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Research on the application of green roof systems in energy-saving design of low-rise public buildings

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Abstract: Low-rise public buildings have large roof-to-volume ratios, so roof heat and moisture transfer strongly affect comfort and HVAC energy. Using coupled simulations, we evaluate green roofs as an envelope strategy and show reduced summer roof heat flux and peak surface temperature, improving top-floor comfort. We propose an integrated "insulation-waterproofing-drainage-vegetation" assembly and climate-adaptive parameter ranges to balance energy savings, durability, and stormwater performance.

Key words: green roof; low-rise public buildings; hygrothermal performance; building energy simulation; stormwater retention; integrated roof design

1 Introduction

Green roofs are increasingly used as roof-envelope measures to address energy, comfort, and ecological goals. Multi-climate studies show performance is climate- and design-dependent: cooling-dominated contexts often benefit most, while heating penalties may occur when insulation and moisture control are poorly coordinated [1]–[6]. Engineering decisions should therefore treat substrate/vegetation, drainage, waterproofing, and maintenance as a single roof system [7].

To support engineering decision-making in low-rise public buildings, this study makes three design-oriented contributions:

- Design parameter guidance: proposes climate-adaptive ranges for key roof inputs (substrate thickness, vegetation coverage/LAI, drainage configuration, and insulation placement) to guide preliminary sizing and sensitivity-aware refinement.
- Roof-system coordination mechanism: explains how the insulation–waterproofing–drainage–vegetation assembly jointly governs coupled heat–moisture transfer, summer cooling effectiveness, and durability risk, helping designers avoid single-variable interpretation.
- Energy–comfort linkage: reports coupled indicators that relate roof-driven heat-flux changes to annual HVAC energy intensity and top-floor comfort outcomes, enabling balanced evaluation beyond energy-only comparisons.

2 Theoretical basis and path framework

2.1 Governing formulations (design-level)

To clarify the design logic, we outline a 1D transient heat-and-moisture model for layered roofs, highlighting how key variables affect surface fluxes and building loads in the coupled simulations.

(1) $\rho c (\partial T/\partial t) = \partial/\partial z (k \partial T/\partial z) + S_T$

Moisture transport in porous substrate can be represented in terms of moisture content θ or relative humidity ϕ:

(2) $\partial\theta/\partial t = \partial/\partial z (D_\theta \partial\theta/\partial z) + S_M$

Accordingly, we emphasize transparent scenario inputs and boundary conditions for design comparison.

2.2 Design variables and scenario space

For low-rise public buildings, influential variables include substrate thickness, moisture holding capacity, vegetation coverage and LAI, drainage design, insulation placement, vapor control, and membrane robustness. Table 1 summarizes representative design inputs used for scenario definition.

Table 1. Representative green roof assembly parameters used to define the scenario space for low-rise public buildings

Item	Symbol	Typical Range / Option	Notes
Substrate thickness	h_s	100–250 mm	Extensive to semi-intensive
Substrate dry density	ρ_s	700–1100 kg/m³	Lightweight mixes lower ρ_s
Thermal conductivity (dry→wet)	k_s	0.25–0.60 W/m·K	Moisture-dependent
Volumetric water content at field capacity	θ_{fc}	0.20–0.40	Storage / ET support
Vegetation coverage	C_v	0.6–0.95	Seasonal variation
Leaf area index	LAI	1.0–3.5	Species and maintenance dependent
Drainage layer thickness	h_d	20–50 mm	With geotextile filter
Insulation (below membrane)	h_i	30–80 mm	Climate-dependent
Waterproofing membrane	—	SBS/EPDM/TPO	Durability / detailing critical
Roof slope	α	0–5°	Affects drainage and retention

3 Technology transfer and implementation case analysis

3.1 Why design-to-operation transfer matters in public buildings

Public buildings are rarely "set-and-forget". Green roofs can underperform when irrigation, drainage, or maintenance deviates from design intent. Design-to-operation transfer packages provide intent, monitoring cues, and O&M actions to sustain performance after handover.

3.2 Case building and roof constraints

A representative two-story community service building with a large flat roof is considered. Constraints include roof dead-load limits, waterproofing reliability requirements, safe access routes for inspection, and stormwater retention objectives.

3.3 Implementation package: what must be communicated

This section is positioned as an implementation/communication deliverable for designers, contractors, and facility managers. A delivery package should explain four operational truths: moisture controls cooling; drainage controls durability; insulation strategy changes winter outcomes; and performance depends on vegetation coverage.

4 Simulation and monitoring-informed performance evaluation

4.1 Evaluation design and metrics

Effectiveness is evaluated along three axes: (i) energy (annual HVAC energy intensity and seasonal peaks), (ii) comfort (peak operative temperature and unmet comfort hours), and (iii) sponge performance (runoff retention ratio and runoff delay).

4.2 Model calibration using monitoring signals

Calibration uses roof surface temperature and heat flux as primary signals, with substrate moisture as a consistency constraint. Indicators include RMSE for surface temperature and NMBE for daily-integrated heat flux.

4.3 Scenario results and cross-climate comparison

Figure 1 compares annual HVAC energy intensity across climate types for a baseline roof and green-roof options. Cooling-dominant climates show larger reductions due to evapotranspiration and lower roof surface temperature. Heating-dominant climates show smaller changes and higher sensitivity to insulation–vapor–moisture coordination; this reflects assembly detailing rather than an inherent green-roof limitation.

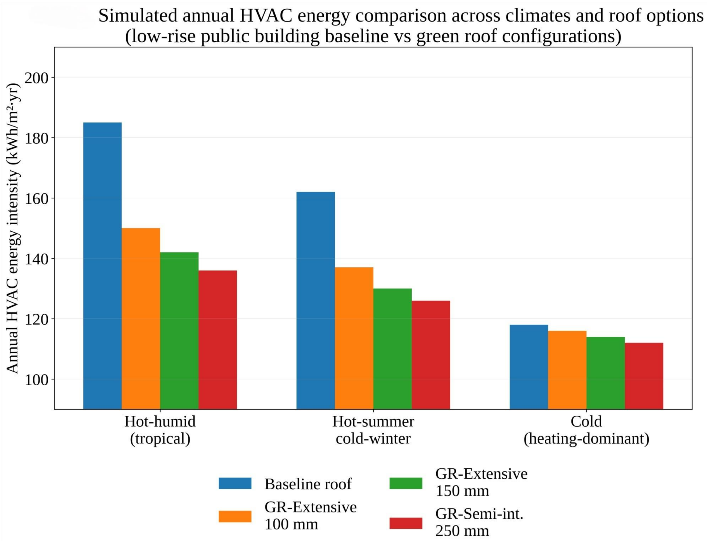

Figure 1. Simulated annual HVAC energy comparison across climates and roof options

Figure 1. Cross-climate annual HVAC energy comparison from coupled simulation for baseline and green-roof options, reported under consistent operation assumptions to isolate roof-driven effects and support parameter selection (e.g., substrate thickness and insulation strategy).

5 Conclusion

Green roof systems can improve energy efficiency, top-floor comfort, and stormwater retention in low-rise public buildings when treated as engineered hygrothermal systems. The results support practical design and O&M decisions (assembly selection, irrigation/drainage, and monitoring priorities). In heating-dominant climates, limited savings or small penalties usually reflect insulation–vapor–moisture coordination and detailing, and can be reduced with climate-appropriate insulation and moisture control.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] Jia SQ, et al. 2024. Building energy savings by green roofs and cool roofs in current and future climates. *npj Urban Sustainability*, 23.

[2] Sommese F, Diana L. 2025. A holistic framework for the implementation of green roofs on existing buildings: A case study in the Mediterranean climate of Naples. *Building and Environment*, 274: 112811.

[3] Bevilacqua P. 2021. The effectiveness of green roofs in reducing building energy consumptions across different climates: A summary of literature results. *Renewable and Sustainable Energy Reviews*, 151.

[4] Yang J, Davidson C, Zhang G. 2021. Evaluation of thermal performance of green roofs via field measurements and hygrothermal simulations. *Energy and Buildings*, 237.

[5] Porcaro M, et al. 2021. Exploring the reduction of energy demand of a building with an eco-roof under different irrigation strategies. *Sustainable Cities and Society*, 74: 103229.

[6] Hamed Y, et al. 2021. Building energy comparison for dynamic cool roofs and green roofs under various climates. *Solar Energy*, 230: 764-778.

[7] Mohsen S, et al. 2022. Sustainable green roofs: A comprehensive review of influential factors. *Environmental Science and Pollution Research*, 29: 78228–78254.