An Investigation into the Viability of a Waste Heat Powered Greenhouse

Do Youl Bae, Calvin Ng, Joseph Pateman

University of British Columbia

APSC 262

April 4, 2013

An Investigation into the Viability of a Waste Heat Powered Greenhouse

Do Youl Bae

Calvin Ng

Joseph Pateman

March 28 2013

APSC 262: Society and Technology II

Professor Carla Paterson

ABSTRACT

UBC plans to build a microbrewery on campus that will produce excess steam as a by-product of the brewing process. This is potentially an abundant source of heat energy and should be retained for use to ensure and further promote sustainability on campus. This investigation assumes the primary source of heat energy is steam supplied from a microbrewery. In order to assess the viability of any potential structures to use this waste heat energy, a triple bottom line analysis will be used along with thermodynamic, material and economic analysis.

This investigation deals with the viability of building a waste heat powered greenhouse on the roof of the new SUB currently under construction at UBC. Originally, the plan involved utilisation of waste heat in the form of steam produced by a proposed microbrewery to be constructed in the new SUB at UBC; however, as plans for the new building changed, the brewery project was moved elsewhere. The crux of the issue remained however, can a greenhouse be constructed, either on the roof of the SUB or elsewhere, that is heated predominantly by waste heat?

Using a triple bottom line analysis which takes into account economic, environmental and social aspects, the viability of such a project was assessed. We found that a greenhouse using an in-soil radiant heating system would be a good solution. Economically, the greenhouse is the most conservative to construct and maintain. Furthermore, it is a viable, low risk revenue stream generated by saving electricity and producing crops that will be grown year-round. Environmentally, the energy savings from using waste heat as opposed to buying electricity, is substantial. Additionally, the materials used in the construction of the greenhouse are long lasting, easily recycled materials. Socially, the greenhouse provides a practical learning environment for students and faculty as well as a source of entertainment for any visitors. This investigation shows that the greenhouse is the most viable option economically, environmentally and socially. We strongly recommend that a waste heat powered greenhouse be constructed on the roof of the new SUB.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

GLOSSARY

Carbon Dioxide - a colourless, odourless gas produced by burning carbon and organic compounds and by respiration. It is naturally present in air (about 0.03 per cent) and is absorbed by plants in photosynthesis.

Corrode - Corrosion is the slow process of destruction or degradation of a material, usually metal or rock by chemical action.

Greenhouse Gas - A gas that contributes to the greenhouse effect by absorbing infrared radiation; carbon dioxide and chlorofluorocarbons are examples of greenhouse gases.

Joule - The SI unit of work or energy, equal to the work done by a force of one newton when its point of application moves one metre in the direction of action of the force, equivalent to one 3600th of a watt-hour.

Oxide - The end product of an oxidation reaction in which a compound loses electrons and often gains an oxygen molecule. For example Al oxidizes in air and becomes Al_2O_3.

Polymer - A family of plastics characterized by long molecular chains which give polymers their unique properties.

Thermodynamic - The branch of physical science that deals with the relations between heat and other forms of energy (such as mechanical, electrical, or chemical energy), and, by extension, of the relationships between all forms of energy.

LIST OF ABBREVIATIONS

AMS - Alma Mater Society

UBC - University of British Columbia

SUB - Student Union Building

SI - International Standard of units (*Système international d'unités*)

1.0 INTRODUCTION

This Sustainability Project report pertains to a proposed greenhouse heated by waste heat energy produced by a microbrewery in the form of steam. This project's stakeholder is Collyn Chan, AMS New SUB Sustainability Stakeholder. The microbrewery along with the greenhouse were originally planned for the new SUB, however, the brewery has been moved to the UBC Farm. For the greenhouse to use the waste heat, the steam will be directly piped from the microbrewery to use in an in-soil radiant heating system that has been proven to boost plant growth and to be more efficient than letting steam directly into the greenhouse. Due to the circumstances, there are many assumptions throughout the report: the location of the greenhouse, microbrewery, the size of the greenhouse, what kind of a microbrewery will be put in place, how big the microbrewery will be, and the length and frequency of microbrewery operations. As can be seen, there are too many variables. Therefore, the calculations and the contents of the report are based on assumptions that have allowed the report to be completed. The overall objective of this project is to conserve energy on campus by reusing the excess waste heat from the microbrewery to create a more sustainable campus. The economic, environmental and social aspects of the project have been investigated as part of a triple bottom line assessment and taken into consideration throughout the report to reflect the principles taught in Applied Science 262. This report will contain the triple bottom line assessment on the proposal and give recommendations and conclusions based upon it.

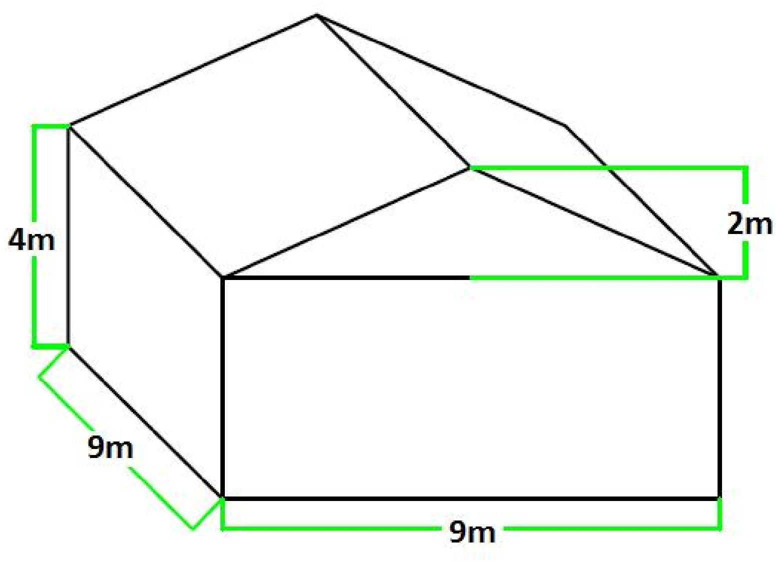
2.0 PROJECT PARAMETERS

To begin to assess the viability of a project such as this, some parameters must be set. In this case, to fully project details such as construction cost, energy needs, crop output, environmental impact etc. parameters of the project have to be decided upon. Parameters include but are not limited to size of greenhouse, material choice, assumed average outside temperature, and desired inside temperature. The selection of these parameters will greatly influence the findings of this investigation.

2.1 THE GREENHOUSE

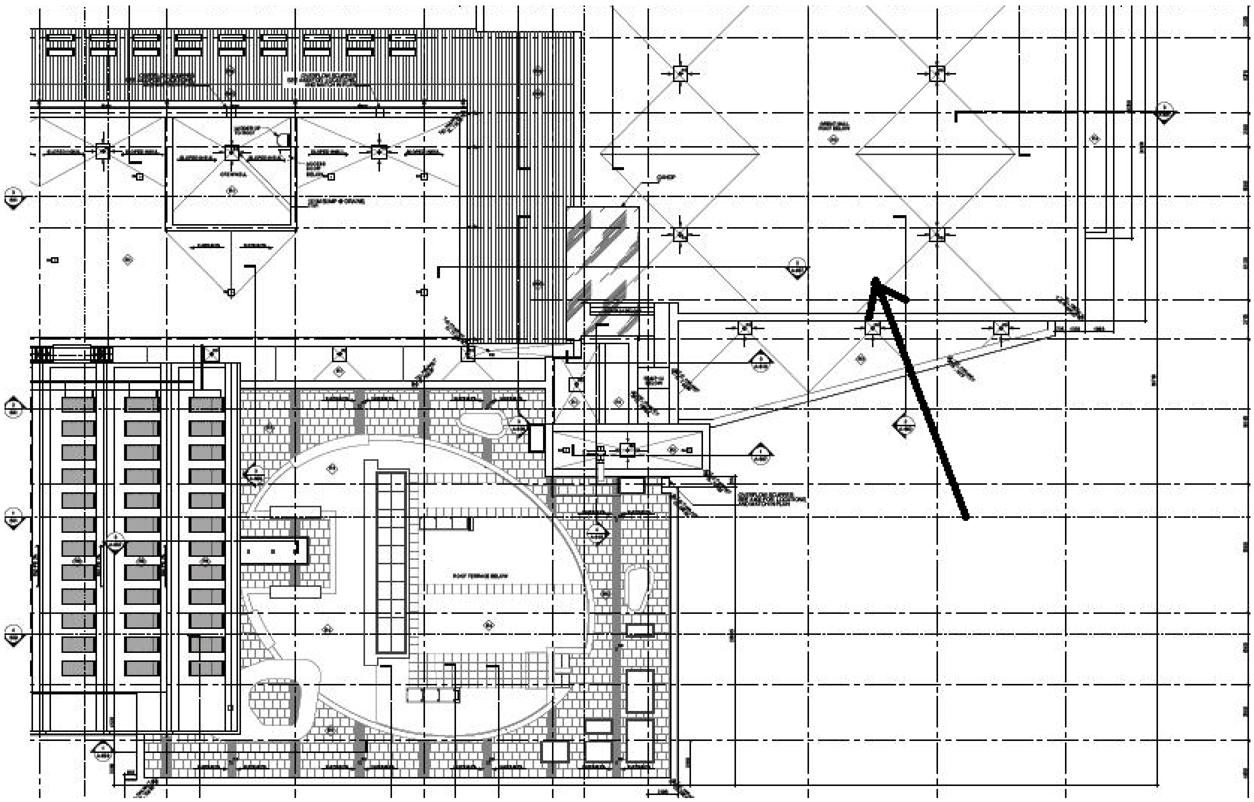
For this project, the greenhouse in question is sized as follows: nine meters wide, nine meters deep, 4 meters high, with a triangular prism roof with base length nine meters, gable height 2 meters and depth nine meters. A simple depiction of the size and shape is shown in Figure 1 below. This size was selected as it will fit in the area supplied to the project on the roof of the SUB but it will not be too large that its energy needs are excessive. Figure 2 below shows the SUB roof layout as well as the allotted area (arrow).

Figure 1



Greenhouse Dimensions. Created by Joey Pateman

Figure 2



SUB Roof Schematic. Supplied by Stakeholder Collyn Chan

Aside from the sizing details, it is important to select materials to be used in the construction of the greenhouse. Two materials are needed, one for the frame and one for the transparent walls of the building. Cost, recyclability and longevity and most desired from these two materials. Common options for the frame include steel, plastic and aluminum while the walls are generally plastic or glass. For the frame, the best option is very clearly aluminum. It is quite strong, quite light and the cost is very reasonable, though not as cheap as steel ("Metal Prices," 2013). Aluminum unlike steel however does not corrode when weathered as it develops a thin oxide layer for protection (Callister, 2007). Additionally, aluminum is 100% recyclable for its lifetime, with no loss of performance (Callister, 2007). For the walls of the greenhouse, glass seems to be the best choice as it is easily recycled and is similar in price to polymer options (Callister, 2007).

2.2 ENERGY NEEDS OF THE GREENHOUSE

Because the greenhouse in question is to be built in Vancouver, the climate and in particular, the average daily temperature is of importance to finding the amount of heat loss and subsequently the energy needs. The desired growing temperature is set as 25° C due to the heat difference in the months May through September, the greenhouse's heating needs are generally met by the sun. For the seven other months of the year, October through April, it is found that the average daily temperature in Vancouver is approximately 5° C ("Average weather for," 2013). This will be the temperature of the atmosphere that we will work with. Energy input needed is equal to the energy lost due to outside temperature differences. This quantity is set as $Q_T=Q_C+Q_A$ where $Q_C = UA\delta T$ and $Q_A = 0.5GN\delta T$ ("*Greenhouse heating and venting*", 2008). U = 4.5 and N = 0.5 are constants while A = $250m^2$ (surface area), G = $405m^3$ (volume) and $\delta T = 25 – 5 = 20°$ C (temperature difference). Calculation gives Q_C = 22500 W and Q_A = 1012.5 W meaning Q_T = 23512.5 W. Adding approximately 10% to account for inefficiencies gives Q_T = 25000W = 25kW, the energy required to heat the greenhouse. This calculation is described in more detail in section 3.2.1.

3.0 TRIPLE BOTTOM LINE ASSESSMENT

There are several indicators in each of the three fields of analysis: Economic, Environmental and Social. Economically capital cost, yearly profit, crop output and break-even time were investigated. Environmentally energy sufficiency, land efficiency, life cycle of materials and the recycling or reuse of materials were investigated. Socially educational value and safety concerns were explored. Together, all of these factors must be considered to conclude whether or not the project is a viable, sustainable choice.

3.1 ECONOMIC ANALYSIS

Economic factors are very commonly looked at and considered in any project. The important components of the economics of a project are capital costs, maintenance costs, projected profits and the time after which the capital investment can be recouped. For this project to be viable, the capital costs and maintenance costs have to be low and the profits have to be reasonable.

3.1.1 Assessing Capital Cost

The most substantial component of the capital cost of construction for this project is undoubtedly the material cost. According to a greenhouse building guide hosted by Western Virginia University, a greenhouse with dimensions roughly double the size of the one in this project can be constructed out of polyethylene and aluminum for approximately $20,000. Because of the material choice of glass being approximately twice as expensive as polyethylene, this cost can be a soft estimate for the material cost of the project. Many glass wholesalers list the cost of double pane, argon filled, aluminum framed glass at between $40 and $70 dollars per square meter. Accounting for the more substantial structural needs that an aluminum greenhouse frame would have as compared to a window, an upgrade to $\$100/m^2$ easily accounts for the material cost of the greenhouse structure. With our surface area of $250m^2$ this gives a material cost of $25,000. In addition to this, 1800 ft of ½" copper tubing is needed to route steam through the soil. At a cost of $45 dollars per 50 ft coil, that adds another $1,640 to the cost giving a total of $26,640 for materials.

The next highest cost in the construction of this project will be the labor cost. It is safe to assume that the job would require the work of several workers, in this case set at 4, and several days to complete. If the 4 workers are to be paid $20 dollars per hour and work 8 hours per day and the job takes 6 days to complete, the total labor cost would be $3,920. This is an extremely conservative estimate; in reality, this job could be completed much more quickly. With labor included, the total capital cost of this greenhouse is $30,560.

After construction, the need for maintenance may periodically arise. $1,000 per year is estimated to be the cost of maintenance. This would cover replacement of any broken windows, or the cost cleaning.

3.1.2 Energy Cost Savings

In sections 2.2 and 3.2.1 it was calculated that the energy required to heat the greenhouse will be 25 kW. If it is assumed that the brewery steam output or other SUB waste heat will completely cover this energy requirement, the savings associated with the energy use are substantial. The greenhouse will require this energy input 24 hours a day for 7 months. Calculation of the total energy usage per year is as follows:

25 kWh used per hour * 24 hours = 600 kWh per day

600 kWh per day * 30 days = 18,000 kWh per month

18,000 kWh per month * 7 months = 126,000 kWh per year

To get the theoretical value of this energy used, we simply take the quantity of energy and multiply by BC Hydro’s energy rates of 10.34 cents or $0.1034 ("Residential rates," 2012). This gives an annual energy savings with a value of $13,028.40.

3.1.3 Crop Outputs

Another important facet of the potential profit this greenhouse could bring is in the crops grown there. If for example we grow strawberries there all year long, the crops produced would be at the cost of only seed, soil and fertilizer. The value of the strawberries would therefore be saved and turned into profit. A greenhouse can typically devote approximately 75% of its floor space to growing space, in this case that results in $60m^2$ of growing space. Strawberry plants can yield 8 kg of fruit per square meter, resulting in a yearly crop of up to 480 kg ("Rotating growing system," 2009). The average market cost of strawberries is around $6/kg and when accounting for seed, soil and fertilizers this leads to a net profit of $2,280 per year ("Rotating growing system," 2009).

3.1.4 Break Even

Ultimately, a project will not be successful if the initial investment cannot be paid within a reasonable time period. If a project takes too long to reach maturation, the risk is too high. The initial cost of this project is $30,560 while the yearly profits are $14,308.40 (after subtraction of maintenance cost) in theory. This means that in only 2.14 years the projects value in savings will have equaled the capital cost. Because nothing being output from the greenhouse will have literal profits or revenue, savings in energy and food cost are the goal. After little more than two years, the project will be purely positive in economic terms making it a very efficient project.

3.2 ENVIRONMENTAL ANALYSIS

An environmental analysis of the proposed greenhouse involves energy sufficiency, material selection and life cycle analysis. It will be shown that the greenhouse is an exceptionally sustainable, long lasting building. Our environmental indicators are joules and greenhouse gas emissions (primarily carbon dioxide).

3.2.1 Energy Sufficiency

First, it must be determined if our proposed 9 meter by 9 meter greenhouse is able to be heated by a microbrewery. To accomplish this, we analyze the thermodynamic properties of the greenhouse. We will solve for heat loss using the following formulae:

$$Q_t = Q_c + Q_a$$
$$Q_c = UA\Delta T$$
$$Q_a = 0.5GN\Delta T$$

To solve for Q_A and Q_C, we must first determine some physical characteristics of the greenhouse. We begin by calculating the surface area, A, of the greenhouse. This is the area that heat is able to leave the greenhouse:

$$A_{wall} = 36 \cdot 4m^2$$
$$A_{roof} = 4.92 \cdot 9 \cdot 2m^2$$
$$A_{gable} = 0.5 \cdot 9 \cdot 2 \cdot 2m^2$$
$$A_{total} = A_{wall} + A_{roof} + A_{gable} = 250.56m^2$$

Next we calculate the volume, G, of the greenhouse. This is the volume that needs to be heated to the desired temperature:

$$G_{room} = 9 \cdot 9 \cdot 4m^3$$
$$G_{roof} = 0.5 \cdot 9 \cdot 9 \cdot 2m^3$$
$$G_{total} = G_{room} + G_{roof} = 405m^3$$

ΔT is the change in temperature required to heat the greenhouse from 5°C to 25°C; this is simply the difference, 20°C. The 5°C comes from the average temperature of the coldest 7 month period in Vancouver. U and N are the heat transfer coefficient and number of air exchanges per hour; we will assume these are constants 4.5 and 0.25 respectively. Thus Q_C, Q_A and Q_T become:

$$Q_c = 4.5 \cdot 250.56 \cdot 20W$$
$$Q_a = 0.5 \cdot 405 \cdot 0.25 \cdot 20W$$
$$Q_t = Q_c + Q_a = 23562.9W$$

We will add approximately 10% overhead to this figure to account for losses and inefficiencies during the transportation of the steam through the pipes to the greenhouse. Thus the total energy requirement becomes 25,000W or 25kW to sustain a temperature of 25°C when the external ambient temperature is 5°C. This can be generated by a microbrewery with a batch size of 337L at a 10% evaporation rate. This is because 33.7 L of water is 33.7 kg of water which if in the form of steam at 140°C has 90000 kJ of energy to give to an environment at 25°C.

3.2.2 Life Cycle

The materials that are used in the construction of the greenhouse will be primarily aluminum and glass. Both of these materials are remarkably long lasting and extremely resistant to corrosion. Glass is nearly impervious to naturally occurring corrosives. This is supported by the fact that it takes approximately 1,000,000 years for glass to naturally decompose. Furthermore, transparent glass allows maximum solar permeation and is easy to clean. Aluminum is also very resistant to corrosion. After very short periods of exposure, aluminum will oxidize and produce a protective layer around itself. It takes aluminum 80 - 500 years to naturally decompose. Given these time scales, naturally occurring “wear and tear” is not an issue. As such, greenhouses can easily last for more than 25 years with minimal maintenance, due to the simplicity of construction and the natural durability of the materials used.

Also considered was using a polymer substitute which has become popular due to its more economical pricing, material strength and light weight. However, plastics are not as durable as glass to the effects of weather and age. Plastic greenhouses are expected to have a much shorter life expectancy. Furthermore, plastics do not allow as much solar radiation to permeate into the greenhouse and are less visually appealing. As such, we ultimately decided on an aluminum and glass greenhouse.

3.2.3 Recycling and Reuse

Once the greenhouse is ready to be decommissioned, the materials used in constructing the greenhouse should be recycled. This is because the process of creating new glass or new aluminum from raw materials contributes a significant amount of greenhouse gases in the form of carbon dioxide. Furthermore, it is not a relatively difficult or expensive process to recycle these two materials because they are both already very commonly recycled.

Recycling glass is a good way to reduce greenhouse gas emissions. Every metric ton of glass recycled saves 315 kilograms of carbon dioxide being harmfully released into the atmosphere. In the case of the greenhouse, we will be able to recycle 250.56 square meters of the greenhouse:

$$A_{greenhouse,total} = 250.56m^2$$
$$T_{glass} = 0.003175m$$
$$D_{glass} = 2579kg/m^3$$
$$R_{CO_2emissions} = \frac{315}{1000} kg_{CO_2emissions}/kg_{glass}$$
$$M_{CO_2emissions} = A_{greenhouse,total} \cdot T_{glass} \cdot D_{glass} \cdot R_{CO_2emissions}$$
$$= 646.275kg$$

Where A is glass surface area, T is glass thickness, D is glass density, R is the CO_2 emissions per metric ton of glass and M is the mass of CO_2 saved. Assuming 1/8 inch thick glass is used and the greenhouse is completely recycled, we will be able to save 646.275 kg of CO_2 from being released into the atmosphere.

Aluminum is the most commonly recycled metal in the world. This is because of the huge energy savings associated recycling aluminum. Only 5% of the original energy required to create aluminum from raw ore is required to recycle aluminum and it causes 97% less water pollution. Furthermore, aluminum can theoretically be recycled an infinite amount of times. Recycling aluminum does not deteriorate the natural properties of the material.

3.3 SOCIAL ANALYSIS

This section of the report will be covering the social portion of the triple bottom line assessment. Besides the economic and environmental aspects of the waste heat powered greenhouse, a social look at the project is important as well, according the triple bottom line assessment. Some social indicators that were used to evaluate the idea in this report were education, safety, foot traffic, and happiness.

3.3.1 Educational Value

One of the most valuable traits of the greenhouse in terms of society and its wellbeing is the educational part of it. Through tours, the greenhouse would be an important educational tool for teaching students about food sourcing, a tool that is lacking in today’s world. People who tour the greenhouse could find out where the food they eat comes from, how it grows, and what it looks like before it is prepared by one of the cooks in the new SUB. People often do not realise that the food they eat comes from farms like the one picture below in Figure 3

Figure 3

Soybean Field. (2007). *Soybean field*. (2007). [Print Photo]. Retrieved from http://blogs.edf.org/innovation/files/2010/11/iStock_000004030044sm.jpg

Additionally, visitors will be informed of how the greenhouse is being heated by the waste heat from the microbrewery. This will raise the visitors' awareness of being energy efficient, being green, and the use of sustainable, renewable energy at UBC. Raising awareness of just what is possible in terms of energy efficiency, use and reuse can be an invaluable resource for education of the public, if they know that possibilities exist they will be more likely to choose them. There are also a number of botany and biology courses related to plants that could glean information from the greenhouse to aid in their education, these classes are detailed in appendix B and number some 29 classes. Some examples of these courses include: graduate study courses in Botany such as Dynamics of Plant Populations, Current Topics in Plant Biochemistry, Plant Molecular Biology, and undergraduate biology courses such as Non-Vascular Plants, Vascular Plants, Weed Science, Introduction to Seed Plant Taxonomy, Plants and Peoples, Plant Physiology I, Plant Physiology II: Plant Development etc.. Classes would be able to go to examine the specimens at the greenhouse, or just spend time in a relaxing environment. Overall, the educational value of the greenhouse heated by the waste heat from the microbrewery is tremendous.

3.3.2 Safety

Another social indicator that was used to assess the greenhouse was safety, after some research, it has been found that regular, long term exposure to pesticides can be detrimental to one’s health ("Pesticides - health," 2010). Some reported long term effects of exposure to pesticides range from attention disorders, reduced reaction time, miscarriages, birth defects to depression, cancer, and even death ("Pesticides - health," 2010). However, this problem is easily remedied by using organic growing techniques which lack the need for harmful pesticides.

As a precaution, and because food is being grown there, the greenhouse would not be open to anytime public visitation. Instead it is recommended that the greenhouse have volunteer guided tours or be open to students taking plant-related courses. This would minimize shrinkage, vandalism and the risk of contamination.

4.0 ALTERNATIVES

When this project was in earlier stages, alternatives to a greenhouse were considered. Possibilities included a spa or recreational facility, multipurpose room or a heat engine designed to recover the waste heat. There were a number of reasons why these projects failed which are detailed in the following section.

4.1 RECREATIONAL FACILITY

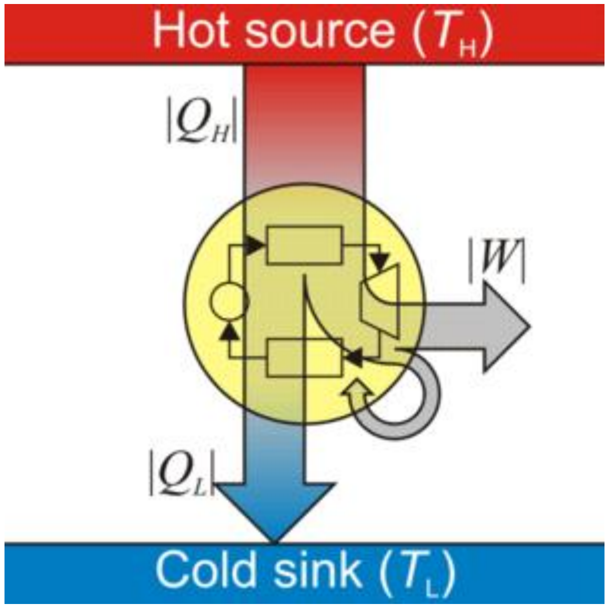
In place of building a greenhouse, a different type of building was investigated early on; a multipurpose room of sorts to be heated by steam or waste heat. The issues of replacing a greenhouse with such a building are that a conventional building has a much higher construction cost and that the materials being used in such a project such as drywall, insulation, flooring, etc. are not recyclable and minimally reusable. Environmentally, the recyclability of the materials used in this project is of extreme importance which is why a greenhouse is a better choice than a conventional building.

4.2 HEAT ENGINE

In consideration of using a heat engine to deal with the waste heat produced by either the brewery or the new SUB, the observation must be made that a heat engine is essentially the opposite of a boiler. In a boiler, energy is consumed and transferred into water which eventually evaporates into steam. In a heat engine, and example of which is depicted below in Figure 4, the energy of the heated gas is transformed into mechanical energy and can be converted to electricity. This process is governed however by the second law of thermodynamics and its maximum efficiency is described by the Carnot equation:

$e_{carnot} = \frac{T_H + T_C}{T_H}$ which yields 28% as the maximum efficiency (Young & Freedman, 2008). As such, using a heat engine to convert waste heat into electricity would be less efficient than simply using the already existing heat to heat the greenhouse. The efficiency of using existing heat to heat a greenhouse is closer to 80%.

Figure 4



Heat Engine Schematic. 2009). *Heat engine schematic*. (2009). [Print Photo]. Retrieved from http://upload.wikimedia.org/wikipedia/en/thumb/a/a2/Heat_engine.png/300px-Heat_engine.png

5.0 CONCLUSION AND RECOMMENDATIONS

In Summation, the greenhouse heated by the microbrewery and/or another waste heat source located in the new SUB has been assessed in terms of economic, environmental and social sustainability using the above indicators on the basis of a triple bottom line assessment. This assessment has found that in terms of all of these factors, a waste heat powered greenhouse has been found to be a valuable addition to our campus. The greenhouse will be a great asset to students who are looking for a place to learn about plants, how their food is grown or how to reuse energy. It will also serve nicely to students and faculty alike who are involved in courses that are related to plants. It can be an extremely safe environment as well as long as proper visitation parameters are enforced. Economically, the project has low initial costs, low maintenance costs and will reap large savings after only two years of operation. The greenhouse will also be constructed of glass and aluminum, materials that are long lasting and easily recycled or reused when disposal time comes. A rooftop greenhouse also spares the usage of arable land elsewhere making any crops produced a supplement.

Based on the findings of this investigation into the viability of this project, it can be concluded that the project is indeed viable and that it is highly recommended that the project be completed. This is assuming that the energy require to heat the greenhouse can be supplied by either the steam from the brewery or some other source within the new SUB.

REFERENCES

Average weather for vancouver. (2013, 01 01). Retrieved from http://www.weather.com/weather/wxclimatology/monthly/graph/CAXX0518

Buecker, B. (2010). Steam generation thermodynamics. *Chemical Engineering*, *117*(12), 44-47. Retrieved from http://search.proquest.com.ezproxy.library.ubc.ca/docview/811397791

Bureau of Energy Efficiency. (n.d.). *Waste heat recovery*. Retrieved from http://www.em-ea.org/Guide Books/book-2/2.8 Waste Heat Recovery.pdf

Callister, W. D. (2007). *Materials science and engineering - an introduction*. (7th ed., pp. 131-170, 544-549, 622-650). York, PA: John Wiley and Sons, Inc.

Dean, M. (1901). *Dean's system of greenhouse heating by steam or hot water*. Boston, Mass: Mark Dean. Retrieved from http://www.biodiversitylibrary.org/title/41736

Energy Efficiency Asia. (n.d.). *Waste heat recovery*. Retrieved from http://www.energyefficiencyasia.org/docs/ee_modules/Chapter-Waste Heat Recovery.pdf

Energy, Mines and Resources Canada, (1979). *Waste heat recovery*. Retrieved from Government of Canada website: http://oee.nrcan.gc.ca/sites/oee.nrcan.gc.ca/files/pdf/commercial/password/downloads/MS_20_waste_heat_recovery.pdf

Greenhouse heating and venting. (2008). Retrieved from https://www.gov.mb.ca/agriculture/crops/greenhouse/bng01s04.html

Hepbasli, A. (2011). A comparative investigation of various greenhouse heating options using exergy analysis method. *Applied Energy*, *88*(12), 4411-4423. doi: 10.1016/j.apenergy.2011.05.022

Metal Prices . (2013, 04 01). Retrieved from http://www.metalprices.com/p/FreeCharts/

Muller, G. (2013). The atmospheric steam engine as energy converter for low and medium temperature thermal energy. *Renewable Energy*, *53*, 94-100. doi: 10.1016/j.renene.2012.10.056

Nishizawa, T., & Hori, Y. (1993). Effects of defoliation and root heating during rest on leaf growth in strawberry plants. *Tohoku Journal of Agriculture Research*, *43*(3,4), Retrieved from http://ci.nii.ac.jp/els/110000982183.pdf?id=ART0001158849&type=pdf&lang=jp&host=cinii&order_no=&ppv_type=0&lang_sw=&no=1361998419&cp=

Pesticides - health effects. (2010, 11 18). Retrieved from http://www.ccohs.ca/oshanswers/chemicals/pesticides/health_effects.html

Residential rates. (2012, 01 01). Retrieved from https://www.bchydro.com/accounts-billing/customer-service-residential/residential-rates.html

Rotating growing system. (2009, 06 12). Retrieved from http://www.abhydroponics.com.au/page/rotating_system.html

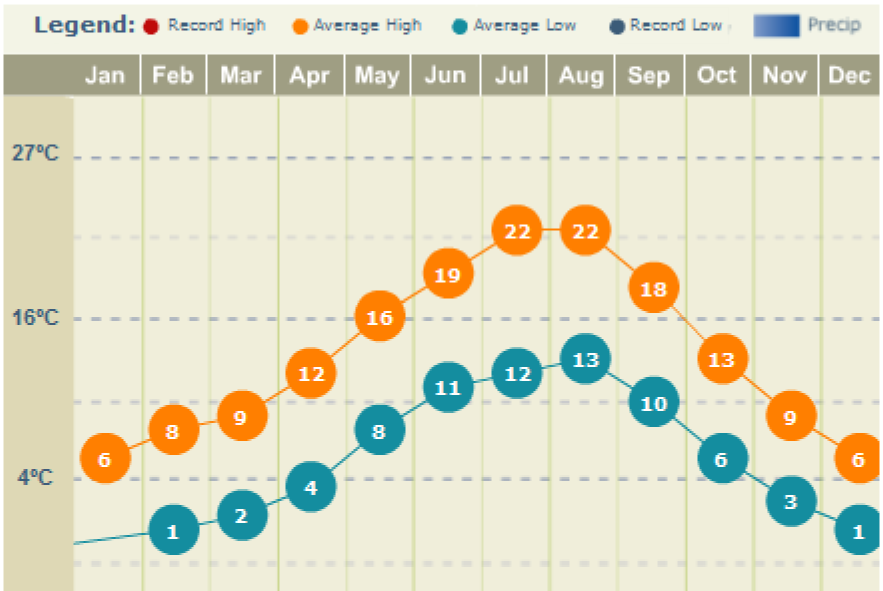
Sachs, R. M., Sisto, I., Jenkins, B. M., & Forister, G. W. (1992). Plant response and energy savings for bench-top-heated greenhouses. *Scientia Horticulturae*, *49*(1,2), 135-146. doi: 10.1016/0304-4238(92)90150-B

Young, H. D., & Freedman, R. A. (2008). *University physics*. (Special ed., Vol. A, p. 700). Boston, MA: Pearson Education, Inc.

APPENDICES

Appendix A

Graph of average high and low Vancouver temperatures by month



(2013). *Average weather for vancouver*. (2013). [Print Photo]. Retrieved from http://www.weather.com/weather/wxclimatology/monthly/graph/CAXX0518

Appendix B

Table listing the various plant-related classes UBC offers.

Class	**Description**
BOTA 501	Seminar in Botany
BOTA 502	Thesis Seminar
BOTA 527	Dynamics of Plant Populations
BOTA 528	Current Topics in Plant Biochemistry
BOTA 544	Plant Molecular Biology Laboratory
BOTA 546A	Topics in Botany - TOPICS IN BOTANY
BOTA 546B	Topics in Botany - TOPICS IN BOTANY
BOTA 546C	Topics in Botany - TOPICS IN BOTANY
BOTA 546D	Topics in Botany - TOPICS IN BOTANY
BOTA 546F	Topics in Botany - TOPICS IN BOTANY
BOTA 548	M.Sc. Major Essay
BOTA 549	Master's Thesis
BOTA 649	Doctoral Dissertation
AGSC 504	Research Methodology in Agricultural Sciences
AGEC 530B	Directed Studies - DIRECTED STUDIES
AGEC 549	Master's Thesis
BIOL 209	Non-Vascular Plants
BIOL 210	Vascular Plants
BIOL 317	Weed Science
BIOL 324	Introduction to Seed Plant Taxonomy
BIOL 343	Plants and Peoples
BIOL 351	Plant Physiology I
BIOL 352	Plant Physiology II: Plant Development
BIOL 406	Plant Ecology I
BIOL 415	Evolutionary Processes in Plants
BIOL 421	Plant-Microbe Interactions
BIOL 433	Plant Genetics
BIOL 440	Plant Genomics
BIOL 462	Ecological Plant Biochemistry