ASSORTMENT OF PLANTS FOR GROWING IN VERTICAL GARDENS OF CENTRAL EUROPE*

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Vertical gardens are a smart and aesthetic solution of how to improve urban microclimate. So far, the assortment of plants suitable for outdoor green wall installations in Czech climatic condition has not been sufficiently explored. Therefore, we decided to establish experimental vertical gardens with a substrate system facing all four cardinal directions in the Prague location. During the experiment, the following species prospered best despite of the vertical garden wall orientation: *Deschampsia caespitosa* 'Goldtau', *Festuca glauca, Festuca ovina, Fragaria vesca* and *Koeleria glauca.* The following species performed well on the south and east wall: *Arctostaphylos uva-ursi, Armeria maritima* 'Leuchtendrosa', *Stipa tenuissima* 'Pony Tails' and *Thymus serpyllum.* In vertical gardens facing north and west, the following woody plants were evaluated best: *Andromeda polifolia, Euonymus fortunei* 'Emerald 'n' Gold', *Pachysandra terminalis, Taxus baccata* 'Repandens', and *Vinca minor.* These evergreens are a true benefit to the garden. The species *Campanula poscharskyana* can only be recommended for the north orientation. *Lysimachia nummularia* performed well just on the west-oriented walls. All the above-listed species can be recommended for planting in vertical gardens with a substrate system in the climatic condition of Central Europe.

green walls, grasses, woody plants, structurally supported gardens, cold resistance of plants

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INTRODUCTION

Vertical gardens have seen a surge in popularity in recent times. According to Wilmers (1990), Newton et al. (2007), Sheweka, Mohamed (2012), it is one of the possible ways to improve microclimate and enhance aesthetic values of built-up areas of modern cities. Though an assortment of plants suited for vertical gardens has been tested in West and South European countries, such plants cannot be completely taken over in the Czech Republic. While selecting the plants, the challenge is the different Central European climate. The cultivated plants are very stressed by frosty winters, as their roots become endangered by freezing of substrate (Pejchal, 2011). In the case of many plants, physical frost damage is caused by the freezing and expansion of the intracellular fluid that result in cell breakage. Spring damage is influenced by the biology of the species in strong response to rapid temperature changes during daytime, whereas fall damages are influenced by photoperiod, soil moisture, and other ambient factors. Winter effects are much more destructive for plants in temperate climates than in polar areas where plants are significantly more adapted to life in frost (Ashraf, Harris, 2005). Likewise, hot and dry summers can cause problems to proper thriving of plants (Pejchal, 2011). If abruptly exposed to high temperatures, the plants die off. When high temperatures start gradually, heat-shock protein synthesis supporting thermoregulation of the organism happens (Ashraf, Harris, 2005).

At the same time, the risks of wind influence are much higher in green walls, as such are usually placed high on a building (Klusova, 2011). According to

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Cao et al. (2013), bigger plants such as shrubs are mostly endangered because stronger wind is able to pull them out of the substrate. Given that lighter substrate is used, there is a large risk of wind erosion whereby the plants are primarily endangered by denudation of the root system. Blanc (2012) recommends that the expositions strongly endangered by wind should be planted with species well persisting in a windy habitat. Those are low growing cushion plants and plants without fragile parts or large leaves that might be easily damaged by wind.

Due to insufficient experience with the assortment of plants suitable for outdoor vertical plant installations in Central Europe, Pejchal (2011) recommends to take over the assortment of plants tested by our nearest neighbours in Austria and Germany. According to Skarzynski et al. (2014), the experience with suitable species can also be acquired from the Lower Silesian lowlands of Poland. Martensson et al. (2014) presented their experience from Malmö, Sweden, with even more extreme climatic conditions than in the Czech Republic. Furthermore, Pejchal (2011) stated that garden woody plants and perennials growing in rock gardens and on dry walls are suitable. Blanc (2012) recommends domestic plants growing on peaks and rocks, i.e., in a vertical position, for cultivation in vertical gardens. He recommends the plants of rocky hillsides to be placed on the upper parts of green walls. He places plants growing on rocky hillsides into the middle parts. Lower parts provide conditions typical for plants that grow naturally in undergrowth.

The most universal plants for green walls are succulents that are suited both for substrate and hydroponic systems. They have a compact habit with a shallow root system and low water requirement. In the environment of the Czech Republic, familias *Sedum* ssp. and *Sempervivum* ssp. (Pejchal, 2011) are most likely to survive, but they are not suitable for covering large areas of green walls, because they do not produce much biomass.

The aim of the work was to evaluate the most suitable plants from potentially promising species recommended by Pejchal (2011), Martensson et al. (2014), Swoczyna et al. (2020) and other selected plants for the habitats of vertical gardens with a substrate system in the climatic conditions of Central Europe for individual cardinal directions.

MATERIAL AND METHODS

The experimental green walls were installed on the grounds of the Czech University of Life Sciences Prague. The experiment monitored how the individual selected species prosper in vertical gardens located in the climatic environment of the Czech Republic, specifically in Prague 6-Suchdol. This locality is situated 274 m above sea level (Czech National Geoportal CENIA, 2020). The average annual amount of rainfall is 500–550 mm, and the average annual temperature is 9–10 °C (Czech Hydrometeorological Institute, 2010).

In terms of technical aspects, four freestanding double-sided green walls were installed on the ground (Fig. 1). These walls were 4 m long and 2 m high. Both sides of the walls facing north-south and east-west were implanted. The patented system of Němec Cascade Garden (Němec s.r.o., Czech Republic) was used for this research. It is an innovative system of vertical gardens based on the principle of separate self-irrigating plastic containers filled with substrate. For this purpose, a lightweight, specially mixed garden substrate (62% peat, 32% compost and 15% perlite) was used. Water was distributed gravitationally to watering troughs. The water was discharged automatically from the storage tank. The process was launched on the basis of the level drop in the irrigation troughs, which was monitored by a level sensor. The automated irrigation system was deactivated during winter. The system was linked

Fig. 1. Free-standing vertical gardens after planting in November 2017

only to the irrigation water drawn from water mains (Kunt et al., 2017).

For this experiment, plants supposed to thrive in vertical gardens were used. In November 2017, the walls were installed and 13 species of plants were placed in each cardinal direction. Each species was represented by 45 pieces. The assortment of plants was selected with respect to environmental conditions and cardinal directions and included ornamental grasses, perennials, and woody plants. Some species are suitable for both sunny and semi-shady habitats, so they were tested for all cardinal directions. Species for sunny habitats were selected for testing only for the south and east orientation. Species that grow naturally in the penumbra were chosen for the north- and west-oriented walls. The species *Arctostaphylos uva-ursi, Armeria maritima* 'Leuchtendrosa'*, Berberis candidula, Cotoneaster dammeri, Gaultheria procumbens, Festuca glauca, Festuca ovina, Fragaria vesca, Koeleria glauca, Koeleria macrantha, Lamiastrum galeobdolon*, *Phleum pratense, Thymus serpyllum* were planted on the south- and east-facing walls. For the west- and north-facing walls, the following species were chosen: *Andromeda polifolia, Deschampsia caespitosa*, *Euonymus fortunei* 'Emerald 'n' Gold', *Festuca glauca, Festuca ovina*, *Fragaria vesca*, *Juniperus communis* 'Repanda', *Koeleria glauca*, *Koeleria macrantha, Lamiastrum galeobdolon*, *Laurocerasus officinalis* 'Caucasica', *Phleum pratense, Taxus baccata* 'Repandens' and *Vinca minor*. Plants not tough enough to survive winter or had low aesthetic benefits on green wall were selected in spring 2018. Some species were excluded from further observation and thus were no longer evaluated. The excluded species were replaced by other potentially more promising ones. To meet the statistical accuracy criteria, 41 pieces from each species were planted. In the new assortment of plants, the number of perennials was increased, whereas the number of woody plants, which appeared to be less promising, was decreased. The new assortment of plants for the south- and east-facing walls was as follows: *Arctostaphylos uva-ursi, Armeria maritima* 'Leuchtendrosa'*, Deschampsia caespitosa* 'Goldtau', *Gaultheria procumbens, Festuca glauca, Festuca ovina, Fragaria vesca, Koeleria glauca, Pachystima canbyi, Phlox subulata, Saponaria ocymoides, Stipa tenuissima* 'Pony Tails' and *Thymus serpyllum.* The assortment for west and north was as follows: *Andromeda polifolia, Campanula poscharskyana, Deschampsia caespitosa* 'Goldtau', *Euonymus fortunei* 'Emerald 'n' Gold'*, Festuca glauca, Festuca ovina, Fragaria vesca, Koeleria glauca, Lamiastrum galeobdolon, Lysimachia nummularia, Pachysandra terminalis, Taxus baccata* 'Repandens' and *Vinca minor*.

The green walls were monitored biweekly from November 2017 to May 2020, and the results were recorded according to the Methodology for evaluating woody plants in a habitat (M a c h o v e c , 1982; P e j c h a l , 2008) and Methodology for appreciation of ornamental plants in a permanent habitat (B u l i r , 2013). The following criteria were evaluated:

Physiological properties: vigour, state of health, changes in colour, habit – compactness – competing with the surrounding species.

Aesthetical properties: how quickly the plants fit into the composition, aesthetical value, year-round efficacy, blooming.

The criteria were evaluated on the basis of a 5-point rating scale (5 points = best score). The plants were evaluated individually.

The weather conditions, decisively affecting both the green wall plants growth and the whole study course, were monitored (Fig. 2). After planting, the seedlings had to cope with repotting plant stress succeeded by an unfavourable winter. The automated irrigation system had been deactivated before the frost arrived. In February 2018, the plants were once watered by the delivery company, unfortunately temperature dropped below –7 °C the next week, and during the following weeks even to –15 °C. This stress period had a fatal impact on many plants. The onset March temperatures rose up to 12 °C, and plants began to sprout; however, repeated sudden mid-March temperature drops caused the sprouting plants an additional damage. Contrarily,

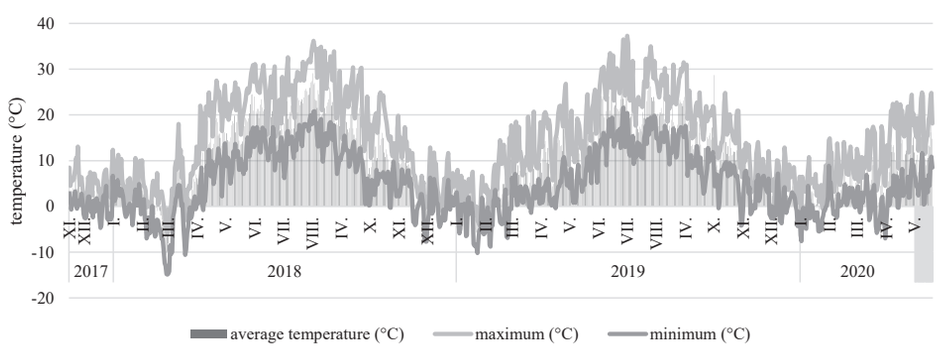

Fig. 2. The course of temperature during the vertical gardens monitoring Source: Meteostation of the Czech University of Life Sciences Prague, 2020 (http://meteostanice.agrobiologie.cz/grafy.php?graf=graf9, adjusted)

Table 1. Survival of plants used in the vertical gardens experiment (2017–2020). The plants' status was checked annualy, each April. System failures are clearly visible in this table. The first one happened in spring, 2018 when more than half of the plants died. The mortality occurred due to a combination of improperly timed watering and late frosts. For the second time, the irrigation system failed only in one half of the south-facing wall. As a result of this failure, all plants in this half died off in spring 2020. Stolen species are not included .

Species	2017		IV/2018				VI/2018		IV/2019				IV/2020			
	planted (pcs)		survived (pcs)		did not survive (pcs)		pcs after second planting		survived (pcs)		did not survive (pcs)		survived (pcs)		did not survive (pcs)	
Cardinal direction	**S**	**E**	**S**	**E**	**S**	**E**	**S**	**E**	**S**	**E**	**S**	**E**	**S**	**E**	**S**	**E**
Arctostaphylos uva-ursi	45	45	0	0	45	42	41	41	20	38	4	1	9	9	15	25
Armeria maritima 'L.'	45	45	16	29	29	10	41	41	27	36	8	0	8	34	19	1
Berberis candidula	45	45	0	1	45	44	x	x	x	x	x	x	x	x	x	x
Cotoneaster dammeri	45	45	0	0	42	23	x	x	x	x	x	x	x	x	x	x
Deschampsia caespitosa 'G.'	x	x	x	x	x	x	41	41	16	39	2	0	2	20	16	8
Festuca glauca	45	45	25	38	10	6	41	41	30	39	11	0	10	30	31	3
Festuca ovina	45	45	34	36	8	9	41	41	30	36	11	0	15	26	26	5
Fragaria vesca	45	45	0	0	42	41	41	41	37	37	2	0	22	32	12	4
Gaultheria procumbens	45	45	0	0	39	23	41	41	7	32	24	4	1	12	30	24
Koeleria glauca	45	45	35	45	10	0	41	41	38	35	3	3	13	15	28	10
Koeleria macrantha	45	45	9	35	26	0	x	x	x	x	x	x	x	x	x	x
Lamiastrum galeobdolon	45	45	0	0	45	45	x	x	x	x	x	x	x	x	x	x
Pachystima canbyi	x	x	x	x	x	x	41	41	7	33	23	6	0	3	30	29
Phleum pratense	45	45	16	15	29	27	x	x	x	x	x	x	x	x	x	x
Phlox subulata	x	x	x	x	x	x	41	41	20	31	15	6	0	2	34	27
Saponaria ocymoides	x	x	x	x	x	x	41	41	22	11	3	19	6	9	15	10
Stipa tenuissima 'P.T.'	x	x	x	x	x	x	41	41	31	33	2	0	29	20	3	8
Thymus serpyllum	45	45	0	0	45	44	41	41	33	37	8	4	3	30	36	2
Cardinal direction	**N**	**W**	**N**	**W**	**N**	**W**	**N**	**W**	**N**	**W**	**N**	**W**	**N**	**W**	**N**	**W**
Andromeda polifolia	45	45	16	0	27	45	41	41	22	30	2	1	18	26	4	5
Campanula poscharskyana	x	x	x	x	x	x	41	41	40	36	0	2	34	6	6	18
Deschampsia caespitosa 'G.'	x	x	x	x	x	x	41	41	41	41	0	0	36	38	0	3
Euonymus fortunei 'E.G.'	45	45	0	0	44	45	41	41	40	31	0	0	36	24	2	7
Festuca glauca	45	45	0	19	44	23	41	41	30	37	4	2	29	37	4	2
Festuca ovina	45	45	44	29	1	15	41	41	35	35	4	2	35	29	4	6
Fragaria vesca	45	45	17	1	6	44	41	41	34	34	2	0	17	29	6	2
Juniperus communis 'R.'	45	45	0	0	33	45	x	x	x	x	x	x	x	x	x	x
Koeleria glauca	45	45	37	45	2	0	41	41	29	37	12	4	25	30	13	7
Koeleria macrantha	45	45	24	8	11	18	x	x	x	x	x	x	x	x	x	x
Lamiastrum galeobdolon	45	45	0	0	45	45	41	41	27	33	4	0	17	11	15	8
Laurocerasus officinalis 'C.'	45	45	0	0	44	45	x	x	x	x	x	x	x	x	x	x
Lysimachia nummularia	x	x	x	x	x	x	41	41	18	37	20	2	15	24	18	15
Pachysandra terminalis	x	x	x	x	x	x	41	41	35	31	2	0	22	19	12	7
Phleum pratense	45	45	13	8	5	37	x	x	x	x	x	x	x	x	x	x
Taxus baccata 'R.'	45	45	0	0	43	45	41	41	40	39	0	0	31	16	3	9
Vinca minor	45	45	0	0	45	45	41	41	36	37	0	0	36	35	0	0

Abbreviations used for cultivars: *Armeria maritima* 'L.' ('Leuchtendrosa'), *Deschampsia caespitosa* 'G.' ('Goldtau'), *Stipa tenuissima* 'P.T.' ('Pony Tails'), *Euonymus fortunei* 'E.G.' ('Emerald ‚n' Gold'), *Juniperus communis* 'R.' ('Repanda'), *Laurocerasus officinalis* 'C.' ('Caucasica'), *Taxus baccata* 'R.' ('Repandens')

S = South, E = East, N = North, W = West

the next month was hot, with mid-April temperature above-averages reaching up to 25 °C. Due to a defect in the automated irrigation system, the plants were left unwatered for three hot weeks. Due to the extremely stressful environment a large number of plants died off and it was necessary to replace them. Some evidently non-promising species were excluded from observation and replaced by new additional species.

New plants were delivered in July 2018. The 2018 summer averages fluctuated around 25 °C, however, there were maxima often reaching almost to 35 °C. For the rest of 2018, the Central European climatic conditions kept the normal. The 2018/2019 winter temperature averages were above-normal, with the lowest fluctuating around zero. The 2019 vegetation period average temperatures reflected the climatic conditions of Central Europe being close to normal. The winter of 2019/2020 was warmer again; the average temperature just rarely dropped below zero. The fluctuating temperatures of March 2020 were stressful for many of the plants. In the spring of 2020, characterized by continuous temperature above-averages, the automated irrigation system was damaged in the centre of the south-facing wall, and most of the plants died.

RESULTS

The south-facing vertical garden

The evaluation of the plants survivability on the south-facing wall was influenced by the irrigation system failure in the spring of 2020. All grass species that showed a high vigour in spite of the irrigation failure were evaluated as the most suitable plants regarding their survivability. As regards perennials, solely *Fragaria vesca* proved to be suitable. Concerning the other plant species, not even 10 seedlings survived per each species (Table 1).

Fig. 3 demonstrates the evaluation of the individual plant species grown in the south-facing vertical garden. *Armeria maritima* 'Leuchtendrosa' reached the highest rating. The only disadvantage was that the species fit into the composition more slowly. *Fragaria vesca* and *Thymus serpyllum* are perennials that can also be recommended for south-facing vertical gardens. Although *Fragaria* does not look aesthetically pleasing in the winter time, it is a vigorous and richly blooming plant. Moreover, it has ornamental fruits during the entire vegetation period. *Thymus* spreads very quickly and fits into the composition, producing ample tiny flowers.

Grasses seem to be the most promising plant species for vertical gardens implantation. They reached the highest rating on the south-facing wall. *Stipa tenuissima* 'Pony Tails' and *Deschampsia caespitosa* 'Goldtau' were assessed as the most valuable from the evaluated grass species. When in bloom, both these species give interest to the garden and look ornamental during the whole winter. These large grasses fit into the composition quickly and look impressive.

Arctostaphylos uva-ursi and *Gaultheria procumbens,* both woody plants, seem to suit vertical gardens adequately. Both of them achieved a similar rating, but

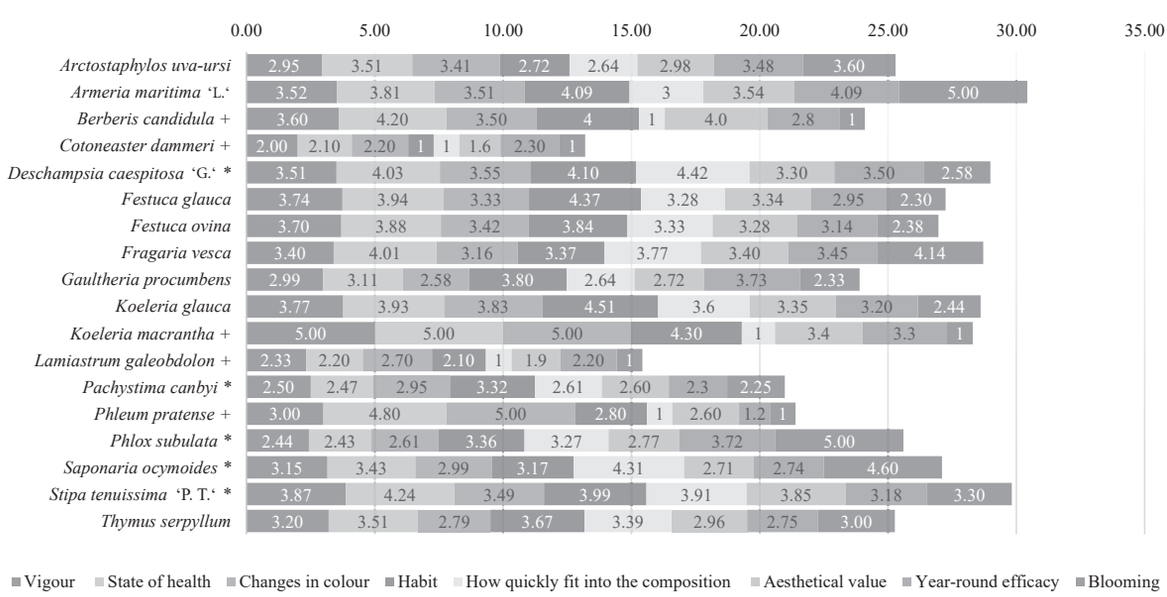

Fig. 3. Comparative point evaluation of individual species grown on the south-facing green wall from November 2017 to May 2020
[+]plants excluded from observation in April 2018
[*]plants included into observation in July 2018

they were not vigorous continuously and did not join the composition quickly. The benefit of *Gaultheria* is that it looks attractive all over the year. Red fruits make the plant decorative throughout the winter. Another woody plant, *Pachystima canbyi*, performed below average.

Phlox subulata and *Saponaria ocymoides* rated the worst in the total sum of points. It was particularly *Phlox* that showed low vigour, and many plants died. *Saponaria* did not do well in winter, as the plant dies down to the ground level in winter and the above-ground part dries up. However, both species produced abundant rich bloom and grew fast.

The species *Berberis candidula, Cotoneaster dammeri, Koeleria macrantha, Lamiastrum galeobdolon* and *Phleum pratense* were excluded from the experiment as early as in April 2018, particularly because they neither thrived, nor looked well in general in the vertical garden. *Koeleria macrantha* was excluded because of being very similar in appearance to *Koeleria glauca.*

The east-facing vertical garden

As regards mortality of grasses on the east-facing wall, only *Festuca glauca* and *Festuca ovina* exhibited an excellent performance. The perennials on the east-facing wall thrived much better than those on the south. The following species exhibited a very low mortality: *Armeria maritima* 'Leuchtendrosa'*, Fragaria vesca* and *Thymus serpyllum.* Contrarily, the species *Pachystima canbyi* and *Phlox subulata* cannot be recommended at all for growing in the substrate with the self-irrigation system used in this experiment (Table 1).

As shown in Fig. 4, the species grown on the east-facing green wall were identical with those south-facing. Like on the south-facing wall, *Armeria maritima* 'Leuchtendrosa' ranked the best also under the east-facing condition where it reached even better results. Both *Fragaria vesca* and *Thymus serpyllum* were graded very high in this case, and they reached better results, equal to *Armeria.* All plants on the east-facing wall were more vigorous and fit into the composition more quickly than on the south wall. As opposed to the south-facing wall, most plants began to bloom one or two weeks later. Other species reached a similar rating on the east-facing wall, and their efficacy was similar to plants of the south-oriented wall.

The north-facing vertical garden

In terms of mortality, all experimental grass varieties exhibited an excellent performance on the north-facing wall, except for *Phleum pratense* which was excluded from testing as early as in spring 2018. Mortality of *Deschampsia caespitosa* 'Goldtau' was more or less average. Zero mortality was recorded only in case of *Vinca minor*. The species *Campanula poscharskyana, Euonymus fortunei* 'Emerald 'n' Gold' and *Taxus baccata* 'Repandens' showed a very high percentage of survival. Though *Andromeda polifolia* and *Fragaria vesca* exhibited a very low mortality. Not many surviving plants were left because many pieces had been stolen (Table 1).

Fig. 5 demonstrates the evaluation of individual plant species grown in the north-facing vertical garden.

'L.'

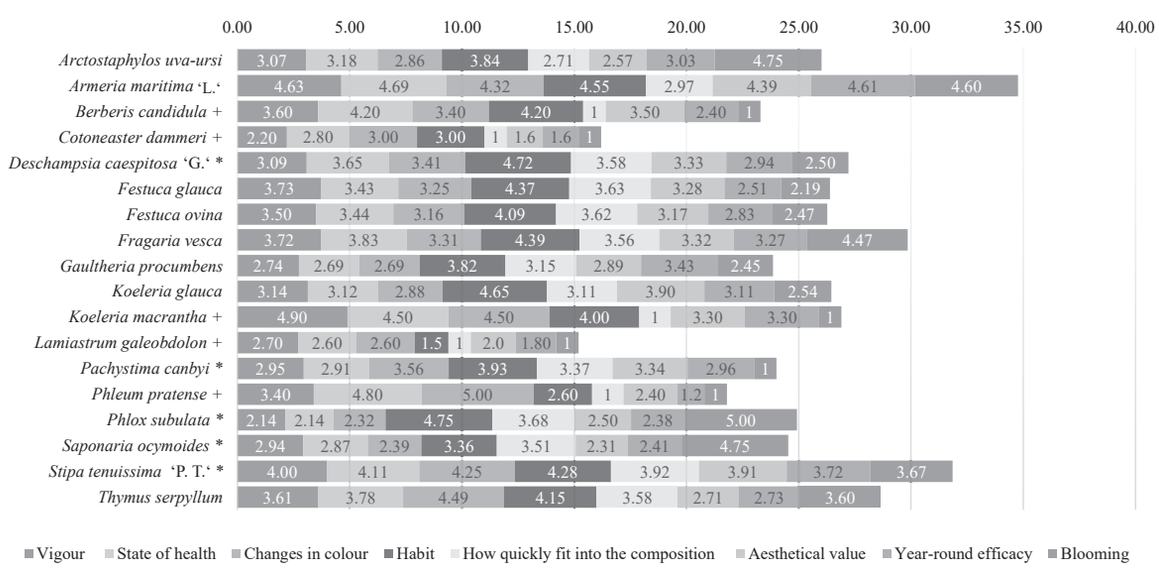

Fig. 4. Comparative point evaluation of individual species grown on the east-facing green wall from November 2017 to May 2020
[+]plants excluded from observation in April 2018
[*]plants included into observation in July 2018

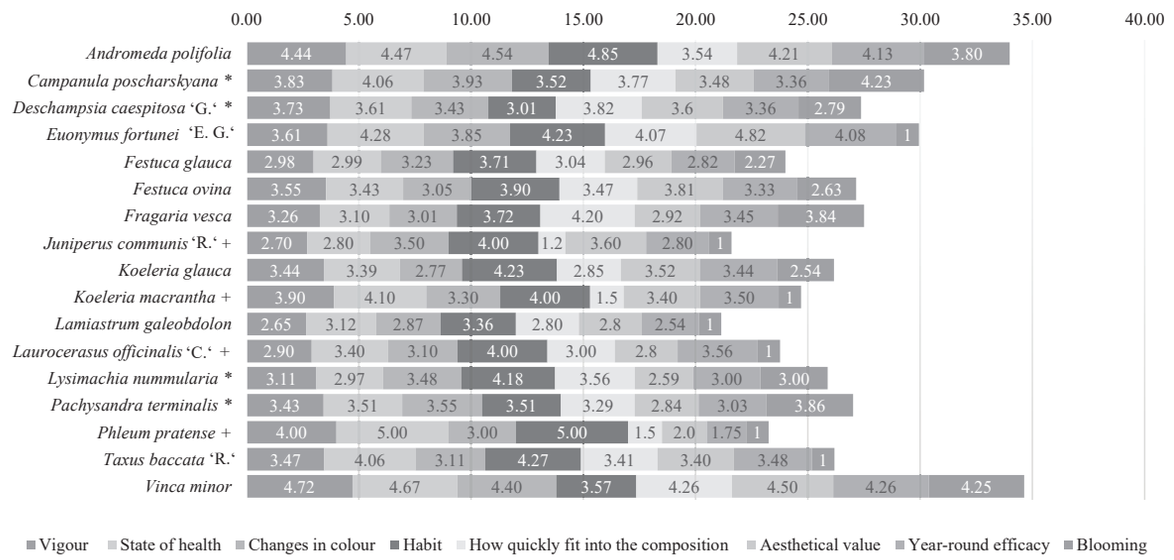

Fig. 5. Comparative point evaluation of individual species grown on the north-facing green wall from November 2017 to May 2020
[+]plants excluded from observation in April 2018
[*]plants included into observation in July 2018

Vinca minor was evaluated as the best suited plant for the north orientation. *Andromeda polifolia* reached almost the same evaluation. Though most plants of *Vinca minor* died after extremely stressful conditions in spring 2018, new plants grew vigorously during further observation. The plants showed a high vigour throughout the year and looked aesthetically pleasing even in winter. The blooms were reasonably lush and looked striking. *Andromeda polifolia* fit in with the garden composition very quickly and was vigorous. It looked very impressive all over the year, particularly while in bloom. Though the blooms were tiny, they looked impressive and lush.

Campanula poscharskyana and *Euonymus fortunei* 'Emerald 'n' Gold' were rated high as well. *Campanula* showed a high vigour, fit in with the composition very fast, and formed dazzling waterfalls bearing loads of starry violet-blue flowers. However, this perennial plant dies down to the ground level in preparation for winter, and its above ground parts die off. It looks impressive only during the vegetation period. *Euonymus* was vigorous and fit into the composition very quickly. Being an evergreen, it enriched the vertical garden and outfitted it in splendour. Its leaves were radiantly yellow during the entire vegetation period and turned crimson red for winter, looking amazing.

On the north-facing wall, grasses achieved a relatively high rating as well. Again, *Deschampsia caespitosa* 'Goldtau' was evaluated as the best plant.

Other plants that scored relatively high were *Fragaria vesca, Lysimachia nummularia, Pachysandra terminalis* and *Taxus baccata* 'Repandens'. *Fragaria* showed low vigour on the north-facing wall and bloomed less than on the east-facing one. In spite of this, it was evaluated very positively on the wall. In the first year of measuring, *Lysimachia* showed high vigour during the vegetation period and grew very fast. Its yellow blooms enriched the garden in an interesting way. However, the plant died down over winter and thus only long cascading shoots were left that looked aesthetically pleasing only from farther distances. During the second year, *Lysimachia* did worse on the north wall. It showed lower vigour and had less shoots. Therefore, it failed to fit into composition sufficiently and almost did not bloom. *Pachysandra* looked good throughout wintertime due to its shiny leaves. However, only a third of these plants came into bloom, and thus, its overall effect mitigated. *Taxus* seemed to be a relatively vigorous woody plant and achieved high rating, particularly because of being an evergreen.

Lamiastrum galeobdolon was one of the plants that scored worst. It cannot be recommended for north-facing vertical gardens. This plant died down in preparation for winter and was neither vigorous, nor aesthetically pleasing during the vegetation period. On top of that, it barely bloomed.

The species *Juniperus communis* 'Repanda', *Koeleria macrantha, Laurocerasus officinalis* 'Caucasica' and *Phleum pratense* were excluded from experiment as early as in April 2018, particularly because they failed to prosper and were not overall effective in the vertical garden. *Koeleria macrantha* was excluded because it looked very similar to *Koeleria glauca.*

The west-facing vertical garden

The west-facing garden plants' mortality was very similar to that of the north-facing plants but for

Deschampsia caespitosa 'Goldtau' exhibiting much lower mortality and *Campanula poscharskyana* showing a very high mortality (Table 1).

The species grown on the west-facing wall were identical to those grown on the north-facing one, the results are shown in Fig. 6. The species *Andromeda polifolia* and *Vinca minor* were evaluated as the best west-facing plants. Other tested species were evaluated almost identically to those grown on the north-facing walls.

Campanula poscharskyana scored differently. This species was much less vigorous on the west-facing wall and thus fitting poorly into composition. The plant rather had single flowers and did not form waterfalls bearing loads of starry violet-blue flowers as on the north-facing wall.

DISCUSSION

Vertical gardens are often established due to their ability to improve the surrounding microclimate. Therefore, the most suitable plants supporting this function and able to withstand extreme conditions should be identified. According to M a r e c e k (1992), plants with large leaves are the best to increase air humidity. For air filtration, he recommends plants with small, hairy or horizontally arranged leaves. This means that all grass surfaces, including vertical, formed especially by low ornamental grasses, will have the highest filtration capacity. D a r l i n g t o n et al. (2001) have compiled a list of plants that, together with the substrate, are able to degrade volatile organic compounds, but only plants growing indoors were included. According to W o o d (2003), specific plant species have the ability to break down atmospheric pollutants from the air, but again these are only indoor plants. It would be appropriate to carry out this research on outdoor plants as well. Vertical gardens perfectly meet the aspect of low vegetation with a large leaf area which, according to M a r e c e k (1992), form the most suitable surface for producing higher amounts of oxygen.

The choice of species suitable for a vertical garden depends primarily on the choice of the cultivation system and the garden orientation to the cardinal directions. To plant a green wall with domestic flora, one could keep the assortment of plants given in the Catalogue of Habitats of the Czech Republic (C h y t r y et al., 2001). B l a n c (2012) recommends planting vertical gardens with native species that occur on rocks, i.e., in a vertical position. This recmmendation best meets the habitat of Cliffs and screes as classified by C h y t r y et al. (2001) who mentioned the fact that habitats can be sunny, but also significantly shady. This results in a whole range of plants capable of growing in rock crevices, usable for all world orientations of green walls. From the habitat of Cliffs and screes, the prosperity of the species *Taxus baccata, Festuca ovina, Galeobdolon luteum, Fragaria vesca* has already been verified. The habitats of Meadows and pastures (C h y t r y et al., 2001) seem to be a suitable resource of plants for both wet and dry habitats with soils either poor or rich in nutrients. The species

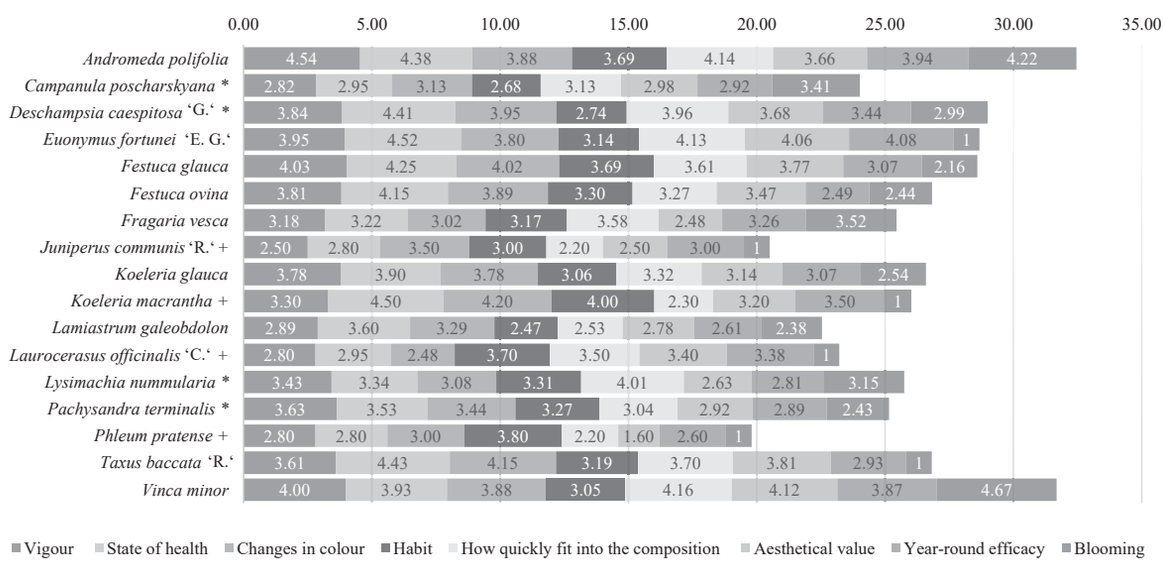

Fig. 6. Comparative point evaluation of individual species grown on the west-facing green wall from November 2017 to May 2020
+plants excluded from observation in April 2018
*plants included into observation in July 2018

Deschampsia caespitosa, Lysimachia nummularia and *Phleum pratense* have already been tested in the research. Dry grasslands are another promising place where to select the plants. Their typical genera *Festuca* ssp. and *Stipa* ssp. were also included in our study. In the future research, some species referring to Forest edge habitats growing in naturally shallow and dry soils (Chytry et al., 2001) could be used. Some plants from the habitat Ephemeris and succulents are also ideal candidates for further testing because the growing conditions in vertical gardens are similarly extreme. We have already tested *Festuca* ssp. and *Koeleria macrantha*. Concerning woody species, the plants of Low xeric scrub habitats can be used. The Catalogue of Habitats of the Czech Republic covers a number of species from the mentioned habitats standardly used in horticultural practice and their further testing in green walls can be promising.

Woody plants belong to the under-represented plants in vertical gardens. Some species (e.g., *Euonymus fortunei, Pachysandra terminalis* and *Vinca minor*) have already been tested elsewhere. In an experiment carried out by Swoczyna et al. (2020), *Euonymus fortunei* 'Emerald 'n' Gold' was grown on the south-facing wall, and its mortality was around 50 %. However, in our experiment it reached above-average results on the west-facing and east-facing walls. Pejchal (2011) recognized *Euonymus fortunei* 'Emerald 'n' Gold' a vigorous or adequately vigorous woody plant. In our experiment, *Pachysandra terminalis* exhibited a very low mortality as opposed to Swoczyna et al. (2020) reporting only a 27.7% plants survival. In the experiment carried out by Skarzynski et al. (2014) this species developed a good coverage. Pejchal (2011) reported on its average vigour. Swoczyna et al. (2020) mentioned a ca. 40% survival rate of *Vinca minor* on the south-facing wall. However, on the west-facing and north-facing walls it exhibited the best survivorship of all plants.

Perennials are the most represented vegetation group of vertical gardens. We have compared some literature results on vertical garden growing of *Armeria maritima, Fragaria vesca* and *Lysimachia nummularia* with our own results. Martensson et al. (2014) and Swoczyna et al. (2020) verified that in the south-facing garden the survivorship of *Armeria maritima* depends on cultivar, fluctuating between 66.7 and 93.3 %. In our experiment, *Armeria* exhibited an average mortality during the first two years and achieved an excellent rating on the west-facing wall. It was impossible to precise the values attained on the south-facing wall because many plants have often been stolen here. *Fragaria vesca* thrived in all cardinal directions. This plant exhibited a high survivability (70 % on average), similarly to studies by Pejchal (2011) and Swoczyna et al. (2020). According to Martensson et al. (2014), *Fragaria* did not look aesthetically pleasing on the whole. However, thanks to its ornamental fruits and flowers it is an interesting ground cover plant. To recommend *Lysimachia nummularia* for a long-term growing in green walls is disputable. It was not aesthetically pleasing during wintertime and required maintenance each spring to improve its appearance. As opposed to that, Pejchal (2011) evaluated it as a suitable high-vigour plant, but that is to say that in this case the plant was monitored only on a one-time basis in vegetation.

Ornamental grasses are often used in green walls mainly for their stability and durability. In our research, *Festuca ovina* was evaluated suitable for vertical gardens due to its very high vigour. This is in line with Skarzynski et al. (2014) who also appreciated its spreading vigour. *Koeleria glauca* exhibited steady good results during our entire experiment except for the last monitored period during the third year. Its aesthetic appeal diminished and about ten plants died off, depending on the cardinal directions. Contrarily, Swoczyna et al. (2020) stated the vigour of this plant still reached over 80 % during the third year of monitoring.

CONCLUSION

The species *Deschampsia caespitosa* 'Goldtau', *Festuca glauca, Festuca ovina, Fragaria vesca* and *Koeleria glauca* are the best choice for all cardinal directions in vertical gardens with substrate. However, all of them have to be cultivated at least once a year to keep their aesthetic value. For the south and east orientation, we can recommend *Arctostaphylos uva-ursi, Armeria maritima* 'Leuchtendrosa', *Stipa tenuissima* 'Pony Tails' and *Thymus serpyllum*. The species suited for the north- and west-facing vertical gardens appear to be *Andromeda polifolia, Euonymus fortunei* 'Emerald 'n' Gold', *Pachysandra terminalis, Taxus baccata* 'Repandens' and *Vinca minor*, all of them adding the value of evergreens. *Campanula poscharskyana* can be recommended only for the north orientation and *Lysimachia nummularia* thrived just when westward-oriented.

To conclude, the aforementioned plants can be recommended for vertical gardens in the climate of the Czech Republic/Central Europe; however, only if planted in a wall with the correct cardinal direction and substrate system.

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