Potted Plants as Active and Passive Biofilters Improving Indoor Air Quality

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Abstract. Plants are the planet's source of oxygen and the sink that removes carbon dioxide produced by burning, respiration and decay of organisms. The studies performed in small chambers indicated that plants also reduce volatile organic compounds (VOC's). All these phenomena result in a fact that potted plants have a potential to improve IAQ and to some extent to support ventilation. Trends to "go green" increase the growing interest in the introduction of a large number of plants to offices. One should remember that work in modern offices is often associated with a high level of stress. Ornamental plants give highly significant reductions in negative mood states – reductions in anger, anxiety, depression, confusion, fatigue and stress. Leaves provide also additional sound attenuation and cooling effect due to evaporation. The paper summarises the R&D project devoted to the development of the efficient, safe and competitive systems of biofiltration based on the properties of potted plants. The paper presents examples of laboratory tests and describes first experiences from applications in two pilot office buildings.

1. Introduction

Plants in the room can have a significant impact on the chemical composition of the air. The ability of plants to take carbon dioxide from the air and release of oxygen in photosynthesis is widely known. During studies on the quality of air in closed ecosystems (e.g. for space travels), scientists discovered the ability of plants to remove many organic pollutants from the air. NASA's study showed that commonly used decorative indoor plants remove formaldehyde, benzene and thichloroethylene [1]. For example, according to these studies, 1 cm^2 of typical room plant leaves removes 0,7–2,3 µg of formaldehyde during the day, while for a spider plant (*chlorophytum*) this value is even 4 µg. Similar research was also carried out in the Soviet Union. However, scientists were rather focused on effective food production for astronauts than on the capacity of plants to purify the air [2].

Currently, one of the trends in the design of office space is biophilic design. This approach aims to create strong connections between nature and anthropogenic environments. Expected benefits are health and wellbeing. Often designer introduces a large number of ornamental plants in the immediate vicinity of workplaces and to rest areas. In this context, research into the ability of potted plants to support ventilation systems has been intensified.

The dissatisfaction of people with the quality of the internal environment is influenced by two aspects: psychological and technological. Psychological tests carried out in office buildings have shown that many of the needs expressed by employees are closely related to traditional needs shaped in the course of human evolution:

- the need for change (the need to receive stimulating environmental signals),
- the need to influence the environment in order to perceive the effects of its operation,
- the need to have your own place with a personal character,
- the need to contact the surrounding world.

Some of these needs can only be met through the proper design of the building, the proper definition of the functions of individual spaces, and through the proper arrangement of interiors, also with the use of ornamental plants.

Research on the level of stress [3] has shown that contact with plants reduces the level of negative emotions. For example, it has been shown that it is easier for hospitalized persons to recover when they can observe a park or forest from a window, not a concrete wall, road or parking. The level of pain threshold is also changed, which is higher (more favourable) in people in rooms with a view of the natural environment.

2. Laboratory tests

In the literature, one can find the results of research on the ability to remove volatile organic compounds from indoor air by more than 100 plant species [4]. The most important factors affecting the process are:

- plant species,
- kind of substrate,
- lighting parameters,
- temperature and humidity of the air,
- type of chemical compound
- the concentration of a chemical compound,
- the presence of a mixture of many compounds.

The ability to reduce the concentration of VOCs in rooms by ornamental plants results from several mechanisms related to: above-ground part of the plant, roots, micro-organisms found in the substrate and the substrate itself. Unfortunately, the tests are carried out according to various scenarios. Moreover, the test results are presented in different units (e.g. % reduction in a given time, μg/h, ppm /(m^2h), h^{-1}). Although any comparisons between tests are difficult, one may observe that the results are very different. Differentiation concerns both measurement series within the same study, results for various plant species and results for the same species, but analysed in various studies [5], [6], [7] and [8]. It should also be noted that in the majority of laboratory tests plants are subjected to concentrations of pollutants many times greater than the values recommended in rooms intended for permanent occupation.

During the project presented in this article three species were examined in laboratory conditions:

- *Sansevieria trifasciata* – figure 4a,
- *Epipremnum aureum* – figure 4b,
- *Dieffenbachia seguine* – figure 4c.

Plants were placed in sealed glass chambers (0.6 x 1.2 x 0.6 m; volume 0.0432 m^3) and then sequentially treated with the following substances: benzene, phenol, formaldehyde, styrene and toluene. A test substance was continuously introduced into the chamber and a change in the concentration of the contaminant was observed over time. The ability of plants to remove pollutants was estimated by comparing the concentration during the measurement series with plants and without plants.

Figure 1. Sansevieria trifasciata

Figure 2. Epipremnum aureum

Figure 3. Dieffenbachia seguine

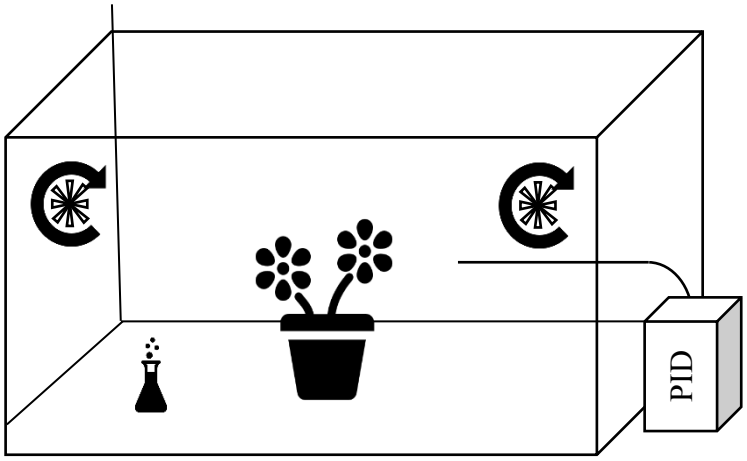

Figure 4. Diagram of the measurement system

The following research strategy has been adopted:

- a plant or group of plants (2 or 3) was placed inside the chamber
- the chamber was closed tightly using special handles,
- fans were turned on to equalize the concentration of test substances in the entire volume of the chamber,
- during the measurements, a constant air temperature (25 °C) and air humidity (65%) were maintained inside the chamber
- the test substance dispenser was introduced through the lock, with the simultaneous recording of the test time and the concentration of the initial substance.
- concentration measurements were carried out continuously using an I-Brid MX6 meter with a PID sensor.
- the recorded results were transferred to a PC and the characteristics were plotted
- after the measurement series was completed, the chamber was vaporized before further tests and plants were replaced.

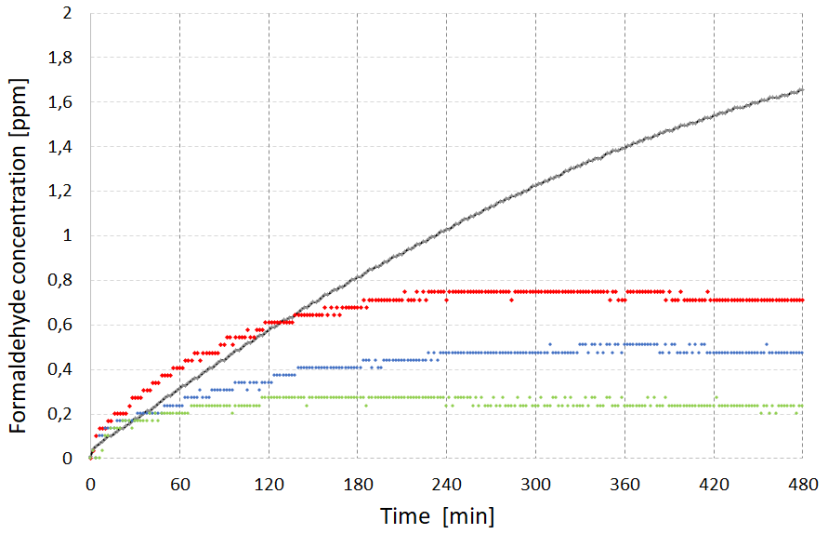

Figure 5. Concentration of formaldehyde in the test chamber with *Epipremnum aureum* (number of plants: 0 – black dots, 1 – red dots, 2 – blue dots, 3 – green dots)

Table1. Reduction of test substance concentration after 8 hours compared to concentration in the absence of plants

Tested substance	2 x *Sansevieria trifasciata* [%]	2 x *Epipremnum aureum* [%]	2 x *Dieffenbachia seguine* [%]
Benzene	56	63	73
Formaldehyde	35	71	88
Styrene	51	84	44
Toluene	32	51	44
Phenol	>93 (1 plant)	>93 (1 plant)	-

3. Passive and active biofiltration

Two plants located in the measuring chamber occupied about 60% of the space. It is, of course, impossible to obtain a similar ratio in real office rooms. Standard places for plant location as a floor, window sill or shelves do not offer much space. Vertical installations (green walls) or suspended vegetation allow designers to increase the number of plants significantly. It is extremely important, as filtration effect of 1 potted plant expressed in CADR (Clean Air Delivery Rate) almost never exceeds 0,1 m^3/h.

An interesting and innovative technique is the biofiltration of air with forced air flow through the root ball and possible carbon filter (figure 6). In such a case CADR may easily reach 20–40 m^3/h. It means that 1 active biofilter during operation is equal to hundreds of passive biofilters [9].

One should remember that only plants in very good condition perform well as biofilters. Therefore, plants used in biophilic design should be serviced by a professional company. It is recommended that plants are periodically relocated so that none of them has been in unfavourable conditions for a long time. Plants showing stress should be placed for some time in spaces illuminated with special LED lamps.

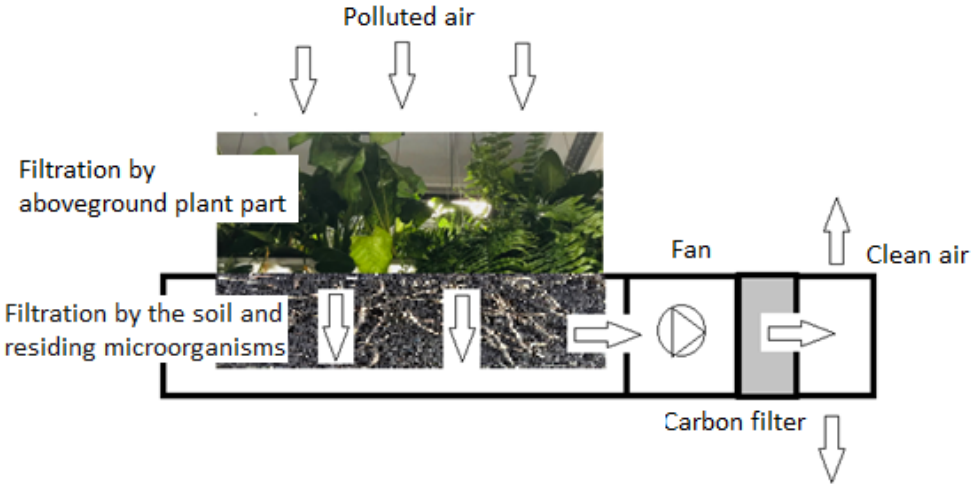

Figure 6. The concept of a biologically active filter with forced air flow through the substrate

4. Applications in pilot office buildings

4.1. Office building in Gdańsk

The office building is rented by an international bank. The building occupied by 263 persons was arranged with 216 professionally serviced potted plants*: Monstera Deliciousa, Fiddle Leaf Plant, Ficus elastic, Money Plant, Monstera (small)*. Moreover, a large number of small pots with *Epipremnum aureum* mounted in vertical panels created green walls with the total area of 38 m^2. The building has a mechanical ventilation that provides 5m^3/h of outdoor air per square meter (air change rate ~ 1,5 h^{-1}).

Figure 7. Resting area arranged with potted plants in pilot office building in Gdańsk.

Table 2 presents the results of the test in the office room designated per 12 persons with approx. 20 big potted plants. Beside measurement team (4–6 persons) the room was empty. The first set of measurements was carried out when potted plants were present in the room. Than potted plants were removed to another room and after 1-hour measurements were repeated.

Point 1 was located in the communication tract. Point 2 was located in the proximity of the location of 4 big plants. In rooms without plants concentrations of VOC and formaldehyde (measured by Air Quality Detector DM106A) were higher by approx. 48% in point 1 and by 145% in point 2.

Table2. Reduction of test substance concentration after 8 hours compared to concentration in the absence of plants

Description	VOC [$\mu g/m^3$]		Formaldehyde [$\mu g/m^3$]	
	Point 1	Point 2	Point 1	Point 2
Potted plants present	289	145	42	21
Potted plants removed	429	352	62	51
Increase of concentration after 1 hour	48,44%	142,76%	47,62%	142,86%

4.2. Office building located in Warsaw

The office building is occupied by a producer of video games. The office part of the building uses 3633 m^2 for 350 employees. Until now, intensive vegetation has been introduced on the area of 2300 m^2. Space is quite densely plotted by employees' desks and accompanying computer equipment. For this reason, as many as 540 out of a total 600 plants were placed in suspended installations pretending ventilation ducts. Their total length is 260 meters. In addition, a green wall with an area of 30 m^2 was placed in the biggest open space office. The following plants were used to arrange the building: *Philodendron Xanadu, Philodendron "CumLuade", Philodendron scandens, Epipremnum aureum, Alocasia Gaganea, Scindaptus pictus, Aglaonema Silver Bay, Chlorophytum comosum, Monster deliciosa*.

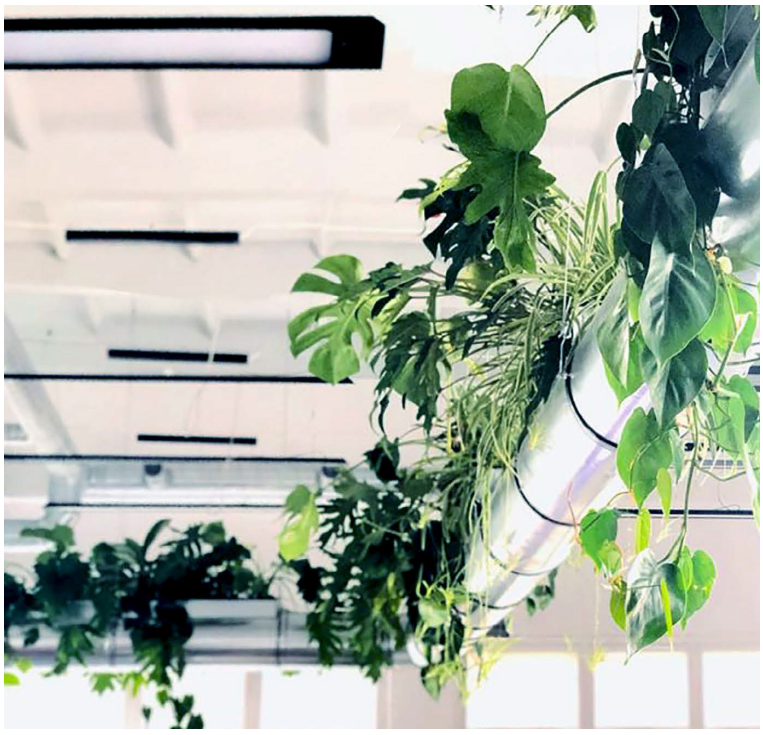

Figure 8. Biofilters mounted in pilot office building in Warsaw.

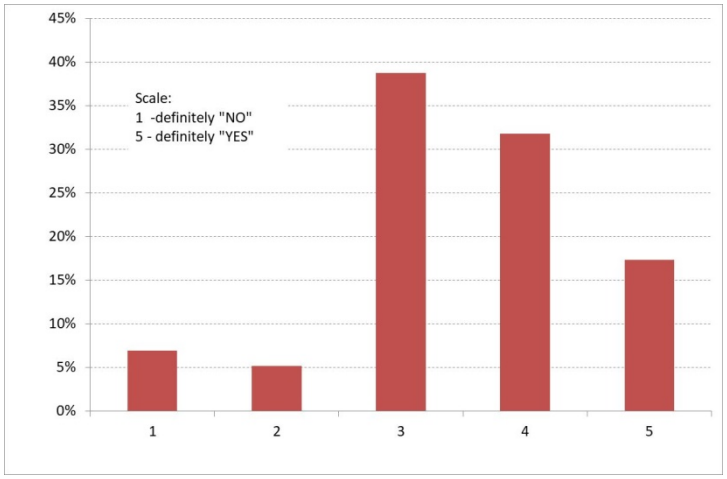

Figure 9. Responses to the question "Since we added the plants, have you been feeling better?"

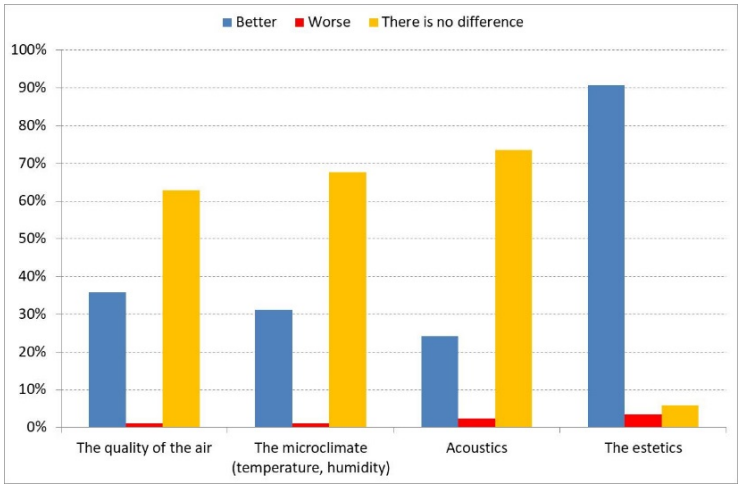

Figure 10. Responses to the question "Has our workplace changed since the green project?"

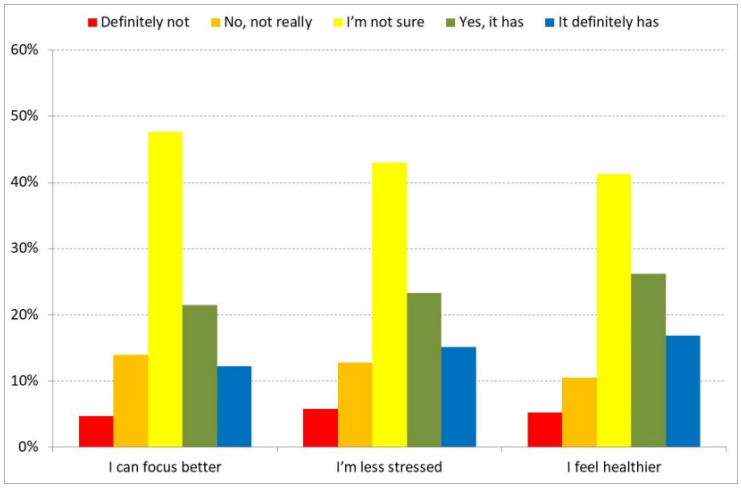

Figure 11. Responses to the question "Would you agree that bringing in plants has had a positive impact on your work?"

After few months staff was asked to respond to the questionnaire via the office network. 173 persons responded to the request that gives approximately 50% response rate. To learn individual attitude to plants people were asked to respond to the question "Do you have plants in your home?". 26% of responders declared that they have no plants in the house, 53,8% declared that they have few plants in the home while 20,2% responded that they have many plants. Then people were asked to answer the question "Since we added the plants, have you been feeling better?" (figure 9). The answers were collected in integers using the scale from 1 (definitely "NO") to 5 (definitely "YES"). Average score 3,47 indicates the self-reported improvement of well-being. More detailed questions showed that people generally accepted the esthetics of offered solution, while some of them see positive improvement in air quality, microclimate and acoustics (figure 10). Moreover, a noticeable percentage of staff voted that they feel healthier (43%), they are less stressed (38%) and they can focus better (34%) (figure 11).

5. Conclusions

The laboratory tests confirmed the ability of plants to remove volatile organic compounds from the air. In real conditions, comparable to laboratory results could only be obtained by filling entire office spaces with plants. Suspended vegetation and green walls allow entering a significant number of plants while maintaining standard floor area per employee. Such solutions were used in two pilot office buildings. The buildings have been equipped with data collection systems (temperature and air humidity, CO_2 concentration, PM_1, $PM_{2.5}$ PM_{10} and optionally TVOC or formaldehyde concentration). However, in order to demonstrate the real benefits of using passive biofilters, quite long measurement periods are needed. The results will be presented in the future.

Surveys carried out among employees in Warsaw show great acceptance of office space arranged according to the idea of biophilic design. Even if the measurements do not confirm such a beneficial effect on health and the increase of individual work efficiency declared by some employees, the satisfaction of the staff will be very valuable to the management.

At the same time, tests of biofilters with forced airflow were completed and in the office building in Warsaw several passive biofilters are converted into active biofilters. That should make a further significant improvement even if they will work periodically.

Acknowledgments

This article was created as part of the project "Carrying out research and development works aimed at creating a prototype of the FLORABO air diagnostics and biological filtration system" No. RPMA.01.02.00-14-6206 / 16-00 financed from the European Regional Development Fund under the Regional Operational Program of the Voivodship Mazowieckie for the years 2014-2020.

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