Assessment of Biowalls:

An Overview of Plant- and Microbial-based Indoor Air Purification System

Prepared By

Ryan Hum and Pearl Lai

Chemical Engineering

April 19, 2007

Prepared for:

Physical Plant Services, Queen's University

For partial completion of APSC 400: Technology and Engineering Management

Acknowledgements

Special thanks to the following people for making this project possible:

Dr. Laura-Lee Balkwill, Queen’s University

Dr. Alex Bielak, Environment Canada

Patti Cook, University of Waterloo

Beth Anne Currie, Centre for Social Innovation

Gillian Dagg-Foster, XCG Consultants Ltd.

Dr. Alan Darlington, Air Quality Solutions

Dale Dilamarter, TEAM instructor

Barrie Jackson, TEAM instructor

Cindy Kambeitz, TRCA

David Lay, Integrated Learning Centre

David Mody, TEAM instructor

Eric Neuman, Queen’s Physical Plant Services

Dr. Juliana Ramsay, Queen’s University

Aaron Savage, Queen’s Physical Plant Services

Renee Stephen, Integrated Learning Centre

Janna Stasiak, Environment Canada

1.0 Executive Summary

In an era when scientists and the public are sensitive to the dangers of global warming and oil shortages, environmental initiatives are becoming an increasingly higher priority among socially responsible organizations. Queen’s Physical Plant Services (PPS) is no different in their desire to gradually turn Queen’s into a “green” campus. One of the technologies that PPS is currently investigating is the concept of biowalls. The purpose of this report is to provide an unbiased source of information for PPS to use while considering whether or not to install more biowalls on Queen’s campus.

Biowalls are indoor biological air purification systems that are composed of a variety of plant species and microorganisms that live in their roots. Through microbial activity, airborne contaminants such as carbon dioxide and volatile organic compounds are degraded into end products that are harmless to humans and the environment.

The information in this report was gathered by consulting a number of different sources. These include journal articles, interviews with biowall experts and professors of psychology and environmental engineering, site visits and the internet.

Studies indicate that in laboratory settings, biowalls are indeed capable of effectively reducing specific volatile organic compound concentrations in the air—even at extremely low concentrations. The wall however does not reduce the level of carbon dioxide significantly. Although these studies are positive, the extent of their real benefit is still unknown. This may be due to a number of factors such as the fact that plants also produce their own carbon dioxide and volatile organic compounds thereby potentially

offsetting the amount that they reduce (e.g. no change in total volatile organic compound levels).

Other areas of concern such as spores, insects, allergies and airborne diseases were found to be insignificant provided that the walls are properly maintained and consist of carefully chosen plant species. Although it has been reported that the use of a biowall can result in energy savings of up to 60%, these savings can not currently be realized since building codes do not allow the reduction of required ventilation on the whim of a non-proven air purification method.

Perhaps the greatest benefits that biowalls have to offer are those that are intangible such as the psychological and branding benefits. Numerous studies have shown that the presence of plants have an undeniably positive impact on psychological well-being with people who are exposed to plants experiencing increased levels of productivity, faster recovery rates from trauma and lower stress levels. Organizations that own biowalls also praised them as an excellent way to improve their company's image and branding within the community.

This analysis of biowall technology shows that while presently the physical benefits may not be as significant, the intangible psychological and branding benefits are enormous and may well be reason enough to justify building one. However, due to the high price tag of this still relatively new technology, a cheaper and more practical alternative may be to build a regular indoor garden if floor space was not an issue. An indoor garden could provide almost all of the same psychological and physical benefits as a biowall at a fraction of the cost.

Table of contents

List of Tables

List of Figures

2.0 Purpose

Queen's Physical Plant Services (PPS) has hired students from APSC 400 - TEAM (Technology, Engineering and Management) to conduct a general overview of the biowall technology. PPS is in the process of considering different options for incorporating green technology in the new Queen's Center—which is slated to be completed by September 2014—as well as in other new campus initiatives. In the case of the new Queen's Centre, Queen's is seeking a LEED™ ((Leadership in Energy and Environmental Design)) silver certification for green building design. Some of the "green" options currently under consideration are green roofs, wind power, grey-water usage as well as geothermal heating and cooling. A living wall is also one such technology that this current report focuses on.

Figure 1: Biowall at the Integrated Learning Centre

Although Queen's already has one living wall inside the Integrated Learning Centre, PPS is looking for a better understanding of how the technology works and whether it delivers on its promises of cleaner air, energy savings and other benefits. The students of TEAM were charged with the task of collecting information about the technical aspects of living walls, results from studies that investigate their effectiveness as well as addressing any critical issues that might be of concern.

This information has been packaged into a concise, unbiased and informative report that can be easily understood by a person with a general background in biology.

3.0 Background

3.1 Air Quality

Did you know?

Studies have reported that 176 million work days are lost annually due to respiratory illnesses with most relating to poor indoor air quality (Fisk *et. al*, 2000).

Research has shown that an estimated 80% of an urban-dweller's time is spent indoors, be it in the home, workplace or school (Hodgson *et al.*, 1997). With such a large percentage of time being spent within a closed environment, it is essential for buildings to provide a high quality air supply in order to ensure the physical well-being of occupants. Poor indoor air quality has been linked to cases of sick-building syndrome where the afflicted usually suffer from a variety of physical symptoms and loss of productivity. More and more studies are now linking workers' well-being with increased employee productivity and business profitability.

One of the major contaminants of indoor air is a class of chemicals called: volatile organic compounds (VOCs) (Guo, H., *et al*, 2003). VOCs are organic chemical compounds that exist in the gaseous phase under normal temperature and pressure conditions. These include chemicals such as formaldehyde, benzene, toluene, trichloroethylene and naphthalene. Rehwagen, Schlink and Herbarth (2003) estimate that in the apartment setting, VOC levels may be upwards of 10 times higher than that outdoors. This is re-iterated by the United States Environmental Protection Agency who notes that indoor air is often two to five more polluted than outdoor air.

Although many of these individual compounds may be present in very low concentrations, the National Occupational Health and Safety Commission of Australia, the World Health Organization and the American Conference of Government and Industrial Hygienists, believe the sum of these mixtures may present cumulative effect on the health of workers and building occupants.

Did you know?

People that are affected by sick building syndrome may experience lower levels of productivity while trying to cope with their symptoms. These symptoms are usually acute; they tend to disappear once the sick occupant leaves the building

Accumulation of VOCs in the air is a cause for concern because they have been known to cause acute and chronic health problems even in relative trace concentrations. Short-term problems include dizziness, fatigue, headaches, skin and eye irritations, and shortness of breath and mucous membrane irritation. However, studies have shown that long-term exposure can also lead to the development of asthma, organ and tissue damage, birth defects and cancer. Collectively, these harmful effects of VOCs have been recognized as components of "sick building syndrome" (Brasche, *et al*, 1999; Carrer, P, *et al*, 1999).

Sources of indoor volatile organic compounds include (Berube, K.A., *et al*, 2004; Isabella, M.A., *et al*, 2005):

- Off-gassing of building materials such as drywall, adhesives, textiles, fabrics, plywood, etc;
- new office furniture, rugs
- cleaning agents, solvents, adhesives, glues, calking agents, paint;
- electronics (computers, photocopiers, fax machines, computer screens)
- human beings (hair spray, body gels, anti-perspirants, and other perfuming agents).

Buildings are becoming more airtight and therefore indoor air quality is dependent on the design and performance of the heating and ventilation system and components (HVAC) of the building (Wood, R.A., 2002; Cochet C, Nibel S, & Nagy, L., 2002). Typically buildings are designed to reduce energy costs associated with heating and cooling. Outdoor air is used to ventilate the indoor environment and dilute the higher indoor concentrations of VOCs.

Table 1 lists the provincial and federal guidelines for maximum exposure limits for some of the more common indoor air contaminants applicable to an indoor residential environment (Reference: National Research Council

Indoor Air Quality Guidelines and Standards, 2005, and American Society of Heating, Refrigeration, and Air-Conditioning Engineers standards, 1989). Limits applicable for a workplace should be comparatively similar since both are environments that people spend large amounts of time in. While adherence to these guidelines is highly recommended, they are not enforced.

Table 1: Canadian Guidelines for Common Indoor Contaminants

Contaminant	**Maximum exposure limits (ppm)**[*1]
Carbon dioxide	3500 [L]
Carbon monoxide	11 [8 hr] 25 [1 hr]
Formaldehyde	0.1 [L] 0.05 [L]**
Lead	Minimize exposure
Nitrogen dioxide	0.05 0.25 [1 hr]
Ozone	0.12 [1 hr]
Sulfur dioxide	0.38 [5 min] 0.019
Benzene	10
Toluene	200
Trichloroethylene	100
Naphthalene	9.5

Microbial contaminants, such as viruses, fungi, mold, bacteria, nematodes, amoeba, pollen, dander, and mites, are also a concern for indoor air quality. Their presence is common in moist environments. When exposed to this kind of contaminant, some people may suffer allergic reactions or other feelings of discomfort such as chills, fever, muscle ache, chest tightness, headache, cough, sore throat, diarrhea, and nausea (OSHA, 1999).

---

* Numbers in brackets [ ] refers to either a ceiling or to averaging times of less than or great than eight hours (min=minutes; hr=hours; yr=year; C=ceiling; L=long term. Where no time is specified, the averaging time is eight hours.)
** Target level is 0.05ppm because of its potential carcinogenic effect. Total aldehydes limited to 1ppm.

3.2 Biowalls

To improve the indoor air quality and reduce operating costs, many researchers are developing novel methods to purify the air without increasing air exchange through the HVAC.

Did you know?

The National Aeronautics and Space Administration (NASA) initially performed experiments using plants to purify the air in a space station (Wolverton, B.C., & Wolverton, J.D., 1993).

Biowalls or "living walls" are a relatively new technology for improving the indoor air quality. As the name suggests, a biological system composed of various plant species and their associated root microorganisms are embedded into a vertical porous matrix. The biological system is maintained by a pump, which feeds nutrients and water to the top of the wall and flows down the surface. Two commercial systems are available in Canada. The passive system purifies the indoor air through convective forces while the active system uses a fan to draw air horizontally through the surface area.

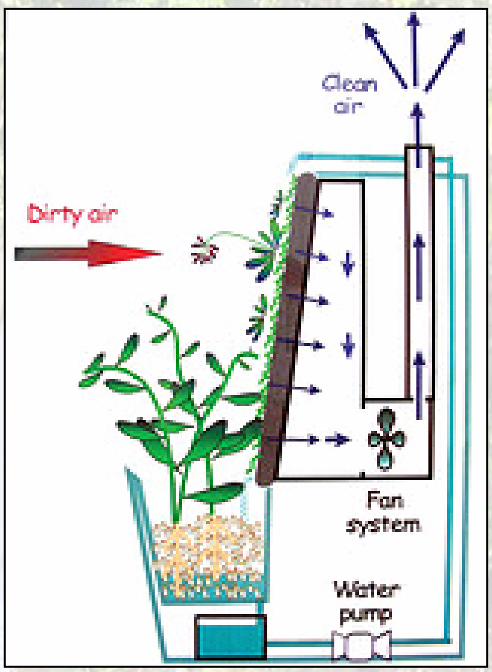

Figure 2: Schematic of a Biowall. Source: www.naturaire.com

Living walls, or biowalls can be found in many urban centers around the world where the constant presence of smog and other city air pollutants means that their potential benefits can be most appreciated. Following in the current trend to move towards environmentally friendlier practices, they are now a common fixture in university campuses, office spaces and recently even in places of worship. Currently approximately 20 biowalls exist in Canada, while various institutions are considering others. These walls vary in size from a few feet high to multi-storey constructions. Others have incorporated a mini-terrestrial or aquatic ecosystem at the base of the wall.

Did you know?

The wall belonging to the University of Guelph-Humber is one of the most recently constructed biowalls and the largest to date spanning a wall area of $170 m^2$.

The first biowall was constructed in 1994 for Canada Life Assurance Co.'s head office in downtown Toronto. Located inside the building's Environmental Room, the wall was host to more than 8,000 plants of 250 different species. The project was a joint venture between Canada Life and the University of Guelph for the purpose of studying the effect of plants on improving indoor air quality. Though the Environmental Room is no longer in operation due to the acquisition of the company by Great West Life in 2003, the wall still served as a necessary stepping stone to prove that the biowall technology works (Darlington, 2007).

Other biowall locations include the Robertson Building (an office complex in downtown Toronto), Toronto and Region Conservation Authority's head office, Queen's University's Integrated Learning Centre and the atrium of the University of Guelph-Humber building.

Dr. Alan Darlington is the inventor of these biowalls and owns the patent on this technology in both countries. Dr. Darlington completed his PhD in horticulture at the University of Guelph in the Controlled Environment Systems Research Facility, under the guidance of Dr. M. Dixon. His research focused on the use of botanical biofilters as a means of maintaining quality of the indoor environment. He is the President and CEO of Air Quality Solutions, the company that builds these walls and he remains to be an Adjunct Professor at the University of Guelph.

Darlington has also recently expanded his business into the United States, building the first biowall in the headquarters of environmental-restoration firm, Biohabitats Inc. in September 2005. There are also plans to introduce smaller versions of the biowall to be used inside residential homes sometime this year. A sample list of existing living walls is included in the Annex 9.5, along with an abbreviated summary.

3.3 Biology Concepts Applicable to Biowalls

Did you know?

Literature has reported that biofiltration is effective for odorous compounds at a removal rate of 98 to 99%, while VOC removal rates range from 65 to 99%.

Source: Air Pollution Control Handbook

Although these biowalls represent a novel approach to maintaining indoor air quality, they are variations of biological processes used in established environmental engineering practices for air and soil remediation. The concepts behind biofiltration and phytoremediation can be adapted to explain the mechanisms of air purification for these biowalls.

The fundamental principle of biofiltration units is that gaseous pollutants are absorbed into a liquid phase and are consumed by microbes and utilized as food or energy sources—thus converted to innocuous metabolic end products (carbon dioxide and water).

Biofilters are comprised of a bed of media on top of a system of perforated pipes. This media provides nutrients such as salts and trace elements to the microorganisms. The soil or compost particles mimic a packed bed, which supports the growth of microorganisms, and becomes the surface for the formation of biofilms. The contaminated air flows through the pipes and is distributed throughout the bed. The pollutants in the air are absorbed in to the water and from the water onto the organic surface of the soil or compost.

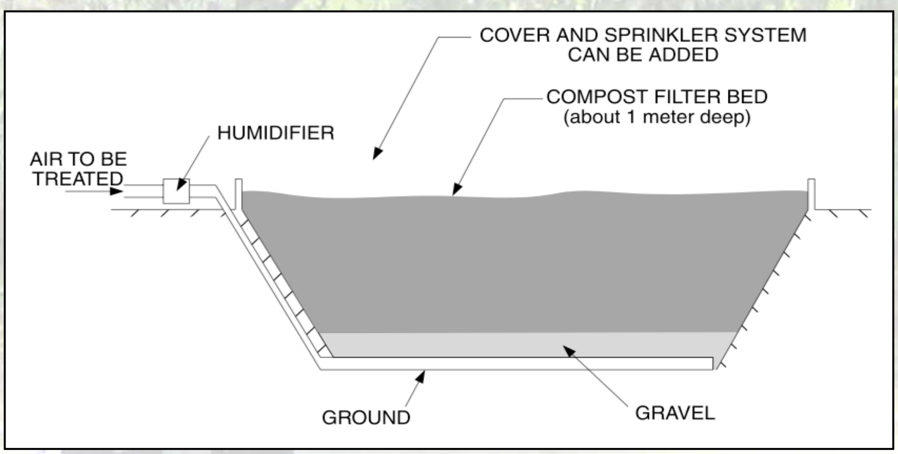

Figure 3: Typical Biofilter Bed. Source: Air Pollution Control Handbook.

The microorganisms then oxidize the absorbed gases to carbon dioxide. Annexes 9.1 and 9.2 contain a larger description of biofilter bed used in industrial air quality control of VOCs as well as their design equations.

In phytoremediation, instead of microorganisms degrading the organic compounds, plants degrade or eliminate toxic compounds from the environment. Many researchers are investigating the use of specialized plants to remediate soil, water and air however this is still in the research phase and has not become a standard bioremediation practice.

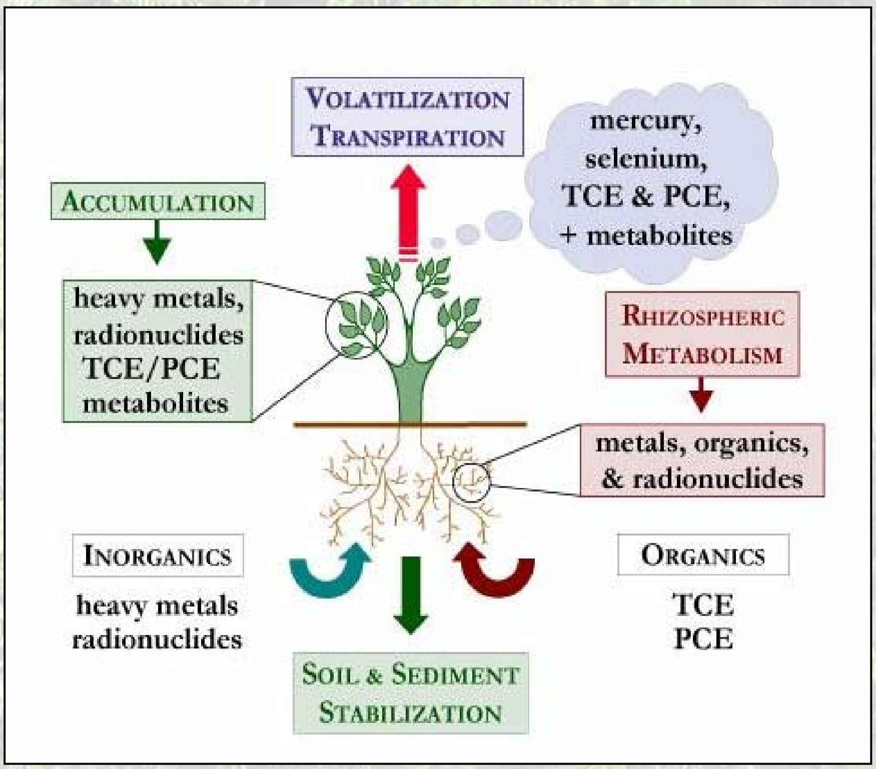

Figure 4: Mechanisms of Phytoremediation. Source: www.uga.edu/srel/Fact_Sheets/phytoremediation.htm

4.0 Methodology

The information that was used in this report was gathered from a variety of sources such as research papers, internet searches and from speaking to experts on the technology and representatives from organizations that own biowalls.

4.1 Literature Review

A plethora of information is available on related concepts such as biofiltration, phytoremediation and the psychological impact of plants. Information from the study of those concepts was pieced together in such a way that the information was applicable to biowalls.

It should be noted that the majority of the available literature was not specifically about biowalls. Currently, there is not much research available on biowalls due in large part because the technology is still relatively young. The few studies that are available are from the developer of the technology, Dr. Darlington. So far, only one study has been conducted on the physical and psychological benefits of the Toronto and Region Conservation Authority's (TRCA) biowall at their head office. Dr. Darlington has plans to conduct more of these studies starting in summer 2007, including a thorough cost-benefit analysis.

4.2 Site Visits

In order to gain a first-hand impression on biowalls, the team went to visit 6 different biowall sites in the Greater Toronto Area; these included:

- Toronto and Region Conservation Authority
- Environment Canada Centre for Inland Waters (Burlington)
- University of Waterloo, Environmental Science Building I

- University of Guelph-Humber Building (Etobicoke)
- Robertson Building (downtown Toronto)
- St. Gabriel’s Parish

Please refer to Annex 9.5 for further information on each of the above sites. At the TRCA, Environment Canada and the University of Waterloo, representatives were available to answer questions specific to their own walls. The questions in these interviews were informal, and did not follow a set outline; however, generally sought their motivation for building the walls, their perceived physical and psychological benefits and problems, and their general understanding of the technology.

4.3 Internet

The internet was also a source for finding the most up to date information on the advancement of biowall technology including coverage in popular press. The internet provided access to online magazine articles that cover interviews with Dr. Darlington and other experts and feature articles on new developments in biowall technology. The University of Guelph-Humber’s 4 story-tall biowall continues to attract a lot of interest from the environmentally conscious community since its construction was completed in May 2004.

4.4 Experts of Biowall Technology

One of the most important sources of information was interviews with people who are knowledgeable in biowall technology and other related fields. These people included Dr. Darlington and some of Queen’s psychology and environmental engineering professors. Their expertise provided the background information necessary for understanding the inner workings of the technology.

5.0 Analysis

5.1 Effects on Indoor Carbon Dioxide and Oxygen Levels

Although it is true plants can decrease the level of carbon dioxide and increase oxygen levels in the environment, noticeable change only occurs as a cumulative effect such as through forests or other large botanical environments.

Did you know?

Generally, during the day plants absorb CO_2 and release O_2 into the environment, while at night, they do the reverse.

Plants are generally known as autotrophs, organisms that can produce their own energy. They absorb carbon dioxide (CO_2) and sunlight from the environment and produce sugars (for future energy use) and breathe out oxygen (O_2); this process is called photosynthesis. At night however, plants undergo a different process called “respiration”. In respiration, much like that in other organisms, the plants absorb O_2 and oxidize the sugar molecules to extract energy in the process re-producing CO_2 and water. Generally speaking, these two processes balance out, therefore resulting in no net change in CO_2 or O_2 levels in the environment.

Plants are able to sequester CO_2 however only as building blocks for growth. Much of the structural material in plants are carbon based molecules generated from atmospheric carbon dioxide, however, the majority of a plant’s mass is in the form of water, upwards of 95%. Therefore, the only amount of carbon reduced in the environment is directly proportional to the rate at which they grow.

It is, therefore, safe to presume that biowalls do not significantly reduce the level of carbon dioxide in the indoor air environment. One hypothetical method to improve the reduction would be to operate the biowall and circulate the air through the building only during the daytime while at night exhausting the air from the biowall to the outdoor environment.

5.2 Effects on Volatile Organic Compounds Levels

Did you know?

Studies have shown that when the indoor level was above 100ppb just having three potted plants in the office can reduce VOCs by up to 75% (Orwell, et al, 2006).

Experimental studies have indicated that biowalls can have a positive effect by reducing the indoor volatile organic compound levels. Although biowalls are a fraction the size of biofiltration systems and the VOC levels in the indoor air environment were more than 100 times less than those treating in industry, the biowall mimicked many of the attributes of the biofiltration system. Just like biofiltration systems, it was concluded that the main mechanism for VOC degradation was through the microorganisms living in the root microcosm of the plants.

Like other organisms, microbes require a carbon source to grow. The VOCs such as benzene, toluene, and formaldehyde are simply an available carbon source for the microorganisms. Although there is much biodiversity in the microbial population, it is believed that many microorganisms developed an ability to degrade VOCs based on environmental pressures or availability. Root microorganisms that live symbiotically with aromatic plants such as mint, rosemary or even mosses have a ready supply of VOCs being released from the plant. Thus, the plants on the biowall are used to support a healthy microbial populations—one, by volume, greater than that achievable in a biofiltration system.

Did you know?

In 2000, Dr. Darlington completed studies where upwards of 90% of the formaldehyde in an air inlet stream was removed per pass through the biowall.

Similar to biofiltration systems, the pollutants in the air are absorbed onto the water and from the water made available to the microorganisms. To increase the removal of VOCs by the biowall, it is recommended that the biowall operate with a low air intake velocity and a low operating temperature (20˚C). This increases the residence time of the VOCs in the biowall and the solubility of the VOC in water so as to make more available to the microbes. It is also hypothesized that the addition of activated carbon or other absorbents into the biowall medium would also increase the amount of VOCs that remains in the system for degradation.

5.3 Effects on Humidity and Particulate Levels

Biowalls can have a minor benefit on the humidity levels and particulate (dust) levels in a building. According to the U.S. Occupational Safety and Health Administration’s (OSHA) guidelines for good indoor air quality in an office environment, temperature and humidity levels should be maintained within the range of 20-24^{o}C and 20%-60% respectively to maximize productivity levels in workers (OSHA, 1999). Although humidity and particulate benefits have not been reported academically, many individuals in our site visits mentioned this as a beneficial quality for the biowall.

Did you know?

Plants have a slight electric charge on their leaves which can hold the dust particles that are suspended in the air.

The biowall is maintained moist by a pump that feeds water to the top of the wall and is allowed to trickle down along the plants and porous matrix. By passing the air through the biowall the air increases its water vapor content towards higher percentage humidity—relative to its temperature. This water flowing down the biowall can also act as a particulate scrubber which removes some dust in the air.

Although humidity and particulate levels in the indoor air environment are important, these remain to be minor side benefits to this technology and would not justify the installation of a biowall. Standard air filters or a humidification system would be more effective and less costly. Furthermore, increasing the humidity levels in air greater than 65% can, under certain conditions, result in mould.

5.4 Psychological Effects

One of the most commonly sited benefits of having plants in the workplace is the apparent effect that they have on increasing worker productivity. A study by Lohr, Pearson-Mims and Goodwin at the Washington State University observed students' performance on a simple computer task when plants were either present or absent from the computer laboratory environment. Of the 96 people who participated in the study, which included students and university employees, the group exposed to the plant-filled environment demonstrated a 12% faster reaction time compared to the group working in the laboratory without plants. In this case, faster reaction time was considered indicative of increased productivity.

Did you know?

Ulrich (1984) also found that hospital patients recovered more quickly when given a room with a "green" view compared to patients with views of brick walls.

Another documented psychological benefit that plants have is their ability to reduce both mental and physical trauma. American psychologists, Ulrich and Parsons conducted studies where subjects who had experienced previous trauma were then exposed to conditions that did or did not involve plants. One of the studies showed that within a group of people who had watched a traumatic video, those who were shown a nature-themed video afterwards recovered more quickly than a group that was shown one about urban life. Recovery was measured by reduction in blood pressure and muscle tension.

Some studies have are also shown that the presence of plants can have an effect on reducing stress. Surrey University in England conducted a study to objectively measure stress reduction using three variables: skin conductivity, heart rate and blood pressure (Surry University, 1997). Test subjects were required to complete a mathematical task while exposed to either no plants or a heavily planted environment. Throughout the task, distractions such as the sound of a telephone ringing or traffic noise were emitted at random intervals. Measurements of skin conductivity showed that the group in the heavily planted office felt less stressed during the test period. They also showed signs of faster recovery from stress during the 10 minutes right after the rest.

Did you know?

Some psychologists believe in a concept called “biophilia” in which humans share an innate bond with nature due to being exposed to the same plants throughout our evolutionary history.

From these studies, it appears that exposure to plants does have an impact on increasing productivity levels in a work environment. These same effects have not yet been demonstrated with biowalls however, all of the effects mentioned above can easily be translated to biowalls which have all the aesthetics of potted plants and the added benefit of providing cleaner air. Cleaner air can have a direct impact on a person’s psychological well-being because it lowers the likelihood of developing sick building syndrome which can influence how satisfied a person is with their job and workplace.

An example of a possible study that can be done to gauge the psychological impact of biowalls is a survey outlined in the annex of the report. Whether or not further studies are done, the overwhelmingly positive impact of plants on psychological well-being suggest that even if biowalls are not constructed, potted plants should be incorporated in any indoor environment.

5.5 Branding

In speaking to owners and operators of biowalls, one of the major benefits of this technology was the “bragging rights” and branding of their organization. The biowalls represented a physical and tangible presentation of their “commitment” to sustainable development and green technologies.

Figure 5: A Passive Biowall at the University of Waterloo

At the University of Waterloo, the Faculty of Environmental Studies installed a biowall to differentiate their faculty from others. A multimedia outlet was set up to draw in younger primary school students to explain the benefits of the plants in the environment—thus creating an environment that conveyed a sense of environmentalism as well as culture for learning. At the University of Waterloo, the biowall became a standard backdrop for photographs and press conferences for the faculty. In Toronto, the Robertson Building houses a collection of non-government organizations. To show leadership in supporting green technologies and “incorporate green elements in the fabric of the building”, the building owner installed both a 250 square foot biowall in the lobby of the Robertson building as well as a green roof. Current tenants in the building include a strong proportion of social and environmental activists.

Biowalls have been a successful technology to brand ones organization as environmentally conscious. Although the technology may not be as beneficial to the environment (compared to proven technologies such as solar panels), it is very tangible, esthetically pleasing and the vertical height provides a tremendous “wow” factor.

5.6 Energy

Theoretically, the use of a biowall as a method of cleaning indoor air in conjunction with the standard HVAC system in buildings can lead to potential energy savings.

Did you know?

Ventilation rates are primarily diagnosed through CO_2 (a by-product of respiration) analysis. The CO_2 serves as an indicator for the air exchange in a building

According to American Society of Heating, Refrigerating, and Air-Conditioning Engineers standards (1989), indoor spaces with typical occupant densities require between 3 to 6 air changes per hour to maintain acceptable indoor air quality standards. The HVAC system requires energy to condition the air that is brought from the outdoors to comfortable temperature and humidity levels of around 22^{o}C and 50% respectively (OSHA, 1999). While biowalls also consume some energy for the water pumps and lighting, these combined requirements are small, totaling approximately 0.005 KW per building occupant. Dr. Darlington’s studies report that an estimated 60% of the “fresh air” required can be produced by the biowall assuming an air flow of 0.05 m^3air/s per m^2 of biofilter area, a building density of 1 person per 20m^2 of floor space and a ratio of 1m^2 of biofilter per 100m^2 of floor space. This translates into an energy savings of about 60% (Darlington et al, 2004).

Unfortunately, since there is no significant change in CO_2 levels from biowalls, these energy savings can not yet be realized as they are not yet recognized as a proven method of air purification. As a result, current building codes do not allow for the reduction of ventilation through the HVAC system even with the operation of a biowall. Until more studies are done to prove biofiltration works on a large scale, biowalls have a limited practical impact on energy reduction.

5.7 Airborne Diseases

Bringing plants into the indoor environment especially in large quantities such as in the biowall can raise concerns about potential airborne diseases; however, when done properly does not increase the spread of microbial contaminants like spores.

Microbial contaminants include viruses, fungi, mold, bacteria, nematodes, amoeba, pollen, dander, and mites. Their presence is common in moist environments. When exposed to this kind of contaminant, some people may suffer allergic reactions or other feelings of discomfort such as chills, fever, muscle ache, chest tightness, headache, cough, sore throat, diarrhea, and nausea (OSHA, 1999). The growth of spores is a plant's response to environmental stress factors. Spores are dormant forms of vegetative cells that have very low energy requirements.

Did you know?

Every surface is covered with microorganisms, many of which are completely benign to humans.

In actuality, airborne diseases should not be a major concern for determining whether or not to build a biowall. An example is Legionnaire's, a disease associated with indoor air contaminant caused by the bacteria, *Legionella pneumophila.* The bacteria thrives in warm water and its potential sources include cooling systems, humidifiers, food market vegetable misters, and even residential tap water (US EPA, 1994). Legionnaire's disease outbreaks are rare, with the last case in Canada occurring in 2005. Since the water in a biowall is being continuously pumped around, the chance of the bacteria growing is unlikely since there is no stagnant water. The development of spores can be avoided with careful selection of the plants used in a biowall that are compatible with the surrounding environment. With regular proper maintenance, any residual spores can be removed.

5.8 Insects

Another reason that some people might be wary about introducing too much plant life into an indoor space is because of their tendency to attract insects. While their presence can be irritating, a more serious concern is the potential spreading of bacteria and diseases such as the West Nile virus they may be carrying.

Plants naturally produce pollens and nectars as part of their normal growth functions. In the wild, their production is essential for attracting insects which serve the vital role of distributing the plant's pollen grains. Some species of insects can even help defend against other harmful species that might attack the plant.

Figure 6: Flower on the Biowall from St. Gabriel's Parish

For indoor plants, the benefits that insects can offer is often not needed and their presence becomes a nuisance more than anything. The insect population can easily be control by biological means using nematodes to control fungus gnats. The Integrated Learning Center hires the services of a local indoor landscaper who comes in monthly to prune the biowall and apply insecticides.

5.9 Allergies

Dust, pollen and certain foods are among some of the things that allergy sufferers are particularly sensitive to. During the flowering seasons, severe irritation of the eyes, nose and throat are not uncommon and can sometimes become serious enough to disrupt one's daily routine. Plants in an indoor environment are a particularly valid concern for allergy sufferers since the space confinement may mean an increase in the concentration of pollen.

Did you know?

On indoor plants, it is often the mold overgrowth and not the flowers that cause allergy.

Source: www.medicinenet.com

The types of plants that are grown on a biowall are carefully picked to be hypoallergenic so that no pollen is released. In 2004, the results of a comprehensive employee survey on health, wellness, job satisfaction and working conditions conducted at the TRCA showed that the installment of a biowall did not cause any worsening of allergy symptoms. In addition, the running water feature of the biowall is able to capture the small amounts of mold or pollen that may be present thereby effectively eliminating any cause of concern.

6.0 Recommendations and Conclusion

Overall, biowalls appear to have many physical and psychological benefits that may be beneficial in a university or office setting. Biowalls can reduce the levels of specific VOCs which have been identified as particularly harmful to humans (such as toluene, ethylbenzene and *o*-xylene). It has been shown that biowalls can be modeled mathematically to an industrial biofiltration system, despite the packing depth difference, and can reduce ambient VOC levels in the low parts per billion.

Regardless of the physical air quality benefits, people generally have an affinity to being around plants. Many studies have proven a link to plants and their beneficial psychological affects on people, including increases in productivity and decreases in stress levels. The biowall is also an attractive and tangible display of ones efforts to integrate green technologies into the building environment and proves to be an effective tool for branding—and an ideal location for photo opportunities. Furthermore, if operated properly and the plants are chosen with expertise, the biowalls should not increase any risks to human health through airborne diseases, allergies or spore levels.

Despite these benefits, some questions remain to be unanswered. With little reduction in CO_2 levels or increases in O_2, it is unclear whether future building codes will permit buildings with biowalls to reduce their number of air exchanges through the HVAC system. Therefore there are likely no current energy savings conveyed through the operation of a biowall. It is also unclear to what extent VOCs are a current problem in buildings on Queen's campus. In addition, conventional and effective practice to reduce VOCs in a new construction is to combat the problem at its source (e.g. to use low VOC emitting material such as low VOC paints and carpets) rather than building a biowall.

Although not covered explicitly in this report, biowalls are a relatively new technology and is currently marketed at approximately $1500/m^2. Furthermore, many organizations with biowalls—Queen's included—have decided to include an operating cost of approximately $8000/year for plant care and services, which include pruning, plant selection or alternation, plant health, etc.

In 2006, a number of studies were published that indicate that simply having three small potted plants can significantly reduce (50-75%) the total VOC levels in a <u>real</u> office of 30-50m^3(Wood, *et al*, 2006). The only consideration was that the level of total VOC needed to be above 100ppb—a concentration level that is much lower than acceptable limits.

Factoring costs, the above mentioned potted-plant studies and the fact that the psychological effects are associated with plants in general (and not isolated to biowalls); it would appear that many of the benefits of these walls can be engendered simply with an indoor garden.

Should total volatile organic compounds rise above 100ppb (a threshold lower than health and safety standards) an indoor garden in the atrium of a building could be sufficient to reduce the levels. With a larger base perimeter, an indoor garden would provide a larger social area for more students and staff to gather and relax. Furthermore, an indoor garden could be built at a lower capital cost and comparable operating costs. There would also be no greater risk with allergens, humidity, or airborne diseases.

Comparing only with a hypothetical indoor garden now, a biowall would only provide two significant benefits. The vertical nature of the biowall would reduce the required footprint in a building. Larger floor spaces generally increases the cost of a building. Conversely, many universities are designed with large atriums to encourage greater social interaction. This leaves branding as the only large exclusive benefit for building a biowall. A lot of money and energy is devoted to marketing and branding a university. Should the university be interested in increasing its image regarding green technologies, a biowall located strategically may be extremely beneficial. There is no price that can be associated with the visual impact of this type of branding

On the other hand, a “green” university which promotes itself on education and scientific merit may wish to brand itself with established environmental technologies that have been proven to increase sustainable development—rather than a tentative image of environmental consciousness.

It is therefore recommended that should floor space not be at a premium, and the university installs buildings with low emitting VOC materials, a large indoor garden would suffice to achieve many of the beneficial physical and psychological qualities of a biowall.

8.0 References

Ventilation for Acceptable Indoor Air Quality. (1999). ASHRAE Standard.

Berube, K.A., Sexton, K.J., Jones, T.P., Moreno, T., Anderson, S., and R.J. Richards (2004). The spatial and temporal variatios in PM10 mass from six UK homes. *Science of the Total Environment*, 324, 41-53.

Brasche, S,M., Bullinger, M., Gebhardt, H., Herzog, V., Hornung, P., Kruppa, B., Meyer, E., Morfield, M., Schwab, R.V., Mackensen, S., Winkens, A, and W. Bischof (1999). Factors determining different symptoms patterns of sick building syndrome—results from a multivariate analysis. In: *Proceedings of Indoor Air*. The 8^{th} International Conference on Indoor Air Quality and Climate, August 1999, Edinburgh, Scotland, UK, 5, 402-407.

Carrer, P, Akcini, D., Cavallo, D., Visigalli, F., Bollini, D., and M. Marconi (1999). Home and workplace complaints and symptoms in office workers and correlation with indoor air pollution. In: *Proceedings of Indoor Air*. The 8^{th} International Conference on Indoor Air Quality and Climate, August 1999, Edinburgh, Scotland, UK, 1, 129-134.

Cochet C, Nibel S, and L. Nagy (2002). Integration of occupational health criteria in the design and assessment of sustainable building—application to indoor air. *Proceedings: Indoor Air,* Monterey, California. 936-941.

Darlington, A.B. (2004). *An Integrated Indoor Air Biofiltration System for Municipal Infrastructure.*

Darlington, A.B., and M.A, Dixon, (2001). The Biofiltration of Indoor Air: Air flux and temperature influences the removal of toluene, ethylbenzene, and xylene. *Environ. Sci. Technol*, 35, 240-246.

FASTS, (2002) Indoor Air Quality in the 21^{st} Century: Search for Excellence. *Indoor Air*, 10, 68-73.

Fisk, W.J. (2000). *Review of Health and Productivity Gains From Better IEQ.* Proceedings of Healthy Buildings 2000 Vol. 4.

Fjeld, T. and C. Bonnevie. (2002). *The effect of plants and artificial day-light on the well-being and health of office workers, school children and health care personnel.* Plants for people, Int. Hort. Exhib. Floriade.

Guo, H., Murray, F., and S.C. Lee (2003). The development of low volatile organic compound emission house—a case study. *Building and Environment*, 38, 1413-1422.

Hodgson, M.J., Oleson, B. and M. Foutain (1997). Environmental acceptability in an Environmental Field Study. *Healthy Building*/IAQ, 1, 195-200.

Indoor Air Pollution: An Introduction for Health Professionals. (1994). United States Environmental Protection Agency.

Isabella, M.A., Stolzberga, R.J. and L.K. Duffy (2005). Indoor climate in interior Alaska: simultaneous measurement of ventilation, benzene and toluene in residential indoor air of two homes. *Science of the Total Environment*, 345, 31-40.

Lohr, V.I., Pearson-Mims, C.H. and G.K. Goodwin. (1996). *Interior plants may improve worker productivity and reduce stress in a windowless environment.* Plants for People.

Magee, C.K., Won, R.J. and E. Lusztyk. (2005). National Research Council Canada - Indoor Air Quality Guidelines and Standards. RR-204.

Orwell, R.L., Wood, R.A., Burchett, M.D., Tarran, J. and F. Torpy. (2006). The potted-plant microcosm substantially reduces indoor air VOC pollution: II. laboratory study. *Water, Air, and Soil Pollution*, 177, 59-80.

Orwell, R.L. Wood, R.A., Tarran, J., Torpy, F. and M.D. Burchett. (2004). Removal of benzene by the indoor plant/substrate microcosm and implications for air quality. *Water, Air and Soil Pollution*, 157, 193-207.

OSHA (1999). *Indoor Air Quality Investigation.* Technical Manual Section 3, Chapter 2. (http://www.osha.gov/dts/osta/otm/otm_iii/otm_iii_2.html#2)

Rehwagen, M., Schlink, U., and O. Herbarth (2003). Seasonal cycle of VOCs in apartments. *Indoor Air*, 13(3), 283-291.

Robertson Building Website. *Biofiltration at The Robertson Building: PLANTS Working for PEOPLE.* Accessed in October 2006. (http://www.robertsonbuilding.com/biowall.htm)

Russell, H. and D. Uzzell. (1997). *The psychological effects of plants on people in office (or other indoor setting).* Surrey University.

Schnelle Jr., K.B. and C.A. Brown. (2002). *Air Pollution Control Technology Handbook.* CRC Press.

Simonich, S.L. and R.A. Hites. (1995). Organic pollutant accumulation in vegetation. *Environmental Science & Technology*, 29, 2905-2914.

Ugrekhelideze, D., Korte, F. and G. Kvesitadze. (1997). Uptake and transformation of benzene and toluene by plant leaves. *Ecotoxicology and Environmental Safety*, 37, 24-29.

Ulrich, R.S. (1984). View through a window may influence recovery from surgery. *Science*, 224, 420-421.

Ulrich, R.S. and R. Parsons. (1992). Influences of passive experiences with plants on individual well-being and health, in: Relf D (ed): Human benefits of plants. Portland, Oregon: p 93-105.

US EPA, (2000). Health Building, Healthy People: A Vision for 21st Century. Office of Air and Radiation.

Wolverton, B.C., and J.D. Wolverton (1993). Plants and soil microorganisms: removal of formaldehyde, xylene and ammonia from the indoor environment. *J. Mississippi Acad. Sci*. 38, 11-15.

Wood, R.A. (2002). "Improving the indoor environment for health, well-being and productivity", Presented at Greening Cities: a new urban ecology. 30th April, 2002. Australian Technology Park, Sydney.

Wood, R.A. (2003). *Improving the indoor environment for health, well-being and productivity*. Greening Cities: a new urban ecology presentation.

Wood, R.A., Burchett, M.D., Alquezar, R., Orwell, R.L., Tarran, J. and F. Torpy. (2006). The potted-plant microcosm substantially reduces indoor air VOC pollution: I. office field-study. *Water, Air, and Soil Pollution*, 175, 163-180.

9.0 Annexes

9.1 Biology 101: Microorganisms and Biofiltration Systems

There exists a large diversity of microorganisms in the environment. Recently, researchers have been investigating the use of microorganisms to degrade organic compounds and waste. These practices are common in many environmental engineering applications such as biofiltration and wastewater treatment.

In biofilters, three types of microorganisms are generally present: fungi, bacteria and actinomycetes. Given the acceptable conditions such as moisture content, temperature, inorganic nutrient content (i.e. nitrogen, phosphorous, trace metals), and pH, microorganism can successfully survive.

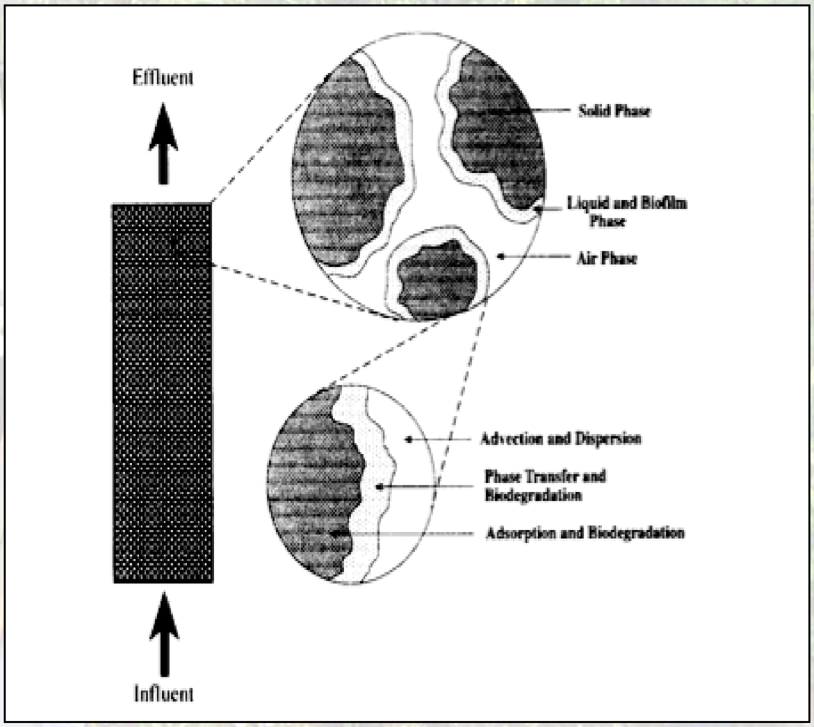

Figure 7: Biofilm Formation Within a Biofiltration System (Hodge *et al*, nd)

Microorganisms can exist as free floating, single cell organisms, however, generally many microorganisms used in environmental engineering practices exist in complex aggregated structures called "biofilms". The formation of biofilms is the mechanism by which microorganisms adhere to surfaces—such as the packing material or soil within the biofilter—and to each other. This complex of microorganisms is supplemented by an extracellular matrix of (primarily) polysaccharides and provides the community a protective layer from the environment. In addition to the protective characteristics of these biofilms, they also have been found to contain water channels that help distribute nutrients and other molecules.

In biofiltration processes, the formation of healthy biofilms—typically by humidifying the air inlet stream—is extremely important. VOCs undertake a phase change from gas to liquid through absorption by water prior to oxidation by microorganisms. It is the aqueous element of the biofilm that is the absorbant.

Like other organisms, microbes require a carbon source to grow. In the process of metabolizing the carbon source the microorganism generates energy (in the form of ATP—adenosine tri-phosphate), CO_2 and water. The VOCs such as benzene, toluene, and formaldehyde are simply an available carbon source for the microorganisms. Although there is much biodiversity in the microbial population, it is believed that many microorganisms developed an ability to degrade VOCs based on environmental pressures or availability. Root microorganisms that live symbiotically with aromatic plants such as mint or rosemary have a ready supply of VOCs being released from the plant. Table 2 outlines a number of compounds degradable in biofiltration operations.

Table 2: Chemicals and Their Biodegrabability Classification in a Biofilter. Source: Air Pollution Control Technology

Gases Classified According to Their Degradability

Rapidly Degradable VOCs	Rapidly Reactive VOCs	Slowly Degradable VOCs	Very Slowly Degradable VOCs
Alcohols	H_2S	Hydrocarbons	Halogenated hydrocarbons
Aldehydes	NO_X (not N_2O)	Phenols	Polyaromatic hydrocarbons
Ketones	SO_2	Methylene chloride	CS_2
Ethers	HCl		
Esters	NH_3		
Organic acids	PH_3		
Amines	SiH_4		
Thiols	HF		
Other molecules with O, N, or S functional groups			

9.2 Design Equation for Biofiltration Systems

In 1999, Heinsohn and Kabel developed a series of design equations for the removal efficiency of biofiltration systems. The removal efficiency is a function of the flow of air through the system, the height of the bed and the adsorption of the VOC into the water:

$$\eta = 1 - \exp(-K_o Z / U_G)\,;$$

$$K_0 = K/H_i;$$

$$K = (\alpha / \delta) D_i \phi \tanh \phi\,; \text{ where}$$

η= removal efficiency

Z=height of packed bed, m

U_g= superficial gas velocity, m/min,

H_i= Henry's constant,

α= ratio of packing surface area to bed volume, m^{-1}

δ= thickness of liquid film, m

ϕ= Thiele number for first order microbial kinetics, and

Di = diffusion coefficient of pollutant I in water, m^2/min.

Since the relative solubility of the compounds is generally constant at a fixed temperature (e.g. H_i is constant) and the kinetics of the microorganism do not change relative to a specific organic compound, the primary design consideration for the biofiltration system is to not be mass transfer limited. In essence, the depth of the bed and the velocity of the air must be controlled such that there is sufficient time for the VOC to get to, and be consumed by, the microorganisms. This is also known as the residence time.

The Air Pollution and Control Technology Handbook (2002) suggest a range of airflow rates of 0.3 to 1.6 m^3/min-m^2, a biofilter media depth of 0.5 to 2.5 m and a minimum residence time of 0.5-1.0 min depending on the biofilter media. Some examples of media include soil, compost, bark and peat. These can also be supplemented with polystyrene spheres, activated carbon or other bulking material that can increase the adsorptive capacity of the media and/or increase the relative surface area within the biofilter.

Literature has reported that biofiltration is effective for odorous compounds at a removal rate of 98 to 99%, while VOC removal rates range from 65 to 99% (Air Pollution Control Handbook). Beyond the design criteria set above, a number of other factors are associated with the efficiency of the biofiltration system. For successful biofiltration, it is recommended that pilot scale testing is completed prior to building a full-scale unit. This is to determine the best biofilter design appropriate for the specific contaminants in the system.

Although biofiltration systems are a relatively new technology, it is now considered a Best Available Control Technology (BACT) for treating contaminated gaseous streams (Control of VOC and HAP by Biofiltration, 2002). Biofiltration units have been effective and economically efficient at removing VOCs.

9.3 Biology 101: Plants and Phytoremediation

The mechanism by which plants take up organic compounds is dictated by the chemical and physical properties of the pollutants, the environmental conditions as well as the plant species (Simonish, S., and Hites, R., 1995). Generally speaking, the three main mechanisms are: 1) through the roots in contaminated soil, 2) through the stomata on the leaf for volatile organic compounds, and 3) particle deposits onto the waxy cuticle of the leaf.

In 1996, Ugrekhelidze *et al* discovered that the uptake of benzene and toluene—two VOCs—is primarily by the plant leaves. Following absorption through the stomatas, the aromatic ring of the benzene and toluene molecules are cleaved and converted into nonvolatile organic acids as part of a modified photosynthesis process. Their studies, supported by others, indicate that the absorption of these VOCs is dependent on the number of stomata and the structure of the cuticle of the plant species. Furthermore, this process was strongly stimulated in light.

A number of studies indicate that potted-plants can have a beneficial effect on the indoor air quality. The first studies in 1993 by Wolverton and Wolverton concluded that plants could reduce air-borne contaminants such as dust and VOCs. Further research indicates that the plants made small direct contribution to the improvements, but were in fact derived from the microorganisms that populate the plants' root environment.

It is known that plants can secrete up to 40% of their net photosynthetic product from their roots. These secretions help sustain and increase the population of species specific communities of root bacteria known as rhizospheres. This root microcosm is, generally, a symbiotic relationship between the microorganisms and the plant, as the plant secretes a continuous carbon source while the microorganisms typically fixes nitrogen for the plants. (Nitrogen is an important compound for all organisms as it is the building block for amino-acids which are used for the production of proteins.)

9.4 Air Quality Questionnaire

In an effort to measure the psychological effects associated with biowalls, a survey was developed to gauge the general well-being and views on air quality of office employees on Queen's campus. However, due to the lack of time and resources, the survey was never distributed. A list of the questions is included as part of this annex.

The groups to be studied are:

1) Group exposed to biowall (offices in the Integrated Learning Centre)
2) Group not exposed to biowall (offices in Chernoff)
3) Group exposed to other art (offices in Agnes Etherington Art Gallery)

These groups were chosen to allow separation of the effects due to the biowall, greening and other fixtures that may influence mood. The survey would be distributed to each of these groups and the responses would be compared.

Workplace Satisfaction Questionnaire

Please answer all questions to the best of your ability in the order that they appear.

Gender: M/F

Age:

1. In which building do you work on Queen's campus? Please specify where inside the building.

2. How long (in months) have you worked at your current job?

3. How would you rate your energy level on a typical day at work?

1---------------2---------------3-----------------4---------------5

extremely low   extremely high

4. Do you spend your breaks inside the building that you work?

If yes, where in the building do you prefer to spend your breaks? What features about it do you enjoy and why?

If no, explain why not?

5. On a scale of 1 to 5, how much do you agree or disagree with the following statements? (1 = strongly disagree and 5 = strongly agree)

I feel that the work I do has purpose. 1---------2---------3---------4---------5

I get along with my coworkers. 1---------2---------3---------4---------5

I feel excited to come to work each day. 1---------2---------3---------4---------5

I find that I can easily get my work done on time. 1---------2---------3---------4---------5

I often feel anxious while at work. 1---------2---------3---------4---------5

6. How many sick days have you taken in the past year (between now and this time last year)?

7. Which of the following, if any, have you suffered from in the past 6 months? (check all that apply). Use an X to indicate one-time, C for constant or S for sporadic occurrences.

___ headache
___ nausea
___ itchy eyes
___ stuffy nose
___ fatigue
___ sore throat
___ dizziness
___ difficulty breathing
___ difficulty concentrating
___ sensitivity to odours
___ muscle pain

8. How do you feel about your workplace's current air quality on a scale of 1 to 5?

1---------------2---------------3-----------------4---------------5
extremely low ... extremely high

9. Are you currently suffering from any medical conditions that might influence your perception of air quality? ___ Yes ____ No. If yes, please elaborate.

10. Thinking about other buildings you have worked in in the past, how would you rank your current workplace building's air quality relative to them?

1---------------2---------------3-----------------4---------------5

far worse ... far superior

11. What do you think could be done to improve the air quality of your workplace?

12. Has there been any recent activity in your workplace that might have an effect on air quality? If yes, please explain.

13. Do you think that implementing plants in the workplace will have a significant effect on improving the air quality of your workplace? Please explain.

14. If your workplace is located in the Integrated Learning Center, do you think the living wall has contributed positively to the air quality in the building? If so, in what way?

15. On a scale of 1 to 5, how would you rate your knowledge of living wall technology?

1---------------2---------------3-----------------4---------------5

no knowledge at all ... extremely knowledgeable

- End of survey – Thank you! -

9.5 Site Visits

All of the following biowalls were constructed by Air Quality Solutions Inc with the exception of the one belonging to Environment Canada.

9.5.1 Toronto and Region Conservation Authority head office

Installation date: April 2004

Motivation for building wall:

- Health benefits
- Energy savings (5-10% reduction in costs)

Wall Specifics:

- Retrofitted into existing building
- Dimensions: 3m wide by 2.5m high
- 2-sided, foliage on both sides of the wall
- Treated air is distributed through the HVAC system
- Capable of handling airflows of 2000 cfm
- Plants are supplied with low natural light supplemented by fluorescent and incandescent bulbs

Price tag: $160,000 (includes cost of HVAC system upgrades)

Other comments:

- One of first walls to have benefits study conducted

Figure 8: Biowall in the Foyer of the TRCA

9.5.2 Environment Canada's Centre for Inland Waters

Motivation for building wall:

- Alternative method for raising humidity levels in the building without using steam equipment
- A nice place for employees to socialize

Wall specifics:

- Passive system – not connected to HVAC system, relies on convection for distribution of treated air
- Pond with live fish at the foot of the wall adds increases aesthetic appeal

Price tag: $10,000-$20,000 (includes cost of sealing water basin to make waterproof)

- Considerably less because system is passive and therefore less complex to install
- Also contracted by a different company – not Air Quality Solutions

Figure 2: Biowall in the Foyer of the Center for Inland Waters, Environment Canada

9.5.3 University of Waterloo, Environmental Science Building I

Motivation for building wall:

- Innovative way to reinvent the look of the building’s outdated foyer while demonstrating concept related to environmental science
- Allows faculty to stand out on campus
- Provides a impressive backdrop for photographs and faculty press conferences

Wall specifics:

- Have 3 walls: 1 in foyer, 2 in courtyard
- Passive system – not connect to the HVAC system
- Walls in courtyard provide sufficient humidity to raise the room temperature during winter months – no need for extra heating

Figure 3: Biowall in the Foyer of the University of Waterloo

9.5.4 University of Guelph Humber Building

Installation date: completed in May 2004

Wall specifics:

- Dimensions: 4 stories – 30ft wide by 55ft high
- Requires the use of a crane to scale the wall during maintenance
- Currently the largest installation by Air Quality Solutions Inc.

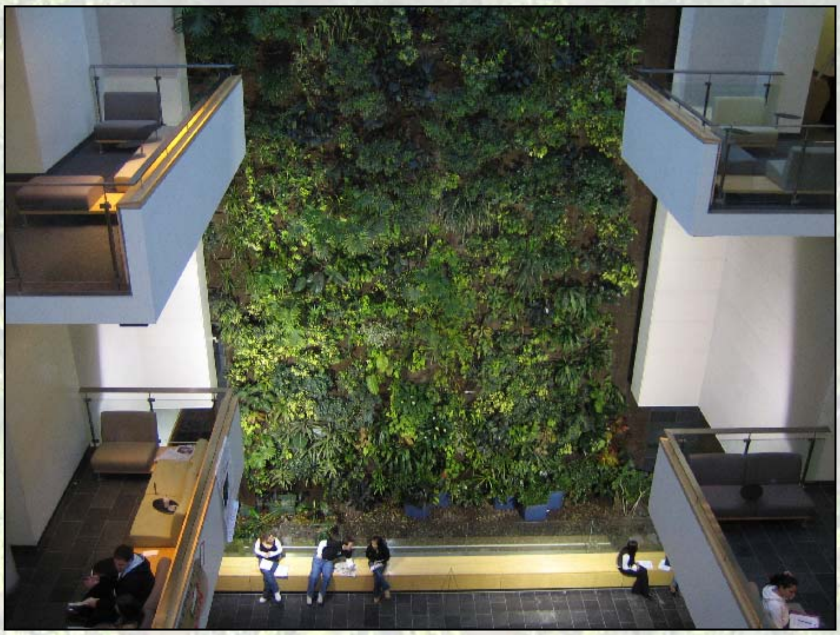

Figure 4: Biowall in the Foyer of the University of Guelph-Humber

9.5.5 Robertson Building

Installation date: March 2004

Figure 5: Biowall in the Foyer of the Robertson Building

Wall specifics:

- Retrofitted into a 90-year old historical building which now houses the offices of numerous non-government organizations
- Size: $24m^2$
- Active system – biowall is connected to HVAC system
- Building also has a $370m^2$ green roof that was built in June 2004

9.5.6 St. Gabriel's Parish

Installation date: 2006

Wall specifics:

- Canada's first environmentally friendly church
- Registered for LEED silver rating

Figure 13: Biowall in the Foyer of St. Gabriel's Parish