# IMPROVING THE INDOOR ENVIRONMENT FOR HEALTH, WELL-BEING AND PRODUCTIVITY

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## Abstract

This paper selectively reviews scientific research on the positive effects on building occupant's health, well-being and productivity that result from the presence of indoor plants in the workplace. Case studies show improvement in indoor air quality, (with a reduction in the levels of volatile organic compounds (VOCs), improved productivity by up to 12%, and reduced absenteeism and staff turnover cost. Indoor air pollution is a health hazard, which causes diseases, lost work days and reduced quality of life. Unhealthy indoor air has been estimated to cost the Australian community $12 billion dollars a year, and is a generally unrecognized significant environmental issue.

## Introduction

The term 'building ecology' has been used to describe a comprehensive systems approach to understanding interactions between building environments and their occupants (Levin, 1981) People react to indoor environments in markedly different ways. Complex modern building environments produce reactions of a psychological (perceptual) and physiological (biological) nature. The reasons why one environment is better than another are complex; besides the physical environment there are all the psychosocial factors that pertain to it, especially in the workplace (Wood and Burchett 1995). People occupy a building in the belief that their working environment is safe. A healthy building is one that does not adversely affect the health of its occupants or the larger environment (WHO, 2000b). Good indoor air quality is essential for the health and wellbeing of building occupants. To quote the American Lung Association (2001) "when you can't breathe, nothing else matters". A building's air quality is thus a major indoor environment issue.

**Indoor Air Quality**

In the field of indoor air quality (IAQ) the World Health Organisation European Centre for Environment and Health (WHO/ECEH, 2000a) recognises that exposures in indoor spaces contribute substantially to total air exposure. Most people in urbanised societies spend over 80% of their time indoors, at home, work or school, (or in transit in vehicles among these locations) (Hodgson *et al.,* 1997; USEPA, 2000). It has also been shown that indoor air, particularly in situations with internal heating or cooling systems (i.e. with windows shut, with or without full air-conditioning systems), may be more polluted than the air outside, except for example, along highways or directly in industrial areas (Smith, 1997; US EPA, 2000). The indoor environment is a dynamic interrelationship between thermal comfort needs, physical factors and chemical and biological factors. The quality of the indoor environment is therefore of critical importance to our health and well being. The need for more adequate control of indoor air quality has been addressed by the WHO/ECEH (2000b) in a set of basic rules on 'The right to healthy indoor air', derived from fundamental principles in the field of human rights, biomedical ethics and ecological sustainability.

Australia has national enforceable standards (NEPMs) for ambient air which are rarely exceeded outdoors, however indoor air has only non-enforceable interim guidelines for some indoor air pollutants (FASTS, 2002). Indoor air pollution is a health hazard, which causes diseases, lost work days and reduced quality of life. Unhealthy indoor air has been estimated to cost the Australian community $12 billion dollars a year, and is a generally unrecognized significant environmental issue (FASTS, 2002).

Building indoor air quality is highly dependent on the design and performance of the ventilation systems and components (HVAC), as is energy consumption. Even if the HVAC system is properly designed and well maintained, indoor air quality problems can arise. Current standards for ventilation systems only apply at the time of building completion. There are no requirements in Australia to ensure that the system still performs to specification in the future. Increasing ventilation is the simplest way to reduce levels of indoor air pollutants, however the trend is to reduce ventilation as a consequence of the need for energy saving. Buildings have become more airtight, with less infiltration/exfiltration as a result. (Cochet et al. 2002).

Outdoor air containing pollutants is typically used as ventilation air without any air cleaning other than filtration for particulate matter. Conventional wisdom often links poor indoor air quality and low ventilation rates. Low ventilation means less dilution of pollutants with indoor sources and therefore higher indoor concentrations, especially of volatile organic compounds (VOCs), primarily caused by emissions from indoor sources. People usually use their own perception of indoor air quality by various sensory processes, however the absence of odours does not necessarily signify healthy air. Many pollutants such as carbon monoxide and carbon dioxide, for example have no odour, whereas. many toxic chemicals such as acetone, ketones and benzene derivatives have pleasant or sweet odours

Information on indoor air quality impacts from manufactured products and equipment is almost impossible to establish if they are not 'labelled' as regards for example, VOC emissions, (Cochet et al. 2002). There are no clear Australian standards, goals or guidelines for the pollutants emitted from products used in buildings (FASTS, 2002). Reliable and easy-to-use indoor air quality models for indoor air quality assessment are lacking because of a lack of appropriate databases on pollutants released from internal sources. Indoor air quality assessment is performed by risk identification (sources) and risk management (source reduction and limitation of exposure to pollutants) (Cochet et al. 2002).

Professor Ole Fanger, President of the International Academy of Indoor Air Sciences, has written " I think it is fair to say that the indoor air quality is quite mediocre in many buildings, even though existing standards may be met." He went on to say " we need a paradigm shift to search for excellence in the indoor environment. Our aim should be to provide indoor air that is perceived as fresh, pleasant and stimulating, with no negative effects on health" (Fanger 2000).

**IAQ and Productivity**

Improving IAQ is among the most profitable investments building managers can make, since even small improvements in IAQ will directly improve productivity. Parallel to the costs of design and construction, energy costs and operation and maintenance costs, are health costs and productivity. Reducing lost time of employees and enhancing their performance, by providing environmental conditions which satisfy needs, reducing the adverse effects of exposures to pollutants and promoting health are essential elements in improving productivity (Tuomainen et al. 2002). An increase of 0.1% to 2% can have a significant impact when related to typical commercial organisational salaries, which can amount to 90% of the total costs (Clements-Croome and Kaluarachchi 1999). Estimates have been made of the total annual costs of four common respiratory infections in the USA is approximately $A 140 billion, the cost of allergies and asthma approximately $A30 billion and the cost of building related health symptoms approximately $A60 billion (Fisk 2000).

"In non-industrial workplaces, the cost of salaries and benefits exceeds energy costs, maintenance costs, and annualised construction costs or rent, by approximately a factor of 100" (Woods 1989). Businesses should be strongly motivated to invest in changes to building designs or building operation if these changes improved worker performance by even a significant fraction or reduced absence from work by a day or more per year (Fisk 2000). In the near term employers may not necessarily respond to productivity and health improvement measures because of uncertainties of knowledge and limited communication of research findings. Good building ventilation creates comfortable and healthy indoor conditions. Doubling of minimum ventilation rates as an easy measure to improve IAQ would increase energy costs, for example, by a modest 5% in most buildings because heating or cooling ventilation air is a small portion of total building energy consumption (Fisk 2000). A healthy workplace has developed and implemented processes, of good practice in management of occupational, lifestyle, social and environmental determinants of health (WHO 2002). Among workplace performance criteria, the environmental factor, amenity, ie. the level of comfort afforded by natural daylight, views, air quality, cooling, heating, lighting and catering facilities, is ranked 5 in a scale of 1 – 5 in importance, in surveys conducted in offices, worldwide. However the actual general workplace amenity is ranked 3. This indicates a potential improvement of 40% in amenity provision. Hard savings in rental cost can be supplemented by soft savings in: staff turnover cost reduction, absenteeism reduction and increased productivity. Providing healthy workplaces that maximise employee productivity and business profitability can generate soft savings, and facility managers can enhance their value to the client rather than simply reducing costs.

A detailed environmental survey in a London commercial building (Clements-Croome and Kaluarachchi 1999) showed that the office physical environment has a direct influence on the health, well-being and the productivity of occupants, besides having a positive effect on creativity and the quality and quantity of work carried out (Clements-Croome and Kaluarachchi 1999). Three independent experimental studies in Denmark and Sweden have shown that improving indoor air quality improves the performance of typical office work such as word processing, proof reading and arithmetical calculations (Wargocki et al. 1999, 2000, 2002). The performance of office work may increase by 5% when the air quality is improved to a high level from a mediocre level often found in practice (Wargocki et al. 2002).

## Volatile Organic Compounds (VOCs)

Volatile organic compounds (VOCs) are a major component of indoor air pollution. VOCs consist of a large number of organic substances, which will volatilise at normal room temperatures. Sources of air-borne pollutants in offices and public buildings include carpets, paint, varnish, glues, furniture, wall coverings and partitions. Office equipment such as photocopiers, laser and matrix printers, carbonless copy paper, correcting fluid and cleaning agents such as bathroom cleaner, window cleaner, liquid soap, carpet cleaner, floor wax, furniture cleaner and bleach, produce VOCs with a wide range of volatility and persistance (WHO, 1989; Fenske and Paulson, 1999; Wolkoff, 1995) Although each compound is likely to be present in very low concentrations, the mixture can produce additive and possibly synergistic effects (Weschler and Shields 1997; WHO 1989; 2000a). Ventilation rates determine the time available for chemical reactions among indoor pollutants to generate new products. Pesticides applied indoors may last for years in carpets, where they are protected from the normal degradation caused by sunlight and bacteria The linkage between ventilation and indoor chemistry is often overlooked. This may be partially explained by the fact that many of the products of indoor chemistry are not readily detected using the standard analytical methods (Weschler and Shields 2000). The products of reactions among indoor pollutants are often more irritating than their precursors. For example, the air oxidation of limonene (the citrus solvent) has been reported to create potent skin allergens (Karlberg et al. 1992) and the products of ozone/terpene reactions cause airway irritation (Wolkoff et al. 1999). Concentrations of organic solvents not exceeding the WHO exposure standards can cause subclinical rhinitis (Muttray et al. 2002) and sensitization from exposure to toluene diisocyanate (TDI) used in the manufacture of common polyurethane products eg. carpet padding in homes and offices may result in “isocyanate asthma”. Adverse responses to even low, normally non-irritating concentrations may include both immediate and delayed symptoms (IRIS, 1998). It is well documented that symptoms including irritation of eyes, nose and skin, headache, fatigue, and difficulty breathing are experienced by a substantial proportion of all office workers e.g. 5% to 40% of workers depending on the symptom (Fisk, 1997, 2000). Clearly, less contact with VOCs is better than more.

**Plants and VOCs**

The economic rationalism of the last decade of the twentieth century caused a critical review of the place of plants and interior plantscaping in commercial and public buildings, which still persists. If life-cycle costing can't be justified, then landscape is considered only as a decoration. Our preoccupation with technology and an international style of functional, environmentally controlled buildings has made it seem that plants and landscaped interiors are out of place. However, Ken Yeang has pointed out with great clarity the fact "that people are constantly moving into new environments, unconnected with the natural environment, tends to give the impression that they are enlarging the range of their evolutionary past. This is an illusion because wherever humans go, they can function only to the extent that they maintain a micro environment that is similar to the one from which they evolved" (Yeang, 1995).

Green plants may be a cost-effective way to facilitate reductions in VOC concentrations. Our current research at the University of Technology, Sydney (UTS) is focused on the roles that indoor potted plants play in improving IAQ. Recent research has shown the capacity of commonly used indoor foliage plants such as Kentia Palm (*Howea forsteriana*), Peace Lily (*Spathiphyllum* 'Petite') and 'Janet Craig' (*Dracaena deremensis*) to reduce and eliminate the VOCs benzene and n-hexane from the air of sealed, laboratory test chambers. The potting mix microorganisms were important in VOC removal, which improved on exposure, after initial adaptation (induction phase), and maintained performance with repeated VOC doses (Wood et al. 1999, 2000, 2001).

To extend our research, a room-sized chamber at the CSIRO Division of Building, Construction and Engineering in Melbourne was used to correlate laboratory test chamber studies at UTS. Benzene removal was studied in the room-sized chamber (in both sealed and ventilated modes) (Wood et al. 2000), and in ventilated laboratory test chambers, to provide conditions more like those in the "real world". As well, VOC removal was studied at lower concentrations than previously used, at the levels of Australian occupational exposure standards (5 ppm benzene and 50 ppm n-hexane). The range of plants tested was expanded to seven - Devil's Ivy *(Epipremnum aureum*), (Queensland Umbrella Tree (*Schefflera actinophylla* 'Amate' Spathiphyllum 'Sensation' and *Dracaena marginata,* as well as the previous three species. The induction phase of VOC removal was also examined in more depth (Orwell et al. 2003)

We found that potted Kentia Palms removed benzene from a closed, room-sized chamber, with 90% removal after 24 hours. Our findings are thus immediately applicable to rooms in the real world. This benzene removal capacity was similar to that in sealed laboratory test chambers, with similar ratios of air volume to plants in the two systems. We also demonstrated benzene removal by plants under ventilated conditions. In ventilated laboratory test chambers, the rate of benzene removal was greater by up to 15% in a chamber with a potted plant of *Spathiphyllum* 'Petite' than without. This additional benzene removal capacity, over and above that provided by ventilation, can be viewed as "bonus" ventilation or as a potential economic saving on air-conditioning costs when plants are an integral part of building design.

Benzene removal activity was demonstrated in all seven plant types studied and followed a similar pattern, with an adaptation phase, improvement on exposure to VOC, and maintenance of activity with repeated doses. Benzene and *n*-hexane removal occurred when only low concentrations were used – these are sufficient to initiate VOC removal activity. Benzene removal in the adaptation phase was found to be linear over the range 1-1000 ppm benzene (Orwell et al. 2003). Further research will study VOC levels in offices with different numbers of plants, VOC removal in ventilated test chambers to compare plant species and hence optimise potted plant performance, and removal of new types of VOCs of concern in IAQ.

Our findings support the view that the potted-plant system represents a potentially more self-sustaining (provided the plants are well maintained), flexible and attractive biofiltration system for the future, that can be used in any indoor space.

- The pot-plant system really does reduce or eliminate VOCs from indoor air within 24 hours.
- The system gets better on exposure to VOCs and maintains performance with repeated doses.
- From 3 to 10 times the maximum permitted Australian occupational indoor air concentrations of each compound can be removed within about 24 hours, under light or dark conditions without saturating the system.
- The pot plant system can also remove very low residual concentrations as well,
- Work at the same rates day and night, and over weekends (when air-conditioning may be turned off).

**Breathing Wall Biofiltration**

The biofiltration of indoor air, combining conventional basic components of a ventilation system with plants is being developed in Canada. The principal component of the biofilter is the ‘breathing wall’, a porous constantly-wetted wall covered with mosses and ferns. When air with low levels of indoor pollutants is drawn through the wall, the continuous flow of water passes into a hydroponic and aquatic system that contain a variety of plant species. This system has been installed in a multifunction meeting room in the head office of Canada Life and Assurance in Toronto, and is significantly effective in reducing the air pollution levels within the room. Smaller, more portable, biofilter systems are being developed to give wider application to commercial and domestic environments.

The indoor potted-plant/growth medium microcosm is a ready to use, readily available, adjunct to the engineering-based biofilter systems.

- ❖ They are cost-effective in comparison to the use of sophisticated air conditioning filter systems;
- ❖ Offer flexibility of location and relocation according to needs;
- ❖ Represent a solution that could be readily developed and refined for each application
- ❖ Do not produce acoustic problems;

- ❖ Do not interfere with any existing air distribution systems or patterns in a room;
- ❖ Installation does not entail alteration to the fabric of a building;
- ❖ Offer flexible routine maintenance;
- ❖ Entail relatively minor capital and running costs;
- ❖ Involve only a very remote chance of a sudden breakdown or failure of operation;
- ❖ Provide a means for discrete implementation of a solution to an environmental problem.

**Healthy Workplaces and Productivity of Office Workers**

The actual activities performed in offices have changed considerably over the past 20 years, but many buildings have not been adapted accordingly. There has been a shift from routine work to work that demands concentration, performed with the aid of equipment that must be ergonomically incorporated into the workplace (Bergs 2002). Most of the complaints about the work environment have a direct technical cause, relating to air quality and thermal comfort. In this respect, advanced climate control and sealed windows have contributed to a perception of lack of control over the environment, which in turn adds to occupant stress. People have 'instinctive behaviour' and 'basic functioning', survival skills learned over the course of evolution: the need for change, the ability to act on the environment and see the effects, identifying the meaning of stimuli, and the need for one's own territory, a place with its own identity and contact with the outside world. If some or all of these basic needs are denied or suppressed, then the perception is of a low-quality workplace. Symptoms, which may relate to both the physical and psychological stresses of the workplace, may include; eye complaints, mouth or throat complaints, skin complaints, nose complaints and neurological complaints.
A poor quality workplace causing health and comfort complaints diminishes productivity. Reduced productivity is difficult to quantify however various studies have been carried out measuring various performance factors. It has been shown that productivity declines sharply as building-related health complaints rise. The average productivity loss in most of these studies was 12%. An unfavourable indoor environment creates a greater tendency for employees to report in sick sooner and to stay away longer (Bergs 2002).

**Productivity and Indoor Plants**

A study in the Netherlands in 2001, involving 250 employees of the Winterswijk Tax Office, using a control group (without plants) and a test group (with plants) found that:
- the test group rated well-being more favourably than the control group
- the same applied to the ratings for the quality of the working area
- the differences that were found were more explicit for the group of employees who work more than 4 hours a day in front of a computer screen
- their productivity improved, especially in terms of efficiency
- the strongest link was found with those working at computer terminals in the experimental group, particularly for quality of the working environment and wellbeing
- loss of concentration dropped, ie. concentration improved in the test group
- no findings with regard to any significant improvement in health

- other environmental factors: reduction in static electricity
- the humidity indoors depends on the outdoor humidity
- plants make a small contribution to reduction of $CO_2$ concentrations (Bergs 2002).

It is always preferable to adopt a preventative approach and provide the conditions for a healthy productive work environment.

**Health and Well-being and Indoor Plants**

A Swedish study in 1993 concluded that if office personnel could view greenery through their office windows, significantly less stress was reported during the working day, compared with office workers who had views to non-vegetated areas, such as streets and parking lots (Fjeld 2002).

A 1998 Norwegian cross-over study, among 51 offices over two three-month periods, evaluating the effects of indoor plants on health and well-being of occupants, found significant reductions in incidence of symptoms such as coughing (37%), fatigue (30%), dry, hoarse throat and dry or itching facial skin (23%). The score sum, as a mean of 12 symptoms (Table 1) was 23% lower during the period when the participants had plants in their offices, than when there were no plants (Fjeld 2002).

In a further study of personnel working in a hospital radiology department, in an intervention study, a 25% decrease in complaints was observed after the introduction of indoor foliage plants and full-spectrum lighting. Particularly significant effects were observed for headache (45%), feeling heavy-headed (33%), fatigue (32%), dry, hoarse throat (22%) and dry/itching skin on hands (21%). There were no changes observed in the concentration of fungal spores due to the introduction of plants and improved lighting

The radiology department director reported that short-term absence due to illness decreased from a usual 15% to 5% (a more than 60% reduction) during the experimental period, and with the plants remaining in the room this decreased rate has persisted for 5 years (Fjeld, T. pers. com.).

A similar Norwegian study, in 1999 conducted in 12 school classrooms found:

- 21% less health and discomfort complaints among the pupils
- significantly reduced complaints regarding fatigue, feeling heavy-headed, dry, itching or
- irritated eyes
- higher level of satisfaction regarding the perception of the visual environment of the classroom
- no difference in the number of mould spores in the indoor air between intervened and control rooms
- lower sickness absence among junior high school pupils
- 35% lower concentration of Total Volatile Organic Compounds (TVOC) in indoor air

In a follow-up intervention study of Norwegian office workers (Fjeld 2002) in an attempt to separate the effects of plants from the effects of full spectrum lighting, the level of complaints was significantly lower among workers who had plants on office desks, adjacent to their computers. Lowest level of complaints was found with plants and a change in light environment, however the perception of the participants was, that a change in the light environment alone did not affect the satisfaction level of the visual environment and hence a significantly more positive evaluation of the work environment was reported (Fjeld 2002).

**Green Architecture – Plants in Buildings Creating an Inspiring Healthy Indoor Environment**

'Green solar architecture' a building design concept developed in Germany, makes the greatest possible use of solar energy to provide energy-efficient and people-friendly buildings, with plants as an integral part of the system. The use of solar energy in combination with interior planting can provide 50-80% of the buildings energy requirements (Schemp 2002). Buildings are designed to have a positive effect on building occupants in both the building's interior space and in the external appearance. A reduction in building operating costs results from lower energy costs, high quality of the building, flexibility of use and recycling of materials.

Seasonal variations are easily adjusted without the use of large numbers of sensors and servo-motors that make 'intelligent buildings' expensive to maintain and vulnerable to mechanical and software breakdowns.

Plants are selected for shading and cooling through transpiration. Indoor temperatures 2-3 degrees below outside air are achieved in summer by coordinating the interior planting, the mass of the building and air exchange through outside vents. Rainwater irrigates the plants, while photovoltaic panels on the roof feed some electricity into the building, supplementing the grid supply.

These buildings are described as pleasant to be in, and interior planting has met with a positive response. The air quality is excellent and the shading and air conditioning functions as well as aesthetics are viewed positively by building occupants reflected in decreased absenteeism (Schemp 2002).

## SUMMARY

Health and environment are the focus of individuals, employers, and organisations such as WorkCover, the National Environment Protection Council and the World Health Organisation, for example.

We now have a wealth of additional evidence to support the use of potted plants to improve indoor air quality. They provide an inexpensive, flexible, portable and aesthetically attractive biofiltration system for indoor air, which is self-sustaining when normal plant care is given. We would encourage both homeowners and building managers to use indoor plants much more to help improve indoor air quality. Architects, designers and engineers might also think more creatively about how they could integrate plants into building designs at an early stage, to make better use of this green technology. Facility managers have the opportunity in a cost-effective way to enhance their value to the client by providing attractive healthy workplaces that maximise employee productivity and business profitability.

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