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# Quantification of fine dust deposition on different plant species in a vertical greening system

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A R T I C L E I N F O

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A B S T R A C T

Urban vegetation has been shown to improve air quality. Green envelopes can provide wide vegetated surfaces in dense cities. This research investigates the performances of four selected plant species used for vertical greening systems, comparing the fine and ultrafine dusts ($PM_{10}$, $PM_{2.5}$) collecting capacity by leaves, under the same conditions (height/location, pollution exposition, weather). The ESEM micrographs (n = 144) taken on the upper leaf epidermis of 20 leaves show different plant species performances, with *Trachelospermum jasminoides* > *Hedera helix* > *Cistus* 'Jessamy Beauty' > *Phlomis fruticosa.* The 100×, 250×, 500×, 2500× magnifications allow counting a wide range of particle sizes, i.e., from 0.1 to 20 μm. The study demonstrates that some variable investigated, i.e., plant species' shape and surface (thick cuticular waxes on leaf epidermis), influence the amount of particles deposed; while others, i.e., season and age of leaves, do not. This study demonstrates that selecting specific plants in green infrastructure is important to exploit their collecting capacity to increase vertical greening systems performances.


## 1. Introduction

Air pollution is among the major environmental issue in urban area (European Environment Agency, 2015; WHO, 2013). Traffic-related particulate matter (PM), consisting in fine and ultrafine dusts, nitrogen dioxide ($NO_2$), and ozone ($O_3$), are the major pollutants influencing urban air quality, with daily limits exceeded in several urban regions (European Environment Agency, 2015). These pollutants are limited by European and national policies (Decree 155/2010 implementing the European Union Air Quality Directive 2008/50/EC) and extensively investigated in epidemiological research for their adverse health effects (WHO, 2005). Epidemiological studies demonstrated a strong correlation between increased air pollution, as high levels of outdoor PM, and adverse health effects (Brook et al., 2010; Dominici et al., 2006; Merbitz et al., 2012; WHO, 2013).

According to the European Commission (European Commission, 2015), nature-based solutions, as vertical greening systems (VGS), can be cost-effective solutions providing environmental, social and economic benefits. Studies conducted mainly on urban trees showed the potential effects of vegetation in improving air quality (Janhäll, 2015; Vos et al., 2013; Yin et al., 2011). Bioremediation effects, although not fully investigated yet, are related to fine dust particles deposition and dispersion and to the uptake of gaseous pollutants such as $CO_2$, $NO_2$ and $SO_2$ by plants (Baik et al., 2012; Gromke, 2011; Janhäll, 2015; Thönessen et al., 2008; Vos et al., 2013; Yin et al., 2011).

Ultrafine dust particles (<2.5 μm) are relevant in the dense urban area because they can be inhaled deeply into the respiratory system and cause health problems and affect human beings (Powe and Willis, 2004). Several studies quantified PM interactions with leaf surface or measured PM fluxes captured by trees in urban or periurban areas (Manes et al., 2016; Nowak et al., 2006). Fine dust particles (PM) can be reduced when particles, specifically the smaller size fractions (<10 μm), are adhered to the leaves (Hosker and Lindberg, 1982; Ottelé et al., 2010; Sternberg et al., 2010). The collecting capacity (aerosols/PM) of vegetation depends on several factors as the plants' density, type and configuration (Lin et al., 2016; Tong et al., 2016; Tonneijck and Blom-Zandstra, 2002). These factors affect both deposition – influenced by the Leaf Area Index (LAI, i.e., leaf area/ground area) or the Leaf Area Density (LAD, i.e., leaf area/plant unit volume) – and dispersion (related to porosity) of particles (Janhäll, 2015). Claims in the literature show that, in the case of urban trees, a positive correlation between particle deposition, hairy leaves and wax content of leaves can be found (Sæbø et al., 2012). As shown by Weber et al. (2014) hairy leaves of

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herbaceous roadside species increased deposition substantially for 3–180 μm particles sizes.

Ottelé et al. (Ottelé et al., 2010) studied the collecting capacity of *Hedera helix* on leaf epidermis with respect of PM adsorption, concluding that counting particles instead of weighing particles on a specific leaf area seems to be a proper way to classify aerosol deposition on vegetation. Pandey et al. (2016, 2015) shows that climbing plants can be differently tolerant to air pollution, demonstrating that the air pollution tolerance index (APTI), based on ascorbic acid content, leaf extract pH, relative water content and total chlorophyll content, is an important parameter to consider. Also Rai in a recent review underlines the use of APTI to evaluate the performances of urban vegetation (Rai, 2016).

### 1.1. Aim of the study and research questions

Although several studies previously cited investigated the effects of urban vegetation on air quality, to date, no studies on PM capture ability by vertical greening systems are available. Additional research is needed especially to evaluate the effects of different plant species on particulate matter, since previous researches regarded only *Hedera helix* (Ottelé et al., 2010; Sternberg et al., 2010).

Differently from the other greening strategies for urban areas, vertical greening systems, as the one investigated in the present research (Fig. 1), can be based on living wall modules, a mat planted with different species, combined with climbing plants attached to a steel mesh. This plant arrangement, together with an accurate species selection, provides a potentially different barrier to PM deposition and gaseous air pollutant absorption compared to trees and shrubs used for other urban greening solutions (Thönessen et al., 2008).

The present study analyses four different species, climbers and shrubs, planted on a vertical greening system located in a dense urban area (in Genoa city centre, Italy), comparing fine and ultrafine dusts ($PM_{10}$, $PM_{2.5}$) deposition under the same conditions (height/location, pollution exposition, weather). The influence of season and age of plants on particle deposition is evaluated, analysing samples collected in different seasons. Finally, the possible influence of rain on particle adherence is further investigated, by reason of the different conclusions drafted by previous studies (Ottelé et al., 2010; Popek et al., 2013; Przybysz et al., 2014). Therefore, the following research questions can be drafted:

- Is there any difference between the plant species analyzed, due to different leaf shape and epidermis, in collecting fine and ultrafine dusts (amount and size of particles)?
- Is there any difference between the time of deposition (3 and 6 months after planting, summer and fall respectively)?
- Can particles be washed away by rainwater from leaves with different leaf shape and epidermis?

The present research allows evaluating the influence of several factors, as the plant species and structure (leaf shape, epidermis, roughness, etc.), sampling season and timing, sampling location, on the amount and size of particles collected, and it provides the data needed for a comprehensive study of the effects of vertical greening system on air quality.

The present study is part of a wide research project focused on the monitoring of the National Institute of Social Insurance (INPS) Green Façade pilot project, which includes the analysis of environmental, economic and social benefits in the context of densely urbanized areas, especially those in the Mediterranean region (http://www.ecosystemics.eu/?page_id=474) (Magliocco and Perini, 2015; Magliocco et al., 2015).

## 2. Methodology

The study is focused on counting fine and ultrafine dust particles on Environmental Scanning Electron Microscope (ESEM) micrographs. Since the aim of the study is to compare different plant species performances under the same conditions (height, pollution exposition, weather), four plant species were chosen among the ones used for the INPS Green Façade. The National Institute of Social Insurance (INPS) Green Façade, the first built in Genoa (Italy), was installed on the south façade of a public institution office building, renovated in the '80 s (Fig. 1). The building is located in the city centre of Genoa Sestri Ponente. The district is characterized by a relatively high population density (13,000 inhabitants/km$^2$) and road traffic which causes severe air pollution. In Genoa city centre air quality monitoring results (http://www.banchedati.ambienteinliguria.it/) show high levels of particulate matter. In 2015, for example, the Regional Environmental Protection Agency's monitoring systems registered values exceeding yearly values (40 $\mu g\, m^{-3}$ according to D.Lgs. 155/2010, Repubblica Italiana, 2010) for 1486 h (i.e., about 60 days; average $PM_{10} = 35.09\, \mu g\, m^{-3}$, n = 293 and average $PM_{2.5} = 21.76\, \mu g\, m^{-3}$, n = 267 in the most polluted station).

Evergreen plant species, with different types of leaf shape and epidermis (roughness), were selected (Table 1). Other parameters for the plants' selection include health, adaptation capacity and foliage density.

The plant species analysed in this study are:

- Cistus 'Jessamy Beauty' (Cistaceae), an ornamental hybrid of a perennial evergreen shrub native of Mediterranean Region (Perini et al., 2016).
- Hedera helix (Araceae), a woody climber native to western, central and southern Europe, with high adaptation capacities in several climate areas. It has both juvenile and mature leaves. The growing speed is medium (0.5 m/year) (Bellomo, 2003).
- Phlomis fruticosa (Lamiaceae), an evergreen large and broad shrub native of Mediterranean Region, growing about 1 m tall and wide, with grey-green ovate leaves up to 12 cm in length with hairs (Poletti, 2015).
- Trachelospermum jasminoides (Apocynaceae), a vigorous medium-sized evergreen twining woody climber growing up to 4–8 m high ("RHS Home Page/RHS Gardening," n.d.).

### 2.1. Sampling and data analysis

The experiment includes two sampling periods (July and October 2015) at the study site, INPS Green Façade. For each of the four plant species analysed, 2 leaves were randomly chosen from the same height, i.e., 5 ± 2 m, to allow the sampling through the windows at a reasonable distance from traffic source (i.e., 2–3 m; Fig. 2). In both cases (July and October) no raining was recorded within the 15 days before sampling, with average rainfall of 4.4 mm for May, June, and July and 4.3 mm for August, September, and October. For the latter the average wind speed recorded is 2.8 m s$^{-1}$, while for the first trimester is 1.8 m s$^{-1}$. Since the species were all planted on the INPS Green Façade in March 2015, the first sampling was done 3 months after planting and the second 6 months after.

To exclude the possibility of contamination after sampling, leaves were sealed in a labelled plastic container. All the leaves were analysed within one week after sampling at the Microlab of Delft University of Technology with ESEM microscope. To investigate the elemental composition of the particles on the leaves the Energy Dispersive X-ray Spectrometry-analysis (EDS-analysis) or elemental-mapping technique was done on a Philips XL30 ESEM with a tungsten filament. The Energy Dispersive X-ray analysis (EDX) system is by EDAX with a super ultra-thin window (version