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

AN INVESTIGATION INTO RENEWABLE ENERGY AND WATER SOURCES FOR NEW STUDENT UNION BUILDING

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APSC 262

April 2010

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Subject: APSC 262

Instructor: Dr. Dawn Mills

Date: April 6, 2010

ABSTRACT

"An Investigation into Renewable Energy and Water Sources for New Student Union Building"
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This report analyzes three renewable resources proposed for use in the new student union building (SUB): solar energy, geothermal energy, and rainwater harvesting. The prime objective of this report is to describe each of these resources in detail and to determine its cost effectiveness and feasibility given the site characteristics. Moreover, recommendations were made regarding the materials and technology to be used. Harvesting solar energy for both lighting and heating is one approach to reducing the building's energy use and can be used in the new proposed SUB at UBC campus. Photovoltaic (PV) solar cells use the sun's radiation to produce electricity. Case studies have proved that PV solar cells are economically and environmentally sustainable. Another renewable resource that can be used to power the building is geothermal energy, which is the exploitable heat within the Earth. Low carbon dioxide emissions and low cost make this form of energy a candidate to power the new proposed SUB. Finally, due to the high annual level of precipitation in Vancouver, rainwater harvesting is an ideal method for meeting the water requirements of the proposed SUB. Rainwater harvesting, an ancient technique, can provide high quality water with no need of chemical disinfectants. It was concluded that solar energy and rainwater harvesting are both feasible and cost effective; in the case of geothermal energy, further research is required to determine these parameters.

Incorporating these resources in the proposed SUB design for the UBC campus could make the SUB one of the most efficient sustainable buildings in the North America.

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GLOSSARY

Electrical Conductivity:	A measure of a material's ability to conduct an electric current
Green House Gasses:	Gases in an atmosphere that absorb and emit radiation within the thermal infrared range.
Geothermal Hot Spots:	Areas of reduced thickness in the mantle which transmits excess internal heat from the interior of the earth to the outer crust.
Hydrothermal Source:	Energy resource related to water heated underground by the Earth's internal heat
Photovoltaic Solar Cells:	Arrays of cells containing a solar photovoltaic material that converts solar radiation into direct current electricity.
Reflector:	A device that causes reflection.
Renewable Energy Sources:	Energy that comes from natural resources such as sunlight, wind, rain, tides, and geothermal heat, which are naturally replenished.
Semiconductors:	A material that has an electrical conductivity between that of a conductor and an insulator.
Solar thermal energy:	A technology for harnessing solar energy for heat.

LIST OF ABBREVIATIONS

GHP:	Geothermal Heat Pump
SUB:	Student Union Building
PV:	Photovoltaic
UV:	Ultra-violet

1.0 INTRODUCTION

This report investigates the use of solar energy, geothermal energy, and rainwater harvesting in the student union building (SUB) proposed for the UBC campus. It investigates the environmental, economic, and engineering factors pertaining to designing a sustainable building. In the past, poor construction practices have generated unacceptable environmental costs. To reduce environmental impacts, all societies must choose the path of “least negative impact” (Friedman, 2007). This project represents a key first step in constructing buildings with minimum carbon footprints. Harvesting solar energy for both lighting and heating is one approach to reducing the building’s energy use. Photovoltaic solar cells use the sun’s radiation to produce electricity. Another renewable resource that can be used to power the building is geothermal energy, which is generated by the continuous thermal flux flowing from the core of the Earth towards its surface (Hammons, 2004). Low carbon dioxide emissions and low cost make this form of energy an ideal candidate to power a ‘green’ building of this kind. Finally, rainwater harvesting, a technique commonly used by ancient civilizations, can provide high quality water with no need of chemical disinfectants or costly filtration. Due to the high annual level of precipitation in Vancouver, rainwater harvesting is an ideal method for meeting the water requirements of the proposed SUB.

2.0 SOLAR ENERGY

In today's society, there is a new generation of people becoming more aware of the negative impacts the consumption of non-renewable resources can have on our planet. As a result of increase in awareness, new technologies using renewable recourses, such as the sun, flourished. The solar energy is provided to our planet by the radiations from the sun. Using a variety of technologies, the thermal energy from the sun can be collected and used in applications such as, "water and room heating for commercial and residential buildings" (Patel, 2006, p 341) and high temperature industrial use like, "[producing] steam for driving electrical generators" (Patel, 2006, p 341).Moreover, the following section will explore the engineering aspect, environmental aspect, and economical aspect of applying solar power.

2.1 ENGINEERING ASPECT OF SOLAR POWER

As a result of increasing awareness among society, new technologies have been engineered in order to use the sun's radiation and reduce the consumption levels of non-renewable energy resources. The main technology used is solar cells, which generate electricity by using the thermal energy from the sun.

2.1.1 Photovoltaic Solar Cells

One of the advancing technical solutions developed to generate electrical power, and to reduce the cost of electricity is the photovoltaic (PV) solar cells. The main component in a solar cell is a "photonic semiconductors" (Randall, 2005, p59); whereby, the semiconductors convert the light from the sun into electric charge (Randall, 2005). As shown in Figure 1, the absorbed energy from the sun radiation is transferred to the semiconductor, which then displaces the electrons and allows them to flow away. Also, using an electric field in the cell the electrons will flow in the "right direction". Moreover, this flow of electrons will produce an electrical current; which, as shown in Figure 2, can be harvested using metal contacts on the top and bottom of the PV solar cell (Randall, 2005).

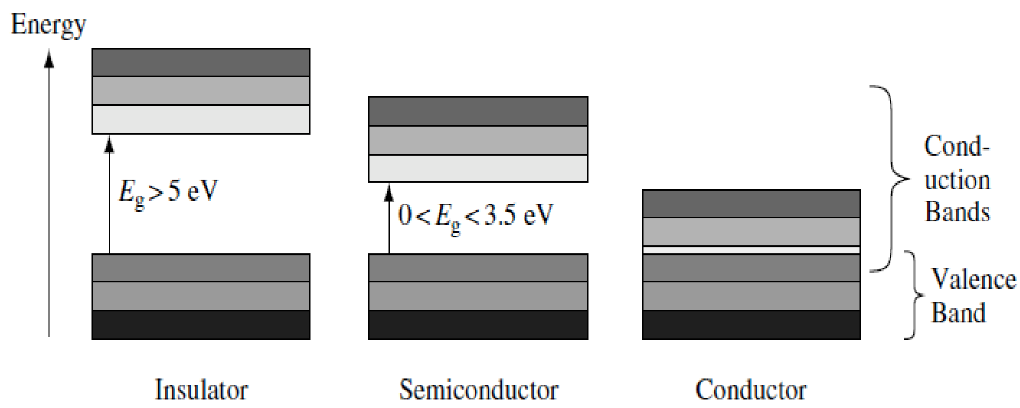

Figure 1: Band gap diagram

Source: (Randall, 2005, p 59)

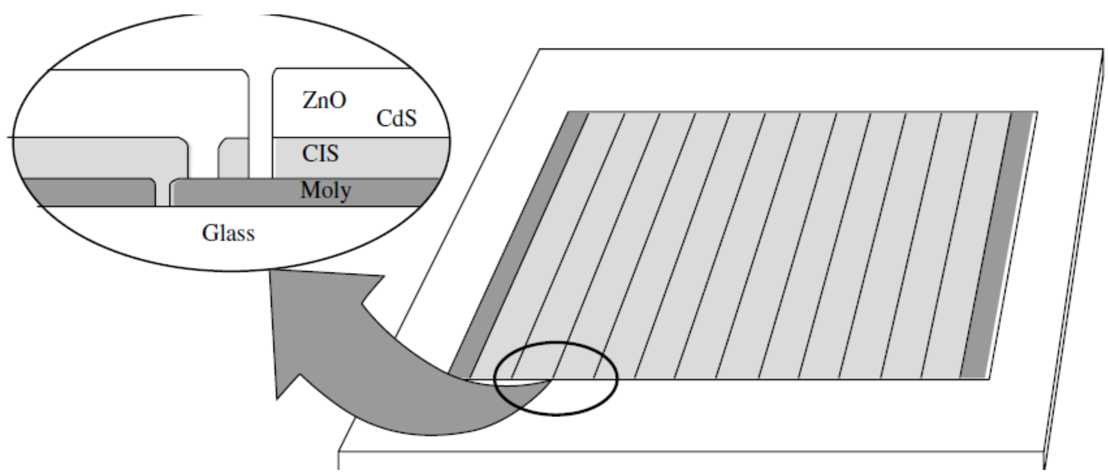

Figure 2: a series-interconnected thin-film technology solar module

Source: (Randall, 2005, p 76)

2.1.2 Solar Windows

In addition to using solar cell panels on the roof of the new Student Union Building to produce electricity, using PV hybrid solar windows can significantly increase the amount of electricity produced. According to a recent research, solar windows have been designed in order to reduce the cost of solar electricity to compete with grid electricity (Davidsson, 2009). Figure 3 demonstrates a diagram of a solar window design. The design consists of PV cells placed on solar absorbers behind the window, and using tillable reflector screens the solar radiation will be focused on to the PV solar cells. Moreover, these reflectors reduce the amount of thermal energy lost through the windows (Davidsson, 2009). As a result, after analyzing the solar window, in a single family house in Solga˚rden, Sweden, it has been noted that “the solar window annually produces about 35% more electric energy per unit cell area compared to a vertical flat PV module” (Davidsson, 2009), shown in Figure 4.

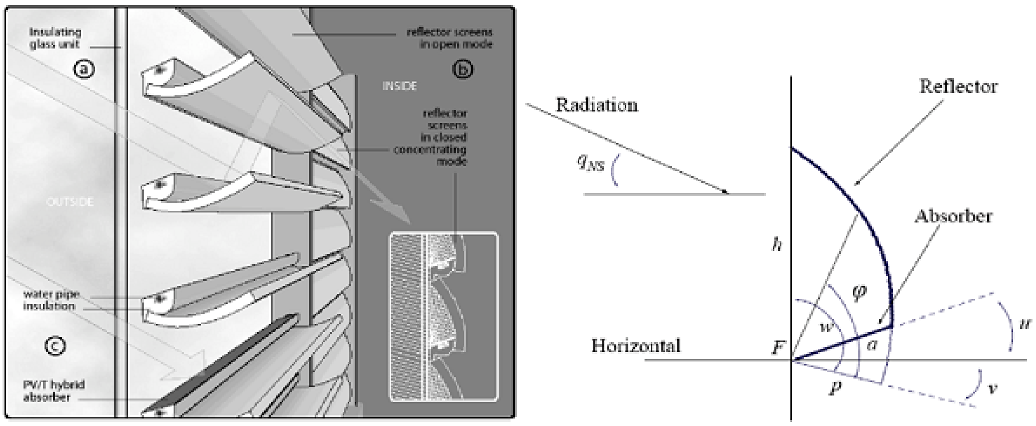

Figure 3: window design

Source: (Davidsson, 2009, p 366)

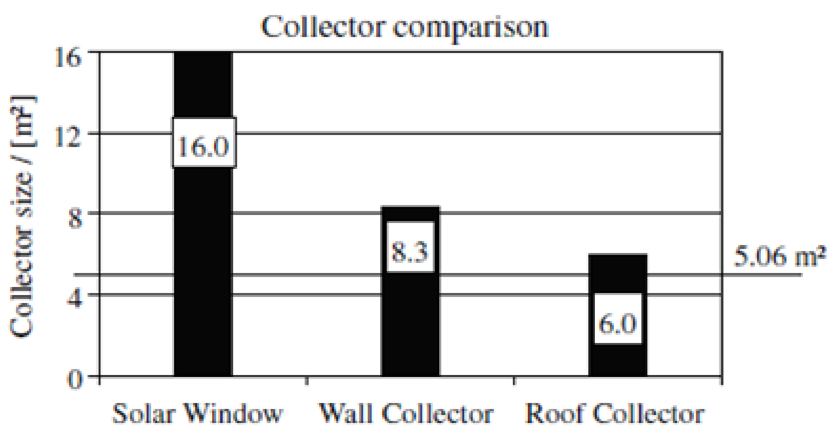

Figure 4: Solar collector comparison

Source: (Davidsson, 2009, p370)

2.2 ENVIRONMENTAL ASPECT OF SOLAR POWER

By consuming the renewable solar energy from the sun to produce electricity and heating for households and industrial use, humans can significantly reduce the negative impacts that non-renewable resources have on the environment. Despite the many positive long term effects that solar power has on the environment, it can also generate waste material while manufacturing the solar cell panels. Additionally, some of the harmful by-products produced by the solar panel industries are the amount of green house gasses, such as Carbon dioxide emission and sulphur hexafluoride, and silicon tetrachloride.

2.2.1 Waste Production& Recycling Issues

Although the long term effects of conserving solar power are positive on the environment, there are still a lot of scepticism and uncertainties regarding the amount of waste generated while producing solar cells. Also, while compromising the amount of green house gasses produced during manufacturing of the solar cells, the sustainability in energy favours the use of solar cells as an alternative energy source.

Moreover, since photovoltaic solar cells consist of semiconductors, they contain highly toxic chemicals such as silicon tetrachloride (Randall, 2005). Hence, more research needs to be done in regards to recycling the solar cell panels.

2.3 ECONOMICAL ASPECT OF SOLAR POWER

As the population of our planet increases, the demand for more energy resources increases. Solar power is an alternative renewable energy resource, which is more economically beneficial compared to the conventional power systems. According to the Handbook of Energy Efficiency and Renewable Energy, “the Canadian government has a goal of supplying 20% of its electricity from renewable sources by 2010. Canada is bound by the Kyoto protocol and aims at reducing its carbon emissions by 5.8% below 1990 levels by 2012” (Kreith, 2007, p 2-42).

Furthermore, in order to make an efficient economical choice, the administrators of the new SUB can follow the model illustrated in figure 5. As shown, using the model you can estimate the level of energy conservation, Qc, which maximizes the energy conservation and it would be the level that is most profitable over the long term (Kreith, 2007). Also, using figure 6, a household can use “marginal analysis” in order to find the same level of conservation (Qc) that will yield the largest net benefit (Kreith, 2007). As energy conservation increases, the point of intersection of the marginal curves coincides with the most profitable level of energy conservation.

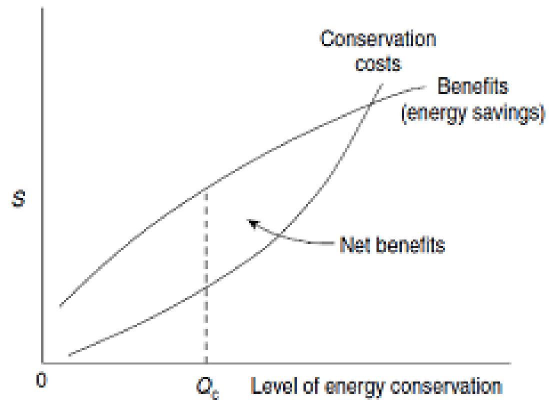

Figure 5: Maximizing net benefits

Source: (Kreith, 2007, p3-3)

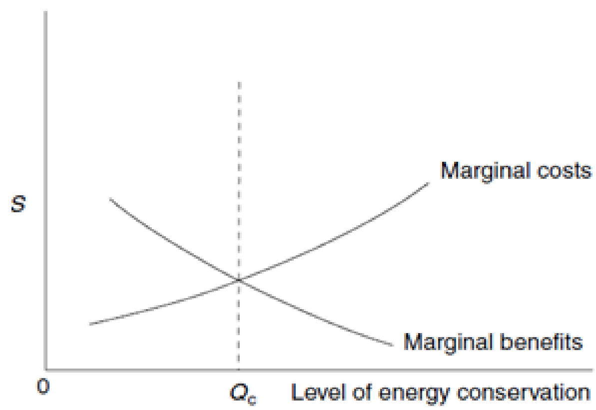

Figure 6: Equating marginal benefits and marginal costs

Source: (Kreith, 2007, p3-3)

Although the initial purchasing of solar cell panels is high, it is a beneficial investment in the property resale value for the future. Moreover, for the design of the new sustainable student union building, the combination of roof solar cell panels along with solar windows will significantly lower the cost of electricity and any other non-renewable resources used as a power system.

3.0 GEOTHERMAL ENERGY

Geothermal energy is a renewable energy resource from the crust of the Earth, which is due to the continuous thermal flux flowing from the core of the Earth towards its surface (Hammons, 2004). Geothermal energy might be used in new proposed Student Union Building (SUB) project. The following section will explore the engineering aspect, environmental aspect and economical aspect of applying geothermal energy.

3.1 Engineering Aspect of Geothermal Energy

Geothermal resources consist of hydrothermal resource, hot dry rock, and geopressured resource(Phair, 1994). These geothermal resources can be generally used in two ways: 1) to be used for electricity generation; 2) to be used directly for heating purpose (Hammons, 2004). Different systems and technologies are involved in these two ways of using geothermal energy, such as heat pump and heat exchanger.

3.1.1 Geothermal electricity generation

There are 24 countries generate electricity from geothermal resources until 2005 (Bertani, 2005). Most of the current geothermal electricity generation plants are based on hydrothermal resource, which is also known as liquid based or liquid dominant (Hammons, 2004). The general process of electricity generation using liquid dominant method is shown in figure 3.1.

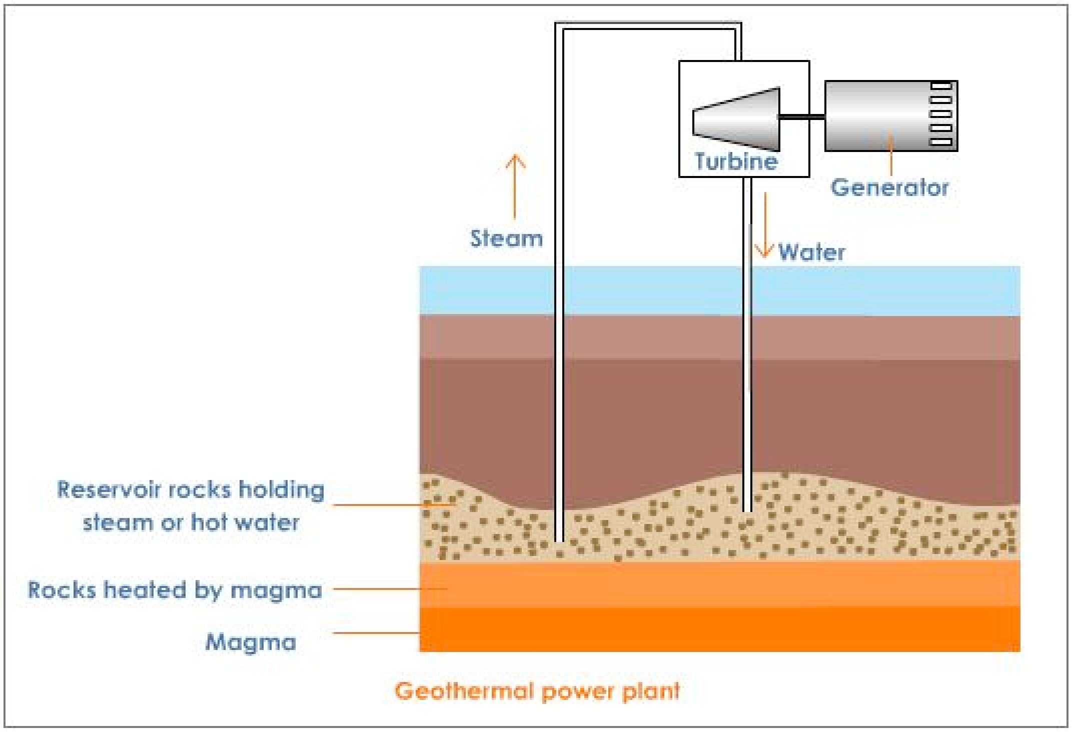

Figure 7: Geothermal Power Plant

Source: http://image.tutorvista.com/content/sources-energy/geothermal-power-plant.jpeg

As shown in figure 3.1, the water is injected into the wells from the porous reservoir rocks; as the water travels up in the well the pressure decreases allowing part of the water to boil; and then a mixture of steam and water will be formed in the wells, which will be separated by the separator installed between the wells and the power plant; next, the steam will enter the turbine to drive the generator, while the remaining water will be injected back to the reservoir and will go through the loop again (Hammons, 2004).

However, using hydrothermal resource to generate power is restricted by geographical location. Figure 3.2 shows the geothermal hot spots, which are locations suitable for constructing geothermal power plants.

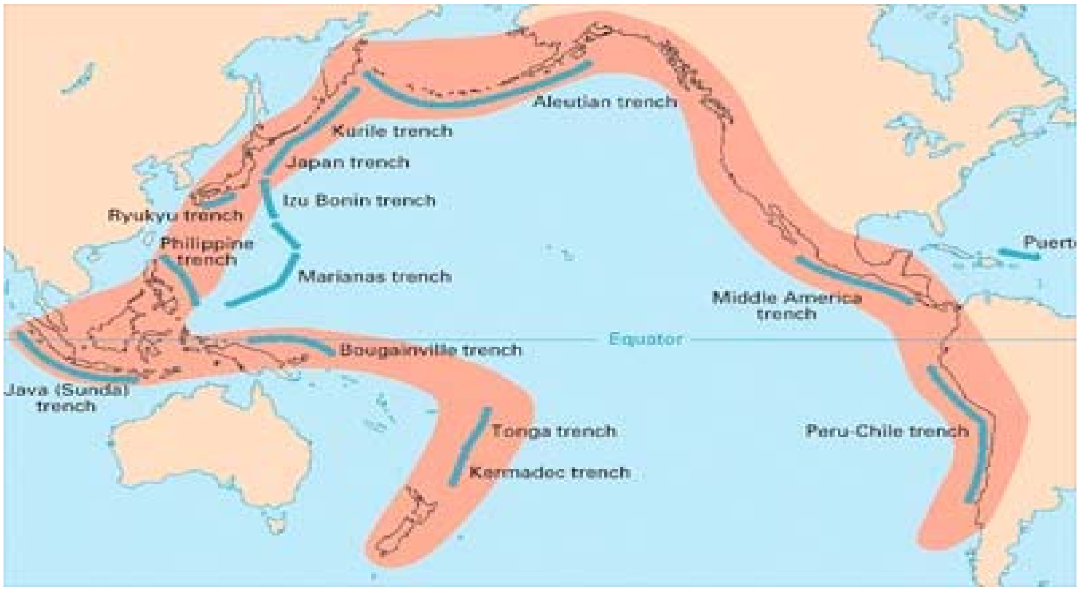

Figure 8: Geothermal Hot Spots

Source: http://www.worldofenergy.com.au/graphics/photos/factsheet7/Pacific_Ring_of_Fire.jpg

According to the above figure, Vancouver locates on the geothermal hot-spot ring, which means geothermal electricity generation is geographically possible for the new proposed SUB project. However, other engineering concerns and technical requirements must be assessed as well, such as the potential variation and changes of the geothermal resource. Moreover, engineering requirements and challenges in operating and maintaining the power plant should be considered.

3.1.2 Geothermal direct heating

An alternative to geothermal electricity generation in using geothermal energy is geothermal heating, which uses geothermal energy directly in heating spaces and buildings. The most common technology involved in geothermal heating is heat pump and heat exchanger.

Vapour compressor heat pump is popular in heating systems for small objects such as house, swimming pool, and schools (Hanuszkiewicz-drapa!a, 2009). Thus, vapour compressor heat pump system might be suitable for new proposed SUB project, which is relatively small in scale. Figure 3.3 below shows the model of vapour compressor heat pump system.

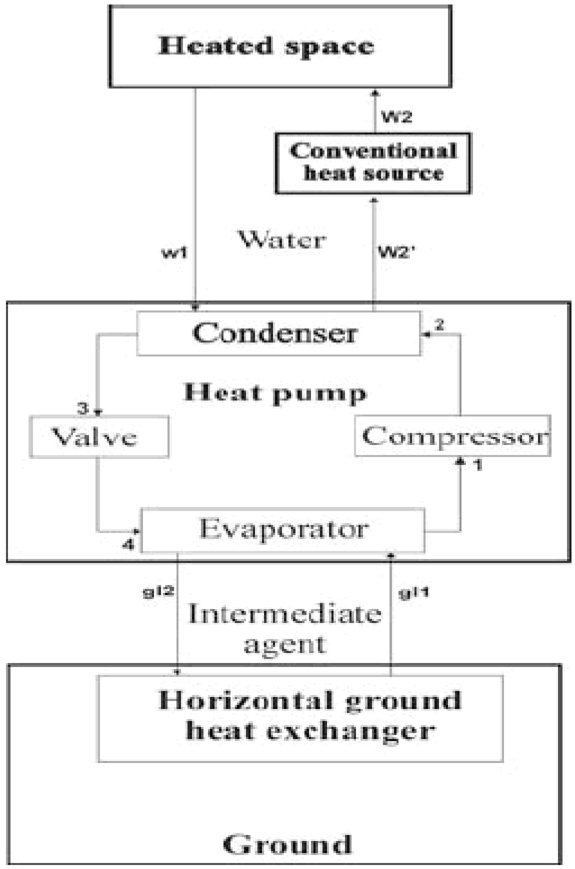

Figure 9: Vapour Heat Pump System Model

Source: (Hanuszkiewicz-drapa!a, 2009)

As shown in figure 3.3, the heat exchanger is installed in the ground, which is used as lower source of heat for the heat pump. The exchangers are usually coils of pipelines, in which there are flows of intermediate agent such as water solution of propylene glycol. The heat is transferred from the exchanger to the heat pump evaporator, and then is transferred through the compressor and released to heating objects through the condenser (Hanuszkiewicz-drapa!a, 2009).

Comparing to other geothermal energy applications, which rely entirely on the geothermal heat source, heat pump is driven by other energy sources such as electricity and solar power (Phetteplace, 2007). Therefore, using geothermal heat pump (GHP) to heat an object is an approach of using hybrid energy sources. The technology of geothermal heat pump is relatively mature, and has been widely used. For example, in United States geothermal heat pump is extensively used in residential marketplace (Phetteplace, 2007). Canada is also one of the leading countries in using geothermal heat pumps shown is table 3.1.

Country	MWt	GWh/yr	Number installed
Austria	300	400	25,000
Canada	445	610	37,000
Germany	560	840	47,000
Sweden	4,200	12,000	350,000
Switzerland	530	790	44,000
USA	8,400	7,200	700,000

Table 1: Leading Countries in GHP

Source: Lund et al., 2008

The engineering fundamentals provide the possibility of using geothermal energy in the new proposed SUB project. However, the economic and environmental factors should also be evaluated thoroughly.

3.2 Environmental Aspect of Geothermal Energy

In general geothermal energy is considered as a sustainable energy source because there is no combustion involved and it is renewable (Hammons, 2004). However, in the entire life cycle of geothermal energy applications there are several environmental impacts that are usually mitigated, such as emission of harmful gases, noise pollution, and water use (Kagel, et al., 2005).

3.2.1 Carbon dioxide emission

Carbon dioxide emitted by geothermal applications is mainly due to the mixture of gases in deep earth and the usage of electricity generated by fossil fuels. The mixture of gases underground usually consists of carbon dioxide (CO_2), hydrogen sulphide (H_2S), methane (CH_4) and ammonia (NH_3). In direct geothermal heat applications, electricity is usually used to drive the heat pump, and the electricity normally comes from traditional fossil fuel power plants, so there are CO_2 emissions as well. The table 3.2 below compares the CO_2 emissions of generating electricity using different types of energy sources.

Geothermal and fossil fuel CO_2 emissions in kg CO_2 per kWh

Geothermal	Coal	Petroleum	Natural gas
0.082	0.968	0.709	0.468

Table 2: CO_2 Emissions

Source: (Hammons, 2004)

Therefore, the CO_2 emissions of geothermal energy are reasonably low comparing with other energy sources.

3.2.2 Water usage

Generally, geothermal power plants require approximate 20 litres of freshwater per MWh, and binary air-cooled plants do not require water while operation, while a coal plant uses about 1,370 litres per MWh (Lund, 2007). Thus, geothermal energy is water efficient comparing to traditional energy sources.

3.3 Economical Aspect of Geothermal Energy

An energy source that is sustainable not only must be renewable, but it also must be cost efficient. Besides geothermal energy there are quite a few renewable energy sources such as: hydro, biomass, wind, and solar. Table 3.3 shows the installation cost and the cost of electricity production from renewable sources.

Current installation cost and cost of electricity generation

	Installment cost USD/kW	Energy cost US cent/kWh
Biomass	900–3000	5–15
Solar photovoltaic	5000–10000	25–125
Solar thermal	3000–4000	12–18
Hydro	1000–3500	2–10
Geothermal	800–3000	2–10
Wind	1100–1700	5–13
Tidal	1700–2500	8–15

Table 3: Installation cost and cost of electricity generation

Source: WEA, 2000

According to table 3.3, both the instalment cost and cost of electricity generation of geothermal energy are significantly lower than other renewable sources, which means geothermal electricity generation has good economical potential. Table 3.4 shows the cost of geothermal energy and other renewable energy sources for heat generation.

	Installment cost USD/kW	Energy cost US cent/kWh
Biomass	250–750	1–5
Solar heat	500–1700	3–20
Geothermal	200–2000	0.5–5

Table 4: Current installation cost and energy cost for heat generation

Source: WEA, 2000

From table 3.3 and table 3.4, it is obvious that the cost of geothermal energy in both electricity generation field and heat generation field are favourable compared with other energy sources.

4.0 RAINWATER HARVESTING

Rainwater harvesting is an ancient technique that has been used for 4000 years to tap a natural water source (Friedman, 2007). Rainwater is high quality water as it is naturally soft and has a nearly neutral pH. Rain, when traveling down a roof or a gutter to storage tank, does not come in contact with oil, animal or chemical or industrial wastes. Thus, the filtration process is simple and efficient requiring no the artificial disinfectants. Rainwater harvesting system is a unique technique that helps to reduce summer water demand. Regardless of the building's complexity the rainwater harvesting systems include the same basic components such as a catchment surface, gutters, storage tank, purification, and delivery system (Figure 10). New filtration and treatment technologies make rainwater harvested in this fashion safe for consumers. Home basements represent good locations for storage tanks, as the water can be gravity fed and protected from freezing (Friedman, 2007). It is also possible to attach to extend the roof for the purpose of increasing the catchment area. This section of the report describes a rainwater harvesting system for the proposed student union building (SUB) currently being designed for the UBC campus. The following subsections describe the engineering design and recommendations. Lastly, maintenance costs are projected.

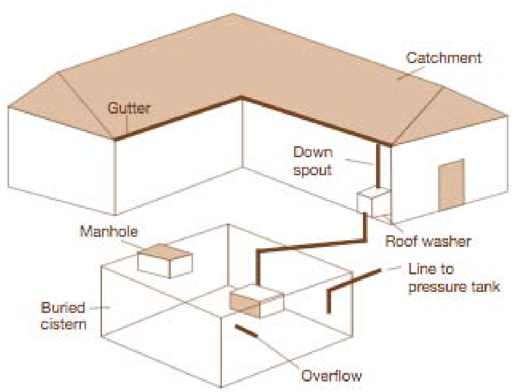

Figure 10: A simple harvesting system with underground storage tank

Source: www.bcd.oregon.gov

4.1 RAINWATER HARVESTING DESIGN

The main components of rainwater harvesting systems are catchment surface, filter, and water storage tank. The design of each component is described in details in the following subsections.

4.1.1 Catchment Surface

The roof of the proposed Student Union Building (SUB) represents the catchment surface. For this reason the choice of roofing material is crucial. The roofing material should not leach any toxic materials. A commonly used brand name product for rainwater harvesting is Galvalume. The main distributor for Galvalume is located in Vancouver, Washington. Galvalume not only ensures efficient rainwater flow; it also does not contaminate rainwater (Galvalume, 2009).

The shape of the roof and the material used for construction will affect the efficiency of the system. However, the factor that has the greatest impact is the amount of area that is covered by the roof. Approximately each inch of rain will produce approximately 1⁄2 gallon of water for every square foot of area covered by the roof (Friedman, 2007). Thus, the volume of water collected each year is a function of the catchment area, annual rainfall and storage capacity. According to the Canadian Meteorological Center, the mean annual precipitation for Vancouver is approximately 1300 mm (Figure 11). In appendix A a table of monthly precipitation in Vancouver is provided (The Weather Network, 2010). Thus, depending on the surface area of the roof, at least 45% of the water demand projected for the new SUB can be met by harvesting rainwater.

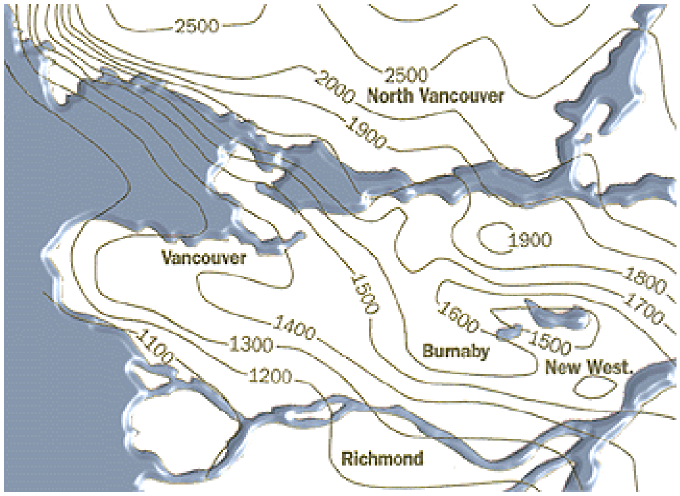

Figure 11: Mean Annual Precipitation for Greater Vancouver

Source: http://www.cherrybouton.com

4.1.2 Filtering

The cleaner the water entering a storage tank, the less often the tank requires cleaning. Rainwater flowing off a roof will contain dust, leaves, sticks, and other debris. A leaf screen covering the gutter can remove much of the larger debris (Figure 12). However, leaf screens must be cleaned regularly; otherwise, they can become clogged and prevent rainwater from flowing into the gutters. In addition, a device known as roof washer should be used to flush off the first rain to fall after a prolonged period of no or little precipitation (Canada Mortgage and Housing Corporation, 2009). The first shower must be flushed off to remove contaminated materials deposited during extended dry periods.

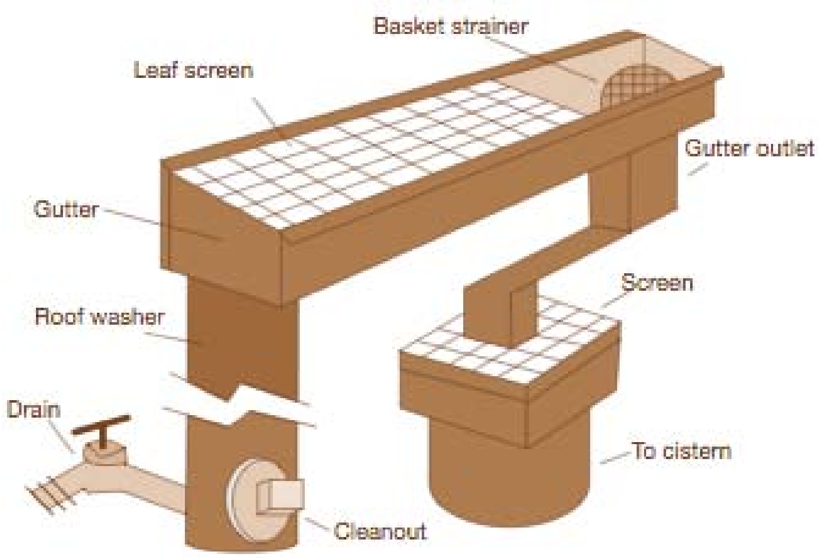

Figure 12: A Prototype Design of a Standpipe Roof Washer and Primary Filter

Source: www.bcd.oregon.gov

For additional filtration, a sediment filter is advisable because it is environmentally friendly (Figure 13). In the figure below rainwater passes thorough four layers consisting variously of sand, gravel, and rock. In addition, a porous screen can be installed as a final filter before the water enters the storage tank.

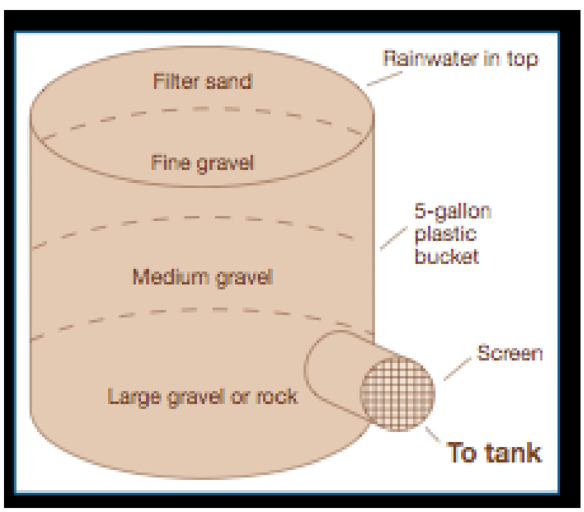

Figure 13: Sediment Filter Design

Source: www.bcd.oregon.gov

Thus filtered, the rainwater is pure enough for use in washrooms and gardens; no further filtering is required. For human consumption, however, additional filtration is essential to ensure that the water is safe and meets Health Canada Guidelines for drinking water.

After passing though the sediment filter, the water can be subjected to Ultra-violet (UV) treatment. UV treatment disinfects water by exposing it to Ultra-violet radiation, which destroys harmful microorganisms. This method of treatment is growing in popularity because it eliminates the need for chemicals (Canada Mortgage and Housing Corporation, 2009). Provided the water is sufficiently clear to allow the UV radiation to penetrate the entire water column, UV treatment is highly effective.

4.1.3 Rainwater Storage

The storage tank is the most expensive component of the rainwater harvesting system. The size of the tank depends on two principle variables: precipitation and demand. The storage tank can be sited above or below ground. However, to prevent the water from freezing in winter, underground storage is required. A fibreglass water tank for storing rainwater has many advantages. It is constructed of long lasting, rustproof fibreglass that is easy to fabricate, ship, and install (Xerxes Corporation, 2009). It can also be manufactured to meet the specifications of designers with respect to size and shape (Figure 14). Underground tanks have a further application. They can be used to store water for fire protection.

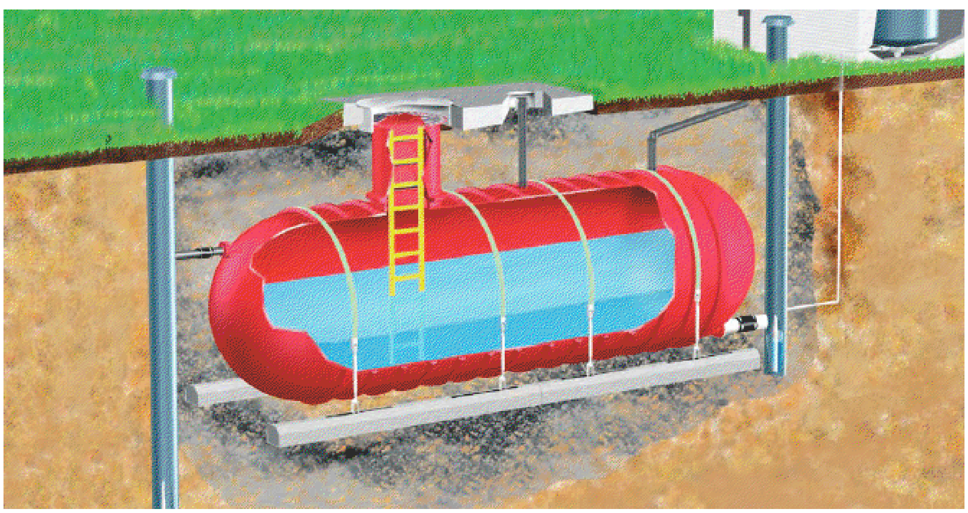

Figure 14: Fibreglass Water Tank

Source: http://www.xerxes.com

4.2 MAINTENANCE COSTS

Maintenance is generally limited to annual cleaning of the tank and regular inspection of gutters and down-pipes. Maintenance typically consists of the removing dirt, leaves and other accumulated material. Cleaning should take place at the end of the summer or prior to a heavy rainfall. Other costs are related to replacing filters and UV lights. UV lights must be replaced after maximum of 10,000 hours of operation. However, overall they are cost effective and only use about the same amount of energy as a 60-watt light bulb (Friedman, 2007). Cartilage filters, however, need to be replaced semiannually.

5.0 CONCLUSION

This report recommends that solar and geothermal energy, along with rainwater harvesting, be incorporated into the design of the new student union building proposed for the UBC campus. Solar energy will reduce UBC's electrical load and its carbon footprint, as will orienting the building to capture the maximum amount of sun light. In addition, geothermal electricity generation and direct heating offer two approaches to exploiting a renewable energy source that is low cost and produces few greenhouse gas emissions. The waste heat associated with geothermal electrical generation and the relatively low efficiency of direct geothermal raise doubts as to the cost effectiveness of harnessing this form of energy. Rainwater-harvesting systems are simple to install, operate, and maintain. The local workforce can be easily trained to maintain such systems, and construction materials are readily available. Should demand grow, both the water collection and storage capacity can be increased. Were these resources to be fully exploited, the SUB proposed for the UBC campus would take its place among the most sustainable buildings in the world.

REFERENCES

Bertani, R. (2005). World geothermal power generation in the period 2001–2005. *Geothermics, 34*(6), 651-690.

Canada Mortgage and Housing Corporation (2009, October 5). Retrieved March 4th, 2010,from http://www.cmhc-schl.gc.ca/en/co/maho/wawa/wawa_002.cfm.

Canada Mortgage and Housing Corporation (2009, June 5). Retrieved February 28th, 2010,from http://www.cmhc-schl.gc.ca/en/inpr/su/waho/waho_009.cfm

Davidsson H., Perers B., and Karlsson B.. (2010). Performance of a multifunctional PV/T hybrid solar window. *Solar Energy, 84*(3), 365-372. Retrieved from http://www.sciencedirect.com/science/article/B6V50-4Y06564-2/2/d699f78c95caf1a18bcb601106c5f031

Friedman, A. (2007). *Sustainable Residential Development*. New York, NY: McGraw-Hill, 133-255.

Galvalume (2009, June 9th). Retrieved March 4th ,2010, from http://galvalume.com.

Goldemberg, J. (2000). World energy assessment: energy and the challenge of sustainability. New York, NY: United Nations Development Program.

Hammons, T. J. (2004). Geothermal power generation worldwide: Global perspective, technology, field experience, and research and development. *Electric Power Components & Systems, 32*(5), 529-553.

Hanuszkiewicz-drapa!a, M. (2009). Heating system with vapour compressor heat pump and horizontal ground heat exchanger. *Archives of Thermodynamics, 30*(4), 201-218.

Kagel, A., Bates, D. and K. Gawell, (2005), A Guide to Geothermal Energy and the Environment. *Geothermal Energy Association*, Washington, D.C., p. 75.

Kreith F., Goswami D. (2007). Handbook of Energy Efficiency and Renewable Energy. *Economics Methods* (pp 2-42- 3-3). CRC Press: Retrieved from CRCnetbase EBook Collection

Lund, John W. (2003). The USA Geothermal Country Update. *Geothermics. European Geothermal Conference 2003*, 32 (4-6): 409–418.

Phair, K. A. (1994). Getting the most out of geothermal power. *Mechanical Engineering*, *116*(9), 76.

Phetteplace, G. (2007). Geothermal heat pumps. *Journal of Energy Engineering*, *133*(1), 32-38.

Patel, M. (2006). Wind and Solar Power Systems: Design, Analysis, and Operation. (2nd Ed.). *Ancillary Power Technologies* (pp.341). CRC Press: Retrieved from CRCnetbase EBook Collection

Randall, J. (2005). Designing Indoor Solar Products - Photovoltaic Technologies for AES. *Fundamentals of Solar Cells* (pp.59-76). John Wiley & Sons: Retrieved from www.knovel.com

The Weather Network (2010). Retrieved March 5th, 2010,from http://www.theweathernetwork.com/index.php?product=statistics&pagecontent=C02096

Xerxes Corporation (2009). Retrieved March 7th, 2010, from http://www.xerxes.com/

Appendix A

Weather Statistic: Vancouver BC

According to the weather network in Canada, each month Vancouver receives at least 35 mm of rainfall. Each rainwater harvesting system is unique and should be proper engineered in terms of the amount of rainwater to collect and the amount of water that is expected to be used. The size of the system will affect the installation and maintenance cost.

Month:	J	F	M	A	M	J	J	A	S	O	N	D
Rain(mm)	132	116	105	75	62	46	36	38	64	115	167	161
Snow(mm)	21	9	4	1	0	0	0	0	0	0	3	19
Total(mm)	150	124	109	75	62	46	36	38	64	115	170	179

Table 1: The Average Monthly Precipitation in Vancouver

Source: http://www.theweathernetwork.com/statistics/