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AN INVESTIGATION INTO SOLAR POWER SYSTEM

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AN INVESTIGATION INTO SOLAR POWER SYSTEM

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ABSTRACT

The report focuses on the feasibility of using solar energy system in the new SUB building. Solar energy is chosen because other potential choices are not suitable for the new SUB due to environmental conditions. The triple-bottom-line approach is conducted to investigate the economic, social, and environmental impacts of using solar energy. Through the economic analysis, the cost of installing a solar energy power system can be retrieved in 42 years in comparison to BC Hydro's electricity price. Although the system is economically efficient, its environmental impacts cannot be ignored; toxic chemicals are used during the production of solar panels and there is yet to be a recycle program for the solar panels. Overall, Canadian Solar CS6P-230 is recommended for installing the solar energy system.

TABLE OF CONTENTS

ABSTRACT ii

TABLE OF CONTENTS iii

LIST OF ILLUSTRATIONS v

GLOSSARY vi

LIST OF ABBREVIATIONS vii

1.0 INTRODUCTION 1

2.0 POTENTIAL CHOICES OF RENEWABLE ENERGY FOR NEW SUB 2

2.1 DETERMINING THE MOST SUITABLE ENERGY 2

3.0 ECONOMICAL ANALYSIS 4

3.1 POWER CONSUMPTION 4

3.2 ENERGY SOURCE – SUNSHINE 5

3.3CALCULATIONS 6

3.3.1 AREA OF THE SOLAR ENERGY SYSTEM 7

3.3.2 BILL COVERAGE 7

3.3.3 SOLAR PANELS REQUIREMENTS 7

3.3.4 INVERTER REQUIRED 8

3.4 SELECTION OF SOLAR PANELS 9

3.4.1 CANADIAN SOLAR CS6P-230 10

3.4.2 SUNPOWER SPR-230-WHT 10

3.4.2 COMPARIOSN BETWEEN CS6P-230 AND SPR-230-WHT 10

3.5 BREAK-EVEN POINT 11

4.0 ENVIRONMENTAL ANALYSIS 12

4.1 GLOBAL WARMING 12

4.2 FAST ENERGY PAYBACK 12

4.3 MANUFACTURING AND PRODUCTION IMPLICATIONS: 13
4.4 PANEL DISPOSAL 13
5.0 SOCIAL IMPACTS 14
5.1 POSITIVE IMPACTS 14
5.1.1 ICONIC MILESTONE OF SUSTAINABILITY 14
5.1.2 JOB OPPORTUNITIES 14
5.2 NEGATIVE IMPACTS 15
5.2.1 ELECTROMAGNETIC FIELD 15
5.2.2 CONSTRUCTION SITE HAZARD 16
CONCLUSION 17
REFERENCES 18

LIST OF ILLUSTRATIONS

Table 1 Pros and Cons of Each Energy Source..2
Figure 1 SUB Power Consumption Chart...5
Figure 2 Monthly Sunshine-hour at Vancouver..6
Figure 3 Comparison of Solar Panels (SRoeCo Solar)..9

GLOSSARY

Photovoltaic – Arrays of cells containing a solar photovoltaic material that converts solar radiation into direct current electricity

Watts – A derived unit of power in the International System of Units; defined as 1 Joule/second

LIST OF ABBREVIATIONS

AC: Alternating Current

AMS: Alma Mater Society

DC: Direct Current

ICNIRP: International Commission on Non-Ionizing Radiation

PTC: PVUSA Test Conditions

PV: Photovoltaic

PVUSA: Photovoltaics for Utility Systems Applications

sqft: square feet

STC: Standard Test Condition

SUB: Student Union Building

UBC: University of British Columbia

1.0 INTRODUCTION

This report investigates the solar energy source for the new SUB; the feasibility of a solar energy system is examined. Focused on the triple-button-line approach, the economical, environmental, and social aspects of a solar energy system for SUB are analyzed in depth. The report starts the investigation by analyzing the operating environment for the solar energy system, and further evaluates and recommends a solar energy system to be used for the new SUB. Moreover, the environmental and social effects of the solar panels and the renewable energy system as a whole are also investigated.

2.0 POTENTIAL CHOICES OF RENEWABLE ENERGY FOR NEW SUB

2.1 DETERMINING THE MOST SUITABLE ENERGY

	Pros	**Cons**
Geo-Thermal	-Reliable -Comfort of constant room temperature -Independent system -Safe and clean – no flame, no fuel, no odors	-Costly installation -Costly and lengthy land survey -only has the ability to maintain and alter the room-temperature -too complex for UBC -Energy source might be unstable due to plate shifts such as earthquakes
Wind Energy	-Non-polluting -Reduces the demand for higher-impact electricity from thermal stations (e.g. oil, natural gas, coal), hydroelectric dams and nuclear generators. -energy independent -most cost-effective	-Not enough wind source in Vancouver thus making the system not cost-effective
Wave Energy	-No waste produced -Inexpensive to operate and maintain	-Wave strength is very weak near the shore of UBC
Solar Energy	-Clean energy, no pollution -No location limits as to where you can place the solar panels -Utilize unused space such as rooftops -Operate independently -Low/No maintenance	-High cost of solar panels -Large area required for installing solar panels -Energy source only available during daylight hours, and the weather can affect the efficiency of solar cells

Table 1 Pros and Cons of Each Energy Source

As seen from the above table, wind energy and wave energy cannot be used for the new SUB. Thus, the choice is between geo-thermal energy and solar energy. The fatal defect of the geo-thermal energy system is that the efficiency of the system will gradually decrease due to heat imbalance between the ground and the system. This is due to the fact that the amount of heat extracted from the ground is more than the heat being put back to the ground. In other words, the gradual cooling of the ground over a long period of time will make the system inefficient. On the contrary, solar energy system will last 20-30 years, depending on the quality of the panels, without this fatal problem. In addition, solar energy system provides just as many advantages as the geo-thermal energy system. From the analysis, solar energy is chosen as the renewable energy to be used for the new SUB.

3.0 ECONOMICAL ANALYSIS

In order to find the most suitable solar energy system for the new SUB, the requirements of the renewable energy system need to be well defined. Our team started the research by performing a requirement analysis on the solar energy system. According to the triple-button-line approach, the economical, social, and environmental requirements are taken into consideration. The followings are a list of the requirements of the new solar energy system for the new SUB:

- The system must at least satisfy the new SUB's energy consumption on a yearly bases
- The system will not interfere with the original design of the new SUB to an extent that the new SUB's blueprint needed to be modified radically
- The system must be cost-effective for up to 25 years
- The system will not affect the health condition of the user
- The system must stay within the budget of the new SUB project

3.1 POWER CONSUMPTION

First of all, the power demand for the solar energy system will be analyzed. The building plan for the new Student Union Building is still undecided at the time of the report, thus an estimated power consumption of the new SUB will be needed. According to the AMS website, the new SUB is expected to be a five-storey building and have a total area of 255,000 square feet. The new SUB includes student social space, student amenities, club space, and services and administration offices (AMS, 2007). Since the new SUB will have the latest generation of electronics, which provide better power efficiency, we estimate the new SUB would consume about the same amount of electricity per year as the old SUB; even though, the new SUB has an area that is 67% bigger than the old SUB.

According to The Sustainability U website, the monthly electricity consumption in the old SUB in the past four years is plotted in the graph below:

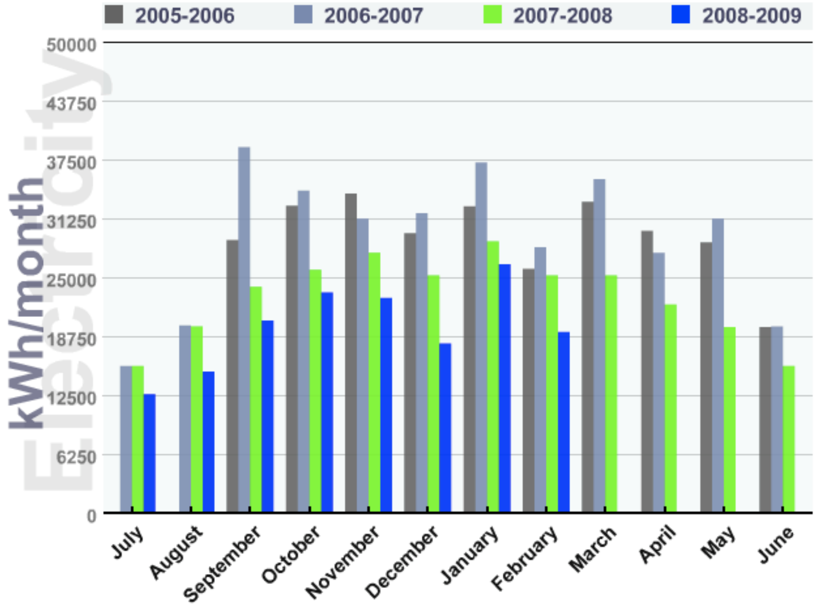

Figure 1 SUB Power Consumption Chart

The power consumption of the old SUB on average is about 274,637 kWh per year (SUB Electricity Use). With a rough idea of how much power the new SUB will be consuming per year, we analyze the source of the renewable energy that will provide the new SUB all the power it needs.

3.2 ENERGY SOURCE – SUNSHINE

Even thought Vancouver is known for its rainy seasons, it does get more than enough sunshine-hour per year to operate the solar energy system effectively. According to Environment Canada, Vancouver has an average of 166 days per year with measureable precipitation and 289 days measureable sunshine (Environment Canada, 2010). However, if we measure and analysis the power consumption of the new SUB and the sunshine-hour of Vancouver on a monthly basis, we would discover two curves with opposite trends.

(Insert Environment Canada sunshine-hr chart)

Bright Sunshine:	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Total Hours	58.6	73.7	128.6	171.2	226.5	216.3	282.1	252.1	175.4	125.9	69.1	58.9	1838.4
Days with measureable	17.2	18.5	23.7	26.1	28.3	27.3	29.1	29.1	26.3	23.6	18.7	16.9	284.7
% of possible daylight hours	21.7	25.8	35	41.7	47.8	44.6	57.7	56.5	46.3	37.6	25.1	23	38.5

(Insert excel graph of sunshine-hr + pwd_con)

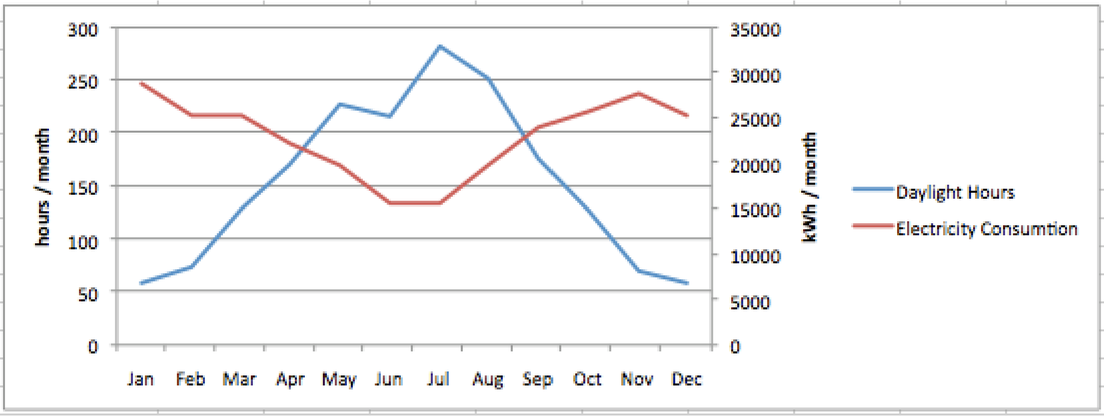

Figure 2 Monthly Sunshine-hour at Vancouver

Since the level of electricity that solar panels produce is proportional to the sunshine-hour, this trend can put the feasibility of solar energy system on jeopardy. To solve this critical issue, our team recommends a solar energy system that is grid-tied, so any excess electricity produced by the solar energy system in the summer can be sold to BC-Hydro. Using the grid as a battery, the shortage of electricity produced in the winter can be compromised. With a negative electric consumption in the summer, the excess electricity can be used in the winter.

The average sunshine-hour per day in Vancouver in the past thirty years is measured to be 5.3 solar hours per day. With source of the solar energy analyzed, we now analyze other aspects that might affect the applicability of a solar energy system for the new SUB.

3.3CALCULATIONS

With a more in-depth research and analysis on the solar energy system, our team has discovered two issues that will greatly affect the design of the solar energy system:

Area available for the solar energy system and the desired bill coverage.

3.3.1 AREA OF THE SOLAR ENERGY SYSTEM

According to the AMS website, the new SUB will be a five-storey building with a total estimated area of 250,000 square feet. Therefore, we estimate the roof area to be around 50,000 square feet. Moreover, taking into account that a roof garden is to be built for the new SUB (Metchie, 2010), we further estimate there will be 30% of the roof available for the solar panels. (15,000 square feet)

3.3.2 BILL COVERAGE

Since the new SUB is designed to be the greenest building on campus, we have decided to make the solar energy system have 100% of the electricity bill coverage.

3.3.3 SOLAR PANELS REQUIREMENTS

- Power Consumption: 274,637 kWh per year
- Energy Source: 5.3 solar hours per day
- Area Available: 15,000 square feet

Now we need to find an array size of the solar energy system that will satisfy the above conditions. The array size is the amount of energy that needs to be produced per second. Due to real world efficiency losses, including irradiance, dust, temperature, and wiring, the expected system power output is to be 75% of the system's size.

$$\frac{274637\ kWh\ per\ year}{365\ days\ per\ year}\ \frac{((5.3\ solar\text{-}hours\ per\ day)\cdot(100\%\ bill\ coverage))}{0.75\%} = 189.29\ kW$$

The Maximum number of solar panels that can be installed on the rooftop of the new SUB can be calculated as followed:

$$\frac{15{,}000\ sqft}{16\ sqft\ per\ panel} = 937\ panels$$

Finally, the power output per solar panel can be calculated as followed:

$$\frac{189\ kW}{937\ panles} = 201.7 = 200\ W\ per\ panel$$

With the analysis on the solar energy system completed, we now look for solar panels that have the minimum power rating of 200W. Since the data of solar panels from the manufactures are measured under the standard test condition, (STC) we start to look for a solar panel that has a power rating of 220 W to ensure the performance of the panels in a real-world environment.

3.3.4 INVERTER REQUIRED

In order to be a grid-tied solar energy system, a power inverter is required to transform the DC power that is produced by the solar panels to AC power since the grid of BC-Hydro only provides/accepts AC power. Due to limited information on a commercial power inverter that is capable of handling hundreds of kilowatts of power, we estimate the price of such inverter to be $100,000 USD (Solar BLVD, 2010).

3.4 SELECTION OF SOLAR PANELS

Since the estimated value of the DC output for the solar panels, as calculated in the previous section, is approximately 200W, we will focus on the solar panels that can actually generate such amount of power. The table below shows some panels ranging between 190 and 230 watts of 5 common manufacturers including Canadian Solar, Kyocera, Sharp, SunPower, and Suntech.

Brand	Model No	Watts DC	PTC Efficiency	True # of Panels	True Total Area (sqft)	True Array PTC Watts	PTC Watts per Sqft	Cost per DC Watt	Cost per PTC
Canadian Solar	CS6P-200	200	88.50%	6	108.35	1062	9.8	$2.80	$3.16
Canadian Solar	CS6P-210	210	88.62%	5	90.29	930.5	10.31	$2.80	$3.16
Canadian Solar	CS6P-220	220	88.73%	5	90.29	976	10.81	$2.80	$3.16
Canadian Solar	CS6P-230	230	88.87%	5	90.29	1022	11.32	$2.80	$3.15
Kyocera Solar	KD205-GX	205	87.80%	6	100.17	1080	10.78	$3.10	$3.53
Kyocera Solar	KD210-GX	210	87.90%	5	83.47	923	11.06	$3.31	$3.77
Sharp	ND-200	200	88.05%	6	109.61	1056.6	9.64	$3.73	$4.24
Sharp	ND-208	208	88.13%	5	91.34	916.5	10.03	$3.73	$4.23
Sharp	ND-216	216	88.19%	5	91.34	952.5	10.43	$3.94	$4.47
Sharp	ND-220	220	88.27%	5	91.34	971	10.63	$3.94	$4.46
Sharp	ND-224	224	88.30%	5	91.34	989	10.83	$3.74	$4.24
SunPower	SPR-200-BLK	200	92.15%	5	70.23	921.5	13.12	$4.20	$4.56
SunPower	SPR-210-BLK	210	92.24%	5	70.23	968.5	13.79	$4.20	$4.55
SunPower	SPR-220-BLK	220	91.95%	5	70.23	1011.5	14.4	$4.20	$4.57
SunPower	SPR-225-BLK	225	92.04%	5	70.23	1035.5	14.74	$4.20	$4.56
SunPower	SPR-230-WHT	230	92.83%	5	70.23	1067.5	15.2	$4.20	$4.52
Suntech	STP190-18	190	89.79%	6	99.08	1023.6	10.33	$2.80	$3.12
Suntech	STP200-18	200	89.90%	6	99.08	1078.8	10.89	$2.80	$3.11
Suntech	STP210-18	210	90%	5	82.57	945	11.45	$2.80	$3.11

Figure 3 Comparison of Solar Panels (SRoeCo Solar)

- True = real world
- True # of panels = the rounded number of panels it would take to get closest to a 1 kW array (1,000 / PTC rating, then rounded to the nearest whole panel)
- Cost per DC and PTC may vary.
- Numbers given are general estimates and vary depending on many factors.

As it is very difficult to state that one brand stands out among the rest as the best, we would recommend two models, so UBC can have more options while choosing the most optimal solar panel for the new SUB. After careful review of the above information, our recommendations are Canadian Solar CS6P-230 and SunPower SPR-230-WHT. In the following we will calculate the approximate costs of both solar panel and their main pros and cons will then be discussed.

3.4.1 CANADIAN SOLAR CS6P-230

Number of modules required: 189000 W / 1022 W = 184.93 = 185 modules

Total area needed: 185 modules * 90.29 sq.ft. per module = 16,703.65 sq.ft.

Total cost: 185 modules * 5 panels per module * 230 W per panel * $2.80 per W = $595,700.00

3.4.2 SUNPOWER SPR-230-WHT

Number of modules required: 189000W / 1067.5W = 177.05 = 178 modules

Total area needed: 178 modules * 70.23 sq.ft. per module = 12,500.94 sq.ft.

Total cost: 178 modules * 5 panels per module * 230 W per panel * $4.20 per W = $859,740.00

3.4.2 COMPARIOSN BETWEEN CS6P-230 AND SPR-230-WHT

As we can see, Canadian Solar CS6P-230 has better cost-performance ratio than SunPower SPR-230-WHT because it provides slightly less amount of power at a far lower price. Therefore, we strongly recommend CS6P-230. However, the problem with CS6P-230 is that it will take up more space than the 15,000 sq.ft. available on the rooftop. If the new SUB does not have enough space to install CS6P-230, we then recommend using SPR-230-WHT which, with its higher efficiency, will only require an area of 12,500.94 sq.ft., and is capable of generating more DC output than CS6P-230.

3.5 BREAK-EVEN POINT

Installing the whole system is considered as an investment, so the return rate must be known. To fully analyze the return rate of the solar energy system, the cost of installation and parts are added together.

(Installation cost+Solar panel cost+inverter cost+Maintainance cost+recyling cost) / amount of money paid towards BC Hydro per year = (1000k+1000k+100k+0+0)/ 50k = 42 years.

The calculation roughly shows that it takes about 42 years to achieve a break-even point.

4.0 ENVIRONMENTAL ANALYSIS

Solar electric systems—also known as photovoltaic (PV) systems— do very little harm to the environment. During operation, PV systems practically do not produce any pollution. Thus, PV can, and should be integrated into the new SUB. The following addresses the positive impacts of a PV system:

4.1 GLOBAL WARMING

Global warming has caused a rise in temperature and in turn has resulted in a rise in sea levels, climate change, glacier retreat and disappearance and acidification of ocean. Compared with other technologies, solar power produces no greenhouse gases, so it does not contribute to global warming.

4.2 FAST ENERGY PAYBACK

Fast Energy Payback: Energy is required to manufacture PV systems. Thus, it is important to evaluate the "energy payback" -- how long it takes a PV system to generate enough zero-emission energy to offset the energy used to produce it. It has been shown through studies that a typical PV system's energy payback ranges from one to four years, far below the life span (30 years) of a quality PV system (U.S. Department of Energy, 2010). Nevertheless, nothing comes for free. There are still negative impacts of using PV systems.

4.3 MANUFACTURING AND PRODUCTION IMPLICATIONS:

Some PV systems use small amounts of toxic chemicals such as cadmium and selenium. In turn, PV factories generate a small amount (minimal relative to waste produced by conventional energy sources) of hazardous waste, which is disposed of according to laws (U.S. Department of Energy, 2010).

4.4 PANEL DISPOSAL

As of current date, only a small amount of PV panels are disposed each year. Thus, disposing panel is not a major concern at the moment. However, it will eventually become an issue that must be dealt with in the future. Unfortunately, solar panel recycling is inexistent in Canada. Recently, First Solar, one of the largest solar companies in US, has launched the industry's first module recycling program, in which the cost of recycling is reflected on the products price -- meaning that recycling is done at no additional cost. Although no recycling program is present, recycling programs should be in practice by the time the solar panels to be used at the new SUB are at the end of their lives (Solar Feeds News And Commentary, 2010).

Although the biggest concern for the technology currently is recycling, solar energy systems, with so many environmental advantages, have proven to be one of the best choices among sustainable energy systems.

5.0 SOCIAL IMPACTS

Nowadays, people are well aware of the extreme climate change around the world. This change is attributed to global warming. To combat global warming, the world starts to adapt the power of renewable energy. Indeed, solar energy is the new upcoming technology that is rapidly leading our resolution of clean energy. The question now becomes to what extend the solar energy will benefit to our society. The following paragraphs will discuss the pros and cons of the solar energy to the society.

5.1 POSITIVE IMPACTS

5.1.1 ICONIC MILESTONE OF SUSTAINABILITY

Adapting solar energy in the construction of the new SUB at UBC can bring about some positive social impacts. To begin, one of the goals of this project is to enhance environmental sustainability by reducing energy and materials consumed in the building. If we succeed in achieving this goal, the UBC can be the first university that constructs one of the largest net-zero buildings in Canada. This project will not just be a night fame building, but it is recognition of us, UBC, being the first university to initiate actions in reducing pollution to the environment in hope to inspire others.

5.1.2 JOB OPPORTUNITIES

Another positive social impact is that this project can create more jobs. If the project involves in installing a 230 kWp size of solar panels, it will become the largest PV installations in B.C (Pegg, 2010). In other words, this will require a lot of man powers not only in construction phase but also the preparation and clean-up phase.

5.2 NEGATIVE IMPACTS

5.2.1 ELECTROMAGNETIC FIELD

Nevertheless, installation of the solar panels on the new SUB could also cause some negative impacts. For example, in modern society, electricity has become the backbone of our living. Our reliance on electricity arises public concern in the issue of its potential adverse health effects. In a research paper, Scaling Public Concerns of Electromagnetic Fields Produced by Solar Photovoltaic Arrays, the author explains how exposure to electromagnetic field could affect one's health. He stated, "If the magnetic fields created by alternating current electric systems sufficiently large, power frequency magnetic field can induce a current in the human body large enough to cause muscle and nerve stimulation that can result in headaches and pains" (Good Company). Later, this research project tries to investigate if the electromagnetic fields created by solar photovoltaic arrays can cause health problems. As we know in direct current system also known as static field, the current does not change over time; therefore, in most general cases, DC does not induce electromagnetic field. To investigate the effects of the solar power systems, the process of converting sunlight to electricity must be examined. First, photovoltaic solar arrays convert sunlight to direct current, which then have to be converted into alternating current in order to supply usable electricity. This process is accomplished by a power inverter. In the report, it states that the magnetic field produced by a power inverter is 50% less than the International Commission on Non-Ionizing Radiation Protection exposure guideline. It is a health protection guideline suggesting that the general public not be exposed to static magnetic fields in excess of 4 million milligauss or power frequency magnetic fields in excess of 830 milligauss (Good Company). Usually people would not have access to the power inverter, and they will be at a safe distance away from inverter. In such a long distance (10 feet), the strength of the magnetic field will decreased proportionally. Base on our limited information, we would say there is no adverse health effect; nevertheless, it is crucial to take this potential health hazard into consideration when installing solar panels.

5.2.2 CONSTRUCTION SITE HAZARD

Another social impact of installing solar panels is that the risks of the workers who are installing the solar panels are increased because the construction sites are often at rooftop, which could cause fall hazard. Nevertheless, there are various techniques to prevent such hazard from happening. Followings are the techniques: KeeGuard rooftop railing, skylight screens roof hatch railings, KeeGuard contractor railing, and lifeline fall arrest (Pollock, 2010).

CONCLUSION

Through the triple bottom-line analysis, we have decided that solar energy module is the most suitable choice for the new SUB. With minimum environmental and social negative impacts, solar power system is the best among all the others options that we took into consideration. In our economical analysis, we further prove that Canadian Solar CS6P-230 is the most cost-performance efficient solar panels available on the market. Thus, we recommend this module to be used in the construction of the new SUB.

REFERENCES

AMSUBC. (2007). New SUB Timeline. Available: http://www2.ams.ubc.ca/index.php/ams/subpage/category/new_sub_timeline/.

Environment Canada. (2010). Canadian Climate Normals. Available: http://www.climate.weatheroffice.gc.ca/climate_normals/results_e.html?Province=ALL&StationName=Vancouver&SearchType=BeginsWith&LocateBy=Province&Proximity=25&ProximityFrom=City&StationNumber. Last accessed 10 March 2010.

Good Company. Available: http://www.oregon.gov/ODOT/HWY/OIPP/docs/EMFconcerns.pdf. Last accessed 20 March 2010.

Metchie, Jensen. 21 January 2010.
Pegg, Kevin. UBC sustainability research on solar panels. Victoria, BC, Canada. Last accessed 30 March 2010.

Pollock, Chris. 29 March 2010. Rooftop Solar Installations = Increased Fall Hazard. Available: http://simplifiedsafety.com/blog/rooftop_solar_installations_increased_fall_hazard/. Last accessed 3 April 2010.

Solar BLVD. (2010). Xantrex GT250 250KW 480 Volt Commercial Grid-Tie Inverter. Available: http://www.solarblvd.com/product_info.php?info=p1943_Xantrex-GT250-250KW-480-Volt-Commercial-Grid-Tie-Inverter.html. Last accessed 27 March 2010.

Solar Feeds News And Commentary. 21 March 2010. First Solar Comes Up with First Solar Panel Recycling Program $FSLR. Available: http://www.solarfeeds.com/energy-boom/11743-first-solar-comes-up-with-first-solar-panel-recycling-program-fslr. Last accessed 3 April 2010.

SRoeCo Solar.. Solar Panel Comparison Chart. Available: http://sroeco.com/solar/learn-solar/solar-panel-comparison/. Last accessed 3 April 2010.

SUB Electricity Use. 12 March 2010. Available: http://sustainability-u.mypassionforaction.org/green-project/student-union-building-electricity-use. Last accessed 3 April 2010.

U.S. Department of Energy. (2010). Clean Energy Payback. Available: http://www1.eere.energy.gov/solar/clean_energy_payback.html. Last accessed 3 April 2010.