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Basic aspects of caring for green façades in the city of Košice

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Introduction: Green façades are increasingly promoted as nature-based solutions for mitigating urban overheating, enhancing microclimate, and supporting biodiversity. However, their role in sustainable water management is still underexplored, especially in continental Central European climates with high variability in irrigation demand.

Methods: This pilot study assessed the establishment and first-year performance of a modular green façade installed at the Technical University of Košice, Slovakia. Six ornamental species ($N = 180$) were cultivated under a gravity-driven irrigation system. Irrigation events were manually recorded from November 2024 to August 2025, and plant survival and vitality were evaluated monthly in relation to meteorological data.

Results: Irrigation demand strongly correlated with air temperature, showing minimal water use during winter dormancy, gradual increase in spring, and a peak in June. The unusually cool July reduced irrigation frequency despite full vegetation coverage. Overall plant survival reached about 90%, with *Carex morrowii* and *Hedera helix* performing best, while *Heuchera* exhibited higher vulnerability to heat stress.

Discussion: The results highlight that Central European green façades require adaptive irrigation management but can effectively contribute to sustainable urban water strategies when resilient species are selected. These findings provide locally grounded evidence supporting the European Green Deal and the UN Sustainable Development Goals.

KEYWORDS

green façade, irrigation management, water-use efficiency, plant survival, continental climate, urban sustainability

1 Introduction

Urban areas are increasingly challenged by overheating and irregular rainfall patterns, both intensified by climate change and rapid urbanization (Kabisch et al., 2017; Coma et al., 2014). The urban heat island (UHI) effect has been widely documented for its negative impacts on public health, building energy demand, and overall urban sustainability (Coma et al., 2014; Wei and Wang, 2022). Cities across Europe are therefore seeking cost-effective, nature-based solutions to improve resilience and meet international climate commitments (European Commission, 2020; Kabisch et al., 2017).

Among such solutions, green roofs and façades have emerged as effective measures to mitigate UHI while enhancing stormwater retention and biodiversity (Wang et al., 2022; Cui et al., 2022; Che and Zhuang, 2024; Rivière et al., 2023). Vertical greenery is particularly suitable in dense urban areas, where horizontal green space is limited. Previous studies have shown that green façades can reduce building energy use (Susca et al., 2022), provide biodiversity benefits when carefully designed (Salisbury et al., 2023), improve pedestrian comfort and wellbeing (Alkadri et al., 2025; Ikei et al., 2025),

and support air quality improvements (Lindén et al., 2023). However, these advantages are conditional on baseline for evaluating species selection in similar climates proper plant selection, irrigation scheduling, and regular maintenance, which remain decisive for long-term performance (Perini and Rosasco, 2016; Fang et al., 2023).

Water use is a central aspect of façade performance. Unlike conventional landscaping, façade systems require frequent irrigation due to limited soil volume and higher exposure to wind and solar radiation. Several studies highlight that irrigation demand is strongly linked to short-term climatic variability, particularly air temperature, while rainfall contributes only marginally (Pérez-Urrestarazu et al., 2016; Bustami et al., 2018; Pięta-Kanurska, 2024). Efficient irrigation scheduling and the integration of alternative water sources, such as harvested rainwater or greywater reuse, are therefore key to ensuring that green façades contribute to sustainable water management in urban areas. This perspective directly connects façade research with broader sustainability agendas, urban resilience, and water strategies (European Commission, 2020).

While the potential of green façades has been extensively documented in Western Europe and Asia, empirical data from Central and Eastern Europe are still scarce. The region's continental climate—with hot summers, cold winters, and irregular precipitation—creates specific challenges for irrigation management and plant survival. In Slovakia, published work has so far concentrated on conceptual designs or laboratory prototypes but no peer-reviewed study has yet evaluated the operational performance of a pilot green façade under real-world outdoor conditions. This lack of context-specific evidence limits the ability of municipalities and designers to apply vertical greenery confidently in local projects.

This paper addresses this knowledge gap by presenting the first season of monitoring a pilot green façade at the Technical University of Košice (TUKE). Moreover, the pilot green façade at TUKE forms part of a broader institutional strategy to transform the campus into a 'green campus'. This includes the implementation of green zones, retention ponds, and rainwater-harvesting systems designed to retain roof runoff, enhance stormwater management, recharge aquifers, and contribute to local cooling and biodiversity (Zeleňáková et al., 2018).

Such integrated strategies align with the emerging paradigm of resilient, water-conscious campus design and offer a meaningful context for the façade's practical relevance and future scalability. The study focuses on three objectives: (i) to analyse irrigation demand in relation to local climate, (ii) to assess plant survival and vitality during the first year of operation, and (iii) to identify species most resilient to continental conditions. Rather than providing universal guidelines, the study offers locally grounded evidence that can inform applications of vertical greenery in similar climates. By documenting practical challenges and opportunities, the findings contribute to the broader knowledge base supporting the European Green Deal (European Commission, 2020) and the UN Sustainable Development Goals (SDG 11: Sustainable Cities and Communities; SDG 13: Climate Action; SDG 15: Life on Land).

2 Materials and methods

To evaluate the establishment and early performance of the pilot green façade, a structured methodology was applied. The approach covered site characterization, system design, plant material, irrigation setup, and monitoring procedures. Similar methodological frameworks are recommended in façade greening research to ensure reproducibility and comparability across studies (Manso and Castro-Gomes, 2015; Bustami et al., 2018). In addition, specific attention was given to irrigation monitoring and water-use estimation, which are increasingly emphasized as critical components in sustainable façade performance assessment (Perini and Rosasco, 2016; Pérez-Urrestarazu et al., 2016; Cuadrado-Alarcón et al., 2024).

2.1 Study site

The pilot façade was established at the Faculty of Civil Engineering, Technical University of Košice, Slovakia (48.72°N, 21.26°E), located in the continental climatic zone of Central Europe (Figure 1).

The northeast orientation exposed the façade to direct sunlight in the morning, with shading from midday onwards. Local climate is characterized by cold winters, hot summers, and irregular precipitation. Daily temperature and precipitation data for the monitoring period (November 2024 – August 2025) were obtained from the Slovak Hydrometeorological Institute (SHMÚ, Košice station), providing the climatic context shown in Figure 2.

2.2 Façade system and plant species

The façade structure consisted of an aluminum subframe with modular containers (30 × 20 × 20 cm). This system was selected for its flexibility and suitability for local climatic conditions. In October 2024, 180 plants (six species, 30 individuals each) were established (Figure 3). Plant selection was based on resilience, shade tolerance, and ornamental value, following previous recommendations for vertical greenery (Perini and Rosasco, 2016; Salisbury et al., 2023).

Although part of the reference literature originates from temperate maritime regions, the final species selection was adjusted to the Central European continental climate of Košice. The choice reflected local nursery availability and previous applications of the same taxa in Eastern Slovakia. Each species was pre-selected for frost tolerance and assessed under site-specific conditions to ensure suitability for the regional climate.

The species included:

1. *Imperata cylindrica* (L.) P. Beauv.: ornamental grass with narrow leaves and characteristic red tips. Although tolerant of sun, the species proved sensitive to frost during its first year and developed slowly in spring. Winter-damaged leaves were removed in early spring to stimulate regrowth.
2. *Hedera helix* L.: evergreen climber with vigorous growth, ensuring rapid façade coverage. While highly resilient, this species requires regular pruning to avoid damage to structures,



FIGURE 1
Location of the pilot green façade in Košice, eastern Slovakia, within the Central European continental climate zone.

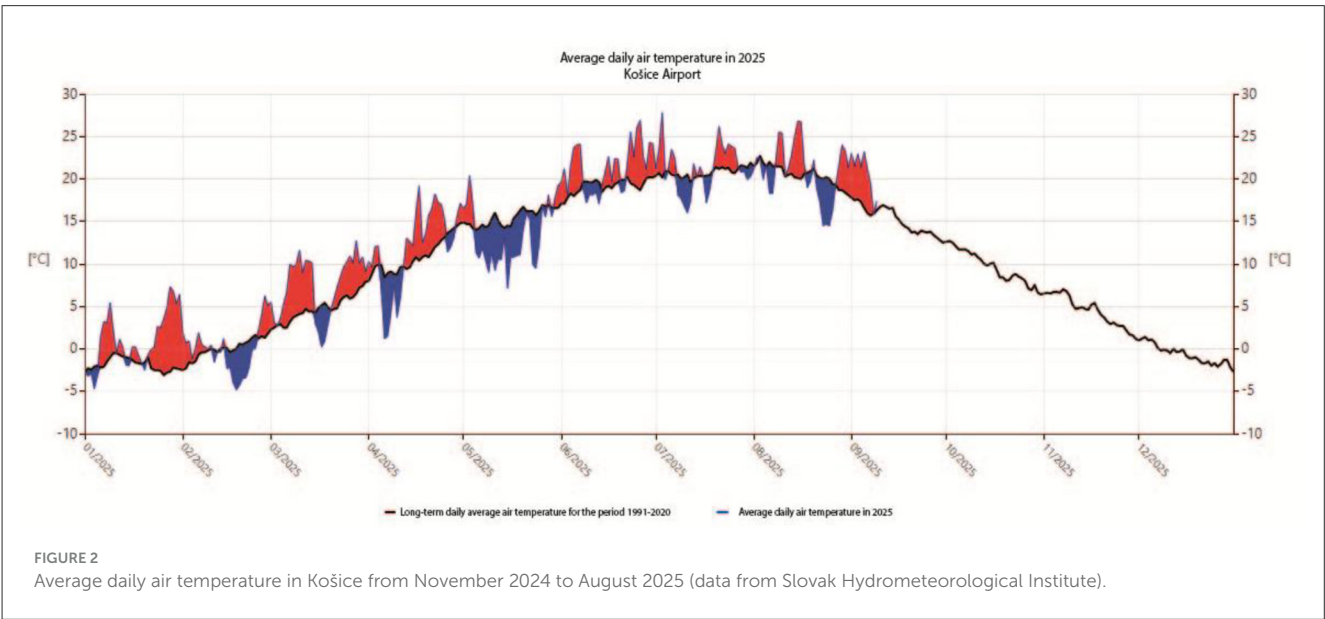


FIGURE 2
Average daily air temperature in Košice from November 2024 to August 2025 (data from Slovak Hydrometeorological Institute).

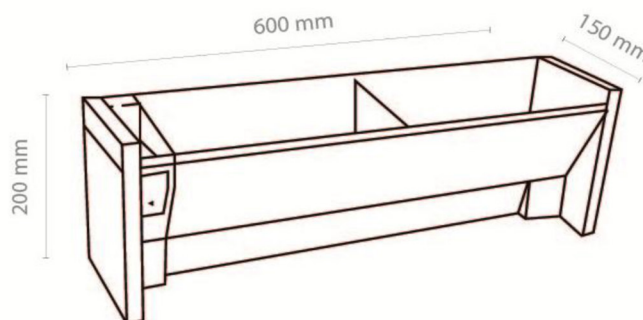


FIGURE 3

Implementation of a green facade on the building of the Faculty of Civil Engineering, Technical University of Košice.

as previously noted in long-term green wall studies (Manso and Castro-Gomes, 2015).

3. *Heuchera spp.*: decorative perennial with foliage sensitive to direct summer sun. Signs of wilting were observed on hot days, requiring frequent watering and removal of necrotic leaves. With adequate care, the species contributed effectively to façade greening.
4. *Carex morrowii* Boott: shade-tolerant ornamental grass forming dense clumps. This species thrived consistently on the façade and showed the highest survival rate, confirming findings from similar façade applications in Central Europe (Perini and Rosasco, 2016).
5. *Hemerocallis spp.*: perennial from the lily family producing striking summer flowers. While undemanding, optimal growth was achieved when combined with shading species to prevent soil overheating. Leaves remained on the plant during winter and were cut back in spring.
6. *Hosta sieboldiana* (Hook.) Engl. 'Frances Williams'/*Hebe spp.*: *Hosta* seedlings arrived in poor condition and were replaced by *Hebe* within the first month. *Hebe spp.* is a hardy evergreen shrub tolerant of sun and suitable for façade placement in lower modules exposed to higher irrigation.

Overall, this species mix provided a diverse representation of functional groups (grasses, perennials, climbers, evergreens), enabling evaluation of resilience and aesthetic contribution under local climatic conditions (Figure 4). The spatial layout was guided by the ecological requirements of the selected species. Shade-tolerant species (*Carex morrowii* Boott, *Hedera helix* L.) were placed in upper, semi-shaded modules, while sun-demanding species (*Heuchera spp.*, *Hemerocallis spp.*) were positioned in lower rows receiving higher irrigation volumes. This arrangement allowed for balanced light and moisture conditions across the façade.

The substrate used in all modules consisted of a peat–perlite–compost mixture (60:30:10) with a pH of ~6.5. The substrate had moderate organic matter content and ensured sufficient drainage. No fertilization was applied during the first year to avoid influencing the natural adaptation process of the plants.

2.3 Irrigation system

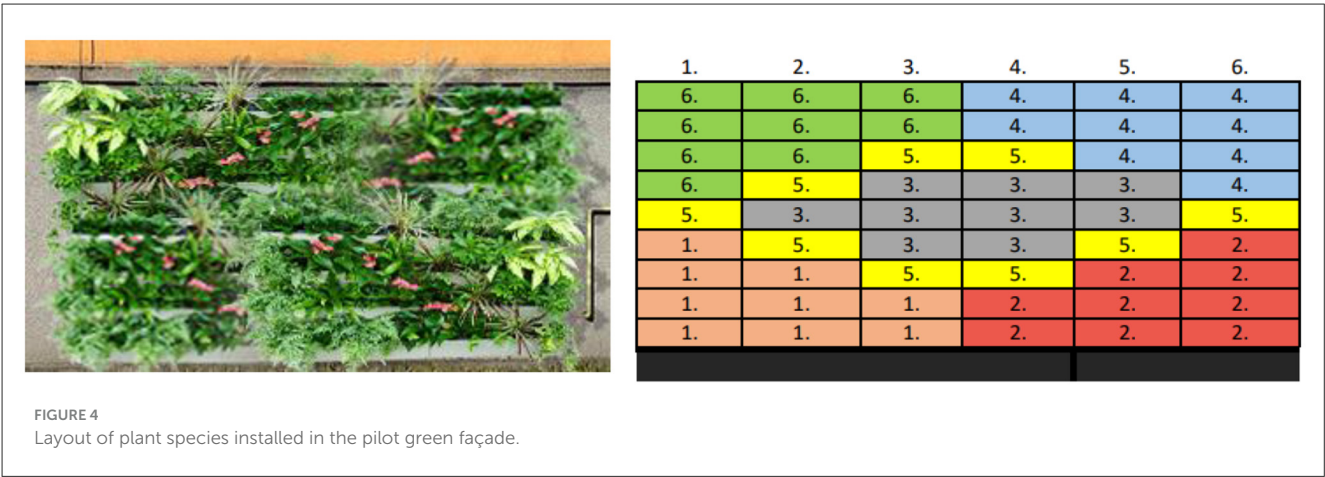
To ensure survival and growth during establishment, a gravity-driven irrigation system was installed at the top of the façade. Water was distributed through polyethylene pipes, allowing infiltration into lower modules. Operation was manual or supported by a timer-based control unit. Irrigation events were conducted in the early morning hours (06:00–08:00 a.m.) to minimize evaporative losses and to match the plants' natural transpiration cycle. Although functional, water runoff was observed before complete infiltration, resulting in uncertainties in the water balance, which is common in pilot-scale systems without integrated recirculation (Bustami et al., 2018).

Irrigation events were logged by date and duration. Supplied water volume was estimated using the basic relationship

$$V = Q \times t \quad (1)$$

where V is the supplied water volume [l], Q is the flow rate [l/min], and t is the irrigation duration [min]. Flow rate was approximated at 8–10 l/min under gravity pressure, based on pipe diameter and observed conditions. Accordingly, each irrigation event supplied ~40–80 l, and over the 34 events recorded during the monitoring period, the total seasonal input was ~1.5–2.0 m³. These values should be considered indicative, since no flow meters were installed and part of the water was lost due to runoff. Future optimization should therefore include storage reservoirs, recirculation pumps, or flow meters to improve water-use efficiency (Pérez-Urrestarazu et al., 2016; Chen et al., 2016; Orel et al., 2024).

Tap water from the municipal supply of Košice was used throughout the monitoring period. Water quality was not directly tested but corresponds to local irrigation standards (pH 7.2–7.5). Future research will include comparative testing of rainwater and greywater sources with detailed chemical and biological analyses.



2.4 Monitoring and data collection

Between November 2024 and August 2025, irrigation frequency and plant performance were monitored. Irrigation events were recorded manually, including date, duration, and basic system parameters. Plant performance was assessed monthly through two metrics:

- **Survival rate:** number of living individuals per species expressed as percentage of the original planting ($N = 30$ each).
- **Vitality:** visual scoring on a 5-point scale (1 = necrotic, 5 = vigorous growth), conducted independently by two observers to reduce subjectivity. This approach is widely used in façade greening assessments (Manso and Castro-Gomes, 2015).

The vitality scores from the two observers were averaged using arithmetic mean to obtain semi-quantitative results. This procedure is consistent with early-phase pilot studies, where the objective was to identify species-specific performance trends rather than to conduct inferential statistics.

Mortality was defined as the complete loss of above- and below-ground biomass with no regrowth observed for at least two consecutive months. No resprouting was recorded among species with potential subterranean organs (e.g., *Hemerocallis* spp.).

Climatic data (daily temperature and precipitation from SHMÚ) were linked with irrigation frequency to evaluate seasonal irrigation demand.

The overview of monitored parameters is given in Table 1, while the complete irrigation record is presented in Table 2.

All irrigation events were logged, including date, duration, and basic hydraulic parameters. An overview of recorded irrigation events is presented in Table 2.

Irrigation Events on the Pilot Green Facade (Nov 2024–Aug 2025).

2.5 Data analysis

Irrigation records were examined in relation to daily climatic data (temperature and precipitation) from SHMÚ. This enabled

identification of seasonal patterns in water demand. Although exact volumes were not measured, irrigation duration and pipe dimensions provided a basis for approximate estimation of water supply. Runoff losses were acknowledged as a limitation, consistent with observations in other pilot-scale systems lacking recirculation or flow meters (Bustami et al., 2018; Pérez-Urrestarazu et al., 2016).

Plant performance was assessed through two complementary indicators: (i) survival rates, expressed as the proportion of living individuals relative to the initial planting ($N = 30$ per species), and (ii) vitality scores, based on a 5-point visual scale (1 = necrotic, 5 = vigorous growth). Independent evaluation by two observers helped reduce subjectivity, following approaches recommended for small-scale ecological monitoring (Manso and Castro-Gomes, 2015).

Descriptive statistics (mean, minimum, maximum, standard deviation) were applied to survival and vitality data. Given the limited sample size, inferential tests were not performed; instead, species-specific patterns and temporal dynamics were highlighted through graphical representation. This exploratory analytical framework focused on three aspects: (i) irrigation demand under variable climatic conditions, (ii) survival differences among plant species, and (iii) seasonal trends in vitality. Such an approach is commonly applied in early-phase green façade evaluations where the dataset does not yet allow full predictive modeling (Perini and Rosasco, 2016; Manso and Castro-Gomes, 2015).

3 Results

The first year of monitoring revealed how the façade responded to continental climatic variability. The results are organized into irrigation demand, species survival, and plant vitality. Together, these findings illustrate the interaction between weather conditions, water management, and vegetation performance.

3.1 Irrigation demand

Green façades require a regular and well-controlled water supply to ensure healthy plant growth. The irrigation method depends on the structure type, its scale, and the quality of the water

TABLE 1 Overview of monitored parameters, measurement methods, and notes.

Parameter	Method	Notes/limitations
Air temperature, precipitation	Daily data from SHMÚ* (Košice station)	Regional dataset; no façade-level sensors
Irrigation events	Manual logging of date and duration; pipe diameter considered	Water volume only estimated; runoff not quantified
Plant survival	Count of living individuals per species ($N = 30$)	Expressed as % of initial planting
Plant vitality	Visual scoring on 5-point scale, monthly monitoring	Subjective; cross-checked by two observers
Façade orientation	Direct observation (northeast exposure)	Constant; shading after noon
Irrigation performance	Visual inspection of water distribution	Runoff observed; no recirculation system

*SHMÚ = Slovak Hydrometeorological Institute.

TABLE 2 Irrigation events recorded on the pilot green façade in Košice (Nov 2024–Aug 2025).

Event No.	Date	Duration (min)	Notes
1	30.10.2024	15	Initial establishment watering
2–3	Nov 2024	10	Winter dormancy
4	05.03.2025	10	First spring watering
5–6	Apr 2025	10	Cool spring conditions
7–11	May 2025	2–8	Increasing demand, shorter intervals
12–19	Jun 2025	3–8	Peak demand, frequent irrigation
20–22	Jul 2025	3–9	Reduced demand due to cool July
23–34	Aug 2025	2–6	Sporadic irrigation, moderate demand

used (Pei-Wen et al., 2021). Drip irrigation is most commonly applied in vertical vegetation systems. It is particularly effective for felt-based modules, where the substrate volume is small and the system dries out quickly, thus requiring frequent application of small water doses (Kaltsidi et al., 2020). In recirculating irrigation systems, excess water is collected and reused for subsequent watering. Such systems are more complex, suitable mainly for large façades, and require more intensive maintenance. The low-tech irrigation system is the simplest among those described: the green façade is irrigated using gravity, with excess water drained into the sewer network (Pucher et al., 2022).

Based on the systems reviewed above, we selected a simple gravity-driven irrigation system. Considering the relatively small façade size, it would be inefficient to install a recirculating system, which is more technically demanding and costly to maintain. Moreover, since the use of modular plant boxes ensures a sufficient substrate volume, a drip irrigation setup was not required.

Irrigation demand closely followed air temperature rather than rainfall. Events were rare and short during the winter months, increased in frequency and duration in late spring, and then decreased again during an unusually cool July (Figure 3). In total, 34 irrigation events were recorded between October 2024 and August 2025, with an average duration of 4.7 min and a cumulative time of about 160 min.

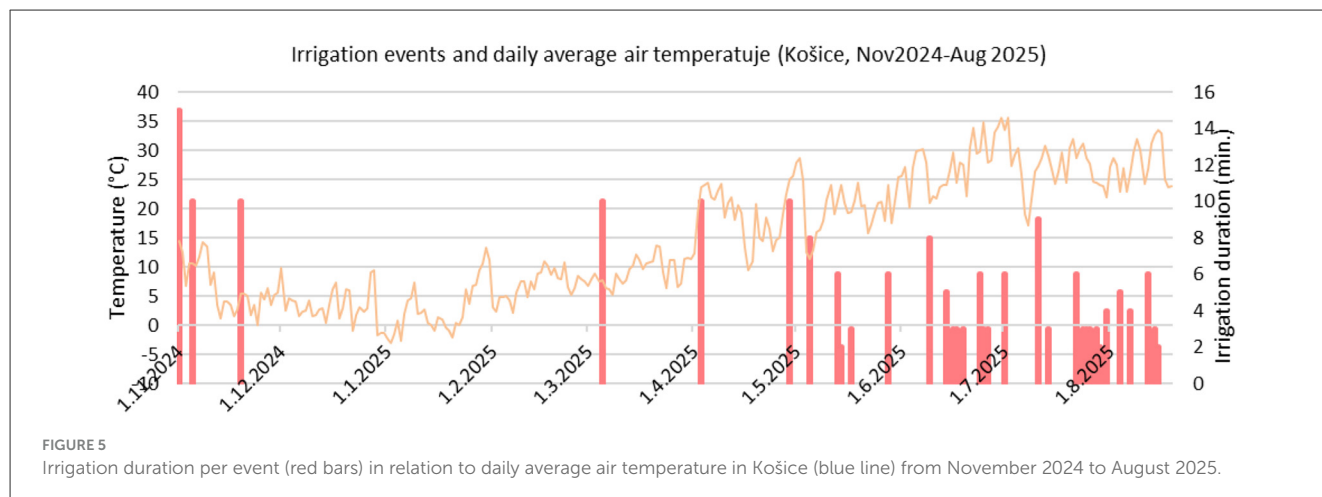
Based on pipe diameter and average flow rate, each event delivered $\sim 40\text{--}80$ L of water. This corresponds to a total seasonal input of $1.5\text{--}2.0$ m³, equal to about 8–12 L per plant. These estimates are indicative, as no flow meters were installed and runoff was observed. Nonetheless, they provide a useful baseline for water demand under Central European conditions.

The comparison with daily temperature records confirms that irrigation was primarily temperature-driven, while short-term rainfall events had limited influence due to the façade's controlled watering regime. This finding is consistent with previous studies indicating that irrigation management in vertical greenery is more sensitive to air temperature than to precipitation, particularly in container-based systems (Pérez-Urrestarazu et al., 2016; Bustami et al., 2018; Hoque et al., 2023).

Across the season, a total irrigation duration of 160 min was recorded over 34 events, corresponding to an estimated water input of $1.5\text{--}2.0$ m³ ($\approx 8\text{--}12$ L per plant). The relationship between irrigation duration and air temperature is illustrated in Figure 5.

3.2 Analysis of temperature fluctuations and irrigation management

The provided data illustrates temperature trends characteristic of a temperate climate zone. The observed temperature patterns directly influenced irrigation strategies and plant physiological responses throughout the year. During the winter months, average temperatures hovered around 5°C, with minimums dropping below freezing. This period is marked by low evapotranspiration from pots and minimal water uptake by plants, aligning with a phase of vegetative dormancy. Consequently, water requirements were significantly reduced. The onset of spring initiated a pronounced temperature increase. By April, recorded temperatures reached up to 25°C. This warming trend signaled the commencement of the plant growing season, necessitating a gradual reintroduction and intensification of irrigation. May and June demanded regular and more intensive watering due to ongoing plant growth and elevated transpiration rates. The beginning of July experienced extreme heat, leading to rapid drying of the potting substrate and, in some instances, plant stress and damage. A subsequent cooling trend in the latter half of July resulted in a reduced irrigation frequency. This pattern persisted



into August, where irrigation intensity was directly proportional to rising ambient temperatures.

Overall, irrigation management during the analyzed period was intricately linked to temperature fluctuations. It was imperative to adapt the frequency and volume of water application to prevailing climatic conditions and the specific physiological demands of the plants. This dynamic approach ensured optimal plant health and resource management.

3.3 Plant survival

At the end of the first growing season, overall survival across all species reached ~90%. However, clear differences between plant groups were observed (Table 3). The seasonal visual development of the green façade from winter dormancy to full coverage is shown in Figure 6. *Carex morrowii* Boott and *Hedera helix* L. achieved full survival (100%), confirming their strong adaptability and robustness under continental climate conditions.

Hemerocallis spp. L. also performed well with 100% survival, maintaining stability despite partial shading. *Imperata cylindrica* (L.) P. Beauv. showed higher sensitivity to frost and slow spring regrowth, resulting in 97% survival. In contrast, *Heuchera* spp. L. was the most vulnerable, with only 90% survival, and frequent signs of decline during hotter periods. *Hosta* spp. seedlings failed to establish and were completely lost by early summer. They were subsequently replaced by *Hebe* spp. which adapted moderately well during the remaining months, though long-term performance could not be fully evaluated within the first year. These findings underline the importance of careful species selection, highlighting the resilience of grasses and evergreen climbers compared to more sensitive perennials.

3.4 Plant vitality

Seasonal changes in vitality followed the transition from winter dormancy to summer growth. Most species started with low vitality scores (1–2) during winter months, then gradually improved from

TABLE 3 Survival of planted species after the first growing season.

Species	Survival (%)	Notes on performance
<i>Carex morrowii</i> Boott	90	Vigorous growth, highest resilience
<i>Hedera helix</i> L.	100	Rapid coverage, minimal losses
<i>Imperata cylindrica</i> (L.) P. Beauv.	97	Frost-sensitive, slow spring regrowth
<i>Hemerocallis</i> spp.	100	Stable under partial shading
<i>Heuchera</i> spp.	90	Vulnerable to heat stress, wilting observed
<i>Hosta</i> 'Frances W.'	0	Failed to establish; replaced by <i>Hebe</i> spp.
<i>Hebe</i> spp.	95	Introduced after replacement, stable establishment

March onwards, reaching peak values in July and August (Figure 7). The highest scores were recorded for *Carex morrowii* Boott (mean 4.2 ± 1.14) and *Hedera helix* L. (mean 4.3 ± 0.95), confirming their strong adaptation to the continental climate.

Imperata cylindrica (L.) P. Beauv. (mean 2.8 ± 1.32) showed slow regrowth in spring but stabilized later in the season. *Hemerocallis* spp. (mean 3.2 ± 0.92) maintained stable growth under partial shading. By contrast, *Heuchera* spp. (mean 1.8 ± 0.92) was the most vulnerable, with frequent signs of wilting and necrosis during hotter days. *Hosta* spp. seedlings failed to establish and were replaced by *Hebe* spp., which achieved moderate vitality (mean 2.7 ± 1.25) during the remaining season. The mean vitality scores for each species across the monitoring period are presented in Figure 8.

Overall, vitality trends confirmed the observations on survival: resilient grasses and evergreen climbers outperformed more sensitive perennials. The quantified vitality scores (Table 4) support these differences and provide a baseline for evaluating species selection in similar climates (Alkadri et al., 2025; Zhang et al., 2024).



FIGURE 6

Visual development of the pilot green façade from winter dormancy (February) to peak coverage (August 2025).

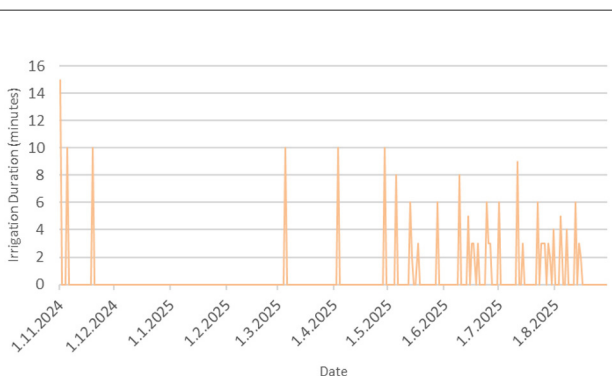


FIGURE 7

Irrigation events on the pilot green facade (Nov 2024 - Aug 2025).

4 Discussion

The monitoring of the pilot green façade in Košice confirmed that vertical greenery in continental climates is feasible but not maintenance-free. The performance strongly depended on plant

selection, irrigation management, and continuous care. Future monitoring phases will incorporate physiological measurements such leaf water potential and estimation of water-use efficiency. Additionally, species will be categorized according to their photosynthetic pathway (C3 or CAM), which may further explain their performance differences under continental climate conditions. Resilient species such as *Carex morrowii* Boott and *Hedera helix* L. achieved full survival and high vitality, while more sensitive perennials like *Heuchera* and *Hosta* showed clear vulnerabilities, a trend also reported in other temperate settings (Alkadri et al., 2025; Wei and Wang, 2022). Irrigation demand closely followed temperature patterns, with peaks in late spring and lower demand during the unusually cool July. These findings align with studies from other European regions, where water use efficiency and species resilience are recognized as critical factors for successful façade greening (Manso and Castro-Gomes, 2015; Perini and Rosasco, 2016; Pérez-Urrestarazu et al., 2016; Bustami et al., 2018; Salisbury et al., 2023).

The results also illustrate practical implications for urban planners and architects. Locally grounded evidence from Slovakia helps inform plant choice and irrigation scheduling under continental climate conditions, supporting the integration of green façades into sustainable building design (Zeleňáková et al., 2018;

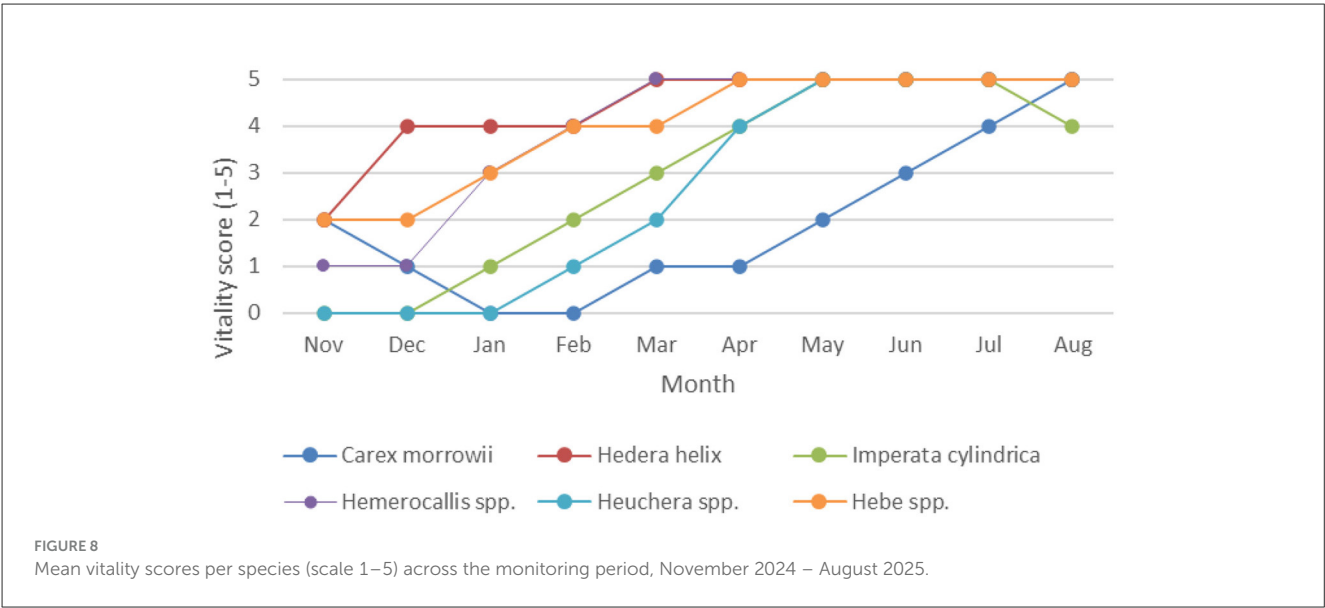


TABLE 4 Mean vitality scores ($\pm$ SD) per species, November 2024–August 2025.

Species	Mean vitality ($\pm$ SD)	Notes
<i>Carex morrowii</i> Boott	4.4 $\pm$ 0.5	Consistently vigorous
<i>Hedera helix</i> L.	4.6 $\pm$ 0.5	Stable evergreen cover
<i>Imperata cylindrica</i> (L). P. Beauv.	3.0 $\pm$ 1.2	Sensitive to frost, improved later
<i>Hemerocallis</i> spp.	3.5 $\pm$ 0.7	Moderate, benefited from shading
<i>Heuchera</i> spp.	2.2 $\pm$ 0.9	Decline under heat stress
<i>Hebe</i> spp.	3.8 $\pm$ 0.8	Stable after replacement

Słyś and Stec, 2020). By demonstrating baseline water requirements and identifying robust species, this study contributes to broader agendas such as the European Green Deal (European Commission, 2020) and the UN Sustainable Development Goals (UN, 2015).

4.1 Limitations

This pilot study has several limitations. First, the monitoring was restricted to a single façade orientation and covered only 1 year of operation, which limits the generalization of results. Plant vitality was assessed visually, introducing a degree of subjectivity despite cross-checking by multiple observers. In addition, no direct measurement of irrigation volumes was carried out, and runoff losses could only be estimated. Furthermore, water quality was not evaluated, meaning differences between rainwater and tap water could not be considered. Substrate parameters such

as humidity, nutrient content, and potential compaction were also not monitored, although they are known to influence plant performance (Bustami et al., 2018; Pérez-Urrestarazu et al., 2016; Coma et al., 2014). Although herbarium vouchers were not deposited during this pilot phase, all species were verified by a certified horticulturist. The authors plan to deposit voucher specimens in a regional herbarium during the next monitoring season to ensure taxonomic traceability.

These constraints underline the exploratory character of the study, but they also highlight key aspects to be addressed in future research, such as multi-orientation monitoring, use of sensors for water and substrate parameters, and standardized vitality scoring.

In addition, the study did not include detailed chemical analysis of irrigation water or substrate nutrients, which could further refine the understanding of plant responses. These parameters are already planned for inclusion in the upcoming monitoring season.

5 Conclusion

The first year of operation of the pilot green façade in Košice demonstrated that vertical greenery in continental climates requires active management. Plant choice, irrigation, and regular care were decisive for overall performance. With around 90% survival, the system proved feasible, particularly for resilient species such as *Carex morrowii* Boot and *Hedera helix* L., while more sensitive species highlighted the need for careful selection and adaptive strategies. Irrigation demand closely followed temperature patterns, with peaks in late spring and lower demand during the unusually cool July. These findings emphasize the role of efficient irrigation scheduling and water-use strategies in climates with strong seasonal variability. Although limited to one façade orientation, 1 year of observation, and simplified vitality scoring, the study provides the first evidence from Slovakia that can support architects, planners, and municipalities in integrating vertical greenery into urban projects. Properly managed green façades

contribute not only to improved microclimate and biodiversity but also to sustainable water use and management in cities, aligning with the European Green Deal and the UN Sustainable Development Goals.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

ZV: Project administration, Writing – original draft, Writing – review & editing, Funding acquisition, Supervision. MKoc: Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Visualization, Writing – original draft, Writing – review & editing. DK: Conceptualization, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. MKoz: Conceptualization, Formal analysis, Funding acquisition, Methodology, Project administration, Resources, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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