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Short communication

# Plant performance in living wall systems in the Scandinavian climate

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## 1. Introduction

The concept of green façades is not new (Koehler, 2008), but their reintroduction may offer benefits in the current urban design, which is increasingly focused on urban densification. The benefits of vertical greening include noise abatement (Van Renterghem et al., 2013), filtering of airborne dust and pollutants (Ottele et al., 2010; Sternberg et al., 2010), and reduction of temperature close to the area of vertical greening (Onishi et al., 2010; Wong et al., 2010; Perini et al., 2011a). The thermal aspects of vertical greening are, however, still under debate (Hunter et al., 2014). One particular type of green façade is living wall systems, which are vertical greening systems where plants are grown without the need for contact with the ground (Koehler, 2008; Francis and Lorimer, 2011; Perini et al., 2011b).

Living wall systems can be seen as an alternative way of introducing urban greening in dense urban areas in the same way as e.g. green roofs, which have shown to support a high arthropod diversity (Rumble and Gange, 2013; Madre et al., 2013). Like plants on green roofs (Emilsson and Rolf, 2005; Emilsson, 2008), plants in living wall systems must be able to cope with extreme conditions, such as high irradiation, considerable differences in temperature and possible water shortage.

The main aim of this study was to determine whether it is possible to grow perennial plants in living wall systems in the Scandinavian climate and we hypothesized that perennial plants could survive in, and would be a viable option for, living wall systems in the Scandinavian climate.

## 2. Materials and methods

### 2.1. Location of the study

A full-scale field experiment was carried out in an industrial area in Malmö, SW Sweden (GPS WGS 84 decimal lat. N55.6108, long. E12.9896). The living wall systems were installed on the masonry wall of a building completed in 1937, facing a southern direction of 172°, approximately 8 metres above ground, to ensure full sun and wind exposure. The site is located in a region with a humid continental climate (Peel et al., 2007), with a local mean annual temperature of 8.7 °C (in both 2012 and 2013), maximum temperature of 30.6 °C (19 Aug 2012) and 29.3 °C (28 Jul 2013), minimum temperature of −14.6 °C (4 Feb 2012) and −15.8 °C (25 Jan 2013) (Swedish Meteorological and Hydrological Institute (SMHI), 2014). The local mean annual precipitation was 574 mm in 2012 and 596 mm in 2013.

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### 2.2. The living wall systems

Two living wall systems were investigated: a Rockwool panel system (RS) and a pumice-filled pocket system (PPS). The RS consisted of 12 prefabricated panels (Vertigreen™, Zinco GmbH) measuring 70 × 50 × 7 cm. The panels contained sheets of Rockwool, and had a plastic cover with predrilled planting holes with a layer of felt at the back for water transport. Each module was designed to have 45 planting holes, 9 large and 36 small. The distance between the large holes was 11.5 and 8.5 cm, the small holes were placed at a distance of 2.5 cm from the large holes. All the large holes were planted, but only two small holes in each section, i.e. six small holes in each module. Cylindrical holes with diameters of 75 and 30 mm were drilled in the Rockwool, to a depth of approximately 4 cm. A single plant was planted in each drilled hole. The plants were distributed so as to ensure that all species were present at all positions in both systems; i.e. the middle, top, bottom and sides. The PPS consisted of 10 on-site constructed felt pocket modules, which were constructed from a capillary mat (Klaver 300 g/m$^2$) and a waterproofed plywood board. Each module measured 60 × 60 cm, and contained 9 pockets, each with a volume of approximately 1500 cm$^3$. Each pocket was filled with pumice and compost (10 vol.%), and either one or two plant species was planted in each pocket to replicate the plant distribution in the RS.

### 2.3. Planting

One individual of the following was planted in the RS (12 replicates) and at the corresponding position in the PPS (10 replicates): *Achillea millefolia* (Ami), *Antennaria dioica* (Adi), *Armeria maritima* (Ama), *Aubretia × cultorum* (Acu), *Bergenia cordifolia* (Bco), *Carex morrowii* (Cmo), *Dianthus deltoides* (Dde), *Fragaria vesca* (Fve), *Iberis sempervirens* (Ise), *Iris sibirica* (Isi), *Molinia caerulea* (Mca), *Nepeta faassenii* (Nfa), *Pilosella aurantiaca* (Pau), *Salvia nemorosa* (Sne), *Sesleria heuffleriana* (She), and *Stachys byzantina* (Sby). The soil was washed off the plant roots prior to planting in the RS in order to achieve good contact with the substrate. The substrate in the PPS contained compost and the substrate on the plants at deliver was only shaken off before planting. The growth substrate in both systems was generously irrigated before and after planting. Planting was carried out on 15th June 2012.

### 2.4. Irrigation and fertilization

During the rest of 2012, both systems were irrigated for 10 min, three times a day; in the evening, night and morning. From the start of 2013, the PPS was irrigated for 15 min twice a day; in the evening and night, and the RS for 1 h every other day. The total water storage of the RS was higher than in the PPS, which also have a higher permeability. Thus, the RS could be irrigated with larger volumes at more sparse intervals without risk of increasing runoff. In 2012, approximately 20 ml liquid fertilizer (Blomstra, Cederroth Sverige AB) was added to each module in both systems, twice during the growing season (from June to September): once, one week after planting and then again after another month. This fertilization was a low establishment dose, one fourth of the recommended, aimed to secure a well-developed rooting system. However, this mode of distribution caused a decreasing growth from the top to the bottom of the systems and fertilization was not distributed hydroponically the following year. Approximately 16 ml liquid fertilizer was added to each module in both systems each month during the growing season of 2013, distributed as 4 ml portions in 4 places across the modules. This is equivalent to a full nutrient fertilization, however, in the low range.

### 2.5. Data collection and statistical analysis

Plant visual quality was assessed on a scale from 0 to 4, as modified from Zollinger et al. (2006), in June and August 2012 and in April, June and August in 2013. Gradations were: 0 = 100%, 1 = >50%, 2 = <25%, 3 = <10%, and 4 = 0% dead or wilted leaves. The area covered by vegetation was measured (vertical × horizontal direction) in June 2012, August 2012 and June 2013. The Wilcoxon signed rank test (IBM SPSS Statistics 20) was used to test the difference between plant visual qualities in the two systems.

## 3. Results

The overall quality of the plants differed between the two living wall systems investigated in June 2012, April 2013 and August 2013 (Table 1). The overall visual quality was better in the RS than in the PPS in both June 2012 and April 2013. However, the visual quality was better in the PPS in August 2013. The overall covered area was greater in the PPS than in the RS on all occasions (Table 2).

The individual visual quality of the 16 plant species used in the experiment (Table 3), 5 species: *Bco*, *Cmo*, *Fve*, *Ise* and *Nfa* had a better visual quality in the RS than in the PPS in June 2012, just after planting. *Ami* and *Dde* showed the opposite behaviour, i.e. better quality, in the PPS in June 2012. *Mca* and *Sby* showed a better quality in the RS than in the PPS in August 2012, towards the end of the growing season. *Bco*, *Cmo*, *Dde*, *Nfa*, *Pau* and *She* had a better quality in the PPS in August 2012.

*Adi* and *Sby* had a better quality in the RS than in the PPS in April 2013, after the winter. *Adi*, *Cmo* and *Fve* had a better quality in the RS than in the PPS in June. *Ami*, *Bco*, *Dde*, *Nfa* and *She* had a better quality in the PPS than in the RS in June 2013. *Fve* had a better quality in the RS than in the PPS in August 2013. *Ami* and *Nfa* had a better quality in the PPS than in the RS in August 2013. No significant difference in quality was found for *Ama*, *Acu*, *Isi* or *Sne* in the two systems investigated.

In June 2012, the area covered by *Acu*, *Isi*, *Mca*, *Nfa*, *Sne*, *She* and *Sby* was significantly larger in the PPS than in the RS. *Acu*, *Bco*, *Cmo*, *Dde*, *Isi*, *Sne* and *Sby* covered a larger area in the PPS at the end of the growing season (August 2012). *Ama* showed the opposite behaviour, and covered a significantly larger area in the RS in August 2012. In June 2013, no significant differences were found between the systems regarding the area covered. *Ami*, *Adi*, *Fve*, *Ise* and *Pau* did not show any significant difference in coverage between the two systems at any time (Table 4).

## 4. Discussion

We have shown that perennial plants can survive in living wall systems in the climate of southern Sweden. The experiment was performed on a south-facing wall, with a highly variable climate including cold winter and spring, and hot dry summers. Most species performed well – in terms of visual quality or large cover area – in both systems, but *Acu*, *Cmo*, *Fve*, *Isi* and *Sby* performed poorly in this experiment. However, the partially evergreen character of *Cmo*, the flowering of *Isi* and *Ise* and the fruiting of *Fve* may make them desirable among perennial plants for green walls, despite their poor performance. These examples illustrate the difficulty of using only quality and coverage as parameters to describe plant performance.

The better quality in the RS during the establishment period and the first growing season, as well as the early spring in 2013, may be explained by better contact between the growth substrate and the roots, and a higher water holding capacity, in the Rockwool than in the pumice. Air-filled space in the mixture of pumice and compost