Samad, & Rahman, 2011).

3.4 Sustainability and Ecological Benefits

Green roofs help improve air quality by absorbing carbon and reducing pollutants through evapotranspiration (Liu et al., 2021). Additionally, green roofs help manage rainwater by reducing runoff volume (Gong et al., 2019), thereby reducing urban flooding (Lee et al., 2013**)** and water pollution (Vijayaraghavan, Joshi, & Balasubramanian, 2012).

3.5 Modeling and Validation

Various energy-based thermal models and mass-balance approaches have been validated against experimental data and the literature, demonstrating high accuracy in predicting green roof performance (Espinosa-Paredes et al., 2020).

3.6 Typical green roof coating

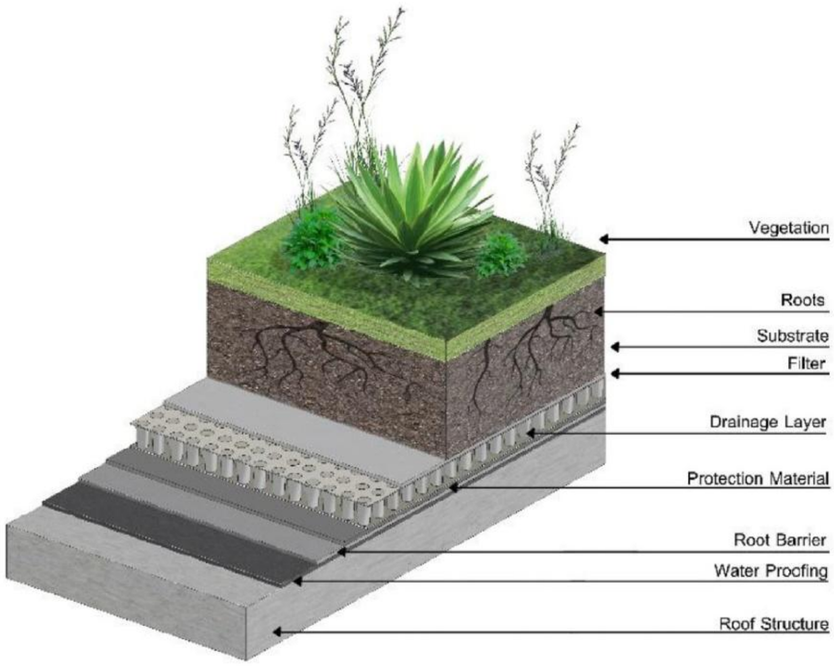

Figure 1. Typical green roof coating (Mihalakakou et al., 2023)

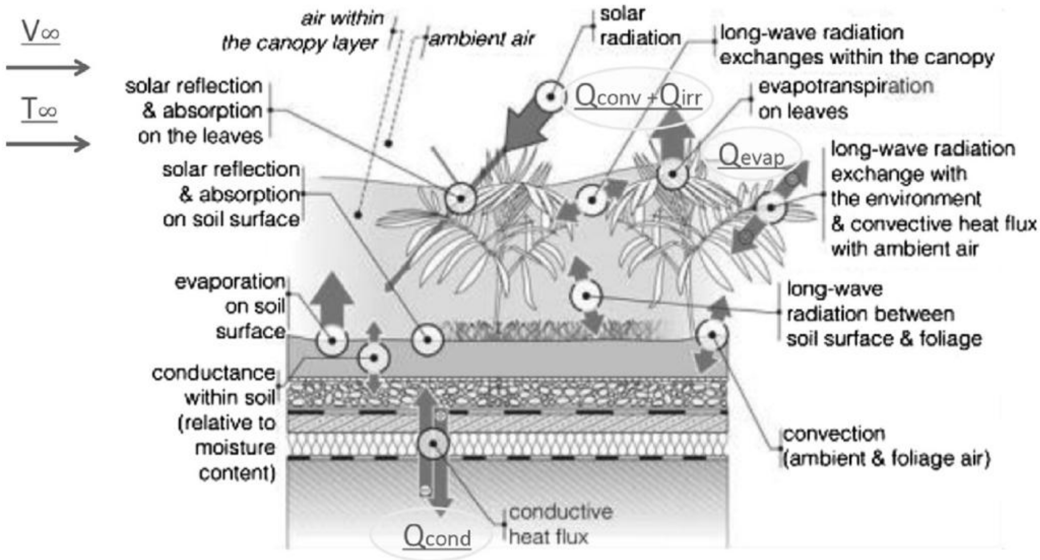

Figure 2. The process of heat transfer in green roofs (Shafique, Kim, & Rafiq, 2018)

4. Conclusion

In conclusion, green roofs provide significant ecological, thermal, and psychological benefits, including reduced building energy consumption, mitigation of urban heat island effects, improved air and water quality, and increased urban biodiversity. Life cycle assessments show that green roofs generally have a lower environmental impact than conventional roofing systems, especially when using environmentally friendly materials. The effectiveness of green roofs depends on various design parameters such as vegetation type, soil depth, and insulation, which can be optimized through modeling and experimental validation to maximize performance. Nevertheless, challenges related to material procurement and long-term maintenance remain, highlighting the need for continuous research and innovation.

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