INTERIOR PLANTS FOR SUSTAINABLE FACILITY ECOLOGY AND WORKPLACE PRODUCTIVITY

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Abstract

Human ecology (i.e. humans in their relationships with the environment) has a history extending up to two million years. Our species has continued to be biologically well adapted to ‘nature’ as we have encountered it over that period. We are reliant on plants for everything we need - from food to shelter, and also, (unknown to our ancestors) plants supply our oxygen, and are the sink for carbon dioxide. Our ancestors also recognised an essential role for plants in providing pleasure, perfumes, peace, piety and glimpses of ‘paradise’. We still have the same requirements as our forebears. In contrast, the increasingly rapid growth of modern cities has been only over the last two hundred years.

How well adapted are we to our new, urban ecology?

I propose that ‘greening the great indoors’ with living plants is an important element in enabling sustainable urban communities of the future, since such communities will increasingly depend on a healthy ‘indoor facility ecology’.

The move to city-living has had great benefits, but at some costs to health and wellbeing. Urban air pollution is a world-wide health concern, as is indoor air quality. Urban air pollution in Sydney alone causes at least 1,400 deaths per year, and we spend 90% of the time indoors, where air is generally more polluted than outdoors. The indoor potted-plant ‘microcosm’ absorbs and degrades all types of air pollution, and is self-regulating in operation.

I outline our UTS laboratory and office ‘field’ studies on indoor-plant removal of airborne volatile organic compounds (VOCs), carbon dioxide and carbon monoxide.

City-dwellers also need continuing psychological links with ‘nature’. The evidence is that humans can only function ‘to the extent that they maintain a micro-environment similar to that from which they have evolved’. City mental health problems are increasing. It has been demonstrated that indoor plants aid both wellbeing and productivity of building occupants. It is expected that, in the future, along with normal fittings, indoor plants will be utilised as a portable, flexible, beautiful, useful, effective, and a relatively low-cost, standard installation to improve indoor environmental quality (IEQ). Hence, e.g. the Green-Star ratings from the Green Building Council for building designs that include indoor-plant installations.

I present a cost-benefit analysis for using indoor plants–clearly the savings will more than cover the costs, thus achieving a win-win situation for indoor air quality and human wellbeing, and as an essential contribution to 'enabling sustainable communities'.

1. INTRODUCTION

1.1 Human Ecology Comes To Town

The theme of this conference is that of 'enabling sustainable communities'. The underlying goal is that of ecologically sustainable development overall, a concept that emerged only 20 years ago, following the Report of the UN World Commission on Environment and Development (UN WCED; 1987) - *Our Common Future*[42] ('Brundtland Report'). The Report defined 'sustainable development' as that which 'meets the needs of the present without compromising the ability of future generations to meet their own needs' (hence the term 'intergenerational equity'). The terms 'built environment' and 'urban ecology' have also gained general currency only over the last couple of decades, and the term 'facility ecology' is newer still. All these terms point to the rapid growth of international concern over global urban and industrial development, and the ability of the planet to sustain all our activities.

Human ecology (i.e. how humans impact on the environment and how the environment impacts on use) has a history extending over anything from half a million to two million years, depending on when a particular author considers *Homo sapiens sapiens* actually to have emerged as a new species, somewhere in Africa. Our species already was, and has continued to be, biologically well adapted to nature, as we have encountered it over that period, with both its constancies and variability. As smart, two-legged, naked apes, we evidently gradually moved out of forests and woodlands, and into drier savannahs and grasslands, hunting and gathering. We tamed fire, for warmth and light, as well as for cooking food. Then, over just the last ten thousand years or so, we got smarter still, as herders and croppers, while settlement and civilisation developed. Our diet has always been mainly a mixture of grains, fruit, nuts and roots, with some animal protein added when the hunt was successful. On a global basis, this diet still holds sway.

We are fundamentally reliant on vegetation for everything we need:
- food and drink
- fodder
- fences and ropes for our animals
- fuel
- shade and shelter
- timber for tools and construction.
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Although our ancestors did not know it, plants are the planet's source of oxygen, and the sink that mops up carbon dioxide produced by burning, respiration and decay of organisms.

As well, our ancient ancestors also recognised an essential place for ornamental uses of plants, to provide:
- pleasure
- perfumes
- peace
- piety
- reminders of paradise.

We still respond to these qualities of plants as those before us did.

The increasingly rapid growth of modern city-living has been only over the last two hundred years or so, since the industrial revolution in Europe really gathered momentum. The growth rate of cities is now outstripping that of world population as a whole[41]. How well adapted are we to our new, urban ecology? Or, how can we mould urban ecology, to adapt it to our fundamental needs?

I propose in this presentation that 'greening the great indoors' with living plants is an important element in enabling 'sustainable urban communities' of the future.

1.2 The way we live now

As a result of the process of urbanisation, in Australia, North America and much of Europe, 80% of people have come to live in urban areas. And, we spend an amazing 90% of our time indoors[13]. The quest for a healthy human ecology has thus, perforce, become the quest for a healthy built environment, and especially a healthy 'indoor facility ecology'.

The move to the city, at least in the western world, has been accompanied by great benefits for most people - better education, less strenuous manual labour, more employment opportunities, more available health services, a wider choice of entertainment, and longer life expectancy[37]. However, urban lifestyles do not offer unmixed blessings. Diseases of sedentary living, such as obesity, diabetes, and cardiovascular problems, are rising with population numbers, and urban mental health is an international concern, raising issues including violence and phenomena such as road-rage[27]. Urban air pollution is a world-wide health concern, as is indoor air quality[13, 28, 48]. Urban air pollution in the Sydney metropolitan area is estimated to cause some 1,400 deaths per year[30]. And since we are indoors 90% of the time, that is where we are breathing the contaminated air (which is generally more polluted inside than outdoors).

1.3 Our innate need for links with nature

City living does not mean that we no longer love 'nature'. Evidence for that assertion? Well, for example, the motto of the real-estate industry is still, and perhaps even more stridently as cities increase in size and density: 'Location, Location, Location!!!' – and a desirable location includes a well-planted vista, with sometimes water as well. Property prices nicely demonstrate the value we urban dwellers place on a pleasing location. As well, gardening, fishing, and out-of-town-weekend-getaways (along with recipes!) are among the top family-favourite websites. And, in any commercial building, it is almost certainly the executives who have the windowed offices with a view, preferably with at least a bit of vegetation visible.

As put by the editor of an international health journal[37], the movement of people from rural to urban environments 'has facilitated their disengagement from the natural environment…[and] the protective factors of nature for health improvement and sustainability have been reduced by our diminishing regular contact with nature'. Or, as stated more straightforwardly by the internationally known architect, Ken Yeang, in his book, *Designing with Nature: The Ecological Basis for Architectural Design*[52], 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 only function** to the extent that they maintain a micro-environment that is similar to the one from which they evolved' (emphasis added).

1.4 Indoor Plants Contribute To Healthy Indoor Facility Ecology

I am presenting here the case for promoting urban greenery, and in particular for 'indoor' plants (i.e. shade-tolerant species we have chosen to bring inside). The international body of evidence, which I can only briefly outline here, is now convincing, that indoor plants can alleviate many of the problems of indoor environmental quality (IEQ), and hence promote the health and well-being of building occupants. Indoor plants are already coming to be recognised as a vital element in enabling sustainable urban communities. In future, it can be expected that, along with lighting, air-con, plumbing, etc., interior foliage plants will be utilised as a portable, flexible, beautiful, useful, effective and relatively low-cost, standard installation to improve IEQ,. Hence the Green Star ratings from the Green Building Council of Australia, for new building designs that include plant installations.

2. POTTED-PLANTS IMPROVE INDOOR AIR QUALITY (IAQ)

2.1 Urban Air Pollution and Health Risks

Urban air pollution arises mainly from the burning of fossil fuels.

Primary emissions include: oxides of carbon (CO_2) (CO), nitrogen (NOx) and sulfur (SOx); 'air toxics', i.e. 'organics' from not-fully burnt fuel, e.g. the 'big four' 'BTEX' (Benzene, Toluene, Ethylbenzene, Xylene) - and 'PAHs' (polyaromatic hydrocarbons); metals; and 'fine particulates' ($PM_{10}/_{2.5}$).

Secondary products are also formed, after further photochemical reactions in sunlight, - more NOx; ozone (O_3); peroxyacetyl nitrate (PAN); and 'smog/haze' (from the mixture).

The short-term health risks of this air pollution include asthma, strokes, heart attacks, and sudden infant death syndrome. Longer-term effects include low birth weights, some cancers, cardiovascular problems, and schizophrenia and other mental illnesses.
Plants, including 'indoor' species, have been shown to absorb and degrade all types of urban air pollutants, **thereby reducing air pollution levels**.

2.2 Indoor Air Pollution and Health Risks

Contrary to what many people assume, urban indoor air is generally more polluted than outdoors, even in the city centre[4,8,13]. This is because, as outdoor air diffuses inside, the pollution load is augmented from indoor sources. These will include more NOx, SOx and CO if gas appliances are present. The CO_2 levels are generally higher, because building occupants have to exhale; and there is also house (or office) dust. The main class of indoor-derived air pollution, however, is from the outgassing of volatile organic compounds (VOCs) from ‘plastic’ or ‘synthetic’, sources. The USEPA has identified over 900 VOCs in indoor air[43](not all at once!) Sources include components of furniture, fabrics, and fittings, paints, glues and varnishes, computers, printers, solvents, detergents, and shampoos, cosmetics, etc. Although great efforts are being made to finish and fit out new buildings with low-VOC materials (see, e.g. Australian carpet standards), it is impossible to eliminate volatiles altogether. In any case, the interiors of a majority of buildings at present still have significant loads of total VOCs (TVOCs).

It is recognised that VOCs are a common cause of ‘Sick-building syndrome’ or ‘Building-related illness’[7, 23, 48]. Even at imperceptible levels, the cocktail of compounds can cause symptoms including loss of concentration, headache, dry eyes, nose, throat, ‘woozy-head’, and nausea. In addition, elevated CO_2 levels can produce feelings of stuffiness, loss of concentration and drowsiness. Longer term, the health problems mentioned above can emerge. The World Health Organisation (WHO) in 2000 predicted that, by 2010, responsibility for healthy indoor air quality (IAQ) will rest with facility managers[48]. **Overseas studies have shown that indoor plants can also reduce dust levels, and tend to stabilise humidity and temperature. They can also baffle noise**. **Our UTS studies, which followed on from the pioneering work of Wolverton *et al* in the USA[45-47], have conclusively demonstrated that indoor potted-plants can eliminate high or low doses of airborne VOCs within about 24 hours, once they have been stimulated to respond by a ‘taste’ of the substances[6,31,32,38,47,48]. We found that the potted-plants can reduce CO_2 and CO levels as well[39]. Below is a summary of our studies on indoor plants to improve indoor air quality (IAQ)**.

2.3. UTS Laboratory Studies Of Indoor-Plant VOC Reduction

Experimental design

We have, so far, laboratory-tested VOC removal capacity in eleven internationally used indoor plant species (see Appendix). We used four test VOCs: *n*-hexane, and benzene, toluene and xylene (three of the ‘BTEX’ group, known or suspected carcinogens; also used indoors as solvents, in manufacture of fittings etc). Four to six replicate pot-plants (in180 or 200 mm pots) were placed individually in bench-top Perspex test-chambers (216 L), and an initial dose of up to 100 ppm of the VOC was injected into each chamber. Rates of removal were measured in a gas chromatograph (GC). After removal of the initial dose, daily top-up doses were applied, over from two to four weeks. The dosages used were from 2 to 10 times higher than the Australian maximum allowable 8-h averaged occupational exposure concentrations.

Findings

There was a common pattern of VOC removal response with all 11 species, as follows:

a) **removal rates started slowly but, over four to five days, they rose to more than 10 times the initial rate; i.e. removal rates were stimulated ('induced') by exposure to the initial dose;**
b) **once 'induced', the potted-plant microcosm reliably eliminated daily top-up doses within ~ 24 hours**
c) **if the dose was doubled, removal rates rose to meet it;**
d) **low, residual concentrations were also removed, effectively to zero (i.e. below detection limit of GC);**
e) **rates were unchanged in light or dark (i.e. worked 24/7);**
f) **in some of the tests the plants were finally removed, and the potting mix placed back in the chambers – and removal rates were maintained! (at least for some days).**

Findings (e) and (f) indicated to us that it was normal microorganisms of the potting mix that were the primary VOC removal agents, which we confirmed by subsequent microbial testing. (These bacteria break down soil organic matter/humus.) The role of the plants here is in nourishing the root-zone microbial communities. This 'symbiotic microcosm' relationship is a universal feature of plant-and-soil interactions.

Practical implications

Although rates of response to the initial dose varied among plant species tested, after a week or so of 'induction', all species showed more or less equal capacity for rapid, sustained VOC removal. The results strongly suggest that the 'potted-plant microcosm' (PPM) of any indoor-plant species will have a similar capacity for efficient, reliable, VOC removal. Nevertheless, we are continuing to test other species.

2.4. UTS Office Study of Potted-Plant Reduction of Air Pollution

Laboratory findings are all very well - but can indoor plants make a difference to IAQ in the real-world? To answer this we conducted a study in real offices[32,50].

Experimental design

We examined the effects of three potted-plant arrangements on total VOC (TVOC) loads, in 60 single-occupant UTS staff offices (12 per treatment), over two 5- to 9-week periods. The offices were in three buildings, two with and one without air-conditioning. Planting arrangements were:

a) 3 floor specimens of *Dracaena* 'Janet Craig' (300 mm pots)
b) 6 floor specimens of *Dracaena* 'Janet Craig' (300 mm pots)
c) 6 mixed 'table-sized' plants - 5 *Spathiphyllum* 'Sweet Chico' plus 1 *D.* 'Janet Craig' (200 mm pots
d) 0-plant 'reference/control' offices.

Weekly samplings were made of TVOCs, CO_2, CO, temperature and humidity.

Findings

TVOC reduction Results showed that:

a) **whenever TVOC levels rose above ~100 ppb, any of the plantings reduced loads back to below 100 ppb;**
b) **plantings worked equally well with or without air-conditioning**
c) **the fact that all plantings worked equally well means that the minimum number needed for efficient air cleansing is lower than any of the plantings used.**

The results show clearly that the PPM works very effectively in the real world, and that a 'jungle' is not needed to achieve the desired result.
We are currently researching minimum numbers and sizes of plants needed for this purpose.

Carbon dioxide reduction
With adequate lighting to power the process, all green plants photosynthesise, i.e. combine water with absorbed CO_2 to manufacture sugars; and in so doing, they release equimolecular concentrations of oxygen (O_2) as a by-product. Thus, green plants refresh planetary air in these two complementary ways. Indoors, the main advantage of ventilation is not so much replenishing O_2 (21% of the atmosphere) as to remove CO_2 (global ambient levels are ~370 ppm – indoor levels are recommended to be kept below 1,000 ppm). Studies have shown that workplace productivity and student performance decline with increasing CO_2[34,35].
Our results showed that in offices with plants, CO_2 levels were reduced by about 10% in the air-conditioned building, and by about 25% in the non-air-conditioned building[39].
We are at present studying factors of lighting and plant placement that may provide even more effective CO_2 reduction.

Carbon monoxide reduction

CO is very much more toxic than CO_2. However, plants and some soil bacteria consume and utilise this gaseous substance as part of their growth metabolism[9,12,17,19,20] .

We found trace amounts of CO in office air - 225 ppb in the air-conditioned building, and only 70 ppb in the building without air-conditioning. However, in offices with plants, levels were reduced to 17 and 10 ppb respectively – i.e. by an average of about 90%[39].

3 URBAN PLANTS IMPROVE WELLBEING AND PRODUCTIVITY

3.1 Urban Green-Spaces

The open green pockets of CBDs – parks and gardens, and pot-planted forecourts and building atria, are oases of restoration for city staff and visitors[27,37]. As indicated above, plants absorb air pollution, and offer coolness and shade. In addition, research has shown, for instance, that spending half an hour (e.g. lunchtime) in the park lowers blood pressure. Other studies have found that being in a garden reduces anxiety and anger, and gives feelings of calmness and pleasure[49]. Tree plantings along roads reduce driver stress, as indicated by lowered blood pressure, heart rate and nervous system measures. Kaplan and Kaplan[18], researching the psychological benefits of natural surroundings, found they relieved 'attention fatigue', and acted as 'restorative environments'. They described such environments as providing four qualities:

- *attracting effortless attention*;
- giving a feeling of temporary '*awayness' or 'escape'* from normal preoccupations;
- *extending scope* - a reminder of being part of a wider whole; and
- *flowing with one's inclinations* (e.g. for rest and intermission from 'busy thoughts').

Green-spaces and planted forecourts etc are important elements of greening the city. But what of the 90% of time spent indoors? There too, plants can continue to provide their restorative function.

3.2 Plant Views

I referred earlier to competition indoors for a desk with a window view, preferably with a bit of vegetation in it. There is an increasing body of literature on the benefits of planted views to building occupant health and wellbeing. Moore (1981)[29] found that prisoners in cells with views of plants and birds, were less disruptive and asked for fewer medications than others. Ulrich (1984)[40] found that patients recovering from surgery, with views of a garden, got home nearly two days earlier than those who looked onto a wall or lift-well. They also used lower levels of painkillers.

In another study, Students with plants in views did better on tests than those without[38]. In a survey study of 100 staff in southern Europe, it was found that those with windows with natural views showed higher feelings of wellbeing, and significantly lower job stress or intentions to quit[21].

3.3 Plants Indoors

Not everyone can be near a window, and even near a window, live plants inside add benefit. Fjeld *et al.* found that, when plants were introduced in an underground hospital radiology department, sick-leave absences declined by over 60%1[4]. This represents a substantial increase in wellbeing and productivity. Other studies have also shown decreases in sick-leave where indoor plants were installed[3,15]. Feelings of calm and pleasure have been reported. Better performance has been recorded, with plant presence, on test computer tasks, card-sorting jobs and creative thinking tests. Reductions in absences for illness among primary school children have also been found. In other studies, reductions have been found in pain perception, anxiety, depression and feelings of hostility.
All these responses to indoor plants indicate improvements in wellbeing and productivity of building occupants.

4. COST-BENEFIT ANALYSIS

It is clear from the above discussion that indoor plants improve IEQ in a variety of ways, and that direct benefits to health and wellbeing have been demonstrated. Studies have also been made of client/customer perceptions of indoor plants in the office, perceptions which, of course, affects business as well.

4.1 Effects of Indoor Plants on 'Business Image'

An American study, with 170 respondents, explored what effects indoor plants had 'on a business's image to a visitor' (potential customer/client). There was universal agreement among respondents on a number of issues, including that indoor plants led to the perception that the business was:

- Warm and welcoming
- Stable and balanced
- Well-run
- Comfortable to work with
- Patient and caring
- Concerned for staff welfare
- Prepared to spend money on added beauty
- Not mean
- Providing a healthier, cleaner atmosphere

It can be expected that the same responses will be shared by the firm's staff also.

4.2 Costs of Indoor Plants

Say the salary of a hypothetical staff member average staff member is about $50,000 p.a.; it might cost up to twice that to actually employ him/her. The cost of maintaining one basic indoor floor plant, whether it is bought and maintained in-house, or hired, is about $200 p.a. It would seem from all of the above considerations, that the plant will more than pay for its presence.

4.3 Cost-Benefit Case Studies

Performance Increases

In study by Lohr (**date**) found that participants showed 12% more productivity and less stress than those who worked in an environment with no plants. Twelve percent of $50,000 is $6000. The hypothetical staff member above is now worth $56,000, for a further outlay of $200 for a plant. A sum of $6000 would provide 30 plants. The improved productivity resulting from reduced sick leave. Discussed earlier, would similarly mean savings to the company.

Increased Retention Rates

As mentioned earlier, intentions to quit are lowered when plants are present. If our hypothetical staff member was employed through a Recruitment Agency the fees are likely to be 10% of the salary, i.e. $5000. In addition, there are costs involved in training a new staff member. If the presence of plants prevents one staff member leaving, the saving is therefore at least $5000 (or 25 plants).

5. CONCLUSIONS

This discussion has indicated the fundamental need for continued linkages between city-dwellers and plants - for cleaner air, calmer spirit, lighter mood, improved concentration and performance, and productivity. One element of maintaining that people-plant linkage is by the use of interior foliage plants as a standard fitting of indoor spaces. This will result in a win-win situation – improvement to IEQ and a vital contribution to enabling sustainable urban communities.

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Appendix

Indoor plant species trialled in laboratory test-chambers:
Aglaonema modestum, Dracaena 'Janet Craig', Dracaena marginata, Howea forsteriana (Kentia palm), Epipremnum aureum (Pothos), Philodendron 'Congo', Sansevieria trifasciata (Mother-in-law's tongue), Schefflera 'Amate' (Qld. Umbrella Tree), Spathiphyllum 'Petite' (Peace Lily), Spathiphyllum 'Sensation', Zamioculcas zamiifilia (Zanzibar).

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