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## PLANTS AS NATURAL ANTI-DUST FILTERS – PRELIMINARY RESEARCH

### ROŚLINY JAKO NATURALNE FILTRY PRZECIWPYŁOWE – BADANIA WSTĘPNE

#### Abstract

In urban areas, particulate matter (PM) are the leading cause of air pollution. They can adversely affect human health. One of the solutions to reduce pollution and improve air quality is the use of plants as natural, biological filters which trap the particles on the leaves. Studies on the assimilation capacity of species (*Hedera helix*, *Parthenocissus quinquefolia*, *Fagus sylvatica*) were analyzed. In addition, based on two examples of structures in Krakow, the storage capacity of vines such as *Hedera helix* and *Parthenocissus quinquefolia* and *Fagus sylvatica* tree, for fraction of PM (0.2–2.5  $\mu\text{m}$ ; 2.5–10  $\mu\text{m}$ ; 10–100  $\mu\text{m}$ ) was estimated. Analyses have shown the particular efficacy of creeping vines in PM capture.

**Keywords:** air pollution, PM, green walls, phytoremediation, ecology

#### Streszczenie

W obszarach miejskich substancje pyłowe są najczęstszą przyczyną zanieczyszczenia powietrza. Cząstki pyłu zawieszonego (PM) mogą szkodliwie oddziaływać na zdrowie człowieka. Jednym z rozwiązań zmniejszających zanieczyszczenie i poprawiających jakość powietrza jest stosowanie roślin jako naturalne, biologiczne filtry, zatrzymujące cząstki stałe na liściach. W artykule przeanalizowano wyniki badań dotyczące zdolności asymilacji pyłów wybranych gatunków: (*Hedera helix*, *Parthenocissus quinquefolia*, *Fagus sylvatica*). Dodatkowo oszacowano zdolność akumulacji pnączy *Hedera helix* i *Parthenocissus quinquefolia* oraz drzewa *Fagus sylvatica* dla frakcji PM (0,2–2,5  $\mu\text{m}$ ; 2,5–10  $\mu\text{m}$ ; 10–100  $\mu\text{m}$ ) na przykładzie dwóch budowli w Krakowie. Analizy wykazały szczególną skuteczność pnączy w wychwytywaniu PM.

**Słowa kluczowe:** zanieczyszczenie powietrza, PM, zielone ściany, fitoremediacja, ekologia

## 1. Introduction

One of the most harmful components of polluted air in cities are particulate matter PM [1], commonly known until the nineties as Total Suspended Particulate (TSP) [2]. They are a mixture of solid and liquid organic and inorganic substances of various sizes, origin and chemical composition. PM are classified in three fractions with diameters: 0.2–2.5  $\mu\text{m}$ ; 2.5–10  $\mu\text{m}$ ; 10–100  $\mu\text{m}$  [3–6].

Particles in the atmosphere can also be classified according to their source: primary and secondary [7] or anthropogenic (combustion of solid fuels, transport, etc.) and natural (volcanic eruptions, forest fires, etc.) [1, 3, 6, 8, 9].

Prolonged PM activity can lead to chronic illness and life expectancy shortened by up to three years [3, 8]. PM particles, especially <10  $\mu\text{m}$  may penetrate the lungs, deep into the alveolas and harm human health [1, 4–6, 10] causing bronchitis, asthma, cardiovascular disease or developmental defects [9, 11].

PM particles show many differences in the way they settle on leaves. The dry accumulation of PM on the leaf occurs through gravity sedimentation, capture, deposition and drilling. It depends on the particle size and method of land development [1, 7]. The number of deposited PMs is affected by: remobilization, amount of wax on leaf surface, climate, environmental factors, weather, leaf size and porosity, micromorphology, and plant height [1, 7, 12–14]. It has been shown that PM is most efficiently absorbed by broad, rough leaves, with a large number of hairs, although smaller leaves with complex morphology, can also be effective [3, 8, 14]. One of the studies showed no correlation between PM accumulation and leaf roughness and size [14]. Another study indicates that it is not the amount of wax, but its chemical composition and structure, that affects the absorption capacity of the leaf [3]. The absorption of PM is negatively influenced by: leaf softness, larger gaps between leaves, or smooth surface. It has been observed that the upper part of the leaf is susceptible to higher gravity sedimentation of larger PMs, where twice as many PM are located as compared to the lower part of the leaf, and PM greater than 10  $\mu\text{m}$  are located only on the upper part of the leaf [4, 12].

Plants in cities regulate air temperature and can mitigate the urban heat island effect. [4, 15]. They can be used as a biological filter to capture PM [1, 7]. Fitoremediation is the only easy, affordable and environmentally friendly way to clean the air [3, 8, 13]. Deposition of PM on leaves can affect their physiological processes, such as photosynthesis. Some of them may be absorbed, but they are more likely to stay on the leaf surface for a short time and then return to the atmosphere or to fall to the ground around the tree with the rain, thereby increasing soil contamination [1, 3, 4, 7, 16].

Trees, due to their size, are more effective in capturing atmospheric PM than other types of vegetation, but planting them densely on a small surface will not increase the accumulation capacity of pollutants [7]. The location and size of the trees in the street section may impede the flow of air and reduce the ventilation of the street [11, 16]. Conifer needles produce a thicker wax layer and more efficiently accumulate PM than leaves, but are less resistant to high levels of contamination [1, 3, 8, 14].

Shrubs are less effective than trees, but they play a large role in the lower layers of plantings. In combination with trees, they form an effective structure for PM interception. However, the influence of the planting structure on air circulation and deposition of pollutants should be taken into account [13, 14]. Green walls can cover the vertical planes of walls and buildings [12, 15]. There are two types of vertical green systems: a living wall consisting of modular panels attached to the support structure and a second type, which takes advantage of the natural ability of the vines to climb directly onto the elevation or by use of cables and ties. The superiority of green walls may be due to a large, biologically-active surface (1 m<sup>2</sup> of vines = about 5 m<sup>2</sup> of leaves) and the vertical-to-horizontal ratio [17]. Installing a vertical green, you have to keep in mind the selection of the species, its gravity, the ability to capture the particles, etc. [4, 15].

## 2. Aim of the work

The aim of the work was to analyze the accumulation capacity of individual PM fractions (0.2–2.5 µm, 2.5–10 µm, 10–100 µm) of three plant species and to calculate the possible amount of PM accumulation by these plant species on the example of two buildings in Krakow. The goal was also to find the best scenario for the harvest of PM by the leaves of the climber, which could occupy the surface of the object possible for greening and by a tree that could grow in the space occupied by the building.

## 3. Methods and research tools

According to [1, 3, 14, 18], an analysis of results available in the subject literature was carried out pertaining to the ability to accumulate PM fractions for species, that were investigated at least 3 times, except for *Fagus sylvatica* (investigated twice). The analyses were presented in the form of arithmetic means. Extreme results used in data analysis were rejected.

Subsequently, based on the leaf index value available in literature, three species were selected: *Hedera helix*, *Parthenocissus quinquefolia* and *Fagus sylvatica*, which were used in further analyzes. Leaf area index (LAI) shows the total leaf area of the plant relative to the surface area above which it is located [19]. Two buildings in Krakow were selected, the walls of which can be greened with the vines of the *Hedera helix* or *Parthenocissus quinquefolia*. The objects were selected on the basis of the following criteria: the functional nature of the facility (public functions) and the size of the area for greening. First building (A) is a tenement house “Pod Pajakiem” at Karmelicka Street 35. The second building was (B), Krakow City Hall at Powstania Warszawskiego Avenue 10 (Fig. 1, 2). The base of the building was calculated using measurement tools built into [21]. The elevation of buildings was calculated using LIDAR data available at: [22].

The ability to assimilate PM (0.2–2.5 µm, 2.5–10 µm, 10–100 µm) by *Hedera helix* and *Parthenocissus quinquefolia*, which could grow on the walls of buildings which are available

for greening was calculated. It has also been calculated how many *Fagus sylvatica* individuals could grow on the area occupied by the building and what would their efficiency in absorbing of PM be.



Fig. 1. From the top: location of the analyzed buildings, presentation of the area occupied by the building (red) and location of the elevation available for greening (green). A – tenement house “Pod Pająkiem”, B – Municipality of Krakow, own work based on photo from [21]

The following assumptions were taken into account during the analysis: Leaf Area Index (LAI) for the *Hedera helix* for the minimum leaf area =  $2.6 \text{ m}^2 / 1 \text{ m}^2$  of the wall and for the maximum leaf area =  $7.7 \text{ m}^2 / 1 \text{ m}^2$  of the wall [4]; LAI for *Parthenocissus quinquefolia* =  $5 \text{ m}^2 / 1 \text{ m}^2$  wall [17]; leaf area of 1 individual *Fagus sylvatica* (age: 100 years, height 25 m, width 25 m, crown area =  $491 \text{ m}^2$  = approx. 1,200  $\text{m}^2$  leaves) [20]. Four experiments have been analyzed, exploring the ability for PM accumulation of different plant species, using a gravimetric method. The averaged results are shown in Table 1.

For vines, the area of the elevation was multiplied by the LAI of a given species and by the average PM accumulation capacity rate according to Table 1. For beech trees, the area of the building’s base was divided by the surface of the tree’s crown. The result corresponds to the number of trees that could grow on the surface occupied by the building. Then, the

obtained number of trees was multiplied by the leaf area of one individual (1,200 m<sup>2</sup>) and by the average PM accumulation value according to Table 1. In the calculations above, the influence of many environmental factors, such as sulphate or nitric oxide concentration, and many others, was omitted.

#### 4. Results analysis

Table 1. Juxtaposition of average PM accumulation values for analyzed species

Species	0.2–2.5 μm [μg/cm <sup>2</sup> ]	2.5–10 μm [μg/cm <sup>2</sup> ]	10–100 μm [μg/cm <sup>2</sup> ]	Sum of PM [μg/cm <sup>2</sup> ]
<i>Hedera helix</i>	1.08	3.10	16.70	20.88
<i>Fagus sylvatica</i>	0.90	2.30	14.00	17.20
<i>Parthenocissus quinquefolia</i>	1.00	2.60	12.00	15.60

Explanation: The table shows the average analyses values from four studies [1, 3, 14, 18], own work

Based on the data obtained, it can be concluded that *Hedera helix* most effectively accumulates a wide spectrum of PM fraction – 20.88 μg/cm<sup>2</sup>. *Fagus sylvatica* performs slightly worse, capturing an average of about 17.20 μg/cm<sup>2</sup>. The weakest assimilation capacity in the wide range was displayed by *Parthenocissus quinquefolia* that accumulates only 15.6 μg/cm<sup>2</sup>. *Hedera helix* has a relatively low value of deposited fine PM, which may stem from the small amount of hairs on the leaf surface. It compensates this by the most effective interception of PM 10–100 μm. The reason for the low effectiveness of accumulation of the 0.2–2.5 μm and 2.5–10 μm fraction for *Parthenocissus quinquefolia* may be a small amount of hair on the leaf surface. *Fagus sylvatica*, like *Parthenocissus quinquefolia*, does not have a large number of hairs on the leaf, with only the main nerve on the underside.

Based on the analysis of the subject literature, the number of particles of PM that can be captured by vines (*Hedera helix* and *Parthenocissus quinquefolia*) greening the facades of the surveyed buildings: tenement “Pod Pajakiem” and the Municipality of Krakow were analyzed/estimated, as well as how many PM could be intercepted by tree species (*Fagus sylvatica*) growing on the surface occupied by these buildings. The results are shown in Table 2.

Based on the analyses conducted, no *Fagus sylvatica* (25 m high, 25 m wide) will fit on the surface occupied by the „Pod Pajakiem” tenement house (A) and the covered facade of this building will retain a total of 706.97 g PM for *Hedera helix* and 540.62 g PM for *Parthenocissus quinquefolia*. It follows that – in this case – only the creeping vine will be able to reduce the amount of PM (Fig. 3).

In the same way, the ability to capture PM on the second analyzed building of the Krakow City Hall (B) was investigated. It has been shown that the area currently occupied by the office (2,900 m<sup>2</sup>) will fit 5 *Fagus sylvestrus* trees (25 m high, 25 m wide crown), which will capture 1,032 g of PM. The area of all leaves of the vines that can cover the undeveloped walls of the office building is 1,300 m<sup>2</sup>, which for the *Hedera helix* will allow for the interception



of 1,397.92 g of PM and 1,018.55 g for *Parthenocissus quinquefolia*. It follows that only the *Hedera helix* covering the facade of the building can capture more PM than five *Fagus sylvatica* trees which could grow on the surface occupied by the building. It also follows that five *Fagus sylvatica* trees planted in this area will capture more PM than the coverage of *Parthenocissus quinquefolia* with the area available for greening on the facade of the building.

Table 2. Juxtaposition of analyzed species

Species	Building/ Elevation – Base	0.2–2.5 $\mu\text{m}$ [g]	2.5–10 $\mu\text{m}$ [g]	10–100 $\mu\text{m}$ [g]	Sum [g]
<i>Hedera helix</i>	A/E	38.38	110.16	5,588.43	706.97
	B / E	72.31	207.55	1,118.07	1,397.92
	A/P	25.03	71.84	387.02	483.89
	B/P	161.30	462.99	2,494.15	3,118.43
<i>Fagus sylvatica</i>	A/P	0.00	0.00	0.00	0.00
	B/P	54.00	138.00	840.00	1,032.00
<i>Parthenocissus quinquefolia</i>	A/E	34.50	92.12	414.00	540.62
	B/E	65.00	173.55	780.00	1,018.55
	A/P	22.50	60.08	270.00	352.58
	B/P	145.00	387.15	1,740.00	2,272.15

Explanation: A – “Pod Pajakiem” tenement house (base of the building – 450 m<sup>2</sup>, elevation for the creeping vine – 690 m<sup>2</sup>), B – Municipality of Krakow (base of the object – 2,900 m<sup>2</sup>, elevation for the creeping vine – 1,300 m<sup>2</sup>)  
E – elevation available for greening, P – base surface of the building, own work

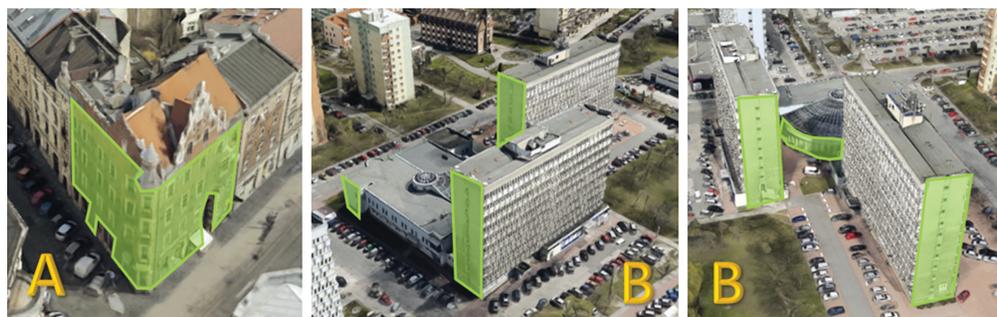


Fig. 2. Visualization of green walls on the facades of the analyzed buildings. The area of green walls excluding window and door openings is marked in green. A – tenement building “Pod Pajakiem”, B – Municipality of Krakow, own work based on photo from [21]

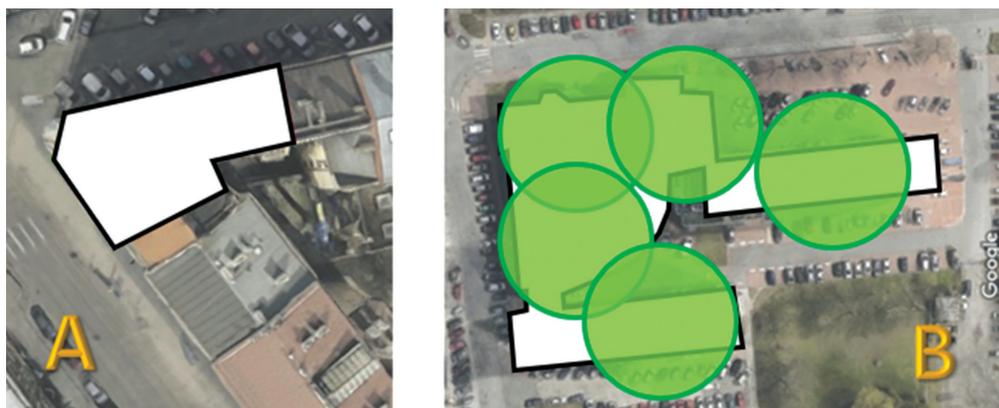


Fig. 3. Illustration of potential tree plantings (green circles) in the areas occupied by the analyzed buildings (white color). A – tenement building “Pod Pajakiem”, B – Municipality of Krakow, own work based on photo from [21]

## 5. Conclusions

Due to the limited area of greenery in the cities, vines that have a high ability to accumulate PM and a very good individual of horizontal-to-vertical surface ratio should be planted. During increasing urban development, it is recommended to introduce a requirement for greening of elevations, especially on public buildings. When introducing trees and bushes into the city, those species that have the best ability to capture PM, such as *Hedera helix*, should be selected.

Most of the studies were carried out at the end of the season, so the obtained data on PM accumulation did not reflect the weight deposited throughout the growing season. The obtained results, developed on the basis of literature data, are influenced by the number of studies, the date of harvesting of the plant material (autumn), the distance from the source of pollutants, the place of research, the weather or the selection of the measurement method. In order to be able to draw more precise conclusions about the capture of PM by plant foliage, more research is needed with more species and in more diverse locations.

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