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Active Green Constructions and Their Impact on Gray Infrastructure

Daniela Kaposztasova [1,*], Katarina Lavkova Cakyova [2], Marian Vertal [2], Zuzana Vranayova [2] and Eva Kridlova Burdova [3]

[1] Center of Research and Innovation in Construction, Faculty of Civil Engineering, Technical University of Košice, 042 00 Košice, Slovakia
[2] Institute of Architectural Engineering, Faculty of Civil Engineering, Technical University of Košice, 042 00 Košice, Slovakia; katarina.cakyova@tuke.sk (K.L.C.); marian.vertal@tuke.sk (M.V.); zuzana.vranayova@tuke.sk (Z.V.)
[3] Institute of Environmental Engineering, Faculty of Civil Engineering, Technical University of Košice, 042 00 Košice, Slovakia; eva.kridlova.burdova@tuke.sk
* Correspondence: daniela.kaposztasova@tuke.sk; Tel.: +421-55-602-4255

Abstract: Addressing climate change necessitates a conscious transition toward sustainable infrastructure solutions. Our vision involved transforming an experimental area into the University Experimental Center. This experimental building serves as a model for gray infrastructure implementation, taking into account its dimensions, layout, flooring, and material composition. Our study aims to compare the retention capacities of various types of vegetated roofs, as determined by different legislations. The findings indicate that the outcomes vary based on the regulations used. This variation subsequently influences the design of associated infrastructures, such as rainwater drainage systems, and the design of stressed structures. This is due to the impact of water quantity on the thermal response of a stressed structure. The water used to irrigate the vegetation layer, along with the water retained by the upper roof, has a positive impact on both the building and its surroundings. Initially, the system comprised two functional components: vegetated roofs and a reference roof. The integrated experimental roof shell, in conjunction with the frame, forms an autonomous system. This system serves as a segment for quantifying water retention, humidity, and temperature across diverse green infrastructure substrates. We analyzed the thermal response of experimental roof constructions and monitored the influence of water and precipitation. Our results indicate that the height of the substrate affects not only the retention capacity but also the thermal response of the vegetated roof.

Keywords: green infrastructures; water retention; energy; environment; sustainability

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1. Introduction

Green construction represents an ecological philosophy and methodology that promotes the development and utilization of built environments in a manner that is harmonious with the natural ecosystem [1]. In response to numerous challenges, the notion of green buildings has been progressively defined and introduced. This definition is dynamic, continually evolving based on the country of origin and advancements in the construction sector [2]. The green transition processes [3] have acknowledged the pivotal contribution that such buildings can make in achieving climate change impacts [4,5]. Environmental considerations, sustainability practices, life cycle evaluations, circular economic models, the use of sustainable materials, and waste recycling strategies constitute the fundamental 'green' elements [6].

Gray infrastructure refers to the conventional, engineered systems that provide essential services such as water supply, wastewater treatment, transportation, and energy [7]. The design, operation, and upkeep of gray infrastructure face substantial hurdles due to climate change, which modifies the occurrence and severity of extreme weather phenomena like floods, droughts, heatwaves, and storms. These events can damage or disrupt gray infrastructure, leading to service failures, increased costs, and reduced resilience. Therefore, it is important to judge the vulnerability and adaptability of gray infrastructure to changes in climate and to implement appropriate measures to enhance its performance and sustainability [8].

A multitude of studies [5–11] furnish pertinent and current data, policies, and technologies that aid in attaining peak carbon levels and carbon neutrality within the construction sector. The EU Climate Law mandates that all EU policies should aid in accomplishing the goals of the EU Green Deal. Additionally, the EU Green Deal encompasses measures to bolster the decarbonization initiatives in the industrial sector, including the sustainability of products and the provision of raw materials [9]. The adopted Circular Economy Action Plan shows opportunities for SMEs in conformance with sustainability standards [9,11].

Active green constructions are buildings that incorporate plants, trees, and other natural elements into their design [12]. Their goal is to lessen the ecological footprint of urban growth, better the quality of air, and boost the occupants' well-being. Active green constructions can also have positive effects on gray infrastructure, which refers to the conventional systems of roads, bridges, pipes, and cables that support urban functions. Some of the benefits of active green constructions on gray infrastructure are:

- reduction in the energy demand and buildings' greenhouse gas emissions by providing natural cooling, shading, and insulation.
- reduction in the stormwater runoff and flooding risks by absorbing and filtering rainwater, thus relieving the pressure on drainage systems.
- increase the lifespan and durability of gray infrastructure by protecting them from weathering, corrosion, and erosion.
- enhancement of the aesthetic and social value of urban spaces by creating attractive and diverse environments that foster community engagement and well-being [12,13].

Active green constructions are not without challenges, however. They require careful planning, design, maintenance, and monitoring to ensure their optimal performance and safety. They also need to be integrated with the existing gray infrastructure in a harmonious and efficient way. Moreover, they may face barriers such as high costs, lack of awareness, regulation gaps, and social resistance. Therefore, active green constructions need to be supported by appropriate policies, incentives, standards, and education to overcome these obstacles and realize their full potential [9–15].

Nature-based solutions (NBS) refer to initiatives that utilize natural processes and elements to tackle societal issues and enhance human well-being in an urban environment. Some examples of NBS include green roofs, urban forests, rain gardens, and community gardens. NBS can provide multiple benefits for urban dwellers, such as improving air quality, reducing heat stress, enhancing biodiversity, promoting mental health, and increasing social cohesion. NBS can also help mitigate and adapt to the impacts of climate change, such as flooding, drought, and extreme weather events. They are based on some basic principles, such as respecting the local context, engaging stakeholders, fostering innovation, and ensuring sustainability. By applying these principles, NBS can contribute to the transformation of urban areas into more resilient, livable, and inclusive places [16,17]. Green roofs, with their social, environmental, and economic benefits, have been adopted in many countries for both new and existing buildings (Figure 1). This concept promotes rooftop vegetation, benefiting both the building and its surroundings. Each element of a green roof, including vegetation, growth medium, filter and drainage layers, and root-resistant waterproofing, plays a crucial role.

By merging green roofs to active green building structures, buildings can attain superior energy efficiency, diminished carbon emissions, enhanced water management, and improved aesthetics.

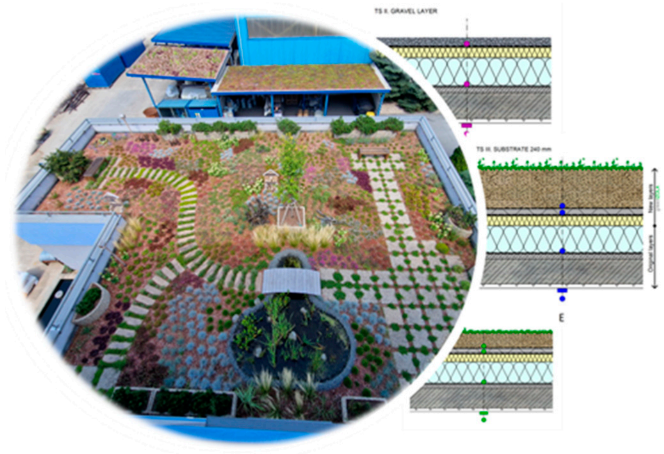

Figure 1. Green building examples of experimental roof (authors' library).

Numerous nations are modifying and overhauling their water management strategies to embrace more sustainable methods. This involves a focus on the implementation of water systems that promote sustainability and aim to alleviate water stress [15–18].

2. Green Roofs and Walls

Green roofs and walls are one of the basic elements of nature-based solutions in an urban environment. The terms green or vegetated roof and wall are relatively well-known, but it is necessary to say that the real application in the climatic conditions of Central Europe, especially Slovakia, is rather exceptional. It turned out that green constructions in built-up areas have many advantages and can contribute to air purification, reduce CO_2 concentration, and support greater biodiversity, and thus create ecosystems in cities and reduce the number of heat waves, but also have an affirmative effect on the building and its surroundings [13,19,20].

A green roof is a specialized roofing system that incorporates vegetation and soil, or an alternative growth medium, installed above a waterproof membrane. Green roofs offer numerous advantages for edifices, including the reduction in stormwater runoff, enhancement of thermal insulation, promotion of biodiversity, and mitigation of the urban heat island effect [13]. An active green building structure refers to a building that integrates renewable energy sources, such as photovoltaic panels, wind turbines, or geothermal systems, to generate electricity and heat for its consumption. The incorporation of a green roof and an active green building structure represents a synthesis of these two technologies that can augment the environmental performance and sustainability of buildings.

3. Materials and Methods

Our research is dedicated to modifying how water is accessed and utilized within structures and their immediate environments. We used research techniques and analytical processes that were grounded in a systemic–constructivist approach and guided by research principles. Legislation varies across countries, leading to different outcomes that can often be too general. The actual retention potential may differ if we use measurement results from specific system solutions for vegetated roofs. This is carried out to comprehend the mutual interactions and intricate interconnections of green infrastructures. Eight phases of building transformation were proposed.

In this article we aimed at our main goal: the transition from the so-called 'gray spaces' to 'green spaces' through the implementation of structures layered with vegetation and to explore the effect of water on the thermal response of the vegetated roof in the studied area.

3.1. Study Location

The experimental area is situated in the industrial zone of Nad Jazerom, a suburb of Kosice. It comprises several components, including service asphalt roads, warehouses, and a four-story administrative building with four terraces that serves as the focal point (Figure 2).

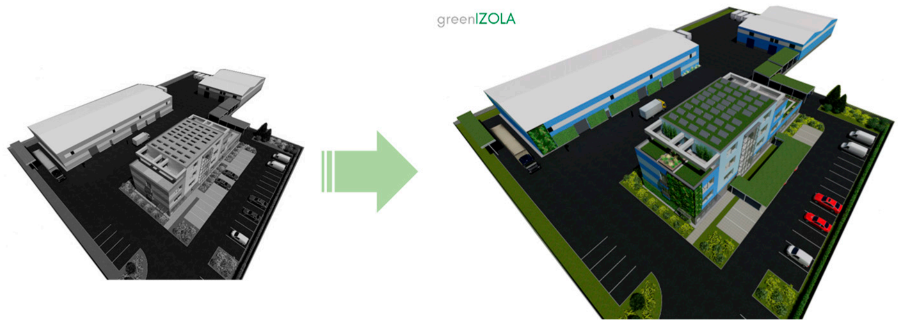

Figure 2. Visualization of proposed transformation.

3.2. Climate Conditions

Kosice experiences four unique seasons, characterized by lengthy, balmy summers with chilly evenings and extended, frosty, snow-filled winters. The amount of rainfall is fairly consistent year-round, with a higher volume in the summer and minimal precipitation in the winter. January is the chilliest month, averaging a temperature of −2.6 °C, while July is the warmest month, with an average temperature of 19.3 °C. According to the Köppen–Geiger Climate Classification, the city of Kosice belongs to the climate zone Dfb, which represents a snow continental climate, which is described as cold (continental) without a dry season with warm summer. However, with climate change, it can be assumed that the climate will gradually transform and approach the climate zone Cfb (temperate oceanic) [21,22].

A meteorological station was installed within the area, which records selected climate parameters such as air temperature and humidity, solar radiation, and the amount of precipitation.

3.3. Zone Transformation from Gray to Green

In our investigation we have outlined an eight-phase plan (as shown in Figure 3) [19]. The first phase involved designing an experimental roof with biodiversity potential.

Figure 3. The roof constructions in the area of interest are divided into phases: phases that have been completed are indicated by a solid line, while phases that are still in the planning stage are represented by a dashed line.

The second phase was the shelter construction with three distinct green roof compositions. In the third phase, we planned to install a green roof on a carport. The fourth phase involved extending the west terrace on the second floor. For the fifth phase, we aim to install a green roof on the north terraces of the fourth floor. The sixth phase will see the creation of a green wall on the east and south sides of the building. In the seventh phase, we plan to install a biosolar roof. Finally, in the eighth phase, we aim to install an intensive green roof on the second north terraces, effectively creating a park on the terrace.

It is assumed that the implementation of the biosolar roof (phase 7) will be the most difficult, mainly because photovoltaic panels are already installed on the roof. In the case of the implementation of a biosolar roof, these panels will have to be dismantled and re-installed on a new anchor system after the construction of the green roof.

During the design, various types of vegetation structures were carefully considered and selected. This ensured a greater diversity of used elements and increased the possibilities of quantifying the impact of the transformation on the building and the surroundings. The proposed constructions differ in the height of the used substrate and the type of substrate, but also vary in the vegetation used.

4. Results and Discussion

4.1. Analysis of the Retention Potential of the Building

The analysis of the retention potential of the building was measured during the year 2021 (Figure 4). Although the Slovak Hydrometeorological Institute notes that the long-term cumulative total of precipitation on the territory of eastern Slovakia is 621 mm/year [23], according to the data measured in the monitored zone, the cumulative total of precipitation for the year 2021 was 764 mm/year (123%).

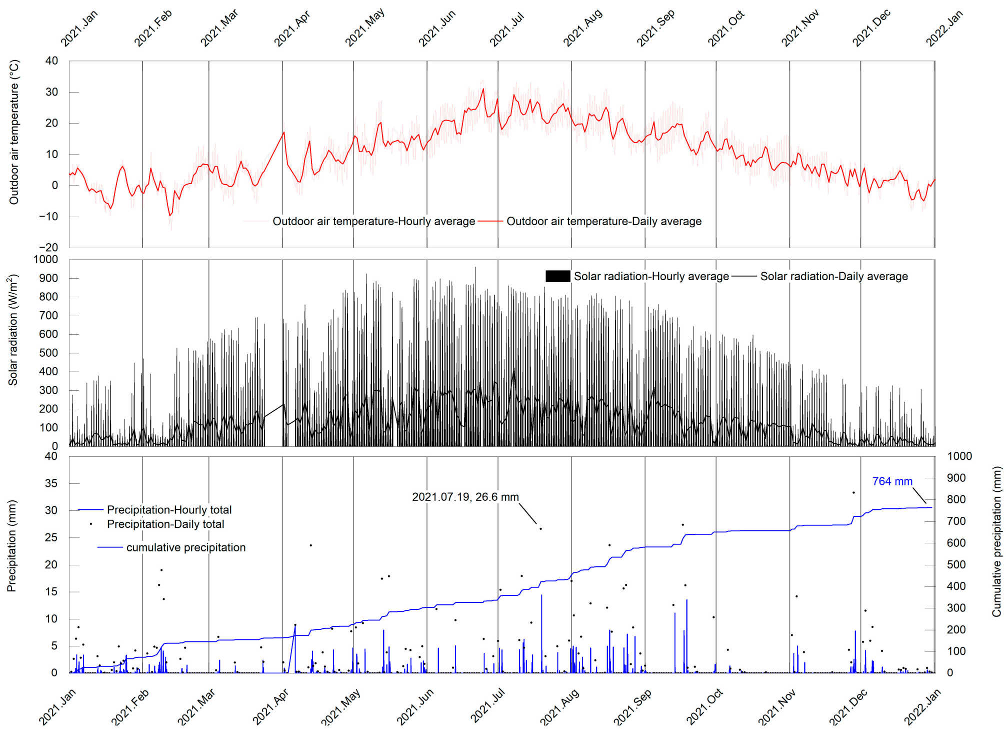

Figure 4. Climate parameters outdoors were recorded from January 2021 to December 2021. These include the outdoor air temperature, represented as average values calculated hourly and daily, the global solar radiation, also depicted as average values determined on an hourly and daily basis, and the precipitation, expressed as the sum of hourly and daily measurements.

Thus, the total precipitation for the year 2021 was greater than the long-term average. In the second half of July 2021, the largest daily increase in precipitation during the summer was recorded, specifically 26.6 mm per day. This period was also characterized by repeated high average temperatures (average air temperature 24 °C): the so-called heat wave. Such flash floods in combination with heat waves can lead to an increased risk of flooding. These results copy the global manifestations of climate change, and it is possible to assume their increased frequency in the coming decades.

4.2. Evaluation of the Building Retention Potential

We proposed three scenarios. The first scenario represents the original state of the building, which is without vegetation. The second scenario considers the currently completed phases of transformation (phases 1 and 4). In the third scenario, the retention potential is evaluated after the complete change and application of all planned green roofs. Since the shelters created during phases 3 and 2 are not part of the administrative building, none of the scenarios with these vegetated roofs are considered.

The standard calculation for annual rainwater is denoted as Q_r and is measured in cubic meters per year (m^3/year):

$$Q_r = AH_zC, \quad (1)$$

where A (m^2) is the drainage area, H_z (mm) is the long-term rainfall total for the given location (764 mm/year), and C (-) is the runoff coefficient.

The impact of implementing green roofs on a building can be estimated, particularly in terms of rainwater accumulation. For comparative purposes, the runoff coefficient for green roofs was evaluated in accordance with several standards: the German standard (DIN 1986-100:2016-12 2016) [23], the Austrian standard (ÖNORM B 2501 2016) [24], the Slovak standard (STN 73 6760 2009) [25], and the FLL directive (FLL 2008) [26–30]. Tables 1 and 2 present the runoff coefficients as per these various standards (DIN 1986-100:2016-12 2016; ÖNORM B 2501 2016; STN 73 6760 2009; FLL 2008), contingent on the thickness of the substrate. The total area of the building, including the roof and terraces, is 560.79 m^2. In its original state, the rainwater flow is 385.6 m^3/year, with a runoff coefficient of 0.9.

Table 1. The annual rainwater flow for the existing condition is determined in accordance with the German, Austrian, and Slovak standards, as well as the FLL directive. The runoff coefficient 'C' for green roofs is utilized, which varies based on the substrate's thickness.

	Green Area	Substrate Thickness	Runoff Coefficient			
	(m^2)	**(mm)**	**DIN 1986-100**	**ÖNORM B 2501**	**STN 75 6760**	**FLL**
Phase 1	17.6	120	0.4	0.3	0.4	0.4
	17.6	240	0.4	0.3	0.3	0.2
Phase 4	34.46	100	0.5	0.5	0.7	0.5
Non-green area	491.13	-	0.9			
Total runoff water per year (m^3/year)			361.62	358.93	365.54	358.93

Vegetation areas currently make up a total of 12.4% of the building's total area. The results in Table 1 present the overall improvement of the drainage conditions of the building; this area is relatively small and negligible. The reduction in runoff rainwater is from 5.2% (STN 75 6760) to 6.92% (ÖNORM B 2501 and FLL) compared to the original state.

Upon completion of all stages, the green space would constitute 82% of the total roof structure area of the building. The establishment of vegetation on the building offers numerous benefits, including the accumulation of rainwater and a decrease in peak water flow.

The annual runoff water volume, as per the Slovak standards (STN 73 6760 2009) and contingent on the substrate height, is 206.45 m^3/year. When calculated according to the Austrian standard (ÖNORM B 2501 2016), the runoff water volume is 159.97 m^3/year. There is a 22.5% difference in the calculated water volume based on the runoff coefficient.

Table 2. The annual rainwater flow, following the full transformation, is calculated as per the German, Austrian, and Slovak standards, along with the FLL directive. The runoff coefficient 'C' for green roofs is utilized, which varies based on the thickness of the substrate.

	Green Area	Substrate Thickness	Runoff Coefficient			
	(m^2)	**(mm)**	**DIN 1986-100**	**ÖNORM B 2501**	**STN 75 6760**	**FLL**
Phase 1	17.6	120	0.4	0.3	0.4	0.4
	17.6	240	0.4	0.3	0.3	0.2
Phase 4	34.46	100	0.5	0.5	0.7	0.5
Phase 5	45.35	200	0.4	0.3	0.4	0.3
Phase 7	213.02	120	0.4	0.3	0.4	0.4
Phase 8	131.75	300	0.2	0.1	0.3	0.2
Non-green area	101.01	-	0.9			
Total runoff water per year (m^3/year)			192.46	159.97	206.45	186.31

The drainage conditions within the building were significantly improved by completely transforming the impermeable surfaces of the roof and terraces into structures with a vegetation layer. If runoff coefficients according to the Slovak standard (the least favorable) are used, the total amount of runoff water per year will be 206.45, which is a reduction in runoff by 46.5% compared to the original state. In the case of a theoretical calculation using data from the Austrian standard (the most favorable conditions), the runoff of rainwater into the building area will be reduced by 58.5% compared to the original state. Therefore, it can be concluded that there is a 12% difference between the most unfavorable and most favorable conditions, according to the calculation.

The runoff water value may vary based on the types of materials used, as opposed to calculations derived from standard guidelines. A laboratory-measured runoff coefficient, specific to the green roof assembly, can be utilized. Bauder, the manufacturer of the green roof structures in use, provided measured runoff coefficients for the green roof assembly composition with a retention element RE40 (proposed in phase 1). The testing was conducted in accordance with the FLL standards (FLL 2008). The measurements indicated runoff coefficients of 0.11 and 0.1 for substrate thicknesses of 100 mm and 120 mm, respectively. Incorporating these runoff coefficients into calculation (1) would reduce the proposed runoff to 104.84 m^3/year. In the calculation, a runoff coefficient of 0.11 is considered for a substrate height of 100 mm (phase 4) and 0.1 for a substrate height of 120 mm or more (phases 1, 5, 7, and 8). Conversely, the calculation of runoff water by the FLL directive, without the use of laboratory-measured data, is 186.31 m^3/year. This signifies a 44% difference compared to the calculation using laboratory-measured data.

4.3. The Effect of Water on the Thermal Response of the Vegetated Roof

Selected physical parameters inside the roof covering of the vegetation and reference roof are monitored for a long time. This made it possible to analyze the thermal response of experimental roof constructions and monitor the influence of water and precipitation, respectively. The findings indicate that the substrate's height influences not only the retention capacity but also the thermal response of the vegetative roof. For the purpose of in situ experiments, the test roof was segmented into three parts, identical up to the level of roof waterproofing (as shown in Figure 5). Above the waterproofing layer, the experimental roof is divided into:

- Experimental segment S1: An extensive vegetative roof with a substrate height of 120 mm
- Experimental segment S2: A reference section with gravel
- Experimental segment S3: An extensive vegetative roof with a substrate height of 240 mm

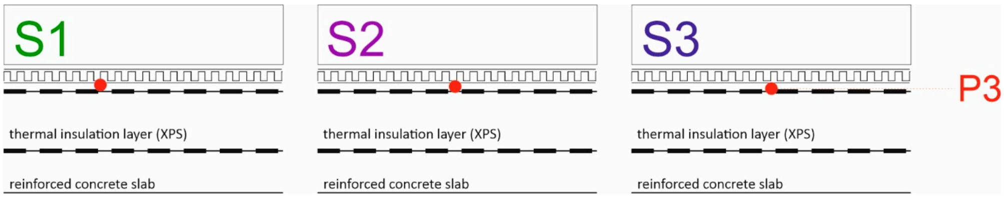

Figure 5. Location of surface temperature sensors (red) for two experimental vegetation segments, S1 and S3, and a reference gravel segment, S2.

Pt100 sensors with accuracy class A and protective class IP69 are used to measure the surface temperature in different layers of the experimental segments. The sensors were placed at the interface of the waterproofing layer and the gravel layer, at reference segment S2, respectively. The sensors were placed at the interface of the vegetation layer at segments S1 and S3, according to Figure 5.

Two time periods lasting six days (144 h) in the summer of 2021 were analyzed. From the perspective of meteorological parameters, including the temperature of outdoor air, relative air humidity, air flow speed, and solar radiation intensity, both periods were similar. However, there was a significant difference in the amount of atmospheric precipitation. The first analyzed time period, which lasted from 16 June 2021 to 23 June 2021, represented typical summer dry weather without atmospheric precipitation, with an average outdoor air temperature of 24.6 °C and a temperature range of 16.9 °C to 31.5 °C (Figure 6A,B).

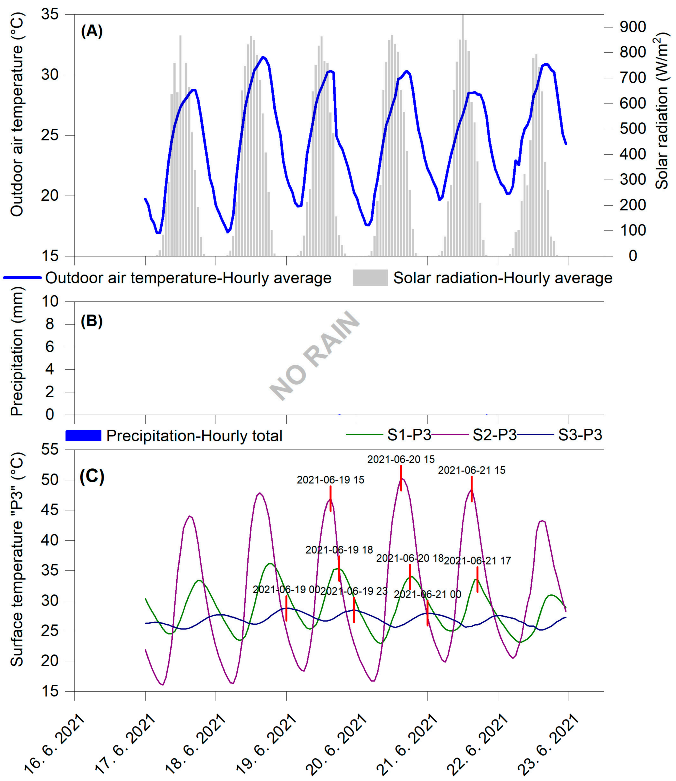

Figure 6. The analysis involves the examination of recorded temperatures at location P3 for experimental vegetative roofs with substrate heights of 120 mm and 240 mm, as well as a reference gravel roof (**C**). This analysis is conducted in relation to marginal conditions (climatic parameters) during the dry summer period from 16 June 2021 to 23 June 2021 (**A**,**B**).

The second period, which lasted from 6 July 2021 to 15 July 2021, was characterized by rainy weather with an average daily temperature of outdoor air of 24.7 °C and a range of temperature of 17.8 °C to 33.2 °C (Figure 7A). This period represented typical summer weather, with rapid downpours lasting up to three hours and a total atmospheric precipitation of 28 mm throughout the entire period. The temporal distribution of precipitation during the rainy season is shown in Figure 7B. The most atmospheric precipitation of 14 mm in 3 h fell on July 12 between 22:00 and 00:00.

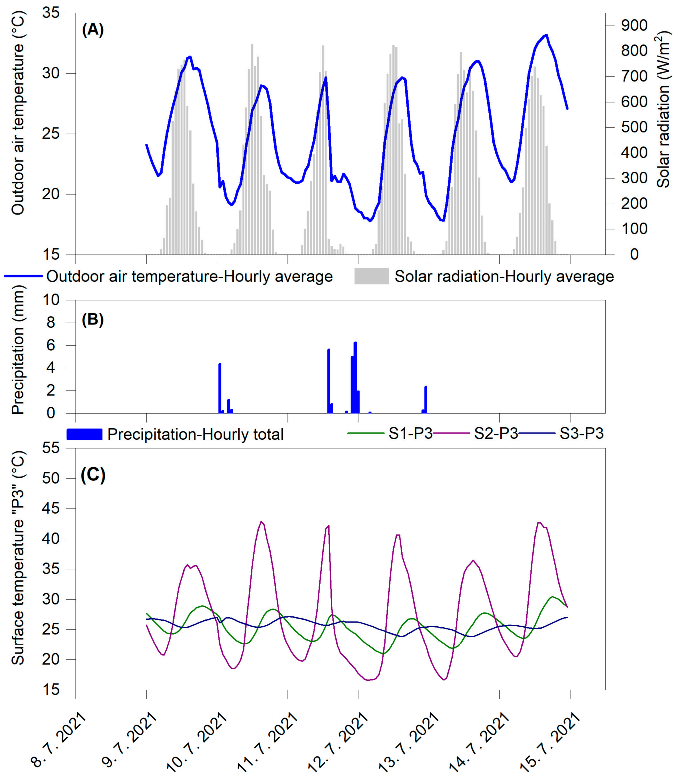

Figure 7. Analysis of measured temperatures at position P3 for experimental vegetation roofs with a substrate height of 120 and 240 mm and a reference gravel roof (**C**) in the context of boundary conditions (**A**), (**B**) (climatic parameters) for the rainy period (the summer period, 6 July 2021 to 15 July 2021).

The temperature curves depicted in Figures 6C and 7C illustrate the impact of vegetated roofs on the temperature distribution within the roof sheath. Figure 6C presents the temperature fluctuations beneath the substrates of the experimental vegetated roofs, juxtaposed with the temperature oscillations under the gravel layer in the reference roof segment during the dry period.

From the standpoint of mitigating overheating in roof structures during summer, the application of vegetated roofs can lead to a substantial decrease in temperatures across all layers of the roof shell. During the dry period, the highest recorded temperature under the gravel layer of the reference roof was 50.3 °C. In contrast, the maximum temperatures under the substrates of the experimental vegetated roofs were significantly lower, reaching 36.1 °C for a substrate thickness of 120 mm and 28.8 °C for a substrate height of 240 mm. Compared to the reference gravel segment, this corresponds to a reduction in surface temperatures by 70% and 57%, respectively.

During the rainy period, the maximum surface temperatures recorded at location P3 were found to be lower than those during the dry period (as shown in Figure 7C). The surface temperature beneath the gravel layer of the reference roof reached 42.9 °C. In contrast, the surface temperatures under the experimental vegetative roofs were significantly lower, with readings of 30.4 °C for a substrate height of 120 mm and 27.3 °C for a substrate height of 240 mm. Compared to the reference gravel segment, these temperatures represent a reduction of 70% and 63%, respectively. Additional temperature characteristics measured at location P3 are detailed in Table 3.

Table 3. Temperature characteristics measured at position P3 for vegetation roof segments (S1 and S3) and a reference gravel roof segment (S2) during the selected period.

	Dry Period: 16 June 2021 to 23 June 2021				Rainy Period: 6 July 2021 to 15 July 2021			
Sensor Position	$T_{e,min}$ (°C)	$T_{e,max}$ (°C)	$T_{e,average}$ (°C)	ΔTs (°C)	$T_{s,min}$ (°C)	$T_{s,max}$ (°C)	$T_{s,av.}$ (°C)	ΔT_s (°C)
S1–P3	22.9	36.1	28.5	13.2	21	30.4	25.5	9.4
S2–P3	16.1	50.3	30.7	34.2	16.6	42.9	27.3	26.3
S3–P3	25.2	28.8	26.9	3.6	23.8	27.3	25.8	3.5

The vegetation layer affects the rate of heat absorption, which is reflected in the displacement of the amplitude of the temperature maximum (Figure 7C). During the two selected time periods, a significant displacement of the amplitude was measured in both experimental vegetation segments compared to the reference gravel segment. In the experimental segment S1 with a substrate height of 120 mm, the shift in the temperature maximum compared to the reference gravel segment was approximately 3 h. In the experimental segment S3 with a substrate height of 240 mm, the shift in the temperature maximum compared to the reference gravel segment was up to 9 h.

The data presented in Figure 8 allow for an analysis of how the presence of water in the substrate impacts the process of reducing peak temperatures in vegetated roofs during hot summer days.

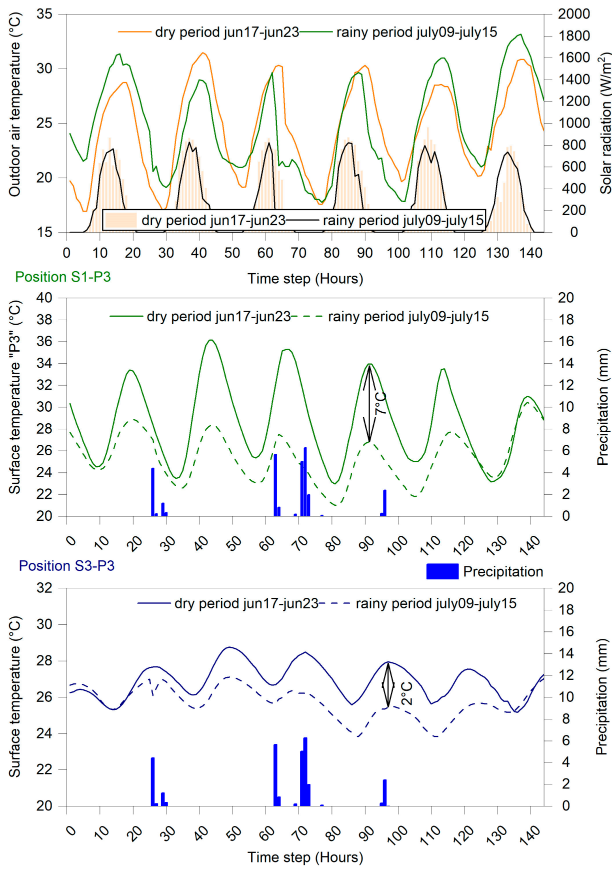

Figure 8. Comparison of temperature courses at position P3 for dry and rainy periods in the context of outdoor air temperature parameters and solar radiation intensity.

By comparing the surface temperatures at position P3 for both observed periods, it is possible to observe significantly lower surface temperatures for the rainy compared to the dry period. The data collected indicate that when water is present in the substrate, it can lower the temperature beneath the substrate by roughly 7 °C, specifically for substrates with a thickness less than 120 mm (as shown in Figure 8). With a substrate with a height of 240 mm, this reduction is less pronounced and is around 2 °C (Figure 8). The cooling of the experimental roofs due to atmospheric precipitation, in addition to the vegetation segments, was also manifested in the cooling of the reference segment with a gravel layer. The following hot days, with a high intensity of solar radiation, gradually dried the substrate layers in both experimental roofs. On the third day after the rain event, the influence of water in the roof substrate on surface temperatures at position P3 in both experimental vegetation segments was negligible.

5. Limitations and Future Steps

We presented our results in relation to the capacity of the water retention and the precipitation amount of the vegetated roof. The conversion of the roof and terraces' impervious surfaces into vegetative structures significantly enhanced the building's drainage conditions. The results stated that the temperature changes under different types of roofs during dry and rainy periods. It shows that vegetated roofs with thicker substrates can reduce the surface temperature and the overheating risk of roof structures more effectively than gravel roofs or vegetated roofs with thinner substrates. The impact of water is primarily in irrigating the vegetation layer of the roof. In addition, the water gathered by the upper roof assembly exerts a beneficial impact on both the building and its immediate environment. For both research purposes and technical requirements, it is necessary to study the interaction of the building structure with the vegetation layer in real climatic conditions. The limitation is in the runoff coefficient being defined only by the height of the substrate: it can be a very inaccurate indicator, and the real amount of runoff water can significantly differ from the calculated amount based on standards. The ability to accumulate atmospheric precipitation is one of the main characteristics of green roofs. Therefore, it is an important aspect to consider when choosing a suitable type of roof, concerning the conditions of the building as well as its surroundings.

In the future, we aim to investigate the transformative idea that involves setting up various vegetative local structures in Kosice. In the Czech Republic [30], there is a certain number of vegetated roofs, which is a small number, but in Slovakia, this number is smaller, but we do not know it exactly: such statistics are still missing. Our objective is to raise the significance of green roofs and their implications. We foresee that the efficacious establishment of these infrastructures will pioneer exemplary practices in Slovakia and Central Europe. Our research will delve into the multifaceted role of water in urban settings, aiming to harness its potential effectively and strategically. This goal will be realized by integrating aesthetically pleasing, functional, and cutting-edge architectural features such as vertical gardens, climate systems for roofs that retain water, rain gardens, and tanks for recycling rainwater. Our primary objective is to address the unique issues faced by urban areas and their residents, which arise from severe weather variations and uneven heating in urban clusters, increasing the generation of organic waste, and its underutilized potential.

For this reason, an in situ experiment was designed to quantify water retention. The experimental measurement will be based on monitoring different roof assemblies exposed to the same conditions of real climate in experimental roof assemblies built into prepared stainless steel test frames (Figure 9).

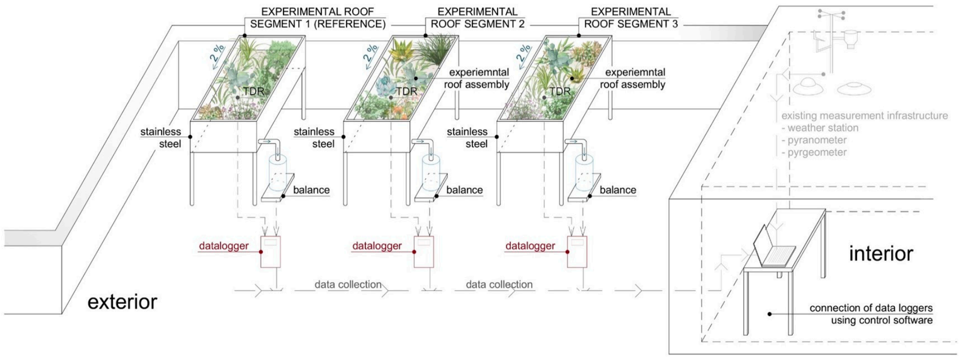

Figure 9. System diagram of connection for the automatic experimental in situ measurement of water retention in green roofs.

6. Conclusions

Rising apprehensions regarding water security, ecology, and quality are exerting a strain on conventional gray engineering infrastructure. Although green infrastructure can mitigate some of this strain, the traditional gray infrastructure remains crucial for ensuring safety during severe storms. To prevent undue artificial disruption of the ecological environment, it is vital to judiciously manage the extent of gray infrastructure in the construction of sponge cities. An effective urban water system management should incorporate a balanced integration of both green and gray infrastructure. Preparing the labor force for future market expectations and needs in green buildings requires workforce forecasting, which involves predicting future labor needs and identifying skill-gap problems. Our study shows the potential of transforming gray infrastructure to green with added values following climate change challenges. It is crucial to inform the public about the potential of blue–green infrastructures and elucidate the advantages of incorporating a hybrid approach in urban locales. We need to remember that the success of active green constructions lies in their harmonious coexistence with existing gray infrastructure. Merging green and gray infrastructure necessitates the adoption of creative strategies and meticulous planning. While the initial setup and upkeep might be expensive, it offers benefits that are sustainable in the long run.

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