An Investigation into Waste Heat Recovery for Usage by a Rooftop Greenhouse

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ABSTRACT

With the creation of a microbrewery, an excess amount of waste heat in the form of steam is produced. In the sustainability principles that the University of British Columbia aims towards, this excess heat is planned to be used as an energy source to provide a greenhouse effect on a rooftop garden. This report is a triple-bottom line assessment on the feasibility of this idea; it is an assessment on the environmental, economical, and social impacts of this waste heat recovery method.

Constraints that are taken into this investigation include various factors. The estimations in overall size and choice of construction materials are chosen based on what is the most sustainable choice. The investigation consisted primarily of research in the academic domain as well as ongoing communication with the primary stakeholder.

The project is economically viable based on the needs of the alma mater society; the capital investment is not too high and the return is net positive. Socially, the pros outweigh the cons. Students can gain valuable horticultural experience plus unique crops that could be grown in the greenhouse would be beneficial for the student union building. The project is also environmentally feasible because of the low material requirements, low energy demand and reasonable lifespan. As a conclusion, it is recommended that waste heat energy be used to heat a rooftop garden, particularly in a greenhouse method. This proposal satisfies a triple bottom line assessment.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

GLOSSARY

1. *Microbrewery* - A brewery that produces a limited amount of beer, typically specialized.

2. *Heat transmission factor* - Given a temperature difference of 1 degree, it is the amount of heat which passes through an area per unit time.

3. *Soil pasteurization* - Non-chemically sterilizing the soil to remove harmful organisms; often done by heating the soil.

4. *Light pollution* - Artificial light that illuminates the night sky, inhibiting observation of astronomical bodies.

5. *Quonset* – A greenhouse frame which is circular and covered with plastic sheeting.

LIST OF ABBREVIATIONS

1. UBC - the University of British Columbia
2. AMS - Alma Mater Society
3. SUB - Student Union Building
4. BTU - British Thermal Unit
5. PVC - Polyvinyl chloride
6. PE - Polyethylene
7. MJ - Megajoules
8. CO_2 - Carbon dioxide

1.0 INTRODUCTION

The University of British Columbia (UBC) Alma Mater Society (AMS) is interested in determining if building a greenhouse on the rooftop of the new Student Union Building (SUB) is a feasible project. A rooftop garden is already planned, as well as a microbrewery* within the SUB. The proposal is to construct a greenhouse that utilizes the waste heat produced from the microbrewery. The purpose of this report is to explore this idea and to assess its feasibility by using a triple bottom line analysis.

The material requirements, energy demand, and the project's life cycle were weighed to determine the environmental impact of the project. Capital investment, operational costs, and user savings were all considered to measure economic feasibility. Maintenance and labor requirements, infrastructure and operational changes, as well as health and educational implications were all considered in the social analysis.

In this report, each individual assessment has a recommendation to the AMS based purely on its own factors. The conclusion contains a summary of each assessment and an overall recommendation.

* This term and all subsequent terms marked with an asterisk are defined in the glossary on p. v

2.0 ENVIRONMENTAL ASSESSMENT

In order to assess the environmental implications of the rooftop greenhouse, several aspects must be examined. These include the material requirements of construction and operation, the energy demand and supply needed for normal operation, and the overall project lifecycle. This section will provide an outline of these topics in relation to the rooftop greenhouse.

2.1 Material Requirements

A greenhouse located on a rooftop is limited in size. Using SUB's floor plans as a gauge, the intended greenhouse size is estimated to be 19.7 ft by 24.6 ft by 12 ft as a freestanding structure. This estimation was determined from a blueprint provided by the primary stakeholder, Collyn Chan. This cropped blueprint can be seen in Figure 1 below with the garden circled in blue and the suggested greenhouse location boxed in red. This structure type increases the amount of sunlight, and can be varied in size (Ross, 1994). A central bench, two side benches, and two walkways can be implemented using a freestanding structure as well, improving the low cost to usable space ratio (Ross, 1994). Suggested minimum sizes are 6 feet wide and 12 feet long for an even-span or freestanding greenhouse (Ross, 1994).

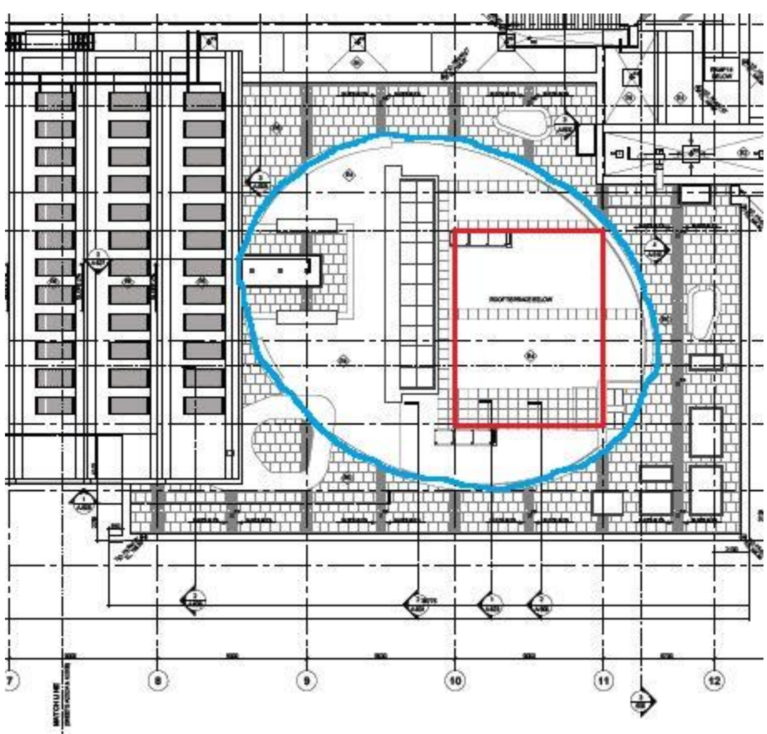

Figure 1: SUB Blueprint with Suggested Greenhouse Location (Chan, 2013)

For any greenhouse, the framing, glazing, heating system, floor, and benches must be considered (Healy, Hanson and Gill). Benches are primarily made of wood. However, a variety of frames are available, ranging in complexity of construction and material demand. These frames can vary in what they are made of, as polyvinyl chloride (PVC), aluminum, steel, and wood are all viable options for design (Edmunds, 2012). An aluminum frame is suggested over plastic piping which is "generally inadequate to meet snow and wind requirements" (Ross, 1994). It also "has the longest life span and allows for light reflectance" (Schenlle and Dole, 2009). The greenhouse covers range from glass, fiberglass, rigid double-wall plastics, and film plastics. Due to common usage and low installation costs a double layer polyethylene (PE) covering is recommended. The light transmission of a PE covering is also comparable to glass, optimal for reducing energy requirements (Ross, 1994).

Additionally, a steam heating system is assumed. This system allows for "a smaller boiler, less plumbing, and no circulating pumps" (Van Berkum, 2012), minimizing heating system material and reducing the overall requirements. It also "allows for use of steam for soil pasteurization[*]" (Buffington et al, 1983). The usage of a steam system allows for varied heating distribution methods. Four main methods are rail heating, under bench heating, in-floor heating, and overhead heating (Van Berkum, 2012). These types have their own pros and cons, such as ability to control temperature and humidity. However, the selection of heating distribution is beyond the scope of this investigation and has minimal foreseeable material implications.

Based on these various aspects of construction, the material requirements for a steam heated greenhouse include a significant amount of lumber, sufficient film plastic coverings, and the appropriate amount of piping. Estimating the greenhouse at 19.7 ft by 24.6 ft by 12 ft, with 6 ft side walls, the double-layer PE covering would need to span across the total surface area of the greenhouse of 1217 square feet. The requirements for lumber and piping are affected by quality of construction, and overall implementation. In comparison to other similar structures however, these requirements are small and manageable.

2.2 Energy Demand

A large variable, and significant point of interest, is the energy demand of a steam heated greenhouse. This involves estimation of the threshold energy needed to operate, including a range dependent on crop production, and estimation of the energy production from the microbrewery.

The University of Florida produced a fact sheet in order to estimate the amount of heating required. Using the typical low temperatures of Vancouver of 6.5 degrees Celsius (Environment Canada, 2013) or 43.7 degrees Fahrenheit produces an expected maximum heating required. Typical greenhouse temperatures range between 10-20 degrees Celsius (50-68 degrees Fahrenheit) (Vaisala). Using this, a differential temperature range of 4.5 degrees Celsius to 14.5 degrees Celsius (or 6.3 to 24.3 degrees Fahrenheit) can be obtained. The surface area of the greenhouse can be estimated to be 1216.90 square feet. Taking the product of maximum temperature difference to be obtained, the surface area and a heat transmission factor[*], we obtain an estimate heat requirement.

The heat transmission factor significantly varies depending on materials used and the wind velocity. However, a transmission factor of 0.75 is used as recommended for a house covered with a double layer of PE. Continuing with a worst case scenario, an additional 10 percent is added due to the windy location of the greenhouse. The final result is that an estimated 6324.84 to 24395.80 Btu/h is obtained. David Ross' example calculation, a larger greenhouse than what is estimated here, requires 76032 Btu/h which he equates to "the equivalent to that in a small residence such as a townhouse." The estimation acquired for the SUB rooftop greenhouse is less than a third of that. It is then concluded, due to manageable heating requirements, that the greenhouse's energy demand can be satisfied.

When considering the light energy needed, the greenhouse is located in an excellent position, as it is elevated and achieves maximum sunlight exposure. As well, it remains relatively unimpeded by other major structures. It is recommended that the location on top of the rooftop be "an east side location [as it] captures the most November to February sunlight" (Ross, 1994). This aids in reducing the additional lighting and heating costs needed. Options such as electric heaters, solar panels, and so forth can be considered to reduce additional costs and fossil fuel consumption.

2.3 Project Lifecycle

The projected greenhouse requires little in terms of maintenance. Being supported by an AMS club, it can be expected that the end users will have knowledge pertaining to greenhouse operations; such areas as “propagation, plant nutrition, soil management, greenhouse structures” (Healy, Hanson and Gill) can be explored in courses in the Faculty of Land and Food Systems at UBC. Thus, what would normally require a small staff can be handled by a group of students. Maintaining humidity and temperature can also be done by these students, and is made easier by the steam heating system as it allows for rapid heating and cooling. This steam-based heating system has a high investment initially, but it has a long life expectancy (Buffington, Bucklin, Henley & McConnell, 1983)

An important factor in the environmental assessment of this project is not simply the short-term, but the overall lifespan of the greenhouse. With aluminum as a framing material choice, the longest lifespan is obtained. It is light in itself, requires less maintenance, and does not deteriorate as badly as wood (Schenelle and Dole, 2009). Aluminum framing is also fairly maintenance-free (Ross, 1994). The deterioration and replacement of the film layer is also considered. Given a double layer polyethylene covering, it is expected that the lifespan be four years (Schenlle and Dole, 2009). However, PE film is fairly inexpensive and several products can be used to extend its life expectancy.

2.4 Environmental Conclusions

In conclusion, given the right design choices, a steam heated greenhouse is a viable project from an environmental perspective. Supported by an AMS club, the maintenance responsibilities can be delegated and minimized to a group of educated students. The material required is not uncommon to other similar structures, and does not provide a major environmental impact. The suggested usage of double layer polyethylene may have a short lifespan, but is a plausible solution and can be revised at a later point in time. The energy threshold for normal operation, 6324.84 to 24395.80 Btu/h, is reasonable and can be satisfied. Environmentally, this project has minimal cons and makes efficient use of waste heat.

3.0 ECONOMIC ANALYSIS

In order to determine the economic viability of the rooftop greenhouse, various factors must be taken into account. These include the capital investment of the project, the operating costs of the greenhouse and the savings for UBC Food Services, which will use the produce grown in the greenhouse. This section will compare the savings with the costs and make a recommendation based purely on economic factors.

3.1 Capital Investments

A greenhouse is a big investment which may have a high initial cost. The capital investment for a greenhouse includes the cost of the greenhouse materials, the cost of the heating system, which includes piping, and the cost of the construction and installation of the greenhouse. The waste heat recovery system is included in the analysis of the heating system, which is a steam-based system that utilizes the waste steam from the planned microbrewery in the new SUB. This steam-based heating system has a high investment initially, but it has a long life expectancy (Buffington, Bucklin, Henley & McConnell, 1983). The economic analysis in this section and the next two sections will examine whether or not the savings from the high life-expectancy outweighs the high capital investment.

Many of the capital investments depend upon the crops grown in the greenhouse. While this has not yet been determined, the assumption is that it will primarily be used for specialty crops. The estimates for the capital costs given in this section are based on the approximated costs in *Starting in the Greenhouse Business* by Healy, Hanson & Gill, which is based on a double-layered polyethylene, quonset[*] greenhouse. The cost of the framing for the greenhouse averages about 0.87 $/Sq.ft. The glazing cost, which will be based on the cost of standard, double-layered polyethylene in this section, is approximately 0.35 $/Sq.ft. The cost of the end walls of the greenhouse, including the sheet and frame and the doors, averages 0.77 $/Sq.ft. The floor - including gravel and plastic for the ground cover - will cost approximately 0.28 $/Sq.ft. Irrigation must be taken into account, which averages approximately 1.02 $/Sq.ft. The benches, which are assumed to be constructed of lumber and wire, should cost approximately 0.70 $/Sq.ft. Based on the assumption that this greenhouse will be used year-round, a cooling system will need to be installed for the summer, which will cost approximately 1.53 $/Sq.ft. The assembly and installation of the greenhouse will have an approximate cost of 1.35 $/Sq.ft (Healy, Hanson

& Gill). The steam-based heating system has a high initial cost of around 2 $/Sq.ft (Nelson, 2002).

The total approximate capital cost is 8.87 $/Sq.ft. Based on the estimated area the greenhouse will cover, 484 square feet, the total capital investment considered for this analysis is $4293.08.

3.2 Operational Costs

There are many economic factors to consider when examining the operational costs of a greenhouse. Certain operational costs that are typical in industrial vegetable-producing greenhouses do not have to be taken into account for this project, such as fuel cost, property cost, and marketing costs. The fuel cost does not have to be taken into account because this greenhouse will be steam-powered, and will use the waste heat from the microbrewery. As the land is already owned by UBC, the property cost will not be considered in this analysis. Finally, the marketing costs will not be considered because UBC does not have to find a market for the crops; the crops will be used by Food Services. Due to this, the product already has a market and so the marketing costs are negligible.

The estimates for the operational costs given in this section are based on typical vegetable producing greenhouses in Canada, based on the average costs in *Commercial Greenhouse Vegetable Production* by Alberta Agriculture and Rural Development, compiled by Dennis Dey. These costs are based on a monthly operational cost estimate. The cost of the growing media and seeds averages around 0.71 $/Sq.ft. Fertilizers are, on average, 0.31 $/Sq.ft. The water and power is approximately 0.34 $/Sq.ft. Insurance for the greenhouse will be around 0.13 $/Sq.ft. Maintenance and repairs must also be considered; they average around 0.11 $/Sq.ft. The potential labour costs are approximately 1.99 $/Sq.ft. There are other miscellaneous costs associated with the operation of a greenhouse; in this analysis, they will be considered to average 0.13 $/Sq.ft (Dey, 2001).

The total of the estimated operational costs per square foot is 3.72 $/Sq.ft. This results in a total operational cost of $1800.48 per month.

3.3 User Savings

The addition of a greenhouse will provide produce for UBC Food Services to use. It will allow Food Services to sell more produce grown at UBC thus reducing the quantity purchased elsewhere, resulting in savings for UBC. This analysis will investigate whether or not the savings from this greenhouse outweigh the costs of building and maintaining the greenhouse, making the project economically viable. As the crops that will be grown in the greenhouse are not currently known, tomatoes will be considered as a standard crop for this analysis. The average gross monthly revenue from tomato production per square foot of growing space in the greenhouse is approximately $8.38 (Dey, 2001). The total approximated gross revenue is then $4055.92 for the greenhouse. Thus, the return is the gross revenue subtracted by the operating cost which is $4055.92 - $1800.48 = $2255.44. This return does not include UBC Food Services' savings by not purchasing this crop from elsewhere. This saving depends on the yield of the crops from the greenhouse because that determines the amount of produce bought outside of UBC that can be replaced by the greenhouse-produced crops.

3.4 Economic Conclusions

The greenhouse has a high capital investment, but this is outweighed in the long-run by the high gross revenue relative to the operating costs and large savings for UBC Food Services. Although the return is not absolutely high due to the small area of the greenhouse, according to the primary stakeholder in the project, Collyn Chan, the ultimate goal of this project is not to earn money. As long as the return is net positive, it is an economically successful project. Thus the greenhouse is economically viable.

4.0 SOCIAL IMPLICATIONS

In order to properly assess whether or not the new SUB should incorporate a rooftop greenhouse, from a societal point of view, many things should be considered. The implications of the maintenance and labour requirements, infrastructure and operational changes, as well as associated health and education will be covered.

4.1 Maintenance and Labor Requirements

The rooftop garden is planned to be run on the AMS Club Model. This means that at least one staff member from the club will be working with the AMS to keep it operational. In order to maintain the greenhouse, more than one person could and should be involved in the operations of the greenhouse. Jobs that are required include: tending to the plants by pruning, watering and weeding, keeping soil healthy, by potentially fertilizing or injecting carbon dioxide (CO_2), and controlling environment settings such as heat and light settings (Nelson, 2002). Another important note to consider is that to provide proper maintenance and labour, technical and horticulture knowledge will be necessary for the AMS Club, since converting the steam to heat in a regulated way needs proper monitoring and control.

4.2 Infrastructure and Operational Changes

For a greenhouse to be more viable than a garden, there are many infrastructural and operational changes that need to take place. Adding the framework and the PE shielding will be necessary. Then, in order to make the greenhouse utilize the steam from the new SUB's microbrewery, the waste heat recovery system will need to be installed. Any monitors or computer systems to record temperature, air and soil humidity, light intensity, and potential air quality are also required. In addition, any extra backup heating or supplemental lighting systems will need to be added to the infrastructure.

In terms of operational changes, the biggest difference between a basic garden and a greenhouse that uses recovered heat from steam is that temperature management and monitoring will need to be performed. As described in section 4.1, this means that the club in charge of maintaining the greenhouse will need to be able to manage the heating system.

With the proposed infrastructure and operations of the greenhouse, there will be many social implications. Firstly, more work will be required. More input from the AMS club associated with the greenhouse will be necessary, but as described in section 4.3, there are also benefits to the individuals who work with the greenhouse. Secondly, there is the problem of light pollution* due to this infrastructure which will affect the general public. Many greenhouses that grow vegetables have supplemental lighting; this is a major concern in the winter when approximately 50% of the low-angled incoming light is reflected off of the roof (Runkle, 2011). This lighting can be on for 12-16 hours a day to improve crop yields, especially in the darker months of the year (Runkle, 2011). The effects of light pollution are evident in local greenhouses, such as in Delta, where the light emitted from the greenhouses is polluting and can be viewed negatively by local residents (DuMont, 2003). Further, this light pollution is a waste of energy, and has been speculated to interfere with feeding patterns of birds (DuMont, 2003). However, the proposed infrastructure should be appealing to the people who work with the garden since they will be sheltered and kept warm while working.

There are many infrastructural and operational changes associated with implementing a greenhouse. Socially, they incur more work, but have the possibility of being viewed in both positive and negative ways with people who work in them, and the local residents.

4.3 Health and Educational Implications

Since their origin in Holland in the 1600s to their first appearance in North America in the late 1700s, greenhouses have had social implications - many good, and some bad (Nelson, 2002). They have historically been used for the rich members of society for the production of flowers and fruit that don’t naturally grow in a given location or at a given time of the year (Nelson, 2002). This is one of the benefits that has persisted throughout time and the new SUB could reap. This greenhouse has the advantage of being a small grower, and so, benefits with specialized crop growth. Examples of typical greenhouse crops can be seen in Table 1. It is inconvenient and economically challenging for large growers to produce specialized crops because there is a limited market, but on the SUB’s small-scale facilities, unique crops are a good way to go (Nelson, 2002). These specialized crops are proposed to be used within the new SUB. This has positive social implications for the consumers, since the crops can be grown entirely organically. In addition, they have no travel costs, since they do not need to be shipped further than down a set of stairs.

As this project is intended to have conservative management, there will be a lot to be learned by students involved in work with the greenhouse (Nelson, 2002). Students and other individuals who work with the club in charge of this greenhouse will have the opportunity to learn about horticulture in a hands-on environment. Many companies that produce seeds, plant material, pesticides, and other related materials look to hire individuals with Science Degrees, as well as those with a horticulture background, so this project offers a large benefit to the individuals who work on it (Nelson, 2002).

Table 1. Availability of specialized greenhouse crops (Adapted from Ross, 1994)

Month	**Crops produced**
January	spring bulbs, azalea, primula, cineraria, calceolaria, cyclamen
February	roses, spring bulbs, oxalis, cineraria, calceolaria, primula, cyclamen, azalea, lilies
March	hydrangea, kalanchoe, cineraria, calceolaria, primula, cyclamen, azalea, lilies, bedding, plants
April	spring bulbs, azalea, lillies, gloxnia, heimalis, begonia, bedding plants, flowering baskets
May	hydrangea, azalea, kalanchoe, lilies, gloxinia, potted roses, late flowering bulbs, geranimum, new guina impatiens, bedding plants, flowering baskets
June	gloxnia, heimalis begonia, foliage, hibiscus, gerbera, potted bedding plants
July	gerbera, gloxnia, streptocarpus, heimalis, begonia
August	hibiscus, azalea, heimalis begonia, foliage plants, field chrysanthemum
September	foliage plants, gloxnia, azalea, hibiscus, ornamental pepper, field chrysantheumum
October	hibiscus, foliage, flowering cabbage, flowering kale, cyclamen
November	poinsettia, cyclamen, Christmas cactus

December	poinsettia, Christmas cactus, cyclamen, heimalis begonia

4.4 Social Conclusions

There are many considerations to be made when looking at the social implications of building a greenhouse atop the new SUB that utilizes the waste heat from the microbrewery. In all, this analysis shows that the pros include specialized food production, vast learning, and valuable experience. The cons include light pollution, much work to set up the infrastructure, as well as a requirement for trained volunteers to operate the greenhouse. However, as a the new SUB is part of UBC, a world renowned University, there will likely be individuals interested in learning enough about greenhouses to volunteer their time in an AMS greenhouse club, and outweigh the cons. In such, the social aspect of this report’s triple bottom line analysis promotes building a greenhouse.

5.0 CONCLUSION AND RECOMMENDATIONS

This report covered a triple bottom line assessment on the proposal of building a greenhouse on the rooftop of the new SUB. This greenhouse will utilize the waste heat steam from the microbrewery that has also been proposed to be built in the new SUB.

When looking into the environmental assessment, material requirements, energy demand, and the project lifecycle were all taken into consideration. The findings were that a steam-heated greenhouse is a positive and sustainable idea for the new SUB, given the right design choices. No material proposed to be used has any large environmental impact, and the construction materials are similar to any other comparable structure. Overall, the minimal cons and efficient use of waste heat energy make this a feasible project from an environmental perspective.

The economic assessment considered capital investments, operational costs, and user savings. The findings were that the large capital investment is outweighed by the long-run return, which is a direct result of low operating costs as well as savings for UBC Food Services. For an industrial project, this would not be economically viable, but for the purposes of the AMS it is.

The maintenance and labor requirements, infrastructure and operational changes, as well as health and educational implications were all considered as a part of the social assessment. The social cons include light pollution, an abundance of work to set up the infrastructure, and the need for well-trained volunteers to run the greenhouse. However, the pros of specialized food production, learning, and valuable experience outweigh the cons. Socially, the findings promote the greenhouse project.

In conclusion, the proposed project of constructing a greenhouse on the rooftop of the new SUB is a viable option. From the triple bottom line assessment performed, all three aspects of the analysis show that this is a positive choice. In such, the suggestion to the AMS is to move forward with the waste heat recovery rooftop greenhouse.

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