The Biowall

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CHBE 484 - Final Project

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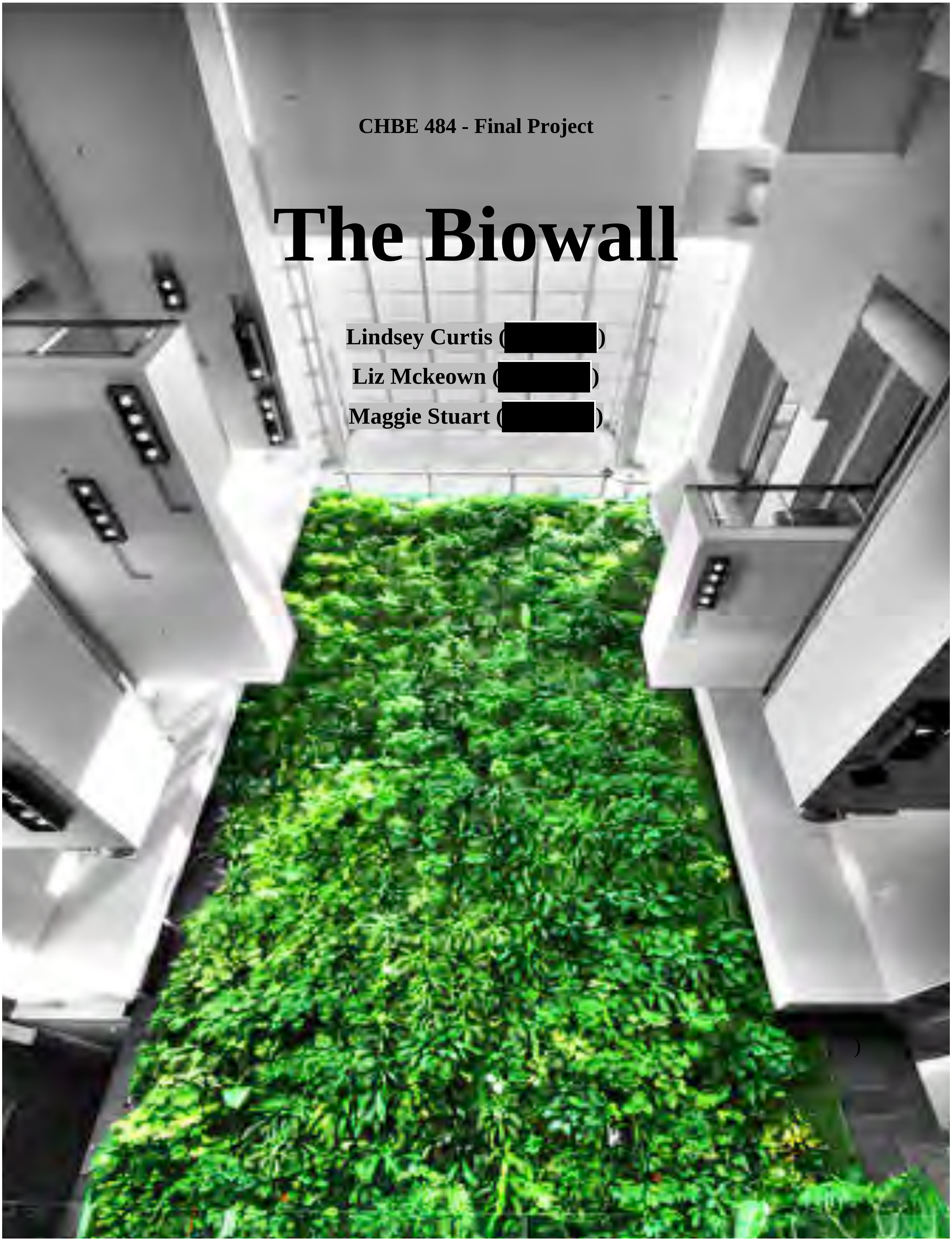

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Executive Summary

The inspiration for this project was to carry out a small green engineering project for a community. The outlined problem was indoor air quality and the approach adopted was the analysis of implementing a biowall. Biowalls are natural air purification systems that help improve the air quality. As air moves through the wall, impurities are removed by the microorganisms that live in the roots of the plants. These green walls are more beneficial than just cleaning the air; they are aesthetically pleasing and can help buildings become greener and energy efficient and thus decreasing carbon emissions.

Through funding from the Fisher Scientific Fund and the Chemical and Biological Undergraduate Council, a small scale biowall was constructed. This biowall was made into an active system by using breathable felt and six fans pulling out the purified air from the roots of the plants. It was constructed to perform air testing in the CHBE building to measure its effects on the air quality. The biowall also represents a way to spread awareness about the importance of indoor air quality.

In addition, the emissions associated with building both the small scale as well as a larger scale wall were researched in order to determine the environmental effects of construction. These values were then subtracted from the energy saving associated with implementing the wall.

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 green wall or 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. It will especially be beneficial to CHBE students, faculty and staff as they spend a large amount of time 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. In addition, biowalls reduce noise pollution, as their plants and planting medium are effective as 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 (Loh, 2008).

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 it gives the company a positive image of sustainability and innovative thinking.

2.0 Background

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, 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 risk of leukemia and lymphoma to those exposed (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] 25 [25 hr]
Formaldehyde	0.1 [L]
Lead	Minimum exposure
Nitrogen dioxides	0.05 0.25 [1 hr]
Ozone	0.12 hr
Sulfur dioxide	0.38 [5 min] 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. The VOCs with 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: 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	Phenols	
Ketones	(not N_2O)	Methylene chloride	Polyaromatic hydrocarbons
Ethers	SO_2		
Esters	HCl		CS_2
Organic Acids	NH_3		
Amines	PH_3		
Thiols	SiH_4		
Other molecules with), N or S functional Groups	HF		

(Hum and Lai, 2007)

2.2 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)

2.3 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.

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 are most likely to remove more VOCs than they omit. This is a very important discovery that will be important to consider which plant species to implement.

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 an air 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).

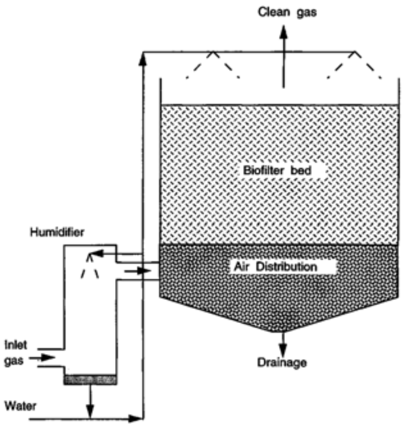

Figure 1: An open Biofilter

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, 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.

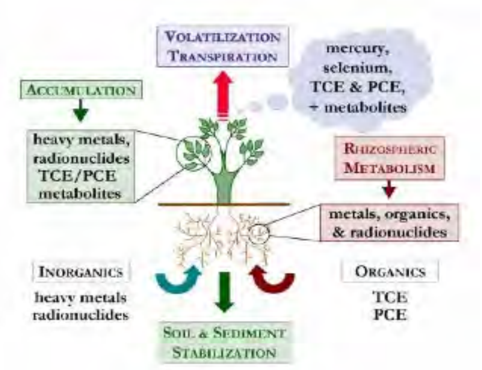

Figure 2: Phytoremediation Mechanism

4.0 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 and having group meetings. With so much time being spent indoors it is extremely important to have a good 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 the sick building syndrome (SBS). Experiencing the symptoms from SBS hinders the productivity of the occupants in the building, which is very undesirable in an active building like CHBE.

4.1 Temperature Control

Temperature control of the in a building is an important factor and it has been observed as an issue in the CHBE building by Figure 11 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, the cooling effect of plants transpiring reduces the heat of the building. The study concludes that the temperatures are lowered by biowalls, as they can bring temperatures to a more human-friendly level. This reveals the biowalls ability in cooling buildings interior and in turned would reduces energy costs for air conditioning systems (Loh, 2008).

4.2 Reduction of Noise Pollution

The main atrium of the CHBE is open to the second floor by a mid-height balcony. The atrium 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)

4.3 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).

4.4 LEED Credits

Biowalls can be used to gain additional LEED credits for a building. LEED, which stands for the Leadership in Energy ad Environmental Design, is an internationally recognized green building certification system. These credits provide third-party verification that a building was designed and built using strategies intended to improve performance such as energy savings, water efficiency, CO_2 emissions reduction, improved indoor environmental quality and stewardship of resources and sensitivity to their impacts. The categories in which the biowall can gain LEED credits are sustainability, energy savings, indoor air quality, health and wellness and acoustics.

Table 3: LEED Credits of a Green Wall

LEED Category	Credit	Associated Point(s)
Sustainability	Credit 3: Integrated Pest Management, Erosion Control and Landscape Management Plan	1
	Credit 5: Site Development: Project or Restore Open Habitat	1
	Credit 6: Stormwater Quantity Control	1
	Credit 7: Hest Island Reduction: Non-Roof	1
	Credit 8: Light Pollution Reduction	1
Water Efficiency	Credit 3: Water Efficient Landscaping	1-5
Energy & Atmosphere	Credit 1: Optimize Energy Efficiency Performance	1-18
Material & Resources	Credit 1.4: IAQ Best Management Practices: Reduce Particulates in Air Distribution	1
	Credit 2.1: Occupant Comfort: Occupant Survey	1
	Credit 3.6: Green Cleaning: Indoor Integrated Pest Management	1
Innovation in Operations	Credit 1: Innovation in Operation	1-4

5.0 Air Quality Survey

We conducted a survey to 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, which could be the result of 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 poorly circulated. The graduate students' rooms of concern were the research labs and several offices on the 5th and 6th 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) have 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: Building Temperature and Relative Humidity

Measurement Type	Winter	Summer
Dry Bulb at 30% RH	20.3°C - 24.4°C	23.3°C - 26.7°C
Dry Bulb at 50% RH	20.3°C - 23.6°C	22.8°C - 26.1°C
Wet bulb maximum	17.8°C	20°C

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 were the odor, poor ventilation, poor temperature control, dryness and ability to cause people to develop headaches after spending a few hours in the building.

6.0 Small Scale Biowall

6.1 Introduction

The feasibility of implementing a biowall into the CHBE building has been registered as a UBC SEEDS (Social, Ecological, Economic, Development Studies) project. The original plan for this project was to build a large scale wall in the CHBE atrium. This wall was projected to be approximately 18' tall by 10' wide. After applying for various funding applications including the Xerox Sustainable Fund and the Innovative Project Fund it was determined that the department was skeptical about implementing such a large structure into the building. Various steps have to be taken at the University of British Columbia in order to change the structure or look of a building. In addition, for the system to be active, which is the most effective method of air purification, the cost would be very high for an existing building. Therefore, the CHBE sustainability club was contacted to discuss an alternative option. It was determined that a small wall could still be effective, and if the system was mobile, it could be used in various areas that have poor air quality. Funding was obtained from the Fisher Scientific "Green Research" Award as well as endowment funding through the CHBE Undergraduate Club. A total amount of $2578 was received, with $1978 from the Fisher Fund and $600 through the Undergrad club.

6.2 Design

The small scale wall dimensions were proposed to be 6 by 4 feet wide. Upon gathering the materials, it was found that the acrylic backing sheet was pre-cut at a size of 6x3 feet and therefore the dimensions changed slightly.

Since a large factor associated with the biowall is its esthetic appearance, finished cedar was used for the outer frame. A layer of plastic lattice was used for the backing support of the wall, which still allows air through the back. The next layer is a sheet of industrial felt, which is 1/8" thick and helps to retain moisture for the plant roots. For the middle layer, where the plant roots are embedded, coconut fibre mats were used. These were spread out evenly over the first felt layer, and then covered with a front layer of felt. In between the two felt layers, an irrigation system was installed. A small reservoir was attached at the bottom of the wall, constructed from a piece of eavestroph, with two end caps sealed with plumbing GOOP ^{TM}. A pond pump was installed sitting in this reservoir, which feeds a ½ inch water line that runs up the side of the wall. This line feeds a pipe with drip holes to slowly saturate the wall. The water then trickles down the wall by gravity. While the majority of the moisture is retained in the coconut matt as well as the felt layers, the excess water is recycled from the reservoir.

Detailed design pictures of the biowall can be seen below, as modeled in Solid Works. In addition, construction pictures of each stage are included in Appendix E

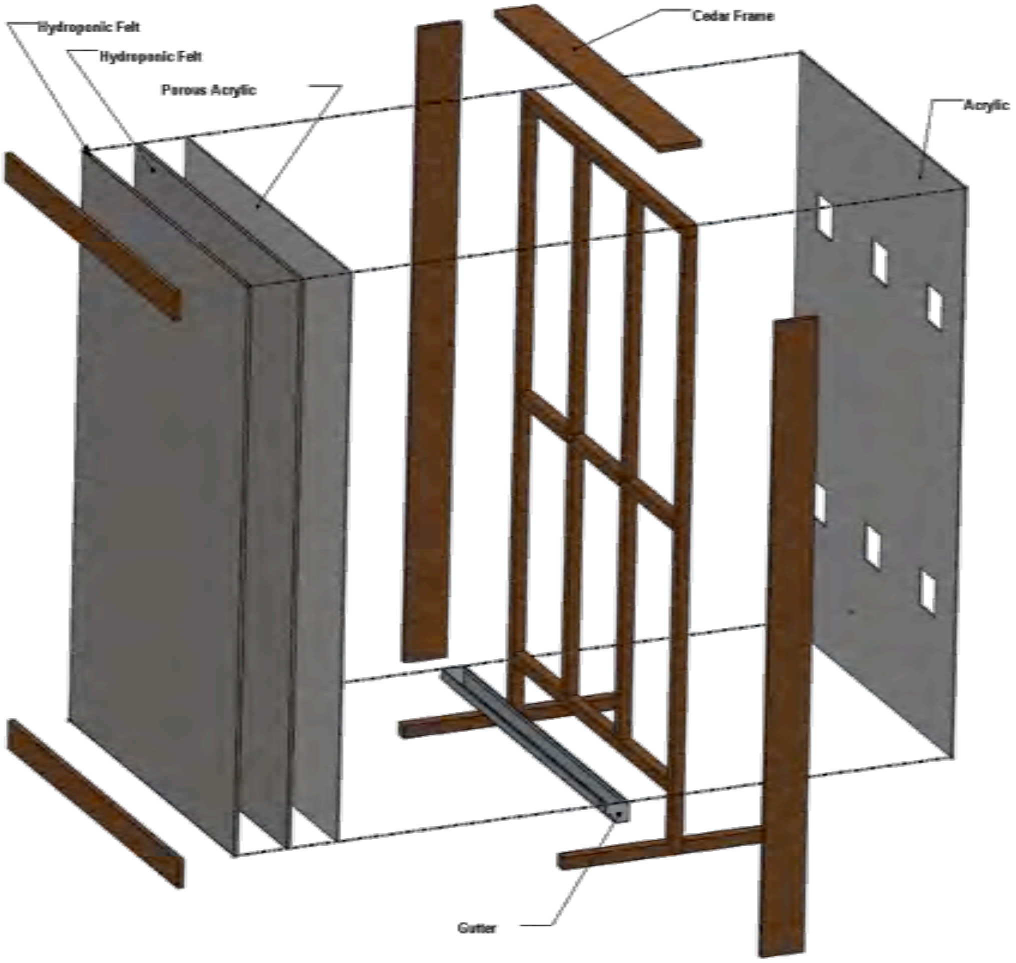

Figure 3: Exploded View of Biowall Structure Design

It can be seen in Figure 3 that six holes were cut into the acrylic sheet. This was done by the CHBE machine shop using a water jet. Six computer fans were installed into these holes to pull air through the wall in order to create an active system. The fans and water pump are connected to an automatic timer which is set to have the irrigation on for one hour every four hours, while the fans remain consistently on.

6.3 Economics

An initial budget was determined for this project to ensure that the design was within the funding amount. This evaluation can be seen in Table 1 of Appendix E. The actual cost of plants was significantly lower than the proposed cost, however the cost of construction labor proved to be more than expected. At the end of construction however there is still a remaining $200. This will be saved for plant replacement, as well as any other maintenance costs. The capital cost of the project was approximately $970, with a labour cost of approximately $500. A detailed breakdown of both the material and plant cost can be found in Appendix E.

6.4 Air Testing

The school of Environmental Health at UBC previously conducted air quality testing for the OCCH 502 graduate class in March 2010. This data was previously taken for the second floor of CHBE after complaints from the office staff. As undergraduate students, air testing on the 3rd and 4th floors was desired, and therefore Dr. Karen Bartlett, the professor of this class was contacted earlier this year to discuss further testing. Air testing was completed throughout the building on March 9th 2011 by a group of OCCH graduate students. In addition to this data, a representative sample space was determined for this project by our group, and multiple tests were completed During March 30-31st and April 4-9th. The sample space chosen was the small computer lab, room 3.18. This room was chosen due to its high occupancy, relatively small size, and amount of electronic equipment.

The testing equipment used included 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. It can be seen in the figure below that the CO_2 levels decreased from the base case measurements to those taken with the biowall present. The data shown has a large peak of CO_2 during the same time period, which is between 11:30 am to approximately 6pm. During this time period the computer laboratory experiences a high occupancy of students, which during the sample times ranged from 10-20 students. It is assumed that during the base case and active and passive system samples, the average occupancy was consistent. From this assumption it can be determined in Figure # that the biowall has a measurable effect on CO_2 reduction. However, further analysis of the active versus passive system proves that during high occupancy of the sample space, the active system reduces the average carbon dioxide levels by approximately 20% where as the passive system reduces the values by 13.3%. This difference in active versus passive systems agrees with other studies by Darlington (2010) a professor at Guelph University, and President of Nedlaw Living Walls. The two peaks seen for the passive wall are due to higher volumes than normal of students in the laboratory on the night before the last day of classes, between the hours of 8pm and 1am.

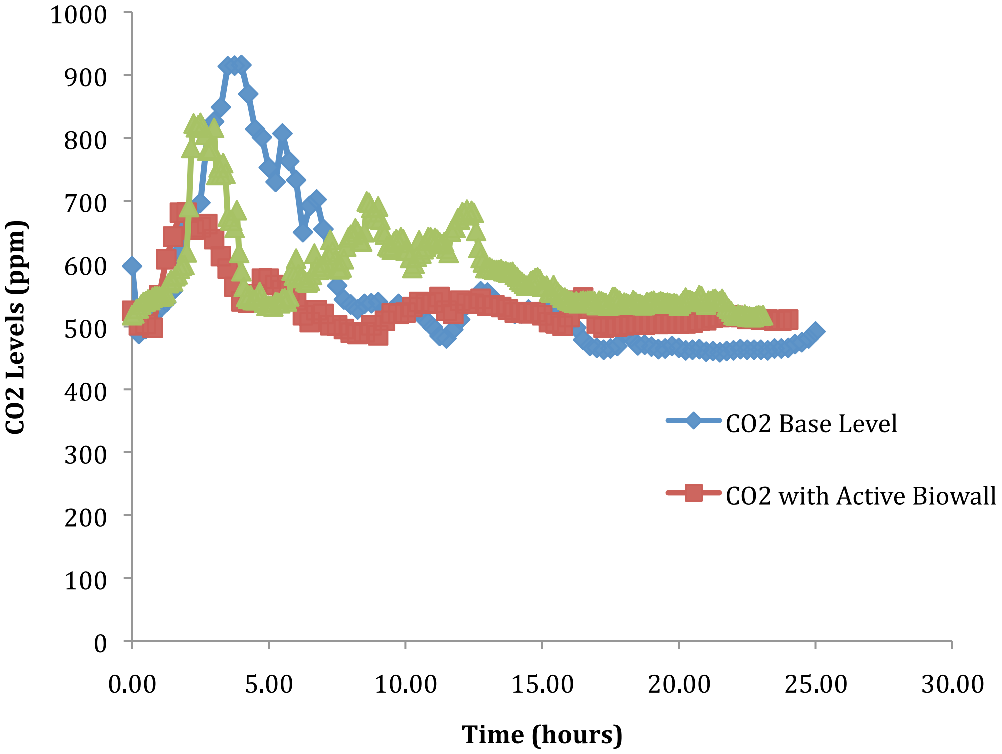

Figure 4: CO_2 Levels Versus Sample Time

In addition to the carbon dioxide levels, the Q-trak monitors the temperature and humidity of the sample space. These values can be seen in Appendix B in Figure 1 and 2. According to ASHRAE 55-1992, comfortable indoor temperature ranges from 20-25°C. Figure 1 shows that the range of temperature is within the acceptable levels, and that during peak occupancy hours the temperature was kept at a more consistent level with the biowall present. However, sources of error associated with this data include the opening of windows in the computer lab.

The relative humidity levels can be seen in Figure 2 of Appendix B. In this graph it can be seen that the relative humidity levels with the biowall present are slightly lower. This can be due to outdoor air entering through the windows, and can also be due to the fact that the irrigation system had not been connected during these sample times. Recent feedback from building occupants has proven that the air quality has improved and the humidity has increased once the irrigation system was operated at regular time intervals during the fan use. The ASHRAE values for acceptable humidity levels are between 30 and 60%.

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 VOC compounds produce a larger current and a higher reading displayed on an ammeter. While the data in the ppbRAE can be logged over a continuous sample time, spot tests were also done around the biowall to determine any change in VOC levels. A group of students wearing hair-spray and perfume were spot tested in the computer lab, giving readings in the range of 0.7 to 1.3ppm. The ambient air was then spot tested to be approximately 0.2ppm, whereas the space close to and around the wall proved to have the lowest level of VOC on the monitor at 0.03ppm. In addition to the spot test, the base case and active system test can be seen in Figure 5 below.

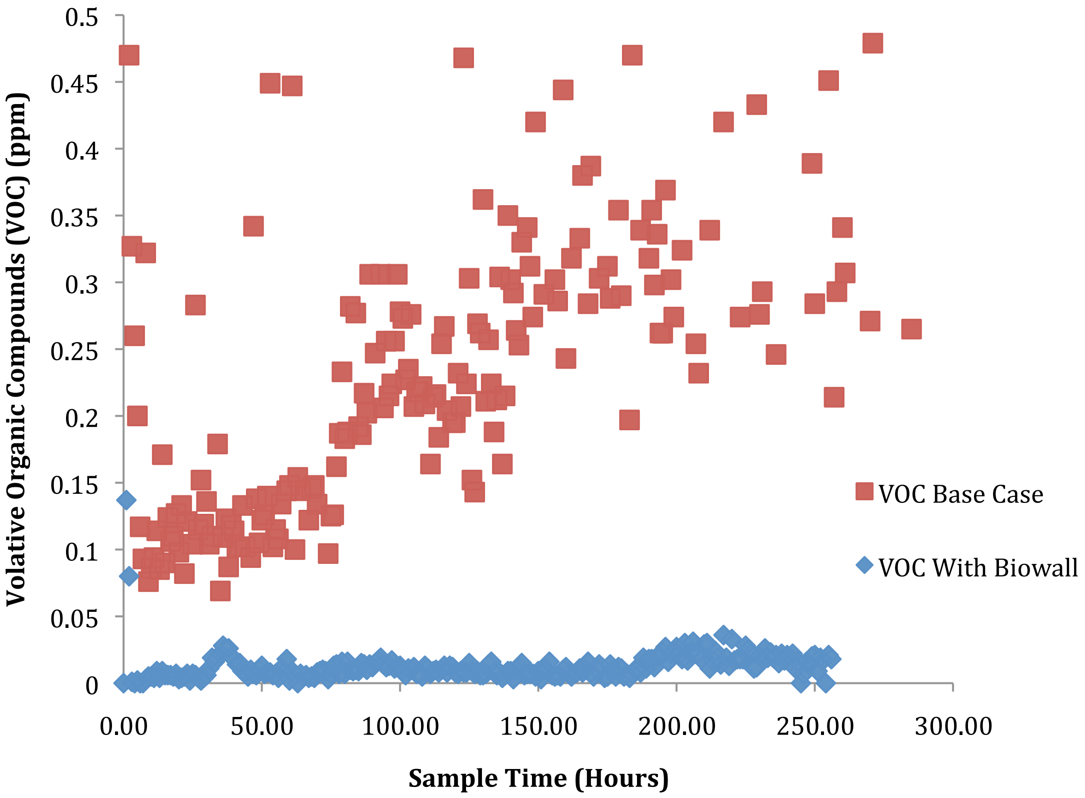

Figure 5: Magnified Sample Space of Volatile Organic Compounds Versus Sample Time

Acceptable VOC levels for indoor air according to the ASHRAE standard 62-1989 are recommended to be within 1/10th of the occupational exposure limits for non-industrial indoor air. The European standard however has a target value of 300ppb (ASHRAE,2007). It can be seen in Figure# above that the base case levels have various readings above this limit, however with the biowall present, the levels are steadily measured below 50 ppb.

The P-trak counts the amount of ultrafine particulate (UFPs) 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). UFPs are usually products of combustion or chemical reactions that occur from a wide variety of sources, and can travel far from their source. According to the TSI P-Trak Guide, the indoor air goal for UFPs can be calculated using equation 1 below.

$$\text{Indoor Air Quality Goal} = \text{Before filter UFP reading} \times [1-(\text{Expected UFP reduction}/100)] \qquad (1)$$

Acceptable values for indoor particulate matter levels are within 20% of the outdoor particulate matter. The outdoor value used is taken from the 2010 study by the OCCH 502 class, which was measured to be between 1550-2000 pt/cc.

Figure 6 below shows the particulate levels in the lab on April 9th 2011, over an 8 hour period. Due to issues with the sampling equipment, the base case data did not log properly and can therefore not be compared to the biowall data. The sensor is soaked in 95% 2-propanol for ten minutes in order for the P-Trak to function properly. It was seen that after an 8 hour period the sensor became low on the alcohol and did not give readings. Therefore the 24 hour data is not available. It can be seen that the levels are varied over the course of the day, and the maximum value obtained was 4387 pt/cc while the average value was 2031ppt/cc.

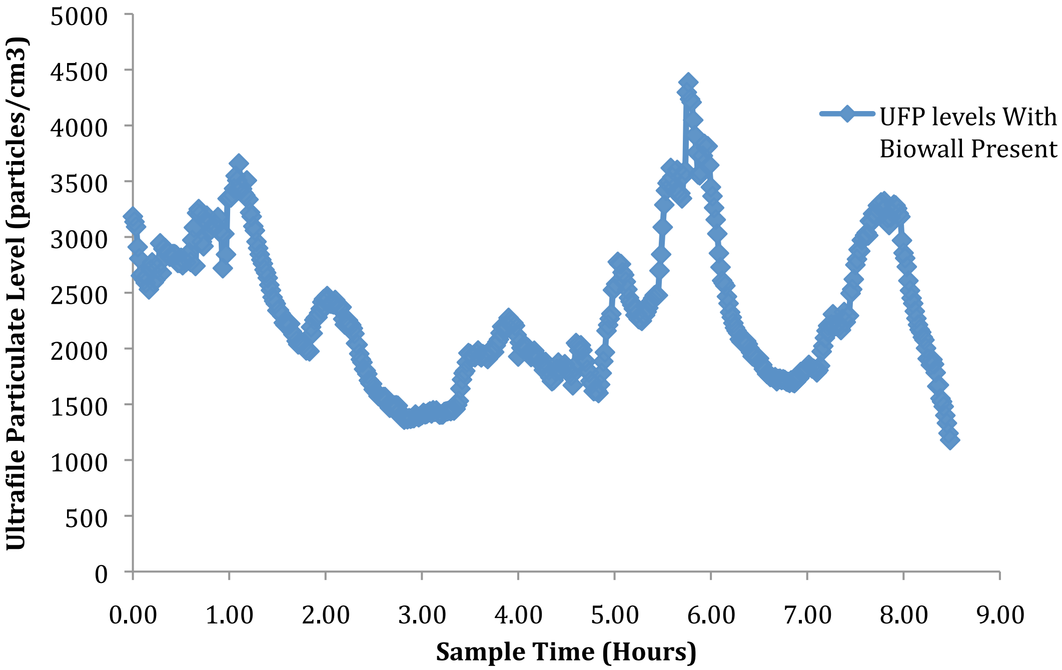

Figure 6: Ultrafine Particulate Levels Versus Sample Time In the Presence of the Active Biowall

The acceptable level value of 20% of the maxium outdoor is 2400 pt/cc. It can be seen here that the levels reach above this limit multiple times during the sampling period; however, the average particulate level is below this limit. Some error in this could be due to the fact that the windows to this room face the building entrance which has high traffic of UBC plant operations vehicles. If the windows were opened at any time during the sampling the particulate matter levels could increase significantly. In addition, the outdoor levels were taken during a completely different time and could therefore be too low for comparison.

When considering the large scale biowall, at ten times the surface area, assuming that the air quality is consistent within the building, the reduction in VOC levels as well as particulate matter and CO_2 levels should be approximately ten times less, assuming the same reduction efficiency of the wall. Therefore the contaminant amounts would be negligible.

7.0 Current CHBE Building HVAC System

The current Heating, Ventilation, and Air Conditioning (HVAC) system in CHBE consists of 4 Air Handling Units- AHU-CB1, CB2, CB3, and CB4; 2 steam converters- HE-CB1, and HEX-CB2; 4 pumps- P-CB1, CB2, CB3, and CB4; the Variable Air Volume (VAV) boxes; a 200 ton McQuay air cooled chiller; and numerous fans.

Both AHU-CB1 and AHU-CB2 run continually, servicing the laboratories and offices in CHBE. They run at 70,000 CFM and have a horsepower of 100. AHU-CB3 services shipping and receiving, runs at 4,000 CFM and has 5hp. AHU-CB4 services the machine shop with a horsepower of 5 and runs at 2,400 CFM. Both AHU-CB3 and AHU-CB4 run according to the weekly schedule.

7.1 Energy consumption

Although specific data could not be found for the energy consumption due to the HVAC system alone, Pulse Energy is used to monitor the steam and electricity usage for the buildings on campus. One source was found that indicates that in the average office building, heating, cooling and ventilation account for 53% of the building’s total energy consumption.

Statistically in Vancouver, January and December are the coldest months of the year. The data for energy consumption in both months shows relatively low electricity usage for December 2010 and January 2011 at 253,541 and 249,876kWh respectively and relatively high steam consumption at 11,758 and 12,153GJ. July and August are shown to be the hottest months of the year and so show relatively high electricity consumption in 2010 at 285,284 and 279,018kWh and relatively low steam consumption at 1,076 and 3,617GJ respectively. It should be noted that the rating given for the steam consumption in August was ‘poor’, meaning that the target value was surpassed, while the other months noted here received a rating of ‘good’. As expected, this data for total energy consumption shows a strong correlation with the expected trend for the energy consumption for an HVAC system in that the colder months use more steam for heating and hotter months use more electricity for cooling.

Converting the electricity usage into gigajoules and summing up the yearly energy consumption gives a total of 77,337GJ, or an average of 212GJ per day. Assuming that 53% of the total energy is due to the HVAC system, the current HVAC system uses on average 112GJ of energy per day, or 40,989GJ per year.

Taking reported values of 0.856kg CO_2 emitted per kWh of electricity and 75kg CO_2 emitted per GJ of steam consumed, gives total emissions of 7,578 tonnes per year or 20.8 tonnes per day. It should be noted that this is for the total energy consumed and not just for the energy of the HVAC system.

8.0 Chemical and Biological Engineering Building with Biowall

8.1 Construction

As previously mentioned, the desired size for the wall is approximately 18’ tall by 10’ wide. The proposed construction of this large-scale wall was scaled up from the small prototype biowall described in section 6.0. Some changes were made to this system in order to account for the differences of it being attached to the building, as well as the necessity of changing certain components in order to scale them up.

Since the large-scale wall is attached to the HVAC system, it will have a high capital cost to implement into an existing structure such as the CHBE building. The desired area for this wall is in the atrium on the main floor of the building. This is a high traffic area, which will create sustainable awareness to any students and staff from external faculties visiting the building. In addition the atrium has high levels of sunlight, and is central to the building for HVAC connections.

The capital costs for a structure of this size have been estimated using various materials in previous feasibility studies. A study from the UBC Mechanical Engineering department determined the capital cost of a similar sized biowall to be approximately $67365 for the costs of vegetation, irrigation and structure materials.

The operation and maintenance of the biowall should be taken into consideration to perform an adequate economic analysis. To increase the sustainability of the biowall, excess water is recycled from the bottom basin back up to the top. Therefore the biowall will consume only around 10 L/day of water. Rainwater will be collected from the roof of the CHBE building to reduce water consumption. The city of Vancouver, British Colombia, has 166 days of measurable precipitation each year. Therefore the amount of water needed is 1990 L/yr. The energy consumption of the pump for the irrigation system uses 216.3 kW·h/yr and assuming it costs $0.10 kW·h, the annual cost is $21.63/yr. The cost of the operation of the fans is $52.56/yr. The annual cost of the plants and nutrients is $900/yr assuming 5 large plants are replaced per month. The maintenance of the wall including pruning, spraying and replanting would occur around 12 hours per month. This would result in an operating cost of $2160/yr. Therefore the total additional cost of the operation and maintenance of the biowall is approximately $3134.19/yr. These calculations can be seen in Appendix D.

8.2 Emissions

In considering whether a biowall is worth considering as a green option in the building, it must consider the environmental impacts of the biowall itself. This includes the manufacturing of the materials as well as the transport. The first step is analyzing the impacts of the small-scale biowall.

8.2.1 Emissions of Small-scale Biowall

The first consideration is the transport of the materials from the store to the Chemical and Biological Engineering building (CHBE). The stores where the materials were purchased include Home Depot, Art Knapp, Canadian Tire, Coe Lumber, Fabricland, and Anitec. Considering that one trip was made to each location and the full return trip was made back to CHBE before going to another location gives a total of 142.4 km traveled. The model of car that was used is the

Toyota 4Runner, which has a fuel economy of 12.6L/100 km. Using the emissions value of 2.3kg of CO_2 per litre of gasoline, that gives a total of 41.27kg of CO_2 emitted.

The next step is to take a closer look at the emissions associated with the wood that was used for the frame. The assumption is made that the total volume of wood used is equivalent of half of a typical cedar tree. The specific data for the emissions resulting from deforestation are difficult to calculate, Houghton puts the total annual carbon dioxide emissions at 2.2Pg, the methane emissions at 2.75Tg, and the nitrous oxide emissions at 5.4Tg, and it is estimated that 3-6 billion trees are cut down every year (Olsen, 2008). Using this number, it is calculated that the half of a tree used to build the biowall accounts for 244kg of CO_2, 0.3kg of CH_4, and 0.6kg of N_2O, all of which contribute to the enhanced greenhouse gas effect.

The acrylic sheet on the back of the biowall is another important source of greenhouse gas emissions. The sheet used measures 5012.08cm^3 in volume and has a density of 1.18g/cm^3, which gives a mass of 5.914kg. Using the value for VOC emissions from the FIRE database for the manufacturing of acrylic, this results in 0.01626kg of VOCs emitted. Also taken into consideration was the cost of transporting the sheet from the place of manufacturing in Zanesville, Ohio, to Home Depot in Vancouver, BC. This data was not readily available, so we found the approximate fuel economy of a typical semi truck , as well as its dimensions (National Semi-Trailer Corp. (2006) Trailer Types). Using this, it is estimated that one semi truck could hold 23400 acrylic sheets. Averaging the range of values we found for fuel consumption (Nylund, 2005), we get 37.5L/100km and it is 4207km from the manufacturer to home depot. The result is 0.15kg of CO_2 per acrylic sheet.

Also on the back of the biowall is a 4’x8’ plastic lattice structure with a thickness of 1/2” and 2” hole openings. The weight of the lattice is 15lbs, and the emission factor according to the Fire database is 0.7lbs VOCs per ton of product. This gives total VOC emissions of 2.381g. Assuming the manufacturer of the PVC is Geon Company, whose plant is located in St Remi, Quebec, then the plastic would have to travel 4564km to the home depot. Using the same dimensions for the semi truck, the amount of PVC used would account for 0.868kg of CO_2.

Next, we will take a closer look at the felt, which forms a good portion of the biowall’s basic structure. The felt we used was made of synthetic fiber as opposed to wool. Synthetic felt can be made either from polyester of from acrylic; we’ll examine the option of polyester. The felt used has a thickness of 1/8” and weighs 18oz/yard^2. Four square yards of felt were used for a total of 4.5lbs. This results in a low level of VOC emissions, at 0.102g. Since the felt is not manufactured in Canada, the emissions associated with shipping the product from Shanghai, China to Vancouver, Canada. Assuming that the Emma Maersk cargo ship is used, there is 1000 tons of carbon dioxide emitted per day (Vidal, 2010). The total distance from Shanghai to Vancouver is 4888 nautical miles, and the ship travels at 12 knots, which means the total journey will take 407.33 hours, or 16.97 days. Knowing that the Emma Maersk is 11000 Twenty-foot Equivalent Units (TEUs) , meaning that it carries a total volume of approximately 14, 960, 000ft^3, the amount of felt used for the biowall accounts for 0.3859kg of CO_2.

Coco fibre was chosen as the growing medium in the biowall. Since this is a natural product, only the environmental impact of the transportation is considered. Again, the Emma Maersk is used as the cargo ship. This gives a result of 4.57 kg total CO_2.

Table 5: Total CO_2 and VOC emissions from small-scale biowall

	Transport	Wood	Acrylic	Lattice	Felt	Coco Fibre	Total
CO_2 (kg)	41.27	244	0.15	0.868	0.3859	4.57	291.2439
VOC (kg)	--	--	0.01626	0.002381	1.02E-4	--	0.018743

8.2.2 Scaling up the Emissions

The proposed biowall would be ten times the size of the biowall that has already been built, therefore increasing the emissions. Since the wall is ten times the size, it requires ten times as much material to build and therefore all of the emissions from the materials are multiplied by ten. In addition, more trips to the store are required and so those emissions are multiplied by three. Finally, once the biowall is scaled up, a concrete basin would need to be added to hold the water at the bottom of the biowall. If the basin is 10’x3’ with a wall thickness of 3” and a height of 6”, then the total volume of the concrete is 3.125ft^3. Since the cement accounts for the major source of emissions in concrete, those

are the only emissions that will be considered. Concrete is generally 10-15% cement by volume, and so using an average value of 12.5%, the total volume of cement needed is 0.39ft^3. Using a cement density of 1506kg/m^3, the total required cement is 16.65kg, which accounts for 14.76kg of CO_2.

Table 6: Total CO_2 and VOC emissions from a large-scale biowall

	Transport	**Materials**	**Cement**	**Total**
CO_2 (kg)	123.81	2,500	14.76	2,638.57
VOC (kg)		0.18743		0.18743

8.2.3 Sources of Error Associated with Emissions

Because of the scarcity of data involving biowalls, there are many estimations that have to be made regarding the total emissions. The biggest source of error will come from us choosing to scale up our emissions from the small-scale biowall in order to calculate emissions from a large-scale wall. We chose to do it this way because that was the most accessible data for us; however, buying the raw material and doing the construction ourselves may not necessarily be the best way to go about building a larger biowall. We would likely consider hiring a company who specializes in the area, changing much of the material used and therefore the emissions. There were also a lot of area in which we had to make estimations, including the size of the semi truck as well as its fuel consumption, the amount of trees that are cut down each year, and the driving routes that would be taken to get to the various destinations.

We also must consider some other factors. First of all, our data for deforestation is from global measurements. This does not take into account the fact that some companies are much more environmentally aware in the way they cut down trees and there are some areas in which deforestation is creating a much more lasting affect. Home Depot is one company that is very aware of this and so they have implemented a Wood Purchasing Policy in which they pledge to greatly reduce their purchasing from endangered regions and to instead purchase only where the forests are responsibly maintained. In this spirit, they are purchasing 90% of their cedar from 2nd and 3rd generation forests in the United States, while the other 10% comes from BC. Another area in which we have to consider external factors is with the synthetic felt. This material can be made from recycled products, therefore reducing its total emissions.

When considering the environmental impact of shipping via cargo ship, the total distances used were the shortest distance between the two points. This distance is considerably shorter than the actual distance a ship would have to take and therefore gives a reduced estimate of the total carbon dioxide.

8.3 Energy Savings and Emission Reduction

Theoretically, the biowall would save energy by reducing the amount of air that needs to be taken in through the HVAC system and by insulating the building to reduce the need for heating and cooling. Currently there are 72 prefilters in CHBE that are replaced twice a year and cleaned on a regular basis, and another 72 secondary filters, which are changed every 2.5 years. Hopefully with a large-scale biowall implemented in the building, the filters would not have to be changed as often, reducing cost as well as the environmental impact of the manufacturing of the filters. Unfortunately, biowalls being a relatively new technology, there are not a lot of figures detailing the potential savings. There is one source studying green facades that finds a potential cooling value of 157kWh per day (Schmidt et al). This represents a savings of 134kg of CO_2 per day. Assuming that this is only valid for the summer months (May through August), that means a reduction in electricity of 19,311kWh per year, reducing the annual CO_2 emissions by 16.53 tonnes. The result is that the CO_2 emissions to build the wall will be offset in 0.16 years, or just under 2 months.

9.0 Conclusion

In conclusion, the benefits of implementing a biowall were considered from an air quality view point, as well as in terms of energy savings in a building compared to the emissions used for construction. Theoretically, the biowall should save energy by reducing the amount of air that needs to be taken in through the HVAC system and by insulating the building to reduce the need for heating and cooling.

It was determined that biowalls have a potential cooling value of 157kWh per day for a building. This represents a savings of 134kg of CO_2 per day. Assuming that this is only valid for the summer months (May through August), that means a reduction in electricity of 19,311kWh per year, reducing the annual CO_2 emissions by 16.53 tonnes.

The air quality testing completed in the undergraduate computer lab in the Chemical and Biological Engineering building showed a reduction in volatile organic compounds as well as reduced levels of carbon dioxide during high human occupancy of the lab. In addition, it was determined that a scale up of this data would reduce the amounts of VOCs by a factor of ten assuming that the air purification efficiency of the wall is the same when scaled up.

Recommendations for further testing are to determine reduction benefits of other areas in the building, as well as further testing to prove the reproducibility of the data obtained.

A biowall would be a beneficial addition to the building in terms of energy savings, improvement of indoor air quality, potential LEED accreditation, and most importantly, improve the well being of the building occupants.

10.0 References

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Appendix A – Air Quality Survey

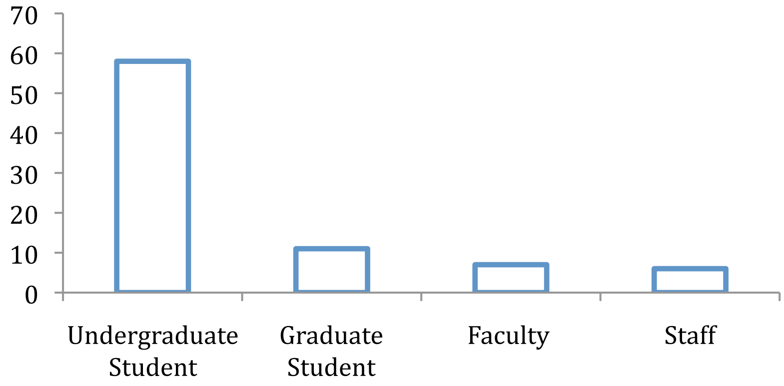

Figure 1: Survey Demographic

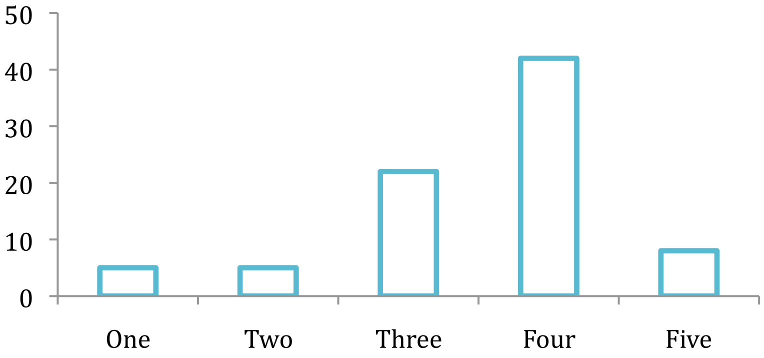

Figure 2: How satisfied are you with the air quality in the CHBE building? With 5 being the best and 1 being the worst.

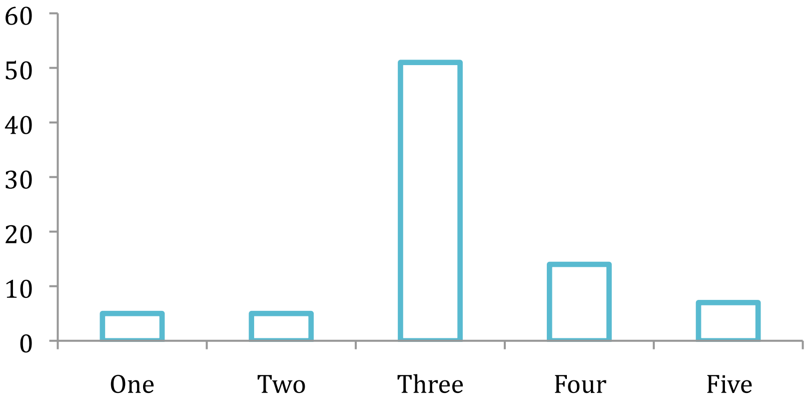

Figure 3: Does the air in your study/work space interfere (1) with or enhance (5) your productivity?

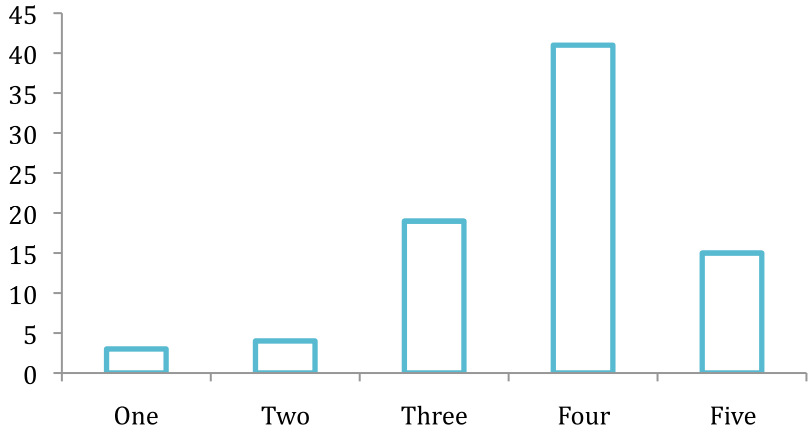

Figure 4: How satisfied are you with the air quality in the main atrium of CHBE?

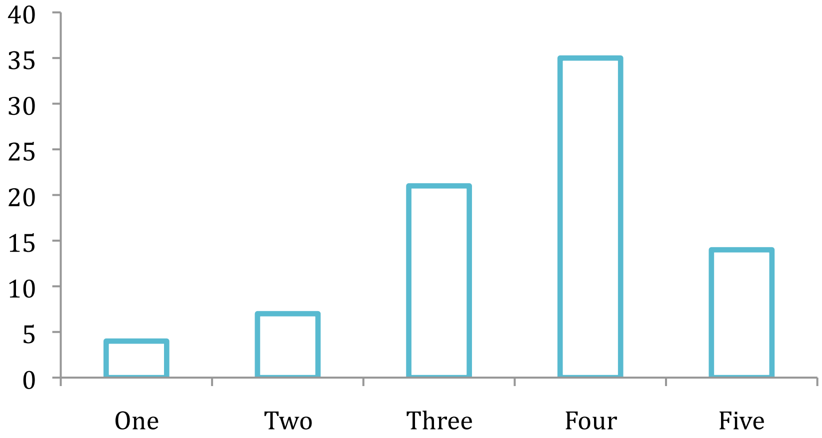

Figure 5: How satisfied are you with the air quality on the second floor?

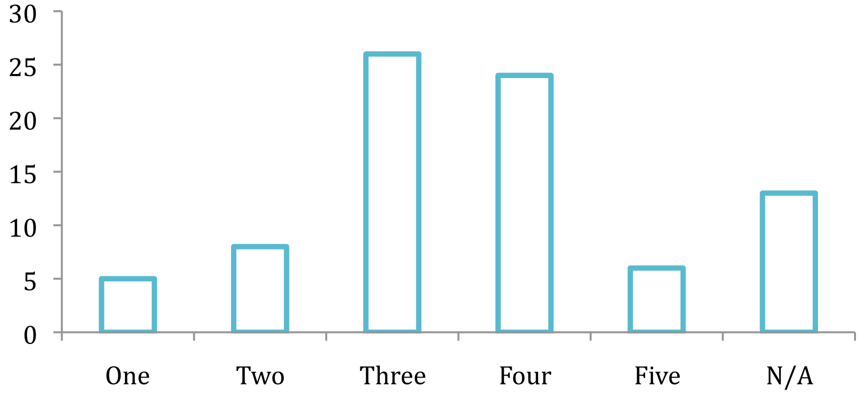

Figure 6: How satisfied are you with the air quality on the third floor in the computer labs?

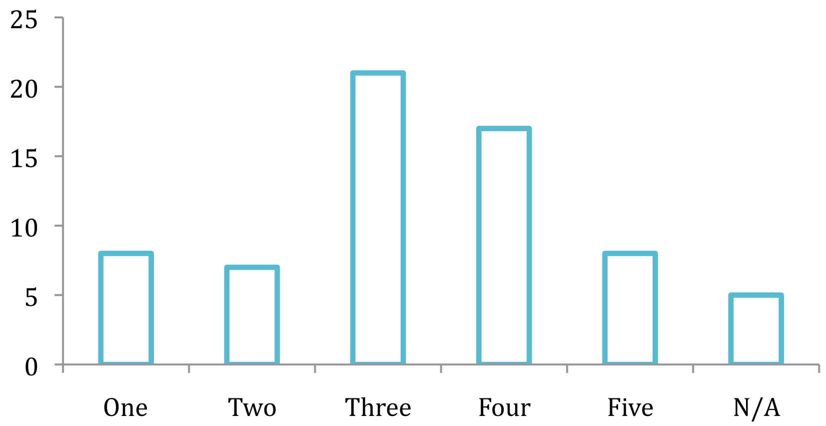

Figure 7: How satisfied are you with the air quality in the fourth floor undergraduate labs?

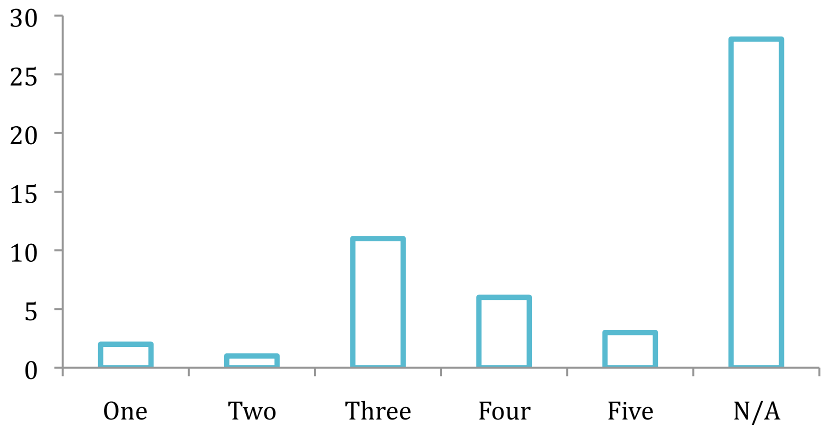

Figure 8: How satisfied are you with the air quality in the fifth and sixth floor research labs?

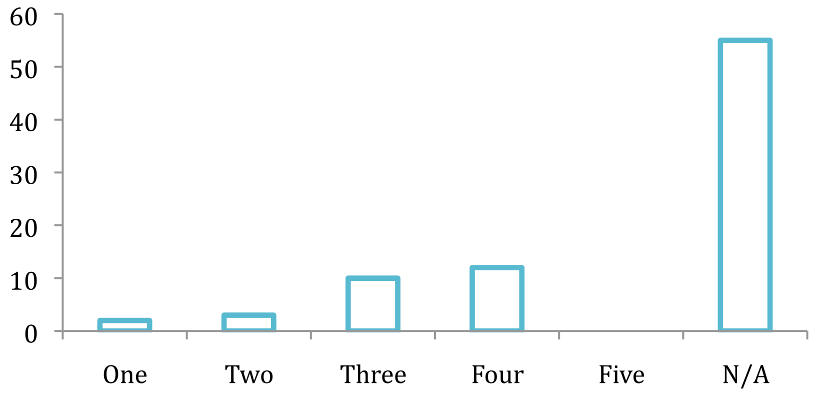

Figure 9: How satisfied are you with the air quality in your office?

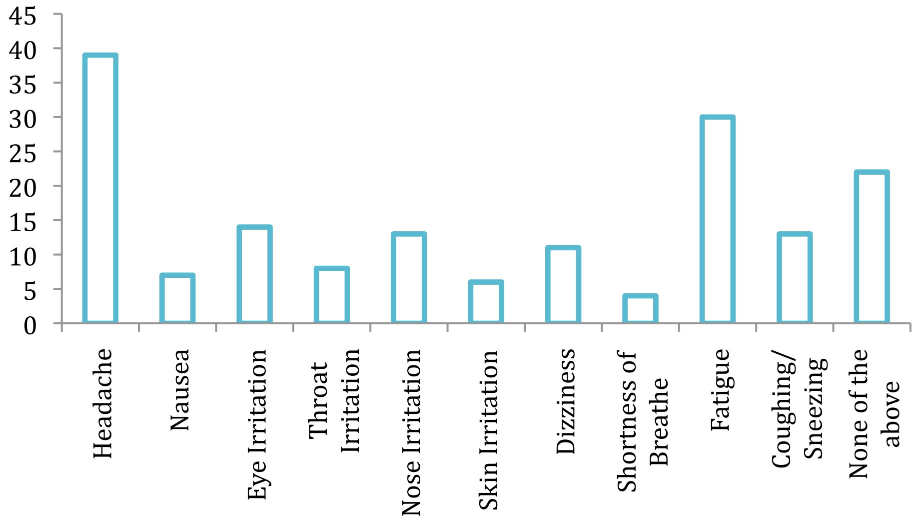

Figure 10: Have you ever felt the following while spending over 2 hours in CHBE?

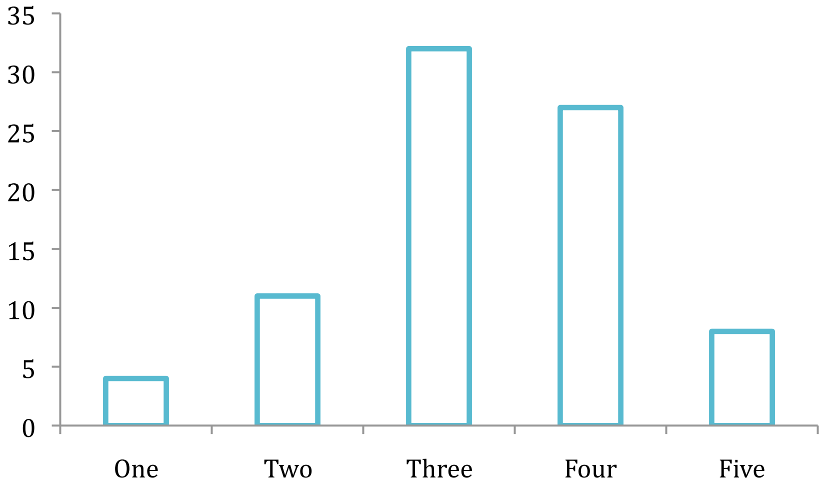

Figure 11: How satisfied are you with the temperature with the work/study area?

Appendix B - Air Quality Testing

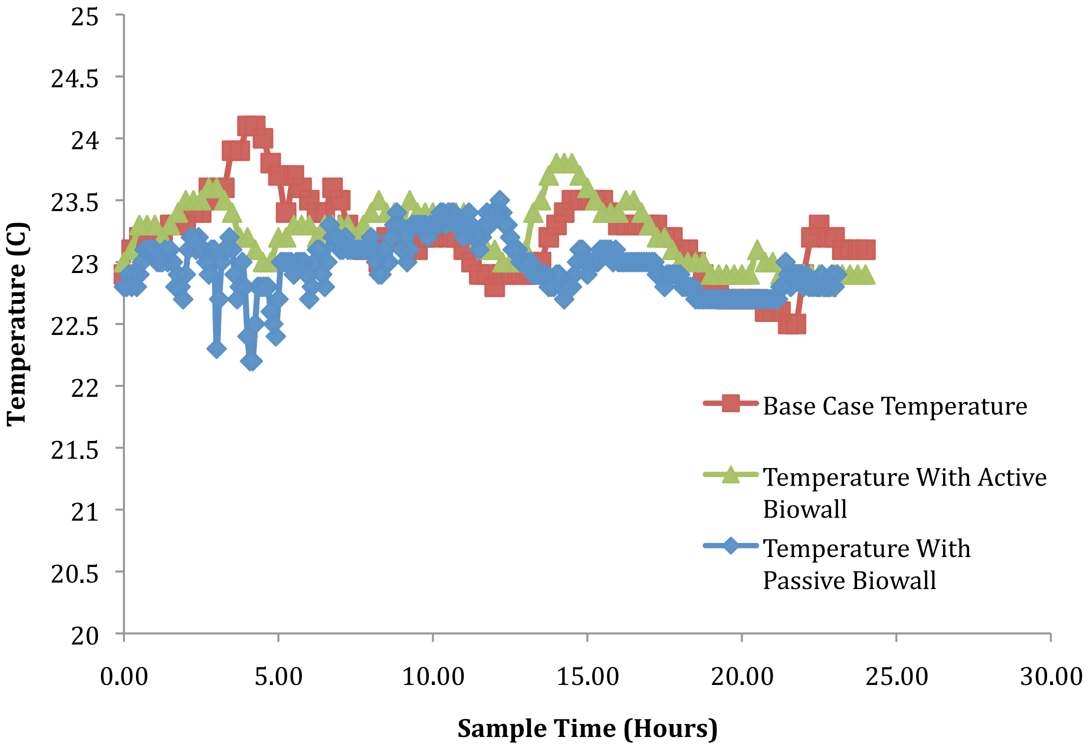

Figure 1: Temperature Data Versus Sample Time

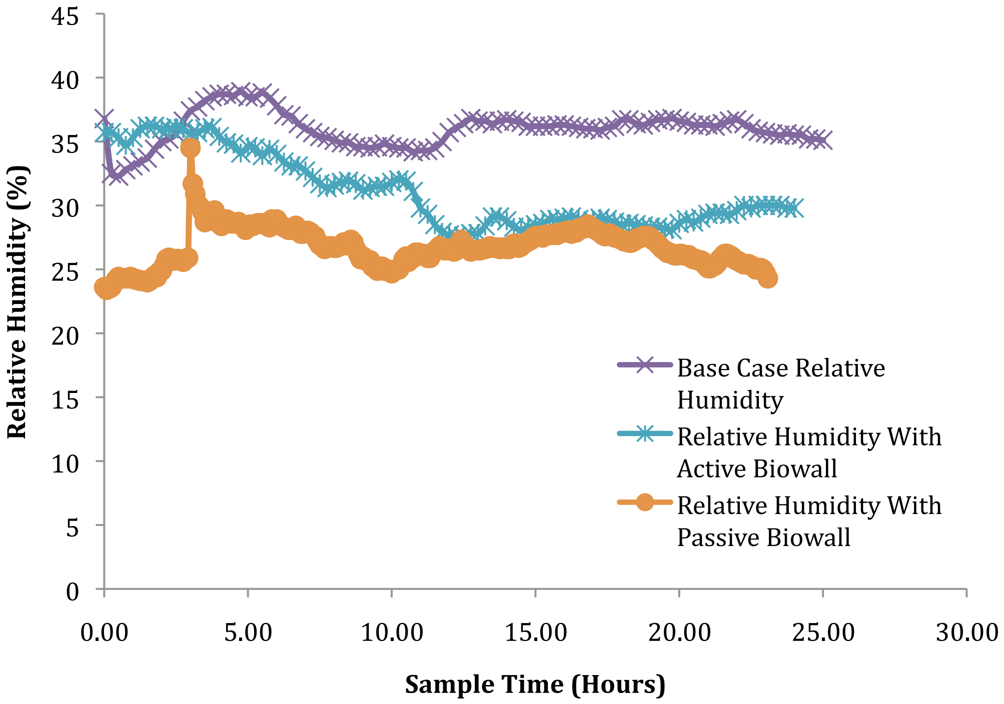

Figure 2: Relative Humidity Versus Sample Time

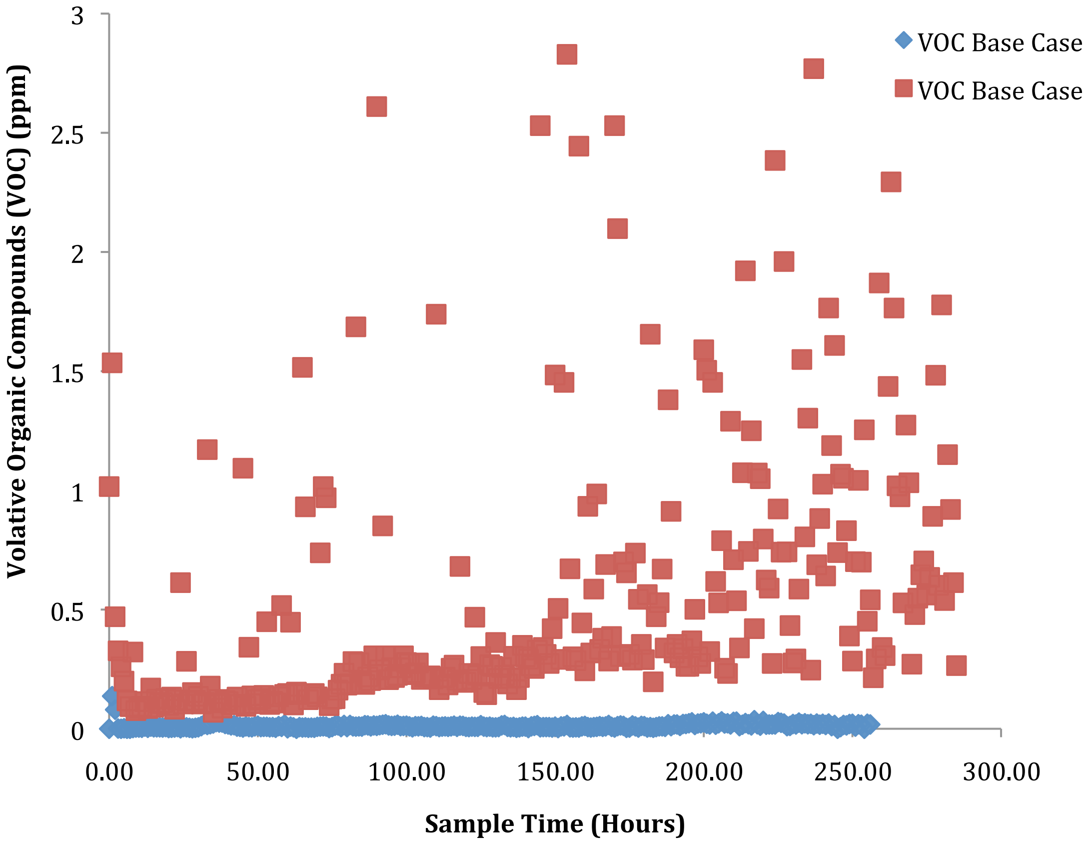

Figure 3: Entire Sample Space of Volatile Organic Compounds Versus Sample Time

Appendix C - Emissions Calculations

Vehicle Emissions of CO_2

Fuel economy of vehicle (L/100km) x Distance traveled (km) x CO_2 emissions (kg/L)

Ex. Toyota 4Runner
12.6L/100km x 142.4km x 2.3kgCO_2/Lgasoline = 41.27kg CO_2

Emissions of Materials

Ex. Acrylic Sheet
Dimensions:
0.29972cm x 91.44cm x 182.88cm x 1.18g/cm^3 = 5.914 kg

VOC Emissions (from manufacturing):
From Fire Database = 5E01lb/ton (eq. 2.75E-3kgCO_2/kg product)
2.75E-3kg CO_2 x 5.914kg product = 0.01626kg VOC

CO_2 Emissions (from transport):
Travel Distance: 4,207km
Semi Truck Info:
Dimensions: 57’ x 102” x 162”
-Made the assumption that 23,400 sheets will fit
-1300 high, 9 lengthwise and 2 wide
Fuel Economy: 22-53 L/100km
-Use average value of 37.5 L/100km

37.5L/100km x 4207km x 2.3kg/L = 3628.54kg CO_2
3628.54kg CO_2/23400 sheets = 0.15kg CO_2/acrylic sheet

CHBE Emissions:

CO_2 Emissions per kWh of electricity: 0.856kg
CO_2 Emissions per GJ of steam consumed: 0.075kg

Table 1: Data from Pulse Energy for Energy consumption in CHBE in 2010

Month	**Electricity (kWh)**	**Electricity (GJ)**	**Steam (GJ)**	**Total (GJ)**	**HVAC (GJ)**	**Emissions (kg CO_2)**
Jan	253142	911.3112	11234	12145.3112	6437.014936	1059239.552
Feb	230064	828.2304	9419	10247.2304	5431.032112	903359.784
March	259150	932.94	8812	9744.94	5164.8182	882732.4
Apr	244636	880.6896	4204	5084.6896	2694.885488	524708.416
May	243167	875.4012	1297	2172.4012	1151.372636	305425.952
June	245043	882.1548	878	1760.1548	932.882044	275606.808
July	285284	1027.0224	1076	2103.0224	1114.601872	324903.104
Aug	279018	1004.4648	3617	4621.4648	2449.376344	510114.408
Sep	248317	893.9412	1357	2250.9412	1192.998836	314334.352
Oct	244700	880.92	2611	3491.92	1850.7176	405288.2
Nov	248356	894.0816	10150	11044.0816	5853.363248	973842.736
Dec	253541	912.7476	11758	12670.7476	6715.496228	1098881.096
			Annual:	**77336.9048**	**40988.55954**	**7578436.808**
			Daily:	**211.881931**	**112.2974234**	**20762.84057**

Appendix D - Construction Costs

Table 1: Proposed Budget

Proposed Budget			
Capital Cost Estimate			
Plants	$594		
Material Costs	$778		
IAQ monitor rental	$200		
Total:	$1,060		
Wages:			
120hrs x $15/hr:	$1,836	(includes 2% UBC fees)	
Total Project Cost:	$2,896		
In-Kind Club Contribution:	$918	60	hrs
Fisher Scientific Fund:	$1,978		
Actual Financial			
In-Kind Hours			
Sustainability Club	$547.50		
CHBE	$180.00		
Revenues			
Fisher Scientific Fund:	$1,978		
Undergrad Club	$600		
Expenses			
Material Costs	$730.00		
Plants	$240.00		
Worker Salaries	$879.75		
Remaining:	$728.25		

Table 2: Building Supply Cost

Actual					
Part	Quantity	Unit Cost	Price	Supplier	Receipt
Gutter	1	$12.49	$12.49	Home Depot	1
2x2x8 cedar	6	$4.41	$26.46	Home Depot	1
3x6 acrylic sheet	1	$91.56	$91.56	Home Depot	1
Plastic pipe	1	$3.89	$3.89	Home Depot	1
1x8x8 cedar	2	$9.73	$19.46	Home Depot	1
1x6x8 cedar	2	$6.63	$13.26	Home Depot	1
4x8 lattice	1	$42.57	$42.57	Home Depot	1
Diamond clear varathane	1	$20.24	$20.24	Home Depot	1
APR 9/16"	1	$4.19	$4.19	Home Depot	1
Nuts	4	$2.79	$11.16	Home Depot	1
Screws	1	$8.99	$8.99	Home Depot	1
PVC plug 1/2"	2	$1.01	$2.02	Home Depot	1
BARBXMFP	2	$2.99	$5.98	Home Depot	1
Pipe clips	1	$1.09	$1.09	Home Depot	1
Gutter hanger	4	$0.99	$3.96	Home Depot	1
SHEP 2" SVL	4	$4.99	$19.96	Home Depot	1
Gutter end cap	2	$1.19	$2.38	Home Depot	1
Machine Screw	1	$6.79	$6.79	Home Depot	1
Vinyl tubing	1	$4.69	$4.69	Home Depot	1
24hr timer	1	$16.97	$16.97	Home Depot	1
Screws	2	$5.29	$10.58	Home Depot	1
Screws	1	$5.69	$5.69	Home Depot	1
Foam brush	2	$1.24	$2.48	Home Depot	1
3x100	1	$3.68	$3.68	Home Depot	1
Tin Snips	1	$9.99	$9.99	Home Depot	2
Pond Pump	1	$59.99	$59.99	Canadian Tire	3
Plumbing Goop	1	$8.79	$8.79	Home Depot	4
Gutter end cap	1	$1.19	$1.19	Home Depot	4
Utility Knife	1	$5.88	$5.88	Home Depot	4
Coco fiber liner	5	$4.99	$24.95	Canadian Tire	5
Plant Food	1	$4.79	$4.79	Canadian Tire	5
Plumbing Goop	1	$7.99	$7.99	Coe Lumber	6
Programmable Timer	1	$18.99	$18.99	Coe Lumber	6
Triple power bar	1	$4.99	$4.99	Coe Lumber	6
GFI outlet	1	$19.99	$19.99	Coe Lumber	7
Felt 3' x 4 m	4	$12.00	$48.00	Fabric Land	8
Computer Fans	6	$14.99	$89.94	Anitec	
		Total:	$646.02		
			$730.00	(plus GST)	

Table 3: Initial Plant Cost

Type	Quantity	Unit Cost	Price	Supplier
	1	$75.00	$75.00	Art Knapp
	1	$90.00	$90.00	Home Depot
	1	$75.00	$75.00	Home Depot
		Total:	$240.00	

Operation and Maintenance Costs

Water Consumption:

Small Scale biowall consumes 1 L/day

1 L/day x 10 = 10 L/day
= 3650 L/yr

Vancouver experiences 850 mm/yr of rainfall

= 850 L/m^2/yr

CHBE roof (not including wings) = 18.5m x 50m
= 925 m^2

Vancouver has on average 166 days/yr of measurable rain

365-166 = 199 days

199 days x 10 L/day = 1990 L/yr

Pumps (Recycling Water) Energy Consumption:

Known values for 2 ft wall in width

Cycle time: 1.25 hrs
Cycles per day: 24 hrs/day ÷ 1.25 cycles/hr = 19.2 cycles/day
Volume of water per fill: 7 L

For 18 ft by 10 ft wall:

Water volumes per fill: 7 L x (10 ft/2 ft) = 35 L

Pump (1 ¼ discharge, 1 ½ HP (1.12 KW))

Approximate head rise : 18 ft + 2 ft (due to losses from piping & fitting) = 20 ft

Approx flow rate at 20 ft : 5.59 gpm

Refill time: 35 L x 0.264 = 9.24 gallons

$$\frac{9.24 \text{ gallons}}{5.59 \text{ gpm}} = 1.65 \text{ minutes} = 99.2 \text{ seconds}$$

Approximate energy consumption per refill/cycle:

(99.2 sec) x (1.12 kW) = 111.1 KJ = 0.03086 kWh

Approximate energy consumed per day:

(0.03086 kWh/cycle) x (19.2 cycles/day) = 0.592 kWh/day
= 216.3 kWh/yr

Operation cost = $ 0.10/kWh

(216.3 kWh/yr) x ($ 0.10/kWh) = $ 21.63/yr

Fans:

(6 watts/fan) x (10 fans) x (24hrs/day) x (365 day/yr) = 525.6 kWh

525.6 kWh x $ 0.1/kWh = $ 52.56/yr

Plants and Nutrients:

(5 plants/month) x (12 months) = 60 plants/yr

(60 plants/yr) x ($ 15/plant) = $ 900/yr (Including Nutrients)

Maintenance (Pruning, Spraying and Planting):

(12 hrs/month) x (12 months) = 144 hrs x $15/hr = $2160/yr

Total Annual Operation and Maintenance Costs: $ 3134.19/yr

Appendix E - Construction Pictures

Figure 1: Cedar Backing Construction

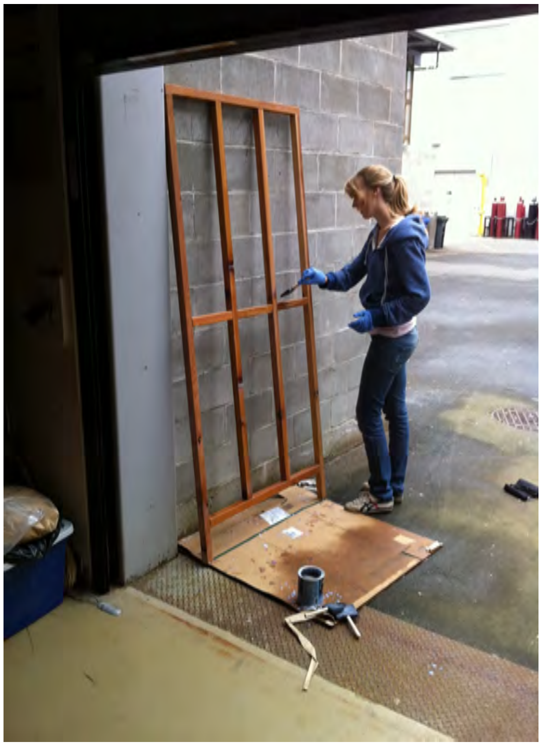

Figure 2: Frame Staining

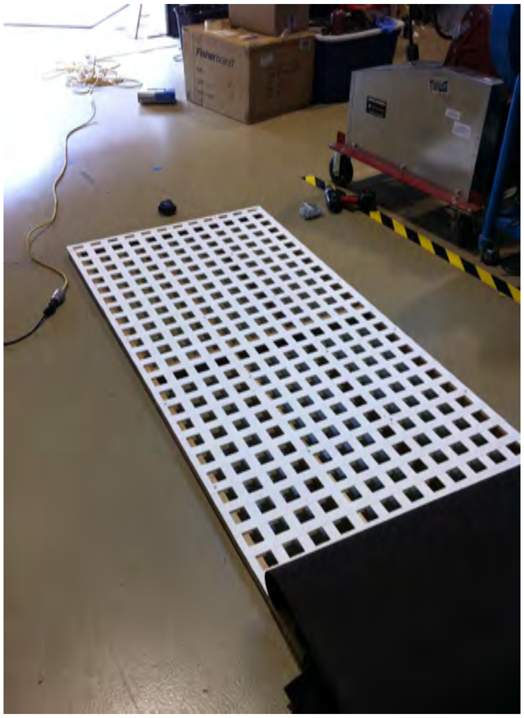

Figure 3: Plastic Lattice Attached to Cedar Backing

Figure 4: Felt and Coconut Matt

Figure 5: Irrigation Piping

Figure 6: Final Felt Layer Front View

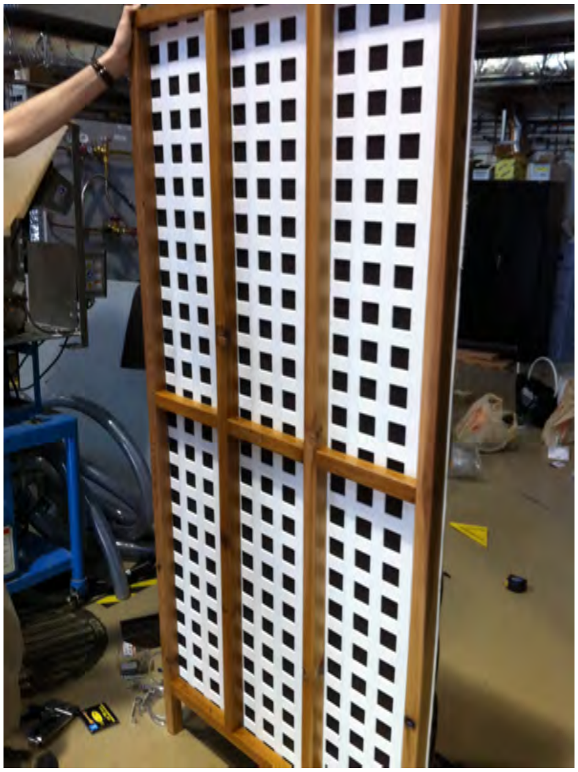

Figure 7: Back View without Acrylic

Figure 8: Side Wall Attachment

Figure 9: Front View

Figure 9: Front View Figure 10: Wat

Figure 10: Water Reservoir

Figure 11: Plant Orientation Planning

Figure 12: Final Planting

Figure 13: Final Structure with Wheels

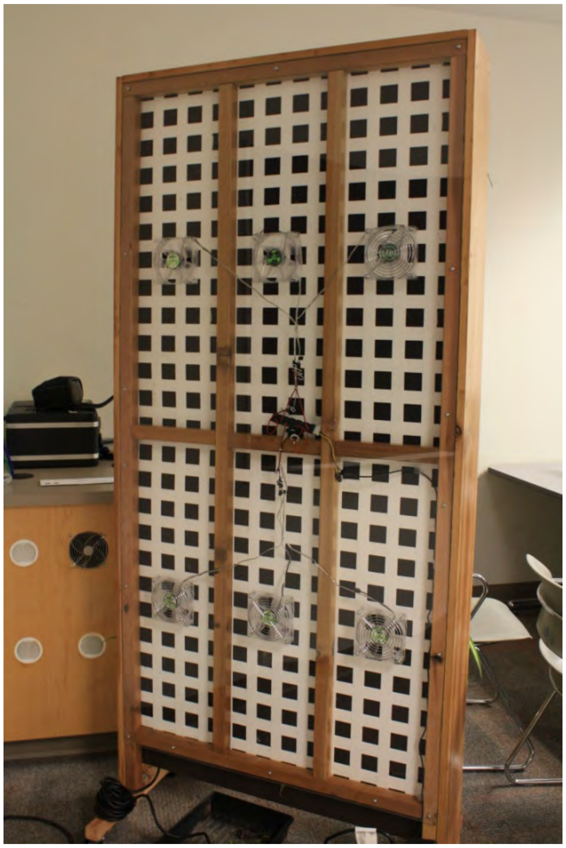

Figure 14: Air Suction Fans

Figure 15: Final Product

Member Contributions

Lindsey Curtis:

- Small-Scale Biowall
  - Introduction
  - Construction
  - Economics
  - Air Testing
- Large CHBE Biowall
  - Construction
  - Capital Cost
- Conclusion
- Appendix B - Air Testing
- Appendix D - Economics
- Appendix E - Construction Pictures
- Biowall Construction
- Liaison with Contacts

Liz Mckeown:

- Current CHBE Building
  - Energy Consumption
  - Emissions
- Large CHBE Biowall
  - Energy Savings
  - Emissions Construction
  - Emissions removed from Biowall
- Appendix C - Emission Data and Sample Calculations
- Formatting and Compiling

Maggie Stuart:

- Introduction
- Background
- Pollution Control Techniques
- Improvement of Air Quality, Health and Well-being
- Air Quality Survey
- Large CHBE Biowall
  - Operating and Maintenance Costs
- Appendix A - Air Quality Survey
- Appendix D - Economics
- Formatting and Compiling
- Biowall Construction