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Luminous – A Solar Tube Lighting Device

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ABSTRACT

In a questofsubstitutes to reduce the consumption of electric energy, the probability of using natural light for lighting through Tubular Daylight Devices (TDD) or Tubular Daylight Guidance Systems (TDGS) appears. These natural luminaires are used in rooms where you want to conserve electricity and relish the comfort of natural light. Because the world's population is growing at an alarming rate, so is the need for essentials. Food, clothes, and shelter are examples of requirements. The biggest difficulty that the government is facing is the rising demand for electricity generation for the whole population, which is required for any country to be labelled a developed nation. The need for shelter is being supplied by a very high rate of colonization, which, if not well regulated, would result in a loss in net sown area, increasing deforestation, and a variety of ecological issues. As a result, the trend is to construct multi-story structures on a relatively tiny plot of ground. It has been noted that buildings in metropolitan cities are relatively near to one another and are not always correctly aligned to the sun. Again, in the modern period, building is done underground, such as the ones employed in universities to build libraries, laboratories, and metro stations. As a result, even during the day, the interior of the structure stays gloomy. As a result, a lot of energy (electrical) is squandered to provide the illumination in the structure throughout the day. So, in this paper, an effort was made to design and execute a system that will outplace present day lighting systems except spending a fortune. As a result, a large quantity of power is required in order to have vision during the day. This power use is wasteful and may be eliminated by using natural light (solar energy) to generate energy to power the bulbs, tube lights, and other lights. Using natural light (solar light) directly by directing it to the interior of a structure or room. This is known as solar tubes, and it is a very simple and cost-effective concept.

Keywords: Tubular Daylight Devices (TDD), Tubular Daylight Guidance Systems (TDGS), Power Consumption, Solar Tubes, Electricity, Solar Energy.

1. INTRODUCTION

Existing energy sources, such as coal, oil, and natural gas, are insufficient to fulfil escalating needs. These, too, are decreasing, and they may be depleted by the end of the century or the start of the next. Power generation in India is now mostly based on nonrenewable energy resources [1]. Coal, petroleum, and other nonrenewable energy resources are examples. The following is a breakdown of the various resources' contributions to power generation [2]:

1) Thermal power generation – 73%
2) Hydroelectric power plants – 21%
3) Nuclear power plants – 1%
4) Others – 5%

It is easy to see how increasing the contribution of alternative power sources will reduce the load on their non-renewable equivalents. In addition, there were several substitutes to traditional day lighting systems, one of which was the solar tube [3].

A. Solar Tube

A solar tube, also known as a light tube or a light pipe, is a device used to convey or distribute natural or artificial light. They are also known as daylight pipes, solar light pipes, sun scopes or sun pipes when used for day illumination.

A solar tube can refer to any of the following:

1) A tube or pipe used to transfer light from one area to another.
2) A transparent tube or transparent pipe for light distribution across its full length, either for equi-distribution or for regulated light leakage.

A tube made with a highly reflective substance directs light beams through a structure, beginning from abeginning point on the roof or one of its exterior walls. Because a light tube is not meant for imaging, picture distortions are not a concern and, in fact, are encouraged in many ways owing to the decrease of "directed" light. This is an old idea that has been around for a long time. The necessity for various alterations is felt, which will lower theequipment cost. The major goal is to build a highly efficient system that can minimize power usage and must be inexpensive in comparison to other systems. Because the efficiency of light transmission is highest when the tube is short and straight. A portion of the light intensity is lost in longer, angled, or flexible tubes. As a result, the approach of directly utilizing solar light appears to be more beneficial.

B. Necessity of Solar Tube

Because our country's population is growing at a rapid pace, the need for essentials is also growing. The high pace of colonization is meeting the demand for shelter, but if not properly managed, it will result in deforestation and other environmental issues. As a result, the trend is to construct multi-story structures on a small plot of ground.

It has been noted that buildings in metropolitan cities are relatively near to one another and are not always correctly aligned to the sun. Again, in the modern period, building is done underground, such as the ones employed in universities to build libraries, laboratories, and metro stations. As a result, even during the day, the interior of the structure stays gloomy. As a result, a lot of energy (electrical) is squandered to provide the illumination in the structure throughout the day. So, in this project, an effortwas made to design and execute a system that would replace current day lighting systems without spending any expertise. As a result, a large quantity of power is required in order to have vision during the day. Existing energy sources are insufficient to fulfil the escalating demands. These, too, are decreasing and may be depleted by the end of the century or may be from the beginning of the next. Power generation in India today is primarily based on nonrenewable energy resources. It is easy to see how increasing the contribution of alternative power sources reduces the load on their non-renewable equivalents. So, this is the primary goal of completing this project[4].

2. METHODOLOGY

The following graphic depicts the basic schematic architecture of a standard solar tube system:

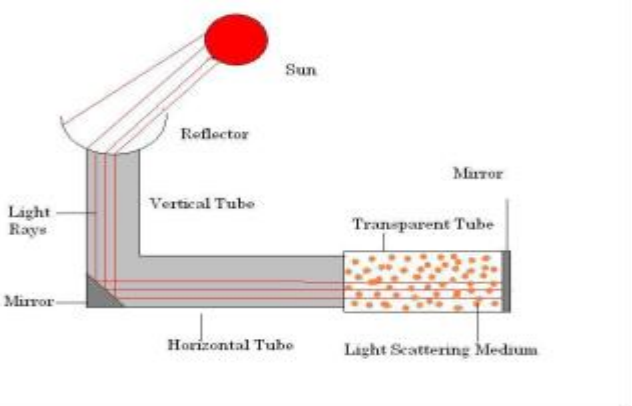

Figure 1: The Schematic Diagram of a Traditional Solar Tube System.

The design of solar tube includes the following parts:

1) PVC tubing.
2) Mirror systems.
3) Transparent tubing.
4) A dome.

A PVC tube with a diameter of around 3.5 inches is used. The tube's length is restricted at around 2.5 feet. To a considerable degree, the intensity of light reaching inside the room is determined by the length of the tube. Even though the length is not modified significantly, the intensity decreases significantly. To reduce deformation caused by high temperatures, the tube is made of high-quality PVC. The tube must remain straight for a big amount of light to enter the room. The glossy metal sheets are fitted inside the tube to correctly reflect the light rays falling on the inside of the tube. Aluminum foil paper with a gauge of 36 is used for this. The sheet has been rolled to the appropriate diameter before being put into the tube. An elbow is placed at one end of this tube, which will be held against the wall. This elbow has been covered with aluminium foil, which is commonly used to wrap food. A flat plane mirror tilted at an angle of 45^0 in the elbow deflects incident light radiations (light rays) into a linear beam of light. This light beam is expected to be almost straight and then go into the tube. Similarly, at the opposite end of the tube, a second 450 elbow and a diffuser are employed to evenly spread the sun's rays in a restricted space[5].

The PVC tube is held in place by inserting one end into the hole bored into the room's wall. Similarly, a transparent tube with a closed or concluded end projects into the room. The transparent tube's closed end is made up of a convex mirror that is bonded to the base of tube in such a manner that it always faces the light ray or beam of light axially. Clay was used for the gluing. This will aid in diverging the light through the glass tube and onto the reflector, which will help to reflect the light throughout most of the room. The reflector is installed on the clear tube near to the wall, and a piece is also thrust into the PVC pipe. These systems were built individually and are integrated in such a way that the desired system is produced. The figure depicts how they are arranged. The entire setup is designed to brighten a classroom.

A. Dome

Figure 2: Dome or Reflector

The Dome is basically an outdoor unit which is also called as reflector. It is hemispheric in shape and made up of glass, polycarbonate or the composite of both. It is designed in such a way that when the sun rays fall on its surface at any angle it deflects these rays perpendicular to the axis of the dome. This is placed on the roof of the small house or a building.

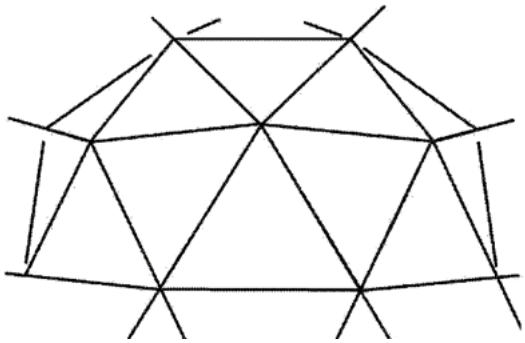

Figure 3: Dome Design Layout (2D)

There have been many developments in reflecting type solar collectors such as parabolic Solar collectors. These types of collectors, however, would require the solar collector system to tilt at differing angles depending on the position of the Sun at a given time and date. A Solar collector system designed as a dome-structure would be stationary, regardless of the time of day or the position of the sun.

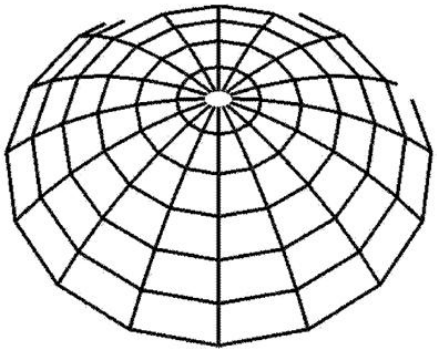

Figure 4: Dome Shape

This method presents an alternative solution for cap turning the Solar resource with a stationary dome or cone shaped solar collector system composed of linked converging lenses, which concentrate the solar energy into specific focal points in the tube.

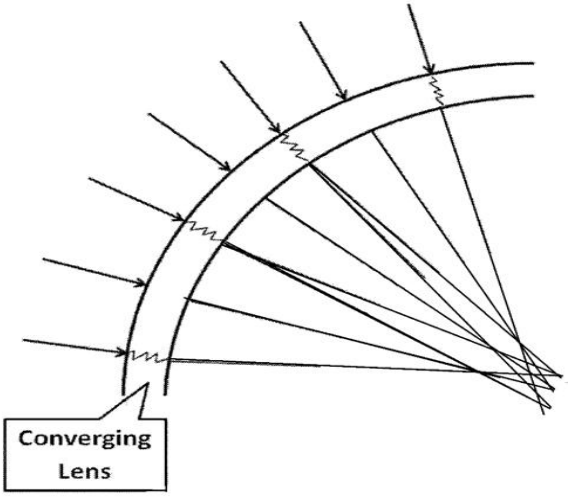

Figure 5: Converging Lens

As the sun's rays hit the surface of the solar dome, the converging lenses refract and focus the Solar energy onto specific points inside the Solar dome. Depending on the location where the solar collector system is installed, the layout of the linked converging lenses may be arranged into a dome shape, as shown in Fig 5.

B. Diffuser

Figure 6: Diffuser

The Diffuser is basically an indoor unit of this system. It is the device which is used to distribute the light rays in a confined space in which we want illumination. This device is made up of polycarbonate material which is transparent as well as it works as an insulating device which prevents heat from reaching inside of a confined space. The diffusers are used to prevent glare and makes sure light is spread evenly across all interior space. This device controls the amount of light required in a confined space.The inner part of the transparent tube is made up of a light scattering medium, which scatters light and is responsible for the brightness of the room. Plastic optical fibers, illuminators are best examples of light scattering materials for transmitting and scattering light also light scattering materials of metal dispersion system are used in most of them.

C. Vertical Tubing

It must feature at a kea way channel through which light ray may pass at a faster pace with little loss of energy and intensity. To achieve a high efficiency, the tube might be simple or complicated. This section is crucial and may be configured in the following ways: - The tube can be made of PVC or plastic, making the configuration as straightforward as a periscope. The basic goal of using this configuration is to convey a straight beam of light through the tube. Furthermore, this is a less expensive option. Figure 5 depicts a schematic of this configuration. The tube might work as an optical fiber that operates on total internal reflection. This will be a more expensive setup than the previous one. Although the arrangement is straightforward once again, there is one major issue connected with it: light must always go from the denser to the rarer medium[6].

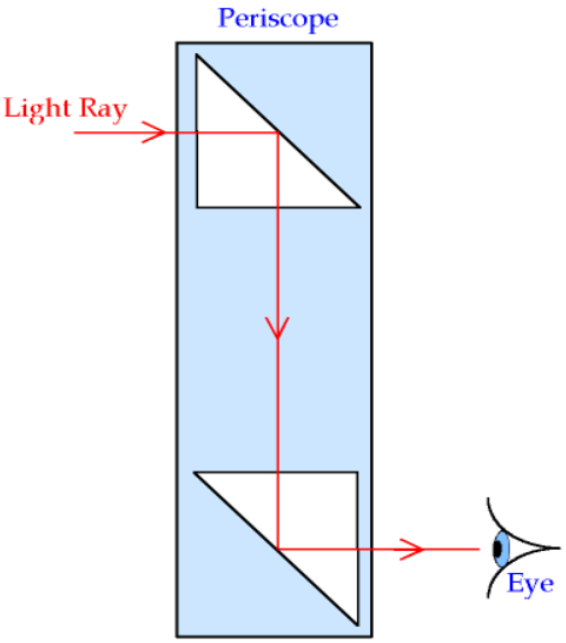

Figure 7: Periscope's Schematic View with Two Prims

D. Horizontal Tube

This is an alternate vertical tube configuration to be used in conjunction with the first substitute arrangement and may not be utilized while the preceding arrangement is in operation. This configuration allows light ray (light beam) to flow forward for illumination, making the project more cost-effective as well less costly, and the tube must be constructed of PVC or plastic.

E. Mirror

In between the horizontal and vertical tubes, a plane mirror inclined at a 45-degree angle with the horizontal might be used. The mirror is used to swap the path of light and so plays a significant role. This confirm that the light reflected by the mirror continues to move in a horizontal direction. There might be a variant layout that employs a prism (rectangular) with various characteristics. Figure 4 displays a mirror image of this setup.

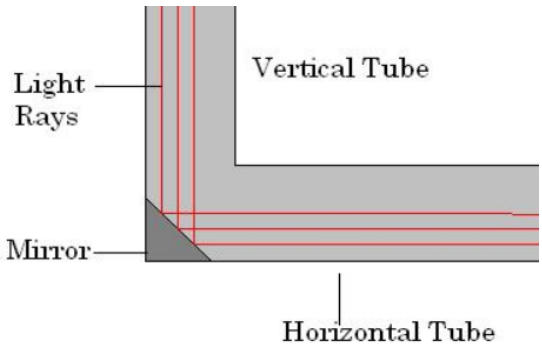

Figure 8: The Horizontal & Vertical Tubes in a Mirrored Arrangement

F. Other Components

The flat plates that will be assist to produce a vacuum in the horizontal and vertical tubes might be among the remaining components. This might also aid in the retention of the light scattering medium within the transparent section. The preparations to sustain the solar tubes both inside and outside the room might be among the other components. Additionally, there will be a plan in place to provide illumination during the night. Solar panels with photovoltaic cells, batteries, and the accompanying wiring are examples of such equipment. A solar tube is made up of the following components:

1) A collector or dome.
2) A PVC pipe.
3) A clear glass tube.
4) A plane reflecting glass.
5) A light reflector.
6) An external reflector composed of several tiny planes reflecting glasses bonded to a plane disc [7].

3. LITERATURE REVIEW

- In year 1986, A US author Paul August Jaster invented the first tubular day lighting device. It was very simple to install without structural changes.

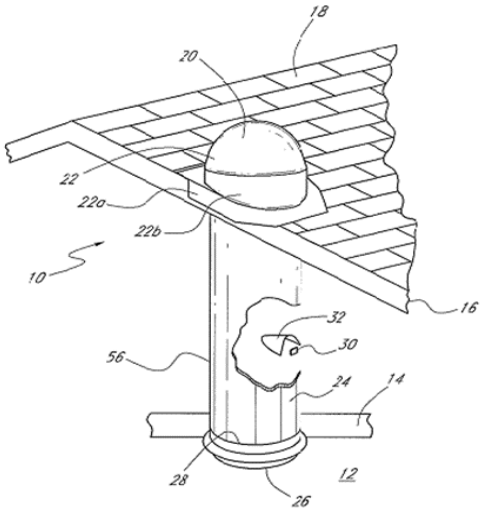

Figure 9: Schematic Diagram of Daylighting Device[8]

later he published an article on 24 February 2011.Auxiliary lighting fixtures with daylighting systems and methods are described. A daylighting device according to certain embodiments disclosed herein includes a tube with a sidewall with a reflective inner surface and an auxiliary or straighten light fixture. The tube can be sandwiched among a transparent cover that receives daylight and a diffuser that is placed within a building's target area. The tube is arranged in certain implementations to guide sunshine passed through the transparent cover towards the diffuse. A lamp minded within the tube and a light control surface composed to reflect light ray exiting the lamp towards the diffuser and to transmit daylight proliferation through the tube from the direction of the transparent cover can be included in the auxiliary light fixture. The lamp can be disposed on the tube's sidewall.

- In March 2010 Mohammed Mayhoub and David j. carder publish an article about the first Hybrid TDD to combine daylighting with LED’s.

Figure 10: Light Guides

Light-reflecting, re-directing, and controlling components have emerged in vernacular architecture. Traditional glass windows may allow light to enter a structure up to 5 meters. However, because sunshine levels decline asymptotically as distance from the window increases, a disproportionate quantity of daylight and accompanying heat gain must be delivered into the front of a room to supply tiny quantities of daylight towards the back. Modern technology limits the efficiency of attempts to divert sunshine to places beyond the building envelope using techniques such as atriums and skylights. Several very efficient reflecting and refractive materials have been discovered during the last 50 years or more, allowing for what has been known as 'light steering.'

4. 3D MODEL

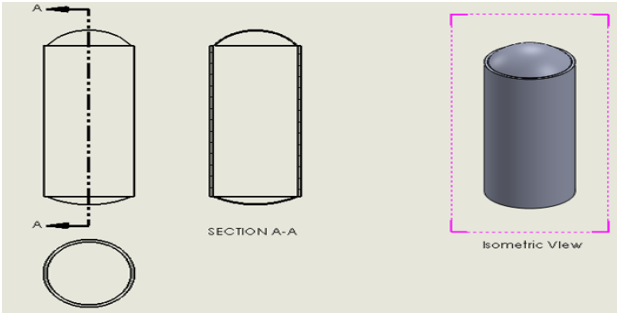

Figure 11: CAD Model

1) After Making a list of all the components in the Solar tube setup, we started developing its 3D model in Solidworks Software.
2) Individual components were made and then assembly of all the components was done to make the final solar tube setup.
3) Then all the components were projected in 2D, so that while manufacturing it will be helpful.

A. Solar Tube Fabrication

The following major steps are involved in the production of a solar tube:

1) PVC tubing
2) Mirror systems fabrication.
3) Manufacturing transparent tubing.
4) Tracking down the collector.
5) Putting the entire arrangement together in one place.

The following steps were completed in the following order:
A PVC tube with a diameter of approximately 3.5 inches is used. The tube's length is maintained at roughly 2.5 feet. To a considerable degree, the length of the tubing determines the intensity of light that reaches the inside of the room. Even when the duration isn't reduced much, the intensity drops significantly. To minimize deformation due to high temperatures, the tube is made of high-quality PVC. The tube must remain straight for a big amount of light to reach the inside of the room. To correctly reflect the ray of light falling on the interior of the tube, the tube is inserted with glossy Aluminum sheets.

For this, aluminium sheet with a gauge of 36 is used. The sheet is placed in the tube once it has been rolled to the required diameter. At one end part(closed part) of this tube, which will be placed against the wall, an elbow is used. This elbow is wrapped in aluminium foil, which is common in food packaging. The elbow is outfitted with a flat plane mirror that is tilted at 45 degrees to divert incident light radiations (light ray) into a linear beam of light. Before going through the tube, this light beam is anticipated to be almost straight. On the opposite end, a clear tube half the length of the tube (PVC pipes) is inserted. The transparent tube is around 68 mm in diameter (external). One end of the tube is closed.

Inserting one end of the PVC tube into the hole drilled into the room's wall secures it in place. The closed end of the translucent tube, on the other hand, extends into the room. The closed or wound up end of the transparent tube is made up of a convex mirror that is connected to base in such a way that it always faces the light in straight path or curve path. The parts were glued together with clay. This will assist to divert light through the transparent tube and onto the reflector, which will reflect light across the whole space. The reflector is attached to the transparent tube near the wall, and a portion is also placed into the PVC pipe. These systems were constructed individually and then put together to create the desired system. The figure depicts how they are arranged. The entire setup is designed to light the plywood-paneled space. The room has a window that allows you to see the room from the front to see if the right quantity of light is leaking in.

B. Preferred Light Layout

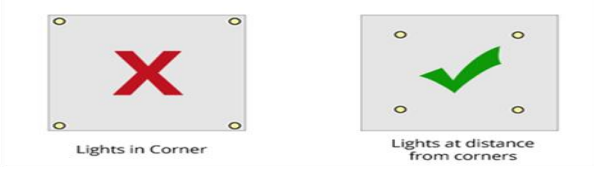

Figure 12: Lighting Arrangement

Lighting design is critical in building projects, and the greatest outcomes are obtained by employing comprehensive lighting calculations rather than "rules of thumb." When opposed to other components such as HVAC equipment and plumbing fixtures, the lighting system is unique since it involves a subjective and artistic dimension. Lighting designs must give enough visibility while also establishing the mood of constructed settings.

C. Deviation from Proposed Arrangement

The planned arrangement was outlined in the project report's opening section. However, we were unable to replicate the arrangement provided during the conception and definition phase throughout the manufacture of the project. Even after adopting various revisions, the goal remained same. During the fabrication stage of the project, the following adjustments were made. The following are some of them:

- First, the vertical or steep tube was illuminated since its inclusion increased transmission deprivations and the intensity of light beam or ray available at the collecting end was inadequate lighting.
- Second, the new system's size was lessening down from 6.5feet to 2.5feet tubing because of non-assimilation of the long vertical or steep tube.
- To transfer light to the exterior, a transparent or crystal-clear hollow glass tube closed rigorously at one end with an outer diameter of 68mm was put in a hollow horizontal PVC tube .
- Following that, contrary to employing a light scattering medium, convex glass was employed due to its simplicity of manufacture, pricing, and other factors. On the convex surface of the convex glass, there is an aluminium coating that acts as a reflecting as well scattering medium. This is used to ensure that the light is oriented correctly. Glass tube also has the advantage of being freely adjustable in length (due to its freedom to move in and out of the horizontal tube). As a result, because lighting is a function of length, the user may control it.
- In the suggested configuration, the flat glass at the end of the light scattering medium has been removed since convex glass has been employed in its stead, as explained above.
- The glass tube was equipped with a German reflector with a 10-inch outer diameter and an open end in front of the lens. It gets light from convex Aluminum coated glass as well as distributed light across the living area. As a result, it aids in the amplification of light dispersion and provides improved lighting throughout.
- Finally, highly good reflecting thin Aluminium sheets are employed to minimize losses caused by the intensity of light transmitted. These are rolled down to the right proportions and then inserted inside the horizontal tube or straight tube over the inside surface over the whole length of the tube. They allow more light to pass through.

5. TESTING

The sun's light is intercepted by a paraboloidal reflector that is manually monitored. Changing the direction of the light reflected changes the intensity of the light reflected. An inclined mirror positioned at a 45-degree angle can catch the reflected light. The light is intercepted by the mirror, which turns it into a parallel beam. This light beam travels axially through a straight or horizontal glass tube within a PVC pipe and falls over a convex mirror at the tube's closed end. The light is reflected or diverted by the convex mirror and reflected by the reflector, lighting the wooden box. To test the brightness of the light, a window is built across face of the reflector from where the box is located. It was determined that around 30% (approximately) of the incident light was collected. Moreover, the user may change the intensity of the light by modifying the length of the transparent glass tube.

A. Cost-effectiveness

Ponder the following cost – effectiveness calculation for a society or community of One thousand (1000) families over the course of 5 years.

Assumptions: -

1) Sunlight is accessible throughout the entire day.
2) The cost of power is set depending on per unit.
3) The maintenance cost is expected to be constant throughout the duration.
4) The cost of maintenance is assumed to be the same as the cost of installation.
5) There is no power outage for the time period specified.

Sunlight is accessible for total time = 10 hours/day

Enlightenment requires a lot of energy. 100× 4 = 400 Watts of electricity = 4 bulbs for this amount of time

Energy waste = 400 Joules/sec

Each day = 3,45,60,000 Joules

Number of electrical units = $[3,45,60,000/(3.6 \times 10^6)] \times 1$ KW h = 9.6 KW h/day

Total electricity units for a year (365days) = 9.6 × 365 = 3504 KW h/year
Cost of this for a society of 1000 dwellings over a five – year period (Rs. 3.50/- per unit)
C = 3504 × 5 × 1000 × 3.5 = Rs 6,13,20,000/-
Cost of (approx.) 1000 solar tubes with installation for 5 years
C1 = (1000× 2000) + (5× 300)× 1000 = Rs 35,00,000

Total saving (percentage) = [(61320000 – 3500000)/61320000] × 100 = 94.29%
Therefore, this system will save around 94.29% of money and may be environmentally benign.

6. ADVANTAGES

- It makes use of an unconventional energy source. This will reduce a family's energy use, at least throughout the day.
- It is a non-polluting source of light.
- It is less expensive in comparison, with a three-year payback time.
- Over-illumination can lead to light pollution, which occurs when unwanted light illuminates the outdoors or other people's property. Over-illumination is usually handled during the building design phase, whereas light pollution is usually addressed by zoning rules. As a result, it aids in the reduction of light pollution[9].

7. APPLICATIONS

1) It is used to illuminate beneath basements in buildings and malls since they are huge and do not allow enough light to enter.
2) It is used to illuminate multi-story parking garages.
3) It's a type of lighting that's employed in libraries.
4) It might be used to illuminate railway stations.
5) It might be used in hotels as well.

8. RESULT

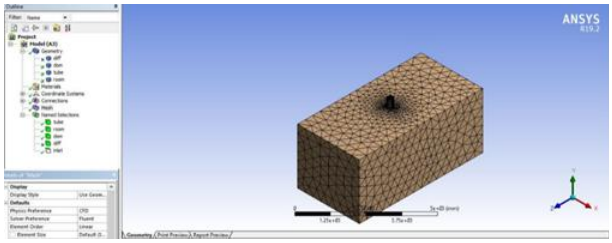

Figure 13: Geometry & Meshing

Above figure shows the components of solar tube which inserted inside the rectangular room created to analyze the room temperature. The outer material of tube is taken Polyvinyl chloride (PVC) and Aluminium is internally layered for the reflectivity of the sunrays. PVC is very light weight also its thermal conductivity is very low, and Aluminium has 88% of reflectivity. The Wall surrounded by all sides is concrete for close reflection between them.

Dome & Diffuser (Inlet & Outlet) has given Polycarbonate plastic material for better insulation purpose as well to distribute the light evenly across the room.

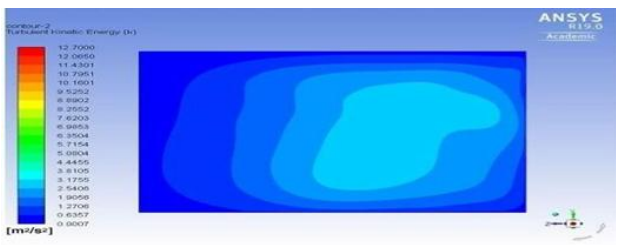

Figure 14: Before Reflection of Light

Above figure shows that the color represents which is dull blue means there is no light transfer in the interior of the room. At the beginning the room is kept at the 27 degree (Normal Room Temperature).

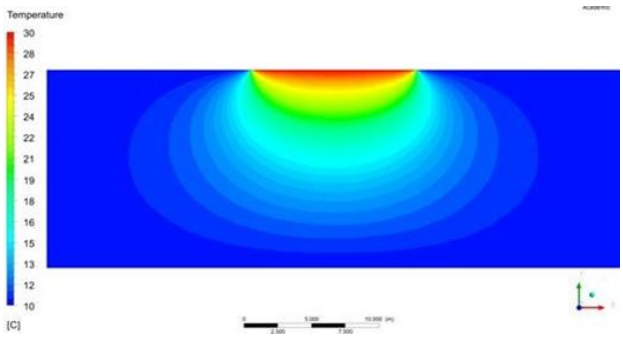

Figure 15: Light Transferring

Above figure shows the light (Sunrays) has started to enter the dome into tube and getting reflected inside tube to diffuser which is transferring in the interior of the room. (In Centralized way from top to bottom).

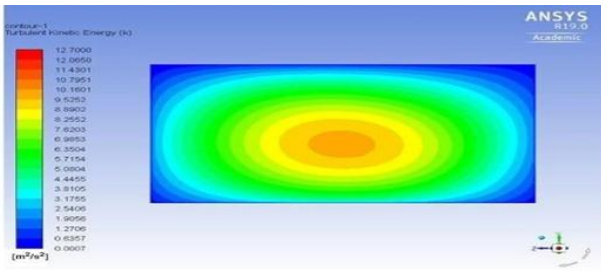

Figure 16: After Reflection of Light

Above figure shows that the room has fully enlightened with light. As bright yellow color is fascinated at the center of the room and has expanded evenly across the interior of the room.

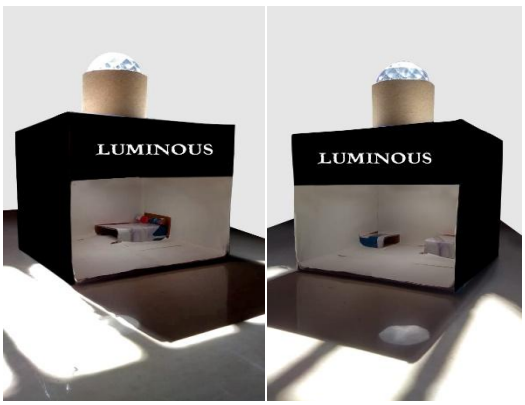

Figure 17: Miniature Model

The experimental setup (with dome and diffuser) and experimental room clearly states that the intensity of the light beam (sunrays) fallen over the dome and gets reflected as well transferred to the diffuser shows how's the light going to give us the illuminating effect.

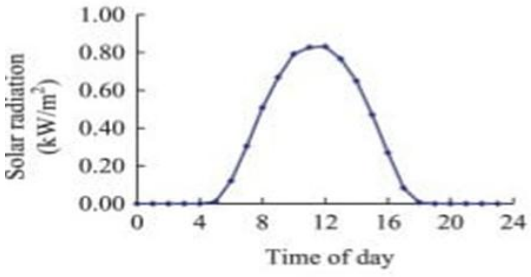

Chart 1: Comparison between Day time v/s Solar radiation

A comparison was done between the daytime (Different position of sun at morning, afternoon and evening) and solar radiation (sunrays). It is seen that during the start of day from early morning 6 – 7 am, we can clearly see there is less sunrays which enters inside the dome rather than at between 11am – 1pm where, the sunrays enter the dome are at very intensity. Due to which we can get more light radiated inside the room.

9. FUTURE SCOPE

Possible extensions of the project can happen based on the form of tubular daylighting devices. Most likely, there will be better adaptive forms of tubular daylighting devices in the nearest future which will give rise to a wide range of discussions on the concept of sustainable buildings. For instance, user control over the amount of light channeled through the Solatube daylighting device can be worked upon towards ensuring maximum visual satisfaction. Further to overcome the major limitation of this project i.e. to get illumination at nighttime, we can add Solar panels or Wind generators in order to generate electricity and store it in a battery and later use it for illumination during night.

CONCLUSION

The primary problem nowadays is electricity generation from environmentally friendly non-conventional energy sources. When it comes to generating electricity from these resources, India is lagging. We would have utilized electricity by transforming solar energy into it, but this idea is usually connected with a lower-than-one efficiency. Furthermore, the efficiency of light transmission alone is the highest. As a result, we have employed direct sunlight to create a glowing effect. As a result, the system will be very efficient, which it would not be otherwise. As previously said, this will lower the amount of energy used to illuminate the lamps that use electricity generated from traditional energy sources for a whole day. On an economic level, this will result in a power savings of up to 88 percent. When consumers move to this source of illumination, they may save a significant amount of money. This will also relieve the strain on other power producing resources, particularly non-renewable energy sources. We anticipate that this will easily replace traditional lighting sources.

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