The plant room

One of the lessons provided by NASA research, writes Ronald Wood, is that closed environments, whether extraterrestrial or decidedly Earth-bound, can be substantially enhanced by nature’s life-support system: plants.

IN THE BEGINNING

Space missions rely totally on recycled air for breathing, because unlike building ventilation there is no possibility of outside air introduction.

Among the air revitalisation systems tested, NASA’s Advanced Life Support project successfully demonstrated the use of plants for air revitalisation for humans, and the robustness of the plant systems as part of a human life support system.

NASA has also shown that plants can be integrated into regenerative life-support systems and controlled to provide a specific desired performance.

In 1973 NASA scientists identified more than 100 VOCs in the air inside the Skylab space station. These were low-level emissions from synthetic materials recirculating in the air the astronauts breathe – air not given the natural cleansing by the Earth’s complex ecosystem.

NASA researcher Dr Bill Wolverton said that the solution was natural. “If man is to move into closed environments on Earth or in space,” Wolverton says, “he must take along nature’s life support system: plants.”

NASA commenced the subsequent experimental program Closed Ecological Life Support Systems, which was part of the preparation for the Human Exploration and Development of Space (HEDS) Mission.

As part of this project, a test at the Johnson Space Centre in Houston was conducted in a sealed chamber. The idea was to demonstrate the use of plants to provide the air revitalisation requirements of a single test subject for 15 days. A Lockheed engineer (Nigel) volunteered for the test.

The primary objectives were:

• Demonstrate the ability of a wheat crop to continuously provide the CO₂ removal and O₂ supply functions for the air revitalisation of a single human test subject for 15 days.

• Demonstrate three different methods of control of the O₂ and CO₂ concentrations for the human/plant system.

• Monitor populations of microorganisms important to human and plant health.

Eleven sq m of dwarf wheat plants consumed the CO₂ and generated O₂ equal to that required by one person over 24 hours.
WE HAVE LIFT-OFF

This test clearly demonstrated how the plant system could be managed with engineering input to achieve high-quality recycled air for astronauts to breathe. Three distinct control methods were used:

- Optimised conditions for the plants for maximum photosynthetic output – integrated physicochemical systems to complement biological air revitalisation.
- Actively controlling the level of biological air revitalisation by modulating the photosynthetic photon flux (light) to control the rate of photosynthesis.
- Passively controlling the level of biological air revitalisation by limiting the amount of available CO₂ to control the rate of photosynthesis.

Similar to conventional industrial waste gas stream air pollution control (APC) technology, the process of bioremediation results in a biochemical change as contaminants or pollutants are metabolised by micro-organisms and broken down into harmless, stable constituents, such as CO₂, water, and salts.

Biological reactors are good at treating highly complex and highly variable waste gas streams over a wide range of contaminant concentrations and loading rates, and the environmental engineering community increasingly has recognised that the use of bioreactors for the treatment of air (for removal of odours and various volatile compounds) often provides economic and operational benefits.

LIVING WALL BIOFILTER

Based on the proven technology from the NASA results and other plant-based research, environmentally active gas-phase biofilters have been developed to deliver improved indoor air quality, remove air contaminants, reduce CO₂ levels and promote the concept of best-practice indoor air quality for the health and well-being of building occupants.

A living wall biofilter is a vertical planted wall that actively draws contaminated indoor air through the planted wall. Here the photosynthesising plants and their root microorganisms break down the contaminants to simple CO₂ and water, producing clean, purified air to complement conventional HVAC air filtration.

This is a practical example of industrial ecology - an industrial process involving a closed loop where waste becomes input for new processes – as happens in nature. In an Australian first, engineering consultants Umow Lai & Associates, installed five living wall biofilters that filter the indoor air in its tenancy, complementing the conventional air filtration (see Ecolibrium, September 2009).

The pay-off is a healthy work environment with improved productivity, reduced absenteeism, and a reduction in ‘flu virus impacts, a result of the mid-range relative humidity from the planted walls.

Canadian architecture firm Diamond and Schmitt Architects has installed biowalls into a number of projects, including the refurbishment of Cambridge City Hall, with spectacular and effective results.

DESIGN IMPLICATIONS FOR ARCHITECTS AND ENGINEERS

A living wall biofilter gives the option of minimum code-compliant fresh-air rates, reducing the need for increased ventilation by filtering up to 0.1 m³/m²/sec while delivering high-quality fresh air to building occupants at low cost, either incorporated into the building’s air-handling system or as a free-standing unit.

There is no by-pass – all of the air goes through the biofilter and low pressure drop provides energy savings. The technology can have a substantial impact on the energy balance and air quality of a space, as well as reducing ventilation rates, while protecting the components of the air-handling system.

A living wall biofilter has low operating and maintenance costs relative to other filtration technologies. The water recirculation pump for a planted wall and the fan that moves the air through the system are the only two energy sinks in the system.

The kWh/m² floor area consumption for the water pump is 2, and the plenum fan is 0.2 for a total 2.2kWh/m² floor area, for an open plan biowall ventilated floor area of 450m².

For comparison, the Property Council of Australia’s best-practice existing office building tenant light and power consumption is 62.5kWh/m² for a building in operation 10 hours a day, 250 days a year.

“Indoor air quality is more than thermal comfort and humidity; it is the air that penetrates into our lungs, providing the vital life force: oxygen”

The NABERS (ABGR) 5 Star benchmark for office tenants is equivalent to 52kWh/m². Clearly, the energy consumption associated with biowalls is relatively minor, and represents minimal ongoing energy costs.

The biowall can move 0.1m³/m²/sec, and coupled with the fact that typical system pressure drops are less than 75Pa, mainly from the diffusers rather than the wall, it explains why biofilters are inexpensive to operate relative to other control technologies. The pressure drop across the mechanical filters in a typical HVAC system in a standard office building is generally less than or equal to 124Pa. The pressure drop across a HEPA filter can range from 250 – 500Pa.

Local filtration reduces unwanted gaseous pollutant and particle re-circulation, with potential improvement in productivity from breathing cleaner air, while providing protection for the HVAC components.

CLEAR AIR, MONEY SAVING

Cleaner air and money savings obviously sound like a good idea, but how can they be achieved? Reducing the ventilation rate is a good place to start.

Usually, increasing the ventilation rate is intended to improve air quality. However, irrespective of building ventilation design, ventilation rates, dilution mixing of building air, displacement ventilation with 100 per cent “fresh air”, or mixed mode, inherently polluted outdoor air combines and reacts with contaminants generated indoors, resulting in poorer air quality - even creating indoor smog in the presence of ozone (Weschler 2006).

Building outdoor air intakes less than 60m above ground level are associated
with significant increases in health-related symptoms in office workers, with 40–140 per cent increased odds of this occurring (US EPA Base Study 2008).

Current ventilation standards, based historically on non-health-related criteria, such as perception of odour, may not be health-protective (Mendell et al, 2008).

Although ventilation rates above 10l/sec-person may reduce adverse health symptoms for building occupants, it comes at the cost of increased energy usage. Doubling the ventilation rate increases costs by about 5 per cent. More than 40 per cent of primary energy is used for buildings in EU countries and in the US (Seppanen, 2008), and is likely to be similar in Australia. Bottom line: there is great potential for significant energy conservation in the commercial building sector (Seppanen, 2008).

THE VITAL LIFE FORCE

There is generally little individual choice over the quality of the ambient air that we breathe indoors, or the total daily exposure.

Indoor air quality is more than thermal comfort and humidity; it is the air that penetrates into our lungs, providing the vital life force: oxygen.

Ventilation alone cannot deal with all types of contaminants in a room. Without effective high-quality filtration, increased “fresh air” simply increases energy costs without a commensurate improvement in indoor air quality.

An increased ventilation rate may only be treating the symptoms rather than the cause, and additional airflow from these ventilation modes substantially increases building operating costs, consuming as much as 30 per cent of the total energy use (Seppanen, 2008).

Compliance with energy rating schemes does not of itself deliver clean, breathable air. Only high-performance filtration can provide this. To be able to breathe deeply is not a luxury it’s a necessity.

THE AIR WE BREATHE INDOORS

More than 50 per cent of the air we breathe comes from contact with the floor around us, with dust exposure up to eight hours or more per day.

Humans are convective heat sources causing increased contaminant concentrations in the breathing zone, with super micron particles up to 5–10 micron showing a “boomerang” effect (Bolster and Linden, 2007).

Displacement ventilation involves supplying “fresh” air from the air supply diffusers located near the floor. The air rises as it is heated and displaces the hot contaminated air to the ceiling, where it is removed.

It is widely believed that low-energy displacement ventilation systems can be better than traditional mixing systems at removing contaminants from a space. This is because there is a belief that these systems will use the same mechanism for contaminant removal as they do for heat removal, where they are clearly more efficient.

“Compliance with energy rating schemes does not of itself deliver clean, breathable air. Only high-performance filtration can provide this”

The heat-extraction problem exploits the natural stratification that develops, extracting the warmest air that naturally sits at the top of the room. However, there is no physical justification as to why this location should correspond to the location of maximum contaminant concentration. In fact, many times it does not (Bolster and Linden, 2007).

SURFACE CHEMISTRY ON BUILDING FILTERS

Loaded particulate filters contribute to reduced air quality. The surface area of captured particles can easily approach 600m² (for a filter area of 0.36m²).

Increasing the outdoor flow rate increases the source strength of the filter.

The proportionality between pollution load and flow rate holds at airflows up to and well above the flow rates commonly used in ventilation systems.

Chemical reactions occur on filters (filter cake) resulting in the formation of noxious compounds. For example, ozone adsorption on particulates, ozone/limonene and ozone/alpha pinene have reaction rates fast enough to compete with ventilation rates (Weschler 2006).

Conventional air filters do not remove these gaseous air contaminants, and are generally inefficient for the smaller respirable particulates.

The disadvantage of conventional high-efficiency particle and chemical filters are the high initial, operation and maintenance costs

ARE WE MEASURING THE RIGHT INDOOR AIR POLLUTANTS?

“There is no quantitative definition of acceptable IAQ that can be necessarily met by measuring one or more contaminants,” ASHRAE Standard 62.1 states.

“With thousands of chemical vapours, particles and microbiological quanta that can be in the air, a direct measure of these constituents is in practical terms impossible. Concentrations that affect humans are typically so small that expensive instruments (and methodologies) are required. Moreover, benchmark thresholds for safe levels are generally unknown.”

Unlike ambient air, which has the NEPC (National Environment Protection Council) and the NEPMs (National Environment Protection Measures), indoor air quality has no coordinated system of control, or even a single area of government (local, state or federal) taking responsibility for it.

A major difference between indoor and outdoor environments is that for a given volume of air there are far more surfaces indoors. ~ 3 m²/m³ vs. 0.01 m²/m³.

“LOW-ENVIRONMENTAL-IMPACT” PRODUCTS

To achieve the maximum interior star rating, manufactured products with relatively low environmental impact are chosen to reduce the impact of toxic emissions. There are no clear Australian standards, goals or guidelines for pollutants that may be emitted by a product.

Building materials emit a myriad of reactive constituents and secondary products.

For instance, the US EPA advises “no-VOC” latex paint does not necessarily
mean no emissions. Linseed oil used as a drying agent in “low VOC paints” can react with ozone, nitrogen oxides or hydroxides (usually from outside supply air) to form oxidation products that are potentially irritating or harmful to health (Weschler 2006).

Triphenyl phosphate is an additive flame retardant and/or plasticiser used in electronic goods such as visual display units. It is continually emitted into indoor air during normal computer operations (500°C), and has a documented allergenic effect (Carlsson et al 2000).

There are more than 75 different brominated flame retardants used commercially, some of which are additive or reactive components in polymers such as polystyrene foams, high-impact polystyrene.

Various “green” or “ecological” materials chosen to mitigate health problems related to indoor air may actually be contributing to the problem as a consequence of chemical transformations.

The analytical methods routinely used in indoor air investigations are missing “biologically relevant” compounds. The term “stealth pollutants” is being used to describe these chemicals, which produce adverse health effects.

FILTRATION FOR ENHANCED IAQ

ASHRAE Standard 189.1 Standard for the Design of High-Performance Green Buildings (2010) with a proposed addendum 62.1.c, will add performance-based air cleaning requirements to the standard, for new buildings and major renovation projects.

Doubtless this will improve indoor air quality through better filtration.

The US Green Building Council LEED rating provides an innovation credit for "enhanced IAQ". The requirements for this credit are described as:

• Modify industry technologies to create a composite filter that is not only capable of removing common particulate matter but also provides removal of gases that are commonly associated with military warfare or terrorism.

• Provide an extremely high level of indoor air filtration by installing a four-stage air filtration system composed of 85 per cent efficient prefilter, 99.95 per cent efficient HEPA filter, and a carbon filter, and address associated pressure drops for the installation.

• Demonstrate a comprehensive design approach that has quantifiable environmental benefits, including calculation of airborne contaminants that this system removes compared to traditional systems.

The Green Building Council of Australia’s innovation category has been introduced to recognise a strategy or technology that has a significant environmental benefit, not otherwise awarded points by Green Star - Office Interiors.

PROSPECTS FOR BETTER INDOOR AIR

The USEPA recently conducted a study to identify current advanced filtration technologies that could be used as a starting point for further developing an advanced air-filtration system for a building’s HVAC system to help remove biological agents from
The requirements were established of Advanced Building Air Filtration Systems, November 2008.

"Clearly, the energy consumption associated with biowalls is relatively minor, and represents minimal ongoing energy costs”

The advanced air filtration system should provide a lower pressure drop than conventional high-efficiency particulate filters, with higher or equivalent efficiency and comparable or lower cost.

The requirements were established considering two criteria: (a) has better performance than the high-efficiency filters (MERV 14, 15, and 16) and (b) does not exceed the pressure-drop limit that common HVAC systems can accommodate.

The performance requirements established were a 99.9 per cent removal efficiency for aerosols with a 1-µm diameter (optical diameter) and with a pressure drop of less than 0.5 in. H2O (124Pa).

Although HEPA filters provide high filtration efficiency, they are not necessarily appropriate for HVAC applications. As a general rule, existing HVAC systems cannot be upgraded to HEPA filters without a complete retrofit of the air-handling system due to the high pressure drop and potential leakage associated with them.

High-efficiency filters (MERV 15 and 16) are recommended by filter manufacturers as a cost-effective alternative to HEPA filters for maximum particulate removal.

Currently, there is no performance criteria established for HVAC air filtration systems designed to protect building occupants against biological agents because there are no defined “safe” levels of exposure to biological threat agents.

THE VERY REAL BENEFITS OF GOOD IAQ

Andrew Persily of the US National Institute of Standards and Technology, and co-authors from ASHRAE, BOMA, USGBC, and USEPA, (Persily et al 2008), have put the case for improved indoor air quality very succinctly.

"IAQ is still not a primary design or building management issue compared to function, cost, space, aesthetics and attributes such as location and parking,” the authors say.

“But given the very real benefits of good IAQ, the potentially serious consequences of poor IAQ and the ability to design, construct and operate buildings with good IAQ using existing knowledge and without incurring significant costs, building owners, designers and other professionals need a better appreciation of the importance of providing good IAQ in their buildings.”

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About the author

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The new Cambridge City Hall defines the civic precinct, which consists of five heritage buildings, including the original town hall built in 1857. Within this heritage context, the presence of the new city hall is established with an open and transparent glazed façade.

A sky-lit central atrium acts as an interior public square.

“Two atrium features a four-storey plant wall bio-filter, a vertical hydroponic system that aids in providing exceptional indoor air quality,” say Diamond and Schmitt Architects, which designed the project.

The new Cambridge City Hall is the first LEED Gold (the equivalent to 5 Star Green Star) city hall in Canada.

**LIGHT AND AIR**

“Exemplary indoor air quality is achieved through the use of a four-storey living wall bio-filter in the atrium,” the architects say.

“Return air is directed through the living wall where a symbiotic plant/microbe ecosystem consumes volatile organic compounds and other air contaminants. The cleansed and humidified air is then distributed through the building ventilation system. Diamond and Schmitt Architects pioneered the use of bio-filter plant walls of this kind, aiding in the development of the prototype and working to enhance their efficiency.”

The building’s design allows natural light to penetrate deep into the building. Skylights in the central, four-storey atrium provide abundant daylight and promote natural ventilation. Operable windows throughout the building allow light and cooler air to enter at low levels. More than 75 per cent of staff workspaces have access to operable windows and more than 95 per cent have views to the outside.

**ENERGY USE**

Cambridge City Hall has an energy cost performance of 42 per cent compared to the Canadian Model National Energy Code for Buildings. A conservative estimate comparing a standard building of the same size to the new City Hall results in a $160,000 savings on energy per year.

Strategies to help achieve energy savings include a high-performance building envelope with energy-efficient windows, increased insulation and sun shading to reduce the solar heat gain.

Energy modelling was conducted at the beginning of design to optimise building orientation and massing design, to envelope, mechanical and electrical systems’ specifications to ensure appropriate consideration of first-time capital expense against life-cycle costing models.

“The building automation system (BAS) ensures a comfortable condition for the new city hall,” the architects say.

**SENSORS AND CONTROLS**

“CO₂ sensors connected to the BAS send greater ventilation to occupied spaces and reduce ventilation to unoccupied spaces, saving energy and providing good air quality,” the architects explain.

The building has an independent weather station on its green roof that relays information about the outside temperature, barometer and wind, which is tied into the monitoring systems to enable efficient operations. All staff areas feature LED message boards to communicate to employees. Prompts to close the windows on extremely hot days and other messages are conveyed to conserve energy and reduce cooling costs.

Several energy-efficiency measures have been implemented in the mechanical design including a high-efficiency modulating gas boiler and a condensing water heater, glycol loop heat recovery, variable frequency drives on pumps and an energy-efficient chiller with free cooling mode.

The projected annual electrical energy consumption is 895 MJ/m²/year.

For more information, go to www.dsai.ca