Beyond Energy Savings: The Role of Green Roofs in Public Buildings for Climate Resilience and Peri-Urban Renewal — Insights from Hungary

Xiaonan Li[1)], Tianyu Zhao[2*)], Kósa Balázs[3)]

[1)] University of Pécs Faculty of Engineering and Information Technology, Boszorkány út 2, 7624, Pécs, Hungary; shininghersey@gmail.com; https://orcid.org/0000-0002-1906-208X
[2*)] Hubei Universisty of Technology, School of Art and Design, Hongshan, Nanli Road No.28, 430068, Wuhan, Hubei, China; tianyu.zhao94@gmail.com; https://orcid.org/0000-0002-2383-2454
[3)] University of Sopron, Faculty of Wood Engineering and Creative Industries, Bajcsy-Zsilinszky u. 4, 9400, Sopron, Hungary; kosa.balazs.84@gmail.com

https://doi.org/10.29227/IM-2025-02-02-097

Submission date: *2025-05-30* | Review date: *2025-06-26*

Abstract

This study investigates the multidimensional impacts of rooftop greening in urban public buildings through integrated energy simulations and urban spatial analysis. Focusing on a school in Szombathely, Hungary, the research employs Energy Plus to quantify energy efficiency improvements while exploring theoretical frameworks for urban-scale benefits. Three core propositions are examined: Rooftop vegetation enhances building energy performance through thermal regulation; Strategic green roof placement enables climate resilience and social comfort improvements; Systematic implementation can create interconnected green networks redefining public space functionality. Simulation results demonstrate a 22% reduction in annual cooling energy demand, with peak reduction of 23.1% in July during summer months. Heating energy savings average 6% annually, reaching 10.5% in February. Theoretical projections suggest significant improvements in pedestrian thermal comfort zones through municipal-scale implementation. The study proposes a conceptual framework for transforming isolated green roofs into continuous urban networks. Spatial analysis indicates potential dual benefits: enhanced heat island mitigation through coordinated vegetation placement and increased social interaction opportunities via strategically connected green spaces. This approach advocates redefining rooftops as multifunctional infrastructure addressing climate resilience and social needs. Methodologically, the research bridges building physics simulation with urban morphology studies, it pioneers an approach that scales localized interventions to urban social experiences. By analyzing how a single school's green roof modifies both its energy profile and surrounding community interactions, we establish a replicable model for converting individual building upgrades into city-wide social space networks. The innovation lies in correlating energy-saving metrics with spatial accessibility parameters to identify "social multiplier nodes" - public buildings whose roof greening can disproportionately enhance neighborhood connectivity. This human-centered methodology empowers planners to prioritize sites where technical improvements concurrently activate underutilized aerial territories as community assets. Importantly, the study demonstrates how standardized building retrofit data can inform place-specific social space design, challenging the conventional dichotomy between energy efficiency projects and public realm development. The outcomes recast green roofs as social infrastructure catalysts, providing policymakers with evidence that technical interventions in public architecture inherently carry untapped potential for reconfiguring urban relationship networks. This paradigm shift positions roofscapes not merely as energy-saving surfaces, but as deliberate instruments for choreographing social encounters across vertical urban dimensions.

Keywords: *Green Roof, Energy Efficiency, Urban Climate Adaptation, Public Building Retrofit, Social Space Networks, Peri-Urban Regeneration*

1. Introduction

Hungary's building stock, particularly those constructed during the socialist era in the mid-20th century, is characterized by low energy efficiency and suboptimal thermal comfort [1][2] and meantime losing social reputation from its residents. A significant portion of these structures—panel houses, row houses, and public facilities—are concentrated in small and medium-sized cities like Szombathely [3][4], where aging buildings present both a challenge and an opportunity for sustainable transformation in terms of both ecological development and public life. These structures are not merely architectural remnants; they are embedded in the urban fabric, shaping the everyday experiences of residents and influencing local microclimates [5]. However, their associated urban environments often lack emotional resonance, suffer from poor comfort conditions, and fail to foster meaningful social interactions.

Amidst the global push for carbon neutrality, Hungarian cities are compelled to accelerate building renovation efforts. Public buildings, in particular, have become focal points for green interventions, given their disproportionately high energy demands and potential to serve as demonstration sites for sustainable practices. In cities like Szombathely, the intimate link between the urban core and surrounding peri-urban villages offers a unique spatial context for integrated green strategies. The abundance of aging schools, offices, and communal facilities provides a rich resource base for exploring scalable green retrofitting models that extend beyond individual buildings to influence broader urban systems.

Green roofs, as a nature-based solution, present a promising intervention in this context [6][7]. They not only enhance the thermal performance of individual buildings but also contribute to climate adaptation and social well-being by creating localized cooling effects, mitigating the urban heat island phenomenon, and fostering new social spaces [7]. When implemented systematically—particularly across

public buildings in strategically connected locations—green roofs have the potential to transform fragmented interventions into coherent green networks, reimagining rooftops as multifunctional infrastructure that bridges energy efficiency, climate resilience, and social interaction.

This research stands from an experimental perspective, that tries to discuss about the possibility of public-space-joined public life improvement through the ecologically sustainable intervention of the built environment. It investigates the energy-saving potential and climate adaptation benefits of green roofs in public building retrofits, focusing on a case study in Szombathely, and discusses the vision in the case of spread and connecting each potential intervention to another. By integrating EnergyPlus simulations with spatial analysis, the study aims to demonstrate how rooftop green intervention can serve as a catalyst for both technical performance improvements and the regeneration of peri-urban landscapes. The findings aim to inform future urban planning strategies, emphasizing the role of public buildings as "social multiplier nodes"—key sites where targeted interventions can generate disproportionate benefits in terms of both environmental sustainability and community connectivity [8].

2. Methodology

2.1 Research Framework

This study aims to discuss about the vision and value of public built environment, which include the public social life and ecological performance aspects. Therefore, fundamentally, it investigates the energy-saving performance and climate adaptation potential of green roof interventions on existing public buildings in Hungary, with a focus on the small-to-medium-sized city of Szombathely. By combining building energy modeling (BEM) simulations, spatial analysis, and field investigations, the study explores how green roofs can contribute to both the thermal performance of individual buildings and the broader urban context.

The research is guided by three core propositions. Green roofs improve the energy performance of retrofitted buildings by reducing heating and cooling demands. Green roofs act as climate resilience nodes that extend localized cooling and social comfort outward from key urban points, creating a distributed network of green interventions across the city. Systematic green roof retrofitting can transform fragmented urban spaces into interconnected green networks, reshaping the functionality of rooftops as public and social infrastructure. This framework addresses both technical performance and the socio-spatial potential of green roofs in Hungarian urban regeneration.

2.2 Context: Public Building Types in Szombathely

Szombathely, located in the Western Danube Valley of Hungary, has a complex urban morphology shaped by centuries of historical development. The inner city retains a medieval-scale street network with multi-story buildings typical of Central Europe, while areas outside the historical core feature four primary building types: 3–4 story brick houses (row houses): tightly connected to the street, minimal green spaces. Slab (panel) houses: 4–6 or 11-story prefabricated concrete apartment blocks; clusters of buildings forming large residential neighborhoods. Single-family houses: detached or semi-detached, often with buffer gardens. Public facilities: typically large-scale, concrete-frame buildings with flat roofs and minimal integration with surrounding green spaces. Among these, panel houses—prefabricated concrete structures introduced in the mid-20th century—present the greatest challenges and opportunities for green retrofitting. They dominate the residential and public building stock in Szombathely, characterized by standardized layouts, limited facade articulation, and large, flat roof surfaces. According to previous studies [9][10], window opening ratios range from 35–47% for multi-story slab houses and 22–30% for high-rise slab houses, leaving 53–78% of the facade surface available for vertical greening.

2.3 Case Study Selection and Representativeness

The selected case study is a three-story primary school located in the suburban area of Szombathely, approximately 1.5 km from the city center. Built in 1980, this building exemplifies the typical prefabricated concrete public building prevalent in Hungarian cities. Its large, flat roof (approximately 940 m²), uninsulated facades, and minimal surrounding greenery make it an ideal candidate for testing green roof interventions. The school is surrounded by apartment blocks and family houses, reflecting the peripheral urban morphology where the city transitions into peri-urban landscapes. The presence of six Scots pine trees (Pinus sylvestris) in front of the building provides partial summer shading but does not significantly influence overall building energy performance. This case study's structural typology, material system, and spatial characteristics are highly representative of Hungary's mid-20th century public building stock, making the findings applicable to a broader context of urban retrofitting across the country. The case study building—a 1980s primary school—exemplifies a typical prefabricated concrete public building in Szombathely. However, this single building is part of a broader urban fabric, where various building types coexist, each with distinct material systems, forms, and green retrofit suitability. To contextualize the broader potential for green interventions in Szombathely, Table 1 summarizes the main public building types in the city, their structural and material characteristics, and their respective suitability for green retrofit strategies.

Tab. 1. Main Building Types in Szombathely and Their Suitability for Green Retrofit

Building Type	Material	Form/Number of Floors	Suitability for Green Retrofit
Panel House	Precast Concrete	4–11 floors, linear layout	High suitability (roof + facade)
Row Brick Houses	Brick walls + Reinforced Concrete	2–4 floors, tight street frontage	Suitable (roof only)
Detached Courtyard House	Brick/Stone/Mortar + Wooden Roof	1–1.5 floors, low density	Suitable (roof + courtyard)
Public Facility Buildings	Concrete Structure	1–3 floors, large block volume	High suitability (comprehensive retrofit)

2.4 Data Collection and Analysis

Data sources for this study include:

On-site observations: documenting the building's spatial and material conditions.

Facade mapping and green potential analysis: quantifying available surfaces for green interventions.

Meteorological data: from the Hungarian Meteorological Service [6], including temperature, precipitation, and solar radiation patterns for Szombathely.

2.5 Simulation Scenarios and Tools

The study uses EnergyPlus software to conduct dynamic building energy simulations, incorporating local climate data from the WRF (Weather Research and Forecasting) model to ensure accurate boundary conditions for Szombathely's temperate, humid (Cfb) climate [6]. Two primary simulation scenarios are defined:

Scenario 1 (Baseline): the building retains its original condition, with no green interventions.

Scenario 2 (Green Roof Intervention): the building is retrofitted with an extensive green roof system (characteristics detailed in Table 2), while other parameters remain unchanged.

2.6 Analysis Metrics

The analysis focuses on the following key metrics:

Annual energy demand (kWh) for heating and cooling.

Seasonal energy performance, with detailed analysis for July (cooling peak) and February (heating peak).

Energy savings per square meter (kWh/m²), providing a standardized measure for retrofit effectiveness.

Simulation results demonstrate that the annual cooling energy consumption decreased by 22% with the green roof intervention, with monthly peak savings reaching 23.1% in July. The annual heating energy consumption was reduced by 6%, with peak savings of 10.5% in February. The total annual energy savings for the building were 8,933 kWh, representing 13.9% of the baseline demand, and the average energy use per square meter decreased from 26.69 kWh/m² to 23.00 kWh/m².

2.7 Coupling Green Roof Interventions with Urban Spatial Networks

This study not only quantifies the energy performance of a single retrofitted building but also situates the intervention within a broader urban spatial framework. By identifying public buildings as potential "climate and social nodes", the research proposes a model in which:

Green roofs improve individual building performance. Strategic placement of green roofs at multiple urban points extends localized climate benefits and enhances public comfort.

Interconnected green roofs form a continuous upper-layer network, visually and functionally redefining rooftops as spaces for environmental adaptation and social interaction.

This approach advocates for a scalable, human-centered strategy for green retrofitting in Hungarian cities, where energy efficiency upgrades align with the reconfiguration of public space functionality.

3. Case study of the experimental building

3.1 Simulation method:

The reference model proposed to renovate is located in Szombathely, which is situated in the western of Hungary (Figure 3). The latitude of Hungary is between 45°45'N and 48°35'N and its climate is erratic due to the combined influence of continental climate, oceanic climate and Mediterranean effect [6]. In Szombathely, the climate is continental and has been classified as Cfb by Köppen and Geiger; namely, warm temperature, fully humid and warm summer [10]. The average annual temperature in Szombathely is 11°C, and summer usually starts from late June to the end of September, in which July is the warmest month. In addition, Szombathely has abundant rainfall, raining heavily even in the driest months.

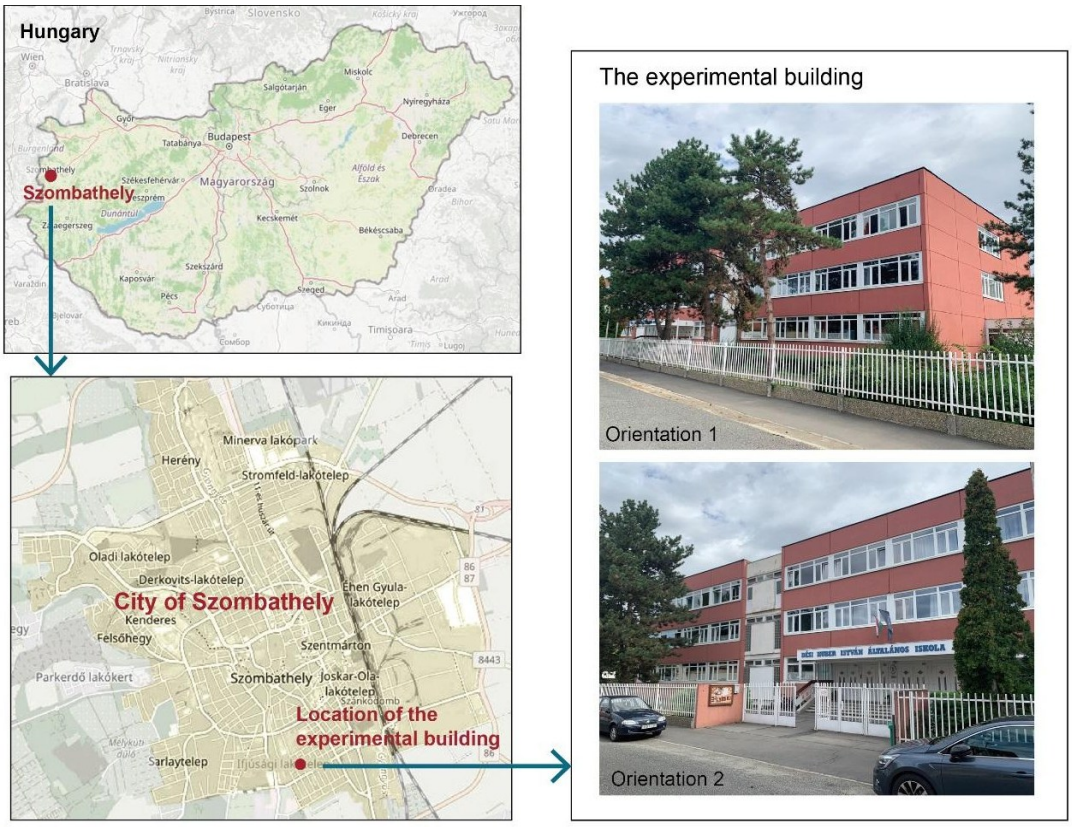

Fig. 3. Location of Szombathely and the experimental building (photos by author)

The building selected for energy consumption analysis is located in the outer area of the city, approximately 1.5 km from the city center (Figure 3). The surrounding area of this building has a tranquil atmosphere as the adjacent area consists mainly of flats and family houses. This building was built in 1980 and faces the southwest direction. It is one of the primary school buildings and has three stories. The building has bare walls and roofs, of which the roof covers an area of nearly 940 square meters. There are 6 scotch pine trees (Pinus sylvestris) planted in front of the buildings, which partly decreased the solar radiation in the summer period.

Furthermore, for the energy consumption simulation of the case study, specialized software was utilized in the design and thermal analysis of the building. Although there are many softwares available for energy consumption simulation analysis, EnergyPlus is the most popular. As it provides a specific module for modeling green roofs, allowing to set vegetation physical properties, such as height, minimum stomatal resistance, leaf area index, thermal properties (albedo and leaf emissivity); etc. This module, therefore, helps in accurately simulating the energy demand before and after the implementation of green roofs.

To explore the energy consumption changes before and after the installation of green roofs, two scenarios were formulated in this study. Scenario 1 maintains the original condition of the experimental building. Scenario 2 refers to the installation of extensive green roofs on the experimental building. Therefore, the difference between Scenario 2 and Scenario 1 lies in the utilization of extensive green roofs, while the rest of the features remain the same. Table 2. Shows the characteristics of the layers of the extensive roof construction systems.

Tab. 2. Main Characteristics of the Extensive Green Roof System

Layer	Thickness (m)	Thermal Conductivity (W/mK)
Vegetation: sedum	0.05	-
Anti-root sheet	0.001	0.33
EPDM waterproofing	0.0012	0.25
XPS insulation	0.035–0.14	0.033
Drainage layer	0.04	0.33
Filter sheet	0.001	0.038
Substructure	0.10	0.435

3.2 The results of building energy simulation

The results of building energy simulation in Szombathely is shown in figure 4, 5 and 6.

- No green roof

Month/ Electricity (kWh)	1	2	3	4	5	6	7	8	9	10	11	12	Annual	Total (kWh)	Energy used/ ㎡
Cooling	0	0	0.2	0.7	68.9	6207.9	10422.5	9284.3	4491.2	7.4	0	0	30483.72	64407.33	12.63/ ㎡
Heating	10031.8	7420.3	908.1	0	0	0	0	0	0	0	4958.7	10604.7	33923.61		14.06/ ㎡

- Extensive green roof

Month/ Electricity (kWh)	1	2	3	4	5	6	7	8	9	10	11	12	Annual	Total (kWh)	Energy used/ ㎡
Cooling	0	0	0	0.2	47.8	4771.4	8075.1	7137.6	3530.6	7.9	0	0	23570.64	55474.25	9.77/ ㎡
Heating	9554.7	6638.7	833.7	0	0	0	0	0	0	0	4732.1	10144.4	31903.61		13.23/ ㎡

Fig. 4. The annual building energy demand between two different scenarios

Figure 4 illustrates the annual energy use of the experimental building in two different scenarios. It is clear that the annual energy consumption for heating exceeds that of cooling in both scenarios. In the scenario of no green roof, heating consumes nearly 3,440 kWh more electricity per year than cooling. However, this difference expands to 8333 kWh per year in the scenario of applying extensive green roof. This is because the cooling energy demand is significantly reduced by installing an extensive green roof on the experimental building. Specifically, the annual cooling energy consumption was decreased by 6913.08 kWh. In addition, compared with the scenario of without green roof, the scenario of applying green roof saves 8,933 kWh electricity of total energy demand, which represents 13.9%. Moreover, the average energy consumption per square meter decreased from 26.69/m² to 23/m² [6].

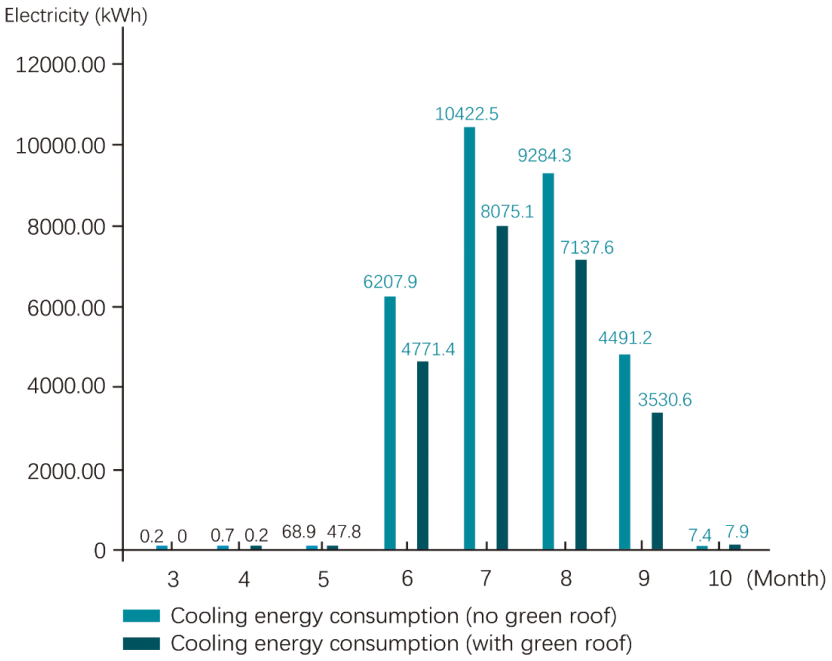

Fig. 5. Annual cooling energy consumption of experiment building in two different scenarios

According to figure 4, there is a significant difference between these two scenarios. It is clear that the scenario of using green roof demands less energy for cooling than the scenario of without applying green roof. In addition, the cooling period of this building mainly starts in June and ends in September, in which the largest cooling energy demand occurred in July. The electricity consumed in this month is over 10 thousand kWh in the scenario of without applying green roof, which rose by 40.4%, compared to June. Instead, the energy consumption dropped to 8075 kWh by applying an extensive green roof. During the main cooling period (June, July, August and September), experimental building saves 23.1%, 22.5%, 23.1% and 21.4% cooling energy by using extensive green roofs, respectively. Moreover, compared with the bare building roof, the annual cooling energy saving rate is more than 22%; also, the cooling energy demand per square meter is reduced from 12.63/m² to 9.77/m².

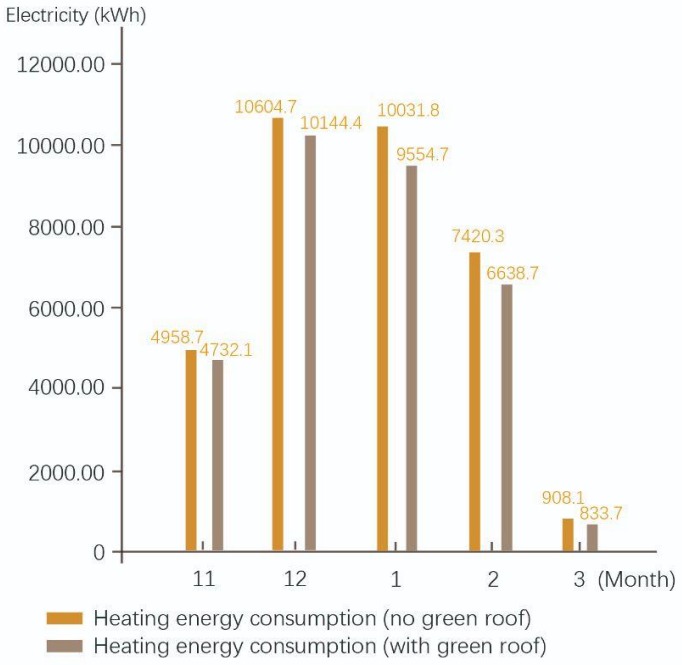

Fig. 6. Annual heating energy consumption of experiment building in two different scenarios

As shown in Figure 6, by applying the green roof, the heating energy demand of the experimental building was also reduced compared to the original scenario. The energy consumption after the installation of green roofs decreased by 4.6%, 4.3%, and 4.8% in November, December, and January, respectively, compared to the energy consumption without green roofs. The largest energy savings occurred in February, reaching 10.5%. Similarly, the heating energy consumption was reduced by 8.2% in March through the use of green roofs. In addition, by using the extensive green roofs, the annual heating energy saving rate of the experimental building reached 6.0%, and the heating energy consumption per square meter was reduced from 14.06 per square meter to 13.23 per square meter.

4. Findings from the case study

The case study highlights the multifaceted role of green interventions—particularly green roofs—in improving the energy performance of existing public buildings, enhancing climate adaptation, and reconfiguring urban spatial relationships in Szombathely, a representative small city in Central Europe. Focusing on a typical prefabricated public building from the socialist era, the research demonstrates how the application of green roofs can significantly reduce annual energy consumption, particularly by lowering cooling demand during the summer months. Simulation results show that the implementation of an extensive green roof system can lead to a 22% reduction in annual cooling energy consumption, with peak monthly savings exceeding 23%, and an average 6% reduction in heating energy consumption throughout the year. Beyond the immediate energy-saving benefits, the study emphasizes the broader urban potential of green roof interventions. Green roofs in public buildings serve as climate resilience nodes, improving indoor thermal comfort while extending localized cooling effects and enhancing social comfort in surrounding public spaces. When strategically deployed across multiple sites, these interventions contribute to a distributed, multi-nodal green network that mitigates the urban heat island effect, promotes biodiversity, and fosters opportunities for community interaction.,

Three key propositions emerge from the study:

1. Green roofs improve the energy performance of retrofitted buildings, reducing energy consumption for cooling and heating, and contributing to building-level sustainability.
2. Green roofs, when applied to public buildings at key urban nodes, create localized climate regulation zones that extend outward, improving social comfort and microclimate conditions in surrounding areas.
3. Green roofs form a connective network when deployed systematically, transforming fragmented rooftops into a visible and functional layer of public space infrastructure that supports climate adaptation, environmental awareness, and social interaction.

5. Impacts on public social life

Scholarly discourse has addressed the greening interventions on individual buildings (e.g., green roofs/facades) and their potential interconnection into larger-scale ecological networks. Such discussions, however, predominantly focus on urban cooling islands, ecological corridors, and carbon sequestration networks [11][12]. Urban social experience—a vital component of public life—is embedded in the public spaces of the built environment. Both research and practice aim to interconnect individual public spaces to form expansive urban spatial corridors. Yet, the convergence of these two approaches remains underexplored.

Building on architectural performance simulations of green roof interventions for public buildings in Szombathely, this study posits that retrofitting multiple public structures (e.g., with green roofs) can simultaneously enhance their ecological performance, propagate sustainability awareness, improve user experience within these buildings, and effectively establish nodes within an urban green space network. As these nodes interconnect, they generate cumulative enhancements to the quality of urban built environments—including visual aesthetics, air quality, and microclimate comfort—thereby elevating social interaction comfort.

In European medium-sized cities like Szombathely, socialist-era public buildings exhibit greater potential for such interventions and networked socio-ecological corridor development compared to earlier or newer structures, owing to their distinctive construction methods and socio-historical significance. The quantity and characteristics of these buildings offer substantial opportunities for greening upgrades and spatial integration into urban social-green corridors. When an ecological intervention benefits both building performance and urban public life, it represents a viable developmental scenario.

6. Conclusion

Every culture and city possesses unique patterns of social space organization, reflecting place-specific cultural identities. For local residents, these patterns are ingrained in their cognitive maps as implicit spatial frameworks. Transforming built-environment greening interventions into interconnected networks can manifest these latent characteristics, articulating a city's distinctive social logic through visible green-social corridors.

In this sense, green roofs are not merely technical additions to individual buildings but are integral components of a larger, systemic approach to urban regeneration. They offer a scalable strategy for reimagining rooftops as multifunctional urban infrastructure—spaces that combine environmental performance with social and spatial functions. Ultimately, the study advocates for the integration of green roof retrofitting into urban renewal policies and practices in Szombathely and similar Central European contexts. By aligning building-level energy efficiency improvements with broader urban sustainability goals, green interventions can play a pivotal role in creating more resilient, livable, and socially connected cities.

Acknowledgments

The research is supported by Chinese Scholarship Council and partially supported by Ministry of Education Foundation on Humanities and Social Sciences (Grant No. 23YJC760168). The authors would like to express their gratitude to the Hungarian Meteorological Service for providing essential climate data that supported the simulation analyses in this study. Special thanks are extended to the Szombathely City Hall and the local planning authorities for granting access to the architectural and planning documents necessary for this research. The authors also acknowledge the support of the academic and professional communities whose insights, case studies, and literature reviews informed the theoretical framework of this study. Lastly, the authors would like to thank their colleagues and peers for their constructive feedback and encouragement during the research process.

References

1. KSH – Hungarian Central Statistical Office, épületállomány, lakásállomány Szombathely (KSH, Budapest, n.d.), https://www.ksh.hu.
2. KSH – Hungarian Central Statistical Office. (n.d.). épületállomány, lakásállomány Szombathely. Available from https://www.ksh.hu.
3. Szombathely Városrendezési Terv / Településrendezési Eszközök. (n.d.). Available from https://www.szombathely.hu.
4. Hegedűs, C. (2020). "Panel és lakótelep: összetartozó fogalmak?", Mérnökvagyok.hu. Available from https://mernokvagyok.hu/blog/2020/02/07/panel-es-lakotelep-osszetartozo-fogalmak/.
5. EX ANTE. (2021). "Debrecen panelházai madártávlatból", Available from http://exante.hu/fepo/69-kepzesi-szolgaltatasok-.html.
6. Hungarian Meteorological Service. (2022). "Climate of Hungary - general characteristics". Available from https://www.met.hu/en.
7. Lesjak, M., et al. (2020). Research on green façade impacts on building energy performance.
8. Jelle, B.P., Breivik, C., & Røkenes, H.D. "Building Integrated Photovoltaic Products: A State-of-the-Art Review and Future Research Opportunities." Solar Energy Materials and Solar Cells, vol. 100, May 2012, pp. 69–96.
9. Horváth, P., László B. (2019). Urban Renewal and Green Infrastructure in Debrecen: A Case Study. Civisporta, vol. 2019, no. 2, 2019, pp. 21–24.
10. CDO (n.d.). Project Management Service. Accessed: Mar. 30, 2025, [Online]. Available from https://code.mpimet.mpg.de/projects/cdo/files.
11. Rahaman Z.A. et al., "Assessing the impacts of vegetation cover loss on surface temperature, urban heat island and carbon emission in Penang city, Malaysia", Building and Environment. vol. 222, August 2022 https://doi.org/10.1016/j.buildenv.2022.109335
12. Lin M. et al., "Modeling green roofs' cooling effect in high-density urban areas based on law of diminishing marginal utility of the cooling efficiency: A case study of Xiamen Island, China", Journal of Cleaner Production. vol.316, September 2021 https://doi.org/10.1016/j.jclepro.2021.128277