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Can House Plants Solve IAQ Problems?

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The idea of common plants solving IAQ problems is attractive. Most people like having plants in their homes and offices and in the hotels, stores, and public buildings they visit. However, important questions exist as to whether plants can actually affect indoor air sufficiently to warrant their use as air cleaners.

Nearly everyone has read or heard a press story about how common house plants can affect IAQ. Many stories say spider plants or Boston ferns remove formaldehdye. The Associated Landscape Contractors of America (ALCA) and their promotional organization Plants for Clean Air Council aggressively promote the idea through press releases, media briefings, and other efforts.

Some scientists and interiorscapers (people who design and provide plant environments in buildings) say that National Aeronautics and Space Administration (NASA) research demonstrates the efficacy of plants as indoor air cleaners. Critics and skeptics include high-ranking officials of the EPA's Indoor Air Division. They say the research, if valid, indicates the need for huge numbers of plants to remove indoor air contaminants as effectively as normal air exchange in an energy-efficient house or in a typical office building. In this article we discuss the research promoting the use of plants, the limitations of the studies, and our own thoughts on the subject.

Advocates' Views

Scientists funded by NASA say their research shows that plants clean indoor air. These scientists and other vigorous advocates say that plants have been cleaning the earth's atmosphere for millions of years. They say that eventually their critics at EPA and elsewhere will realize that using plants is the most reasonable method for indoor air pollution control.

NASA research tested plants' ability to clean indoor air for possible use in space stations. Even before awareness of indoor air pollution increased in the early 1980s, NASA had funded research on using plants to biologically treat waste water. Biological waste water treatment technology proved effective and is used at small- to medium-scale municipal sewage treatment plants and to reclaim water for irrigation.

NASA is concerned about poor indoor air depositing gaseous contaminants on critical electronic components inside spacecraft. NASA contractors test for excessive emissions from both building materials and items taken aboard spacecraft. They even test astronauts' space suits for emissions. Chemicals depositing on spacecraft electronics can cause short-circuiting, arcing, or bridging. The sensitivity of the electronic components and the value of the space program missions have justified carefully cataloguing thousands of materials and products from ball-point pens, cameras and space suits to paints and gaskets. The testing has been so extensive that NASA's emission data may prove applicable to evaluating mundane indoor air pollution sources.

Plant Studies

Dr. Bill C. Wolverton, since retired from NASA's Stennis Space Center in Mississippi, carried out much of NASA's research. He had previously studied the use of plants for waste water treatment. He researched the effectiveness of plants in removing the common indoor air pollutants benzene, trichloroethylene, and formaldehyde. Since leaving NASA, Wolverton has continued to conduct research with funding from ALCA.

While at NASA, Wolverton and his colleagues placed over a dozen popular indoor plants in sealed plexiglass chambers of 0.44 to 0.88 m3 (18.54 - 34.08 ft3). In the early work he tested all three chemicals by injecting them into the chamber to reach concentrations from 15 to 20 ppm. After 24 hours, chemical measurements were only fractions of the chemicals measured in the chamber air immediately after injection.

Reported removal rates were from 10 to 70% of the initial concentrations. In control tests without plants Wolverton reported that chamber leakage could account for from 2.8 to 10% of the reduction in chemical concentration.

Then the researchers ran tests on the removal of benzene and trichloroethylene at 0.1 - 0.4 ppm. These lower concentrations are slightly closer to those measured in indoor air although still 100 to 1000 times higher than typical indoor air concentrations. The reported removal rates ranged from 9.2 to 89.8% and averaged 45.1% for the 15 plants tested. The researchers reported that at low concentrations (<<0.15 ppm), pots containing potting soil alone without a plant present removed 20.1% and 9.2% of the measured initial benzene and TCE concentrations respectively. Removal by leakage was reported at 5.3 and <<1.0% for benzene and TCE respectively.

Foliage Not the Key

Because the researchers initially assumed that the plants removed the chemicals by uptake through the leaves and photosynthetic processes, they carefully measured leaf surface area. However, when researchers removed the lower leaves or all leaves of some test plants, they found that the percentage of the tested chemicals removed actually increased. Although initially puzzled by this result, they later observed that this "...occurred only when large amounts of foliage covered the potting soil surface reducing contact between the soil and the air inside the chamber."

Researchers then removed only the lower leaves and the results showed that soil surface exposure to the air was important. Further studies investigated the role of soil microorganisms in the chemical removal process. Soil bacteria measurements did not always correlate with increased chemical removal, leading to the hypothesis that "other yet unidentified biological factors may also be important." They did not say what those factors might be.

Soil Bacteria

The scientists identified several common soil bacteria isolates in the root-soil zone. The researchers said they were "common soil microorganisms" most of which are "known to be capable of biodegrading toxic chemicals when activated by plant root growth." [During a recent phone conversation, Wolverton told ***IAB*** that he has reviewed the extensive Australian and Canadian literature on soil microorganisms. He believes the selection of the right bacteria is the key to improving system efficiency.]

The belief that soil bacteria were important led to efforts to increase air-soil contact. Researchers used fans to move air rapidly through the soil, and they used activated carbon in conjunction with the plants in some tests. According to the final report, these studies were not part of the NASA-ALCA two-year study. Air concentrations of 0.15 and 0.25 ppm of TCE and benzene respectively were reduced to close to zero in two hours using an eight-inch activated carbon filter system with a golden pothos plant. Concentrations of 36 ppm of both chemicals also dropped to nearly zero in two hours by the same system.

Researchers' Conclusions

The NASA report concluded that the charcoal-fan-plant combination was “an essential part of an indoor air pollution control system with plants to remove high concentrations of pollutants such as cigarette smoke and organic solvents.” The researchers concluded that the activated carbon adsorbed the chemicals and held them until the “plant roots and microorganisms can utilize them as a food source, therefore, bioregenerating the carbon.”

Philip Morey of Clayton Environmental Consultants [Morey is now with Air Quality Sciences, Inc.] confirmed the potential efficacy of the bacteria. Morey is a plant physiologist by training and is well known for his studies of microorganism-related problems in buildings. He told us that there are typically 10^{10} to 10^{12} mg of bacteria in a spoonful of soil. The bacteria eat sloughed-off plant cells, thus creating a species-specific symbiosis. Additionally, Morey said that because house plants are generally wide-leafed they intercept much light. This makes them suitable for low-light conditions.

Limitations of the NASA Plant Tests

We have to ask how well the tests run on plants help us understand their actual performance in buildings. A number of conditions in the NASA tests were not “real world,” and this raises questions about the applicability of the results. Because of this limitation, we can't yet evaluate plants' efficacy as indoor air cleaners.

Dynamic chamber studies with air exchange rates and mixing resembling real-world conditions would help significantly. The results could easily be modeled to predict performance in real-world settings. The best test, of course, would be to place the plants in typical rooms in homes and office buildings. Then scientists could evaluate the actual impact of plants on indoor air concentrations of organic chemicals.

Failed Field Study

To date, advocates have not reported the results from actual field tests. One field study was begun and failed, according to a strong advocate of the interiorscape approach to IAQ control. Stuart Snyder is the president of Aqua/Trends of Boca Raton, Florida, a firm that sells irrigation systems for interiorscapes. He offered his explanation as part of a 13-page letter to Robert Axelrad, Director of EPA's Indoor Air Division.

Responding to what he calls EPA's criticism of the NASA work, Snyder wrote, “In many ways small systems are better able to isolate factors, and more clearly define mechanisms at work.... Larger environments are too subject to conflicting variables. Real life, field studies with their complex dynamics are also valuable, and should be implemented at later stages of research -- they are however, more difficult to accurately stage and evaluate”

Snyder continued, “Scaled up studies must be made at some point. Associated Landscape Contractors of America have already attempted a controlled study in an office building. It failed as a study because of these difficulties.” The office-building study was done for over a year under realistic conditions and with as much control as can be achieved in a field study, There was no indication that the presence of plants had any measurable effect. HBI Inc., which conducted the study, reported virtually no effect of plants on the VOC concentrations.

John Girman's Critique

John R. Girman (Chief of the Analysis Branch at EPA's Indoor Air Division) has prepared a memo that details some shortcomings of the NASA study's claims for the efficacy of plants. The memo was included in correspondence between Axelrad and Snyder. Girman's memo responds to some of the technical issues presented by Snyder and other advocates of IAQ control with house plants. The memo's title is “Comment on the Use of Plants as a Means to Control Indoor Air Pollution,” (undated.) Girman analyzes the notion that NASA research shows plants are effective at removing indoor air pollutants at realistic concentrations and time frames. He calculates that at the most favorable conditions, it would take 680 plants in a typical house to achieve the same pollutant removal rate Wolverton and his colleagues reported they achieved in the test chamber.

Girman, a chemist by training, is a thoughtful, experienced, and knowledgeable indoor air researcher who brings important technical insights to EPA's Indoor Air Division. Because the interest in NASA's research is so large, we present Girman's memo in its entirety.

Comment on the Use of Plants as a Means to Control Indoor Air Pollution **by John Girman**

“Several issues must be addressed before the use of plants can be considered to be an effective means to control indoor air pollution. It is certainly true that plants remove carbon dioxide from the air. It is also well known that plants can remove other pollutants from water and this forms the basis for many pollution control methods. However, the ability of plants to control air pollution, particularly indoors, is less well established. Even ignoring the debate about what specific processes are important in the removal of airborne pollutants by plants, e.g., photosynthesis in leaves, deposition on foliage, microorganisms in roots or soil, etc., and accepting the validity of the laboratory experiments that Wolverton has conducted, there are still basic concerns about the effectiveness of controlling indoor air pollution with plants.”

“For example, if a particular plant can remove 90% of a specific pollutant in 24 h in a closed chamber (which appears to be one of the better test results), then the pollutant concentration at the conclusion of the test is only 10% of the initial concentration. [The highest removal rate reported by Wolverton in the NASA study was 89.9% of the initial concentration after 24 hours.] The equation

$$C = C_0e^{-kt}$$

determines the concentration in the chamber, where
C = concentration of the pollutant at time t,
C_0 = the initial concentration of the pollutant,
k = the first order pollutant removal rate constant, and
t = the time in hours since the beginning of the test.

Rearranging the equation, we obtain

$$-(1/t)\ln(C/C_0) = k.$$

Since for our example, t = 24 h and C/C0 = 0.10, k or the pollutant removal rate is 0.096 h-1. Determining the pollutant removal rate constant in this manner is useful for two reasons: (1) it allows comparison of a pollutant removal process with the most common pollutant removal rate of the plant to environments other than just a test chamber."

“The pollutant removal rate of a plant in the test chamber (with appropriate considerations of scale) can be compared with ventilation rates (the most common pollutant removal process) of typical environments. Office buildings have ventilation rates ranging from about 0.5 h^{-1} (or half an air change per hour) to about 2 h^{-1}. A typical residence may have a ventilation rate of about 0.75 h^{-1} and a tight house may have a ventilation rate of 0.25 h^{-1}. Thus, even ignoring scale up considerations for the moment, the pollutant removal rate of plants in chambers, 0.096 h^{-1}, is much lower than typical low ventilation rates found in residences and offices.”

“However, scale-up considerations are also important. It appears that the average chamber volume used in Wolverton's tests was 0.5 m^3. This means the results must be appropriately scaled-up for use in a larger environment to allow for differences in volumetric loading (the number of plants per volume of space). This does not appear to have been done. The volume of a typical house in the U.S. is 340 m^3 with a floor area of 139 m^2 (1500 ft^2). Thus, the recommendation that one plant be used per 100 ft2 implies the use of 15 plants in a typical house. [ALCA recommends 1 plant per 100 ft^2. Wolverton recently told us he now recommends 2 or 3 plants/100 ft^2, but he says “he is “just throwing a dart."] This would provide for 340 m^3/15 plants or 23 m^3 per plant, not 0.5 m^3 per plant as in the chamber. This means that each plant would have to clean 46 times more volume than it did in the test chamber or, as would actually happen, it will clean the larger volume less effectively. To be more precise, each plant will have a pollutant removal rate which is only 1/46 of the rate it would have in the chamber, i.e., only 0.002 h^{-1}. Thus, plants at the volumetric loading recommended would be expected to contribute relatively little to pollutant removal in any indoor environment with typical ventilation."

“To achieve the same pollutant removal rate as realized in the test chamber, one would need to have the same volumetric loading, i.e., 680 plants in a typical house (340 m^3 divided by 0.5 m^3 per plant). This does not seem practical and this forms the basis for concern that adequate and realistic scale-up considerations are necessary before the use of plants can be recommended as a means to control IAQ. Similar concerns apply to the use of plants to control IAQ in office environments. It is hardly surprising that the attempt to validate the test chamber results by Associated Landscape Contractors of America did not provide measurable success.”

“In addition, many of the reported tests relied upon a fan to circulate air containing pollutants near the plant. This would serve to inflate pollutant removal rate of a plant in a test chamber unless fans were also used to circulate air containing pollutants in a house or office. (The use of fans in this manner would increase operating costs and requires a separate analysis to determine if bringing in additional outside air for ventilation would be more cost effective.) It also appears that a large part of the test space was occluded by the plant itself, which also tends to inflate the pollutant removal rate. This would not be practical in most indoor environments.”

“The above is not intended as a criticism of small chamber testing. Small chamber testing, when used in conjunction with modeling, is an important tool for improving IAQ. EPA has encouraged its use for source emission characterization, for product comparisons and to evaluate various mitigation actions.”

“However, there are aspects of Wolverton's chamber test conditions which must be addressed in translating his results to typical indoor environments. The test method employed by Wolverton is a static test method, in which a one-time injection of a pollutant occurs. This is appropriate only for certain types of indoor air pollution, i.e., when the pollutant source does not emit pollutants continuously. Many important pollutant sources, such as building materials and furnishings, are continuous emitters. In the case of continuous sources, plants would be even less effective in real environments than the test results would indicate. This occurs because, while the plant is removing a particular pollutant, more of that same pollutant is being emitted at the same time by an indoor source of that pollutant. These types of sources can be dealt with by chamber studies which incorporate dynamic conditions, i.e., continuous injection of a pollutant. In addition, because indoor environments, with few exceptions, always have some ventilation, realistic chamber tests usually incorporate some ventilation. The effect of this ventilation is easily accounted for by modeling.”

“Using the same conditions as the example above (0.5 m^3 chamber, one plant per chamber; pollutant removal of 90% in 24 h under static conditions), one can model that under dynamic conditions which include some ventilation (a low rate of 0.5 h^{-1} and a continuous pollutant source, the pollutant removal at steady state would be only 16% rather than 90%. This result, when considered in concert with the need for very large amounts of plants in indoor environments to achieve results comparable to those of small test chambers, suggests that a great deal of validation remains before the use of plants can be recommended for effective control of indoor air pollution."

"Finally, few technologies produce only benefits; there is often some drawback. Humidity and microbial contaminants are potential concerns in some indoor environments and applications. The use of large numbers of plants in an indoor environment could increase the humidity to problem levels. The use of fans to draw air over the soil of large numbers of plants may have the potential to cause microbial problems. In addition, while our understanding of the degradation products produced by plants metabolizing pollutants is limited, we must be certain that these products are not problems themselves. For example, there are literature reports that the degradation products of trichloroethylene metabolism by plants are dichloroethylenes and vinyl chloride, which are also harmful pollutants. Should the performance of plants in controlling air pollutants improve greatly, this aspect would require a thorough examination." [end of Girman comment]

IAB Comments

We think Girman has raised some excellent points while being rather generous with the NASA research. The 90% removal rate was one of the highest reported. The average NASA study measurement was 45.1%, about half the value used by Girman. We believe Wolverton's claim that research will allow selecting the most effective plants, but he told us that a variety of plants were likely to be needed to deal with the wide range of indoor air contaminants. Thus, the removal rate for all chemicals per plant may be near the average.

How much of the reported removal occurred by adsorption of the chemicals on the chamber walls? We asked some of the best indoor air scientists we know to speculate on this question. Given the results reported by NASA, some theoretical considerations, and each one's experience, the estimates we feel comfortable reporting are between 10 and 20% of the total mass introduced into the chamber.

The question arises as to whether Wolverton made "initial" measurements before or after the occurrence of any possible sink effect. As we read his reports, in some cases his measurements were made very quickly, while in others they waited for 30 or even 60 minutes. The removal rates were calculated by subtracting the final concentration from the initial concentration to determine the percent removed. Theoretically, the control test with the pot full of soil without a plant should be a good indicator of the total removed by adsorption on the chamber walls, pot, and soil and by leakage from the chamber. However, it does not allow us to separate these various potential loss mechanisms. Thus, the removal by plants may be even less.

Future Issues

We do not think the research reported to date suggests a significant role for plants in cleaning indoor air. Phil Morey told IAB: "I've been in buildings where there are hundreds of plants, and I've never considered them a significant factor [in terms of controlling VOC concentrations]. Morey said it is perfectly reasonable that a bacterium at the root-hair interface could consume VOCs.

Indeed, Morey cautioned that there is a large literature on plants themselves being a source of VOCs. Leaves have chemicals for insect defense, and some of these chemicals are semi-volatile compounds that sit on the leaf surface. Some are volatiles like terpenes. We need more work to check the possible negative consequences of introducing large numbers of plants into building environments.

Both Snyder and Wolverton were critical of Girman's memo and of EPA's attitude as they see it. However, Wolverton told IAB he has seen progress and is optimistic from his conversations with EPA officials. IAB contacted NASA officials connected with the research; they think the idea is interesting but that more research is needed. They also said NASA has not advocated using plants to clean indoor air.

We think EPA should guide Wolverton, ALCA, NASA, and others interested in testing or promoting the use of plants to clean indoor air. Both chamber and full-scale testing should be encouraged, but careful experimental design is required. The research done to date does not demonstrate familiarity with many of the techniques now widely used by indoor air researchers. We feel that the reporting and the limited methodologies reported in the NASA study and a more recent study conducted by Dr. Wolverton are inadequate. We hope that their future work will address some of these concerns.

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