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Testing results for plant range suitability for growing in vertical gardens with a substrate system

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Abstract: Vertical gardens are becoming increasingly popular worldwide, but their significant expansion in Central Europe is limited by climate. The biggest obstacle to growing plants is the freezing winter. Due to the risk of damage to the irrigation systems, it is necessary to turn it off in the winter, and the plants must be able to survive this period without watering. This is a significant limiting factor, especially for the assortment of evergreen plants, although they are very popular for their aesthetic effect when grown in green walls. During the research described, mainly xerophilous plants were tested for planting in vertical gardens. Due to the system used by the company Němec s.r.o., which operates on a system of self-watering flowerpots, the growing environment was not quite suitable for a larger part of the plants tested. In the second phase of the research based on previous experience, plants of mesophytic to hygrophilous nature were used that showed much greater potential for use in the above-mentioned system. Observations in the first phase of the research took place on the CULS (Czech University of Life Sciences) campus in Prague, from November 2017 to May 2020. Testing of another assortment of plant species is currently underway at the same location, with promising results from July 2024. The result of this testing is a suitable assortment of plants that can be recommended for use in vertical gardens with a substrate system in the climatic conditions of the Czech Republic.

Keywords: vertical gardens, green walls, structure gardens, vertical garden assortment, substrate system, irrigation.

Introduction

The use of greenery on structures is currently a very popular solution for increasing the proportions of greenery in urban environments. Greenery helps improve the microclimate, as well as the aesthetic values of built-up areas in cities (Wilmers 1990; Newton et al. 2007; Sheweka & Mohamed 2012; Yeh 2012). Vertical gardens are an ideal solution for mitigating the heat island effect in areas where it is not possible to place other greenery due to spatial limitations (Yeh 2012). With the increasing height of buildings and therefore technical areas, it is necessary to balance their share with greenery. Vertical gardens are perfectly suited for this purpose (Perini et al. 2013). In some construction sectors, the prevailing opinion is that greenery takes up space for technical infrastructure. Green walls solve this problem because they take up virtually no space on city streets (Manso & Castro-Gomes 2015). Their benefit may also be the possibility of covering unsightly building structures to increase the aesthetic value of the buildings (Wood et. al. 2014). From a local point of view, the installation of a green wall has a significant impact on the thermal performance of the buildings. Thanks to thermal insulation and air cooling through evapotranspiration, it can affect the energy consumption of the buildings (Wood et al. 2014). Locally, greenery also contributes to enhancement of an air quality. Timur & Karaca (2013) state that vertical gardens also significantly reduce the concentration of toxins.

In Western Europe, but also in the world´s large metropolises, exterior and interior green walls are increasingly being installed (Blanc 2012). However, we cannot adopt their range for exterior use because the Central European climate poses a problem for growing plants on structures. The biggest obstacle in this sense are low temperature periods in freezing winters (Pejchal 2011). Due to the risk of damage to the irrigation systems, it is necessary to turn them off in the winter, thus the plants must be able to survive this period without watering (Burian 2019). This is a significant limiting factor, especially for the range of evergreen plants, although they are very popular for growing in green walls due to their aesthetic effect. When choosing specific plant species for vertical gardens, it is necessary to take into account the climatic factors that will affect individual plants. These are temperature and humidity conditions, wind direction and speed, as well as orientation to the cardinal points (Hopkins & Goodwin 2011). The location of the plant within the wall also plays a major role. The same plant can thrive in a completely different orientation and exposure if it is placed correctly at the top or bottom of the wall, depending on the situation (Blanc 2012). It is advisable to choose plants not only according to climatic conditions, but also according to the character of the building from an aesthetic point of view (Manso & Castro-Gomes 2015). Another benefit is that plants growing in vertical positions are less susceptible to pest attacks due to limited accessibility and sufficient sunlight (Timur & Karaca 2013).

Material and Methods

The monitored vertical gardens were located in Prague – Suchdol on the premises of the Czech University of Life Sciences (CULS). The location is at an altitude of 274 m. above sea level (https://geoportal.gov.cz/). The average annual precipitation is between 500–550 mm and the average annual temperature is between 9–10 °C (https://portal.chmi.cz/).

The research in both phases used the patented Němec Cascade Garden system from Němec s.r.o. It is an innovative system of vertical gardens, which is based on the principle of separate plastic self-watering containers filled with substrate. Various versions of lightweight horticultural substrate with different grain sizes and pH values were used, specially mixed for the purposes of this research, the results of which are now being evaluated and will be presented later. Water is distributed here by gravity into irrigation boxes. The system was connected only to irrigation water, which was pumped from the water main system (Kunt et al. 2017; Čechová et al. 2023).

The research was conducted in two phases. Primarily, mainly xerophilous plants were tested for growing in green walls, in the period from November 2017 to May 2020. However, the environment in the self-watering flowerpot system was not suitable for a large part of the plants. In the second phase of the research, for the above reasons, plants of mesophytic to hygrophilous nature were used, which, based on previous experience, showed greater potential for use in the above-mentioned system. In the initial phase of the research, 4 pieces of double-sided green walls with a length of 4 m and a height of 2 m were planted. The orientation to the cardinal points was north-south and east-west. For the second phase of the research, one piece of experimental green wall with an orientation to the east and to the west was used. These orientations were chosen due to the representative location of the experimental green wall on a selected area in the center of the university campus, and also due to the clearly different climatic conditions of east and west exposures.

According to Čechová et al. (2023), 13 plant species were selected for each cardinal point for the initial research of xerophilic species. 45 plants of each species were represented. The assortment was chosen concerning habitat conditions and world orientation; therefore, ornamental grasses, perennials, and woody plants were represented. The southern and eastern walls were planted with the following species: *Arctostaphylos uva-ursi*, *Armeria maritima*, *Berberis candidula*, *Cotoneaster dammeri*, *Gaultheria procumbens*, *Festuca glauca*, *F. ovina*, *Fragaria vesca*, *Koeleria glauca*, *K. macrantha*, *Lamiastrum galeobdolon*, *Phleum pratense*, *Thymus serpyllum*. The following species were chosen for the western and northern orientation: *Andromeda polifolia*, *Deschampsia caespitosa*, *Euonymus fortunei* ‘Emerald ‘n Gold‘, *Festuca glauca*, *F. ovina*, *Fragaria vesca*, *Juniperus communis* ‘Repanda‘, *Koeleria glauca*, *K. macrantha*, *Lamiastrum galeobdolon*, *Laurocerasus officinalis*. *Phleum pratense*, *Taxus baccata* ‘Repandens‘, *Vinca minor*.

In the spring of 2018, unpromising plants that did not survive the winter or showed low aesthetic value in the wall were evaluated. Monitoring of these species was

discontinued for further observation and they were replaced by other potentially more promising species. Each of the species was planted in the amount of 41 pieces, for statistical accuracy, despite frequent theft of whole plants. The number of perennials in the new assortment was increased at the expense of woody species that proved to be less promising for further cultivation.

The new range for south and east exposures consisted of: *Arctostaphylos uva-ursi*, *Armeria maritima*, *Deschampsia caespitosa* 'Goldtau', *Gaultheria procumbens*, *Festuca glauca*, *F. ovina*, *Fragaria vesca*, *Koeleria glauca*, *Pachystima canbyi*, *Phlox subulata*, *Saponaria ocymoides*, *Stipa tenuissima* 'Pony Tails', *Thymus serpyllum*. The range for the west and north exposures was *Andromeda polifolia*, *Campanula poscharskyana*, *Deschampsia caespitosa* 'Goldtau', *Euonymus fortunei* 'Emerald 'n gold', *Festuca glauca*, *F. ovina*, *Fragaria vesca*, *Koeleria glauca*, *Lamiastrum galeobdolon*, *Lysimachia nummularia*, *Pachysandra terminalis*, *Taxus baccata* 'Repandens', *Vinca minor*.

All green walls were monitored at regular intervals of two weeks from November 2017 to May 2020, and the results were recorded according to the research methodology, which was based on the methodologies for Evaluating Woody Plants in situ according to Machovec (1982) and Pejchal (2008), and the methodology for Evaluating Ornamental Plants in Permanent Habitats (Bulíř 2013). The above-mentioned methodologies were further adapted for the needs of the research.

The following criteria were visually assessed and evaluated:

Physiological properties: Vitality, Health status, Color changes, Habit – compactness – limiting surrounding species.

Aesthetic properties: Speed of integration into the composition, Aesthetic value, Year-round effectiveness, and Flowering. The criteria were evaluated on a five-point evaluation scale, with 5 points meaning the highest rating.

Mortality assessment of individual species was always carried out in spring, as the winter period is the most critical for plants. The number of dead and surviving plants was always recorded in April. Due to frequent thefts, both values had to be stated.

In the secondary phase of the research, a completely different assortment from the original observation was chosen. Identical species were chosen for exposure to both sides of the world: *Acorus gramineus*, *Bergenia cordifolia*, *Butomus umbellatus*, *Caltha palustris*, *Carex elata* 'Bowles Golden', *Hippuris vulgaris*, *Iris ensata* 'Amethyst', *Juncus inflexus*, *Lythrum salicaria*, *Mentha aquatica*, *Naumburgia thyrsiflora*, *Trollius europaeus*, *Sagittaria latifolia*, *Veronica beccabunga*.

The evaluation methodology was simplified in this case for better clarity and evidence of the results. The individual parameters were combined into cumulative evaluations and parameters evaluated accordingly to the same five-point evaluation scale.

The following criteria were evaluated: Vitality and Aesthetic value. The evaluation of plant mortality in the second phase of the research was carried out only in the spring of 2025, because the research is still in an active phase at this moment.

Results

Plant growth depends on the weather conditions in a given year. After the plants were planted in the fall of 2017, they had to cope with the stress of transplanting, as well as winter conditions. Due to significant temperature fluctuations in the winter and spring of 2017/2018, a significant proportion of the plants were damaged and died. The effect was due to the alternation of unusually warm days with sudden drops to frosty days and incorrect timing of watering in combination with the subsequent failure of the irrigation system. Some demonstrably unpromising species were excluded from observation during planting and replaced with new ones in July 2018.

The winters of 2018/2019 and 2019/2020 were warmer than normal, which had a positive effect on the vitality of the plants. Unfortunately, in the middle of the south-facing wall, an irrigation failure occurred in the spring of 2020, and most of the plants died there. In the case of the second phase of observation, the winter was average in terms of temperature, with fluctuations in air temperature to significantly freezing values compared with the initial phase of the research. However, the failure of irrigation in June 2025 also had a significant impact on the well-being of the plants.

Dry-loving plants for the south and east exposures

After the irrigation failure, all grass species were evaluated as species with the best survival ability. Of the perennials, only *Fragaria vesca* overcame the irrigation failure with reasonable vitality.

Armeria maritima achieved a high rating among perennials, the only drawback of which was the slow covering of the growing containers. *Fragaria vesca* and *Thymus serpyllum* also proved themselves among perennials. In the winter, *Fragaria* is not aesthetically impressive, but in the growing season, it is characterized by a high vitality and decorates the wall with its flowers and fruits; *Thymus* very quickly joined the composition and enhanced it in the spring with its small blossoms. All the listed species showed a low mortality on the east exposure.

On the contrary, low ratings were recorded among perennials for *Phlox subulata* and *Saponaria ocymoides*. Where, especially in the south exposure, *Phlox* showed low vitality, resulting in the mortality of a significant number of pieces. Nevertheless, both species bloomed abundantly and significantly and were also able to quickly integrate into the composition. A low evaluation of the aesthetic appearance in the winter period was recorded for the species *Saponaria ocymoides*.

Based on all observations, the most promising group appears to be ornamental grasses. The highest points from this group were achieved by *Stipa tenuissima* 'Pony Tails' and *Deschampsia caespitosa* 'Goldtau'. Both species were interesting during the flowering period and beyond. Even in the winter period, the grasses acted as decorative elements. Inclusion in the composition was also evaluated positively, because these are larger grasses. The ability to self-seed, i.e., to colonize empty flowerpots, is also a benefit of *Stipa*. Regarding mortality, the worst evaluation was recorded for *Festuca glauca* and *F. ovina*.

The promising woody plants tested, in the south and east exposures, generally appeared to be reasonably to below average. The species *Arctostaphylos uva-ursi* and *Gaultheria procumbens* did not show continuous good vitality or involvement in the composition. Their benefit was the fruits, which increased their effectiveness in the winter period. Another evaluated woody species was *Pachystima canbyi*, which achieved a below average overall rating with high mortality. The species *Berberis candidula*, *Cotoneaster dammeri*, *Koeleria macrantha*, *Lamiastrum galeobdolon*, and *Phleum pratense* were eliminated from the experiments in April 2018, mainly due to poor growth and overall effectiveness in the vertical garden. *Koeleria macrantha* was eliminated due to excessive similarity to *K. glauca*.

Dry-loving plants for the north and west exposures

For both the north and west, the best-rated woody species were specifically *Vinca minor* and *Andromeda polifolia*. The plants showed good vitality and aesthetic value throughout the year, even in winter. The pluses of both species were abundant flowering and quick integration into the composition. On the north wall, zero mortality was even recorded for *Vinca minor*. As for other woody species, the species *Euonymus fortunei* 'Emerald 'n gold' was also very well rated, the undisputed benefit of which is its evergreen nature, and colorful aspect in winter. *Pachysandra terminalis* and *Taxus baccata* 'Repandens' achieved relatively good ratings mainly due to their evergreen nature. In addition, low mortality was recorded for the *Taxus* and *Euonymus* species.

Of the perennials, *Campanula poscharskyana* can be selected among the most promising species, which was vital, quickly integrated into the composition and bloomed very prominently. The disadvantage in this case was the winter period, when the plant is dormant. It was interesting that in the northern exposure the species had a very low mortality rate, but in the western it was high. Other highly rated perennials were *Fragaria vesca* and *Lysimachia nummularia*. Although *Fragaria* was rated worse on the northern wall than on sunnier sites, its effectiveness was still rated positively. *Lysimachia* had an excellent rating during the growing season due to its rapid growth and the presence of flowers. However, its vitality gradually decreased in the northern exposure. *Lamiastrum galeobdolon* was one of the plants with the lowest rating due to its low vitality and the associated low aesthetic value.

All species of grasses monitored were rated positively for both northern and western orientations, with very low mortality. *Deschampsia caespitosa* 'Goldtau' was rated as the best of them, but on the northern side a higher mortality was recorded compared to other grass species.

The species *Juniperus communis* 'Repanda', *Koeleria macrantha*, *Laurocerasus officinalis*, and *Phleum pratense* were removed from the trials in April 2018, mainly due to poor growth and overall performance in the vertical garden. *Koeleria macrantha* was removed due to its excessive similarity to *Koeleria glauca*.

Mesophytic to hygrophilous plants for the western and eastern exposures

Since the experiment with mesophytic to hygrophilous plants in vertical gardens is still in the evaluation process, only partial results for one season are presented. A longer observation period will be necessary to conclude.

In this case, only perennials were selected for testing, with a few exceptions in the grasses. It was interesting to note that at the beginning of cultivation, hygrophilous plants were more pronounced, specifically *Acorus gramineus*, *Butomus umbellatus*, *Carex elata* 'Bowles Golden', and *Juncus interflexus*. After the irrigation failure, these species were suppressed by other species with more pronounced vitality. Subsequently, *Mentha aquatica*, *Veronica beccabunga*, *Iris ensata* 'Amethyst', *Naumburgia thyrsiflora* were pronounced for both orientations, and *Sagittaria latifolia* also appeared locally. However, the most versatile species appears to be *Bergenia cordifolia*, which was highly rated both before and after the irrigation failure, has good winter performance, and significant spring flowering.

In terms of mortality, it was interesting that all monitored species survived the first winter in their original numbers. Only the species *Mentha aquatica* and *Veronica beccabunga* recorded mortality. However, these plants have an excellent ability to reseed, which they applied to free flowerpots. They did not fall out of the composition and, at the last measurement in October 2025, significantly dominated the monitored object by their mass.

Discussion

When comparing the two monitored objects, it is necessary to consider the different observation times and also the different weather conditions, which are essential for plant development. In the first experiment, the plants were placed in single-species groups. This was a purely experimental object. The second monitored object is also an aesthetic element in the CULS campus, so it was more appropriate to place the plants diversely, i.e., a mixture of all species. Plants with less vitality may suffer due to this strategy, as they may be suppressed by other, more vital species.

When comparing the assortment in both experiments, the second case appears to be more promising in terms of vitality, mainly due to the considerable growth force of the plants supported by a significant supply of water. Thanks to this, the plants are able to create a large amount of biomass in a short period of time, which quickly covers the wall and gives a holistic impression. As for the aesthetic value, the evaluation of this data is burdened by subjective opinion. Plants from the first trial have an undeniable advantage in greater variability of overall structure or even in more pronounced flowering. Also, in evergreen species, there is undoubtedly a greater selection of species from the first trial.

The most universal choice for growing in vertical gardens with a substrate system, based on testing, appears to be ornamental grass species. *Deschampsia caespitosa* ‘Goldtau‘, *Festuca glauca*, *F. ovina*, *Fragaria vesca*, and *Koeleria glauca* can be recommended for all world orientations. With appropriate watering, *Carex elata* ‘Bowles Golden‘ can also be used. The suitability of *Festuca ovina* is also confirmed

by Skarżyński et al. (2014) due to its ability to provide good coverage. According to Swoczyna et al. (2020), the vitality of *Koeleria glauca* was 80% even after the third monitored year, which corresponded to the results on the CULS campus. Thanks to its vitality and interesting appearance, *Stipa tenuissima* 'Pony Tails' was identified as the best-rated grass, which was, however, tested only for southern and eastern orientations. According to Suárez-Cáceres et al. (2022), *Stipa*, on the other hand, had low coverage and high mortality.

Among perennials, *Fragaria vesca* can be recommended for all world orientations. Its good vitality and survival ability is also confirmed by Pejchal (2011) and Swoczyn et al. (2020), who report an average survival ability of 70%. According to Martensson et al. (2014), *Fragaria* has the ability to produce decorative flowers and fruits, but it does not have an overall attractive appearance. For southern and eastern orientations, the species *Armeria maritima* and *Thymus serpyllum* can also be recommended, which had very good results in all evaluated parameters. However, *Armeria maritima* does not achieve the desired rapid coverage, which is also confirmed by Martensson et al. (2014). For north-oriented plantings, the species *Campanula poscharskyana* can also be recommended. The species *Lysimachia nummularia* was well evaluated on a west-oriented experimental wall, and its use is also recommended by Pejchal (2011).

Bergenia cordifolia can also be recommended for western and eastern orientations. Thanks to its evergreen nature and ability to cope with both heavy watering and drying out, it appears to be a universal plant for use in vertical gardens. Acorus gramineus has good vitality only with stable irrigation. According to Suárez-Cáceres et al. (2022), it had a coverage of 55-60% in the green wall, which corresponds to the experiments at the Czech University of Life Sciences in Prague. *Mentha aquatica* and *Veronica beccabunga* can be described as plants with a significant ability to survive in vertical gardens, which, although they were the only ones to show mortality in some plants after the first monitored winter, were subsequently able to reseed, and in the autumn of the same year, they can be described as the most dominant plants in the entire composition.

Arctostaphylos uva-ursi can be recommended as a suitable woody species for green walls with a southern and eastern orientation, but it was rated worse in terms of overall coverage. On the other hand, for northern and western orientations, the choice of suitable woody species is wider: *Andromeda polifolia*, *Euonymus fortunei* 'Emerald 'n Gold', *Pachysandra terminalis*, *Taxus baccata* 'Repandens' and *Vinca minor*, all of which have added value as evergreens. According to Swoczyna et al. (2020), *Euonymus fortunei* 'Emerald 'n Gold' has a high mortality rate in southern orientation, which was not confirmed in an experiment with a more suitable western and northern orientation. *Pachysandra terminalis* can also be recommended according to Pejchal (2011) for its vitality, and according to Skarzynski et al. (2014) for its high-quality coverage. *Vinca minor* had below-average survival on the southern wall, which does not correspond to the results at CULS, where it was

excellently evaluated in almost all monitored aspects, although tested only on the northern and western exposures.

Conclusion

In the above discussion described plants can be recommended for growing in vertical gardens with a substrate system in the climatic conditions of Central Europe.
However, only under the condition that they will be grown with the recommended world orientation.
Individual species must also be chosen with regard to their irrigation requirements, because plants with different irrigation requirements cannot be combined.

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