*Proceedings of Sixth International Conference on Indoor Air Quality, Ventilation & Energy Conservation in Buildings – Sustainable Built Environment, Oct 28-31, 2007,Sendai, Japan, Volume III, 249-256*

# USE OF LIVING POT-PLANTS TO CLEANSE INDOOR AIR – RESEARCH REVIEW

Jane Tarran†, Fraser Torpy and Margaret Burchett

*Faculty of Science, University of Technology Sydney (UTS)*

*PO Box 123, Broadway, NSW 2007, Sydney, Australia*

## ABSTRACT

Urban indoor air quality (IAQ) is an international health issue, since city dwellers spend 90% of their time indoors. Research by a number of authors is reviewed here, demonstrating a range of capacities of indoor plants to improve IAQ and promote occupant wellbeing. Our laboratory studies, with nine 'indoor plant' species, and our 'field' studies in 60 offices, show that potted-plants can reliably reduce total volatile organic compound (TVOC) loads, a major class of indoor pollutants, by 75%, to below 100 ppb. They work equally well with or without air-conditioning, and in light or dark. An evaluation of these studies is presented, plus novel research showing that potted-plants can also remove indoor CO and, sometimes, $CO_2$. The evidence overall clearly shows that the potted-plant microcosm represents an innovative technology for solving indoor air pollution, which can otherwise cause a range of adverse health effects, including 'building-related illness'. This portable, flexible, attractive, low-cost technology can complement any engineering measures and can be used in any building. To ensure sustainability of the urban environment, satisfying the 'triple bottom line' of environmental, social and economic considerations, indoor plants can be expected to become standard technology for improving IAQ - a vital building installation element.

## KEYWORDS

VOC, indoor air, IAQ, indoor plant, pollution reduction

## INTRODUCTION

Urban air pollution, mainly emanating from fossil fuel combustion, is an international health problem. For example, in Australia (as in most developed countries) about 80% of people live in urban areas, where, for example in Sydney alone, air pollution causes an estimated 2,400 deaths p.a. (NSW EPA 2006). In addition, urban dwellers spend about 90% of our time indoors (at home, school or office) (Cavallo et al. 1997; US EPA 2000; Environment Australia (EA) 2003) where air pollution is typically even higher than outdoors (Brown 1997; Smith 1997; EA 2003). The outdoor-derived load of $NO_x$, $SO_x$, $CO_2$, CO, organics, particulates etc. diffuses indoors, where it is augmented by indoor-derived contaminants, mainly volatile organic compounds (VOCs), outgassing from other petroleum-based products, such as 'synthetics' in furnishings, detergents, paints, printers, 'air fresheners' and the like. The chemical mixtures, even at imperceptible levels, can cause 'building-related illness' and symptoms of headache, sore eyes, nose and throat, or nausea (Carrer et al. 1999; World Health Organisation

†*Corresponding author: Tel: +61 2 9514 4038; Fax: +61 2 9514 4079; E-mail: Jane.Tarran@uts.edu.au*

(WHO) 2000; Mølhave and Krzyzanowski 2003). Dust, moulds and flueless gas appliance emissions can add to pollution loads.

As outlined below, indoor potted-plants have been shown to remove most types of air-borne pollutants arising from either outdoor or indoor sources. Studies have also shown that, where indoor plants have been installed, staff wellbeing is improved with sick-leave absences reduced by over 60% (Fjeld 2002; Bergs 2002). The aims of this paper are to provide a review of research on indoor plants to improve IAQ, to outline findings of our own studies, and to present new data that further demonstrate the ability of potted-plants to remove indoor air pollutants and enhance IAQ.

**Potted-plants improve a number of aspects of IAQ**

Yoneyama et al. (2002) reviewed absorption and metabolism of $NO_2$ and $NH_3$ in 220 species (sun- and shade-loving plants, the latter of which can be used indoors). In a UK study of homes with flueless gas appliances, Coward et al. (1996) found that houses with six or more potted-plants showed reductions of over one third in $NO_2$ levels. In 1999, Lee and Sim, in a study of Korean species, showed that indoor plants absorb and metabolise $SO_2$. In the USA, Lohr and Pearson-Mims (1996) showed that indoor plants significantly reduce dust (particulate) levels. In a study by Costa and James (1999), it was found that potted-plants also reduce indoor noise levels. The pioneering screening studies on indoor-air VOC removal by Wolverton and colleagues (1989; 1991; 1993) showed reductions in VOC levels with over 50 species. Wolverton suggested that both plants and potting-mix microorganisms could be involved in the process. Following the work of Wolverton et al., we conducted detailed bench-top test-chamber investigations on VOC removal by potted-plants, initially using seven 'international' species. We then conducted a 'real-world' study of potted-plants to enhance IAQ, using 60 offices and three planting regimes, and we recently completed laboratory trials with two previously untested species. The results of all these studies, summarised below, amply demonstrate the ability of indoor potted-plants to eliminate indoor VOC loads, and mechanisms involved.

## LABORATORY STUDIES OF POTTED-PLANT VOC REMOVAL

The seven species we originally tested were the commonly used, 'international species' *Spathiphyllum* 'Petite' (Peace Lily), *S.* 'Sensation', *Dracaena* 'Janet Craig', *D. marginata*, *Howea forsteriana* (Kentia palm), *Epipremnum aureum* (Pothos, Devil's Ivy) and *Schefflera* 'Amate' (Dwarf Queensland Umbrella Tree) (Tarran et al. 2002; Wood et al. 2002; Orwell et al. 2004). Four VOCs were tested: benzene, toluene and xylene (three of the 'BTEX' 'dirty four' outdoor-derived organics, known or suspected carcinogens, but also used indoors as solvents) plus *n*-hexane. An initial dose of up to 100 or 150 ppm of the VOC was injected into the test chambers (vol. 216 L; described below) followed by daily top-up (or doubled) doses, over two to four weeks. These dosages are from 2 to 10 times higher than the Australian maximum allowable 8-h averaged occupational exposure concentrations (ASCC 2006). The potted-plants proved highly effective in eliminating the VOCs, as follows: (a) after the initial dose, removal rates gradually rose, over four or five days, to more than 10 times initial rates; (b) once stimulated ('induced'), the potted-plant microcosm (PPM) eliminated daily top-up doses within about 24 hours; (c) when the dose was doubled, removal rates rose to meet it; (d) low, residual concentrations were also removed, effectively to zero (i.e. below detection limits of gas chromatography (GC)); (e) rates remained unchanged in light or dark (day/night, 24/7); and (f) finally, removal rates remained unchanged (in the short term) when plants were removed and potting-mix in pots replaced in the chambers. Findings (e) and (f) pointed to soil microorganisms being the primary agents of VOC removal, and this was confirmed by microbiological testing. The normal role of these microorganisms is breaking down soil organic matter. The role of the plants here is nourishing their species-specific root-zone microbial communities. This symbiotic microcosm relationship is a universal feature of plant-and-soil interactions. Soil microorganisms are known to break down liquid petroleum, so are used in bioremediation of spills. However, this was the first demonstration of removal of gaseous-phase VOCs by *in situ* soil microorganisms. These studies showed that the PPM represents a self-regulating biofilter and phytoremediation unit of indoor air.

## POTTED-PLANT VOC REDUCTION IN THE 'REAL-WORLD' - OFFICE STUDY

How many plants would make a difference to IAQ in the real-world? To start to answer this, we sampled the effects of indoor plants on total VOC (TVOC) loads in 60 single-occupant offices (12 per treatment), over two 5- to 9-week periods, in three buildings (two air-conditioned, one naturally ventilated) (Burchett et al. 2005; Wood et al. 2006). Three planting regimes were used, plus reference offices, as follows: (a) 3; or (b) 6, floor specimens of *Dracaena* 'Janet Craig' (300 mm diam. pots); or (c) 6 mixed 'table-sized' specimens comprising 5 *Spathiphyllum* 'Sweet Chico' plus 1 *Dracaena* 'Janet Craig' (200 mm pots). We found that: (i) ambient indoor TVOC loads ranged from ~80-400 ppb; (ii) whenever levels rose above ~100 ppb, any of the three plantings reduced loads by up to 75%, to ~60 ppb (always below 100 ppb again); and (iii) the plantings were equally effective with or without air-conditioning. The results demonstrate that the PPM works very effectively in the real world, being induced to respond by TVOC loads above ~100 ppb, reducing them down to below 100 ppb once more (very clean air). Since the three plantings worked equally well, it means that the smallest was still more than enough for this air-cleansing purpose. Subsequent laboratory trials (Orwell et al. 2006) confirmed the graded induction of VOC removal from a low threshold in the range encountered in the office air and, from there, to meet tested concentrations of up to 500 times as high (to 100 ppm). One of our current research directions is to determine the minimum amount of potted-plant material needed for this VOC removal.

## INDUCTION OF VOC REMOVAL IN TWO UNTESTED PLANT SPECIES

The main aim of this more recent test-chamber study was to compare VOC removal capacities in two untested species - *Aglaonema modestum* and *Zamioculcas zamiifolia*. A second aim was to examine whether removal rates with either species could be correlated with any plant or potting-mix attribute.

### Materials and methods

Plants in 200 mm pots were used (Tropical Plant Rentals, Sydney). Plant and potting-mix variables were analysed to provide alternative bases of comparison of removal rates: leaf area, and fresh and dry weights of shoots, roots and potting-mix. Benzene was used as the test VOC. Six replicate perspex test chambers were used (0.6 x 0.6 x 0.6 m) as described in previous studies (e.g. Orwell et al. 2006). Pots were first watered to saturation, drained for 1 h and placed in chambers, and an initial dose of 25 ppm benzene was injected. Benzene vapour concentrations in the chamber air were sampled (using a 1.0 mL syringe) at hourly or daily intervals, as required, using a GC. Leak tests were carried out before and after experiments to ensure that benzene removal was solely related to the

PPM. Three sets of data were collected for each species: (a) *induction removal rate*: time taken for the PPM to be stimulated to heightened activity and removal of initial dose - typically several days to one week; (b) *secondary removal rate*: time taken to remove a second, top-up dose; generally some days shorter than induction period; and (c) *maximum removal rate*: our previous results had shown that maximum removal rates are normally achieved after the removal of the second dose, so, in these trials, removal of the 3rd dose was taken to represent maximum removal rate.

**Results**

Benzene removal rates with the two species are shown in Figure 1. The *Zamioculcas* and *Aglaonema* showed similar patterns of induction of a stimulated VOC removal with the first dose, and, by the third dose, each removed the high benzene dose effectively to zero in less than 48 h. These results show a similar pattern to those of the seven species previously tested.

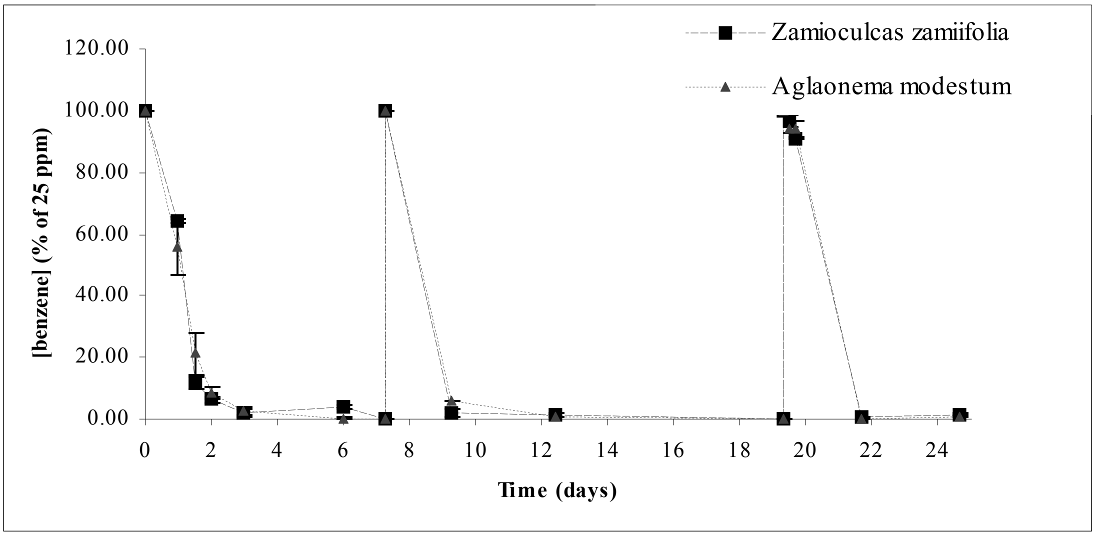


Figure 1. Removal of benzene from test-chamber air by potted *Zamioculcas zamiifolia* and *Aglaonema modestum*, challenged with three consecutive doses of 25 ppm benzene (means ± SE; n=6).

Plant and potting-mix parameters of the two species are shown in Table 1. The *Zamioculcas* had 70% more leaf area and larger root and shoot weights than *Aglaonema.* The potting-mix of *Aglaonema* had a greater water-holding capacity than that of *Zamioculca*s.

Table 1. Plant and potting-mix variables in two test species (means ± SE; n=6).

| Plant or Potting-Mix Property | | *Aglaonema* | *Zamioculcas* |
|---|---|---|---|
| *Shoots* | Leaf area ($cm^2$) | 2256 ± 588 | 3861 ± 81 |
| | Wet weight (g) | 229 ± 43 | 1149 ± 63 |
| | Dry weight (g) | 22.8 ± 4.6 | 66.0 ± 1.6 |
| | Water content (%) | 90 | 94 |
| *Roots* | Wet weight (g) | 155 ± 11 | 781 ± 60 |
| | Dry weight (dwt) (g) | 13.8 ± 2.1 | 80.4 ± 4.6 |
| | Shoot/root (dwt ratio) | 1.7 | 0.8 |
| *Potting-mix* | Wet weight (g) | 2313 ± 289 | 2649 ± 115 |
| | Dry weight (g) | 876 ± 14 | 2191 ± 93 |
| | Pot volume (incl. root mass) ($cm^3$) | 4360 | 4206 |

Table 2 presents the results of the maximum benzene removal rates on the basis of alternative parameters. There were no correlations found between removal rates per pot and any plant attribute *per se*. However, hourly removal rates per kg wet weight of potting-mix were equal, which is consistent with the potting-mix microorganisms being the main VOC removal agents. Rates per kg dry weight of potting-mix were different, however, suggesting that it is the water-holding matrix that is important for the microorganisms functioning in VOC removal. The findings contribute to the body of evidence showing that the PPM of any species can be expected to have a capacity for VOC removal.

Table 2. Averaged hourly, fully induced benzene removal rates (ppm/h) in two test species, expressed on basis of alternative pot-plant parameters.

| Rates of removal(ppm/h) / Property | | *Aglaonema* | *Zamioculcas* |
|---|---|---|---|
| *Per pot (as indicated in Fig. 1, after day 20)* | | 0.5 | 0.5 |
| *Shoots* | Leaf area (/$m^2$) | 2.2 | 1.3 |
| | Wet weight (/kg) | 2.1 | 0.4 |
| | Dry weight (/kg) | 22 | 7.5 |
| *Roots* | Wet weight (/kg) | 156 | 0.64 |
| | Dry weight (g) | 36 | 6.3 |
| *Potting-mix* | Wet weight (/kg) | 0.2 | 0.2 |
| | Dry weight (/kg) | 0.6 | 0.2 |

## EFFECTS OF POTTED-PLANTS ON $CO_2$ AND CO LEVELS IN OFFICES

With adequate lighting, green plants photosynthesise and, in the process, refresh air in two ways - absorbing $CO_2$, and releasing equimolecular concentrations of $O_2$ as a by-product. There has been no research on the ability of indoor plants to refresh air via this gas exchange. However, it is recognised that the main purpose of ventilation is not so much to replenish $O_2$ as to remove $CO_2$ (Höppe and Martinac 1998). Studies have shown that student performance declines with increasing $CO_2$ (Shaughnessy et al. 2006), as does workplace productivity (Seppänen et al. 2006). Carbon monoxide is a very much more toxic fuel combustion product. However, plants and some soil bacteria consume CO. In plants, CO can stimulate root growth and seed germination and alleviate salt stress (Dekker and Hargrove 2002; Huang et al. 2006; Xu et al. 2006; Liu et al. 2007). Bacteria can use it as a nutrient (King and Crosby 2002; King 2007) and in normal metabolic redox processes (Tolli and King 2005; Chan and Steudler 2006). There has also been no previous research on effects of indoor plants on CO levels. Therefore, along with our studies on potted-plants to reduce office TVOC levels (discussed above), we also sampled $CO_2$ and CO levels in two sets of 12 offices. The results of this preliminary study are presented below.

### Methods

The study was conducted May–October (winter/spring; outdoor max. temp. range 17-21°C). The offices had areas of 10-12 $m^2$ (vol. 30-50 $m^3$). One building was air-conditioned, offices being supplied with 6-8 air changes $h^{-1}$, with 10-15% external air input. The other building was not air-conditioned; windows were frequently closed and flueless gas heaters were intermittently used. Weekly 5-min samplings of $CO_2$ and CO were made in all offices, over two 9-week periods, each comprising ten 30-sec readings taken from all parts of the office, using a Portable IAQ-Calc Indoor Air Quality Meter (TSI Inc., MN, USA). In each building, 6 offices were unplanted (reference), and 6 supplied with three floor-specimens of *Dracaena* 'Janet Craig' (300 mm pots).

**Results**

Combined results for levels of $CO_2$ and CO in offices, with and without plants, are shown in Table 3. We found that potted-plant presence was associated with significant reductions in both $CO_2$ and CO concentrations ($P<0.004$) in offices without air-conditioning. In the presence of plants, $CO_2$ levels were reduced by about 10% in offices in the air-conditioned building, and by about 25% in the naturally ventilated building. We are investigating factors of lighting, plant placement and species differences that may render the PPM more effective in $CO_2$ reduction. The CO concentrations were greatly reduced with plant presence, with or without air-conditioning, down to about 8-14% of those in unplanted offices (Table 3). We are further researching this impressive phenomenon, including the relative roles of plant and potting-mix microorganisms in the removal.

Table 3. Effects of three potted-plants (floor specimens of *Dracaena* 'Janet Craig') on levels of $CO_2$ and CO (ppm) in office air, in an air-conditioned and a naturally ventilated building ($n \geq 50$ offices / treatment).

| Air conditioning | No. of plants | Mean [$CO_2$] ± SE (ppm) | Mean [CO] ± SE (ppm) |
|---|---|---|---|
| Yes | 0 | 409 ± 6.2 | 0.225 ± 0.035 |
| Yes | 3 | 366 ± 7.3 | 0.017 ± 0.008 |
| No | 0 | 386 ± 17 | 0.071 ± 0.024 |
| No | 3 | 290 ± 15 | 0.010 ± 0.005 |

## CONCLUSIONS

| Air conditioning | No. of plants | Mean [$CO_2$] ± SE (ppm) | Removal % | Mean [CO] ± SE (ppm) | Removal % |
|---|---|---|---|---|---|
| Yes | 0 | 409 ± 6.2 | | 0.225 ± 0.035 | |
| Yes | 3 | 366 ± 7.3 | 10 | 0.017 ± 0.008 | 92 |
| No | 0 | 386 ± 17 | | 0.071 ± 0.024 | |
| No | 3 | 290 ± 15 | 25 | 0.010 ± 0.005 | 86 |

Together, the numerous studies reported here, from both our own research and a number of different sources around the world, show conclusively that the potted-plant microcosm (PPM) can greatly improve IAQ by removing many major pollutants. Thus the PPM represents an adaptive, self-regulating, portable, flexible, low-cost, sustainable and beautiful biofiltration and bioremediation system for IAQ. This innovative technology can complement any engineering measures and can be used in any building. To ensure sustainability of the urban environment, satisfying the 'triple bottom line' of environmental, social and economic considerations, it is expected that indoor plants will become standard technology - a vital building installation element, for improving IAQ.

## ACKNOWLEDGEMENTS

We thank Horticulture Australia Ltd, Rentokil Tropical Plants, National Interior Plantscape Association, Tropical Plant Rentals, The Container Connection and the Flower Council of Holland, for funding support. We also thank former colleagues, R. Wood and R. Orwell, for their major part in our studies reported here.

## REFERENCES

Aust. Safety & Compensation Council (ASCC) (2006) “Adopted National Exposure Standards for Atmospheric Contaminants in the Occupational Environment”, [NOHSC: 1033,1995].

J. Bergs (2002) “Effect of healthy workplaces on well-being and productivity of office workers”, Proceedings of International Plants for People Symposium, Floriade, Amsterdam, NL.

S. K. Brown (1997) “Volatile organic compounds in indoor air: sources and control”, Chemistry in Australia, Vol. 64 (Jan/Feb), 10-13.

M. D. Burchett et al. (2005) “Improving Indoor Environmental Quality Through the Use of Indoor Potted Plants”, Final Report to Horticulture Australia Ltd, Sydney.

P. Carrer et al. (1999) “Home and workplace complaints and symptoms in office workers and correlation with indoor air pollution”, Proceedings the 8$^{th}$ International Conference on Indoor Air Quality and Climate, Vol. 1, 129-134.

D. Cavallo et al. (1997) “Exposure to air pollution in home of subjects living in Milan”, Proceedings of Healthy Buildings/IAQ ’97, Vol. 3, 141-145.

A. S. K. Chan and P. A. Steudler (2006) “Carbon monoxide uptake kinetics in unamended and long-term nitrogen-amended temperate forest soils”, FEMS Microbiology Ecology, Vol. 57 (3), 343-354.

P. R. Costa and R. W. James (1999) “Air conditioning and noise control using vegetation”, Proceedings of the 8$^{th}$ International Conference on Indoor Air Quality and Climate, Vol. 3, 234-239.

M. Coward et al. (1996) “Pilot Study to Assess the Impact of Green Plants on $NO_2$ Levels in Homes”, Building Research Establishment Note N154/96, Watford, UK.

J. Dekker and M. Hargrove (2002) “Weedy adaptation in *Setaria* spp. V. Effects of gaseous environment on giant foxtail (*Setaria faberii*) (Poaceae) seed germination”, Amer. J. Botany, Vol. 89 (3), 410-416.

Environment Australia (EA) (2003) “BTEX Personal Exposure Monitoring in Four Australian Cities”, Technical Paper No. 6: EA, 2003. Canberra, ACT, Australia.

T. Fjeld (2002) “The effects of plants and artificial daylight on the well-being and health of office workers, school children and health-care personnel”, Proceedings of International Plants for People Symposium, Floriade, Amsterdam, NL.

P. Höppe and I. Martinac (1998) “Indoor climate and air quality”, International Journal of Biometeorology, Vol. 42, 1-7.

B. K. Huang et al. (2006) “Carbon monoxide alleviates salt-induced oxidative damage in wheat seedling leaves”, Journal of Integrative Plant Biology, Vol. 48 (3), 249-254.

G. M. King (2007) “Microbial carbon monoxide consumption in salt marsh sediments”, FEMS Microbiology Ecology, Vol. 59 (1), 2-9.

G. M. King (2002) “Isolation and characterization of novel aerobic CO-oxidizing bacteria”, Abstracts of the General Meeting of the American Society for Microbiology, Vol. 102, 247.

J.-H. Lee and W.-K. Sim (1999) “Biological absorption of $SO_2$ by Korean native indoor species”, In, M.D. Burchett et al. (eds) “Towards a New Millennium in People-Plant Relationships, Contributions from International People-Plant Symposium”, Sydney, 101-108.

K. Liu et al. (2007) “Carbon monoxide counteracts the inhibition of seed germination and alleviates oxidative damage caused by salt stress in *Oryza sativa*”, Plant Science (Oxford), Vol. 172 (3), 544-555.

V. I. Lohr and C. H. Pearson-Mims (1996) “Particulate matter accumulation on horizontal surfaces in interiors: influence of foliage plants”, Atmospheric Environment, Vol. 30, 2565-8.

L. Mølhave and M. Krzyzanowski (2003) "The right to healthy indoor air: status by 2002", Indoor Air, Vol. 13, Supplement 6, 50-53.

New South Wales Environment Protection Authority (NSW EPA) (2006) Cited in The Daily Telegraph, 24/02/06.

R. L. Orwell et al. (2004) "Removal of benzene by the indoor plant/ substrate microcosm and implications for air quality", Water, Air, and Soil Pollution, Vol. 157, 193-207.

R. L. Orwell et al. (2006) "The potted-plant microcosm substantially reduces indoor air VOC pollution: II. Laboratory study", Water, Air, and Soil Pollution, Vol. 177, 59-80.

O. Seppänen, W. J. Fisk and Q. H. Lei (2006) "Ventilation and performance in office work", Indoor Air, Vol. 16, 28-36.

R. J. Shaughnessy et al. (2006) "A preliminary study on the association between ventilation rates in classrooms and student performance", Indoor Air, Vol. 16, 465-468.

J. Tarran et al. (2002) "Quantification of the Capacity of Indoor Plants to Remove Volatile Organic Compounds under Flow-through Conditions", Final Report to Horticulture Australia Ltd, Sydney.

J. Tolli and G. M. King (2005) "Diversity and structure of bacterial chemolithotrophic communities in pine forest and agroecosystem soils", Applied & Environmental Microbiology, Vol. 71 (12), 8411-8418.

US EPA (2000) "Healthy buildings, healthy people: a vision for the 21$^{st}$ century", Office of Air and Radiation.

B. C. Wolverton, A. Johnson and K. Bounds (1989) "Interior Landscape Plants for Indoor Air Pollution Abatement", Final Report, NASA Stennis Space Centre MS, USA.

Wolverton Environmental Services Inc. (1991) "Removal of Formaldehyde from Sealed Experimental Chambers, by *Azalea, Poinsettia* and *Dieffenbachia*", Res. Rep. No. WES/100/01-91/005.

B. C. Wolverton and J. D. Wolverton (1993) "Plants and soil microorganisms: removal of formaldehyde, xylene, and ammonia from the indoor environment", Journal of the Mississippi Acad. Sci., Vol. 38 (2), 11-15.

World Health Organisation (WHO) 2000 "The Right to Healthy Indoor Air – Report on a WHO Meeting, Bilthoven", NL, European HEALTH Targets 10, 13.

R. A. Wood et al. (2002) "Potted-plant/growth media interactions and capacities for removal of volatiles from indoor air", Journal of Horticultural Science and Biotechnology, Vol. 77 (1), 120-129.

R. A. Wood et al. (2006) "The potted-plant microcosm substantially reduces indoor air VOC pollution: I. Office field-study", Water, Air, and Soil Pollution, Vol. 175, 163-180.

J. Xu et al. (2006) "Carbon monoxide-induced adventitious rooting of hypocotyl cuttings from mung bean seedlings", Chinese Science Bulletin, Vol. 51 (6), 668-674.

T. Yoneyama et al. (2002) "Metabolism and detoxification of nitrogen dioxide and ammonia in plants", In, K. Omasa et al. (eds) Air Pollution and Plant Biotechnology – Prospects for Phytomonitoring and Phytoremediation, Springer, Tokyo, Japan, 221-234.