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Reducing Formaldehyde Exposure in Office Environments Using Plants

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Formaldehyde is a toxic substance with adverse health effects detectable at low concentrations. Formaldehyde causes irritation of the eyes, skin and respiratory tract, wheezing, nausea, coughing, diarrhoea, vomiting, dizziness and lethargy at levels as low as 50 parts per billion (ppb) (0.05 ppm) (Horvath et al, 1988). Formaldehyde has also been associated with aggravation of asthma, emphysema, hayfever and allergy problems at low levels (EPA, 1987). Formaldehyde is currently considered a potential carcinogen to humans (EPA, 1987). Formaldehyde is a ubiquitous gas found in elevated concentrations in indoor environments. Concentrations of formaldehyde are typically an order of magnitude greater inside buildings compared to outdoor air (Godish, 1990). Formaldehyde concentrations are particularly high in portable buildings due to the presence of more formaldehyde emitting materials and the relatively smaller interior volumes of air (Sexton et al, 1983). Major sources of formaldehyde indoors are pressed wood products, such as particle board and plywood (Elbert, 1995: Myer and Hermans, 1985), and urea formaldehyde foam insulation (Spengler and Sexton, 1983). Other sources include carpets, curtains, floor linings, paper products, cosmetics and soaps, tobacco smoke and gas combustion (Spengler and Sexton, 1983: Godish, 1990).

Methods to reduce indoor formaldehyde include source removal or use of non-polluting materials, emission reduction through physical or chemical treatments and dilution through ventilation and air purification. While most solutions involve dilution through ventilation, increased interest in the scientific literature (Wolverton et al, 1989: Godish and Guindon, 1989) as well as in the popular media has been given to the use of plants to purify air in buildings . Most studies however, have been conducted in the laboratory (Levin J, 1992: Godish T and Guindon C, 1989) and are difficult to extrapolate to real life situations (Wolverton et al, 1989: Godish and Guindon, 1989).

MATERIALS AND METHODS

Data on formaldehyde concentrations in indoor air were obtained from office environments. Monitoring was conducted in 18 conventional office buildings and 20 portable buildings used as offices in Perth, Western Australia. Monitoring was conducted using passive monitors for formaldehyde. Three or more monitors were placed in each of the conventional office buildings for 3 to 4 days. The office buildings were selected after the occupants of each of the buildings complained of

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indoor air quality problems and therefore may not be totally representative of the office buildings in Perth. Two monitors were used in each of the portable buildings and monitoring was conducted over 2 days. The portable buildings studied were all on Murdoch University campus.

Experiments to test the effectiveness of plants to reduce formaldehyde levels under real life conditions were conducted in 5 adjacent portable office buildings with dimensions 2.8 x 2.9 x 2.40 m (height). The volume of each room is 19.63 m^3 with a floor base of 8.18 m^2.

Past experiments with plants as air purifiers have often been concerned with the use of a single plant species. In a real life situation homes have a diversity of species. Plant species included a selection of plants typically found indoors which were placed in groups of five plants. Each group was identical by having plants of the same size and of the same five species. Plant species in each group are listed in Table 1. The study protocol included monitoring formaldehyde concentrations in the buildings under increasing numbers of plants by adding five plants to the experimental buildings every 2 days to a maximum of 20 plants after 9 days. The protocol is shown in Table 2. Two buildings were used as controls where no plants were placed inside.

Table 1. Plant species

Common name	Scientific name
Spider plant	*Chlorophytum comosum*
Fig tree	*ficus* sp.
Cast-iron plant	*Aspidistra elatior*
Dumb-cane	*Dieffenbachia amoena*
Arum ivy	*Epipremum aureum*

Table 2. Number of plants added each 2 days

Days	Number of plants in building 1, 2&3
Day 1	0
Day 3	5
Day 5	10
Day 7	15
Day 9	20

Formaldehyde monitors developed for this study use are based on the work by Levin et al (1985, 1986) and have been extensively used in other studies (Dingle et al, 1992). Uptake rate was calculated at 60 mL per minute and was not influenced by sampling time or relative humidity, as verified by Levin et al (1986). Sensitivity of the monitors were 1 ppb in a 24-hour sample and 3 ppb in an 8-hour sample (Levin et al, 1986).

Filters were treated with 2,4-dinitrophenylhydrazine. Formaldehyde 2,4-dinitrophenylhydrazone was analysed by high performance liquid chromatography with a mobile phase of 70% Methanol in water. Hydrazone was detected with a variable detector at 365nm. Retention time at a flow rate of 1 ml per minute was 2.9 minutes. Additional details of the technique are reported in other studies (Dingle et al, 1992).

RESULTS AND DISCUSSION

Average levels of formaldehyde in office buildings ranged from background levels of 10 ppb to 2110 ppb. Concentrations in the 18 conventional office buildings ranged from 10 ppb in an established office building to 78 ppb in a new four storey office building. Formaldehyde concentrations in 20 portable buildings ranged from 420 ppb to 2110 ppb (Table 3). The highest levels of formaldehyde found were in newly constructed portable buildings. All these levels exceeded the recommended indoor guideline of 100 ppb and frequently exceeded the occupational standard of 1000 ppb.

Table 3. Formaldehyde concentrations in conventional office and portable office buildings.

Building	Mean (ppb)	Range (ppb)	Number of buildings
Conventional Offices	22	10-78	18
Portable Office Building	1138	420-2110	20

The results of the study of the affect of plants on formaldehyde concentrations are shown in Figure 1. These 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.

Table 4. Concentration of formaldehyde compared to number of plants.

Number of plants	Mean concentration of formaldehyde(ppb)
0	856
5	866
10	871
15	834
20	761

The current exposure guideline for formaldehyde non industrial indoor air environments is 100 ppb in Australia (ANZEC, 1990). Exposure standards in the United States (CARB, 1992) and Canada (Health and Welfare Canada, 1989) are 100 ppb with a target level of 50 ppb. Worksafe Australia (1995) have an occupational standard of lppm (1000ppb). The WHO (1987) set a standard of 82 ppb. Levels of formaldehyde in office buildings ranged from background levels of

10 ppb to 2110 ppb (Table 3). Levels in conventional office buildings ranged from below 10 ppb to 78 ppb with a mean level of 22 ppb.

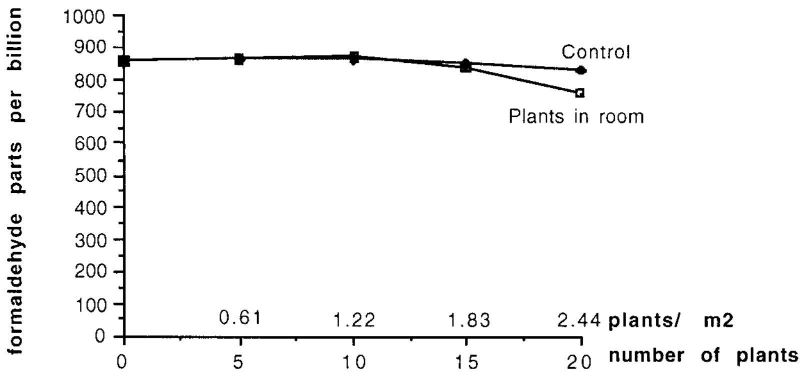

Figure 1. Affect of plant numbers on formaldehyde concentrations.

Major sources of formaldehyde indoors are pressed wood products such as particle board and plywood (Elbert, 1995: Myer and Hermans, 1985), although other sources have been identified including DMDHEU-finished cotton fabrics (Andrews and Traskmorrell, 1997). The importance of these sources are determined by source strength, source loading, and the presence of source combinations. Source strength affects indoor levels because the more potent source will release higher levels of formaldehyde. The Australian Wood Panels Association in Australia support a voluntary E2 emission standard. In addition, 60% of all particle board in Australia has decorative overlay which reduces emissions to an El standard. This percentage is likely to be higher in office buildings.

Levels of formaldehyde in portable office buildings ranged from 420 ppb to 2110 ppb. These buildings frequently exceeded the Australian occupational standard of 1000 ppb and all buildings exceeded the recommended level of 300 ppb established by the American Conference of Government Industrial Hygienists in the United States (ACGIH, 1990).

Studies in the United States have reported levels of formaldehyde in mobile homes ranging from less than 10 ppb to as high as 2840 ppb (Hanarahan et al, 1985), with the majority of mobile homes under 400 ppb (Sexton et al, 1986). Formaldehyde concentration levels are particularly high in portable buildings due to higher load factor, that is, they tend to use more formaldehyde emitting materials and they have relatively smaller interior volumes (Sexton et al, (1989). No controls currently exist on the emission of formaldehyde from plywood used on the interior of portable buildings in Australia. In addition, portable buildings have much lower air exchange rates than conventional homes, which leads to an accumulation of formaldehyde concentrations (Sexton et al, (1989). In 1984, the US department of housing and Urban Development, imposed limits on the formaldehyde emissions from some types of particle board and interior plywood at 300 ppb and 200 ppb test chamber concentrations respectively, to attain indoor air concentrations of no more than 40 ppb in manufactured housing (CARB, 1992).

Botanical air purification presents a novel approach to the control of indoor air pollutants. Studies conducted in the laboratory have shown contradictory results and have lead researchers to suggest that purification occurred through the root soil interphase of the plants and are not a result of absorption or photosynthesis at the leaf surface. Further research has suggested that reduction of formaldehyde occurs as a result of the structure and water content of the soil (Godish and Guindon, 1989).

The effectiveness of plants as air purifiers has come under considerable critique as a result of the design of the experiments. The original studies that showed plants as purifiers were based on a single release of formaldehyde in sealed chambers (Levin, 1992). The major contributors to indoor formaldehyde concentrations are from composite woods which continue to release formaldehyde over many years (Dingle, 1995). The small scale of these experiments also made it difficult to extrapolate to real life situations.

Figure 1 shows there was no decrease in formaldehyde concentrations with 5 or 10 plants present compared to no plants present and compared to the control. There was a very small reduction in formaldehyde concentrations with 15 plants, although this decrease is not considered significant at this level. A more substantial decrease of around 100 ppb was found with 20 plants in the buildings. These results suggest that achieving an 11% reduction in formaldehyde levels in a real life situation would require the equivalent of one plant to each cubic meter (m^3) or 2.4 plants to every meter square (m^2). In a 340 m^3 home this would mean more than 340 plants. While no field tests have been reported some researchers have calculated that 680 plants would be required in a 340 m^3 home to achieve a significant reduction in formaldehyde levels (Levin, 1992)

The most marked reduction in formaldehyde concentrations occurred when 20 plants were present, with no significant reductions occurring when 5, 10, or 15 plants were present. This raises the question of why formaldehyde concentrations were reduced with the addition of only 5 plants from 15 to 20, while no corresponding changes were seen when 5 plants were added at each of the earlier stages of the experiment. This may be explained by a threshold effect at which a certain reduction rate of formaldehyde must be achieved before an actual reduction of formaldehyde concentrations in the air occurs.

Emissions of formaldehyde depend on environmental factors, including the equilibrium concentrations in the air. In stable environmental conditions, formaldehyde will continue to be emitted from the source to reach the equilibrium concentration. If removal of formaldehyde is greater than the release, concentrations will be reduced. If removal is less than the release, concentrations will increase to an equilibrium level where formaldehyde release will equal formaldehyde removal. It is therefore possible that a small number of plants will remove formaldehyde from the air. However, the removal is not likely to be important if strong source emitters are present as the formaldehyde release rate is increased to compensate for the reduction. A reduction in formaldehyde concentration will therefore only occur when sufficient plants are present to reduce formaldehyde below the equilibrium level

Formaldehyde concentrations in conventional office buildings do not appear to be a concern, although elevated levels were reported in a new office building with new furnishings. These levels may be a cause for concern with sensitized or susceptible individuals. Portable office buildings represent a significant health risk to occupants as a result of the elevated levels of formaldehyde, often exceeding the occupational standard. Preliminary experiments with plants as air purifiers, suggest that plants in indoor environments may act to remove small amounts of formaldehyde from the air. However, they do not appear to be an efficient means of removal and require large numbers to achieve any detectable reduction in formaldehyde concentrations.

REFERENCES

Andrews BAK., Traskmorrell BJ. (1997) Long term emmissions from DMDHEU-finished cotton fabrics. Textile Chemist Colorist. 29: 16- 19

American Conference of Governmental and Industrial Hygienists (ACGIH) (1990) 1990- 1991 Threshold limit values for chemical substances and physical agents and biological exposure indices. Cincinnati, OH, USA

Australian and New Zealand Environment Council (ANZEC) (1990). Discussion paper on indoor air pollution. Sydney, NSW, Australia.

California Air Resources Board (CARB) (1992) Formaldehyde as a Toxic Air Contaminant. Technical Support Document. Part A" Exposure Assessment. January. Sacramento, CA, USA

Dingle P (1995) Personal exposure to formaldehyde. PhD thesis. Murdoch University, Perth, Western Australia.

Dingle P, Murray F, Jiang X. (1992) Air quality in indoor environments. 11th International conference Clean Air Society of Australia and New Zealand July 5-10. 2: 116-125

Elbert A (1995) Influence of hardner systems and wood on the formaldehyde emission from urea-formaldehyde resin and particle boards. Holzforschung 49: 358-362

Environmental Protection Authority (1987) Assessment of Health Risks to Garment Workers and Certain Home Residents From Exposure to Formaldehyde. Office of Pesticides and Toxic Substances. Washington D.C., USA.

Godish T, Guindon C (1989) An assessment of the botanical air purification as a formaldehyde mitigation measure under dynamic laboratory chamber conditions. Environ. Pollut. 61-62: 13-20

Godish T (1990) Indoor air pollution control. Lewis Publishers Inc., Michigan,

Hanarahan L, Anderson H, Dally A, Eckmann A Kanarek M (1985) Formaldehyde concentrations in Wisconsin mobile homes. J Air Poll Con Assoc. 35: 1164-1167

Health and Welfare Canada. (1989) Exposure guidelines for residential indoor air quality. A report of the Federal-Provincial Advisory Committee on Environmental and Occupational Health. Ontario. Canada, Horvath E, Anderson H, Pierce W, Hanarahan L, Wendlick J. (1988) “Effects of formaldehyde on mucous membrane and lungs: A study of an industrial population. J Amer Med Assoc. 259: 701-707

Levin H (1992) Can house plants solve IAQ problems? Indoor Air Bulletin. 2: l-5.

Levin J-O, Andersson K, Lindahl R, Nilsson C-A. (1985) Determination of sub-part-per-million levels of formaldehyde in air using active or passive sampling on 24-Dinitrophenylhydrazine-coated glass fiber filters and high performance liquid chromatography. Analytical Chemistry, 57: 1032-1035

Levin J-O, Lindahl R, Andersson K.(1986) Passive sampler for formaldehyde in air using 2,4-Dinitrophenylhydrazine-coated glass fiber filters. Environ. Sci. Technol. 20: 1273- 1276

Myer. B, Hermanns K (1985) Formaldehyde release from pressed wood products. In: Turoski (ed.). Formaldehyde: Analytical Chemistry and Toxicology. American Chemical Society, Washington DC: 101-116

Sexton K, Liu K, M. Petreas.(1986) Formaldehyde concentrations inside private residences: A mail out approach to indoor air monitoring. J Air Poll Con Assoc. 36, 698-704

Sexton. K, Petreas M, Liu.K (1989) Formaldehyde exposures inside mobile homes.Environ Sci. Technol 23: 985-988

Spengler, JD, Sexton, K (1983) Indoor air pollution: A public health perspective. Science 221:9-16

Worksafe Australia (1995) Exposure standards for atmospheric contaminants in the occupational environment. National Exposure Standard [NOHSC: 1003 (1995)l

Wolverton, B, Johnson R, Bounds K (1989). “Interior landscape plants for indoor air pollution abatement, Final report - September 15 1989.” Stennis Space Center, Mississippi: National Aeronautics and Space Administration. Science and Technology Laboratory. MS 39529-6000.

World Health Organisation. (1987) Formaldehyde, In Air Quality Guidelines for Europe. WHO Regional Publications, European Series No 23. Geneva, Switzerland.