Building and Environment 147 (2019) 67–76

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Foliage houseplant responses to low formaldehyde levels

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A R T I C L E I N F O

Keywords:
Phytoremediation
Indoor air quality
Hue spectra
Plant monitoring

A B S T R A C T

House plants are reported to 'clean' formaldehyde from indoor environments and thus reduce its deleterious health effects. We measured formaldehyde removal rates at concentrations similar to those caused by new furniture or office photocopiers. We also measured CO_2 and humidity changes, counted the stomata density and monitored leaf color and shape changes. Controls were an artificial polyester "fern" and methanol as the VOC. All plants reduced formaldehyde from 0.75 ppm to below 0.2 ppm in six hours.. The plants fall into two major groups with different responses: one group showed high removal rates: Boston fern (0.85 $m\,h^{-1}$), golden pothos (0.41 $m\,h^{-1}$), Spanish moss (0.44 $m\,h^{-1}$) and spider plant (0.40 $m\,h^{-1}$) - faster than the artificial fern (0.09 $m\,h^{-1}$). They also show no change in color and appear to completely assimilate formaldehyde. Another group absorbed formaldehyde at a significantly lower rate (dumb cane: 0.07 $m\,h^{-1}$; aloe vera: 0.17 $m\,h^{-1}$; and Chinese evergreen: 0.09 $m\,h^{-1}$) and had a generally different overall behavior from the 'fast' group - different CO_2, humidity and variance changes - suggesting a different formaldehyde absorption mechanism. An 'intermediate case', snake plant (0.29 $m\,h^{-1}$), has a slower rate than the fast group but also exhibited other changes, suggesting some combination of both mechanisms. Overall good correlations between formaldehyde uptake rates and stomata counts, total leaf area and water evapotranspiration rates were shown by all these plants.

1. Introduction

Indoor foliage plants are commonly grown indoors for decorating or improving an environment. They are brought into indoor settings in various forms *e.g.* potted plants or green walls. They can grow under low light and need little care. Research on benefits of indoor plants spans noise reduction, air conditioning, contribution to positive outcomes on health and comfort of occupants and air pollution abatement [1]. For indoor removal of air pollution, many foliage plants have been shown to reduce particulate matter [2], carbon dioxide [3,4], carbon monoxide, nitrogen dioxide [5], ozone [6] and volatile organic compounds (VOCs) [7–11]. Petit et al.'s review covers recent work in all these areas [12]. Following Wolverton et al.'s pioneer work on VOC removal at the US National Aeronautics and Space Administration, plants incorporating leaves, roots, soil and associated microorganisms were shown to reduce benzene, trichloroethylene and formaldehyde [7]. Removal of VOCs by potted plants is known to occur through both biodegradation by microbes residing in potted soils and on plant leaves and through diffusion and metabolism by plants themselves [9,13]. Examples of indoor foliage plants that have been experimentally shown to effectively remove VOCs are: English ivy (*Hedera helix*) and lucky bamboo (*Dracaena sanderiana*) for benzene removal, snake plant (*Sansevieria trifasciata*) for toluene removal, spider plant (*Chlorophytum comosum*) for ethylbenzene removal [7,10,11]. An extensive list of VOCs and plants that remove them has been collated by Petit et al. [12].

Formaldehyde is the most abundant of aldehydes found indoors at a range of 16–49 ppb, while outdoor levels are generally below 16 ppb in urban areas [14]. In Thailand, a mean concentration of formaldehyde in 12 office buildings in Bangkok was 29 ppb, while a mean outdoor concentration was 8 ppb [15]. Indoor sources are building materials, furnishings and other customer products. The recommended level for occupational exposure to formaldehyde is 0.75 ppm [16]. However, occupant exposure to low levels of formaldehyde still causes irritating effects such as increased sensitization and asthma [14]. Many phytoremediation studies have demonstrated the ability of household plants to remove formaldehyde. However, these previous studies have focused on levels in the 1–20 ppm range or significantly higher than the levels typically found in non-industrial microenvironments [7,8,12,17,18]. Plants that respond to these high concentrations may differ in their response to lower concentrations. Furthermore, the gas flux, across the air boundary layer adjacent to the surface of the leaf, is a function of the difference in concentration. In a well-mixed core, the mass transfer of

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https://doi.org/10.1016/j.buildenv.2018.09.053
Received 6 August 2018; Received in revised form 20 September 2018; Accepted 29 September 2018
Available online 02 October 2018

the gas flux is governed by the boundary layer resistance. Petit et al. [12] noted that potted plant efficiencies for removal of VOCs at high concentrations in sealed chambers are possibly due to various factors such as plant species, VOCs, pollutant concentrations etc. Thus, we aimed to measure the ability of indoor foliage plants to remove low formaldehyde levels in a controlled approach with a small chamber. We also extended our work to phenomenologically examine the formaldehyde entry pathways of plants in relation to their evapotranspiration and CO_2 production. This included measurement of morphological and color changes to determine whether the plants were useful indicators of low levels of formaldehyde.

2. Materials and methods

2.1. Plants studied

We chose eight foliage plants reported to effectively remove formaldehyde [9,17,19–21] and commonly used for decorating or planting indoors in Thailand [22]. The plants included golden pothos (*Epipremnum aureum*), spider plant (*Chlorophytum comosum*), dumb cane (*Dieffenbachia seguine*), Boston fern (*Nephrolepis exaltata*), aloe vera (*Aloe vera*), snake plant (*Sansevieria trifasciata*), Chinese evergreen (*Aglaonema* sp. *'Phetnamnueng'*), and Spanish moss (*Tillandsia usneoides*). We also chose an artificial Boston fern for comparison with the living Boston fern. The artificial Boston fern had 21 fronds, made of woven polyester fabric. Some of these plants have also been studied for their ability to trap indoor particulate matter in our previous work [2]. Live plants were obtained from a garden shop in Mahasarakham (16°10′38″N 103°18′3″E). They were estimated to be about three months in age. Each plant was supplied in a plastic pot containing soil except for Spanish moss, which was placed in an open stainless steel wire cage.

We measured leaf surface area of the test plants by photogrammetry with a MATLAB program (R2015A version 8.5.0.197613). Details of the measurements have been reported already [2]. Total two-sided leaf surface areas of individual plants are summarized in Table 1.

2.2. Experimental setup

Fig. 1 shows the 0.21 m^3 acrylic experimental chamber, equipped with two small fans on the walls for providing a well-mixed core. A 2.2 m LED strip light (8520 SMD LED module) was installed at the ceiling edges. Its total power was 44 Watt, providing about 330 lux measured at 0.1 m above the floor, equivalent to a photosynthetic photon flux density (PPFD) of ~4.8 $\mu mol\, m^{-2} s^{-1}$. This level of the light intensity is recommended for general work area in workplace [23]. An industrial camera (UI-1580LE, IDS Industrial cameras, Germany), connected to the computer, was placed above the chamber, for photographing the test plant, through an optical flat window in the ceiling. The chamber was totally covered with black cloth to block ambient light. The plant pot and soil were covered with a high density poly ethylene (HDPE) bag and then wrapped with aluminium foil and fastened with a cable tie, allowing only the aerial part of the plant to be exposed to gaseous formaldehyde during the test and placed in the center of the chamber at a height of 0.2–0.3 m above the chamber floor. Dust or soil on the leaves was wiped away, with a water-moistened

Table 1
Leaf area and number of stomata.

Plant	PP[a]	Total leaf area (m^2/plant)[b]	Loading factor ($m^2\, m^{-3}$)[c]	Stomata density (number per mm^2)			Total number of stomata per plant
				Upper epidermis	Lower epidermis	Total	
golden pothos	C3 [28]	0.23 ± 0.05	1.07	0	56	56	6.3×10^6
spider plant	C3 [28]	0.11 ± 0.03	0.53	0	94	94	5.2×10^6
dumb cane	CAM [29]	0.12 ± 0.03	0.58	17	25	42	2.6×10^6
Boston fern	CAM [30]	0.33 ± 0.02	1.57	0	52	52	8.5×10^6
aloe vera	CAM [31]	0.03 ± 0.01	0.14	18	19	37	5.3×10^5
snake plant	CAM [31]	0.12 ± 0.04	0.58	29	32	61	3.7×10^6
Chinese evergreen	CAM [29]	0.18 ± 0.05	0.85	0	27	27	2.4×10^6
Spanish moss	CAM [32]	0.26 ± 0.02	1.24	22	43	65	8.4×10^6
artificial Boston fern	na	0.39 ± 0.02	1.85	0	0	0	0

[a] PP = photosynthetic pathway.
[b] Total leaf surface area per plant – considering both sides.
[c] Ratio of leaf area to chamber volume.

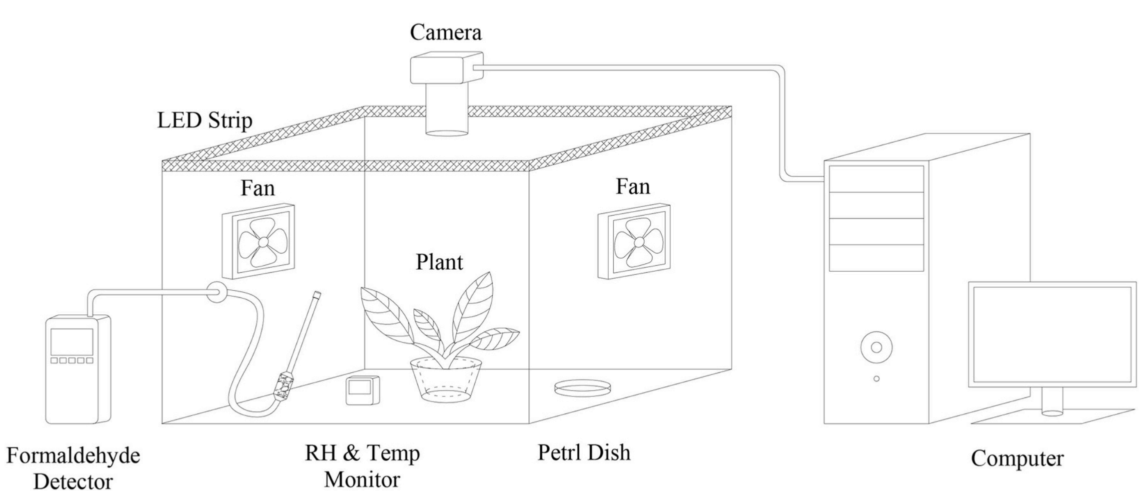

Fig. 1. Experiment setup.