Sustainable lighting system for Raymound building

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4/8/2011

Task divisions

Overall design -------------Zhao and Zara
Simulation   ---------------Zara
Calculation of tube size---- Zara
Calculation of sphere size --Zhao and Zara
Materials ----------------- Zhao
Drawing -------------------- Zhao and Zara
Economical analysis ---------Zhao and Zara
Write up --------------------Zhao and zara

Executive summary

Raymound buillding located on the Macdonald Campus of McGill is a historical site. Despite the age of the building some aspects of the building have been renovated to keep up with regulations. One renovation has been overlooked. This is the lighting system, therefore our design focuses on providing raymound building specifically room R4-045, R3 – 048 and R2- 0 45 with sustainable light. Our technique invovles the use of direct sunlight as the power source of the entire system. The design is composed of three sections; solar collector, solar transport system and distribution system. The following report will dicuss the technical aspects, tests complied with the use of Ecotect, as well as a cost of the overall design.

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Introduction

In times where demands for energy consumption is increasing the need for alternative sources and practices are becoming compulsory. Buildings use up to 40% of the world's energy, and most of it used is for artificial lighting [1]. The problem of over consumption of energy is due to the either the inconsiderate behavior or scarce awareness of the building inhabitants, or the building operators [1]. One of the most abundant clean and renewable resources is sunlight. Sunlight is already used to power photovoltaic cells, used for passive heating of water, and other systems. In a similar manner sustainable solar systems can be used to provide healthful visible light in a specified area or multiple areas.

Some benefits of sunlight systems include promoting energy conservation. Since artificial light is powered from electricity then carbon foot print can be reduced with the use of sunlight systems for lighting and other purposes[6]. Government incentive is always the driving force for big investment in areas that promote energy conservation. Most of the energy conservation techniques are founded to some extent by the government. For eaxmple an American company called Solatube Inc. has an energy star rating, and through gouvernment inicitives got more publicity of the company as well as increased pubilicity for its products [5].

Electrical light is accountable for a major fraction of the electrical consumption with in non- residential buildings therefore another benefit of sunlight systems includes reducing operational costs [7]. This is because by introducing more natural light in a selected area the need to utilize artificial light decreases; in addition, when more natural sunlight is available less light fixtures are needs, as well as less investment to operate artificial light; For example less investment in light bulbs, LED light bulbs and overall less light fixtures.

Studies have shown that sunlight is necessary for all life forms on earth including human beings [1]. Sunlight is used to treat depression, is also needed to produce vitamin D as well as provide other health. Another benefit of sunlight tubes is that natural light allows for increased productivity [1]. This is basically due to psychological perception of the flowing for time, which is not experienced in locations where only artificial light is available [1]. Contribution of sunlight in an indoor environment can greatly increase the visual comfort [2].

Another benefit of sunlight systems is that it stimulates innovations for example "solar blinds, novel glazing or coating materials and sunlight-redirecting devices, whose directional properties need to be assessed accurately to allow their efficient integration into buildings and to benefit from their potential as energy-efficient strategies" [2]. Innovation also tends to form new industries which are good for economy.

Daylight system use windows, skylights, or light pipes to expose an area with sunlight to reduce the dependability of electrical lighting systems [1]. Traditional light pipes transmit natural sunlight from the point of collection located commonly on the rooftop of buildings, or external walls, to areas where sunlight is scarce[1]. Essentially our goal is to develop a design that will integrate daylight systems into the exsisting infrastructure of raymound building. The targeted areas are R4 – 045, R3-048, and R2- 045.

Some of the design paramerters include the inconsistency of the sunlight availability. Meaning as the year progresses, the earth receives different sun irradiance[8]. Another is that the system depends on the geographical location. Weather conditions, such as cloud cover, rain and snow can obstruct the amount of sunlight entering the system. Even dust and bird secretions can limit the amount of sunlight.

Design

The components of the system has gone through some major changes since the last purposal of the double light tube. This new plan is designed for the purpose to optimize the amountof sun transfered into the system as well as maximum anount of light transported for rooms R4- 045, R3- 048, R3- 0 45. A schematic of the whole design is shown (see figure 1). The solar capture system setting on the top of the building roof soecifically 1 m. The solar transfer system supports the solar capture system which travels along the vertical wall of the building and transfers the sunlight to the distribution system which is located in the ceiling of each floor.

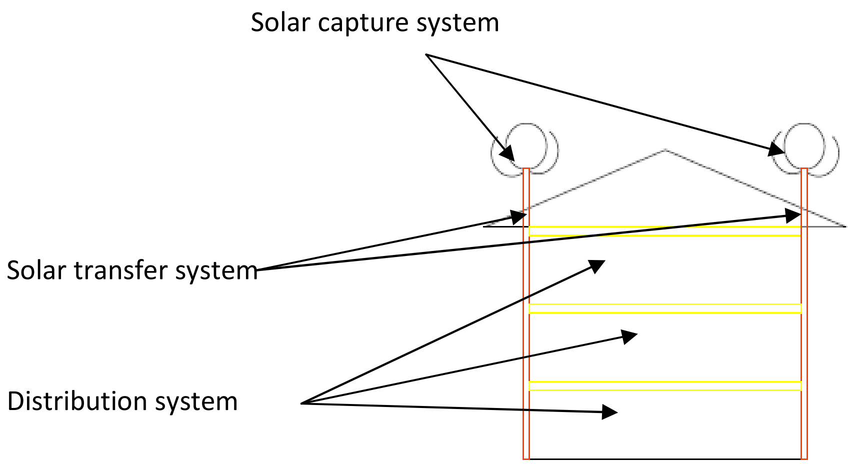

Figure 1: Shematic of the sustainble lighting system

Solar capture system:

The solar capture is the first part of the system. This apparatus is used to introduce the light into the rest of the system. This is an important stage," because it allows to have a major or minus availability of natural light, depending on its acceptance capability of sun radiations"[9]. Some different designs of light capture devies include mobility while some are fixed [1]. Pur design incorporates both type of systems, where one component is stationary and the other mobile. This component of the system is inspired by the behaviour of sunflowers due to the shape and the similar function of the sunflower. This was purposly conducted to gain as much sunlight sunlight as plausible. This component is nicknamed to be the flower and will be reffered to as such.

At the center of the flower is a sphere which has the sole purpose to admit sunlight into the rest of the system. As for petals of the flower surrounded the sphere these pivit up and down through out the day to get the optimum amount of sunlight. During bad wheather conditions these petals will completely closed so the the mirrors are not damages and the extra weight of the snow does not damage the motors that pivit the petals.

In order to completely sheild the whole surface of the sphere from the bad weather, the curve of the petals should be equal to the curve of the sphere. One piece of transfer aluminum pipe supportsthe ball and four petals. Considering the wind pressure and the weight of the apparatus, needs to be bolted. Fiber glass will be used to insulate the aluminum pipe located exterior to the building. The rough solar capture schematic is shown (see Figure 2, also see appendex figure 6).

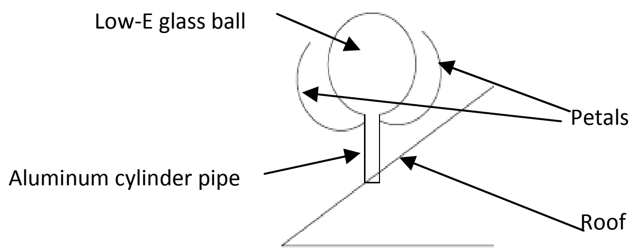

Figure 2: Rough schematic of solar capture

The main part of is a ball in the center of the capture system. The function of the ball is about absorb the optimum amount of sunlight. In order to realize the function, materials need high solar transmission and insulation properties also required for the cold region such as Saint- Anne – de – Bellevue. Low-E glass is suitable for our design, where E is mean emissivity. Emissivity defined by Webster's Seventh New Collegiate Dictionary as "the relative power of a surface to emit heat by radiation." Emit means to "throw or give off." Obviously, low-E glass has a low rate of emission, which provide insulation against heat and cold but allows solar energy gain. In addition, low-E glass reduces the U- factor by suppressing radiative heat flow and transparent to transfer visible light. U-factor is one of the main indexes for the low-E glass, and it measures the heat transfer rate from the material. When comparing the three main types of the low-E glass these are high solar gain, moderate solar gain and low solar gain. For our design it is favourable to obtain the high solar gain, since MacDonald Campus located in the cold region [2]. Double-Glazed with High-Solar-Gain Low-E Glass is chosen in our design, the properties of this material include that U-factor=0.29, solar heat gain transmitted (SHGC) = 0.71, and visible light transmitted (VT) = 0.75, which type of glass performed better in the winter, since long winter period in Montreal, this type of glass is suitable.

The petals of the "flower" design help to capture more sunlight and also protect the center ball during the bad weather. The shape of the petals illustrate (see Figure 3 in appendex). Each of the petals control by Photosynthetic Light (PAR) Smart Sensor which can measure the light range that effects photosynthesis and some additional accessories can be combined according to the requirement of the customers. According to the mechanics analysis, small motors which can shift 14lb are chosen to motive the petals. Petals can be bended in different angles to catch the maximum sunlight according to smart senor. The material used for the petals is called. Silver mirrors have a high reflecting rate is about 92% which helps reflect sunlight to the "center ball". Silver mirror has a long life span and can protect the sphere because this material is not easily oxidized and can be resistant to corrosion as well as humidity. Silver mirror also easy to handle therefore costomization of the material is plausible.

Solar transfer system

The purpose of the transfer system is to transmit sunlight from a lighting source to a point at some distance with minimum losses and low cost. The traditional light tube is one that simply a method of transporting light where there is an insignificant amount of sunlight or in locations where sunlight is nonexistent [9]. This component is a simple tube coated with a reflective material. There are many shapes that can be utilized for this purpose. For example light pipes triangular, rectangular, rhombic and hexagonal cross sections[10]. Avoiding to the lighting ray influenced at the transfer pipe curve, a cylinder shape will be choose for transfer system.

In order to realize the transfer system, some requirement of the material should be include: desired a high light reflective coefficiency and refractive index, no haze factors which impact human health, in addition, the price of the materials also should be considered. The material has high reflective coefficient in order to reduce the loss of light during the transmission process. 5052 Aluminum is one of the cheapest and common materials used in transfer pipe due to its good properties such as good strength, good erosion resistance and easy form performance. When compared with the other materials such as silver, aluminum has a very relative high performance and low cost[11]. The high reflective coefficient of aluminum allow transfer pipe direct and diffuse light coming from light source to the diffuser. Figure 4 illustrates the transfer system and the distribution system.

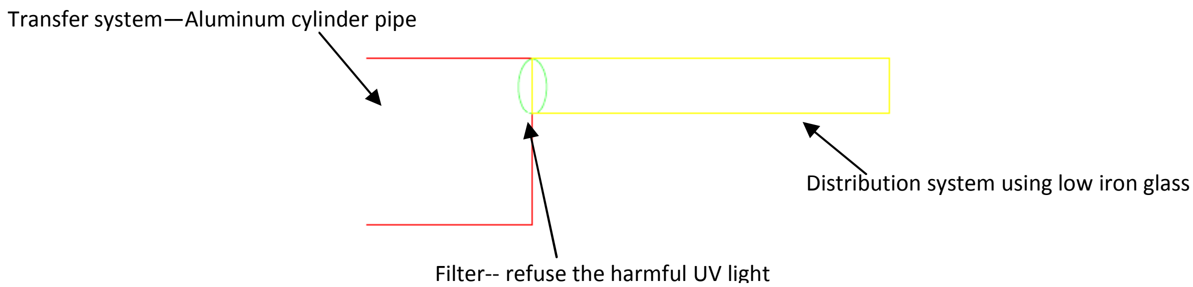

Figure 3: transfer system and the distribution system

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Distribution system

Distribution is very important part in our design. Our original design called for pipe length to be 3 m for each floor. So then the design was that R4-045 and R3 -048 will have pipes that will carry light vertically down from the ceiling to the floor. This was not plausible considering the results of the calculation. I.e. there was just not enough space to put the tube inside the room, with the amount of light we needed to suplly (see appendex figures 8 and 9 for various alterations conducted to the double light pipe). Then only place in the rooms that had enough space to put the tubes was horzontaly along the ceiling instead of verticle from ceiling to floor . Before design the distribution system, we consulted to the optical fiber lighting system which can only carry the light but not create light. It is only a lighting transmitted media. But the material was to expensive for the quantities we required. So we made our own, by using the same materials a fiber optic cable will have but bigger, so that we reduce the cost of many optical fibers.

The improved clarity of low iron glass is very suitable for our design, which has ultra clear property and provides a higher degree of transparency. This optimum clarity is achieved by removing most of the iron oxide content used to produce glass. Flat Glass Company (http://www.zjfmg.com/en/product.htm) provides a type of glass called "super white pattern glass" which has light transmission is greater than 92%. Using this kind of glass, distribution system can supply mostly light from the transfer system. In order to eye's health, we add a small piece of filter between the transfer system and distribution system, which can refuse the harmful sunlight coming into the distribution system in order to protect the human eyes. Since the life span of the filter is shorter than other materials, we need to change the filter at least one month; therefore, a small piece of removable part should be fixed on the distribution system where also need to easy touch the filter part.

Methods

For proper desgining of the system it is important to understand the limitations of the various parameters that will affect the system. Our system depends on the availability of sunlight w hich unpredicatblem , and is both time and position varying. The maximum amount of sunlight an area on earth gets is when the sun is right above the desired area. In our case when the sun is direcllt above Saint Anne – de - Bellevue that is when the maximum anount of sunlight is achieved.

Then the the mathematical law known as the Inverse Square Law (see equation 1) for light intensity illustrates that the light intensity reduced as the square of the distance from the lighting source [3].

$$E = \frac{I}{r^2} \quad \text{(equation 1)}$$

Other equations such as reflective law and Snell's law (see equation 2) show the light behavior when ray transferred in solar transfer system [12]

$$\frac{sin\theta_1}{V_{L_1}} = \frac{sin\theta_2}{V_{L_2}}$$

Ecotect is suitable software to simulate whole system and also help to analysis the final results. In addition, basic mechanisms help to test and determine the size of the system. Safety factor makes the analysis more security in the calculation of our design according to unexpected weather conditions.

It is also well understood that the light intensity that reaches the surface of the earth is 168W/m2 [13]. Due to light's heavy independence it is necessary to consider the elevation of montreal needs to be taken into consideration since there are no elevation values of Saint –Anne – de – Bellevue is available. The elevation of montreal according to environment canada of the McGill weather observatory is 45.5° [14]. It also needs to be noted that only 40% of the sunlight is visible light [13].

Calculations

Please refer to the excel spread attached for further details on the calculations conducted. A summary of the results are shown (see tables 1 – 3)

Table 1: General requirements of the rooms

Room	Area (m^2)	Height of room (m)	Standard light Intensity (W/m^2)	Light required (W)	Amount of light targeted (W)
R4-045	78.70	3	1.3	103	154
R3-048	71.88	3	1.3	94	141
R2-045	135.42	3	1.3	177	266

Table 2: General considerations made for the calculations

Considerations	Values
Amount of light absorbed by Earth's surface	168 W/m^2
Amount of sunlight due to Montreal's elevation (45.3°)	117.7 W/m^2
40% of sunlight is visible light	47 W/m^2
75% of Visible light is absorbed through the low –e glass sphere	35.31 W/m^2

Table 3: General results of the tube size for different rooms

Room	Distance (m)	Irradiance (w)	Light needed at entry point (W)	Light required (W)	Diameter required for 6 tubes (cm)
R4-045	4	2.21	204	154	18.86
R3-048	7	0.72	190	141	10.25
R3-045	10	0.35	325	266	11.82

The value of 6 tubes was decided because we thaught it would give an even distribution. Testing through simulation will provide a good determination as to how many light tubes will be sufficient.

Simulations

It is necessary to test one's design. Due to financial and time limitations, simulations of the design were conducted. Even so there are computational limitations of dell laptop computers, so analysis of only one floor could be completed. Despite this there are promising results and further testing would be required.

The dayight analysis was conducted using an autodesk aplication called Ecotect. This program is used for both sound and light analysis. The figures bellow (see figure 4) shows the results for the room R4- 045. The figure 4 displays the best result achieved after various trials. As can be seen the simulation result shows that 5 tubes will be enough to light the room, instead of 6. This will reduce the cost of the final design.

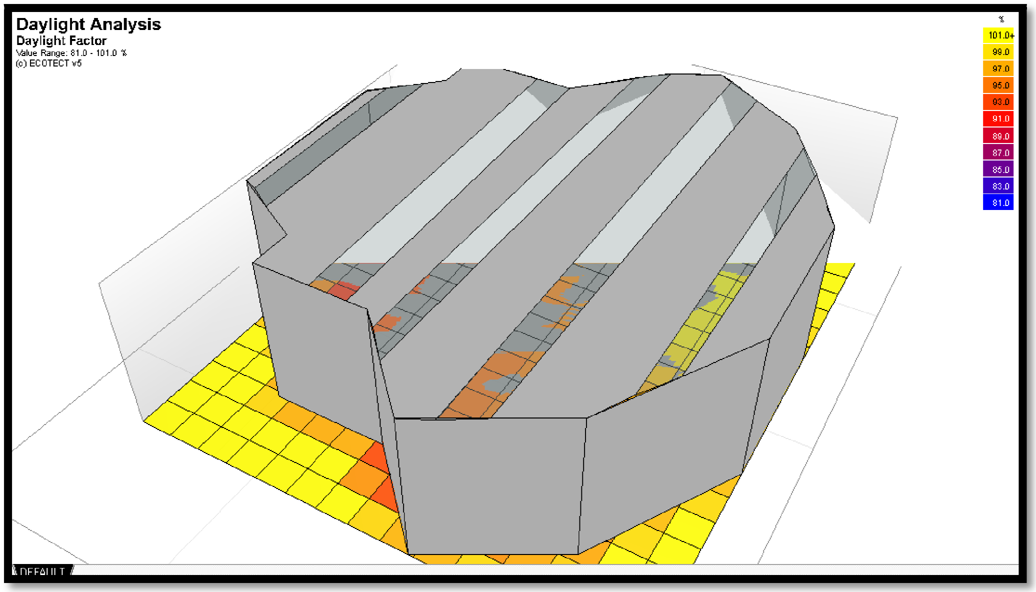

Figure 4: 3D Simulated rendering of the final design for R4-045

The second figure here shows the contour mapping conducted to understand the dispersion of daylight. This shows that the back of the room obtains the most light and decrease as one gets close to the door which is what we anticipated, due to the geometry of the location.

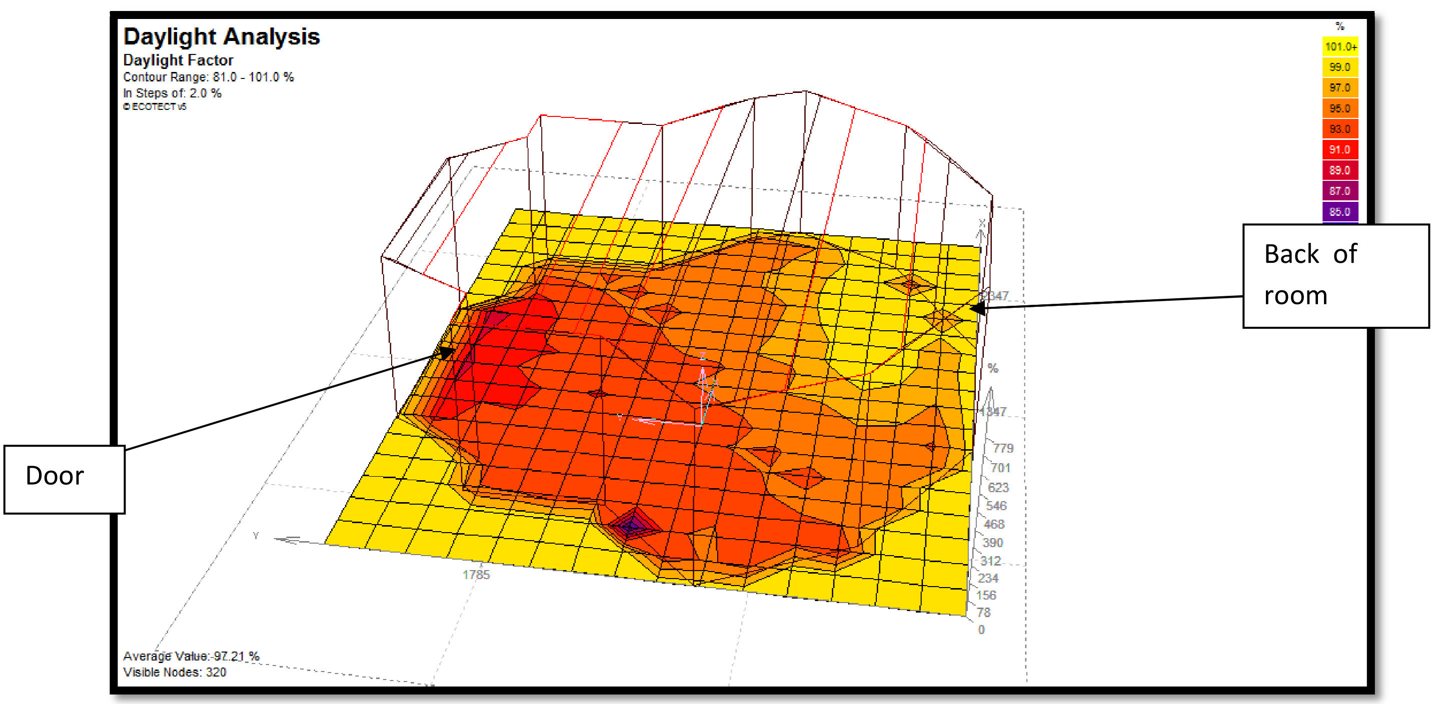

Figure 5: Contour result of the final design for R4- 045

Cost analysis

The cost analysis is also completed on the attached excel sheet please refer for further details. A summary of the results is shown (see table 4)

Table 4: initial cost analysis of Materials and insulation

materials	Quantity	Price	Total price
Aluminum 5052 - H32	105	135	14175
Low -E - glass ($/m2)	0.413	300	123.9
Mirror	0.5	117	58.5
Ultra white pattern glass			1360
Filter ($/each)	5	2.5	12.5
motor ($/each)	15	25	375
photosynthetic light (PAR) smart sensor ($/each)	15	300	4500
Fiber glass ($/m)	1	8.24	8.24
diffuser ($/each)	15	34	510
Labor cost ($/ h)	5	10	6000
total			27123.14
taxes			2305.4669
total cost after taxes			29428.6069

Results and Conclusion

Our original design of using double light pipes (i.e. two co-centric pipes) where the inner pipe was aluminum and the outer pipe was a transprent material. After various calculations for this design it was considered as unfeasible for the space it was being designed for. The double light pipe design would be better applied to open spaces such as a library or open concept offices.

In this paper, we design a system that can transfer the sunlight through solar transfer system to a place where natural light cannot be directly exposed. There are three main parts of our design: solar capture system, solar transfer system and distribution system. In the solar capture system part, we design a "flower" shaped device that can gain the natural sunlight and then transfer sunlight to the transfer system. Additional parts of the capture system can help capture more sunlight to the transfer system. In transfer system, we plan to use build a simple cylinder pipe which admits the light transfer from solar capture system to a distribution system. The distribution system needs enough space for settling the system.

We provided our design for the Raymond building where located in McDonald campus in Montreal region. Decided the proper size of the system by using some mathematical theorems and mechanical analysis also be illustrated in the paper. Simulated the whole system for R4-045 room by Ecotect, and get the daylight distribution graph. The initial cost of the system is expensive, but it promotes the use of clean energy. As well as the option for integrating different systems such as integration of LED systems and solar panels when there is not enough sunlight in bad weather. Our design about sustainable lighting system is not only for energy conservation but also good for environment and human health.

Reference

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Appendex

Vairables

$L = \text{ the intensity in} \frac{W}{m2}$
$r = \text{ the prependicular distance from the point source } (m)$
E=*irradiance at distance* r (W)
V_{L_1} *is the longitudinal wave velocity in material* 1 (m)
V_{L_2} *is the longitudinal wave velocity in material* 2 (m)

θ_1 *is the angle of incident* (°)
θ_2 *is the angle of refracted* (°)

Figures

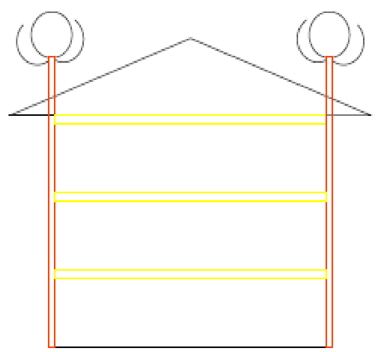

Figure 6: Shematic of the sustainble lighting system

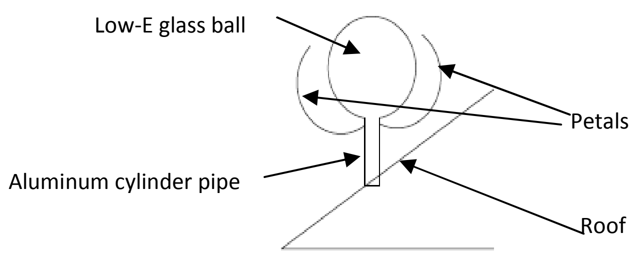

Figure 7: Rough schematic of solar capture

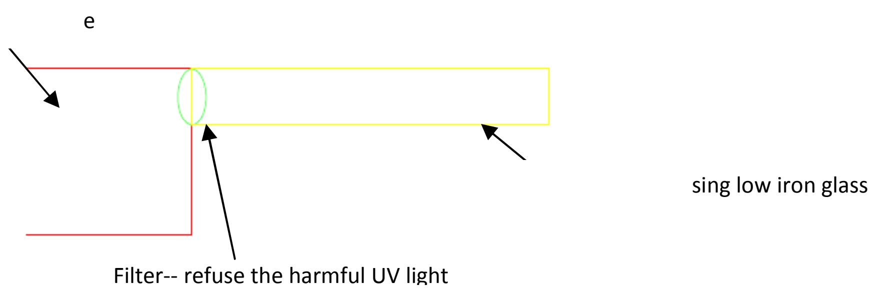

Figure 8: transfer system and the distribution system

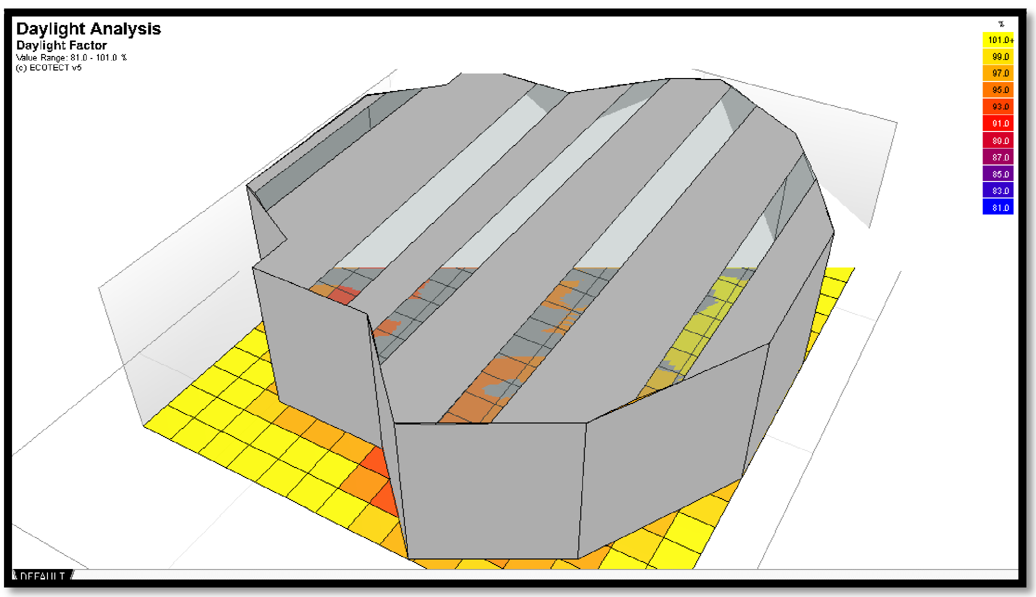

Figure 9: 3D Simulated rendering of the final design for R4-045

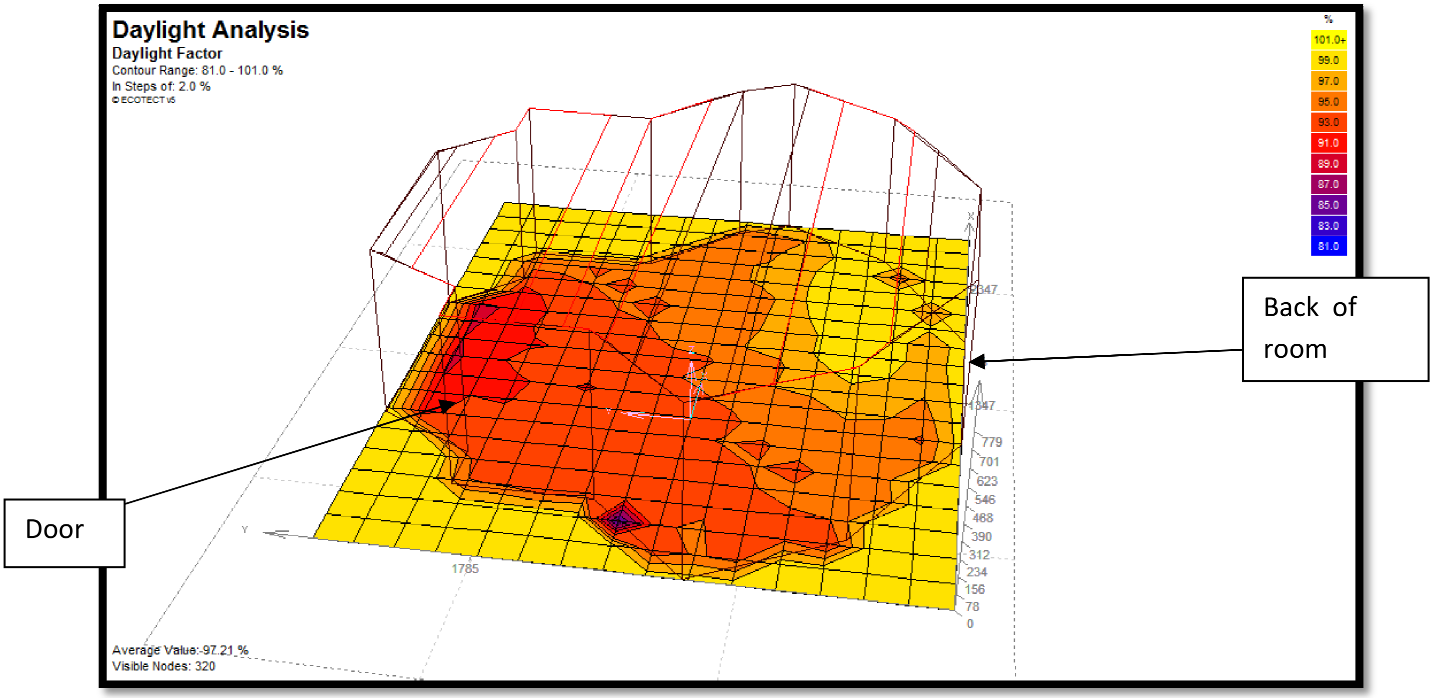

Figure 10: Contour result of the final design for R4- 045

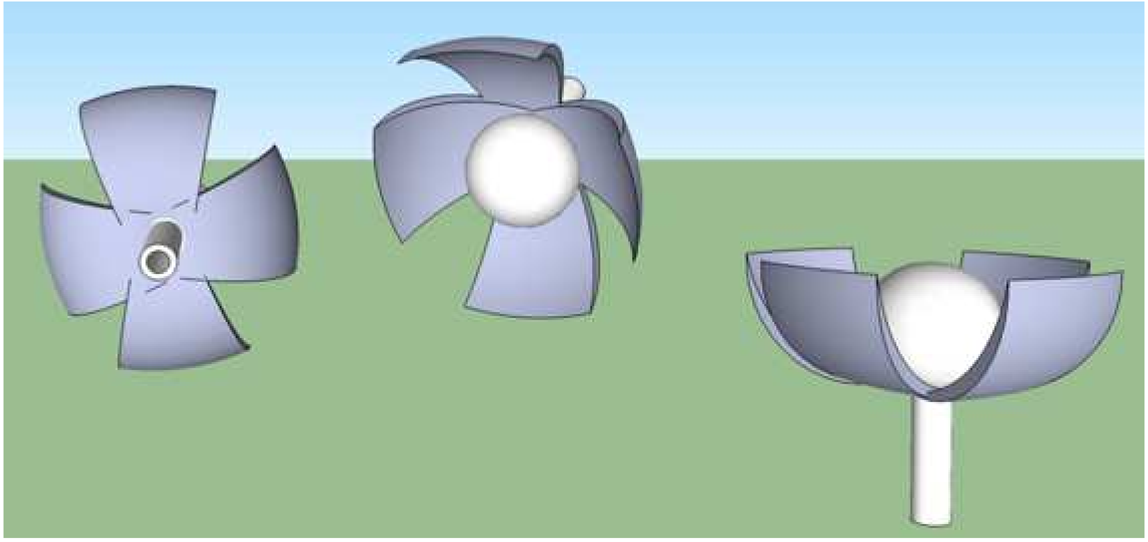

Figure 11: Solar capture, flower system

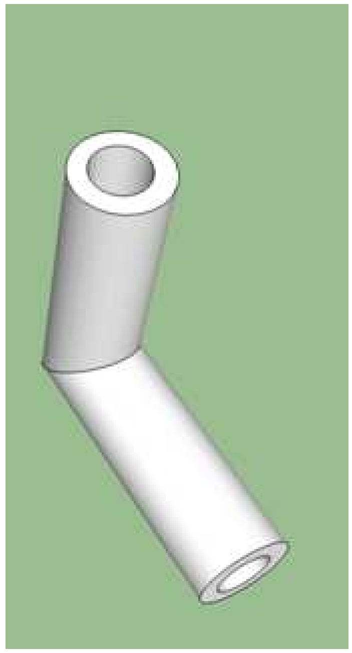

Figure 12: transfer system, the verticle pipe is the aluminum pipe comming transfering the light down and the verticle tube is what distributes the light into the room

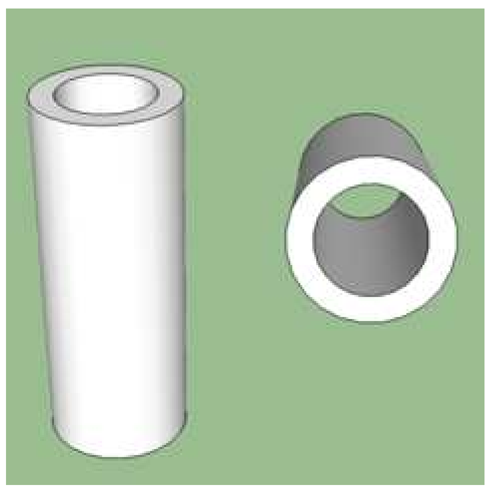

Figure 13: double light tube wit the inner aluminum tube height 3m and the external pipe to be 3 m

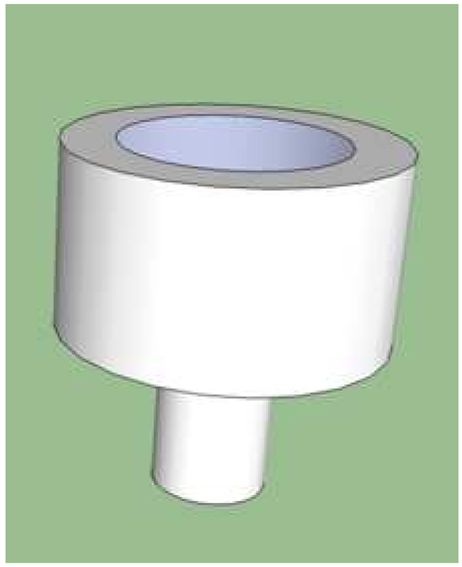

Figure 14: double light pipe where the transparent part of the tube is only 1 m long, and the aluminum pipe is 3 m long

Aknowledgement : We would like to offer a special thank you to all those people who helped us with this project

Dr. Grant
Dr. Conor Sampson
Danilio Aquino