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Feature from **Environmental Building News**
October 1, 2008

Bringing Nature Indoors: The Myths and Realities of Plants in Buildings

An **Executive Summary** is available for this article.

They maintain humidity, increase productivity, and reduce stress. They even scrub the air of dangerous chemicals. Whatever problems we create for ourselves in our buildings, plants are there to help cure them. Or are they? Although some promising studies have led to glowing accounts in the popular press, scientific study of the role of plants in the indoor environment is still young.

Studies supporting the use of plants for cleaning indoor air come with serious caveats, and some indoor-air experts argue that plants may do more harm than good. At the same time, there is both scientific and anecdotal evidence that plants can improve workplace and household conditions. People like having plants around.

Despite their widespread use, plants are an afterthought in most buildings—a decoration to be considered, along with hanging pictures, after the building is already designed and even built. Interior landscapers, as well as building scientists, suggest that considering plants earlier in the design process and educating building owners and tenants are necessary to maximize the benefits of indoor plants while minimizing the risks of moisture and air quality problems.

Plants and the Indoor Environment

The most widely touted claims for indoor plants focus on their ability to clean the air of harmful chemicals, particularly volatile organic compounds (VOCs). Although these claims don't yet have solid scientific backing, some studies have shown promising results. If proven, the ability of plants to clean the air could result in less demand for ventilation, leading to lower energy use by mechanical systems, although this benefit could be offset by the need for those systems to handle the added moisture load from large planters or hydroponic systems.

Cleaning the air

Most claims for the ability of plants to clean the air stem from research conducted in the 1980s by a group of scientists at the National Aeronautics and Space Administration (NASA) led by B. C. Wolverton, Ph.D. The research was jointly funded by NASA and the Associate Landscape Contractors of America (now the Professional Landcare Network), and explored the potential of plants to clean indoor air on Earth and in space. Wolverton and his team put plants in sealed plastic chambers in various configurations and injected one of three chemicals—formaldehyde, benzene, or trichloroethylene—commonly found in indoor air. After 24 hours, they measured the concentration of the test chemical in the chamber and found that 10%–90% of pollutants had been removed, depending on the chemical present and the plant used.

Wolverton and his team then attempted to isolate the part of the plant that was cleaning the air. Defoliated plants removed slightly less of a chemical from the air than plants with leaves left intact, but more than soil alone. This led the researchers to believe that the interaction between the plant roots and the soil microbes was important to chemical removal. They developed a system with a fan that drew air through both an activated carbon filter and the plant's soil, and found that

The indoor gardens at the Genzyme Center provide informal meeting spaces for occupants.

this significantly increased the rate at which a plant could clean the air.

Wolverton's results were promising, but subsequent analysis has diminished that promise. Alan Darlington, Ph.D., of the Canadian company Nedlaw Living Walls, tried unsuccessfully to replicate Wolverton's results as part of his doctoral work at the University of Guelph. And according to Hal Levin, a research architect and indoor air quality consultant, the study does not reflect real-world conditions in buildings. "A dynamic test involving an air-change rate equal to those in real buildings and achieving steady-state conditions [of chemical concentrations] is a far more relevant test," he told *EBN*. In a real building, VOCs are released over a period of time, not all at once as in the study, and air moves through the space and mixes with fresh outside air. Wolverton's study, and many based on it, fail to take these dynamics into account.

Even if plants respond to airborne toxins in a building the way they did in Wolverton's study, filtering an entire building would take an enormous number of plants. According to calculations performed in the early 1990s by John Girman at the U.S. Environmental Protection Agency, it would take 680 plants in a 1,500-ft^2 (140-m^2) home to achieve the level of filtration found in the Wolverton study. A 1999 Australian study by Peter Dingle, one of a handful to study plants in real-life conditions, came to similar conclusions. Dingle placed a mixture of large and small plants in 88-ft^2 (8.2-m^2) portable offices with high levels of formaldehyde and then measured the concentration of the chemical over time. Dingle did not find reductions in the chemical until 20 plants were present, when there was an average 11% reduction in formaldehyde levels. The study suggests that relying on potted plants for air filtration in a home or office is impractical: it would take an average of 0.2 plants per square foot (2.4 plants/m^2) to replicate Dingle's results.

The Genzyme Center's 12-story atrium creates optimal conditions for the building's 18 indoor gardens.

Although the research on potted plants as air filters is inconclusive, studies of more sophisticated biofilters are more promising. Darlington's company, which grew out of his research at the University of Guelph, has developed a hydroponic living wall in which water is filtered through a growing medium while fans draw air through the root zone of the plants, exposing it to the microbes believed to be responsible for filtering air. According to Darlington's

Extensive indoor gardens at the IBN Institute for Forestry and Nature Research in the Netherlands contribute to humidity control and indoor air quality.

measurements, up to 80% of contaminants can be removed from indoor air, with 30%–60% being a more likely removal rate during normal operation. Another study of similar systems found that a biofilter removed around 20% of formaldehyde in a single pass of air through the filter and lesser amounts of other VOCs. However, study of these systems is only beginning, and it is too soon to know how effective they will be in the long term. Another challenge is that the systems are not able to process high enough volumes of air to be effective as replacements for ventilation with outside air.

Cleaning the water

The principles of biofiltration can also be used to treat wastewater on site. Instead of using chemicals, these hydroponic systems use plants as well as bacteria, fungi, snails, clams, and fish to break down organic matter and other pollutants. In many places, the treated water from these systems is reused within the building to flush toilets or irrigate landscaping (see *EBN* Vol. 5, No. 4).

Reducing the need for ventilation

Some argue that the use of plants as air filters has the potential to save energy by reusing inside air instead of conditioning outside air for ventilation. Darlington has modeled his living wall systems for energy performance and, although he has yet to measure their performance as installed, he believes the systems reduce the need for outside air by as much as 4–8 cubic feet per minute (2–4 l/s) per person, which in turn saves heating and cooling energy. Even with its fans running, the living wall and a mechanical system that conditions recycled inside air could use up to 90% less energy than heating or cooling outside air in some conditions. The system also provides humidification, particularly helpful in the winter in cold climates; of course, in warmer climates, that added moisture could require dehumidification, increasing energy use.

Risks to indoor air

There are potential problems with introducing large numbers of plants into buildings, especially with hydroponic systems. “There is a substantial risk of moisture-related problems including but not limited to mold in buildings with extensive plantings,” according to Levin, who added that moisture has been linked with asthma and allergy problems among occupants. The amount of water that evaporates through plant foliage (*transpiration*) increases with light levels and temperature, and also with decreased humidity. A study by the Canada Mortgage and Housing Corporation of sources of moisture in homes found that indoor plants release about 0.13 gallons (0.50 l) of moisture per week per plant.

Another risk from indoor plants is exposure to insects and the pesticides used to control them. Overly moist soil and standing water provide habitat for mosquitoes, sciarid flies, and cockroaches, and all plants provide food for aphids. One way to control these pests is through chemical use, particularly in North America, where more chemicals are approved

This large atrium in the Terrence Donnelly Center for Cellular and Biomolecular Research at the University of Toronto provides natural daylight for the large trees planted there.

for indoor use than in Europe and other parts of the world. Kenneth Freeman, of the international indoor landscaping company Ambius, maintains that "the risk of accidental exposure is very low" because most pesticides used in the U.S. are applied directly to the soil instead of being sprayed on foliage. In Europe, where such pesticide use is less common, plant maintenance companies (including Ambius) focus on cleaning and pruning plants to keep them healthy, using nonchemical pest-management strategies and replacing diseased or damaged plants when necessary. "Without pesticides, you learn a whole range of techniques that make the plants healthier," Freeman said.

Plants and Occupant Well-Being

Indoor plants are often touted for their ability to increase productivity and feelings of well-being among occupants, and studies looking at this issue have had promising results. Much of the research in this area has been funded by the indoor landscaping industry, however. It can also be difficult to separate the effects of plants from those of the conditions conducive to plant growth: daylighting and moderate temperatures and humidity. It is also unclear whether plants offer any advantages over views of nature through windows, paintings, or photographs.

Increasing productivity

Only a few studies have looked directly at the effects of plants on productivity, and all have focused on office workers. In 1995 and 1996, a team of researchers led by Tove Fjeld, Ph.D., at the Agricultural University of Norway performed a controlled study in the offices of a Norwegian oil company. The study involved 51 employees divided into two groups; all of the employees worked in identical 107-ft^2 (10-m^2) offices with large windows along one wall. Researchers placed several plants—13 small plants along the window and one larger planter by the door—in half of the offices for three months. They surveyed occupants before, during, and after the experiment, asking about health and concentration. Many participants reported improvements in their symptoms after the addition of the plants; improvements in these symptoms likely increased productivity, although that was not measured (see table). The plants were then moved to the offices of the other half of the participants and the experiment was repeated, with similar results.

PLANTS IN THE WORKPLACE IMPROVE HEALTH

Symptom	Score Before Plants*	Score After Plants*	Percent Improvement
Fatigue	0.82	0.58	29
Heavy-headedness	0.71	0.58	18**
Headache	0.33	0.27	18**
Dizziness or nausea	0.27	0.22	19**
Concentration problems	0.50	0.42	16**
Eye irritation	0.70	0.59	16**
Nasal symptoms	0.60	0.43	28**
Throat irritation	0.83	0.62	25
Cough	0.38	0.24	37
Facial-skin irritation	0.88	0.68	23
Scalp or ear irritation	0.56	0.51	9**
Hand-skin irritation	0.52	0.50	4**

*Average scores on a scale of 0–3, with 0 representing no symptoms and 3 representing severe symptoms
** Difference considered not statistically significant

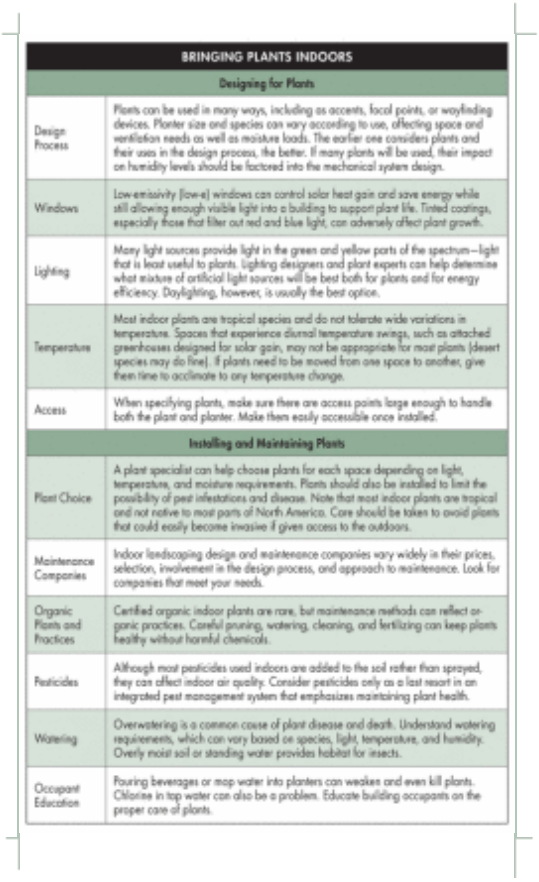
Fjeld hypothesized that the positive effect of the plants was due to both psychological effects and increased air quality. "The presence of plants can probably result in a positive change in the psychosocial working environment," Fjeld wrote about her research for the organization Plants for People. "The resultant feeling of well-being also affects how the individual assesses his or her state of health." This increased feeling of well-being is reinforced, in Fjeld's opinion, by improved air quality due to the presence of plants (her research did not include air-quality measurements). Fjeld followed her experiment with a questionnaire about the plants themselves and found that 56% of the participants thought the plants took up a lot of room, but only 11% felt that the plants had caused problems in the workplace. The majority of participants believed that the plants had contributed to better indoor air quality and reported that they felt more comfortable with the plants; the majority also suggested that plants be used in the office in the future. Only one participant (out of 51) felt that plants should not be used in the office.

Another study, by Virginia Lohr, Ph.D., of the horticulture department at Washington State University, looked at how plants affect people performing a timed computer task in a windowless room. Participants answered questions before

and after the task, and their blood pressure was measured throughout the experiment. Participants with plants in the room reported feeling slightly more attentive than those in a room without plants. The group with plants also showed smaller increases in blood pressure during the task and greater decreases in blood pressure after the task than the other group.

Researchers at the Center for Building Performance and Diagnostics at Carnegie Mellon University have incorporated these two studies (and others) into their Building Investment Decision Support (BIDS) program, a case-based decision-making tool that calculates the economic value of investments in green building strategies. Their results show that, assuming the findings of these studies are valid, the return on investment for plants is quite high, given the low initial costs of plants and the high costs of employee salaries. For example, to replicate Fjeld's findings in a typical office with 500 employees with an average salary of $45,000 would take around $98 per employee to purchase plants and $60 per employee annually to maintain them. Assuming a 2.3% improvement in productivity per employee, the annual savings would work out to $975 per employee, a return on investment of 995%. (For more on productivity, see *EBN* Vol. 13, No. 10.)

Simulating nature



BRINGING PLANTS INDOORS

Designing for Plants	
Design Process	Plants can be used in many ways, including as accents, focal points, or wayfinding devices. Planter size and species can vary according to use, affecting space and ventilation needs as well as moisture loads. The earlier one considers plants and their uses in the design process, the better. If many plants will be used, their impact on humidity levels should be factored into the mechanical system design.
Windows	Low-emissivity (low-e) windows can control solar heat gain and save energy while still allowing enough visible light into a building to support plant life. Tinted coatings, especially those that filter out red and blue light, can adversely affect plant growth.
Lighting	Many light sources provide light in the green and yellow parts of the spectrum—light that is least useful to plants. Lighting designers and plant experts can help determine what mixture of artificial light sources will be best both for plants and for energy efficiency. Daylighting, however, is usually the best option.
Temperature	Most indoor plants are tropical species and do not tolerate wide variations in temperature. Spaces that experience diurnal temperature swings, such as attached greenhouses designed for solar gain, may not be appropriate for most plants (desert species may do fine). If plants need to be moved from one space to another, give them time to acclimate to any temperature change.
Access	When specifying plants, make sure there are access points large enough to handle both the plant and planter. Make them easily accessible once installed.
Installing and Maintaining Plants	
Plant Choice	A plant specialist can help choose plants for each space depending on light, temperature, and moisture requirements. Plants should also be installed to limit the possibility of pest infestations and disease. Note that most indoor plants are tropical and not native to most parts of North America. Care should be taken to avoid plants that could easily become invasive if given access to the outdoors.
Maintenance Companies	Indoor landscaping design and maintenance companies vary widely in their prices, selection, involvement in the design process, and approach to maintenance. Look for companies that meet your needs.
Organic Plants and Practices	Certified organic indoor plants are rare, but maintenance methods can reflect organic practices. Careful pruning, watering, cleaning, and fertilizing can keep plants healthy without harmful chemicals.
Pesticides	Although most pesticides used indoors are added to the soil rather than sprayed, they can affect indoor air quality. Consider pesticides only as a last resort in an integrated pest management system that emphasizes maintaining plant health.
Watering	Overwatering is a common cause of plant disease and death. Understand watering requirements, which can vary based on species, light, temperature, and humidity. Overly moist soil or standing water provides habitat for insects.
Occupant Education	Pouring beverages or mop water into planters can weaken and even kill plants. Chlorine in tap water can also be a problem. Educate building occupants on the proper care of plants.

It is not clear whether plants offer an advantage over views or depictions of nature, in part because the air-cleaning effects of plants remain unproven and in part because scientists still don't fully understand the connection between humans and nature. Research on the effect of nature in the healthcare field has found that patients with a view to a natural landscape outdoors had faster recovery rates and used less pain medication than those with a view of a brick wall. Other research has focused on depictions of nature—photographs or paintings—and has found similar results (see *EBN* Vol. 15, No. 7). Little research has compared results from views of nature with those from depictions of nature or indoor plants, however.

Similarly, no studies have been done to compare real with artificial plants, but Judith Heerwagen, Ph.D., a psychologist who focuses on the relationship between humans and nature, believes there might be benefits to the real thing. "Real plants show several features that separate them from artificial plants, and these may be important—growth, change over time in blossoming and budding, and problems if the plants are not properly attended to," she said. Change over time—in this case, a cycle of growth and dormancy—is one of the principles of biophilic design, which attempts to foster humans' inherent connection to the natural world. Although views of nature provide that connection, "plants are reminders that a place is supportive of human life," according to Heerwagen, and may make that connection stronger and more visceral.

Plants and the Design Process

"A lot of architects don't think enough about plants in buildings," said Kenneth Freeman of Ambius. Plants in most buildings are added as an afterthought or brought in by occupants to decorate their workspaces and common areas. For hydroponic biofiltration or wastewater systems, early consideration in the design process is key. "It's critical that we're there at the design phase," said Darlington. He noted that, although adding a living wall or simple plantings to an existing building is possible, certain aspects of building design are hard to retrofit. Daylighting, temperature, and humidity are all affected by building orientation and the design of mechanical systems, which must take plants into account to function properly.

Integrating plants into building design is becoming more common, particularly in the healthcare field but also in office buildings and some homes. Plenty of interior landscape companies offer plant installation, rental, and maintenance options at different price points. Many companies maintain lists of species and information on plant requirements on

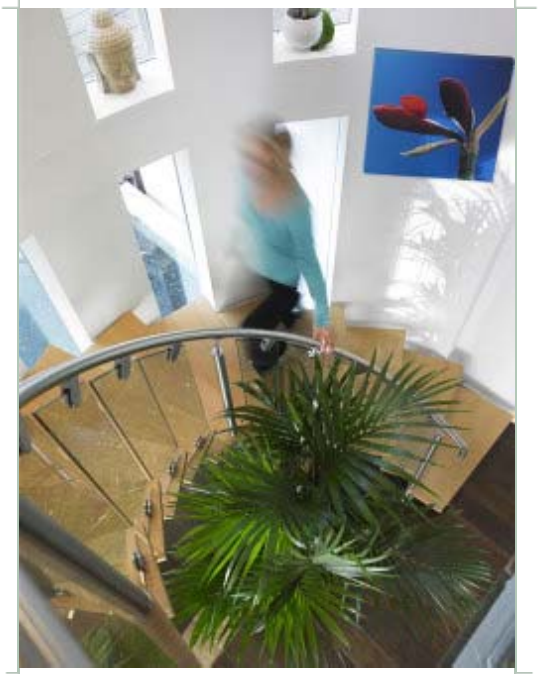
their websites. Nonprofit organizations such Green Plants for Green Buildings offer lists of these companies as well as summaries of much of the scientific research on indoor plants and case studies of buildings that have used plants effectively.

The Genzyme Center in Cambridge, Massachusetts, is one example of such integration (see case study in *BuildingGreen Suite*). Architecture firm Behnisch and Behnisch sought to create a healthy and productive environment by designing the building from the inside out. A 12-story, daylit atrium fills the building with natural light, and most workspaces have views of the outdoors. The firm also incorporated into the building 18 indoor gardens, which serve as informal meeting spaces and relaxation spots for employees. With more space devoted to these common areas, private offices are smaller, promoting communication and teamwork among employees of the biotechnology company.

Although flowering plants provide color, they can require more care than nonflowering species. Variegated foliage can also be used to bring color to a space.

For architect Stefan Behnisch, plants are integral to the design process. “The interior gardens are not an afterthought; they are integrated in the concept right from the beginning, they are part of the design philosophy,” he said. In some buildings, such as the Genzyme Center, the gardens serve a primarily aesthetic function, and the changes to the building’s design and mechanical systems are slight. In other buildings, such as the IBN Institute for Forestry and Nature Research in Wageningen, the Netherlands, “the gardens are the climatic lung of the building, the breathing apparatus,” said Behnisch. In those cases, Behnisch works closely with landscapers as well as engineers from early in the process to make the space appropriate for both people and plants. This is not as hard as some people imagine, Behnisch argues. “You just have to pick the right plants, ideally plants that have a natural habitat that is as close as possible to what you experience in buildings,” he said.

Final Thoughts



Plants are amazing—using sunlight, water, and available soil nutrients they grow, reproduce, absorb carbon dioxide, and generate oxygen. Outdoors, they not only provide habitat for myriad species but also serve as the lungs of the Earth. Indoors, they may not be quite the superheroes the popular press makes them out to be, but they certainly appear to be beneficial. Whether they contribute meaningfully to indoor air quality or not, plants appear to provide a psychological boost to building occupants that leads to increased feelings of well-being and productivity. Making plants part of the design process and making sure they are appropriately maintained and well cared for is vital to harnessing those benefits.

– Allyson Wendt

For more information:

Ambius
www.ambius.com

Building Investment Decision Design Tool
Carnegie Mellon University
cbpd.arc.cmu.edu/bids/

Green Plants for Green Buildings
www.greenplantsforgreenbuildings.org

Sidebar: The Myth of Oxygen-Stealing Plants

Plants in a closed bedroom will steal oxygen from the air, suffocating you while you sleep. True or false?

Plants carry out photosynthesis during the day, using sunlight to turn carbon dioxide and water into sugars and oxygen. At night, however, most plants do the opposite and, like humans, consume oxygen and produce carbon dioxide in the process of respiration. This process is relatively inefficient for plants, and they do not use enough oxygen to pose a threat. Plants generally take in more carbon dioxide during the day than they release at night, providing a net benefit to indoor air quality.

Sidebar: The Myth of Plant-Killing Low-E Windows

Windows with low-emissivity (low-e) coatings will adversely affect plant growth by interfering with photosynthesis. True or false?

Plants need light to grow and depend on light in the visible spectrum, especially red and blue light, for the process of photosynthesis.

Low-emissivity (low-e) windows are designed to allow as much visible light into a building as possible while controlling the flow of heat—the longer wavelengths at the infrared end of the light spectrum. The visible transmittance rating of a window indicates how much visible light will be available for plants to use. Most manufacturers offer two transmittance numbers, one for the unit as a whole and another for the glass. Low-e glass generally transmits 70%–75% of visible light, which is plenty for plant growth.

Tinted coatings, however, can interfere with plant health if they filter out the colors most important for photosynthesis: red and blue. Margaret McMahon, Ph.D., an associate professor of horticulture at Ohio State University, says that white, silver, and gray tints are best for plants, since they transmit all parts of the visible light spectrum equally. Tinted coatings that are meant for shading have low visual transmittance ratings, usually 40%–50%, and do not allow enough light through for most plants. Certain low-light species, however, might survive or even thrive in these situations.

IMAGE CREDITS:
1. Photo: Anton Grass
2. Photo: Roland Halbe
3. Photo: Christian Kandzia
4. Photo: David Cook
5. Source: Fjeld et al. “The Effect of Indoor Foliage Plants on Health and Discomfort Symptoms Among Office Workers” (1998), Indoor and Built Environment (Vol. 7, No. 4), p. 204-209.

6. (no credit)
7. Photo: McCaren Designs
8. Photo: Ambius