Title	**Improving Building Energy Efficiency Through Implementation Of An Active Indoor Rhizospheric Microbe Air Processing System**
Author Name	West, Cortney
Journal Name	The University of Arizona
Year	2016
Volume and Issue	
Pages	
Abstracts	Commercial energy use in Arizona is different from the rest of the United States because of their high demand for air conditioning. Nearly half of the energy used in commercial buildings goes to heating, cooling, and ventilation. In an attempt to reduce overall every use in buildings, looking at these categories led to an examination of ventilation in buildings, which is the main cause for high heating and cooling costs. Ventilation of fresh air is required in order to provide a safe, healthy environment, with acceptable indoor air quality. Indoor air quality and pollution has continuously come to light as a major health concern for building occupants. Chemicals used in manufacturing allow consumers to buy and expose themselves to toxic substances such as volatile organic compounds on a daily basis. With minimal regulations on indoor air, it is important to find ways to better filter and clean it. The traditional solution is ventilation, but more fresh air ventilation means more heating and cooling. This paper explores the research that has been done on plants and phytoremediation and the applicability to indoor air quality. With the proof that certain combinations and amounts of plants can filter the air of volatile organic compounds, systems are explored for indoor air filtration instead of mechanical ventilation. This type of system can greatly reduce heating and cooling costs in buildings due to the reduction of outdoor air being brought in and requiring conditioning. A system of this type is a feasible solution to indoor air quality and can lead to a significant reduction in energy use. The proposed AIRMAPS is a system that in certain quantities can reduce the need for fresh air ventilation by 25%, which in turn has shown through the validation by eQUEST, that the energy used for heating, cooling, and ventilation fans can also be reduced by approximately the same amount. The plants used are spider plant, dumb cane, English ivy, and golden pothos. The average formaldehyde removal by each of these plants is a low approximation of 75% per cubic meter. This paper also considers the growing materials used for the plants; activated carbon, potting soil mix, and grow-stones, as well as their formaldehyde removal capabilities.
Keywords	Energy Reduction; Indoor Air Quality; Plants; Rhizosphere; Root Zone; Architecture; Energy Efficiency

Title	**A lack of consensus in the literature findings on the removal of airborne benzene by houseplants: Effect of bacterial enrichment**
Author Name	Wararat Sriprapat, Stuart E. Strand
Journal Name	Atmospheric Environment

Year	2016
Volume and Issue	131
Pages	9-16
Abstracts	Removal rates of benzene and formaldehyde gas by houseplants reported by several laboratories varied by several orders of magnitude. We hypothesized that these variations were caused by differential responses of soil microbial populations to the high levels of pollutant used in the studies, and tested responses to benzene by plants and soils separately. Five houseplant species and tobacco were exposed to benzene under hydroponic conditions and the uptake rates compared. Among the test plants, *Syngonium podophyllum* and *Chlorophytum comosum* and *Epipremnum aureum* had the highest benzene removal rates. The effects of benzene addition on populations of soil bacteria were determined using reverse transcription quantitative PCR (RT-qPCR) assays targeting microbial genes involved in benzene degradation. The total bacterial population increased as shown by increases in the levels of eubacteria 16S rRNA, which was significantly higher in the high benzene incubations than in the low benzene incubations. Transcripts (mRNA) of genes encoding phenol monooxygenases, catechol-2,3-dioxygenase and the housekeeping gene rpoB increased in all soils incubated with high benzene concentrations. Therefore the enrichment of soils with benzene gas levels typical of experiments with houseplants in the literature artificially increased the levels of total soil bacterial populations, and especially the levels and activities of benzene-degrading bacteria.
Keywords	Benzene, Hydroponic, Phytoremediation, Soil microbial, Volatile organic compounds, Formaldehyde

Title	**Toward effective design and adoption of catalyst-based filter for indoor hazards: Formaldehyde abatement under realistic conditions**
Author Name	Kwang Hoon Han , Jensen S. Zhang, Bing Guo
Journal Name	Journal of Hazardous Materials
Year	2016
Volume and Issue	331
Pages	161-170
Abstracts	Catalytic oxidation at ambient temperature has drawn wide attention as a new promising method of air cleaning, converting hazardous materials into non-hazardous ones. However, limited information is available regarding catalytic filter performance/characteristics under real operating conditions, especially on service efficiency and byproducts. Also, no practical scale-up method/evidence for filter performance evaluation is currently available to scale-up laboratory results to real application conditions. These limitations and knowledge gaps prevent building owners/designers from adopting this new promising technique in their commercial/industrial applications. The present study conducted experiments

	from small-scale to full-scale chamber tests which challenged a developed catalytic filter under realistic conditions. Formaldehyde was selected for approach demonstration due to its indoor ubiquitousness and criticality for human health even at low-levels. Results showed that the competition level for reaction sites in filter media had a crucial role in the performance for formaldehyde abatement, a high initial (77%; under no competing pollutants) to a typical stable level (23–32%), depending on the coexistence of other pollutants and moisture in the air, that the employment of this type of filter might generate byproducts (opposite to previous literature reports), and that small-scale column tests represented a good indication for large-scale filter performance as a practical screening method.
Keywords	Formaldehyde abatement, Manganese oxide catalyst, Full-scale chamber test, Room-temperature oxidation, PTR-MS

Title	**Assessing the Indoor Pollutants Effect on Ornamental Plants Leaves by FT-IR Spectroscopy**
Author Name	A. Husti, M. Cantor, R. Stefan, M. Miclean, M. Roman, I. Neacsu, I. Contiu, K. Magyari and M. Baia
Journal Name	Acta Physica Polonica
Year	2016
Volume and Issue	129
Pages	129-142
Abstracts	Air pollution has become a mass phenomenon, a major and global problem of modern society, affecting billions of people and environment. People are exposed to various levels of pollutants not just in the outdoor environment, but also in indoors. The quality of life and well-being of employees can be increased by incorporating ornamental plants in the work environment. Among the great variety of plants species able to remove/reduce indoor air pollutants Dracaena deremensis, Sansevieria trifasciata and Ficus elastica were hereby investigated. Their ability to remove chemical pollutants was evaluated in real-life conditions and the changes induced by the environmental stress on the structure and biochemical composition of the plants leaves were evidenced by the Fourier transform infrared spectroscopy. The most pronounced concentration decrease was noticed for the CO2 (58.33% removed concentration), whereas the mean value of the removed concentration of other chemical pollutants was of _25%. The Fourier transforms infrared spectra analysis revealed that, although the plants are subjected to the chemical pollutants action, they maintain the structure by adjusting their metabolism. A decrease in the overall protein contribution in the amide bands and an increase of the bands assigned to polysaccharide vibrations, illustrate the consequences of the pollution action. Moreover, the chlorophyll presence is evidenced in the IR spectra of all samples by the bands around 1040, 1445, 1620, and 1735 cm1. The results show that the Fourier transform infrared spectra are an important source of information for the rapid characterization of the chemical structure of the biological systems under environmental stress.
Keywords	Air pollution, environmental stress, ornamental plants

Title	**Impact of formaldehyde and VOCs from waste treatment plants upon the ambient air nearby an urban area (Spain)**
Author Name	Eva Gallego , Francisco Javier Roca , José Francisco Perales, Xavier Guardino , Enrique Gadea , Pedro Garrote
Journal Name	Science of The Total Environment
Year	2016
Volume and Issue	568
Pages	369-380
Abstracts	Emission factors of formaldehyde and VOCs were determined for two waste treatment plants (WTP) located in the metropolitan area of Barcelona city. Formaldehyde emission factors were determined from the biogas engines exhausts and the process chimneys (after the biofilter process), and VOC emission factors were determined in the process chimneys. Formaldehyde and VOC were dynamically sampled using DNPH-coated adsorbent tubes with ozone scrubber and multi-sorbent bed tubes (Carbotrap, Carbopack X and Carboxen 569), respectively, using portable pump equipment. Formaldehyde emission factors from biogas engines were found between 0.001–0.04 g s^{-1}. Additionally, formaldehyde and VOC emission factors from process chimneys were found to be between 0.0002–0.003 g s^{-1} and 0.9 ± 0.3 g s^{-1}, respectively. Employing real emission factors, the expected concentrations derived from the WTPs in their nearby urban areas were calculated using The Atmospheric Pollution Model (TAPM, CSIRO), and impact maps were generated. On the other hand, ambient air formaldehyde and VOC concentrations were determined in selected locations close to the evaluated waste treatment facilities using both active and passive samplers, and were between 2.5 ± 0.4–5.9 ± 1.0 μg m-3 and 91 ± 48–242 ± 121 μg m-3, respectively. The concentrations of formaldehyde and VOC derived exclusively from the waste treatment plants were around 2% and 0.3 ± 0.9% of the total formaldehyde and VOC concentrations found in ambient air, respectively.
Keywords	Formaldehyde, Volatile organic compounds, TD-GC/MS, Waste treatment, Outdoor air quality

Title	**Removal of Indoor Volatile Organic Compounds via Photocatalytic Oxidation: A Short Review and Prospect**
Author Name	Yu Huang , Steven Sai Hang Ho , Yanfeng Lu , Ruiyuan Niu, Lifeng Xu , Junji Cao and Shuncheng Lee
Journal Name	Molecules
Year	2016
Volume and Issue	21, 1
Pages	56

Abstracts	Volatile organic compounds (VOCs) are ubiquitous in indoor environments. Inhalation of VOCs can cause irritation, difficulty breathing, and nausea, and damage the central nervous system as well as other organs. Formaldehyde is a particularly important VOC as it is even a carcinogen. Removal of VOCs is thus critical to control indoor air quality (IAQ). Photocatalytic oxidation has demonstrated feasibility to remove toxic VOCs and formaldehyde from indoor environments. The technique is highly-chemical stable, inexpensive, non-toxic, and capable of removing a wide variety of organics under light irradiation. In this paper, we review and summarize the traditional air cleaning methods and current photocatalytic oxidation approaches in both of VOCs and formaldehyde degradation in indoor environments. Influencing factors such as temperature, relative humidity, deactivation and reactivations of the photocatalyst are discussed. Aspects of the application of the photocatalytic technique to improve the IAQ are suggested.
Keywords	VOCs, formaldehyde, photocatalysis, review, influencing factors

Title	**The Effects of Indoor Foliage Plants on Perceived Air Quality, Mood, Attention, and Productivity**
Author Name	Desto Jumeno and Hiroshi Matsumoto
Journal Name	Journal of Civil Engineering and Architecture Research
Year	2016
Volume and Issue	3,4
Pages	1359-1370
Abstracts	People put plants indoors to create a pleasant interior space and to make the indoor air fresher. However, the placement of indoor plants is more instinctive or artistic rather than rational. Thus, this necessitates a systematic method for placing plants indoors to gain positive results for improving the quality of our well-being. This paper aims to investigate the effect of the number and size of plants on perceived air quality, mood, attention, and productivity. An experiment consisting of two variations on the number of plants and three variations on the size of plants was conducted for this study. 18 subjects consisted of 10 males and 8 females with average age of 23.5 years old participated in the study. All subjects performed in all treatments in the experiment with a repeated measures design. From the experiment, it was found that room with 3 small and medium sized plants (3-S and 3-M) produced the highest mood, room with 1-S, 3-M and 3-L produced the smallest reaction time, room with 1-S produced the highest productivity, and room with 3-S has the highest perceived air quality. In conclusion, the number of plants had an impact on the mood of the subjects; the larger the number of plants, the better the mood of the subjects. It was also revealed that Interactions between the number and the size of plants affected the perceived air quality and reaction time.
Keywords	Indoor foliage plants, number and size of plants, perceived air quality, mood, attention, productivity, secondary task reaction time, repeated measures.

Title	**Removal of Low-Molecular Weight Aldehydes by Selected Houseplants under Different Light Intensities and CO_2 Concentrations**
Author Name	Jian Li , Chun-Juan Xie , Jing Cai , Liu-Shui Yan and Ming-Ming Lu
Journal Name	Atmosphere
Year	2016
Volume and Issue	7, 11
Pages	-
Abstracts	The removal of five low-molecular weight aldehydes by two houseplants (Schefflera octophylla (Lour.) Harms and Chamaedorea elegans) were investigated in a laboratory simulation environment with short-term exposure to different low light intensities and CO_2 concentrations. Under normal circumstances, the C_1–C_5 aldehyde removal rates of Schefflera octophylla (Lour.) Harms and Chamaedorea elegans (Lour.) Harms ranged from 0.311 μmol/m^2/h for valeraldehyde to 0.677 μmol/m^2/h for formaldehyde, and 0.526 μmol/m^2/h for propionaldehyde to 1.440 μmol/m^2/h for formaldehyde, respectively. However, when the light intensities varied from 0 to 600 lx, a significant correlation between the aldehyde removal rate and the light intensity was found. Moreover, the CO_2 experiments showed that the total aldehyde removal rates of Schefflera octophylla (Lour.) Harms and Chamaedorea elegans (Lour.) Harms decreased 32.0% and 43.2%, respectively, with increasing CO_2 concentrations from 350 ppmv to 1400 ppmv. This might be explained by the fact that the excessive CO_2 concentration decreased the stomatal conductance which limited the carbonyl uptake from the stomata.
Keywords	Houseplants, light intensities, CO_2, low-molecular weight, aldehydes, removal

Title	**Levels of volatile organic compounds in homes in Dalian, China**
Author Name	Guirong Song, Aisong Yu, Kiyoshi Sakai, Md Khalequzzaman , Tamie Nakajima, Fumihiko Kitamura, Peng Guo, Kazuhito Yokoyama, Fengyuan Piao
Journal Name	Air Quality Atmosphere Health
Year	2016
Volume and Issue	10
Pages	171-181
Abstracts	This paper measured selected individual volatile organic compounds (VOCs), including formaldehyde, in residences in Dalian, evaluated the association between the apartment characteristics and VOC concentrations, and explored the associations between chemicals and sick building syndrome (SBS). Higher VOC concentrations were measured indoors than outdoors in summer (August to September) and winter (January to March) in Dalian, and there were no strong

	correlations between the indoor and outdoor concentrations of most VOCs. This indicates the dominance of indoor sources as compared to outdoor sources. Formaldehyde was the most abundant compound in this study, followed by toluene, benzene, xylene, and styrene. These pollutants increase the occurrence of SBS. Thus, the VOC levels in dwellings in Dalian should be regulated, in view of SBS risks.
Keywords	Volatile organic compounds, Formaldehyde, Sick building syndrome

Title	**Changes in air ions concentration depending on indoor plants activity**
Author Name	N. Siņicina and A. Martinovs
Journal Name	Agronomy Research
Year	2016
Volume and Issue	14, 1
Pages	236 –243
Abstracts	Lack of negative ions in the air can cause deterioration of the health which is described in many scientific articles. At the same time, an air saturated with negative ions can improve the state of health and provide a comfortable indoor environment. In addition, there are considerable evidences that drowsiness, apathy, headache etc. get even worse indoors, and these health problems may be effectively eliminated with a help of moderate concentrations of negative ions. Literature sources and earlier researches state that plants may be able to produce a variety of air ions, including negative light ions. The most plants emit different types of volatile organic compounds, and the indoor plants can improve the air quality: they effectively remove organic pollution and reduce the number of microorganisms in the air by releasing phytoncides. In this article, the regularity of influence of plants on the number of ions in the room is being proved, basing on a series of experiments performed with the following plants: Spathiphyllum, Pinus mugo, Aloe arborescens, Chlorophytum comosum, Cactaceae opuntia.
Keywords	Air ions, plants, microclimate

Title	**Household air pollution and its effects on health**
Author Name	Komalkirti Apte and Sundeep Salvi
Journal Name	F1000 Research
Year	2016
Volume and Issue	5
Pages	-
Abstracts	Household air pollution is a leading cause of disability-adjusted life years in Southeast Asia and the third leading cause of disability-adjusted life years

	globally. There are at least sixty sources of household air pollution, and these vary from country to country. Indoor tobacco smoking, construction material used in building houses, fuel used for cooking, heating and lighting, use of incense and various forms of mosquito repellents, use of pesticides and chemicals used for cleaning at home, and use of artificial fragrances are some of the various sources that contribute to household air pollution. Household air pollution affects all stages of life with multi-systemic health effects, and its effects are evident right from pre-conception to old age. *In utero* exposure to household air pollutants has been shown to have health effects which resonate over the entire lifetime. Exposures to indoor air pollutants in early childhood also tend to have repercussions throughout life. The respiratory system bears the maximum brunt, but effects on the cardiovascular system, endocrine system, and nervous system are largely underplayed. Household air pollutants have also been implicated in the development of various types of cancers. Identifying household air pollutants and their health implications helps us prepare for various health-related issues. However, the real challenge is adopting changes to reduce the health effects of household air pollution and designing innovative interventions to minimize the risk of further exposure. This review is an attempt to understand the various sources of household air pollution, the effects on health, and strategies to deal with this emergent risk factor of global mortality and morbidity.
Keywords	air quality, particulate matter, air pollutants

Title	**Biomonitoring and Remediation by Plants**
Author Name	Gyan Prakash Gupta, Umesh Kulshrestha
Journal Name	Plant Responses to Air Pollution
Year	2016
Volume and Issue	53
Pages	119-132
Abstracts	Dealing with environmental pollution promises to be one of man’s most urgent problems in the years to come. This chapter deals with different components of air pollution biomonitoring and their remediation by using different plant species of herbs, shrubs, and trees as green technology. Various methods of biomonitoring apply the whole or part of an organism to measure the exposure of a plant as well as accumulation of a pollutant. They have the great advantage to show clearly the effects of air pollutants as bioindicator plants. Bioindicators can reveal the impact and the cumulative effects of different pollutants. Phytoremediation is a set of processes such as rhizodegradation, phytostabilization, phytofiltration, phytoextraction, phytodegradation, and phytovolatilization. Through these processes plants remediate the pollutants, partially and sustainably from the atmosphere. Atmospheric gases (NO_2, SO_2, O_3, etc.), heavy metals, and VOC pollutants are reduced by absorbing and metabolizing them into less toxic compounds by site-specific plants or through the changes in the plant genome by overexpression of pollution-fighting genes through genetic engineering.

Keywords	Biomonitoring, Phytoremediation, Air pollution, Bioindicator

Title	**The Potted-Plant Microcosm Substantially Reduces Indoor Air VOC Pollution: I. Office Field-Study**
Author Name	Ronald A. Wood, Margaret D. Burchett, Ralph Alquezar, Ralph L. Orwell, Jane Tarran, Fraser Torpy
Journal Name	Water, Air, and Soil Pollution
Year	2016
Volume and Issue	175, 1
Pages	163–180
Abstracts	Volatile organic compounds (VOCs) are major contaminants of indoor air, with concentrations often several times higher than outdoors. They are recognized as causative agents of "building-related illness" or "sick-building syndrome". Our previous laboratory test-chamber studies have shown that the potted-plant/root-zone microorganism microcosm can eliminate high concentrations of air-borne VOCs within 24 hours, once the removal response has been induced by an initial dose. However, the effectiveness of the potted-plant microcosm in 'real-world' indoor spaces has never previously been tested experimentally. This paper reports the results of a field-study on the effects of potted-plant presence on total VOC (TVOC) levels, measured in 60 offices (12 per treatment), over two 5–9 week periods, using three planting regimes, with two 'international indoor-plant' species. Fourteen VOCs were identified in the office air. When TVOC loads in reference offices rose above 100 ppb, large reductions, of from 50 to 75% (to <100 ppb), were found in planted offices, under all planting regimes The results indicate that air-borne TVOC levels above a threshold of about 100 ppb stimulate the graded induction of an efficient metabolic VOC-removal mechanism in the microcosm. Follow-up laboratory dose-response experiments, reported in the following paper, confirm the graded induction response, over a wide range of VOC concentrations. The findings together demonstrate that potted-plants can provide an efficient, self-regulating, low-cost, sustainable, bioremediation system for indoor air pollution, which can effectively complement engineering measures to reduce indoor air pollution, and hence improve human wellbeing and productivity.
Keywords	indoor air pollution, VOC, TVOC, "sick-building syndrome" , "building-related illness", environmental biotechnology, bioremediation phytoremediation, potted-plant

Title	**The Potted-Plant Microcosm Substantially Reduces Indoor Air VOC Pollution: II. Laboratory Study**
Author Name	Ralph L. Orwell, Ronald A. Wood, Margaret D. Burchett , Jane Tarran, Fraser Torpy
Journal Name	Water, Air, and Soil Pollution

Year	2006
Volume and Issue	177,1
Pages	50-80
Abstracts	Indoor air-borne loads of volatile organic compounds (VOCs) are usually significantly higher than those outdoors, and chronic exposures can cause health problems. Our previous laboratory studies have shown that the potted-plant microcosm, induced by an initial dose, can eliminate high air-borne VOC concentrations, the primary removal agents being potting-mix microorganisms, selected and maintained in the plant/root-zone microcosm. Our office field-study, reported in the preceding paper, showed that, when total VOC (TVOC) loads in reference offices (0 plants) rose above about 100 ppb, levels were generally reduced by up to 75% (to < 100 ppb) in offices with any one of three planting regimes. The results indicate the induction of the VOC removal mechanism at TVOC levels above a threshold of about 100 ppb. The aims of this laboratory dose-response study were to explore and analyse this response. Over from 5 to 9 days, doses of 0.2, 1.0, 10 and 100 ppm toluene and *m*-xylene were applied and replenished, singly and as mixtures, to potted-plants of the same two species used in the office study. The results confirmed the induction of the VOC removal response at the lowest test dosage, i.e in the middle of the TVOC range found in the offices, and showed that, with subsequent dosage increments, further stepwise induction occurred, with rate increases of several orders of magnitude. At each dosage, with induction, VOC concentrations could be reduced to below GC detection limits (< 20 ppb) within 24 h. A synergistic interaction was found with the binary mixtures, toluene accelerating *m*-xylene removal, at least at lower dosages. The results of these two studies together demonstrate that the potted-plant microcosm can provide an effective, self-regulating, sustainable bioremediation or phytoremediation system for VOC pollution in indoor air.
Keywords	indoor air pollution, VOC, TVOC, toluene *m*-xylene , “sick building syndrome”, “building related illness”, environmental biotechnology, bioremediation, phytoremediation, potted-plant

Title	**Efficiency of Volatile Formaldehyde Removal by Indoor Plants: Contribution of Aerial Plant Parts versus the Root Zone**
Author Name	Kwang Jin Kim, Mi Jung Kil, Jeong Seob Song , Eun Ha Yoo
Journal Name	Journal of the American Society for Horticultural Science
Year	2008
Volume and Issue	133, 4
Pages	521-526
Abstracts	The contribution of aerial plant parts versus the root zone to the removal of volatile formaldehyde by potted *Fatsia japonica* Decne. & Planch. And *Ficus benjamina* L. plants were assessed during the day and night. The removal capacity of the entire plant, aerial plant parts, and root zone was determined by exposing

	the relevant parts to gaseous formaldehyde (2 $\mu L \cdot L^{-1}$) in airtight chambers (1.0 m^3) constructed of inert materials. The rate of formaldehyde removal was initially rapid but decreased as the internal concentration diminished in the chamber. To compare the removal efficiency between species and plant parts, the time interval required to reach 50% of the initial concentration was determined (96 and 123 min for entire plants of *F. japonica* and *F. benjamina*, respectively). In both species, the aerial plant parts reduced the formaldehyde concentration during the day but removed little during the night. However, the root zone eliminated a substantial amount of formaldehyde during the day and night. The ratio of formaldehyde removal by aerial plant parts versus the root zone was similar for both species, at ≈1:1 during the day and 1:11 at night. The effectiveness of the root zone in formaldehyde removal was due primarily to microorganisms and roots (≈90%); only about 10% was due to adsorption by the growing medium. The results indicate that the root zone is a major contributor to the removal of formaldehyde. A better understanding of formaldehyde metabolism by root zone microflora should facilitate maximizing the phytoremediation efficiency of indoor plants.
Keywords	*Fatsia japonica*, *Ficus benjamina*, indoor air quality, potted plant, phytoremediation, volatile organic compounds

Title	**Screening Indoor Plants for Volatile Organic Pollutant Removal Efficiency**
Author Name	BAI Yan Bin, LIU Xing Rong
Journal Name	HortScience
Year	2008
Volume and Issue	44,5
Pages	1377-1381
Abstracts	Twenty-eight ornamental species commonly used for interior plantscapes were screened for their ability to remove five volatile indoor pollutants: aromatic hydrocarbons (benzene and toluene), aliphatic hydrocarbon (octane), halogenated hydrocarbon [trichloroethylene (TCE)], and terpene (α-pinene). Individual plants were placed in 10.5-L gas-tight glass jars and exposed to ≈10 ppm (31.9, 53.7, 37.7, 46.7, and 55.7 $mg \cdot m^{-3}$) of benzene, TCE, toluene, octane, and α-pinene, respectively. Air samples (1.0 mL) within the glass containers were analyzed by gas chromatography–mass spectroscopy 3 and 6 h after exposure to the test pollutants to determine removal efficiency by monitoring the decline in concentration over 6 h within sealed glass containers. To determine removal by the plant, removal by other means (glass, plant pot, media) was subtracted. The removal efficiency, expressed on a leaf area basis for each volatile organic compound (VOC), varied with plant species. Of the 28 species tested, *Hemigraphis alternata*, *Hedera helix*, *Hoya carnosa*, and *Asparagus densiflorus* had the highest removal efficiencies for all pollutants; *Tradescantia pallida* displayed superior removal efficiency for four of the five VOCs (i.e., benzene, toluene, TCE, and α-pinene). The five species ranged in their removal efficiency from 26.08 to 44.04 $\mu g \cdot m^{-3} \cdot m^{-2} \cdot h^{-1}$ of the total VOCs. *Fittonia argyroneura*

	effectively removed benzene, toluene, and TCE. *Ficus benjamina* effectively removed octane and α-pinene, whereas *Polyscias fruticosa* effectively removed octane. The variation in removal efficiency among species indicates that for maximum improvement of indoor air quality, multiple species are needed. The number and type of plants should be tailored to the type of VOCs present and their rates of emanation at each specific indoor location.
Keywords	volatile organic compounds, benzene, toluene, octane, trichloroethylene, α-pinene, phytoremediation, indoor air quality

Title	**Potted-plant/growth media interactions and capacities for removal of volatiles from indoor air**
Author Name	R. A. Wood, R. L. Orwell, J. Tarran, F. Torpy & M. Burchett
Journal Name	The Journal of Horticultural Science and Biotechnology
Year	2002
Volume and Issue	77
Pages	120-129
Abstracts	Results are presented of an investigation into the capacity of the indoor potted-plant/growth medium microcosm to remove air-borne volatile organic compounds (VOCs) which contaminate the indoor environment, using three plant species, *Howea forsteriana* (Becc. (Kentia palm), *Spathiphyllum wallisii* Schott. 'Petite' (Peace Lily) and *Dracaena deremensis* Engl. 'Janet Craig'. The selected VOCs were benzene and n-hexane, both common contaminants of indoor air. The findings provide the first comprehensive demonstration of the ability of the potted-plant system to act as an integrated biofilter in removing these contaminants. Under the test conditions used, it was found that the microorganisms of the growth medium were the "rapid-response" agents of VOC removal, the role of the plants apparently being mainly in sustaining the root microorganisms. The use of potted-plants as a sustainable biofiltration system to help improve indoor air quality can now be confidently promoted. The results are a first step towards developing varieties of plants and associated microflora with enhanced air-cleaning capacities, while continuing to make an important contribution to the aesthetics and psychological comfort of the indoor environment.
Keywords	indoor environment, VOC removal, sustainable biofiltration system

Title	**Biological treatment of indoor air for VOC removal: Potential and challenges**
Author Name	Benoit Guieysse , Cecile Hort, Vincent Plate, Raul Munoz, Michel Ondarts, Sergio Revah
Journal Name	Biotechnology Advances
Year	2008

Volume and Issue	26, 5
Pages	398-410
Abstracts	There is nowadays no single fully satisfactory method for VOC removal from indoor air due to the difficulties linked to the very low concentration (μg m^{-3} ranges), diversity, and variability at which VOCs are typically found in the indoor environment. Although biological methods have shown a certain potential for this purpose, the specific characteristic of indoor air and the indoor air environment brings numerous challenges. In particular, new methods must be developed to inoculate, express, and maintain a suitable and diverse catabolic ability under conditions of trace substrate concentration which might not sustain microbial growth. In addition, the biological treatment of indoor air must be able to purify large amounts of air in confined environments with minimal nuisances and release of microorganisms. This requires technical innovations, the development of specific testing protocols and a deep understanding of microbial activities and the mechanisms of substrate uptake at trace concentrations.
Keywords	Biofiltration, Indoor air quality, Sick-building syndrome, Volatile organic compound, Green building

Title	**Efficacy of Indoor Plants for the Removal of Single and Mixed Volatile Organic Pollutants and Physiological Effects of the Volatiles on the Plants**
Author Name	Mung Hwa Yoo, Youn Jung Kwon and Ki-Cheol Son
Journal Name	Journal of the American Society for Horticultural Science
Year	2006
Volume and Issue	131, 4
Pages	452-458
Abstracts	Foliage plants of *Hedera helix* L. (english ivy), *Spathiphyllum wallisii* Regal (peace lily), *Syngonium podophyllum* Schott. (nephthytis), and *Cissus rhombifolia* Vahl. (grape ivy) were evaluated for their ability to remove two indoor volatile organic air pollutants, benzene and toluene. Removal was monitored when the aerial portion of plants was exposed singly to 1 $\mu L \cdot L^{-1}$ or to 0.5 $\mu L \cdot L^{-1}$ of each gas in a closed environment over 6-hour periods during the day and the night. Selected physiological processes were assessed before and immediately after treatment to determine the effect of the gases on the plants. The effectiveness of plants in the removal of air pollutant(s) varied with species, time of day, and whether the gases were present singly or as a mixture. When exposed to a single gas, *S. wallisii*, *S. podophyllum*, and *H. helix* displayed higher removal efficiencies ($ng \cdot m^{-3} \cdot h^{-1} \cdot cm^{-2}$ leaf area) of either gas than *C. rhombifolia* during the day. The efficiency of removal changed when both gases were present; *H. helix* was substantially more effective in the removal of either benzene or toluene than the other species, with the removal of toluene more than double that of benzene. When exposed singly, the removal of both compounds was generally higher during the day than during the night for all species; however, when present simultaneously, *H. helix* removal

	efficiency during the night was similar to the day indicating that stomatal diffusion for english ivy was not a major factor. The results indicated an interaction between gases in uptake by the plant, the presence of different avenues for uptake, and the response of a single gas was not necessarily indicative of the response when other gases are present. Changes in the rates of photosynthesis, stomatal conductance, and transpiration before and after exposure indicated that the volatiles adversely affected the plants and the effects were not consistent across species and gases. Deleterious effects of volatile pollutants on indoor plants may be critical in their efficacy in improving indoor air quality and warrant further study.
Keywords	Benzene, toluene, volatile organic compounds, stress, injury, indoor pollutants, phytoremediation, detoxification

Title	**Formaldehyde removal by common indoor plant species and various growing media**
Author Name	Ahu Aydogan, Lupita D. Montoya
Journal Name	Atmospheric Environment
Year	2016
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Abstracts	Three porous materials (growstone, expanded clay and activated carbon) were evaluated as hydroponic growing media and for their individual ability to remove the indoor volatile organic compound formaldehyde under three conditions: growing medium alone, dry medium in a pot, and wet medium in a pot. The total percent-reduction of formaldehyde by each growing media was evaluated over a 10-h period. In all cases, activated carbon achieved the highest removal under the three conditions studied with average percent reductions measured at about 98%. Four common interior plants: *Hedera helix* (English ivy), *Chrysanthemum morifolium* (pot mum), *Dieffenbachia compacta* (dump cane) and *Epipremnum aureum* (golden pathos) growing in growstone were then tested for their ability to remove formaldehyde. The removal capacity of the aerial plant parts (AP), the root zone (RZ) and the entire plant (EP) growing in growstone were determined by exposing the relevant parts to gaseous formaldehyde (~2000 $\mu g\ m^{-3}$) in a closed chamber over a 24-h period. The removal efficiency between species and plant parts were compared by determining the time interval required to decrease about 2/3 of the total formaldehyde concentration reduction, $T_{2/3}$. The $T_{2/3}$ measured were 23, 30, 34 and 56 min for EP of *C. morifolium*, *E. aureum*, *D. compacta and H. helix*, respectively. The formaldehyde removal by the root zone was found to be more rapid than the removal by the aerial plant parts.
Keywords	Volatile organic compounds, Formaldehyde, Indoor air quality; Interior plants, Growing media