Critical Review: How Well Do House Plants Perform as Indoor Air Cleaners?

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SUMMARY

In the late 1980's, research indicated that plants had the capability to remove volatile organic compounds (VOC) from indoor air. The findings were based upon chamber studies involving injection of a pollutant into a small, sealed chamber and following the pollutant decay, with and without plants present. The results were striking with removal rates up to 90% in 24 hr. Other studies examining this effect followed. Today, even a casual search of the internet will find many articles extolling the benefits of using plants as indoor air cleaners. However, there has been little critical analysis of the application of plants to actual indoor environments and only a few field studies have been conducted. A critical review of results of both laboratory chamber studies and field studies leads to the conclusion that indoor plants have little, if any, benefit for removing indoor air of VOC in residential and commercial buildings. Finally, recommendations for improving future studies are presented.

KEYWORDS

Plants, pollution reduction, VOC, air cleaning

INTRODUCTION

Using plants indoors to control indoor air pollution is an attractive, popular concept and many articles in the popular press and internet extol and promote their use as indoor air cleaners. Today, a search of the internet will find many articles promoting the use of plants as indoor air cleaners. While several scientific papers have been published on studies of pollutant removal by plants in small test chambers under controlled conditions, as yet, there has been little critical analysis of the studies and their results. Far fewer field studies have been published. This paper will briefly review results of both laboratory chamber studies and field studies, followed by a critical analysis of these results and the implications for indoor air cleaning. Finally, recommendations for improving future studies are presented.

STUDIES OF POLLUTANT REMOVAL BY PLANTS

In the late 1980's, published research indicated that plants had the capability to remove pollutants from indoor air (e.g., Wolverton et al., 1989). The findings were based upon studies involving the introduction of a pollutant or pollutants into a small, sealed chamber. The chamber volumes typically ranged from 0.31 to 0.88 m^3. Many pollutants were studied, including benzene, xylenes, tricholorethylene and formaldehyde at concentrations of ~15 to 20 ppm. The decay of the pollutant concentration over time, with and without plants present, was then followed. The reported results were striking, with reductions that averaged 10 to 70% in a 24-hr period. Wolverton and colleagues later conducted tests on the removal of benzene and trichloroethylene at concentrations ranging from 0.1 to 0.4 ppm. The reported reductions ranged from 9.2 to 90%.

Studies examining this effect by other researchers followed. For example, Wood et al. (2003) used small chambers (0.22 m^3) and several plant species to study the removal of benzene and hexane over 24 hours from initial concentrations of 25 ppm for benzene and 100 ppm for hexane. Quantitative results were not given for the concentration reductions but estimated concentration vs. time plots indicate reductions by potted plants exposed to daily introductions of pollutants of ~80% for benzene and ~70% for hexane.

To test the validity of laboratory results, the Associated Landscape Contractors of America (ALCA) worked with Healthy Buildings International to conduct a field experiment (HBI, 1992). HBI sampled for toluene, xylene, 1,1,1-trichlorethane and benzene for several months in two very similar floors of an office building in Arlington, VA, USA. Identical ventilation systems on both floors had their outdoor air damper set and unchanged for the duration of the study. For the first month, no plants were on either floor; for the next four months, plants were only on the 9^{th} floor; and for the last four months, plants were on both the 9^{th} and the 11^{th} floors. The number of plants installed by ALCA was not reported but is probably consistent with the ALCA recommendation of one plant per 9.29 m^2 (100 ft^2). Pollutant concentration maxima were all in the 10's to 100's of ppb range: toluene, ~210 ug/m^3; xylene, ~300 ug/m^3; 1,1,1-trichloroethane, ~700 ug/m^3; and benzene, ~18 ug/m^3. The presence of plants produced no reduction of pollutant concentrations. The authors concluded that the "levels of VOCs on the ninth floor remained essentially the same as those on the eleventh floor throughout the duration of the study."

Dingle et al. (2000) reported on a field study of three portable office buildings in Perth, Australia to test removal of formaldehyde by plants. Five plants (five species) were added to each room every two days to a maximum of 20 plants (at 2.44 plants per m^2) after nine days. Two adjacent portable office buildings were used as controls with no plants. The mean formaldehyde concentrations were about 850 ppb, except with 20 plants. The authors state that the results show "no change in formaldehyde concentrations with the addition of 5 or 10 plants in the rooms and only an 11% reduction in formaldehyde concentrations with 20 plants in the room." They did not indicate that this reduction was statistically significant.

Wood et al. (2006) reported on field studies of pollutant reductions using plants in three office buildings in Sydney, Australia. In one building, the nine offices studied were served by three separate air-conditioning systems; in the second building, the eight offices studied were served by a single air-conditioning system, supplying about 0.6 to 1.2 outside air changes per hour; and the third building was naturally ventilated with windows almost always closed during the study. In the third building, nine offices were studied in the first phase, and eight offices were studied in the second phase. All offices were designed for single occupancy and had 10-12 m^2 in floor area. Five-minute samples of total volatile organic compounds (TVOC) were measured weekly with a portable photoionization detector, and individual VOC were measured using passive samplers and gas chromatography/mass spectroscopy.

In the first and third buildings, after one month of pretesting, subsets of three office buildings were randomly supplied with 0, 3 or 6 potted "Janet Craig" plants. Weekly measurements were made over nine weeks and then the potted plants were randomly reassigned among the offices for a second nine-week period. For the second part of the investigation, two types of potted plants were used in the second and third buildings. After one month of pretesting, four offices were randomly supplied with 0 or 6 plants. Air was sampled for nine- and five-week periods in the second building and for nine weeks in the third building.

With no plants in the first and third buildings, the mean indoor TVOC concentration was 110 $\pm$ 15 ppb. Periods with 3 or 6 plants had a pooled TVOC concentration of 80 $\pm$ 7 ppb, a 27% reduction but only at $p < 0.09$. TVOC concentrations were identical with either 3 or 6 plants. When only periods with TVOC concentrations greater than 100 ppb (9 of 18 weeks) were used to calculate means, the reductions were statistically significant ($p < 0.05$): 0 plants, mean concentrations 190 $\pm$ 40 ppb; 3 plants, 105 $\pm$ 15 ppb; and 6 plants, 100 $\pm$ 10 ppb. Results of the nine-week study in the second investigation were similar. Concentrations for 14 individual VOC are also reported. No trend is evident from these data: individual VOC concentrations with 6 plants appear to be randomly higher or lower than those with no plants.

DISCUSSION

At first glance, the pollutant reduction by plants in chamber studies seems remarkable. However, closer examination suggests otherwise. Little has changed in terms of quantitative VOC reductions by plants in chamber studies since the early Wolverton studies, i.e., the best result for the removal of a single injection of a VOC remains about 90% in a 24-hour period. Thus, the conclusions of a previous analysis using a mass-balance model by Girman (reported by Levin, 1992) are still valid. This analysis concluded that pollutant removal in a chamber of 90% in 24 hours was only 0.096 hr^{-1}, less than the removal achieved by the natural ventilation rate of a very tight house (e.g., 0.2 h^{-1}). Moreover, this removal was achieved with a plant loading in chambers (approximately one plant per 0.5 m^3) far in excess of what would be reasonable for indoor environments. To achieve results equivalent to those of chamber studies would require 680 plants for a 340 m^3 (1500 ft^2) house. Yet ACLA recommends one plant per 9.29 m^2 (100 $ft^{2)}$ and a reduction in plant loading to 1 plant per 0.5 m^3 means that the plants in such an environment would have a removal rate equivalent to only 0.002 hr^{-1}.

Significant methodological issues also plague these chamber studies. The chamber test was a static test method, i.e., pollutants are injected and then the pollutant decay is measured. This does not mimic the behaviour of pollutants such as formaldehyde that are continuously emitted. Reductions for pollutants continuously emitted would be much lower. In addition, pollutant removal rates in these studies are too often reported as only the percent removed, rather than mass of pollutant removed per hour per plant. This makes it difficult to translate the results to other scenarios, e.g., to proposed use in an actual room or building, or to compare this method to more traditional pollutant removal methods such as ventilation or air cleaning with filters or sorbents. It should also be noted that the chamber studies used pollutant concentrations an order of magnitude or more higher than those generally found in indoor environments. Also, many chamber studies employed air circulation fans, which would tend to increase pollutant losses to interior surfaces.

Results from the field studies are more difficult to assess. The methods used to measure formaldehyde (passive monitor) and VOCs (passive sampler, photoionization detector) are not very accurate. In addition, although ventilation dominates the VOC removal processes in virtually all real world buildings, ventilation was not measured in any of these studies. It is not possible to obtain meaningful quantitative results of pollutant removal in a field study without also measuring ventilation rates. The ventilation rate variability in most buildings is simply too large a confounder.

With this caveat firmly in mind, it is hardly surprising that the HBI study failed to find any effect on pollutant removal by plants, despite a reasonably strong study design in terms of using controls. The study by Dingle et al. found only an 11% reduction in formaldehyde with the highest loading of plants (20 plants in a room or a loading of 2.44 plants per m^2), which is not feasible in the real world and is probably not statistically significant.

Only in the field study by Wood et al. are pollutant reductions statistically significant, and then only when indoor TVOC concentrations are above 100 ppb. However, these results are not consistent with the fact that doubling the number of plants did not cause a statistically significant reduction (i.e., a reduction of only 105 $\pm$ 15 ppb to. 100 $\pm$ 10 ppb) and with the fact that individual VOC concentrations did not appear to be reduced. It is possible that variations in ventilation may have been responsible for any apparent pollutant reductions. In this regard, the indoor carbon dioxide (CO_2) concentrations in the buildings ranged from 285 to 420 ppm (outdoor CO_2 was not sampled), suggesting that building ventilation rates were high, occupancy was low, or both conditions existed during the study. It is also likely that sampling for TVOC for 5 minutes per week is insufficient to characterize indoor concentrations.

CONCLUSIONS

Several laboratory studies have shown that plants can remove airborne VOC. However, a careful examination of studies does not find convincing evidence that the use of plants indoors can result in meaningful reductions in indoor VOC concentrations. Several improvements should to be made to studies intended to demonstrate that plants can be used to improve indoor quality. Concentrations used in chamber studies should be representative of concentrations found in actual indoor environments. Also, such studies should use analytical methods of high accuracy and sensitivity to measure VOC concentrations and should focus on individual VOC. They should also use mass-balance models to design and assess study results. Chamber study results should be reported as mass of pollutant removed per hour per plant to facilitate comparisons with other removal methods to assist building designers, managers and owners in determining whether using plants is an appropriate pollution control technique. For the same reasons, plant loadings should be reported. Finally, to be convincing, any field study must also measure ventilation rates since ventilation rates typically dominate pollutant removal processes. At present, it is premature to recommend that using plants indoor is viable means of controlling indoor air pollution.

DISCLAIMER

The opinions expressed in this paper are those of the authors and do not necessarily reflect the positions of the California Air Resources Board.

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