Ambius White Paper

Plants in "Green Buildings"

Kenneth Freeman
International Technical Director

The cost of energy is at record levels and likely to remain high for the foreseeable future. Add to that the threats to the environment resulting from the profligate use of natural resources and fossil fuels, then the need to design and manage buildings to be as energy-efficient as possible becomes much more urgent. Whilst most new buildings are already designed to be as energy-efficient as engineers think possible, there are innumerable older buildings where large-scale, engineered 'greening' is either impracticable, or prohibitively expensive.

This White Paper explores the use of interior plants as part of a sustainable building management system. By exploiting the physical properties of living plants, it is possible to reduce our reliance on energy-consuming engineered and manufactured products: the multi-tasking abilities of plants can be exploited to enhance indoor air quality, help regulate temperature and even reduce nuisance noise. What's more, the effects of interior plants can often be obtained at much lower costs than specially-made 'Green Building' products.

ambius

Contents

Green Building rating schemes

Many countries have systems in place to measure the environmental impact of buildings and there are often incentives for developers to build 'green'. The most well-known examples of green building rating systems are LEED (Leadership in Energy and Environmental Design), managed by the United States Green Building Council, and BREEAM (the Building Research Establishment's Environmental Assessment Method), operated by the UK Building Research Establishment. Around the world, other green building rating systems are in place, usually derived from the BREEAM methodology. For example, the Australian Green Building Council has the Green Star rating system.

All of these rating systems have versions for new and refurbished existing buildings, and also for different types of building (for example, offices, houses, hospitals, schools and even whole neighbourhoods). They also have one other critical feature in common - they are devised and managed by building engineers, architects and constructors, so have an understandable bias towards engineered and manufactured solutions to green building issues. The rating systems are also heavily biased towards built-in systems, rather than anything added at fit-out or post-occupancy. This is neither unexpected, nor unreasonable: it is often much more cost-effective to build systems into the fabric of a building that is designed with energy efficiency in mind than to expend more time, effort and resources in retro-fitting equipment.

Apart from being locked into existing leases, the main barrier to why businesses don't occupy green buildings is the lack of available environmentally-friendly buildings. Companies remain convinced that renting a green building is more expensive and that the pay back period is too long.

Cushman and Wakefield 2008 UK Cities Monitor survey

How can plants be used as part of a green building management system?

Interior plants have a number of roles to play within a green building. Some effects are large and, if required, need a great deal of planning as they become an integral part of a building's fabric. Other benefits can be obtained with the minimum of effort, although the effects may be

on a smaller scale. Whatever the effort involved, however, one thing is certain - the building will be greener in more ways than one.

Over the next few pages, three major themes will develop: the effects of plants on indoor climate, air quality and noise reduction. We will start with benefits that work best on large scale, relatively complex installations that require planning, project management and some construction considerations. We then consider progressively simpler solutions that can be added at the fit-out or even post-occupancy stage.

Cooling a building by shading with plants

At the extreme, interior plants are the basis of a system known as 'Green Solar Architecture', pioneered in Germany by Dieter Schempp. In this system, the interior climate is regulated with the plants, which are chosen for their survivability in the indoor environment, and which also guarantee good air quality and humidity regulation, especially in the winter when the plants can help maintain the ideal relative humidity of 40% to 60%.

This concept requires a great deal of planning and interdisciplinary cooperation. Building engineers take part and contribute their specialist knowledge, for example planting must be designed and carried out with lighting, water and drainage specialists. The plants are selected to include a proportion of species that shed some of their leaves in winter, which allows more solar energy into the building for heating, whilst in summer they grow to provide shade and contribute to cooling by evapotranspiration. Indoor trees, which can be as large as 8 m (25 feet) tall, can cast shadows and shade windows much more cost-effectively than complex manufactured and engineered products (*Fig. 1*). In practice, temperature reductions of the order of 2 °C - 3 °C (4 °F - 5 °F) below the outside temperature have been achieved. This is a result of the combination of interior planting, the mass of the building and air exchange in summer through ventilation openings in the building facades.

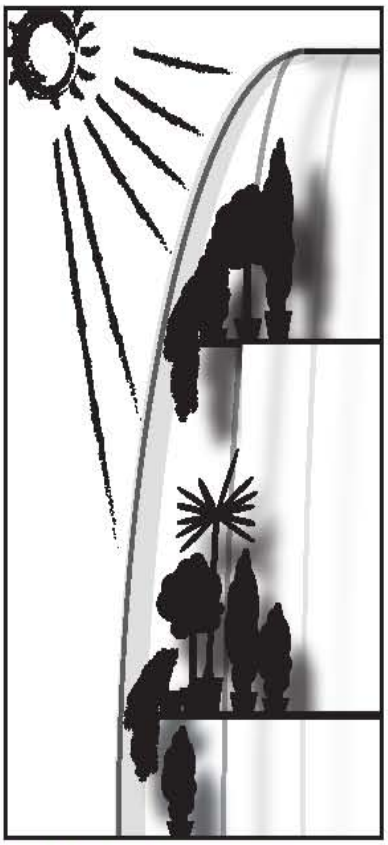

Fig. 1: shading effects of plants

Even without going to the levels of designing a building along Schempp's lines, interior plants can be used very effectively to cool buildings. Available in almost any form, from tall palms with feathery fronds to densely-canopied trees and bushes, interior plant displays can be designed to cast as much or as little shadow as you need. By taking advantage of the variety of heights and forms of plants, it is possible to create light or heavy shade at any time of day and during all seasons. The natural ability of plants to orient their foliage towards a light source will help to ensure that direct sunlight is intercepted by the leaves. Dappled, diffused light will make its way to the inside of the building adding atmosphere and interesting shadows to complement the visual appeal of the plants themselves.

The shading benefits of plants can be exploited in all types of building and location. Small plants near windows can obviate the need for blinds and still provide the benefits of a view. In atriums and other highly glazed spaces, large plants and trees can be used to replace manufactured products such as brise soleils and provide other indoor climate benefits such as cooling through evapotranspiration (see below) and improving air quality (see page 6).

Cooling and humidifying buildings through evapotranspiration

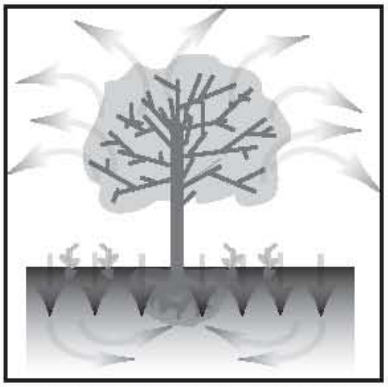

Fig. 2: flow of water through a plant display, from irrigation water through the soil and transpired by the plant resulting in cooling of the air.

Evapotranspiration is the process by which water moves from the soil, via the plant (and from the soil surface) into the atmosphere through evaporation and transpiration. Almost all of the water given to a plant will be released into the air during the time that plants are actively photosynthesizing. The rate of evapotranspiration is governed by light levels, temperature, relative humidity, air movement and plant species and plant size.

As water evaporates in the air, cooling takes place as heat energy is used to drive the process (*Fig. 2*). The precise scale of the

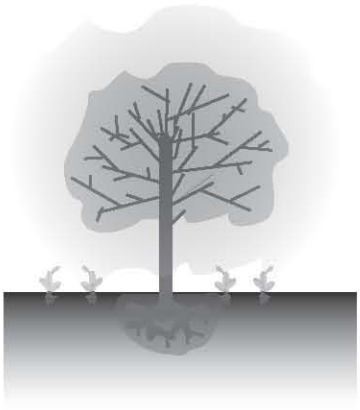

Fig 3: localized humidification around the canopy of a tree.

effect is difficult to predict indoors as factors such as air flow vary considerably - there may be localized areas of high air flow and others of relative stagnation, and such air may be a mixture of fresh and recirculated air.

Nevertheless, large-scale interior planting in atriums will have a measurable effect on temperature as has been demonstrated in a large number of tall buildings around the world and with those buildings constructed according to Schempp's 'Green Solar Architecture' principles.

Plants can also help to keep the air in buildings fresh and at the optimum humidity level of between 40% and 60%. (*Fig. 3*) In large-scale schemes, such as those that are built in to a building's fabric, the effect can be quite large. However, in many situations, especially those buildings equipped with air-conditioning systems, the effect is often small and localised as any excess humidity is often quickly removed.

Humidification by transpiration (the transport of water through the plant, from root to leaf and out into the atmosphere) is governed by species, light levels, humidity and temperature. The more active the plant is, the greater the transpiration rate. Conversely, plants that are under stress, e.g. under attack by pests, or too dry, often reduce transpiration by closing the pores (stomata) in their leaves. The greatest benefit is therefore derived from healthy, well-maintained plants. The second mechanism is evaporation from the soil, which has a localised humidifying effect. Dry air tends to be a bigger problem in the winter months, when ventilation from the outside (even if available) is reduced and heating turned up.

Although interior landscaping won't completely solve a dry air problem, it can make a useful contribution, especially if plants are sited near to where people work. Experimental data from several studies over the last few years has shown that interior plants can increase humidity in offices by as much as a fifth.

Reducing dust with interior plants

Research in the USA has shown that buildings with interior plants have less airborne dust than those without. The research (carried out by Virginia Lohr and Caroline Pearson-Mims) suggests that the accumulation of particulate matter on horizontal surfaces in interiors can be reduced by as much as 20% by adding foliage plants. Their experiments did little to explain the precise mechanisms at work, although increased humidity and electrostatic effects seem to be implicated as possible mechanisms, by which particulate matter is can be reduced by attraction and adherence to leaf surfaces. (*Fig 4*) This keeps offices cleaner, reduces the risk of allergies and helps to protect sensitive electronic equipment. It is even reasonable to suggest that levels of airborne particles such as fungal and bacterial spores will also be reduced, further enhancing air quality and hygiene (and countering some of the objections of using plants in health care environments). However, the ability of plants to remove dust is limited, and will depend on the number of plants installed and the level of dust present.

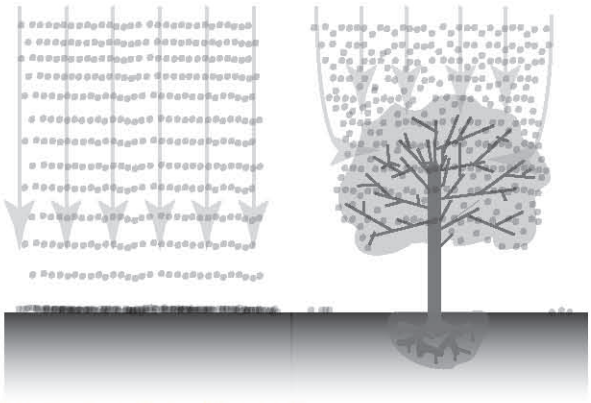

Fig 4: interior plants differentially attract dust.

'... experiments documented that the accumulation of particulate matter on horizontal surfaces in interiors can be reduced by as much as 20% by adding foliage plants.'

from 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, No. 14,.

Carbon dioxide reduction

Elevated concentrations of carbon dioxide are known to induce drowsiness and the consequent reduction in concentration and productivity. Unless indoor air can be continuously refreshed, human activity in modern, well-sealed buildings can result in surprisingly high levels of carbon dioxide. Plants naturally extract carbon dioxide during photosynthesis and replace it with oxygen, thus reducing carbon dioxide concentrations and increasing oxygen levels. Research to date suggests that bushy plants with a high photosynthetic rate are particularly effective in the presence of light, whereas succulent plants from hot arid areas, especially those in the Crassula family, are more

effective at night due to their particular way of assimilating carbon dioxide during the cool of the night.

"We found that potted-plant presence was associated with significant reductions in both CO_2 and CO concentrations 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."

from: Tarran, J., Torpy, F. and Burchett, M (2001). Proc 6th Int. Conf. on Indoor Air Quality, Ventilation & Energy Conservation in Buildings.

As a general rule, the capacity of plants to remove carbon dioxide is determined by their ability to intercept light. Factors such as leaf size, overall height, position in the office, orientation of the office, and the position of the sun during the day (or season) are key factors in determining the photosynthetic rates of plants and their subsequent value in buildings.

Precise calculations on the capacity of interior plants to remove carbon dioxide are difficult due the large number of variable factors. However, using some very conservative estimates, we believe that at least 300g (10 oz) of carbon dioxide (net of that released through plant metabolism) can be removed from the atmosphere for every square metre of leaf surface per year in typical interior conditions. (This equates to approximately 170 litres, or 6 cubic feet, of CO_2 gas) In brighter conditions (such as in an atrium), using the most actively photosynthesizing plants, much more would be possible.

Whilst it may be possible to use such a fixation of carbon as part of a measured carbon footprint reduction programme, there are a number of caveats and confounding factors to include in the calculations, such as the complexities of calculating a full lifetime analysis of carbon assimilation by the plant, against the resources used during its growth and preparation for use as an interior landscape plant and its subsequent disposal at the end of its life.

Indoor air pollution

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 indoor air quality.

from: Tarran, J., Torpy, F. And Burchett, M (2001). Proc 6th Int. Conf. on Indoor Air Quality, Ventilation & Energy Conservation in Buildings.

The work of Bill Wolverton, both during his time with the National Aeronautics and Space Administration (NASA) and afterwards, is among the most frequently quoted in plant benefits research. He showed that plants can absorb pollutant gases such as formaldehyde, benzene and trichloroethane, which are released in small quantities by

a whole range of materials and human activities. Most of his research on these so-called volatile organic compounds (VOCs) was carried out on plants grown in optimum conditions on a small laboratory scale, which until recently had little support from the scientific community who wanted to see data taken inside real buildings with sensible planting densities, realistic light levels and air exchange rates.

" ...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."

from: Tarran, J., Torpy, F. And Burchett, M (2001). Proc 6th Int. Conf. on Indoor Air Quality, Ventilation & Energy Conservation in Buildings.

Such data are now being produced and published, not least the work carried out by Dr Ron Wood, Professor Margaret Burchett and others in Australia. Their experiments, in real offices, have shown that several common species of interior landscape plants have the ability to remove compounds such as benzene and hexane, sometimes in the order of a 50% - 75% reduction in concentration of total volatile organic compounds. It appears that there is an interaction between the plant roots and soil microbes. What's more, these effects have been observed at planting densities in offices that are both practicable and affordable - indoor jungles are certainly not required.

So powerful are the new data that the authors are brave enough to assert that *"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 indoor air quality."*

Acoustic benefits of interior plants

Interior plants have an impressive ability to multi-task. As well as looking beautiful, we have shown that they improve indoor air quality and help regulate the indoor environment. One other important benefit is their ability to reduce noise levels in buildings, reducing the need for expensive (and often ugly) manufactured acoustic panels.

Our own research, and that carried out by scientists at South Bank University in London, indicates that plant displays are effective

at absorbing, diffracting and reflecting sound. The balance varies with the frequency at which the sound is generated and the room's physical properties. The type of plant, its size, shape, the container, top dressings and the compost all have an effect on the sound reduction capabilities of plant displays. The following table shows how a wide variety of indoor plants can absorb sound at different frequencies.

	Table of Absorption Coefficients [1]					
	Sound Frequency					
Plant Species	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
Ficus benjamina	0.06	0.06	0.10	0.19	0.22	0.57
Howea forsteriana	0.21	0.11	0.09	0.22	0.11	0.08
Dracaena fragrans	0.13	0.14	0.12	0.12	0.16	0.11
Spathiphyllum wallisii	0.09	0.07	0.08	0.13	0.22	0.44
Dracaena marginata	0.13	0.03	0.16	0.08	0.14	0.47
Schefflera arboricola	-	0.13	0.06	0.22	0.23	0.47
Philodendron scandens	-	0.23	0.22	0.29	0.34	0.72
Comparisons						
Bark mulch	0.05	0.16	0.26	0.46	0.73	0.88
Thick pile carpet	0.15	0.25	0.50	0.60	0.70	0.70
Plasterboard	0.30	0.15	0.10	0.05	0.04	0.05
Fresh snow, 100 mm (4")	0.45	0.75	0.90	0.95	0.95	0.95

[1] An absorption coefficient of 1 means that 100% of the sound (at the stated frequency) is absorbed, whereas a coefficient of 0.15 means that 15% of the sound (at the stated frequency) is absorbed.

Data produced by Peter Costa (South Bank University, London) in 1995 as part of series of experiments carried out for Rentokil Research and Development

As well as absorption, plants affect room acoustics by diffraction and reflection, particularly at lower frequencies. This works because the leaf size of indoor plants is small by comparison to the wavelength of the noise. Plants with lots of small leaves are useful as they scatter and diffuse sound. At higher frequencies the leaves may reflect sound towards other surfaces that may then absorb the noise.

So, how can you practically use plants to reduce noise? First, use large plant containers. These contain more compost and have a greater area of top dressing, both of which have a significant effect

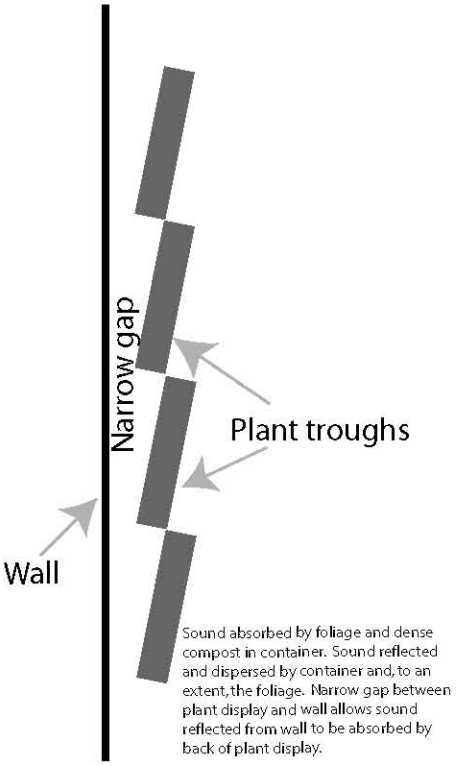

Fig. 5: possible sound-absorbing arrangement of plants.

Fig. 6: screen plant display in an open-plan setting.

on noise reduction in their own right, so it follows that they make a larger impact on the room acoustics. It will also be possible to get larger plants, or several plants into the container as well.

Secondly, use a mixture of different plant species and sizes. Experiments have shown that arrangements of different plants in groups appear to work better than individual plants and that several small arrangements are better than one big one.

Next, position several arrangements around a space rather than concentrate them in one location. In this way the surface area of the plants exposed to noise may be maximized and individual work areas in an office space will all benefit from a localized effect.

Edges and corners are better than the centre. Plants placed near the edges and corners of a space are better than plants in the middle. This is because sound is reflected from the walls straight into the foliage. Troughs and barrier planters should be placed a few centimetres (inches) away from the wall, so that they can absorb reflected sound from the wall as well as sound reaching them directly. Angling them slightly away from being parallel with the wall will also help to disperse reflected sound. (*Fig.* 5)

Finally, consider using screen plants instead of office partitions. (*Fig.* 6) Open-plan offices are often very noisy places. The hum of computers, the ringing of telephones and the buzz of conversation all make for a surprisingly noisy environment. Often these spaces are divided up with partitions or ranks of filing cabinets. Acoustic panels can be used, but these can be expensive, whereas plant screens and barrier arrangements can be an effective alternatives, cheaper and able to contribute to the environment in more than one way.

Providing a view of nature

Finally, interior plants have a unique ability - not just a replacement for manufactured or engineered solutions, but a direct replacement

for nature itself. A bold claim indeed, but one that can be made with confidence in the context of green buildings.

Access to views of nature for office workers is both desirable and a recognised best practice - indeed, access to views features in several green building rating schemes. However, it is not always possible, especially in buildings with a deep floor plan or in new buildings that they may be constructed with fewer windows to reduce heat loss (also something that may feature in a rating system, although how this contradiction can be reconciled is never made clear.)

Fig. 7: large-scale interior landscaping used as a substitute for an exterior view.

One solution would be the provision of good quality interior landscaping, which can be employed to provide substitute views by giving people access to an indoor garden or views of vegetation, especially if there is an atrium or other large space. (*Fig 7*) By adding full-spectrum lighting, a combination of plants and artificial daylight can help overcome some of the problems of lack of access to natural daylight and may even counteract some of the problems associated with Seasonal Affective Disorder.

What about the lack of formal credits for interior plants?

We have clearly demonstrated that interior plants have a useful role in green buildings - their use can reduce energy needs directly through their ability to cool buildings and also reduce the reliance on energy-intensive systems and products by their abilities to improve indoor air quality and reduce noise. Not only that, they achieve all of these feats with the minimum of maintenance and with a production system that, compared with product manufacturing, is achieved with very low inputs.

In the UK and USA, it is possible to make reasoned arguments to green building rating assessors that the use of plants fulfils some of a developer's requirements to minimize energy consumption and

A few things to remember about using plants in green buildings

- Most of the environmental benefits of plants can be obtained without the requirement to specify unusual or expensive plants.
- The costs of installing and maintaining plant displays are a minute fraction of the annual running costs of a typical commercial building.
- Plants that are absorbing noise will be improving air quality and removing dust at the same time.
- Existing buildings can be made more sustainable with plants without the need for large-scale capital expenditure.
- Interior plants don't need drinking water - they can be irrigated with grey water or rain water, so you won't be increasing your demand on metered potable water.
- For best results, interior plants need to be cared for by competent people. The benefits of interior plants diminish rapidly if they are neglected.
- Interior plants have very low requirements for inputs of fertilizers and they can be grown in environmentally-friendly composts.
- There are interior plants available that will thrive in all interior conditions - your interior landscape objectives can be met without the need for additional light, heat or cooling resources.
- For new buildings, architects and developers should discuss interior landscaping proposals in plenty of time. Large-scale planting requires a degree of project management expertise and an understanding of the time scales required to source, acclimatize and install large trees.

provide alternatives to manufactured goods and engineered systems. However, such arguments have to be made on a case-by-case basis and will be subject to the whims, prejudices or knowledge of the assessors. Without wishing to disparage the professionalism of green building rating assessors, there is a gap in their education, and that of the people who devise the schemes.

The Australian Green Building Council has formally recognised the value of interior plants and will give credits for their installation and ongoing maintenance. However, whilst this is a welcome recognition of the value of interior plants, it is possible that in some buildings (such as those designed with plants in mind from the outset), the award of a limited number credits fails to recognise the total green building value of the plants.

Conclusions

Interior plants can no-longer be considered a luxury. They are a demonstrably valuable and cost-effective way of enhancing the indoor environment by improving indoor air quality, cooling the building and reducing noise. Building operators can make existing buildings more environmentally friendly simply by replacing, or reducing the need for manufactured products and engineered systems with plants. Architects can make an even bigger impact by designing buildings with plants in mind, making buildings green in more ways than one.

There is a powerful set of arguments for the inclusion of plants in green building rating systems. How such a contribution can be quantified in such a system will require a great deal of thought. The inclusion of plants in the Australian Green Building Council's 'Green Star' rating system is a good start, but refinement and development of the concept in LEED and BREEAM would really give the benefits of interior plants the visibility they deserve.

About the author

Kenneth Freeman is Ambius's International Technical Director, based in London. An expert in interior landscaping, he has been directly involved in all aspects of research into the benefits of interior plants as well as the development of horticultural best practices. He has developed a range of education and training programmes and is the author of continuing education programmes for architects in the UK as part of the Royal Institute of British Architects Continuing Professional Development Core Curriculum and in the USA as part of the American Institute of Architects Continuing Education System.

E-mail: kenneth.freeman@ambius.com
Telephone: +44 (0) 7789 273478

About **Ambius**

Ambius is the global leader at enriching work places. Our services create harmonious surroundings that improve well-being, productivity and enhance brand image.

We are the world's largest interior landscaping company, with businesses in 18 countries in Europe, North America, South Africa and the Asia-Pacific region. Depending on where you live, Ambius can also offer additional services such as exterior landscaping, seasonal and holiday decorating, corporate art, ambient scenting and fresh fruit and flower deliveries.

Ambius is backed by unmatched technical resources, collaborative research with leading universities and the combined expertise of some of the worlds most knowledgeable and experienced people, as well as the resources of the world's leading business services company - Rentokil Initial.

Ambius is ethically and environmentally aware. We are members of the UK Green Building Council, the US Green Building Council and the Australian Green Building Council. We are committed to improving the environment with our services and are actively working at reducing our own environmental footprint.

Full details of our services, values and vision can be found on our web site: **www.ambius.com** .

Ambius White Papers are published by Ambius University

Ambius
485 Half Day Road
Suite 450
Buffalo Grove, IL 60089
USA