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# Microclimatic conditions of 'Green Walls', a new restoration technique for steep slopes based on a steel grid construction

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ABSTRACT

The greening of shotcrete walls represents a major challenge due to the extreme environmental conditions for plants and its technical implementation aiming to establish a sustainable vegetation layer. The objective of the study was to assess the performance of an innovative 'Green Wall' system (double-layered, integrated irrigation, filled with excavation material, application on vertical inclination) with respect to its microclimatic characteristics.

The measurement campaign was conducted from June 2015 to September 2016 in Plon (Steinach am Brenner, Tyrol, Austria). Microclimatic parameters (air temperature, air humidity, short-wave radiation, substrate temperature and wall surface temperature) were investigated by sensors installed in different layers of the greenery system, as well as in a control area (bare concrete wall).

Results indicated a pronounced insulation effect of the 'Green Wall' system during summer and wintertime. Analyses in July 2015 (30% vegetation cover) and July 2016 (100% vegetation cover) indicated that reductions of temperature fluctuations were predominately attributable to the substrate layers of the greenery system and less to the vegetation cover. Furthermore, reductions of albedo (reflectivity) and heat stress were achieved.

In conclusion, the 'Green Wall' system is a promising technique with positive effects regarding temperature and radiation as well as human thermal sensation and therefore recommendable for use also in urban areas. In rural areas it helps to optimize landscape aesthetics, as even vertical slopes can be greened.



## 1. Introduction

The continuing expansion of traffic and transport systems is accompanied by a rise in the number of steep slopes, representing a widely visible disturbance in the landscape. Thus, an ecologically oriented and sustainable solution to well integrate these slopes into the landscape is required. Soil bioengineering methods are well suited for the visual integration of engineering structures enabling vegetation according to the landscape nature and structure (Bloemer et al., 2015), since they can be used for restoration works (e.g. in quarries and natural rocky slopes) fulfilling ecological (improvement of landscape) as well as protective (e.g. from rockfall, erosion, enhanced surface flow) functions (Beikirchner et al., 2009).

Despite technological developments of recent years, the sustainable greening of steep slopes still poses a particular challenge for soil-bioengineering approaches due to extreme environmental conditions (Obriejetan, 2015). Thus, the choice of a proper greening method is crucial for successful bioengineering solutions. Since steep slopes, like shotcrete walls, can have inclinations of almost 90° the only effective greening method is some kind of vertical greenery system, which according to Ottelé et al. (2010), fit in the principle of ecological engineering (Odum, 1996; Odum and Odum, 2003; Mitsch, 2012) by developing new sustainable ecosystems (Mitsch and Jørgensen, 2003). A 'Green Wall' has aesthetical, ecological and environmental benefits, and can be seen as an ecological project assisting ecological protection and restoration (Cai et al., 2015). It provides a mimicry of vertical natural habitats, increasing heterogeneity and habitat diversity for plants and anthropods

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**Fig. 1.** Field experiment on the shotcrete wall along a highway exit. (A) Shotcrete wall without greenery system in May 2015 and (B) three months after installation in September 2015.

(Madre et al., 2015; Lundholm and Richardson, 2010). Numerous research projects have shown that plants contribute significantly to the regulation of urban climate, store water in their substrates and essentially improve air quality (Doick and Hutchings, 2013; Hunter et al., 2014; Manso and Castro-Gomes, 2015; Scharf and Simon, 2015; Zupancic et al., 2015; Jim, 2015; Schettini et al., 2016; Vox et al., 2016). Thus, vertical greening methods are already used in cities also to counterbalance the urban heat island (UHI) phenomenon (Wong et al., 2010; Stec et al., 2005). UHI can be mitigated by vegetation due to its shading effect and evapotranspiration from the leaves especially in summertime (McPherson, 1994; Slingerland, 2012; Safikhani et al., 2014; Stec et al., 2005), while in wintertime, the presence of plants acts as thermal insulation (Vox et al., 2016). In cities, greening is particularly interesting in terms of heat stress, which poses a serious environmental risk to human's health and well-being (Walikewitz et al., 2015; Kjellstrom and McMichael, 2015). The most important meteorological variables concerning thermal sensation and heat stress are air temperature, relative humidity, wind velocity and mean radiant temperature ($T_{mrt}$). They are required to calculate thermal indices such as the Universal Thermal Climate Index (UTCI, Walikewitz et al., 2015), which provides an assessment of the human reaction to the outdoor thermal environment with respect to heat stress (Bröde et al., 2010). Several studies confirmed that vegetation is a natural tool for controlling microclimatic conditions as it is blocking incoming solar radiation (Perini et al., 2011; Safikhani et al., 2014) and therefore can limit the fluctuations of wall surface temperatures by as much as 50% through the shading effect (Dunnet and Kingsbury, 2008). Additionally, green surfaces have different solar radiation reflection (albedo) compared to artificial hard surfaces (20–30% for vegetation, 5% for asphalt, Perini and Rosasco, 2013; Mariani and Pangallo, 2005). Light surfaces usually are more reflective than dark ones (Akbari, 2009; Häckel, 2012).

The cooling and insulation ability of vertical greenery systems is also valuable in prolonging the lifespan of building façades (Wong et al., 2010), since short- and long-term changes in temperature, lead to uneven internal tensions which often causes cracking in materials like concrete (Weber, 2013). In the last years, this thermal buffering potential has been considered in numerous studies. Hoelscher et al. (2016) detected maximum differences in surface temperatures between greened and bare walls of 15.5 °C, and Wong et al. (2010) found a maximum reduction of 11.6 °C in a free standing wall in Hortpark (Singapore) with vertical greening types. Mazzali et al. (2013) so far measured the highest differences of up to 20.0 °C.

Especially alongside roads, greening systems do also function as a protection from harmful substances by keeping away corroding substances like sodium chloride (NaCl), contained in de-icing salt solutions, leading to pitting corrosion on reinforcing steels (Weber, 2013; Hensen et al., 2009). Thus, plants for greening methods in such locations have to be chosen carefully and must be resistant against environmental influences like de-icings salts or exhaust gases.

This study was conducted from June 2015 to September 2016 and focused on the greening of shotcrete walls along traffic infrastructure, which is an enormous challenge due to the high inclination of almost 90°. Up to now, research only dealt with this kind of greenery system in case of slopes with angles of 30° at a maximum on solid ground and 70° on natural soil (Obriejetan, 2013). As a result of the exposed position, extreme wall surface temperatures are reached, and plants have to cope with reduced soil depth and water supply and the impact of de-icings salts. We tested a greenery system, which consists of a galvanized double-layered steel grid construction that is mounted on a wall with an inclination of at least 85°, filled with substrate and combined with an integrated automatic irrigation system. Since this kind of greenery system was first invented in 1987, information about long-term stability is not available yet, but its lifetime is expected to be 40–50 years (galvanized) respectively 70–80 years (additional protection by plastic coating, Krismer GmbH, personal communication, December 14, 2016). The used substrate was gained in the course of a nearby tunnel construction (Brenner Base tunnel, Austria/Italy), trying to determine if a recycling of the excavation material for greening purposes is possible.

The objective of this study was to assess the performance of the greening system in this new way (double-layered, inclination, integrated irrigation, excavation material) with respect to its microclimatic characteristics. Microclimatic conditions (air temperature, air humidity, short-wave radiation, substrate temperature and wall temperature) of the 'Green Wall' and a shotcrete wall without a greenery system were compared and UTCI was calculated.

## 2. Material and methods

### 2.1. Installation of experimental plots

In June 2015, a shotcrete wall along a highway exit was selected for the field experiment (Fig. 1). Therefore, right next to an uncov-