UBC Social, Ecological Economic Development Studies (SEEDS) Student Reports

Geothermal Heating/Cooling and Rainwater Harvesting

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UBC APSC 262 – SUB RENEWAL PROJECT

Geothermal Heating/Cooling and Rainwater Harvesting

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Abstract

Due to the increasing student population, UBC is planning on building a new Student Union Building to better serve the campus' needs. Not only will this serve as a focal point for the campus, it will demonstrate the university's commitment to sustainability. This report analysis two technologies, Geothermal Heating and Cooling and Rainwater Harvesting which could be used in the new building that could decrease its energy and resource needs. This will help the building meet the stated goals of LEED Platinum+ and Living Building certification.

In this report, these technologies will be evaluated using triple bottom line principles. This requires looking not only at the economical assessment of the technology, but also the environmental and social impacts. This will take into account the full societal costs of implementing the technology and will allow the designers of the new SUB to make informed decisions to meet their resource efficiency goals.

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1.0 INTRODUCTION

The current Student Union Building (SUB) at UBC is the main student driven space on campus. Students from all faculties use this building and it serves as a focal point of the school. However, it was opened in 1968 and has increasingly become inadequate to serve the student population. As such, it had been decided to build a new Student Union Building. This new SUB will not only better serve students needs, but also will stand as an example of UBC's commitment to sustainability. UBC has stated these goals in its *Vision for Climate Action*[1] with the commitments to:

- Become a net positive energy producer by 2050
- Partner for change
- Use the campus as a living laboratory
- Account for the full costs of decisions

Specifically for the new SUB, it is desired to achieve LEED Platinum+ and Living Building certification. To aide in this goal, thus report will outline, using triple bottom line analysis, two technologies for the new SUB, which will reduce its energy and resource consumption.

- Geothermal Heating and Cooling
- Rainwater Harvesting

2.0 GEOTHERMAL HEATING-COOLING

Heating, Ventilation and Air Conditioning (HVAC) is one of the largest uses of energy in a commercial building. According to the American Department of Energy, up to 65% of total energy use in a building the old SUB's age or approximately 50% in a new building[2] is consumed by HVAC. Due to this significance, it was chosen to look at HVAC improvements in the name of energy conservation.

One way to achieve significant savings in heating and cooling a building is a geothermal heat pump system. This system takes advantage of the moderate and relatively stable temperatures below ground, using the earth as either a heat source (in the winter) or a heat sink (in the summer) to boost the efficiency of the HVAC system.

Physically, a geothermal system uses a standard reversible refrigeration cycle, using the building and ground as either the hot or cold heat rejection sites, instead of the ambient air in a standard HVAC system. Figure 1 shows a schematic of the system. The ground will usually provide a

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[1] http://www.sustain.ubc.ca/campus-sustainability/greening-the-campus/climate-action
[2] http://www.eia.doe.gov/emeu/cbecs/cbecs2003/

more favorable temperature to draw heat from than the outside air, leading to increased efficiencies.

This report will now comment on the economic, social and environmental suitability of this technology.

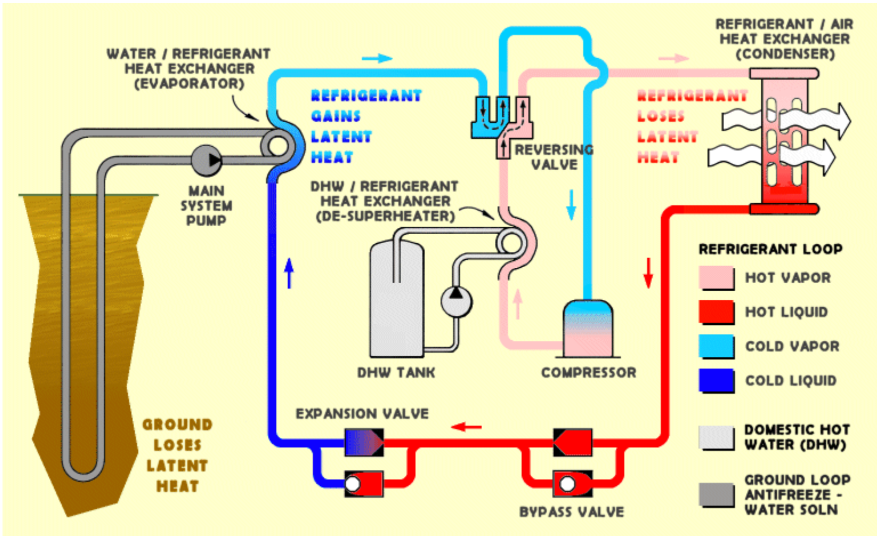

Figure 1: Geothermal Heating Schematic[3]

3.0 ECONOMIC ANALYSIS

In the economic analysis of any long term project, one must consider the capital costs and annuities of the project. In the case of a comparing a proposed renewable energy source to current practices, an incremental analysis must be done. Since geothermal systems are typically characterized by high purchase prices, the economic decision to accept this system should be based on the ability of the net savings to cover the premium of the high capital over the life time of the new SUB.

It should be noted that due to the absence of actual structural data for the new SUB and the lack of information about current energy practices of the SUB, it is not possible to calculate a reasonable estimate cost or make a direct comparison to current practices. However, enough studies and data exist for other cases to prove the financial benefits of a geothermal system.

3.1 CAPITAL COST

As it was mentioned above, the majority of costs come from the initial purchase of the geothermal system. Since this is a brand new building and not a retrofit, the upfront cost would include the heat pump itself, duct work, installation, hydraulic system, and drilling. The heat pump unit is generally no more expensive than conventional furnaces or air conditioners.

[3] http://www.geo4va.vt.edu/A3/GHP-heating.gif

Furthermore, the ductwork is fairly standard, yielding no real additional costs. Installation of the heat pump will actually be cheaper, due to the absence of gas line connections. However, because of lower water supply temperatures inherent in geothermal systems, the number of hydraulic lines is generally greater, to create a larger radiation source. Given that the above factors do not create large price differences between geothermal and conventional system, the majority of additional capital comes from drilling. However, there are considerable variations in the drilling, due to soil type, proximity to water, and desired loop type[4]

The results of the analysis performed by the Washington State University Energy Program, the breakdown of costs over 20 years for HVAC systems, including Geothermal and conventional rooftop units is shown below[5]

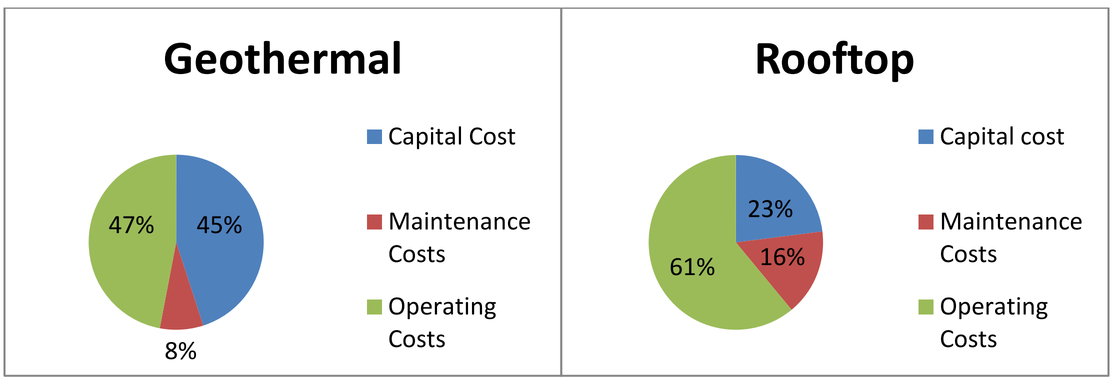

Figure 2: Cost Breakdown of Geothermal and Rooftop HVAC Units

As it can be seen, relative to typical HVAC units, the capital of Geothermal HVAC systems makes up almost 50% of the total cost over a span of 20 years. In addition to this, the following are typical upfront costs provided by GeoExchange Canada[6]

Electric furnace and air conditioning	$9,000
High-efficiency propane furnace and air conditioning	$11,000
GeoExchange System	$23,000

Table1: Upfront costs of various heating and cooling systems

Specific to UBC, the difference in capital cost would actually be greater. Due to the presence of the UBC Steam Plant, there would be no upfront cost for an alternative heating unit. Should the new SUB consider using the steam plant as the heat source, it would be more accurate to compare the cost of the geothermal system to the cost of fitting the new SUB on the steam plant's heating grid. Given this data and UBC's situation, the capital cost for a geothermal system will be higher.

[4] http://www.geoexchange.ca/en/costs_geoexchange_system_p56.php
[5] http://www.repartners.org/tools/doc/GHPEcoAtlanta.doc
[6] http://www.geoexchange.ca/en/costs_geoexchange_system_p56.php

3.2 OPERATION AND MAINTANANCE COSTS

Despite the relatively high capital cost, operation and maintenance costs are much lower than traditional heating, cooling, or HVAC systems. The savings are the result of the absence of burning fuels and the high level of efficiency. Furthermore, geothermal systems are immune to the changes of fossil fuel prices, which are presently increasing. Finally the cost of maintenance is found to be lower than conventional systems.

Currently, the SUB is heated by the steam plant, which uses natural gas as its fuel source. Should the new SUB use a geothermal system instead of relying on the steam plant, the cost of natural gas would be completely eliminated. An example of this kind of saving can be seen in the case study of Bob McMath Secondary School in Richmond B.C. Due to the elimination of roughly 1800 Gigajoules of natural gas and 1.2 million kilowatts of electricity to run a conventional heating and cooling system, the school has incurred annual savings of $11000[7]. It is likely the geothermal system will yield higher savings in the future due to the increasing cost of natural gas. The price of natural gas is predicted to increase from $8.50/GJ in 2008 to $27/GJ in 2040[8]

In addition to the cost of operations, the maintenance cost is generally very low for geothermal systems. In the Washington State University Energy Program's report, it was found that geothermal heat pumps yield the lowest maintenance cost among other conventional HVAC systems [9]

[7]http://www.geo-exchange.ca/en/UserAttachments/article15_RichmondBC.doc
[8]http://www.utilities.ubc.ca/climateaction/Xconteststage2/Cory%20Bigham%20Proposal_XContest_Cory_Bigham.doc
[9]http://www.repartners.org/tools/doc/GHPEcoAtlanta.doc

Equipment Type	No. of Bldgs.	Avg. Age	Maint. Cost Range ($/SM/YR)	Mean Maint. Cost, 1997 ($/SM/YR)
Geothermal Heat Pump[a]	25	5	.05 – 3.47[C]	1
Water-Source Heat Pump[b]	17	17.5	.20 – 7.50[d]	3.33
Packaged Air-to-Air Heat Pump[b]	10	1.51	1.10 – 6.20[d]	5.03
Split System Air-to-Air Heat Pump[b]	6	23.7	.96 – 4.93[d]	4.02
Reciprocating Chiller[b]	76	22.2	.59 –14.03[d]	4.39
Centrifugal Chiller[b]	207	20.7	.16 – 26.60[d]	5.53
Absorption Chiller[b]	27	29.3	.62 – 12.62[d]	7.96

Tabl2: Comparison of Total Maintenance Costs by System Type

Notes:

a) *Average of in-house (incl. overhead and benefits) and contractor (incl. overhead and profit) total maintenance costs for most recent year of Caneta Research study.*
b) *Data for conventional HVAC systems in Caneta Research Study come from Analysis of Survey Data on HVC Maintenance Costs, ADM Associates, Inc., prepared for ASHRAE Technical Committee 1.8, December 1985.*
c) *1997 dollars*
d) *1983 dollars*

Source: Survey and Analysis of Maintenance and Service Costs in Commercial Building Geothermal Systems, D. Cane, A. Morrison, B. Clemes, C. Ireland, Caneta Research Inc., for the Geothermal Heat Pump Consortium, RP-024, Revised October 1997.

The enhanced performance of geothermal pumps is likely due to the relative simplicity of the system with fewer moving mechanical components, and absence of combustion. Furthermore, geothermal systems do not need to be exposed to the outside. As a result, geothermal systems are protected against maintenance costs incurred by weather damage or vandalism[10]. Due to the absence of natural gas and design of geothermal systems, the operating and maintenance costs will be lower.

[10] http://www.repartners.org/tools/doc/GHPEcoAtlanta.doc

3.3 INCENTIVES

In addition to the direct savings of the systems, carbon tax savings and third party sponsored incentives and will add to the benefits of a geothermal system. By employing a geothermal system, the natural gas used by the steam plant to heat the SUB will no longer be used. As a result, the carbon emissions associated with the natural gas will be eliminated, thus eliminating the taxes associated with the carbon emissions. In British Columbia, TD Canada Trust, ecoEnergy, BC Hydro, Fortis BC, and Terasen gas are a few companies offering incentives, ranging from low financing rates to actual cash benefits, to geothermal projects. These savings and benefits will further lower the operating and maintenance costs and increase future savings.

3.4 COMPARISON WITH OTHER TECHNOLOGIES

When comparing a new geothermal system with a steam plant or other alternatives, one must compare the long term costs to realize the potential savings in either choice. Again, due to a large number of variables and unknown factors of the current and future situation, it is difficult to do a direct comparison. However, given the following examples, it is safe to assume that the premium of the capital cost will be recovered within the life time of the SUB.

In the study performed by the Washington State University Energy Program, the net present value over a span of 30 years with a discount rate of 4.5 to 6% was found for numerous HVAC systems. It was found that the geothermal system had the lowest net present value.[11]

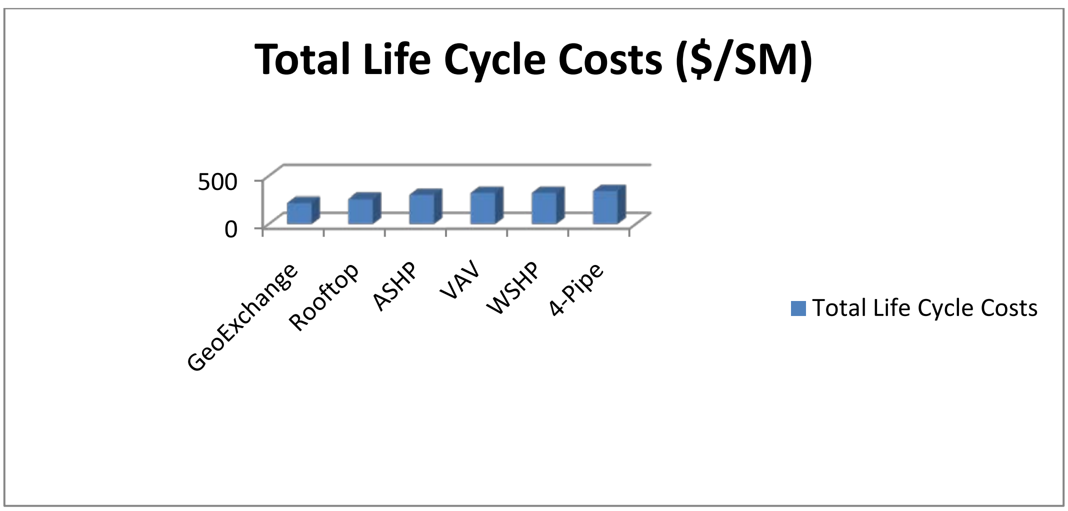

Figure 3: Total Life Cycle Costs

Rooftop = Rooftop DX with gas heat VAV = Variable air volume
ASHP = Air-source heat pump WSHP = Water-source heat pump

[11] http://www.repartners.org/tools/doc/GHPEcoAtlanta.doc

Another example is Truscan Realty in Toronto. The use of ground source heat pumps allowed them to incur energy cost savings of up to 6600$ annually. After government subsidies, it is expected to have an incremental payback period of 6.5 years compared to conventional systems[12]. In Vancouver, a Multi-residential unit on West 4th was retrofitted with a geothermal system. It is reported that the expected payback period is roughly three years[13].

3.5 ECONOMIC RECOMMENDATIONS

From the above discussion, it can be seen the common economic attributes of geothermal systems include high capital costs and low operation and maintenance costs. Specific to Canada, carbon tax credits and third party sponsored incentives help mitigate upfront costs and increase savings. Given these economic elements, it can be seen that investing in a geothermal system will yield positive benefits within the lifetime of the SUB's existence. As a result, given that the capital cost can be covered, the use of a geothermal system would benefit the SUB economically.

4.0 ENVIRONMENTAL BENEFITS

In this section, the environmental benefits of using geothermal energy are discussed. Geothermal energy produces much less pollution than other forms of energy. There is no fuel used to generate the power and therefore no pollution is made. The one major pollution issue with geothermal is the released gas from the depth of earth. This gas can be a mixture of carbon dioxide, silica, sulfur dioxide, hydrogen sulfide, methane and ammonia which all contribute to global warming and acid rain. This issue is not a big problem though, since the gas can be contained easily from the hydrothermal well. Some of the captured gas can even be processed and sold for industrial uses.

Another environmental advantage of using geothermal energy is that large plants are not needed for power production and hence there is less construction impact on surrounding areas. Also, geothermal power generation does not require any outside condensing unit, as you get with conventional air conditioners. This in turn means no noise pollution generated.

A geothermal facility does not required miles of buried pipelines (as a gas plant does) to carry the fuel to keep it running. A pipeline can have many environmental impacts such as accidental fuel spill or elevated temperature which affects the wildlife around the area.

Geothermal energy usage not only produces little pollution, but it also contributes to environmental protection. By transferring renewable thermal energy to and from the ground at efficiencies of 300% and 400%, geothermal systems reduce the need to extract, transport, and

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[12]http://oee.nrcan.gc.ca/residential/business/articles.cfm?attr=12
[13]http://www.geoexchange.ca/en/UserAttachments/article11_KitsilanoBC_2211WestFourth.doc

burn fossil fuels, and require less generation and transmission of electricity than traditional heating and cooling systems.

4.1 ENVIRONMENTAL IMPACTS

Geothermal systems use refrigerants. A refrigerant is a compound that takes away excess heat by undergoing phase change. Refrigerants not only have global warming effects by depleting the ozone layer, but they are also toxic. Due to that reason, refrigerants should be removed and recycled at all times. Another concern regarding refrigerants is temperature control. Refrigerant temperature must be within limits at all times to keep from freezing or baking the ground.

Open loop systems require a large supply of clean water. Water used in the system must be returned to the environment via an acceptable method. Close loop systems use anti-freeze solutions to keep water from freezing in cold temperature conditions. Many of these solutions produce CFC's and HCFC's which add to the environmental concerns since they also advance ozone layer break-down.

Comparing the environmental benefits and impacts of geothermal system with other power generation systems, it can be observed that the environmental benefits far outweigh the costs. Geothermal power generation is hence a feasible method from the environmental aspect.

5.0 SOCIAL IMPACT

As one of the greenest and most environmental-friendly universities in the world, University of British Columbia is trying hard to promote sustainability in as many ways as possible. Currently, UBC has many different sustainable projects such as the Sustainable Initiative Campaign, the North America's Greenest Building, UBC Sustainable Sport Center and UBC even offers a master program of engineering in clean energy. These examples illustrate how UBC values sustainability.

As for the new Student Union Building, UBC is gathering the newest and cleanest technologies to implement for UBC students. Geothermal is one of those alternatives being considered for this purpose. It is simply the extraction of heat stored in the core of the earth by drilling the holes down to the heated region under the ground. Then, the water is sent through the drilled hole. Once the water reaches the hot region, it turns into a steam, which moves upward and is later used to drive the turbine, producing electricity through an electric generator.

Despite the fact that Geothermal has a higher capital cost in comparison to other power generating alternatives, it requires less maintenance and operating cost. Considering the size of the new SUB and how many students will benefit from this project, it is prospected that it will not take long to pay back the investment. Although, the fluids, drawn from the earth, carry a mixture of toxic gases such as carbon dioxide (CO_2), hydrogen sulfide (H_2S), methane (CH_4) and ammonia (NH_3), the impact caused by these gases can be compromised or eliminated via a chemical management plant, which could be easily implemented due to its lower cost and simplicity.

If the geothermal power generation is installed in the new SUB, it surely will promote sustainability and greener energy for UBC while setting a higher standard for the energy solution system. Moreover, the geothermal is safe and more reliable compared to other conventional power generations. The most important aspect of geothermal is that it is a renewable energy resource since the energy extracted is relatively small in comparison to the energy stored in the Earth. Therefore, geothermal seems to be the most promising power generation method for the new sustainable SUB.

6.0 RAINWATER HARVESTING

Water harvesting had been widely used in several countries such as England, Germany, and India for drinking or agriculture where there is more than 200mm annual rainfall. Vancouver has a consistently significant annual rainfall of 1117mm (www.TheWeatherNetwork.com). Rainwater harvesting can be used for both for cleaning as well as drinking. However, the level of filtration would vary as well as the maintenance cost. We would like to propose a hybrid design where a larger portion of the collected water can be supplied to the washrooms, and a smaller portion of the collected water can be filtered further for drinking.

In addition to feasibility, having a water harvesting system at the SUB can also improve the water safety. The Cholera epidemic is one of the disasters which hit many countries including Russia, Europe, Canada and United States of America in the past ("How Epidemics Helped Shape the Modern Metropolis", John Noble Wilford, April 15, 2008). This epidemic could have been avoided by using rainwater harvesting systems in order to isolate water consumption of buildings. Learning for the past, some European countries such as England have broadly developed and used water harvesting systems. Similarly, the student union building can take advantage of the system to avoid future epidemics.

The rainwater harvesting system proposed is intended to be used in parallel with the external water pipe to reduce the external water consumption and allow us to switch to the independent water system in case of a water shortage or contamination.
It's important to keep in view that a rainwater collection systems are often less expensive than a drilled well, and rainwater is naturally soft, has no iron, odor causing sulphur, or other problems associated with well water

The main water safety factors for the design of the rooftop to capturing water are:

- Material used in the roof where the water is collected
- Material used for the cistern where water is stored
- Cistern Isolation
- Filtration standards
- Presence of birds or rodents

The following discussions about the design consider these issues and propose suitable design choices.

6.1 SYSTEM DESIGN

The basic construction is shown in the figure below.

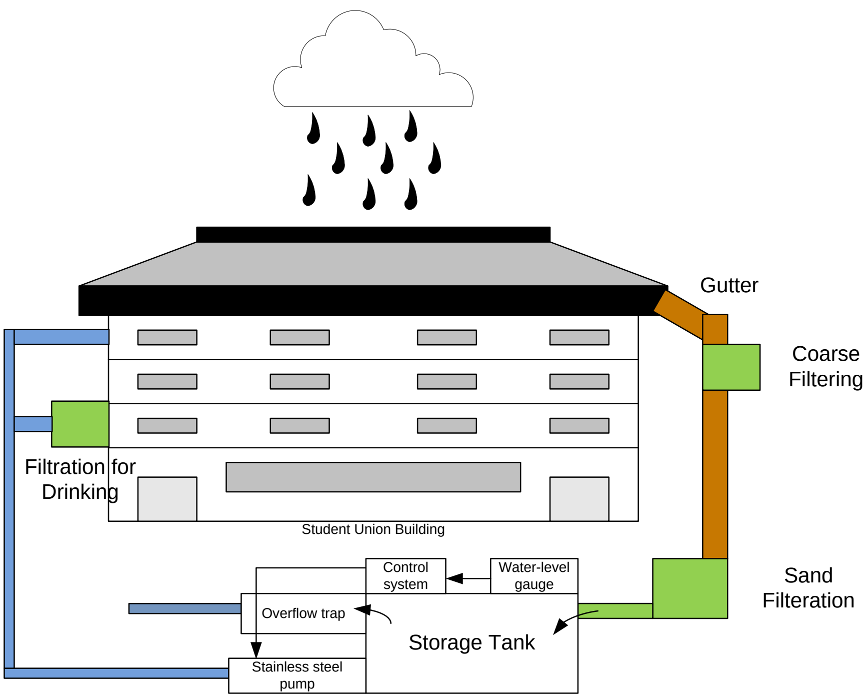

Figure 4: Rainwater harvesting system block diagram

The system contains a tilted rooftop designed to direct water into the gutters. The microbiological quality is affected primarily by the season, temperature and water treatment (Canada Mortgage and Housing Corporation, CMHC, Canada, 2009). The water quality was found to be better at sites with steel roofs than at those with asphalt shingle roofs. Hence we recommend the rooftop to be made of steel. Also, research observations show that rainwater quality tended to improve during the winter months.

Before entering the gutters, the rainwater passes through a pre-treatment devices such as gutter screens and leaf-catchers which for coarse filtration which prevents leaves and large particles to enter the next stage. The next stage is a sand filtration.

6.2 BASIC FILTRATION

Sand Filtration is a traditional low cost and effective method of water purification. It involves biological processes. The annual maintenance cost is low since the only maintenance is exchanging the surface layer of the sand.

6.3 STORAGE TANK

The water leaving the sand filter enters the storage tank. The tank has an overflow trap which allows water to flow out when exceeding the standard capacity.
Many residential rainwater harvesting systems have tanks with up to $68m^3$=4m*4m*4.25m capacity which is about the size of a room. For the SUB we don't anticipate the consumption to exceed $400m^3$. Contrary to popular beliefs, rather than becoming stale with extended storage, rainwater quality often improves as bacteria and pathogens gradually die off (Wirojanagud et al., 1989).

Furthermore, research studies show that physicochemical properties of rainwater primarily depend on the roof and cistern material and site environment. The storage tank must be carefully enclosed to prevent contaminations. It is found that concrete cisterns tended to raise the pH of stored rainwater, whereas the pH remained constant when stored in plastic cisterns. On the other hand, glass fiber water tanks don't rust. Therefore there are several options available for the material of the cistern. It is recommended to use a durable tank to avoid any replacement costs. Nevertheless, there is a minor annual tank cleaning cost which needs to be taken into account. Such cleaning should take place annually before the start of the major rainfall season.

6.4 DRINKING WATER FILTRATION

Post-cistern treatment devices such as carbon filters and UV lamps eliminate micro-organisms and particles that are larger than 20-micron. This stage has a great value because it can prevent the epidemics caused by water contamination. Although there is some maintenance cost involved in this higher level of filtration, it is quite suitable for drinking. Hence, the Cafeteria section of the SUB can use these facilities to get drinking water instead of delivering plastic water bottles. TROJANUVMAX is one of the state-of-art water purifiers which claims to eliminate 99.99% of viruses and bacteria by using ultra violet light without the use of chemicals. The only maintenance cost is the cost of annual lamp replacement. This system also informs the users when the maintenance is required.

7.0 CONCLUSIONS AND RECOMMENDATION

The main objective of this project is to conduct a triple-bottom line assessment and make recommendations for a type of renewable energy source for the new SUB at UBC that is going to be completed in 2014. Analyzing the energy consumption of a commercial building, it is shown that approximately 60 percent is used for heating, cooling and water heating. Geothermal power, the process that utilizes the transfer of heat between the earth and the building, is a relatively new type of renewable energy that is gaining popularity in heating and cooling applications. It has already been implemented in apartment buildings in Vancouver as well as in the buildings at the UBC Okanagan campus, proving its practicality for the use with the new SUB.

Geothermal power has displayed a great potential in terms of its economic values. Although the capital cost of setting up a geothermal system is relatively high, geothermal system requires low maintenance and operating cost. In the long run, the savings from the operating period will outweigh initial premium, making geothermal an attractive investment for the University. In addition, geothermal power has very promising environmental benefits, including minimal CO_2 emissions, low noise and air pollutions as well as zero fuel consumption. Because geothermal system utilizes heat from the earth, which is available constantly, it ensures a reliable and quiet temperature comfort for the students year round. Being one of the cleanest renewable energy resources currently available, geothermal power will also help promote UBC towards its goal in becoming global leader in campus sustainability.

In addition to geothermal power, rainwater harvesting has also been investigated. Because of Vancouver's high annual rainfall and its low capital and operating cost, this option seems suitable for the use with the new SUB. Rainwater harvesting involves utilizing rainwater for several water applications within the building, including the distribution system for geothermal power. This is an example of the possibility of synergizing several renewable energy sources together in moving UBC towards its goal in becoming a net energy producer by 2050.

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