UBC Social Ecological Economic Development Studies (SEEDS) Student Report

An Investigation Into Renewable Energy: The Solar Canopy Illumination System

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Abstract

The new student union building at the University of British Columbia is targeting Leadership in Energy and Environmental Design (LEED) Platinum building certification. Among the requirements that must be met to earn this certification is the requisite that at least 20% of the building's consumed energy be derived from renewable sources. The Solar Canopy Illumination System developed by the Structured Surface Physics Laboratory at the University of British Columbia provides the ability to illuminate the interior of the building – including rooms with no windows – using natural sunlight. Since interior lighting comprises a significant portion of a building's energy usage, the solar canopy system is ideal for facilities, such as the new student union building, which seek to aggressively pursue sustainable building design.

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Glossary

Angle of incidence - The angle at which a ray of light approaches a surface.

Environmental footprint - The net effect a system or process has on the environment.

Luminance – The quantitative measure of the brightness of a particular light source.

Sustainability - The ability to satisfy the needs of the current generation without compromising the ability of future generations to satisfy their own needs.

List of Abbreviations

LEED – Leader in Energy and Environmental Design

MNECB – Model National Energy Code for Buildings

SUB – Student union building

1.0 Introduction

Lofty goals for sustainability have been set for the new Student Union Building (SUB) at the University of British Columbia. With LEED Platinum certification targeted, at least 20% of the energy needs of the building must be satisfied by renewable sources, and this is not a trivial requirement for a major campus building to meet. Achieving this target will require the usage of multiple sustainable energy sources, as well as a significant effort in minimizing the energy demands of the facility.

The Solar Canopy Illumination System developed by The Structured Surface Physics Laboratory at UBC is an innovative method of harnessing sunlight to illuminate the interior of the building. BC Hydro estimates that upwards of 30% of a building's energy consumption is allocated to lighting, therefore it is logical to utilize as much natural light as possible. Modern architecture has already taken note of this fact, as evidenced by the increase in the size and number of windows in new buildings. The solar canopy takes this concept further and overcomes the limitations of windows by providing a way in which natural light can be piped into the interior of the building.

2.0 How It Works

The goal of the project is to provide the new SUB building with a source of renewable energy that will help it reach the 20% renewable energy quota. This quota is required to achieve LEED platinum certification which UBC is aiming for. In order to facilitate this, we propose the implementation of a solar canopy placed onto the outside of the new SUB. The principle of the canopy is not simply to provide renewable energy to power the SUB, but to reduce the amount of power consumption in the SUB through renewable means. This power consumption particularly targets lighting, which is predicted to account for 40% of the SUB's power consumption. (2)

The renewable energy source is sunlight; the solar canopy takes this sunlight and redirects it into the building to create natural lighting. This technology was created and developed at UBC, so that makes it an even greater reason to integrate this into the new SUB. The exterior of the canopy is an array of mirrors as can be seen in Figure 1. The mirrors are directed to face the sun at all times of the day, so as to be as efficient as possible. To do this every square shaped mirror is attached to 3 fibers, 2 that are attached to the top two corners of each mirror and one in the middle. The central fiber is fixed, and the other two fibers are used to rotate all the mirrors through 180 degrees. Because of the arrangement of the mirrors all of the fibers can be linked together and attached to two linear actuators, one to rotate all mirrors to the left and one for the right. As can be seen in Figure 1 the sunlight is directed into the canopy and bounces off two mirrors that direct the light to the light pipe, which is what goes across the ceiling of the building and provides light.

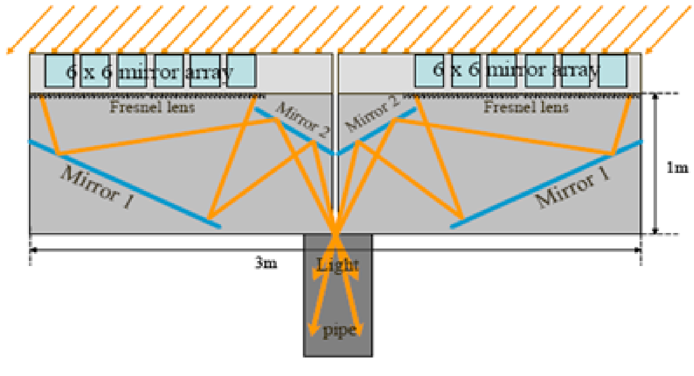


Figure 1 – A Schematic Top View of the Mirror Array and Redirecting Optics Within the Canopy Structure (1)

A cross section of the light pipe is seen in figure 2 below. The pipe is layered with a reflective film that reflects light along the entire pipe. On the bottom is an optical lighting film which, at a specific angle, allows total internal reflection to occur and the light beam is transported down the pipe. However if the angle of incidence is not correct then the light passes through the lighting film, lighting the area below. The amount of light that passes through the film can be controlled by the extractor at the top of the pipe. With a change in the width of the extractor this allows a bigger or smaller fraction of light to escape. Obviously the solar canopy cannot provide sufficient lighting 24 hours a day, through night-time and dull days. To counteract this, multiple fluorescent light bulbs are placed along the length of the pipe. These bulbs are capable of being powered by different amounts of electricity, to produce more or less lighting to maintain a constant luminance inside the building, therefore saving energy.

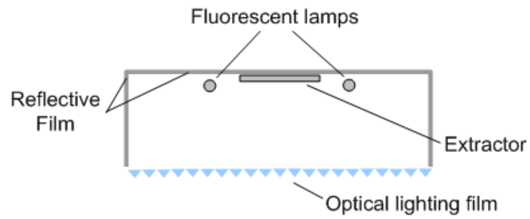


Figure 2 – Cross Section of the Light Pipe (1)

To calculate the specifications for the design of the solar canopy a test room was built which had the specifications given in Figure 3.

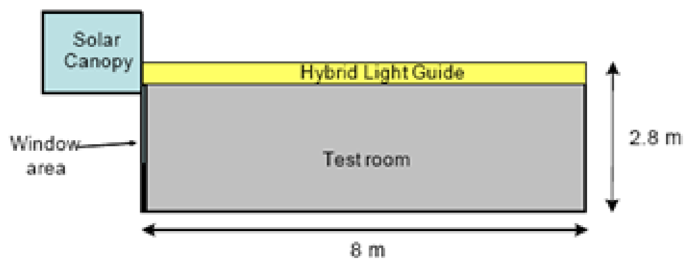


Figure 3 – Specifications of the Test Room (1)

The test room also had a window that could be blacked out or left open, so as to simulate an actual office setting, and also to test the lighting guides light intensity when placed under realistic situations. The test room was built outside and was oriented with the solar canopy facing south, which is where the sun is located for most of the day. The first test that was executed was to measure the luminance throughout the room from just an open window. The luminance readings were taken at 1 meter intervals directly under the light pipe (which is off for this test) at a height of 0.8 meters off the ground. The results of the test are given below in figure 4.

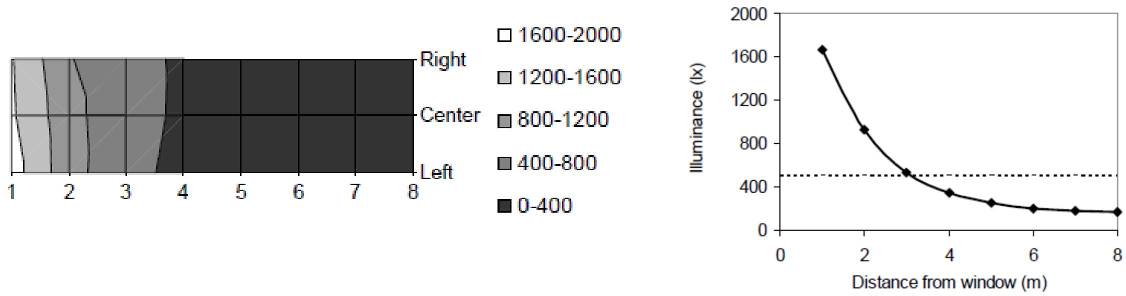


Figure 4 – Luminance Distribution Due to South Wall Window(1)

As can be expected the luminance is very large within 1.5 meters of the window and it exponentially drops off to a luminance of about 200 for distances of 6 meters from the window.

The next test that was conducted was to blackout the window completely and light the room purely from the fluorescent light bulbs on max power. Again the luminance readings were taken at 1 meter intervals directly under the light pipe at a height of 0.8 meters off the ground. The results of the test are given below in figure 5.

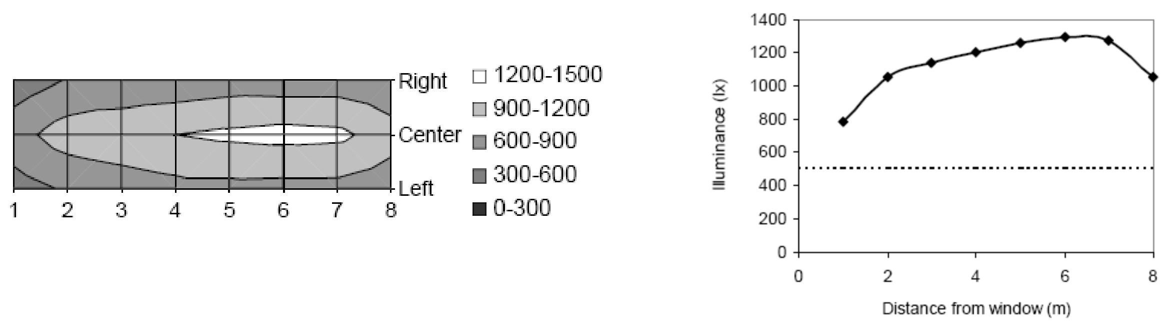
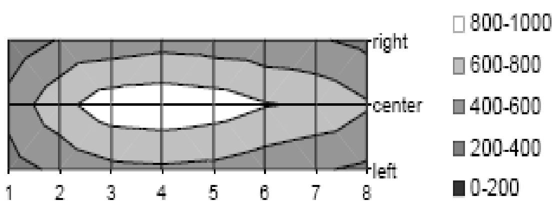


Figure 5 – Luminance Distribution Due to Electrical Lighting (1)

As can be seen the luminance levels are all above 800 for the entire length of the room.

A luminance threshold was then determined based on a comfortable lighting setting. This threshold was set to 500 which can be seen from the dotted lines in both the previous two figures. This level is the luminance level that gives sufficient lighting to not seem dim or dull, and anything over this threshold is more than adequate to light an area. The final test that was conducted was to measure the effectiveness of the solar canopy with a closed window, with the fluorescent light bulbs completely turned off. The results were gathered on a day in the middle of the summer at almost noon when the sun is very high in the sky. They were measured at the same locations as the previous two tests and produced the following results in figure 6.



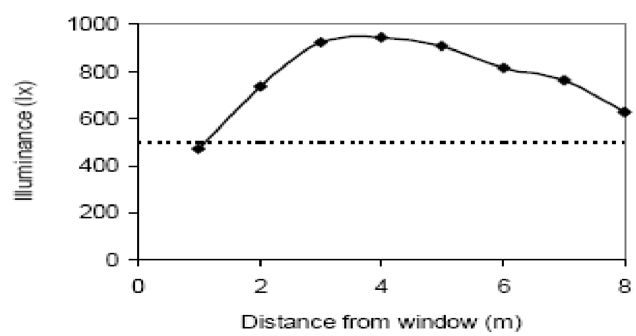


Figure 6 – Luminance Distribution Due to Solar Canopy (1)

Two things have to be noted in these results; the first is that the scale for black to white has changed from the previous charts. The second is that the solar canopy was designed to not release any light for the first 1.5 meters of the room, because realistically a window would provide this area with enough light on most sunny days. As can be seen from the results, the solar canopy is more than capable of providing more that the 500 threshold throughout the room. The lighting inside the room can be seen in figure 7 below.

Figure 7 – Inside of the Test Room Lit Purely by Sunlight (1)

Of course the solar canopy is not adequate on its own to light rooms or buildings for all hours of the day to a luminance greater than 500. Therefore the fluorescent lights have to be turned to some level that allows the luminance in the room to be greater than 500. As such, in every room the design of the solar canopy is unique depending on the length of the room, the number of windows and other factors. This means a careful algorithm, based on the results above, has to be made in order for the solar canopy to be as efficient as possible, using few electric lights and as much natural lighting as possible.

Other factors that effect the solar canopy is if on a sunny day the sun passes behind a cloud the intensity of sunlight drops considerably changing the room luminance. In order for the lights to seem as though they do not ‘flicker’, which would be disturbing for whoever is in the room, an algorithm to gradually turn the power of the electric lights up was formed. This algorithm is explained in figure 8.

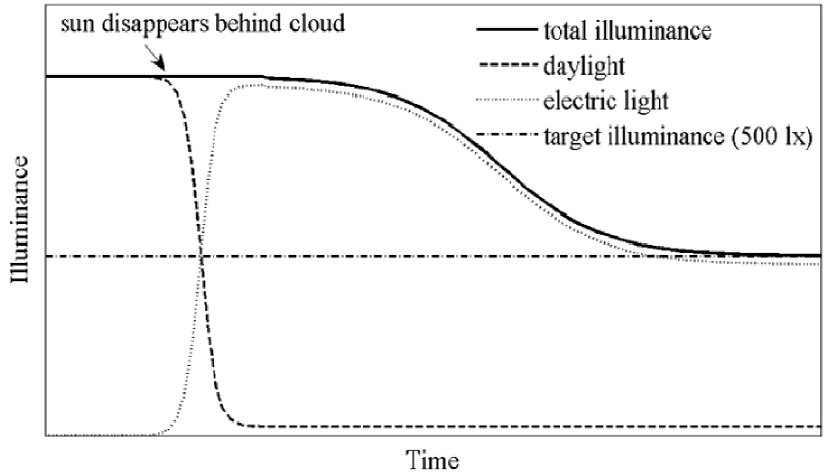


Figure 8 – Change in the Distribution of Light Sources When the Sun Disappears Behind a Cloud (1)

This concept is a big feature of the solar canopy as it slowly adjusts to the outside environment without disturbing the work of the people inside. As can be seen, when the sun disappears behind a cloud the electric lights immediately kick in to the level of luminance that the solar canopy was previously providing. Then to reduce energy consumption it slowly decreases the power given to the lights so that the luminance in the area is above the threshold of 500. This aims to use the least amount of power without disturbing anyone.

During winter days the effectiveness of the solar canopy is obviously very limited in comparison to the summer days. Due to the fact the days are shorter and the sun is lower in the sky electric lights are used more. However during the summer days the solar canopy can be used for most of the day which significantly reduces the power consumption for lighting. To test the effectiveness of the canopy the constructed test room was left outside for a year still oriented south. The periods within the year where the solar canopy was effective were recorded and are displayed in figure 9.

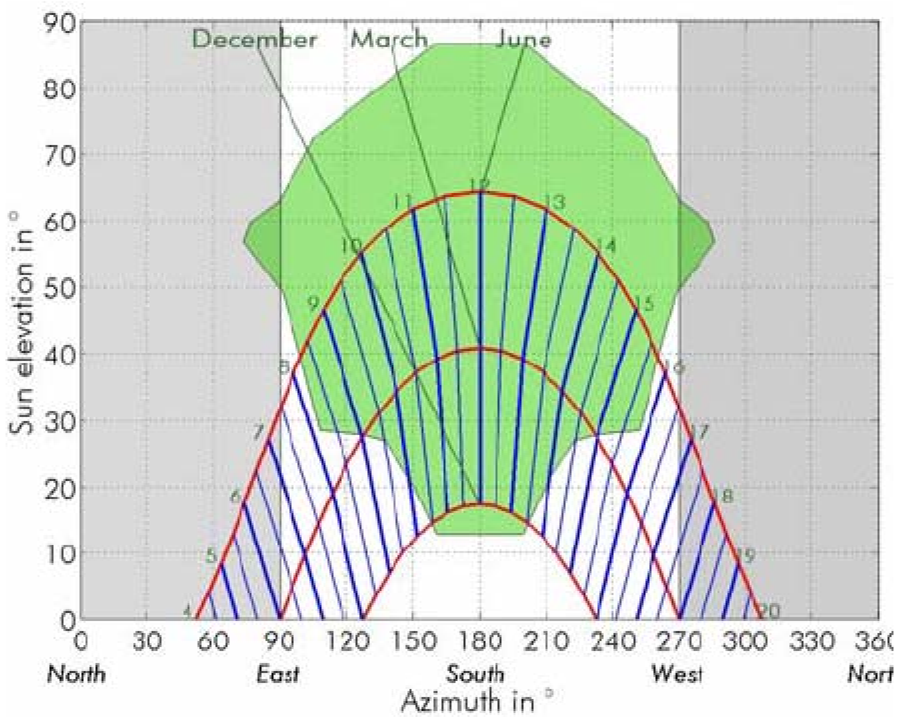


Figure 9 – Periods During the Year Where Solar Canopy is Sufficient to Provide All Lighting (1)

The area in green represents the periods where the solar canopy is capable of providing a luminance of 500 or greater by itself, assuming ideal outside conditions (clouds, weather). Note that the figure does not include all months, and months such as

July and August would come in slightly higher than the June displayed. Also the first six months would be similar to the last six months in reverse order – for example, March would be similar to October.

3.0 Implementing the Solar Canopy: Benefits and Consequences

The solar canopy will be used to satisfy the renewable energy requirements of reducing the new SUB's dependency on the current non-renewable energy sources. UBC currently generates its electricity from a natural gas powered steam plant. The plant runs at 65% efficiency and UBC is looking for ways to reduce the need for energy from the plant (1). A large portion of the energy demands for campus buildings come from lighting requirements and the solar canopy will effectively reduce the amount of energy needed to light the New SUB. The following table (figure 10) shows the load distribution for a typical office building operating at 83 ekWh/m^2. (Note that the current SUB requires 298 ekWh/m^2 and that the point of this table is to show the relative distribution of common electrical loads).

Electical Loads (for 83 ekWh/m2 office building)

Loads	ekWh/m2	kWh/yr
Space Cool	0	0
Heat Rejection	0	0
Ventilation Fans	0	544
Pumps and Auxillary	0	1,318
Miscillaneous Equipment	35	834,994
Area Lights	32	768,338
Annual Electricity Load		1,605,194

Figure 10. Electrical Loads for a Typical Office Building (2)

From the table, it follows that 47.9% of a building's electrical load goes towards lighting. Lighting represents a significant amount of the total load, and thus is worthy of innovative ideas to reduce that loading in order to reduce the entire buildings energy needs. As opposed to proposing different ways to create energy for lighting, the Solar Canopy will cut down on the actual energy demand of the building. This is superior to attempting to remedy the issue of energy consumption, through addressing the root problem.

3.1 LEED Platinum Plus Certification

One of the overarching goals of the New SUB project is to satisfy the LEED Platinum Plus criteria for energy consumption. This will include designing the New SUB to exceed the Model National Energy Code for Buildings (MNECB), as issued by the federal government. The goal will be to run at least 60% better energy performance than that outlined by MNECB, with the possibility of working towards net zero energy in the future (2). In order to receive LEED certification, the building's energy consumption cost must be reduced by 25% relative to a reference building from MNECB. Extra certification points will be awarded for greater than 25% reduction as outlined below in figure 11.

Figure 11. Certification Points Awarded for Percent Reduction in Design Energy Cost Relative to MNECB. Adapted from (3).

Points	MNECB (%)
1	24
2	29
3	33
4	38
5	42
6	47
7	51
8	55
9	60
10	64

In order to achieve LEED Platinum Plus, 80 or more points must be awarded; note that there are many more categories for a building to receive points such as, water management, site development, materials and indoor environmental quality. The implementation of the solar canopy project will contribute to the overall reduction in energy cost and help meet the LEED standards.

3.2 Environmental Impact

The design of the Solar Canopy has obvious environmental benefits by reducing the demand on the front-end of the energy production cycle. There are, however, environmental impacts with the use of this technology mostly stemming from the manufacturing and care of materials used. The majority of materials used to construct the Solar Canopy are metals and glass. By design, there will be little need to replace parts during operation due to the Solar Canopy's simplicity. There are no resources being expended during operation besides basic cleaning and washing of the outer canopy. The selection of building materials then, is the most important step when considering the canopy's environmental footprint. Specific materials are not listed for the project besides the fact that they are to be lightweight and inexpensive. This will most likely include basic glasses and mirrors and lightweight metal products such as aluminum. In order for the project to sustainable, all broken and discarded materials will be attempted to be reused onsite or recycled.

3.3 Financial Impact

The Solar Canopy is similar to other sustainable building design innovations in that the initial construction price is higher than standard practice, and more importantly, will result in lower operating costs down the road. Due to the fact that only two small actuators are needed to slowly rotate the mirrors with the sun's movement, the complexity of the system and thus its start-up cost is kept to a minimum. The research group is in the process of doing a more involved cost analysis assessment and so no quantitative results can be discussed. That being said, the team is very optimistic that it can be financially viable in the Vancouver area. As with the environmental impacts, the selection of materials will greatly affect the total cost of the project and the lifespan of those materials must be taken into account when determining the overall cost. The costs of retrofitting a building with the Solar Canopy is relatively low since the light guides are designed to fit into existing ceiling paneling, which is standard in most commercial and industrial buildings. This is good news for the New SUB as it is not currently considering using the Solar Canopy technology but will have the opportunity to integrate it into the new building once a rigorous lifetime cost analysis is completed.

3.4 Social Implications

Occupants of the New SUB will not be directly interacting with the Solar Canopy, however, its impact will be felt by everyone who enters the building. It is generally accepted that humans prefer natural light over artificial light and this has been supported by clinical studies. One problem with artificial light is that it often results in over-lighting of a building's interior, this leads to headaches, fatigue, stress, anxiety increase and even decreased sexual function (4). The hybridized approach of using the Solar Canopy in conjunction with fluorescent lighting will result in only the minimum amount of artificial light being emitted into a room at any given moment. People tend to be happier and more productive when exposed to natural light and this clearly helps the new SUB achieve its social goals of a comfortable and effective living space.

4.0 Conclusion

When taking into account the usage of renewable energy, sources such as geothermal, wind, and photovoltaic cells are often the first systems to be considered. While these sources do have tremendous upside, they also have significant drawbacks; the most typical of these being the cost of implementation. With this in mind, the researchers at the Structured Surface Physics Laboratory at UBC have undertaken the development of a cost effective method to distribute natural light throughout the interior of a building. This system can supplement the use of other sustainable energy sources to drastically reduce the energy costs of the building.

Overall the solar canopy is capable of providing natural lighting inside a building with no significant disadvantage when compared to normal electrical lighting. However it has a huge advantage; the set up of the solar canopy allows it to reduce the power consumption for lighting by as much as 25-30%. Being a product that was developed and manufactured on the UBC campus it would only be fitting that it be integrated into the new student union building on that very campus.

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