Interior Plants: Their Influence on Airborne Microbes inside Energy-efficient Buildings

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Recent studies have shown that low-light requiring houseplants can influence removal rates of indoor air polluting chemicals from sealed chambers. This study addresses the influence of large numbers of houseplants on airborne microbial levels inside energy-efficient buildings. Portions of a tightly sealed, energy-efficient home located in South Mississippi served as "real world" test chambers. A plant-filled sunroom and an adjacent living room were tested in two studies, each three months in duration and at different seasons of the year. A plant-free bedroom, located in another section of the home, served as a control. Although humidity levels in the plant filled sunroom were higher than the plant-free bedroom, airborne microbial levels were found to be more than fifty percent higher in the plant-free bedroom. These findings indicate that houseplants are influencing the level of microbes in air where large numbers of plants are grown. This is a significant finding because it indicates that large quantities of houseplants may be used to increase humidity levels and suppress levels of mold spores and other airborne microbes inside energy-efficient buildings, while reducing air polluting substances.

Increased use of synthetics in building materials, furniture, floor carpeting, copying machines, computers and other materials inside tightly sealed, energy-efficient buildings has created serious indoor air pollution problems or "sick building syndrome." Because of this practice during the past twenty-five years, indoor air pollution has cost many people their health and billions of dollars in medical bills, sick leave and lost earnings (EPA, 1988, 1989a, 1989b).

New synthetic products outgas hundreds of complex organic chemicals trapped inside tightly sealed buildings (EPA, 1988). People also contribute to indoor air pollution. With each breath exhaled, hundreds of substances (bioeffluents) are emitted into the air (Wang, 1975).

Seeking to improve indoor air quality, the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) in 1981 recommended an increase in the minimal supply of outdoor air from 0.142 to 0.283 cubic meters per minute per person (ASHRAE Standard 62-1981). In 1989, a recommendation was made for an additional increase from 0.283 to 0.566 cubic meters per minute per person (ASHRAE Standard 62-1989). Since this has not eliminated sick building syndrome, further increases have been proposed to solve the indoor air quality problem. A recent study published in the New England Journal of Medicine concluded that increasing building ventilation rates up to 1.81 cubic meters per minute per person did not eliminate sick building syndrome (Menzies et al., 1993). Therefore, increased ventilation rates do not appear to be a solution to indoor air pollution.

Since planet Earth's clean air originates from living, green plants, the concept of designing houseplants inside tightly sealed buildings to purify and revitalize indoor air has a valid scientific basis. As early as 1772, Joseph Priestly demonstrated how plants could restore air made bad by products of animal respiration and burning candles. This concept will require treating each building as a miniature earth with its own built-in living air purification system. The initial research on the use of living plants to purify and revitalize air in sealed chambers was conducted by the National Aeronautics and Space Administration (NASA) at the John C. Stennis Space Center, Mississippi, for use in establishing future habitable moon bases (Wolverton et al., 1984, 1985, 1989).

Since 1980 many experiments have been conducted on the ability of interior plants to remove volatile organic chemicals (VOCs) from sealed chambers (Wolverton, 1989; Wolverton, B.C. and J. Wolverton, 1991; Wolverton, J. and B.C. Wolverton, 1991; Wol-

verton and Wolverton, 1992a, 1992b). Recent studies have addressed how plants influence removal of indoor air polluting chemicals and why some plants are more effective than others. Research studies have shown that houseplants absorb, metabolize or translocate air polluting organic chemicals to microbes growing on and around plant roots where they are biodegraded (Wolverton and Wolverton, 1993; Giese et al., 1994).

Scientific research data indicates that each plant has its own genetic code that enables it to culture specific microbes required to meet its needs (Rovira, 1959, 1965, 1970; Rovira and Davey, 1974) Because some microbes are more effective in biodegrading certain chemicals than others, plants that culture on their roots specific microbes capable of degrading indoor air polluting chemicals appear to be more effective as pollution fighters than plants without these microbes. To date, more than fifty interior plants have been tested in sealed experimental chambers for their effectiveness in removal of certain commonly found indoor air polluting chemicals (Wolverton and Wolverton, 1992b, 1993).

Concern has been expressed that if large numbers of interior plants are placed in tightly sealed, energy-efficient buildings, excessive increases in relative humidity levels will occur because of transpiration. The major concern is that increased humidity levels will cause excessive growth of mold spores and other airborne microbes, and thus create a greater indoor air pollution problem than currently exists. This study addresses the influence of interior plants on levels of humidity and airborne microbes, not in experimental chambers, but in the "real world" of a tightly sealed, energy-efficient building.

MATERIALS AND METHODS

A home, using houseplants for both indoor air purification and treatment of bathroom wastewater, was studied to determine the influence of large numbers of houseplants on airborne microbes. Figures 1 and 2 give diagrams of the home and sampling stations for airborne microbes. The sunroom planter system (Figure 1, sampling stations 1-5), which has been in operation for more than six years, has a total surface area of 31.4 m^2 and two sliding glass doors connecting it to the living room area. Under normal operating conditions, the sliding glass doors are open and were installed primarily to isolate this area for test purposes. Approximately 33 percent of the total sunroom floor area contains houseplants. The living room contains approximately 82.2 m^2 and the bedroom and bath contain approximately 20.6 m^2 of floor space.

Humidity levels in the sunroom and adjacent living room area are controlled by a central heating and air-conditioning heat pump. Vents placed in the sunroom are used for air distribution and air circulation. During each four-hour exposure period, the central heating and air-conditioning unit was turned off to prevent air circulation between the sunroom and living room. With vents and sliding glass doors closed, humidity levels were elevated within the sunroom because of plant transpiration.

A bedroom and bath located in another section of the home (Figure 2) served as a control. This bedroom is located in a section of the house free of influence from houseplants and contains a separate heating and

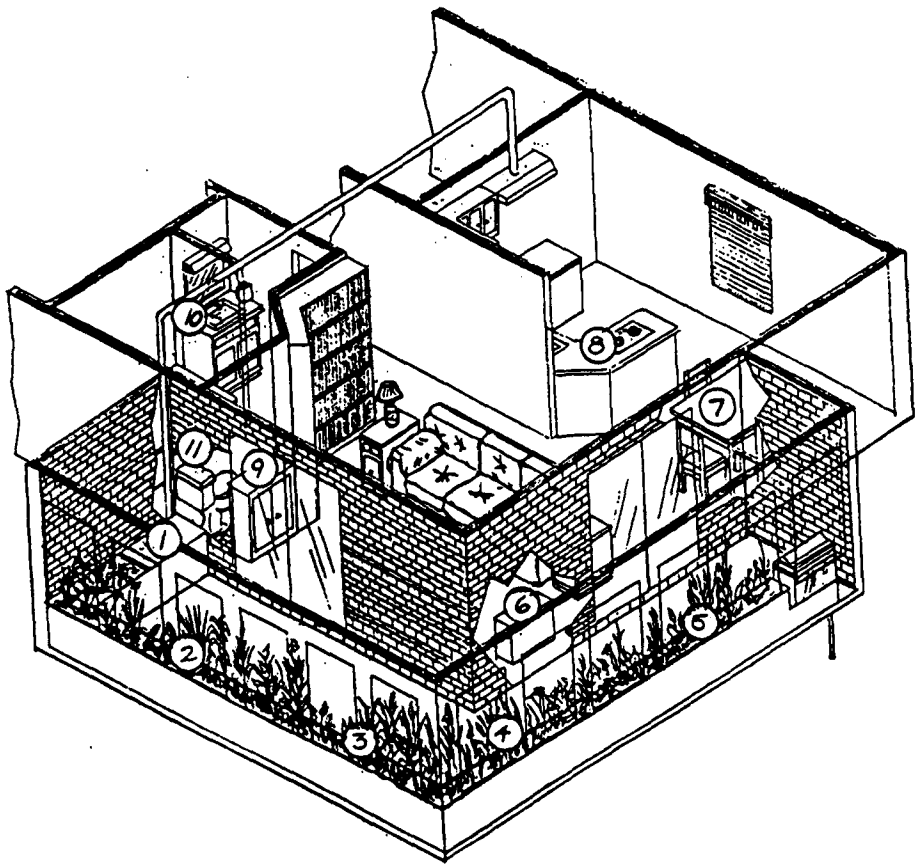

Figure 1. Home using indoor air purification/wastewater treatment system. Numbers represent location of airborne microbe studies.

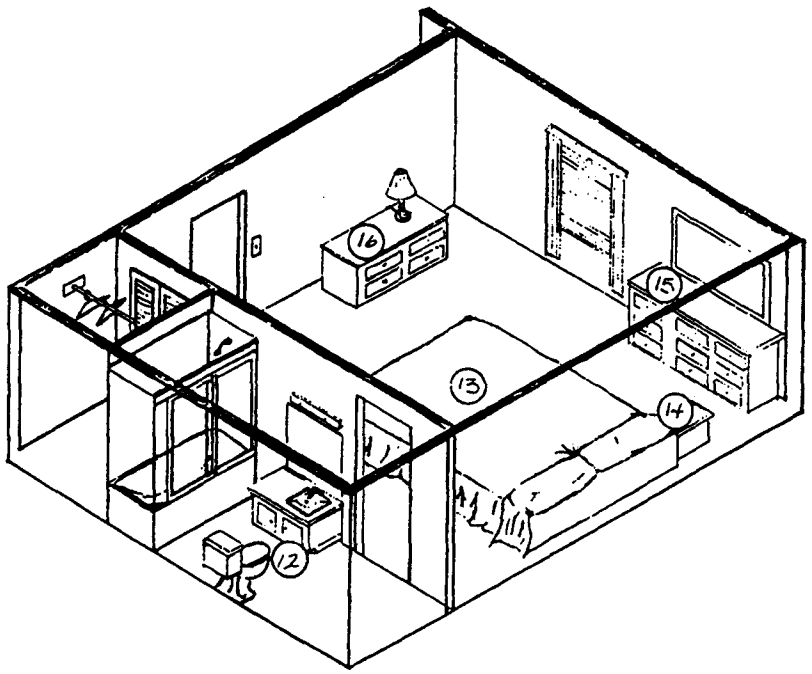

Figure 2. Bedroom and master bath without houseplants. Numbers represent location of airborne microbe studies.

air-conditioning system. Air circulation within this room was also turned off during each four-hour exposure period. All three test areas have wall-to-wall carpeting.

Petri dishes containing plate count agar (PCA) were used to collect and culture airborne microbes. Lids from petri dishes were removed during each four-hour exposure period. Temperature and relative humidity levels were recorded during each exposure period. Upon completion of each four-hour exposure, lids were replaced on petri dishes. Dishes were then placed in an incubator at 28° C for 48-hours. After 48-hours, petri dishes were removed from the incubator and the number of "colony forming units" (cfu) were recorded. During the first three-month study conducted during cooler months (Tables 1, 3, 4), only total cfu's were recorded. During the second three-month study conducted during warmer months (Tables 2, 5) colony morphology was used to distinguish between bacteria, actinomycetes, and fungi.

The sunroom hydroponic planter system contained the following houseplants during tests for airborne microbes: weeping fig (*Ficus benjamina*), peace lily (*Spathiphyllum* sp.), areca palm (*Chrysalidocarpus lutescens*), corn plant (*Dracaena fragans* 'Massangeana', lady palm (*Rhapis excelsa*), warneckei (*Dracaena deremensis* 'Warneckei'), dumb cane (*Dieffenbachia* 'Exotica compacta'), Ficus alii (*Ficus alii*), dumb cane (*Dieffenbachia camille*), elephant ear philodendron (*Philodendron domesticum*), golden pothos (*Epipremnum aureum*), arrowhead vine (*Syngonium podophyllum*), snake plant (*Sansevieria trifasciata* 'Laurentii'), croton (*Codiaeum variegatum*), and umbrella grass (*Cyperus alternifolius*).

RESULTS AND DISCUSSION

As demonstrated in Tables 4 and 5, a bedroom containing no plants and with mean relative humidity levels of 56.54 percent and 60.75 percent respectively had over fifty percent more colonies of airborne microbes than a sunroom filled with houseplants. As shown in Tables 1 and 2, the sunroom had mean relative humidity levels of 72.18 percent and 74.80 percent, respectively. A living room area open to the sunroom except during each four-hour test period had higher levels of airborne cfu's than the plant filled sunroom (Tables 1 and 2), but fewer cfu's than the control bedroom that contained no plants (Tables 4 and 5). Total airborne microbes found in the plant-filled sunroom and plant-free bedroom are compared in Figure 3. Although Actinomycetes are true bacteria, they are included with molds in Tables 2 and 5 because their filamentous colonies are similar to some true fungi when cultured on agar surfaces.

These data indicate that plants are directly or indirectly suppressing the growth of airborne microbes in their immediate area. It has been known for many years that plants emit chemicals such as terpenes and

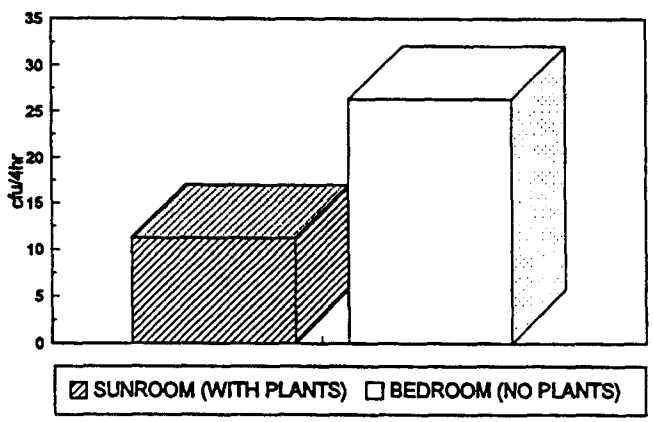

Figure 3. Total mean airborne microbial levels during the six-month study.

various kinds and amounts of phenolic compounds that may be allelochemicals (Weaver and Klarich, 1977). An allelochemical is a substance produced by one organism that influences another organism. Production by plants of allelochemicals that are harmful to other plants is called allelopathy. Allelochemicals may be emitted from plant leaves or secreted by plant roots to reduce competition by other plants or protect them from harmful microbes, insects or animals (Rice, 1979; Tukey, 1970; Whittaker and Feeney, 1971).

Volatile substances emitted by houseplants may be an important factor in controlling the numbers and types of airborne microbes found in areas containing large numbers of plants. This phenomenon can help explain how low-light requiring houseplants, that evolved in a humid environment underneath the canopy of tropical rain forests, protect themselves from being overwhelmed by molds and other microbes that normally flourish in damp, warm, low-light environments.

Although relative humidity levels in excess of 75 percent in plant-free buildings may cause health problems associated with excessive mold growth, more health problems have been associated with low relative humidity levels (Reinikainen et al., 1991, 1992). A factor that significantly increases the health hazard from indoor air polluting substances is low relative humidity levels. Cold winter air is naturally dry. Once furnaces or other heating devices are operated during winter months, a bad situation gets worse. Dry, arid conditions inside buildings irritate sensitive membranes in the nose, and leave one more susceptible to assaults by indoor air polluting chemicals, viruses and other allergens. Dry air triggers asthma and nasal congestion. If one suffers frequent winter colds or allergy attacks, low humidity may be one of the major causes.

In studies conducted of relative humidity levels between 15 and 55 percent, there was evidence that human colds were more frequent at low relative humidity levels (Green, 1984). When electronic humidifying machines are used to increase humidity levels, they may become contaminated with microorganisms that cause human diseases. Also, if distilled water is not used, mineral particles may concentrate and become aerosolized causing respiratory problems.

Data in Tables 1 and 2 indicate that houseplants may be used instead of humidifiers for adding moisture to offices and homes. Plants transpire mineral-free moisture that appears to contain substances that suppress growth of airborne microbes. These data suggest that if increased humidity levels inside energy-efficient buildings are from houseplants, airborne microbial levels may be less than from humidity increases by other means.

Technical data in this report further supports the concept of living plant filters for improving indoor air quality. Although comparative studies with plant-filled rooms and plant-free rooms are an important first step in demonstrating the ability of houseplants to suppress airborne levels of microbes, additional studies should be conducted. This research should be directed toward identification of volatile substances emitted by houseplants that may act to inhibit microbial growth.

Table 1. Airborne Microbes Found in Plant-filled Sunroom. Duration: September - November.

Sample Stations	Airborne Microbes cfu/4-hr Mean[a]	Temp. °C Mean[a]	Relative Humidity, % Mean[a]
1)	5.20 ± 3.06[b]	22.2	70.60
2)	3.60 ± 1.02	21.5	76.00
3)	4.40 ± 1.36	21.0	70.00
4)	5.00 ± 2.50	21.6	72.30
5)	4.00 ± 3.40	24.4	72.00
Mean for all sample stations:	4.44 ± 0.60	22.1 ± 1.19[b]	72.18 ± 2.09[b]

[a]Data are the mean of 5 or more samples taken at each station.
[b]Standard Deviation

Table 2. Bacteria, Actinomycetes and Molds Found in Plant-filled Sunroom. Duration: June - August.

Sample Stations	Airborne Bacteria cfu/4-hr Mean[a]	Airborne Actinomycetes and Molds cfu/4-hr Mean[a]	Temp. °C Mean[a]	Relative Humidity, % Mean[a]
1)	3.00 ± 2.68[b]	3.60 ± 2.87[b]	23.76	74.30
2)	1.00 ± 0.70	4.75 ± 4.02	25.72	76.30
3)	4.00 ± 2.76	5.00 ± 6.10	22.77	74.30
4)	1.20 ± 0.98	5.60 ± 3.93	23.26	74.50
5)	1.40 ± 1.96	4.60 ± 3.93	25.30	76.20
Mean for all sample stations:	2.12 ± 1.18	4.71 ± 0.65	24.12 ± 1.10[b]	75.12 ± 0.9[b]

[a]Data are the mean of 5 or more samples taken at each station.
[b]Standard Deviation

Table 3. Airborne Microbes Found in Living Room[a]. Duration: September - November.

Sample Stations	Airborne Microbes cfu/4-hr Mean[b]	Temp. °C Mean[b]	Relative Humidity, % Mean[b]
6)	7.40 ± 2.06[c]	21.94	59.50
7)	6.80 ± 2.48	20.90	65.50
8)	7.20 ± 2.56	21.45	60.50
9)	7.00 ± 2.90	21.73	66.00
10)	10.40 ± 2.58	24.14	64.30
11)	8.80 ± 4.12	24.14	64.30
Mean for all sample stations:	7.93 ± 1.28	22.38 ± 2.34[c]	63.35 ±2.46[c]

[a]Isolated from plants during each 4-hour test period.
[b]Data are the mean of 5 or more samples taken at each station.
[c]Standard Deviation

Table 4. Airborne Microbes Found in Plant-free Bedroom. Duration: September - November.

Sample Stations	Airborne Microbes cfu/4-hr Mean[a]	Temp. °C Mean[a]	Relative Humidity, % Mean[a]
12)	12.00 ± 4.56[b]	22.10	52.00
13)	11.40 ± 8.11	21.00	58.00
14)	11.80 ± 4.62	22.50	55.00
15)	8.40 ± 5.31	22.30	60.00
16)	20.20 ± 12.09	24.00	57.70
Mean for all sample stations:	12.76 ± 3.94	22.38 ± 0.96[b]	56.54 ± 2.77[b]

[a]Data are the mean of 5 or more samples taken at each station.
[b]Standard Deviation

Table 5. Bacteria, Actinomycetes and Molds Found in Plant-free Bedroom. Duration: June - August.

Sample Stations	Airborne Bacteria cfu/4-hr Mean[a]	Airborne Actinomycetes And Molds cfu/4-hr Mean[a]	Temp. °C Mean[a]	Relative Humidity, % Mean[a]
12)	3.00 ± 1.17[b]	6.80 ± 5.38[b]	24.48	64.00
13)	9.00 ± 3.46	5.60 ± 3.32	22.28	58.70
14)	6.80 ± 3.12	5.60 ± 3.72	22.77	60.00
15)	6.80 ± 3.19	4.80 ± 3.19	23.21	60.30
16)	11.40 ± 4.22	7.20 ± 2.32	23.65	62.00
Mean for all sample stations:	7.56 ± 2.53	6.00 ± 0.88	23.28 ± 0.75[b]	61.00 ± 1.83[b]

[a]Data are the mean of 5 or more samples taken at each station.
[b]Standard Deviation

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