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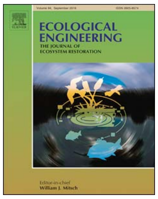

Research Paper

Comparative experimental approach to investigate the thermal behaviour of vertical greened façades of buildings

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ABSTRACT

Greening the building envelope is not a new concept, however it has not been fully approved as an energy saving method for the built environment. Vertical green can provide a cooling potential on the building surface, as plants are functioning as a solar filter and prevent the adsorption of heat radiation of building materials extensively. In this study a comparative thermal analysis of vertical green attached to a façade element is presented. An experimental set up (stationary conditions) has been developed to measure the temperature gradient through a reference cavity wall, in order to quantify the contribution of vegetation to the thermal behaviour of the building envelope. The results show temperature differences between the bare wall and between the different vertical greening systems analysed, up to 1.7 °C for the direct greening system and 8.4 °C for the living wall system based on planter boxes after 8 h of heating for summer conditions, due to the different "material" layers involved. However, the insulation material of the bare wall moderates the prevailing temperature difference between the outside and inside climate chamber, resulting in no temperature difference for the interior climate chamber for summer conditions.

1. Introduction

In dense urban areas the prevalence of paved surfaces (with low albedo) and a lack of natural vegetation are among the major causes of the phenomenon called urban heat island effect: temperature difference between cities and suburban or rural areas is determined by this phenomenon (Taha, 1997; Dunnett and Kingsbury, 2008). Introducing vegetation back in our cities is a possibility to alter the microclimate in street canyons (Alexandri and Jones, 2008; Hoelscher et al., 2015). Greened paved surfaces intercept solar radiation and can reduce warming of artificial surfaces as asphalt of concrete, thus reducing the urban heat island phenomenon by two to four degrees Celsius (Onishi et al., 2010; Taha, 2008). Outer surfaces of buildings offer a great and unused amount of space for re-introducing vegetation in our cities; green roofs and green façades are possibilities to fulfil this opportunity (Perini, 2013).

Vertical greening systems have a positive influence on the building envelope in terms of thermal performances, as demonstrated by several studies (Pérez et al., 2014; Susorova, 2015). Hunter et al. (2014) show that green façades, like other forms of green infrastructure, are increasingly being considered as a design feature to cool internal building temperatures, reduce building energy consumption and facilitate urban adaptation to a warming climate. In the beginning of the eighties Krusche et al. (1982) estimate the thermal transmittance (U) of a 160 mm plant cover at $2.9\ \mathrm{W\,m^{-2}\,K^{-1}}$. Also Minke and Witter (1982) suggested some ideas to reduce the exterior coefficient of heat transfer. By reducing the wind speed along a green façade they suggested that the exterior coefficient of heat transfer of $25.0\ \mathrm{W\,m^{-2}\,K^{-1}}$ can be lowered to $7.8\ \mathrm{W\,m^{-2}\,K^{-1}}$ which is comparable to the interior coefficient of heat transfer. Holm (1989) shows with field measurements and his DEROB computer model the thermal improvement potential of leaf covered walls. A layer of vegetation, as a green façade made of *Hedera helix* can enhance the thermal performances of buildings also during winter season (Cameron et al., 2014). The authors found the largest savings in energy due to vegetation associated with more extreme weather, such as cold temperatures, strong wind or rain, increasing energy efficiency by 40–50% and enhancing wall surface temperatures by 3 °C. Perini et al. (2011) show the influence of a green layer on the reduction of the wind velocity along the surface of a building. An extra stagnant air layer in optimal situations can be created inside the foliage, so that when the wind speed outside is the same as inside R_{exterior} can be equalized to R_{interior}, where R is the thermal resistance ($\mathrm{m^2\,K\,W^{-1}}$). In this way the building's thermal resistance can be increased by $0.09\ \mathrm{m^2\,K\,W^{-1}}$. Vertical greening systems insulation value can be

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optimized by covering with high density foliage, creating a stagnant air layer behind the foliage (Perini et al., 2011), exploiting supporting system materials and their insulation effect and plant species characteristics (Cameron et al., 2014).

Eumorfopoulou and Kontoleon (2009) reported the temperature cooling potential of plant covered walls in a Mediterranean climate; the effect was up to 10.8 °C. Another recent study by Wong et al., 2010 on a free standing wall in Hortpark (Singapore) with vertical greening types shows a maximum reduction of 11.6 °C. The green plant layer will also reduce the amount of UV light that will reach building materials, since by constructing green façades great quantities of solar radiation will be adsorbed for the growth of plants and their biological functions (Krusche et al., 1982). Since UV light deteriorates the mechanical properties of coatings, paints, plastics, etc. plants will also affect durability aspects of constructions (Wong et al., 2010). However, in the case of green façade directly attached, climbing plants may deteriorate the building envelope outer layer, especially in the case of plaster walls (Perini and Rosasco, 2013; Bellomo, 2003).

Susorova et al. (2014) demonstrate that façade orientation plays an important role as well for cooling capacity due to shadow and evapotranspiration provided by plants. In addition, studies show a potential energy saving for air conditioning that can be obtained with vertical greening systems up to 40–60% in Mediterranean area (Alexandri and Jones, 2008; Coma et al., 2014; Mazzali et al., 2013, 2012; Scarpa et al., 2014).

The discussed studies, showing the potential effects of vertical greening systems on the microclimate, are all done under variable environmental conditions.

The present study aims to classify the thermal benefits of green façades or plant covered cladding systems under boundary conditions. The results of this study can be used for giving evidence of the effects of vertical green as an “extra insulation” layer”, to support the decision process for architects, building owners, etc. This “technical/thermal green” strategy of increasing exterior insulation properties of vertical surfaces stimulates upgrading or retrofitting of existing (under-insulated) façades without the added cost of interior or traditional exterior insulation systems. An insulation material mitigates the impact of the created temperature difference between inside and outside (Hagentoft, 2001). In the research work done by Eumorfopoulou and Aravantinos (Eumorfopoulou and Aravantinos, 1998), it was found that a planted roof contributes to the thermal protection of a building but that it cannot replace the thermal insulation layer. From a scientific point of view it is relevant to verify if this effect is also valid for green façades.

A comparison between a bare façade and a plant covered façade is investigated in order to quantify the contribution of vegetation to the thermal behaviour of the building envelope, with three different greening systems applied (a direct green façade and two different living wall systems), during summer and winter seasons.

The experimental study aims at identifying differences between the bare wall and between the different vertical greening systems, due to the different layers involved (a biotic and biotic components).

The experiment presented seeks at analysing the relation between vegetation and the built environment. In particular it is focused on the possible contribution of vertical greening systems in improving the thermal behaviour of the building envelope.

The main objective of the presented study is to measure the temperature gradient through a vertical greened façade element, to quantify the thermal resistance of vertical greening systems and to understand the thermal behaviour in warm (up to 35 °C) and cold conditions (down to −5 °C).

2. Experimental set up and methodology

This research describes a procedure for comparative measurements of steady-state (stationary condition) heat transfer through a cavity wall with three different vertical greening systems: *Hedera helix* directly to the wall and two living wall systems are based on mineral wool and planter boxes. The bare wall configuration serves as a reference measurement, besides it gives information over the total energy performance of the composite façade when it is covered with vertical green. The living wall system based on planter boxes uses *Lamium galeobdolon, Carex, Alchemilla,* and *Host,* the one based on mineral wool*: Ferns, Geraniums, and Carex.* According to Perini et al. (2016), although species have different evaporation capacities, which affect the cooling effect, the major role is played by the supporting system itself. The analysis of these greening systems using different configurations, layers and materials will provide useful information about the influence of the systems’ characteristics on thermal performances. The bare wall stratigraphy analysed represents a typical/common European building envelope.

The designed apparatus – called “hot box” – is intended to reproduce different boundary conditions of a specimen between two different environments, in the presented research is chosen for an “indoor” and “outdoor” environment. A digital temperature controller and convective heater as well as infrared radiation bulbs maintain the box temperature as close as possible to environmental outdoor conditions. The total energy input represents the heat transfer through the test system. An automatic data collection system is used in this experiment, so that tests can be conducted over a long period of time (if needed) to assure steady-state conditions and to determine reproducibility of the laboratory measurements.

This study investigates the effects of vertical greening systems in warm (up to 35 °C) and cold conditions (down to −5 °C). For this reason, representative days are chosen and analysed (according to e.g. Coma et al., (2017)). Each system was measured 3 times for summer and winter condition. The summer measurements are conducted over a time span of 8 h when it is assumed to reach a steady state situation. The winter measurements are conducted over a larger time span of 72 h to reach a steady state situation.

2.1. Experimental details of the climate chamber

The climate chamber used in this experiment was designed and constructed according to NEN-EN 1934. The standard requires a “hot” chamber on one side of the tested specimen and a heat sink in the form of a “cold” chamber in which environmental conditions are imposed.

The constructed box (the so called “outside and inside” climate chamber) is insulated from its surroundings using 200 mm (two layers overlapped of 100 mm) of expanded polystyrene insulation (EPS) insulation material, with a conductivity of 0.036 W/m K. The two layers of EPS are glued together and fixed to a plywood face of 18 mm in order to get some stiffness between the panels. In the so called “outside” climate chamber extra insulation material is attached to the EPS in order to minimize heat loss. For this application ISOBOOSTER-T1 sheets of 240 mm thickness are used with a U – value of 0.42 W/m^2 K. The outside and inside climate chambers have the same dimensions and are as follows (Figs. 3 and 4):

- length L = 1.10 m
- width w = 1.40 m
- height H = 1.40 m

In the middle of the box a cavity wall is constructed as reference material and to test vertical greening systems placed in front of it (Fig. 4). The cavity wall also directly forms a sample holder for vertical green cladding systems. For the living wall systems an air cavity is created between living wall panel and the façade (Figs. 1 and 2).

In this way the box is divided into two chambers: an “outside” climate chamber and an “inside” climate chamber as it is mentioned in the text. In order to minimize the heat loss through the walls of the “outside” climate chamber, an extra insulation layer of 100 mm EPS with an