UBC Social Ecological Economic Development Studies (SEEDS) Student Report

# Enhancing CHBE Indoor Air Quality: Biowall Technology


**Lindsey Curtis, Maggie Stuart**

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Dr. Anthony Lau

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Lindsey Curtis

Maggie Stuart

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# Table of Contents

## List of Tables and Figures

## 1.0 Introduction

Indoor Air Quality (IAQ) is an extremely important factor of a building, as it consists of the air within and around it and relates to the health and well being of its occupants. It has come to our attention that many students, faculty and staff are unsatisfied with the air quality in the Chemical and Biological Engineering Building. From conducting an air quality survey to the occupants of the building, the consensus was that the building has problems including poor ventilation, circulation, odor, temperature control and 'sick building syndrome' (SBS). The technology that we are proposing to help improve the air quality and well being of the building and its occupants is a biowall.

The concept of a biowall is an innovative project that utilizes sustainable air purification methods. They 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 volatile organic compounds (VOCs), benzene, toluene and other toxic fumes are degraded into end products that are harmless to humans and the environment.

Improving the air quality of the Chemical and Biological Engineering building will have direct benefits to the health and wellness of all students in the campus community who have lectures in the building. Since the wall is proposed to be in the lobby of the building, the esthetic component of the system will benefit all visitors to the building as well as those in the faculty. Biowalls can also effectively improve the thermal performance of a building, thus resulting in less energy consumption and greenhouse gas emissions (Loh, 2008). In addition, biowalls reduce noise pollution, as their plants and planting medium are effective sound barriers. Another benefit of the biowall will be educating those who pass through the building regarding the importance of air quality, and workplace health.

This innovative technology has been implemented in several Universities in Eastern Canada including: Queen's, Guelph and U of T. It has also become an attractive addition to companies as it not only improves the IAQ of the building and the well being of its occupants but gives the company of positive image of sustainability and innovative thinking.

# 2.0 Indoor Air Quality

## 2.1 Volatile Organic Compounds

Volatile Organic Compounds (VOCs) are gaseous organic chemical compounds that have significant vapor pressures and can affect human health and the environment. VOCs are numerous and varied and are emitted by mostly indoor sources. They can be 10 times more concentrated indoors than they are outdoors. Sources of indoor volatile organic compounds include:

- 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)

(Berube, 2004)

VOCs are not acutely toxic but they do have chronic health effects that contribute to sick building syndrome (SBE). SBE is a collection of symptoms that include nose, throat, eye, skin irritation, headache, fatigue, dizziness, nausea and shortness of breath. 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. Studies have also shown that prolonged exposure of VOCs can increase leukemia and lymphoma (Hum and Lai, 2007).

Indoor VOCs include chemicals such as formaldehyde, benzene, toluene, alcohols, trichloroethylene and naphthalene. Below are the Canadian guidelines for indoor air contaminants.

Table 1: Canadian Guidelines for Indoor Air Contaminants

| Contaminant | Maximum Exposure Limits (ppm)* |
|---|---|
| Carbon dioxide | 3500 [ L ] |
| Carbon monoxide | 11 [ 8 hr ]<br>25 [ 25hr ] |
| Formaldehyde | 0.1 [ L ]<br>0.05 [ L ] ** |
| Lead | Minimum exposure |
| Nitrogen dioxides | 0.05<br>0.25 [ 1 hr ] |
| Ozone | 0.12 hr |
| Sulfur dioxide | 0.38 [ 5 min ]<br>0.019 |
| Benzene | 10 |
| Toluene | 200 |
| Trichloroethylene | 100 |
| Naphthalene | 9.5 |

* Numbers in brackets [ ] refers to either a ceiling or to averaging times of less than or greater than eight hours (min = minutes; hr = hours; L = long term. Where no time is specified, the average is eight hours.)
** Target level is 0.05 ppm because of its potential carcinogenic effect. Total aldehydes limited to 1 ppm.
(Hum, Lai, 2007)

Volatile organic compounds have different degradability and those that can be degraded by biofiltration methods are shown below in Table 2. Those with a rapid degradability will most likely be the contaminants that are removed by the biowall. Those with a very slow degradability would be more difficult for the plants to remove.

Table 2: Chemical and their Biodegradability Classification in a Biofilter

| 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 | | | |

(Hum and Lai, 2007)

## 2.2 Improvement of Air Quality, Health and Well-being

Many CHBE students spend a large portion of their time inside the building in class, working on assignments, having group meetings, etc. With so much time being spent indoors it is extremely important to have a high indoor air quality. To help lower energy costs, buildings are built as air tight as possible. This does trap the conditioned air but it also traps the gases pollutants that arise. Elevated VOCs and poor ventilation result in sick building syndrome (SBS). Experiencing the symptoms from SBS hinders the productivity made in the building, which is very undesirable.

## 2.3 CHBE Chemical Inventory

As chemical engineering students we are aware of some of the volatile organic compounds that are being used daily in the building. With undergraduate and graduate students conducting experiments every week for hours at a time, there is reason for concern regarding what chemicals are being used in CHBE. Interest in the chemical database was sparked in being able to determine some sources of VOCs in the building, and how their recirculation could be limited.

A recent project through the CHBE sustainability club was to create a chemical data base throughout the building. Over the summer months, all of the chemicals in the Clean Energy Engineering building, Stores, as well as the undergraduate and graduate laboratories were recorded. Through the database chemicals can be found by their common name and a list of their quantity, purity, and storage location.

From a common list of chemicals that emit VOCs, their locations and storage methods were summarized in Table 3. Monitoring where the VOCs in the building are coming from would be a difficult task. However, it is possible to limit the potential of VOC emissions from chemicals that are known to have high vapor pressures. For volatile compounds like benzene, ethanol, acetone and other low MW compounds, the vapor pressure produced at room temperature is significant.(Gernon et al., 2010)

Ensuring that large volumes of these chemicals are being stored with proper ventilation is essential.

Table 3: CHBE Chemical Database Summary

| Chemical Name | Purity/ Grade (%) | Location (CHBE) | Storage | Quantity | Temperature ($^oC$) | Vapor Pressure (mmHg) | Molecular Weight (g/mol) |
|---|---|---|---|---|---|---|---|
| **Formaldehyde** | 37 | 5.02 | Cabinet | 1L | 20 | 1.3 | 30.03 |
| **Benzene** | Absolute | 5.42 | Fumehood | 350mL | 22 | 230 | 78.11 |
| **Toluene** | A.C.S | 6.28 | Fumehood | 13L | 20 | 22 | 92.14 |
| | 98 | 5.02 | Cabinet | 2L | | | |
| **Tri-chloroethylene** | A.C.S | 5.22 | Cabinet | 1L | 25 | 75 | 131.4 |
| **Naphthalene** | 98 | 5.42 | Cabinet | 1.1L | 25 | 0.087 | 128.16 |
| | | | | | | | |
| **Acetronitrile** | | 5.02 | Cabinet | 2L | 27 | 100 | 41.05 |
| **Acetone** | | 5.02 | Cabinet | 4L | 20 | 180 | 58.08 |
| | A.C.S | 6.18 | Cabinet | 4L | | | |
| | 58.8 | CERC 1.45 | Fumehood | 4L | | | |
| **Methanol** | | 5.02 | Cabinet | 16L | 20 | 97 | 32.04 |
| **Butanol** | | CERC 2.72 | Cabinet | 3L | 20 | 5 | 74.12 |
| **Isopropanol** | 99.5 | 5.02 | Cabinet | 40L | 25 | 44 | 60.1 |
| | | 6.18 | Cabinet | 8L | | | |

## 2.4 Temperature Control

Temperature control of the in a building is an important factor and it ahs been observed as an issue in the CHBE building. This is shown by Figure 14 in Appendix A. The evapotranspiration from living walls contributes to the lowering of temperatures around the planting. The Institute of Physics in Berlin conducted a study with 56 planter boxes on four floors and they obtained a mean cooling value of 157kWh per day

(Schmidt, 2006). In the summer, buildings with a vegetation-covered wall, the surrounding air temperature can be decreased. The study concludes that the temperatures are lowered by biowalls can bring temperatures to a more human-friendly level. This not only also for cooling buildings interior but it also reduces energy costs (Loh, 2008).

### 2.5 Reduction of Noise Pollution

The main atrium of the CHBE is open to the second floor by a mid-height balcony. It is very open and the noise travels to the second floor offices. There are many students moving through the atrium, as there are classrooms located on the first floor. This makes it loud on the second floor and can disrupt faculty and staff in their offices. The biowall can act as a sound barrier. The planting medium and plants would be able to reduce the amount of noise being travelled to the second floor. Their effectiveness of sound attenuation comes from green roof research. As well as, living systems have been used on many highways to reduce noise pollution and this is has been found to be an effective method. (Loh, 2008)

### 2.6 Reduction of Particulate Matter

It has been proven that plants can reduce the particulate matter in a building. Particulate matter in indoor air can be too high and can cause irritation of the eyes, throat and nose. Plants increase humidity, thereby increasing the amount of particulate matter binding to the plant. This would reduce the amount of particulate matter inside the building, thus reducing or eliminating the health effects (Lohr, 1996).

## 3.0 Pollution Control Techniques

The method at which the biowall removes air pollutants needs to be defined to get a clear understanding of its method. Biofiltration and phytoremediation are two biological air pollution control techniques that form the theory of the biowall. The biowall is a simplified version of a combination of these two techniques.

### 3.1 Biofiltration

Biofiltration is a relatively recent pollution control technique that uses living material to capture and biologically degrade process pollutants. It uses microorganisms to oxidize VOCs and oxidizable inorganic vapors and gases in a sir stream producing innocuous end products. Many biofiltration systems are started with microorganisms from uncharacterized sources such as sewage treatment plants and compost. There are three main biofiltration systems; biofilters, bioscrubbers and air biotrickling filters. The biowall is most similar to biofilters.

In biofilters, the microorganisms are attached to the porous packed bed. In this packed bed biodegradable volatile contaminants are absorbed and diffused into the wet biofilm that grows on the porous packed bed particles. Thus, in this biofilm, the microorganisms oxidize the VOCs and oxidizable inorganic gases into carbon dioxide, water, mineral salts and biomass. The clean exhaust leaves the open top of the biofilter. Below is a schematic diagram of an open biofilter. (Janni et al, 1998)

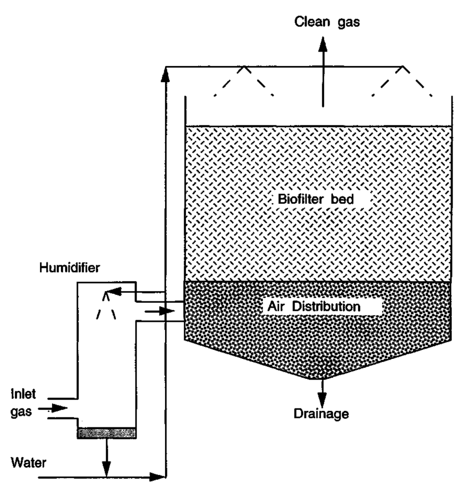


Figure 1: An open Biofilter

### 3.2 Phytoremediation

Phytoremediation involves the use of plants to degrade, contain or stabilize various environmental contaminants in the soil, water and air. This has become an emerging technology because of the development of understanding of the molecular and biochemical mechanisms of the metabolism of various chemicals in plants. Some advantages to phytoremediation include, it is aesthetically pleasing, solar-energy driven cleanup technology, useful for treating a wide range of environmental contaminants and it's useful in low levels of contamination. This has not become a standard bioremediation practice and further research is still needed.

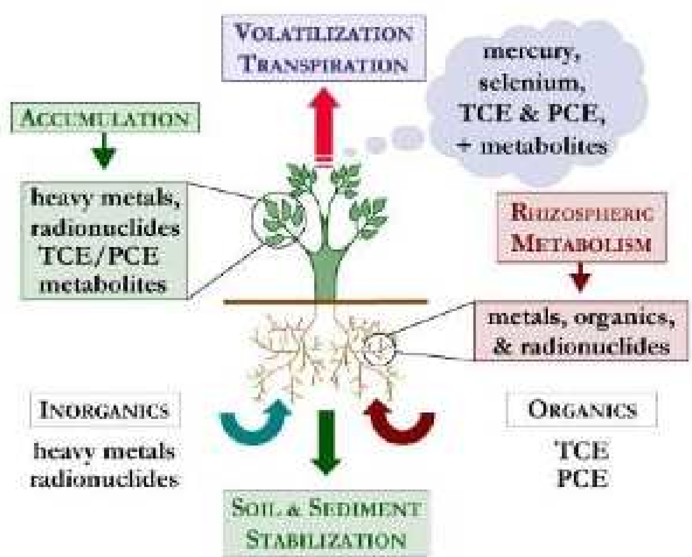


Figure 2: Phytoremediation Mechanism

## 4.0 Plants and Planting Medium

### 4.1 Plant Selection

Plants are chosen for their ability to tolerate indoor lighting conditions and their ability to improve indoor air quality. Important factors to consider when choosing plants for a project are the orientation, climate, light and wind exposure, and maintenance regimes. There are so many different plants that can be used, therefore the choice of plant species is completely dependant on the above factors. The following are some examples of plants that are can be used in the biowall.

- Aglaonema (Algaomema commutatum) & Spathiphyllum spp. (mixed aroids)
- Spider plant (Chlorophytum)
- Croton (Codiaeum)
- Cordyline
- Dragon Plant (Dracaena)
- Ficus (verigated)
- Rubber Plant (Ficus Elastica)
- Ivy (Hedera)
- Palms (Dypsis, Howea, or Chamaedorea spp.)
- Maidenhair Fern (Adiantum)
- Philodendron (several species)
- Purple Heart (Setcreasea pallida, similar to the common Tradescantia)

## 4.2 Plant Mechanism

The mechanism that plants take up organic compounds, are dictated by the physical and chemical properties of the pollutants, the plant species and the environmental conditions (Simonish, S., and Hites, R., 1995). From this, there are three main mechanisms that plants actually take up the pollutants. The mechanisms are through the roots in the contaminated soil, through the stomata on the leaf and particle deposits onto the waxy cuticle of the leaf. These mechanisms can be explained by biofiltration and phytoremediation, which were previously mentioned.

There have been numerous studies accessing where the primary uptake of VOCs is on the plants. A study perform by Ugrekhelidze *et al* discovered that the uptake of two VOCs toluene and benzene was primarily by the leaves of the plant. The foreign compounds can penetrate into the leaf in two ways, through the stomata or the epidermis.

For gaseous pollutants it was primarily done through the stomata. After the absorption, the aromatic ring of benzene and toluene molecules are converted into non-volatile organic acids. The ability of a hypostomatous leaf to take up benzene and toluene from air by its adaxial side and transform them into non-volatile components indicates that the leaf cuticle is permeable to the aromatic hydrocarbons. The amount of absorption of contaminants is dependant on the number of stomata and the structure of the cuticle (Ugrekhelidze *et al,* 1996).

Many other studies have shown that the roots take up most of the VOCs out of the air. Once the VOCs are degraded, the products can be used to food for the plant. It seems to be dependant on the species of the plant and the origin and type of the contaminant.

There have been studies that reveal that some plants actually emit VOCs. A study done by the American Society for Horticultultural Science found 23 volatile compounds in Peace Lily, 16 in Areca Palm, 13 in Weeping Fig, and 12 in Snake Plant. Although, plants most likely remove more VOCs than they omit. This is a very important discovery that will be important to consider which plant species to implement.

### 4.3 Planting Medium

There are two types of planting medium that can be used; soil and hydroponic medium. Soil is easier to maintain and require cheaper fertilizers. Although hydroponic medium is more favourable and more commonly used as there are no pests, weeds, less water, cleaner and more growth. The most preferred hydroponic medium is a 50/50 mixture of vermiculite and perlite. Coconut fibre is also becoming one the most popular growing mediums (Butkovich *et al*, 2008).

## 5.0 Design

### 5.1 Biowall Type

Biowall structures have been separated into two categories relating to the nature of their purification method. These structures can be set up as either a passive or an active structure. Each structure is conducive with its name in that the active system actively purifies air through a distribution method such as the HVAC system of a building, while the passive system relies on plants purifying the air in the room without aid in the movement of the air.

### 5.2 Passive System

The passive system has less of an effect on the overall air quality in the building. This is expected as the distribution of clean air is not aided by fans or building circulation systems such as the HVAC. The circulation of unclean air through the wall is reliant on the “breathing” of the plants.

This method is recommended for small rooms with poor air quality such as copyrooms or small computer labs.

### 5.3 Active System

The active system is generally attached to an HVAC system in the building and can therefore distribute air throughout the building. This concept is a sustainable alternative for cleaner indoor air, as the biowall can clean used air already in the building through the recirculation ducts. Filtering this air through the biowall will eliminate these ducts from circulating contaminated air from one room to the next. This also reduces the intake of outdoor air and therefore reduces the energy consumption of the HVAC system.

Use of an active system can require a large scale biowall, if it is circulating air throughout a large building, such as CHBE. For example the biowall at Queen’s University is 3 stories high, and is attached to three separate air ducts in the building.

### 5.4 Hybrid System

A combination of the active and passive systems can be used, and is also less expensive. Air is still drawn through the biowall to ensure proper filtering of the air through the root systems of the plants. This is done by a negative pressure system attached to the back of the wall. Clean air is blown out the top of the wall and is distributed throughout the area. Ideally the recirculation ducts are above the wall, and the clean air being blown through the top of the system is taken into these ducts and redistributed throughout the building. This way there is less complication with designing the system to be hooked up directly to the HVAC, but the purified air can still be distributed throughout the building.

### 5.5 Structure

Figure 1 shows three possible design structures for a biowall system. The panel system consists of individual panel structures which are attached to cladding rails on the building wall. Each wall panel contains the growing medium, as well as the plants. This system is beneficial because each panel can be pre-grown and construction of the wall takes very little time.

The felt system consists of a felt layer in which the roots of the plants are embedded in small felt pockets filled with growing medium. Behind the growing medium is a waterproof backing of marine plywood or an ‘eco sheet’ which is made from waste plastics. The front of the system is held on by ties through the back panel.

The third system is a trellis system which consists of a few small planters on the top and bottom of each story of the biowall. This system is used for biowalls that incorporate vine-like plants that are able to climb a trellis structure. This system is less likely to be used as an active system.

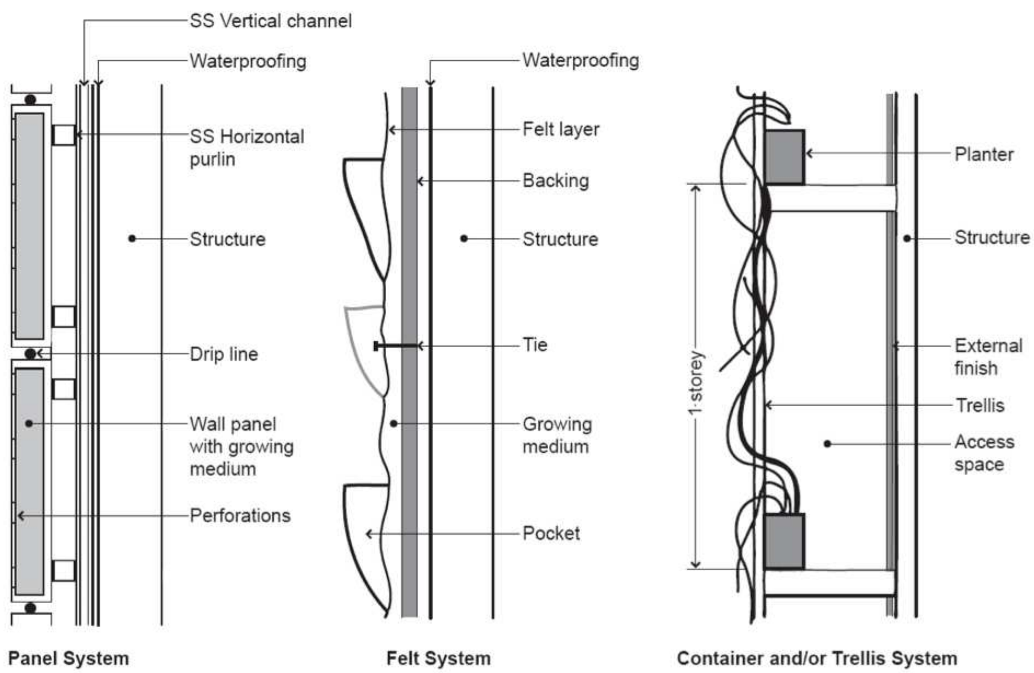


Figure 3: Three Biowall Structure Examples

### 5.6 Irrigation

There are two main types of irrigations systems that can be used in biowall structures. The first is a drip line which is connected to the top of each panel system, or can be run through the biowall at each storey, and distribute down the wall by gravity. The second method is a reservoir system, where small reservoirs are located behind each plant cell that overflow into the adjacent cell and continue throughout the wall in an serpentine fashion.  To limit water use, plants that do not require a lot of water will make the biowall more stainable.

For small structures the reservoir system can be filled manually and watered as frequently as other indoor plants in the building. However, for large systems an ideal irrigation system will be automatic and built in to the wall. This set up consists of a water reservoir at the bottom of the wall, which is pumped to the top of the wall and distributed through a drip line. An alternate option would be to connect to an available water line in the building and simply draw water from this when needed.

As the biowall is a green initiative and promotes energy savings and sustainability, water use should be kept to a minimum. High water flows associated with the biowall at Guelph are an example to learn from. The CIRS building at UBC has decided not to incorporate a biowall into their building design due to the issues of high water consumption. (Cayuela, 2010)When considering implementation in CHBE it will be very important to assess the types of plants in terms of watering requirements, and find the most energy efficient method of watering the wall, with the least amount of water volume.

## 6.0 CHBE Air Quality Survey

A survey was conducted with the students, faculty and staff about the air quality in the CHBE building. The survey was mainly filled out by undergraduate students (70%) and their responses revealed that many were unsatisfied with the air quality. Many complained about an odor in the main atrium that is not helped by constant re-painting of the atrium walls. Particular rooms of concern for the students included the classrooms on the first floor, the third floor computer labs and the undergraduate labs on the fourth floor. The air was observed to be dry and badly circulated. The graduate students' rooms of concern were the research labs and several offices on the 5$^{th}$ and 6$^{th}$ floor. It was expressed that the research labs were cold and dry resulting in throat irritation. Faculty and staff were concerned about the air quality in many offices in the CHBE building and the copy room on the second floor.

As you can see from the above responses, almost every floor and area of the CHBE building was expressed as an area of concern. In addition, 57% of the people who answered the survey were unsatisfied with the temperature of the building. Temperature is one of the most important indicators of a building's indoor air quality (IAQ). The American Society of Heating, Refrigeration, and Air-Condition Engineers (ASHRAE) has published recommend standards for thermal comfort parameters. Maintaining a building within the following ranges of temperature and relative humidity will satisfy thermal comfort requirements of most occupants.

Table 4: ASHRAE Temperature Regulations

| Measurement Type | Winter | Summer |
|---|---|---|
| Dry Bulb at 30% RH | 68.5°F - 76.0°F | 74.0°F - 80.0°F |
| Dry Bulb at 50% RH | 68.5°F - 74.5°F | 73.0°F - 79.0°F |
| Wet bulb maximum | 64°F | 68°F |

Relative humidity * 30% - 60% 30% - 60% * Upper bound of 50% RH will also control dust mites. ASHRAE Standard 55-1992, Thermal Environmental Conditions for Human Occupancy (PHNC, 2010).

Many symptoms of VOC exposure are experienced in the CHBE building with high response of headaches and fatigue. The results are shown and summarize in Appendix A. From the written results, the main complaints about the air quality in the CHBE building is the odor, poor ventilation, poor temperature control, dryness and ability to cause people to develop headaches after spending a few hours in the building.

## 7.0 Implementation Initiatives

In a previous biowall implementation study done by Allan Darlington in 2004, air quality testing as well as air quality satisfaction surveys were completed before and after the implementation of the biowall system. It was determined that the overall well being of the building occupants increased after the implementation as well as the perceived air quality by the occupants.

Air quality testing is scheduled to be conducted in March 2011 to determine the pre-installation quality of the building, and determine the feasibility of implementing a biowall. In addition to the preliminary air quality surveys that were completed, a post-installation survey will be issued to determine the change in perceived air quality by occupants.

To raise awareness of the project and its sustainable initiatives, a small scale structure is planned to be built which will stand alone in the atrium. This small biowall will be portable and therefore, it will be a temporary structure that will not affect the original design of the building.

### 7.1 SEEDS Registration

The feasibility of implementing a biowall into the CHBE building has been registered as a UBC SEEDS (Social, Ecological, Economic, Development Studies) project. SEEDS supports sustainability on campus through collaboration between staff, faculty and students. It is a way to initiate relationships between groups of individuals who would otherwise not have the opportunity to work together, while involving a real-life operational sustainability issue at UBC. This project is being conducted with the help of a team of undergraduate, graduate and faculty members in CHBE. Increased interest in sustainable benefits of the biowall has interested the CHBE sustainability club. We have proposed the idea to the club president who is helping us to apply for further funding towards the feasibility study. The SEEDS registration form can be found in Appendix C.

### 7.2 Cost Analysis

The capital cost of the biowall is approximately $100-130 per square foot. With measurements of approximately 100 square feet, our biowall project will cost a minimum of $10, 000. This estimate was derived from a consultation through the company Green Over Grey, which specializes in eco-friendly initiatives. Under most circumstances, a project like this would be partially undertaken by the students and faculty within the Chemical Engineering Department. However, to avoid liability issues and to allow the system to perform at optimum capability, we feel that awarding the construction contract to a local company would be the most reasonable option. Therefore, the provided quote includes salaries, supply costs, equipment, installation and project designs. Students and faculty will be an active participant in the design, implementation, and maintenance of this project.

UBC building operations will be scheduled to perform a quote in the CHBE building to determine how much it would cost to attach the structure to the HVAC, as well as alternative options such as a hybrid-passive system.

### 7.3 Potential Funding Applications

For the implementation of this project, there must be funding available. Currently this project is a feasibility study, however, many aspects of the feasibility study may need funding. The estimate from the UBC New Job Strategy Committee is free, which includes setup and installation cost estimates. According to the Facilities manager Adam McCluskey, all projects under $50,000 are coordinated through the construction office and internal trades handle the labor. UBC usually requires three quotes from external companies, and determines if they can build the project for less within the university staff.

Funding applications that we have applied for include the Xerox sustainability fund, which we were not granted, based on a larger number of projects than funding. The project fell short in supporting the energy saving initiatives of the biowall. Future funding that will be applied for including the Fisher Scientific fund, which is being supported through the CHBE sustainability club.

There are many companies currently supplying funding for green initiatives through contests, including BC Hydro and TD Canada Trust. We plan to use all of these resources and try to raise as much money as possible.

## 8.0 Air Quality Testing and Monitoring

## 8.1 Air Quality Testing

In support of the feasibility study on the effects of a biowall, the air quality throughout the building is scheduled to be tested on the third, fourth and fifth floors of the CHBE building. Due to lack of availability of air quality testing equipment on campus, the testing will be conducted in collaboration with Dr. Karen Bartlett's OCCH 502 graduate class, next term. Previous air quality testing performed in CHBE in April 2010 by the same class was conducted on the second floor in various offices as well as the copy room.

The air quality instrumentation that we will be learning to operate includes the P-track for particulate matter measurements, the Q-track for humidity and CO2 levels, and the ppbRAE for VOC levels.

The Q-trak is a real time data logging analyzer which conducts spot checks for carbon dioxide, temperature and relative humidity. It can be used for 24 hour monitoring of a certain area inside a building and logs the respective levels with respect to time. The TSI Q-Track Plus 8554 Air Quality Monitor uses an infrared sensor to analyze for $CO_2$.

The P-trak counts the amount of ultrafine particulate in the air in the range of 0.02 to 1 micrometer. These particles are the ones that often accompany or signal the presence of a pollutant that is the cause of complaints about indoor air quality (Envirotest, 2010).

The ppbRAE is a highly sensitive Photo-ionized detector (PID) which provides true parts-per-billion levels for the total VOC concentration in the sampling area. The ppbRAE is the most sensitive hand held VOC monitor available. A PID detects ions using high-energy photons in the ultraviolet range. The molecules are broken down into positively charged ions, which are ionized when they absorb energy from the UV light. The gas is electrically charged and the ions produce an electric current which are detected by the monitor. Therefore, a higher concentration of the VOC compounds produce a larger current and a higher reading displayed on an ammeter.

In addition, to determine the air flow patterns and circulation, an air flow visualization smoke tube was used. This system generates a non-toxic smoke which is the same density as air. The smoke that is generated shows the air flow patterns throughout the room produced by the ventilation system. This system also shows the pressure differentials, meaning whether they are positive or negatively pressurized in comparison with adjacent rooms and hallways.

### 8.2 Monitoring Methods

Real time monitors in HVAC systems can be an effective way of monitoring the VOC and CO2 levels that are being recirculated throughout the building. Such monitors can be mounted in the air ducts behind the biowall filter and logged in real time through a computer program. High levels of CO2 or VOCs can signal fans to turn on and off when the air quality is back to acceptable levels. The use of such monitors can reduce energy costs and optimize proper ventilation. (Aiken, 2009)

As mentioned previously, it is difficult to propose ways of monitoring which areas contaminants are coming from in the building, especially since VOCs are given off by so many sources in a building. However, by monitoring VOCs in the recirculation ducts, the indoor air quality can be improved by increasing the amount of outdoor air intake when VOC readings are detected.

To create awareness in the faculty, it could also be an interesting addition to the CHBE website to log the real time VOC and CO2 levels online, and show the effects of the biowall purification. This concept has already been introduced at Queen's university in their Integrated Learning Center.

## 9.0 Conclusion

In Conclusion, adults currently spend about 80% of their time indoors, and consume an average of 15kg of air per day (Aiken, 2009). Therefore, indoor air quality is becoming an increased concern for office buildings, schools as well as homes. Biowall technology is a sustainable initiative that can potentially save on utility cost, while improving indoor air quality. In addition, living in an urban environment limits interaction with nature, which has been proven to cause increased depression and anxiety (Darlington, 2004). Adding green spaces to buildings can improve the overall well being of occupants, and create a healthier environment for everyone. Biowalls are a new technology that can add appealing green space, while actively enhancing the air quality in a building.

Implementing a biowall into the CHBE building would be an interesting feature for all visitors to the building, and create the image of promoting sustainable initiatives on campus. The biowall would also help enhance the air quality in the building, and potentially reduce the energy required for the HVAC system by filtering the recirculated air.

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# Appendix A – Survey Results

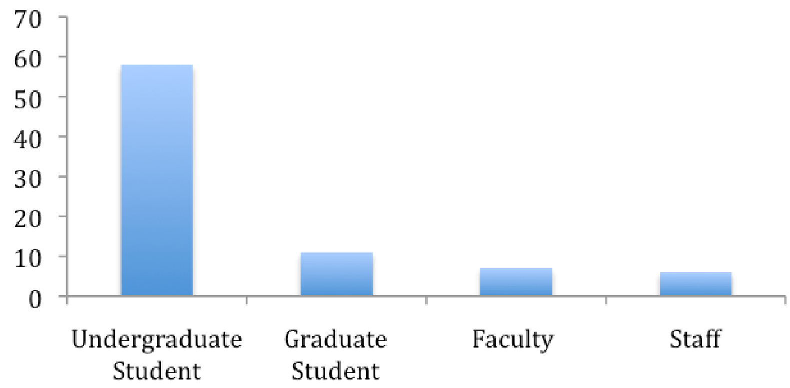


Figure 4: Survey Demographic

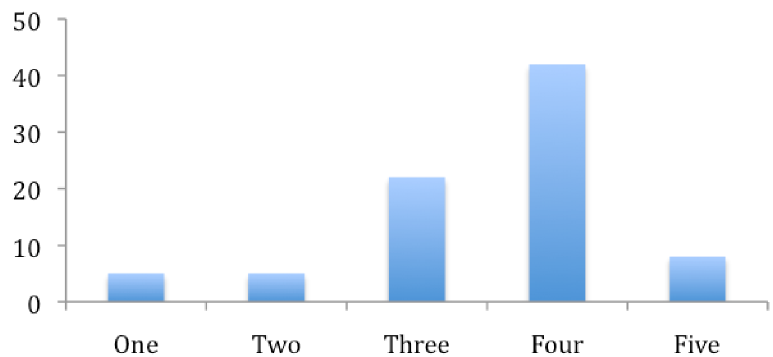


Figure 5: How satisfied are you with the air quality in the CHBE building? With 5 being the best and 1 being the worst.

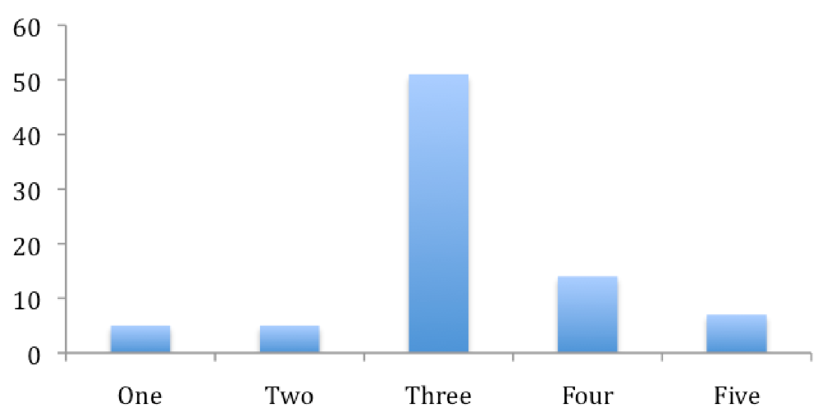


Figure 6: Does the air in your study/work space interfere (1) with or enhance (5) your productivity?

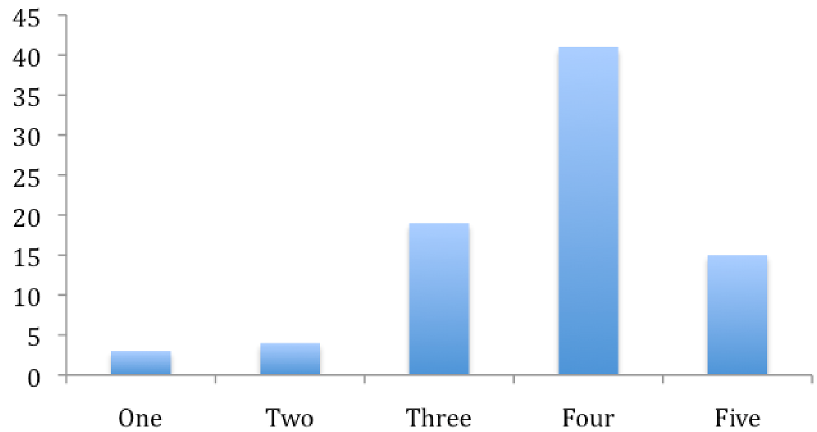


Figure 7: How satisfied are you with the air quality in the main atrium of CHBE?

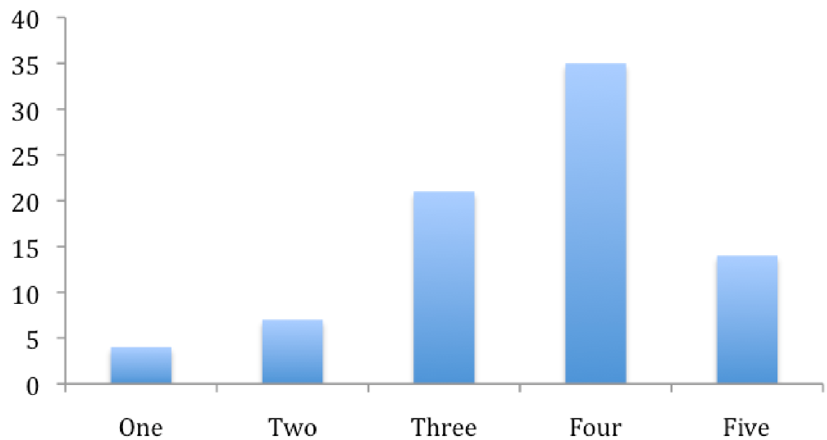


Figure 8: How satisfied are you with the air quality on the second floor?

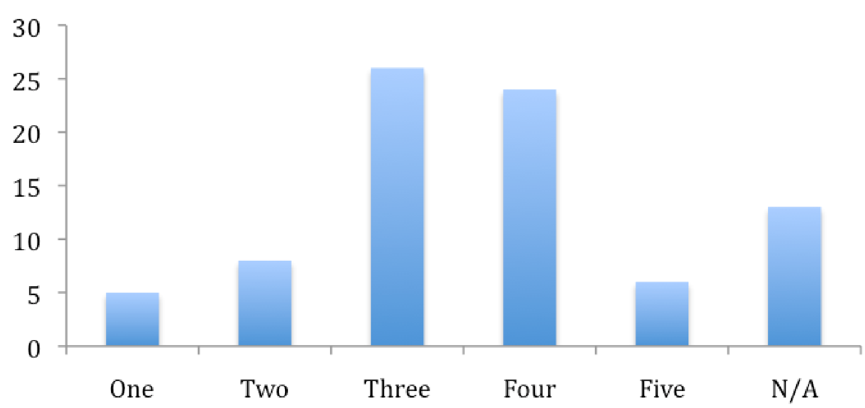


Figure 9: How satisfied are you with the air quality on the third floor in the computer labs?

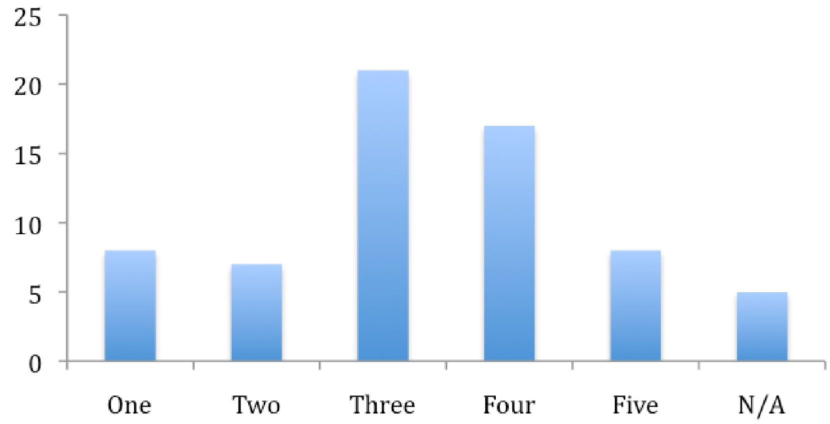


Figure 10: How satisfied are you with the air quality in the fourth floor undergraduate labs?

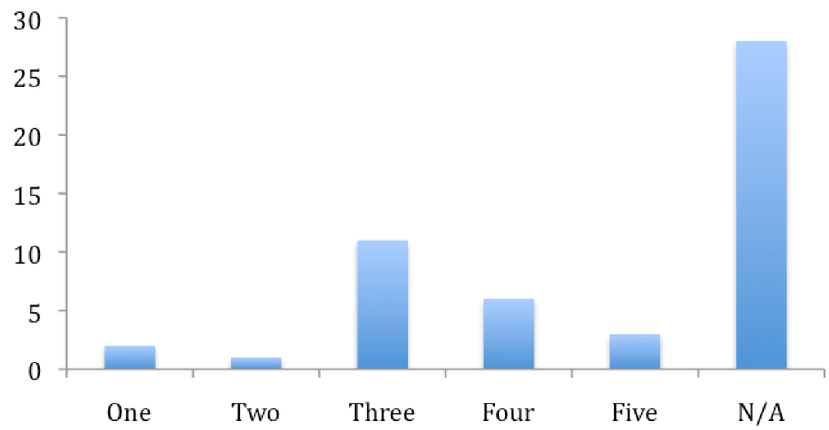


Figure 11: How satisfied are you with the air quality in the fifth and sixth floor research labs?

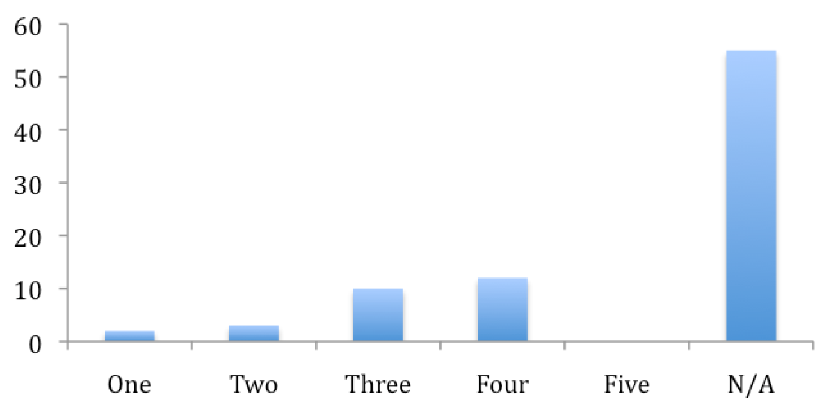


Figure 12: How satisfied are you with the air quality in your office?

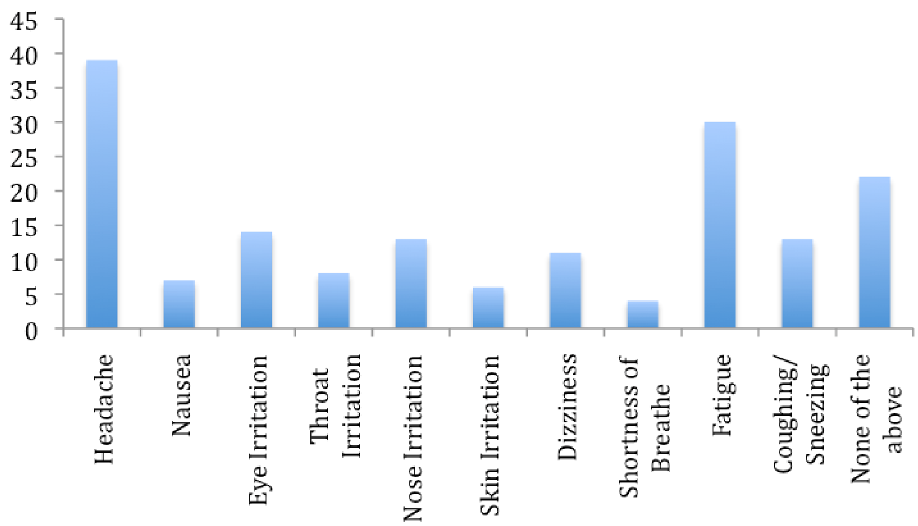


Figure 13: Have you ever felt the following while spending over 2 hours in CHBE?

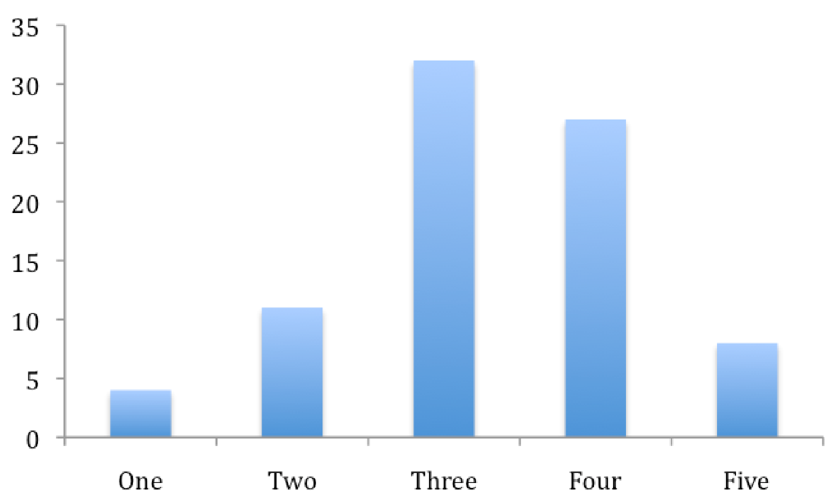


Figure 14: How satisfied are you with the temperature with the work/study area?

# Appendix B – Email Correspondence

Hi All,

Please see Adam's response regarding the Bio Wall proposal. As part of your feasibility study, you will need to prepare a request for a quote to actually build and install the unit. There are many policies and procedures that need to be followed prior to approval for any type of project that affects the building.

Ivan can be your department point of contact to get the quote.

One question ants go on the bio wall? What if someone has severe hayfever?

Joanne

Joanne Dean

Manager, Administration

Department of Chemical and Biological Engineering

**From:** McCluskey, Adam [redacted]
**Sent:** October-29-10 10:07 PM
**To:** Dean, Joanne [redacted]
**Cc:** Englezos, Peter (fwd); Ellis, Naoko
**Subject:** RE: Application for BioWall Funding - we need your advice

Joanne,

After reviewing the application, I have a few comments. While ultimately I know that the University and specifically our sustainability department embraces initiatives such as this, we need to be aware of a few things.

A project such as this would first need to be approved by our New Job Strategy Committee which meets every week. A work request would need be submitted with all available documentation requesting an estimate from our end on how much this would cost to setup and install. As a rule (compliant with our collective agreement with the union) all projects under $50,000.00 in costs are coordinated through our Construction Office with our internal trades handling the work. The project coordinator would then st mits and approvals and liaise with the contractor and our trades. Requests for estimates are free...but the number we give could look very different from the estimate you received.

To answer each of your questions:

1. Who will pay for the attachment to the HVAC system?
   **You**
2. How much will it cost to attach to the HVAC system?
   **The project would have to be reviewed by our Tech Services department for feasibility (this happens automatically during the estimate process).**
3. How much will upkeep cost and who will pay?

**Unsure of the upkeep at first glance but as this would be a client initiative (verses core) the upkeep would be client funded.**

4. What if the wall causes issues with the HVAC system? I'm assuming that our regular service levels for the building will not cover this.

**Our technical services department would know whether there was a potential for the wall to affect building systems...they wouldn't allow it to proceed if it could lead to "breaking the building"**

5. Will the building need to be rebalanced if this is added to HVAC?

**Unlikely, but again our tech services department would have the final say**

6. Will we require an engineers' report prior to building?

**7. Do we need permission from Campus Planning to alter the appearance of our atrium?**

**Possibly. Now that I have a better idea of what this would look like we would need approval from planning or the architect. Honestly, I don't think that would be an issue. The University is typically supportive of these initiatives.<an style='color:#1F497D'>**

**To really move forward on this and get some concrete answers and figures, a request for estimate would have to be submitted. I can champion the request on my end.**

**I hope this helps,**

**Adam McCluskey**
**Facilities Manager**

-----Original Message-----
From: Cayuela, Alberto
Sent: Monday, November 29, 2010 11:41 AM
To: Sawada, Brenda; 'Lindsey Curtis'; 'Naoko Ellis'
Cc: Karen Bartlett
Subject: RE: SEEDS project-CHBE Biowall

Brenda, Lindsey and Naoko,

We had originally intended to build a living wall in the main four-storey-high atrium of the CIRS building. The type of living wall that we had considered was the biowall air biofiltration system design by Alan Darlington at the University of Guelph. After performing engineering analyses on it (both from researchers and CIRS consultant) we uncovered a few concerns that prompted us to change our strategy, these include:
-The type of biowall proposed by the Guelph team requires significant energy and water flows (including a significant amount of electricity required for artificial lighting);
- In Ontario it is claimed that this type of biowall can in addition to purify and oxygenate the indoor air, dehumidify the indooor air in the summer and re-humidify it in the winter. We in the Westcoast have the opposite problem, we don't get humid summers and are our winters are comfortable humid.
- The type of biowall proposed is mainly made of exotic species imported from nurseries in Florida; and
- Initial caoital costs and maintenance and operation costs were very high.

So, instead of proceeding with a living wall as described above we decided to investigate other options for future deployment in the CIRS building. As such we decided to provide structural, mechanical, electrical and BMS (building management system) preparations in the living wall designated area of the atrium. Based on this it is still our plan to demonstrate a living wall type of system that works for CIRS and as such welcome your suggestions. It will be important to couple this project with some significant research opportunities and to identify potential funding sources and partners.

We will be building an exterior vegetated wall, called a "decidious" wall and a green roof as part of our goal of demonstrating and studying these technologies.

Cheers,
Alberto

# Appendix C – SEEDS Registration Form

**DRAFT**

Date:

# PROJECT DESCRIPTION FORM

## PART 1: STAFF INFORMATION

*Anticipated Staff Commitment:*

- *Define project clearly using this form*
- *Meet initially with student(s)*
- *Meet bi-weekly with students (or as agreed) to determine progress and provide guidance and support throughout the project*
- *Hold final meeting for presentation of research/recommendations*

Principal Staff Name: Lori Tanaka

Position: Main office secretary Department: CHBE

Address: 2360 East Mall, Vancouver V6T 1Z3

Phone: [redacted] Fax: [redacted] Email: [redacted]

Additional Staff Names:

| Name: | Position/Department: | Phone/Email: |
|---|---|---|
| Ivan Leversage | safety program officer | [redacted] |

## PART 2: PROJECT INFORMATION

**Topic:** Air quality improvement Category: CLIMATE AND ATMOSPHERE FINANCIAL WATER TRANSPORTATION MATERIALS ENERGY FOOD SYSTEMS COMMUNITY LAND

**Working Title:** Improving air quality in CHBE through a BIOWALL – feasibility study

**Overall Purpose:** To identify areas of concern for air quality in CHBE; to investigate the feasibility of a biowall in CHBE in improving the air quality

**Contribution to Sustainability at UBC:** To provide the ground work for air quality improvement; to add a feature which can enhance social sustainability in CHBE.

**Outline of Project Details:**

- Collect air quality data in various parts of CHBE (look into previous assessment data)
- Work out logistics and design related to biowall
- Gather information on stakeholders on implementing the biowall

**Anticipated Dates for Initiation** and **Completion of Project:**

Initiation: Sept 22, 2010
Completion: April 30, 2011

NEXT STEPS



- **Project Name** : CHBE Biowall Implementation
- **Project Description** : Improving the air quality of the Chbe building through a sustainble biowall system.
- **Project Length** :
- **Start Date** : 11-Oct-10 30-Apr-11
  29
- **Working Days** : Monday - Sunday

| Level | Task | PIC | Start Date | Finish Date | WD | DC | DR |
|---|---|---|---|---|---|---|---|
| **1** | **Feasibility Study** | **Biowall Team** | **11-Oct-10** | **03-Dec-10** | **54** | **2** | **52** |
| 1.1 | Air Quality Testing | Lindsey and Maggie | 18-Oct-10 | 04-Dec-10 | 48 | -5 | 53 |
| 1.2 | Reasearch on Plant and Soil type | Liz and Kaitlynn | 19-Oct-10 | 05-Nov-10 | 18 | -6 | 24 |
| 1.3 | Pricing and Quotes | Stephanie | 01-Nov-10 | 30-Nov-10 | 30 | -19 | 49 |
| 1.4 | Proposal to the Department | All members | 21-Nov-10 | 22-Dec-10 | 32 | -39 | 71 |
| **2** | **Implementation** | **Marketing Dept** | **01-Jan-11** | **30-Apr-11** | **120** | **-80** | **200** |
| 2.1 | Design and Location | Lindsey Maggie | 02-Jan-11 | 01-Feb-11 | | | |
| 2.2 | Purchasing Supplies | Lindsey and Stephanie | 03-Feb-11 | 15-Feb-11 | 13 | -113 | 126 |
| 2.3 | Installation | All members | 15-Feb-11 | 31-Mar-11 | 45 | -125 | 170 |
| **3** | **Maintenance/ Monitoring** | **Public Relation Dept** | **01-Apr-11** | **30-Apr-11** | **30** | **-170** | **200** |
| 3.1 | Define Responsible Maintenance Persons | Lindsey | 01-Apr-11 | 15-Apr-11 | 15 | -170 | 185 |
| 3.2 | Develop Maintenance Plan | All members | 01-Apr-11 | 15-Apr-11 | 15 | -170 | 185 |
| 3.3 | Define Air Quality Monitoring Plan | All members | 15-Apr-11 | 30-Apr-11 | 16 | -184 | 200 |