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Vraag: **Phytoremediation of indoor air pollutants by ornamental potted plants**

The positive effects of indoor plants on human wellbeing, productivity and mental health have been reported in several studies (Lohr et al., 1996, Kim et al., 2010a,b). Furthermore, a well-known fact is that the plants can also effectively improve the indoor air quality in term of reducing CO_2 and releasing O_2 through light-dependent process of photosynthesis and increase air humidity by water vapor transpired from leaves through microscopic leaf pores, namely "stomata". Precisely the ability of leaves to exchange gases and, thus, to take up different pollutants from indoor air (e.g. VOCs, ammonia, ozone, particulate matter) makes the plants a cost effective and sustainable technique to ameliorate indoor air quality.

Since the pioneer studies conducted by NASA during the 1980s where was successfully demonstrated that plants are able to remove airborne pollutants (Wolverton et al., 1984), numerous of experiments aiming to understand the mechanisms and assess the efficiency of air phytoremediation (the use of plants to remove airborne pollutants) of different plant species have been published in the scientific literature (Godish et al., 1989; Wolverton et al., 1996; Liu et al., 2007; Aydogan et al., 2011, Abbass et al., 2017). An overview of a short literature review of the available recent published studies focused on the effectiveness of indoor plants to remove airborne pollutants from indoor air is shown in Table 1.

A large part of the studies is focused onto the air phytoremediation of VOCs. In fact, for the last 25 - 30 years more than 50 different studies, by more than 10 different research groups have tested approximately 200 species for VOC removal capacity, primarily focused in testing of the most well-known air polluting species such as benzene, ethylbenzene, xylene and toluene (BTEX), formaldehyde and trichloroethylene (Irga et al., 2018; Bandehali et al, 2021). Most of the studies reported high (above 65%) phytoremediation efficiency for various VOCs of the most commonly used indoor plans. For example, Teiri et al. (2018) reported formaldehyde removal efficiency of 65-100% with maximum elimination capacity of 1.47 mg/h for a m^2 of leaf area, during 48h exposure, by the very commonly used indoor parlour palm (*Chamaedorea elegans*). Moreover, the study also found that formaldehyde concentrations up to 14.6 mg/m^3 did not show any effect to the plant growth. Similar results were published by Aydogan et al. (2011), where the formaldehyde removal efficiency of about 90% for 24h period was determined for other four indoor plant species (*Hedera helix* (English ivy), *Chrysanthemum morifolium* (pot mum), *Dieffenbachia compacta* (dump cane) and *Epipremnum aureum* (golden pathos)). In a study evaluating the effects that the presence of plants in classrooms might have onto the pupils and the indoor air quality, performed in various classrooms in Netherlands by the Netherlands Organisation for Applied

Scientific Research (TNO) and a research company of applied plant sciences (Pythagoras) reported formaldehyde elimination rate of 20 mg per hour for 5000 g of leaf mass using *Spathiphyllum* in a controlled test conditions in a phytotron (Duijn et al., 2011). The authors also reported that the formaldehyde removal ability of the tested specimens was not dependent from the applied photosynthyc active light radiation (PAR) and remains present even at 0 PAR (i.e. dark conditions). In term of benzene, toluene, ethylbenzene and xylene (BTEX) a study published by Sriprapat et al. (2013) showed that *Zamioculcas zamiifolia* has a high potential of removing all four compounds from indoor air for a long-time exposure. The study also showed the tested plant was able to lower the concentration of BTEX in contaminated air from about 20 to 0 ppm within 12 days for benzene, 13 days for toluene, and 14 days for ethylbenzene and xylene, respectively. The authors suggested that the different diffusion rates of the gaseous pollutants are a rate-limiting process during phytoremediation. Similar results were observed during another study, where uptake of toluene and ethylbenzene have been examined for twelve plant species (Sriprapat et al., 2013). The removal efficiency of toluene was averaged at about 77%, while the ethylbenzene removal efficiency was averaged at about 70% across all examined species for 72h of exposure. High benzene removal efficiency (91% - 97%) have been reported by Parseh et al. (2018), where two plant species (*Schefflera arboricola and Spathiphyllum wallisii*) were exposed to benzene containing atmosphere at concentrations between 3.6 – 29.5 μg/m³.

In term of ozone removal, a study published by Abbass et al. (2017) showed that the five-tested species of the most commonly used indoor plants have moderate (0.9 – 9%) ozone removal efficiency. Moreover, the authors also observed that the ozone removal efficiency decreased in subsequent exposures. This suggested that ozone has affected the structure or composition of the leaf surface, which leaded to reduction of in ozone removal activity. Such structural changes of the plant leaves due to ozone exposure have been reported also in other studies (Kozlowski, 1980; Lambers et al., 2008). In more recent study Gubb et al. (2022) investigated the NO_2 removal efficiency of a combination of three plants species (*Spathiphyllum wallisii 'Verdi', Dracaena fragrans 'Golden Coast'* and *Zamioculcas zamiifolia*) at different light conditions and in 'wet' and 'dry' growing media. The authors reported NO_2 removal of 62 ppb (with calculated CADR of 0.145 $m^3h^{-1}plant^{-1}$) measured at 'wet' and light conditions. The lowest NO_2 removal (47 ppb or 0.095 m^3h^{-1} plant $^{-1}$) was obtained at 'no light' and 'wet' conditions. The authors also reported similar NO_2 removal (42 - 49 ppb or 0.082 – 0.101 m^3h^{-1} plant $^{-1}$) by using bare growing media tested at the same conditions. It is important to be noted here, that the NO_2 concentrations of the performed experiments were measured using 'low-cost' electrochemical gas sensors. No information regarding their accuracy nor calibration procedure was provided by the authors. Many studies already showed significant temperature dependency of the electrochemical NO_2 sensors used in this study (Borowiak et al., 2019; Rogulski et al., 2022).

With respect of particulate matter (PM), while the ability for phytoremediation of the aerosolised PM by outdoor plants is well established (Sæbø et al., 2012), little data exists on PM phytoremediation from indoor air. The study by Stapleton et al. (2018) assessed the effectiveness of plant species to reduce ultrafine particle concentrations in simulation chambers. Most of the tested species were capable of ultrafine particle reduction with maximum reduction of 19.9% (*Juniper plants)*. The overall household ultrafine particle reduction was estimated to be 11% using *juniper plants*. Moreover, the study also showed strong correlation between the plant surface and the ultrafine particle reduction. Similar results were reported by Gawrońska et al. (2015), where the ability of plants to take up indoor PM was statistically significant. Further, their results also demonstrated that the plants were capable of accumulating significantly more PM than flat surfaces within the indoor environment, indicating that more than simple gravitational forces were involved in PM accumulation on aerial plant parts. In more recent study, Mukesh and Rai (2022) assessed the ability of eleven different plant species including: *Sansevieria trifasciata, Epipremnum aureum, Araucaria heterophylla, Eranthemum purpureum, Phoenix roebelenii, Dracaena reflexa, Ficus retusa, Codiaeum variegatum, Platycladus orientalis, Cupressus macrocarpa,* and *Hylocomium splendens* to remove airborne PM through lab experiments conducted in controlled environment chamber. The authors used the calculated deposition velocities and clean air delivery rates (CADRs) to quantify the PM removal efficiency for each plant species. The obtained deposition velocities were ranging between 1 cm h^{-1} and 93 cm h^{-1} with CADRs ranging between 0.002 m^3 h^{-1} to 0.084 m^3 h^{-1} (Mukesh and Rai, 2022).

Many of these experiments, however, have been the subject of criticism in term of translating the findings to the real indoor environments. For instance, most of these studies utilize small scale (<1m^3) in vitro chamber system, constraining the generalisation of the results to building scale settings (Torpy et al., 2018). In contrast with the small-scale chambers, buildings are much more complex systems with more dynamic air exchange with the exterior and varying rates of indoor pollutants (e.g. VOCs, PM). Moreover, the chamber-to-room volume ratios typically utilized in most experiments would be too small to be representative of in situ functional pollutant removal, due to the kinetic of this removal from such small atmospheric volumes relative to the size of the air cleaning system. For example, a study by Kim et al. (2009) the authors found that the VOC removal rate of a phytoremediation experiment in a sealed 60 m^3 room is 1/20th of that measured in a 1m^3 chamber under otherwise identical conditions. Moreover, when the plans were tested in actual office environments (rooms with interior volumes of 275 and 350 m^3, containing 16 to 19 occupants and 22 to 25 plants per office), no reduction was found in benzene, toluene, ethylene, or xylene concentrations (Kim et al., 2011). Additionally, the initial VOC concentrations to which the plants were exposed are substantially higher than is relevant to in situ levels (chamber-based VOC concentrations are usually tested in ppm range, while typically indoor VOC concentrations are in ppb range (Torpy et al., 2018)). Nevertheless, the static chamber tests might be useful in obtaining qualitative information regarding the efficiency of a system to reduce air pollutant concentrations, but they cannot provide information on their quantitative efficiency in in situ environments (Irga et al., 2018).

Despite of the strong empirical proof-of-concept provided by several studies, to what extend the indoor plants really have an impact on IAQ is still under debate (Thomas et al., 2015; Waring, 2016). Unaddressed challenges exist for the practical use of potted plants to create meaningful air quality effect. The few existing in-situ studies reveal inconsistencies in air quality improvement (Llewellyn and Dixon, 2011). A study published study of Cummings and Waring (2019) showed that the VOC removal ability of the potted plants is orders of magnitude lower than the removal rate already provided by the outdoor-to-indoor exchange in typical building (~1/h). Similarly, Mukesh and Rai (2022) showed that the estimated CADRs for the tested for PM removal various potted plants (CADRs 0.002 m^3 h^{-1} to 0.084 m^3 h^{-1}) were significantly lower than those obtained by the typical filter-based air purification systems (170–800 m^3h^{-1}), meaning that passive plant systems cannot compete with conventional air purifiers. Moreover, the authors also found that large quantities of plants (e.g. ~170 m^2 of moss or ~2040 Cypress plants) would be required to achieve even modest reductions in indoor PM concentrations under real-world conditions, thus highlighting their limited role in controlling indoor PM levels. Also, the French Agency for Food, Environmental and Occupational Health & Safety (ANSES) and the French Environment & Energy Management Agency (ADEME) suggested ventilation and aeration as more efficient methods for remediation of indoor air pollutions than the phytoremediation by plants, because of the low efficiency and wide variety of influencing environment parameters of indoor air purification using plants (Ademe, 2011; Anses, 2017).

Table 1 Overview of recent scientific litterateur of effectiveness of indoor plants to remove airborne pollutants

Authors	Study	Results	Conclusion
Mukesh and Rai (2022)	The study quantify the ability of eleven different plant species (*Sansevieria trifasciata, Epipremnum aureum, Araucaria heterophylla, Eranthemum purpureum, Phoenix roebelenii, Dracaena reflexa, Ficus retusa, Codiaeum variegatum, Platycladus orientalis, Cupressus macrocarpa,* and *Hylocomium splendens*) to remove airborne PM through lab experiments conducted in controlled environment chamber. Deposition velocities and clean air delivery rates (CADRs) were used to quantify the PM removal efficiency for each plant species.	The average deposition velocities were reported at 93 ± 9 cm h^{-1} for the moss plant, between 29 ± 3 cm h^{-1} to 37 ± 4 cm h^{-1} for the needle-leaved plants, and between 1 ± 2 cm h^{-1} to 13 ± 2 cm h^{-1} for the broad-leaved plants. The estimated CADRs of the tested plants were calculated between 0.002 ± 0.004 m^3h^{-1} to 0.084 ± 0.009 m^3h^{-1}	The authors concluded that the estimated CADRs for the tested plants were significantly lower than those of filter-based air purification systems (170–800 m^3h^{-1}), meaning that passive plant systems cannot compete with conventional air purifiers. Moreover, the authors also found that large quantities of plants would be required to achieve even modest reductions in indoor PM concentrations under real-world conditions, thus highlighting their limited role in controlling indoor PM levels.
Armijos-Moya et al. (2022)	This study investigates the capacity of two species of plants (*peace lily* and *Boston fern*) and three kinds of substrates (expanded clay, soil, and activated carbon) to deplete formaldehyde (at concentrations of 300 ppb) and CO_2 in a glass chamber (0.033 m^3) under controlled conditions. The concentrations of the target gases inside the chamber were monitored using calibrated electronic sensors for formaldehyde (DART-sensor) and for CO_2 (VAISALA CO_2 probe GMP252). To evaluate the efficacy of the phytoremediation between the experiments, the clean air delivery rate (CADR) was used.	The study reported formaldehyde removal ranging between~0.07–0.16 m^3h^{-1} for bare soil and around ~0.03 m^3h^{-1} for the tested plants. In reducing CO_2 concentrations, the calculated CADR were 0.01 m^3h^{-1} and 0.02 – 0.03 m^3h^{-1} for *peace lily* and *Boston fern* respectively.	Based on the obtained results, the authors concluded that that soil, in general, was most effective in reducing formaldehyde concentrations in the chamber, while the tested plants were as effective as dry expanded clay. The authors also pointed that in their experiments the substrate is an important ally in reducing gaseous pollutants such as formaldehyde.

Al Qassimi and Jung (2022)	In this study, the effect of the planting volume on the reduction of the formaldehyde and VOC concentrations was investigated for three types of air-purifying plants: *Pachira aquatica*, *Ficus benjamina*, and *Aglaonema commutatum.* The experiments were conducted in controlled-indoor environment (two walk-in rooms) where the indoor VOC and formaldehyde concentrations were monitored. .	The reduction ratios for formaldehyde were reported between 9.7% (*Aglaonema commutatum*) – 42.2 % (*Ficus benjamina*). The study reported slightly higher (up to 86.4% for benzene and up to 62.7% for toluene) reduction efficiency for other VOCs compounds for the tested plants.	From the reported results the authors showed that the greater the planting volume, the greater the reduction effect of the VOCs. Although, the experiments were performed in controlled spaces simulating real indoor environments, during the experiment the environment was not occupied. The authors also suggest performing additional experiments in occupied places in other to further investigate the effects that human activities might impose to the ability of the potted plants to reduce indoor pollutants.
Gubb, C. et al. (2022)	In this study the authors investigate the ability of the combination of the three plant species *Spathiphyllum wallisii 'Verdi'*, *Dracaena fragrans 'Golden Coast'* and *Zamioculcas zamiifolia* to remove in situ concentrations (100 ppb) of NO_2 in real-time at two typical indoor light levels (i.e. 0 and 500 lx) and in 'wet' and 'dry' growing media conditions. The removal efficiency tests were performed inside a 150 L chamber under controlled conditions. The NO_2 concentrations inside the chambers were constantly monitored during the performed experiments using electrochemical sensors.	The calculated $CADR_p$ during the performed experiments were reported between 0.095 and 0.145 m^3h^{-1} plant $^{-1}$ The highest NO_2 removal (62 ppb with $CADR_p$ of 0.145 m^3h^{-1} plant $^{-1}$) after 1h for was measured for *Dracaena fragrans 'Golden Coast'* at 'wet' and 'light' conditions, where the lowest (47 ppb or 0.095 m^3h^{-1} plant $^{-1}$) for *Zamioculcas zamiifolia* at 'no light' and wet conditions. The authors also reported NO_2 removal between 42 ppb (0.082 m^3h^{-1} plant $^{-1}$) and 49 ppb (0.101 m^3h^{-1} plant $^{-1}$) by using bare growing media tested at the same conditions.	The study demonstrated that although less effective than the active methods (e.g. ventilation) potted plants can be used to passively remove indoor NO_2 concentrations under typical indoor conditions. However, the authors also highlights the limitations of the reported study (performed under controlled conditions) and recommend more extensive and "real-life" studies of the application of potted plants to reduce indoor NO_2 concentrations

Ullah et al. (2021)	In this study the authors investigate the possibility of removing different types of VOCs (polar and non-polar) by using combination of two different plant species (a C3 plant (*Zamioculcas zamiifolia*) and a crassulacean acid metabolism (CAM) plant (*Sansevieria trifasciata*) in controlled environmental chamber.	The authors reported more than 95% increase of removal of the initial VOCs concentrations when the plants are used together in comparison with the two type of plants were tested separately in the same conditions. The authors also reported reduction of the CO_2 levels during the experiments from 410 ppm to 160 ppm.	Based on the obtained results the authors concluded that overall, a mixed plant of *Z. zamiifolia* and *S. trifasciata* was more efficient at removing mixed pollutants and reducing CO_2 than individual plants.
Siswanto et al (2020)	The study assessed the PM and VOCs one pass removal efficiency of an active botanical biofilter using horizontally grown plan species (*Epipremnum aureum).*	The study reported for PM2.5, PM10 and VOCs removal efficiency of 54.5%, 65.42% and 46%, respectively. Additionally, the tested system recorded CADR values of 29.5 $m^3 h^{-1}$ of PM-free air and 24.5 $m^3 h^{-1}$ of VOCs-free air for 0.12 m^2 of the green area.	The authors concluded that the system can be used to efficiently remove PM and VOCs from indoor environments. However, the authors also recommended further research to better assess the removal efficiency in different indoor environments.
Yan and Su (2020)	The study investigates the formaldehyde removal efficiency of a combined plant-microbe technology by adding cultured microorganisms into the rhizosphere of three plant species, *Tradescantia zebrina Bosse (T. zebrina), Aloe vera (Haw.) Ber (A. vera)* and *Vigna radiata (Linn.) Wilczek (V. radiata)*. The tested systems were exposed to 0.72 mg/m^3 for 24h.	The study reported increase of the formaldehyde removal efficiency of 6.9 – 90.5% (23.1 – 97.6 µg/h/g) from the tested plants with microorganisms versus the ones without microorganisms (18.5 – 59.3 µg/h/g).	Based on the results obtained from the experiments the authors concluded that the formaldehyde removal in plant only systems occurred through redox and enzymatic reactions, while in the plant-microbe systems occurred mainly via microbial degradation processes.

Salvatori et al. (2020)	The study investigates the possibility of using photosynthetic process of *Laurus nobilis L.* (common laurel), for reducing peak CO_2 concentrations in an air-tight museum environment. The phytoremediation potential of the test species was assessed at CO_2 concentrations of about 1000 ppm using controlled closed "walk-in" chamber (2.5 x 3.9 x 3.0 m).	The study estimated average daily CO_2 removal ranging between 0.52 and 0.99 mol CO_2 $m^{-2}day^{-1}$.	The reported results showed potential use of *Laurus nobilis L.* for reducing CO_2 concentrations in an air-tight museum environment.
Irga et al. (2019)	The study assessed the single pass removal efficiency (SPRE) for benzene and ethyl acetate of various plant species typically used for botanical air filtration (*Chlorophytum orchidastrum, Nematanthus glabra, Nephrolepis cordifolia 'duffii' and Schefflera arboricolainc*) at concentration levels of in situ relevance.	The authors reported SPREs were between 45.54 and 59.50% for benzene, and between 32.36–91.19% SPREs of ethyl acetate, with *C. orchidastrum* and *S. arboricola* showing significantly higher ethyl acetate SPREs than the other tested species.	Based on the findings during the performed experiments, the authors concluded that plant type influences botanical biofilter VOC removal. In addition, they suggested that ethyl acetate SPREs were dependent on hydrophilic adsorbent sites, showing that with increasing root surface area, root diameter and root mass all leaded to increasing ethyl acetate SPRE. On the other hand, the high benzene SPRE of *N. glabra,* was related with the high wax content in its leaf cuticles.
Li et al. (2019)	In this study the authors assessed the formaldehyde removal efficiency of three different species of potted *Chlorophytum Comosum*: with only green leaves (GC), combination of half green and half white leaves (CC), and purple leaves (PC). The plants were exposed to formaldehyde concentrations for seven days in controlled chamber environments.	The results showed formaldehyde removal efficiencies in the daytime were 71.07% (± 0.23), 84.66% (± 0.19), and 46.73% (± 0.15) at 1 ppm for GC, CC, and PC plants, respectively, and were 36.21% (± 0.24), 62.15% (± 0.19), and 34.97% (± 0.11) at night.	The authors suggested that higher plant physiological activities (e.g., photosynthesis, respiration, and transpiration) during the daytime could be the reason for higher removal efficiency in comparison at night. The authors also showed that all the tested plants are

			tolerant up to the 8 ppm of formaldehyde concentration for 7 days under dynamic fumigation and needed 10–15 days for self-recovery.
Wannomai et al. (2019)	The study evaluated the removal efficiency of Trimethylamine (TMA) (fishy odour) from indoor air by eight types of potted plants species (*Prickly pear cactus*, *Dracaena sanderiana Sander*, *Dieffenbachia camilla*, *Tradescantia spathacea*, *Peperomia magnoliifolia*, *Chlorophytum comosum*, *Cereus hexagonus (L.) Mill*., and *Scindapsus aureus*) at light and dark conditions. The study was performed inside a chamber different light conditions with TMA concentrations of 150 ppm.	The study reported high TMA removal efficiency (> 80%) for *C.comosum*, *D. camilla*, *P. magnoliifolia*, and *S. aureus* only at light conditions, while *C. hexagonus (L.) Mill.*, *Prickly pear cactus*, *D.sanderiana Sander*, and *T. spathacea* showed high removal efficiency (>90%) at light as well as at dark conditions. The main removal mechanism for all tested species was shown to be uptake via photosynthesis and open stomata.	Based on the results from the study, the authors concluded that the tested plants could be potentially used for mitigating the fishy odour or TMA concentrations in indoor environments. The authors also showed that the light conditions have a significant impact on TMA removal for the tested species.
Cummings and Waring (2019)	The study aimed to assess the potential impact on the indoor VOC loads by the potted plants. To achieve this the authors reviewed 12 published studies of performed chamber experiments on VOC reduction by various potted plant species. To be able to compare the impact, the 198 results from the reviewed studies were translated to clean air delivery rates (CADR, m^3/h). The CADR is described as a clean air metric that can be normalized by volume to parametrize first-order loss indoors.	The results showed nearly four orders of magnitude spanning of the obtained CADR for potted plants, with a median value of 0.023 m^3/h and mean 0.062 ± 0.089 m^3/h per plant (ranging from 0.0004 to 0.2 m^3/h per plant). The results suggested that a placement of 10 – 1000 plants/m^2 of a building's floor space is necessary for the combined VOC removing ability by potted plants to achieve the same removal rate that outdoor-to-indoor air exchange already provides in typical buildings (~1/h)	The authors concluded that future experiments should be focused to the VOC uptake mechanisms, alternative biofiltration technologies, biophilic productivity and well-being benefits or negative impacts of other plant-sourced emissions instead of the potted plants' (in)abilities to passively clean indoor air.

Teiri et al. (2018)	The study investigated the ability of potted plant (*Chamaedorea elegans*) in formaldehyde removal from indoor air. The investigation was performed inside a chamber under controlled environment, where different concentrations of formaldehyde (0.66 - 16.4 mg/m³) were continuously introduced.	The results of the study showed that the plant efficiently removed formaldehyde from polluted air by 65 - 100%, depending of the inlet concentrations, for a long-time exposure. A maximum elimination capacity of 1.47 mg/m².h was achieved with an inlet formaldehyde concentration of 14.6 mg/m³. However, a noticeable decrease of the removal efficiency was observed for concentrations higher than 12 mg/m³, suggesting that the plant removal capacity was fillet. The entire plant showed more removal in daytime rather than night-time and darkness. The removal ratio of areal part to pot soil and roots was found to be 2.45:1 (71%: 29%). the removal of formaldehyde from the soil and roots the authors attributed to the pollutant adsorption and metabolism by the microorganisms in the soil.	From the results obtained during this study, the authors concluded that phytoremediation can be one of the most effective, economically and environmentally friendly indoor air purification methods.

Parseh et al. (2018)	The study examined the phytoremediation of benzene from polluted air by two plant species (*Schefflera arboricola* and *Spathiphyllum wallisii*). The experiments were performed in a Plexiglas chamber (84 cm x 62 cm x 72 cm) maintaining constant inside temperature of 21±3°C and relative humidity of 81±6%. A natural light source with a dark-light cycle of 12h were used during the experiment. The benzene removal efficiency was tested for a period of 36 days at various inlet concentrations in the range of 3.5-29.5 μg/m³.	The average removal efficiency at various inlet concentrations including 3.5-6.5, 10.5-16.3, and 25-30 μg/m³ were reported to be 97%, 94% and 91%, respectively.	The results showed that *Schefflera arboricola* and *Spathiphyllum wallisii*, as ornamental plants, have a good potential for benzene removal from indoor air.
Stapleton et al. (2018)	The study assesses the effectiveness of plants to decrease ultrafine particle concentrations in indoor environments. Ambient ultrafine particle concentrations were measured for three hours in and outside a polycarbonate chamber with and without plants using a condensation particle counter. Reduction in ambient ultrafine particle levels between blanks and treatments of the tested plant species were compared using infiltration factors (Finfs).	*Juniperus chinensis* 'San Jose' showed the highest per-plant ultrafine particle reduction (5.5%), while *Dracaena deremensis compacta* showed almost no ultrafine particle reduction. A linear relationship between number of within-chamber plants and percent ultrafine particle reduction was found (r^2 = 0.95) for *juniper plants*, the maximum achieved Finfp reduction was 19.9%. Plant surface area was associated with ultrafine particle reduction (r^2 = 0.85) when comparing statistically significant results. Humidity and temperature were irrelevant to reduction. Household ultrafine particle reduction was estimated using *juniper plants* (11%).	The results from this study indicate that plants may provide a small, yet statistically significant ultrafine particle reduction in homes with the co-benefit of greening the indoor environment.

Abbass et al. (2017)	The study determined ozone deposition velocities for five common indoor plants Peace Lily, Ficus, Calathia, Dieffenbachia, Golden Pothos) during their exposure to ozonated air stream with concentration of 60±1.2 ppb in a glass chamber. During the tests, each specimen was exposed to 8h of ozonated air followed by 16h of non-ozonated stream.	The ozone deposition velocities of the tested plants were ranging from 0.5 to 5.5 m/h. The ozone removal effectiveness of the tested plant species was calculated as a function of the ratio of plant leaf area to volume of typical indoor environment at 0.9 – 9%.	The tested plant has shown moderate ozone deposition velocity and modest contribution to indoor ozone removal effectiveness for reasonable indoor loading factors of plant leaf surface area. The study also showed that the ozone possibly changes the composition or structure of the leaf surface lowering its removal ozone effectiveness of these species.
Gawrońska et al. (2015)	The study investigates the ability of spider plants (*Chlorophytum comosum L*.) to take up particulate matter (PM) in the indoor air of five rooms housing different activities (a dental clinic, a perfume-bottling room, a suburban house, an apartment and an office).	The total amount of PM accumulated on the leaves of the spider plant differed between the rooms examined and ranged from 13.62 to 19.79 $\mu g/cm^2$, with the largest and smallest amounts recorded for the office and the suburban house, respectively. The amount of PM accumulated on the leaves were significantly higher in comparison with the amount deposited on aluminium plates, suggesting that the accumulation of the PM on leaves involves factors/forces other than gravitation.	Spider plants (Chlorophytum comosum L.) grown indoors accumulate particulate matter of both categories and all size fractions, irrespective of their location and the type of activity taking place in the examined room. They therefore phytoremediate PM from indoor air. The fine PM is accumulated to greater extend in the cuticles of the leaves.

Sriprapat et al. (2014)	The study examined the air born uptake of toluene and ethylbenzene by twelve plant species. The examined species were placed in glass chambers with volume of 15.6 L, where toluene or ethylbenzene were injected to generate concentration of 20 ppm (12µmol) inside the chamber.	The toluene removal efficiency was found to average around 77% after 72h of exposure across the twelve-examined species, where the highest toluene removal efficiency of ~85% was found in *Sansevieria trifascianata*. In term of ethylbenzene, the average removal efficiency was found to be ~70% after 72h of exposure between the twelve-examined species. the highest ethylbenzene removal efficiency of ~93% was found in *Chlorophytum comosum*.	All twelve-examined species showed more than 70% toluene and ethylbenzene removal efficiency after 72h of exposure.
Sriprapat et al. (2013)	The study assesses the potential of *Zamioculcas zamiifolia* to reduce the concentration of benzene, toluene, ethylbenzene and xylene (BTEX) from contaminated indoor air. The plants were exposed during 72h to contaminated air containing one of each of tested compounds in a glass chamber. The concentration of each of the tested contaminants were 20 ppm. During the test the chamber were kept at 32±5°C with 12h natural light-dark cycles.	The study found that *Zamioculcas zamiifolia* plants was effective in decreasing the studied compounds in the contaminated air within 120h. The BTEX removal efficiency of the studied specie was found to be 0.96±0.01 mmol/m² for benzene, 0.93±0.02 mmol/m² for toluene, 0.92±0.02 mmol/m² for ethylbenzene and 0.86±0.07 mmol/m² for xylene during 72h of exposure. The study also reported that 80% benzene, 76% toluene, 75% ethylbenzene, and 73% xylene were removed by stomata, while 20, 23, 25, and 26% of them were removed by non-stomata pathways or cuticles, respectively.	*Zamioculcas zamiifolia* has the potential to reduce the concentration of BTEX from contaminated indoor air. The physicochemical properties of each BTEX may affect its removal. The stromata removal pathways are dominating during BTEX removal.

Aydogan et al. (2011)	The study evaluated three types of growing media (growstone, expanded clay and activated carbon) and four common interior plants (*Hedera helix* (English ivy), *Chrysanthemum morifolium* (pot mum), *Dieffenbachia compacta* (dump cane) and *Epipremnum aureum* (golden pathos)) for their abilities to remove formaldehyde from air. Formaldehyde uptake of the individual growing media was evaluated under three conditions: dry media, dry media in a pot and wet media in a pot. A clear glass chamber at constant temperature of 21 ± 1°C was used. Artificial lighting was provided during the experiment using a fluorescent bulb in 12h cycles (day/night). A stream of formaldehyde vapours was injected to the chamber resulting initial formaldehyde concentration of ~1.63 ppm (~2000 μg/m³) inside the chamber where the selected growing media and plans were exposed.	The formaldehyde removal efficiency of activated carbon measured after 10h were 97.6%, 94.1%, and 88.9% for dry media, dry media in a pot and wet media in a pot, respectively. The removal efficiency of the other two media were 26.4%, 47.5%, 62.6% (expanded clay) and 17.4%, 39.3%, 62.3% (growstone) for dry media, dry media in a pot and wet media in a pot, respectively. the total reduction of gaseous formaldehyde of the examined plant species achieved by aerial parts (AP), the root zone (RZ), and the entire plant (EP) in a 24h period was as following: for *Hedera Helix* - 81% (AP), 85%(RZ), 88%(EP); for *Chrysanthemum morifolium* - 92% (AP), 88% (RZ), 84% (EP); for *Dieffenbachia compacta* - 92%(AP), 92% (RZ), 96% (EP); and for *Epipremnum aureum* - 95% (AP), 93% (RZ), 94% (EP).	From the three-growing media studied, activated carbon alone showed the highest formaldehyde removal at about 98% for period of 10h. The other two media showed similar formaldehyde removal efficiency of under wet conditions at about ~62%. The four-plant species studied demonstrated similar abilities to remove formaldehyde (around 90%) for 24h period. All four-plant species demonstrated quicker uptake rate of formaldehyde under dark versus light conditions.

Duijn et al. (2011)	The study assessed the effect that plants located in the classroom can have onto the indoor air quality and the people in the room (students and teachers). The study aimed to investigate the effects of plants in the classrooms on the five following categories: 1) Effect onto the IAQ of the classroom: in term of relative humidity, temperature, CO_2 and formaldehyde concentrations. 2) Effect on the well-being of the students in the classroom (subjective experience) 3) Effect on learning performance of the students (objective effects on both creative and standard tasks) 4) Effect on the work performance, well-being and health of the teachers 5) Effect on education regarding nature conservation, sustainability and experience of nature	The overall results from the study showed: - 10% – 20% CO_2 concentration removal in classrooms with plants in comparison with these without plants - The control condition tests of formaldehyde removal rate of *Spathiphyllum* showed: 20 mg formaldehyde per hour removal rate for 5000 g leaf mass The formaldehyde removal rate was relatively constant regardless light conditions - 7% less health complaints from the students and teachers -	Based on the obtained results, the study concluded: 1. The present of plants in the classroom and enough light (> 15 PAR) the study documented - 10% -20% reduction of CO_2 concentrations - 7% less health complaints from the students and teachers - 20% better score in performed creativity tasks and tests - The air purifying effect from the plants reduces the “bad odours” to a 0 level within 45 min 2. The positive effects on air purification from the plants are still present in lower light conditions (< 15 PAR), but in slower rate. - 20% better score in performed creativity tasks and tests 3. No adverse effects on the state of the pupils’ health was observed due to presence of the plants

Kim et al. (2010b)	The study assessed the efficiency of volatile formaldehyde removal of 86 species of plants from five general classes (ferns, woody foliage plants, herbaceous foliage plants, Korean native plants, and herbs). Phytoremediation potential was assessed by exposing the plants to gaseous formaldehyde (2 µL/L) in airtight chambers (1 m^3).	Among the 86-species tested, nine (*Osmunda japonica*, *Selaginella tamariscina*, *Davallia mariesii*, *Polypodium formosanum, Psidium guajava, Lavandula spp., Pteris dispar, Pteris multifida*, and *Pelargonium spp*.) have shown excellent formaldehyde removal characteristics (e.g., 1.87 $\mu g/m^3.cm^2$ or greater leaf area over 5h). In contrast, the average formaldehyde removal among all the species tested was only 1.0 $\mu g/m^3.cm^2$ leaf area over 5h or 0.20 $\mu g/m^3.h.cm^2$.	The tested species showed overall good formaldehyde removal characteristics. However, some of the species were more efficient than others, therefore the authors separated them into three general groups based on their formaldehyde removal efficiency: excellent (greater than 1.2 $\mu g/m^3$ formaldehyde per cm^2 of leaf area over 5 h), intermediate (1.2 or less to 0.6), and poor (less than 0.6). Species classified as excellent are considered viable phytoremediation candidates for homes and offices where volatile formaldehyde is a concern.

Liu et al. (2007)	The study screened 73 ornamental plant species for their ability to remove volatile organic compounds from air. The experiment was conducted in a Plexiglas chambers under controlled temperature of 25 ± 10°C and relative humidity of 55 ± 15% with 14h light period. The plants were exposed to a benzene atmosphere with concentration of 150 ± 6.7 ppb.	From the 73 tested plant species, 23 did not alter the benzene concentration in air, 13 species removed between 0.1 - 9.99% of benzene in contaminated air, 17 species removed 10-20%, and 17 species removed 20-40%. Three species removed 60-80% of benzene in experimental air. 10 of the species with higher benzene removal were additionally tested for two more days (8h exposure per day) to quantify their benzene removal capacity. The determined benzene absorption rates normalized for leaf were as following: *Crassula portulacea (Crassulaceae)* - 503.4 μg/m².min, *Hydrangea macrophylla (Hydrangeaceae)*- 203.9 μg/m².min, *Cymbidium Golden Elf (Orchidaceae)- 185.7 μg/m².min*, *Ficus microcarpa var. fuyuensis (Moraceae)- 177.4 μg/m².min*, *Dendranthema morifolium (Asteraceae)- 142.3 μg/m².min*, *Citrus medica var. sarcodactylis (Rutaceae)- 115.8 μg/m².min*, *Dieffenbachia amoena cv. Tropic Snow (Araceae)- 80.0 μg/m².min*, *Spathiphyllum Supreme (Araceae)- 74.2 μg/m².min*, *Nephrolepis exaltata cv. Bostoniensis (Davalliaceae)- 51.0 μg/m².min*, and *Dracaena deremensis cv. Variegata (Dracaenaceae) - 41.0 μg/m².min*.	From the 73 tested commonly used as ornamental plant species, 10 have been found to be most effective at removing benzene from air. *Crassula portulacea (Crassulaceae), Hydrangea macrophylla (Hydrangeaceae), Cymbidium Golden Elf (Orchidaceae), Ficus microcarpa var. fuyuensis (Moraceae), Dendranthema morifolium (Asteraceae), Citrus medica var. sarcodactylis (Rutaceae), Dieffenbachia amoena cv. Tropic Snow (Araceae), Spathiphyllum Supreme (Araceae), Nephrolepis exaltata cv. Bostoniensis (Davalliaceae, and Dracaena deremensis cv. Variegata (Dracaenaceae)*emerged as the species with the greatest capacity to remove benzene from indoor air.

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