Modifying The Design Of Solar Tube To Produce Cost Effective Dispose Of Sunlight In Multi-Storey Buildings

Vineet Kumar Singh, Amit Kumar Jain

Abstract: - Since the population of world is increasing at a very faster rate, the demand for the basic necessities is also increasing. Such necessities include food, clothing, shelter etc, the main challenge the government is facing is the increasing demand for the power generation for the entire population which is necessary for any country to be called a developed nation. The demand for shelter is being met by the very rapid rate of colonization which if not properly controlled will definitely lead to reduction in net sown area, increased deforestation and various ecological problems. So the trend is to build the multi-storey buildings on a very small piece of land. It has been observed that the buildings in metropolitan city are very close to each other and sometimes they are not properly oriented to the sun. Again the present era construction is being carried out underground such as the ones used in colleges for constructing library, laboratory, and metro stations. So the interior of the building remains in darkness even in the daytime. Thus to create the illumination in the building during the day, a lot of energy (electrical) is wasted. So in this paper an attempt is being made to produce and implement a system that will replace the existing day lighting systems without incurring a huge sum of money. So, a huge amount of electricity is consumed in order to have a visibility within during the daytime. This power consumption is really unnecessary and can be avoided by using the solar energy to produce the electricity to glow the bulbs, tube lights etc. Using solar light directly by making it to travel to inside of a building or a room. This is a very simple and economical concept and is known as solar tubes.

Keywords: - Power Consumption, Solar Energy, Electricity, Solar Tubes.

I. Introduction

The existing sources of energy such as coal, oil, etc, .are not adequate to meet the ever increasing demands. These are also depleting and may be exhausted at the end of the century or the beginning of the next century. Now a day, in India power generation is mainly due to non renewable energy resources. [1] These non renewable energy resources include the coal, petroleum, etc. The contribution of the various resources towards the power generation is as below: - [2]

1. Thermal / coal based power generation- 73%
2. Hydro electric power plants - 21%
3. Nuclear power plants- 01%
4. Others - 05%

It can easily be understood that when the contribution of the other power sources is increased the burden on their non renewable counterparts will definitely be lessen. [3] Further there were various alternatives to the existing day lighting systems and one of them is Solar Tube.

II. Solar Tube

Solar tube or Light tubes or light pipes are used for transporting or distributing natural or artificial light. In their application to day lighting they are also often called sun pipes, sun scopes, solar light pipes, or daylight pipes. [4]
Generally speaking, a solar tube may refer to:

- A tube or pipe for transport of light to another location, minimizing the loss of light;
- A transparent tube or pipe for distribution of light over its length, either for equi-distribution along the entire length or for controlled light leakage.

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A tube lined with highly reflecting material leads the light rays through a building, starting from an entrance-point located on its roof or one of its outer walls. A light tube is not intended for imaging, thus image distortions pose no problem and are in many ways encouraged due to the reduction of "directional" light. This is the old concept that has been in a use for a long time. The need of making some modifications is felt and will reduce the cost of the equipment. The main aim is to implement a highly efficient system which can reduce the consumption of electricity and must be cheap as compared to the other systems. Since Light transmission efficiency is greatest if the tube is short and straight. In longer, angled, or flexible tubes, part of the light intensity is lost. So, the method of using the solar light directly seems to be more efficient one. *Need of Solar Tube:* Since the population of our country is increasing at a very faster rate, the demand for the basic necessities is also increasing. The demand for shelter is being met by the very rapid rate of colonization which if not properly controlled will definitely lead to deforestation and various ecological problems. So the trend is to build the multi-storey buildings on a very small piece of land. It has been observed that the buildings in metropolitan city are very close to each other and sometimes they are not properly oriented to the sun. Again the present era construction is being carried out underground such as the ones used in colleges for constructing library, laboratory, and metro stations. So the interior of the building remains in darkness even in the daytime. Thus to create the illumination in the building during the day, a lot of energy (electrical) is wasted. So in this project an attempt is being made to produce and implement a system that will replace the existing day lighting systems without incurring a huge sum of money. So, a huge amount of electricity is consumed in order to have a visibility within during the daytime. The existing sources of energy such as coal, oil, etc, are not adequate to meet the ever increasing demands. These are also depleting and may be exhausted at the end of the

century or the beginning of the next century. Nowadays, in India power generation is mainly due to non renewable energy resources. It can easily be understood that when the contribution of the other power sources is increased the burden on their non renewable counterparts will definitely be lessen. So this is the main aim of doing this project.

III. Modified Design of the Solar Tube System

The basic schematic layout of conventional solar tube system is as shown in the figure below:-

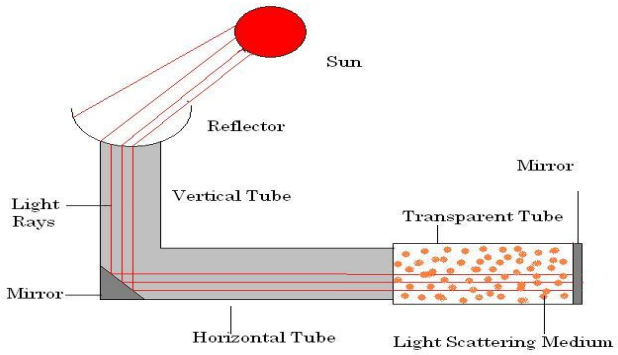

Fig 1:- The schematic layout of the conventional solar tube system.

The modification in design of solar tube includes the following:-

1) PVC tubing and mirror systems.
2) Transparent tubing and mirror systems.
3) Locating the collector.
4) Assembling the whole arrangement in one single location.

A PVC tube of diameter about 3.5 inches is taken. The length of tube is kept around 2.5 feet. The intensity of light reaching inside the room, to a large extent, depends upon the length of the tubing. The fall in intensity is considerable even when the length is not changed much. The tube is of very good quality PVC material so as to avoid distortion due to high temperature. The tube must be kept straight so that the large amount of light must reach inside the room. The tube is inserted with the shiny aluminium sheets so as to properly reflect the quality of light falling on the inside of the tube. For this, the aluminium sheet of 36 gauge size is used. The sheet has been rolled to the proper diameter and then it is inserted into the tube. At one end of this tube which will be kept against the room is provided with an elbow. This elbow is coated with an aluminium foil used to wrap food items. The elbow contains a flat plane mirror inclined at an angle of 45^0 so as to deflect the incident light radiations into a linear beam of light. This beam of light is supposed to be almost straight and then travel through the tube. While on the other end of the tube (PVC pipes), a transparent tube is inserted to half of its length. The diameter of the transparent tube is almost 68 mm (external). The tube is closed at one end. The PVC tube is supported by putting its one end into the hole drilled into the wall of the room. While the transparent tube projects out into the room with closed end into the room. The closed end of the transparent tube consists of a convex mirror glued to the base in such a way as to always face the light axially. The gluing has been done using clay. This will help in diverging the light thorough the transparent tube on to the reflector which will reflect the light on the large portion of the room. The reflector is mounted close to the wall on the transparent tube and a part is also inserted into the PVC pipe. These systems were independently built and are assembled in such a way as to produce the required system. The arrangement of these is shown in the figure. The whole arrangement is so devised to illuminate the room made of plywood. The room is provided with a window to look into the room from the front whether the proper amount of light is leaking into the room or not.

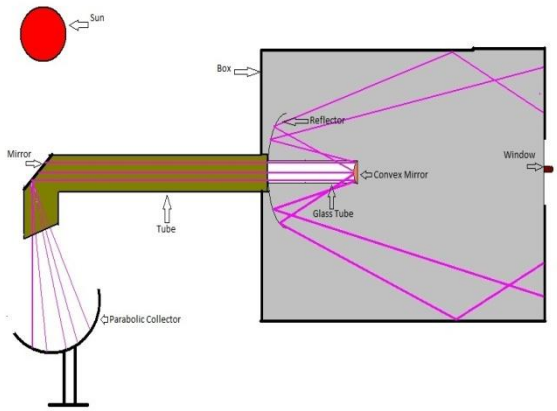

Fig 2:- Modified Solar Tube system

Metallization

Metallization is a process of depositing a very fine layer of a metal on another material. Metal electrodes of Aluminum are deposited on another material using vacuum technology. In vacuum metalizing a metallic coating material placed in a vacuum chamber with the work piece to be coated. The material that is being applied is then heated until it starts to evaporate; this vaporized metal condenses on the product or work piece as a thin metallic film. This technique utilizes a principle of depositing a very fine layer of any metal that is capable of reflecting a greater portion of light energy. The thickness of the film is of the order of microns and at such a minute value of material thickness; material tends to behave as a perfect reflector. The technique that we made use of during our project utilizes a vacuum based metalizing technique since a lesser amount of heat is required to melt the aluminum as the melting point lowers down due to the reduction in pressure. So here a brief description of the vacuum coating unit is given.

Process Characteristics

- Done within a vacuum
- Vaporizes the metal
- Can be used on glass, plastic, metal, ceramic, and paper materials
- Pieces being coated must be extremely clean
- It produces a very thin coat of metal

Description of Unit

The vacuum coating unit is a hind made product and has the following important parts as listed below:-

- Vacuum chamber with its accessories
- Pumps for producing vacuum

- Vacuum measuring gauges
- Electrical supply
- Valves s/a backing, baffle, roughing, air admittance valve

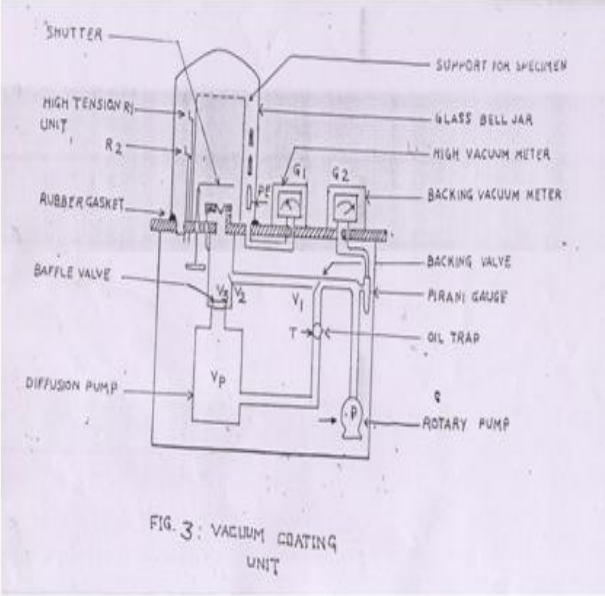

Fig 3:- Schematic of Vacuum Coating Unit

Operation

Before the start of metallization the machine has been recommended for use as per some technical guidelines so as to produce the sound coatings on the substrate. There are four kinds of the valves that are integral with the machine and in the beginning all valves were closed. This will ensure safety and proper operation of the coating unit. Then the rotary pump is switched on. This tends to build the pressure in the lines connecting the pump and as the pressure on the suction side of the pump falls below 0.005 torr, the valve V1 is opened. One torr of pressure is equal to one millimetre of mercury column and this unit of pressure is used to measure the pressures equivalent to the vacuum pressures. Now the circulation of the water is made available in the tubing surrounding the diffusion pump. The water is used for the cooling operation of the machine and is a de-mineralised water so as to avoid the problem of dust and corrosion. The reason behind using such a machine with so much care is the cost associated with the machine as it can coat a number of objects at a time. After half an hour, diffusion pump is ready for use. Since V1 is already closed and now the valve V2 is adjusted to connect the rotary pump with the vacuum chamber. As the pressure inside the vacuum chamber falls below 0.001 torr, the high tension supply is made available which helps in the ionization of the rarified air takes place. This ionization takes about five minutes to complete. As a result of which the surface of the substrate watch glass here, gets cleaned. The presence of oxides affect the effective coating to take place on the surface of the substrate as the proper bonding is inhibited. But when pressure in the chamber falls below 0.002 torr, suddenly the valve V2 is closed and V1 is opened again. Along with the V3 is opened. As a result of which the vacuum chamber is connected to diffusion pump [5]. The final pressure was measured to be 0.00001 torr. At this time the low tension supply is made ON. As a result of which the aluminium melts and evaporates and can conveniently be deposited on the watch glass. After the deposition has taken place, each and every valve except V4 is closed while it is opened leaking-in of air into the chamber and to relieve vacuum inside the chamber. This is all about how the metallization or vacuum coating has taken place. The various parts of the system are listed below and will be explained subsequently:-

1. Solar collector/ray concentrator
2. Vertical tubing
3. Horizontal tubing
4. Plane mirror
5. Transparent horizontal tube
6. Vertically held plane mirror
7. Light scattering medium
8. Other parts

Proposed Working

The working and use of the various parts of the various parts constituting the solar tube is as described below:-

Solar collector/ray concentrator

An efficient day lighting set-up requires a parabolic collector to track the sun and concentrate its light. The main objective of using this device is to produce a parallel beam of light while it travels through the tube. The working of this device may be based on the basics of the reflection or the refraction. The view of the hemispherical kind of the reflector is shown in figure 2. The various alternative arrangements for this can be as discussed below:- The arrangement may use a parabolic reflector that can transform a parallel beam of light into a concentrated that can be used to produce a parallel beam again that can be made to move through the tube. Another arrangement may use a sun tracker being guided on the rails so that the reflector surface will always be such as to always face the sun. However, this arrangement need to be power operated to work in an efficient manner which can thus be used by using a solar panel arrangement in addition to it. One more arrangement is also possible which is rather conventional. This uses a lens that can help concentrate light to a point which can then be utilized to parallel beam of light. [6] However this arrangement is already patented under 1986 patent, but some improvements are still possible.

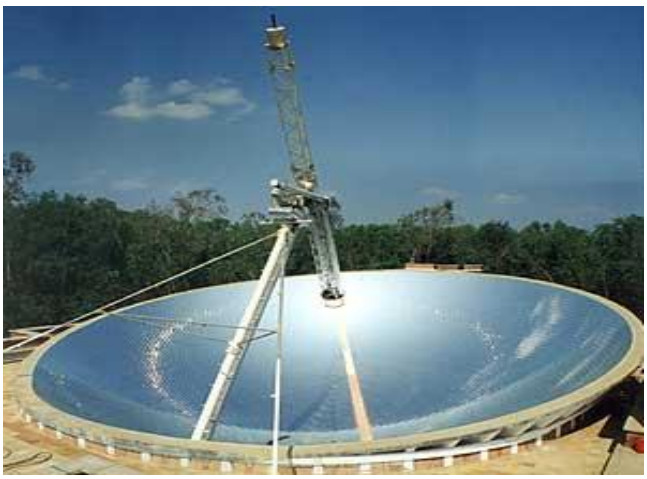

Fig 4:- A view of hemispherical type of reflector

Vertical tubing

It shall include an evacuated path through which light can travel at a higher speed and there must occur a minimum loss of energy and intensity. The tube may be simple as well as complex to give a very high efficiency. This part is very critical and may have the following alternative arrangements: - [7] The tube can be of PVC or the plastic thereby making the arrangement as simple as the periscope. The main objective to use this arrangement is to have a parallel beam of light to move through the tube. This is, further, rather a cheaper arrangement. The schematic of this arrangement is shown in figure 3. The tube can be an optical fiber whose working is based on the total internal reflection. These will rather a costly arrangement as compared to the previous one. Although the arrangement is again a simple one but one main difficulty is associated with it, being that the light will always be required to travel from the denser to the rarer medium.

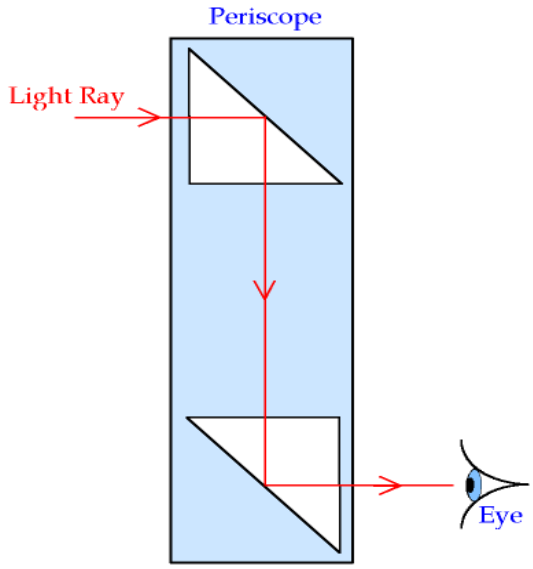

Fig 5:- The schematic view of periscope using two prisms

Horizontal tube

This is a tube that is an alternative arrangement to be used in conjunction with the first alternative arrangement of the vertical tube and may not be in use when the previous arrangement is used. This arrangement is used for the light to move forward for illumination and will make the project cost effective and cheaper and the tube shall be the one of PVC or plastic make.

Mirror

This may include a plane mirror which shall be inclined at an angle of 45 degrees with the horizontal in between the horizontal and vertical tubes. The use of the mirror is made to ensure to change the path of light travel and thereby acting as a vital component. This further ensures that the light coming after being reflected from the mirror will move onward in the horizontal direction. There can be an alternative arrangement also that may use a prism (rectangular) which may give other properties. The view of this arrangement using a mirror is shown in the figure 4.

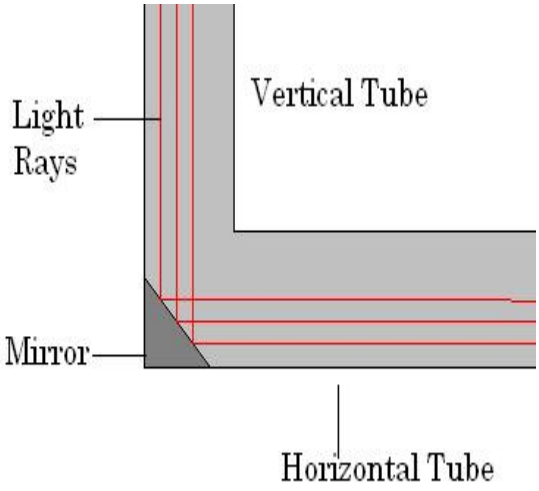

Fig 6:- The view of the horizontal, vertical tube with a mirror arrangement

Transparent horizontal tube

A part of the horizontal tubing is made transparent and is separated from the latter from inside. The main objective of using this is to have a better illumination in the room. An alternative arrangement may use separate horizontal tube starting from the trailing edge of the horizontal opaque tube. This tube may contain a light scattering medium so as to produce the better illumination and a better coloring effect. The arrangement is as shown in the figure 5.

Light scattering material

The inside of the transparent tube is filled with the light scattering medium that will scatter the light and shall be responsible for causing the luminance in the room. Known light scattering materials for transmitting and scattering light include light scattering members in the form of plastic optical fibers, illuminators and light scattering materials of the metal dispersion systems. The example may include a mixture of 100 parts of methyl phenyl silicone rubber and 5 parts of glass beads.

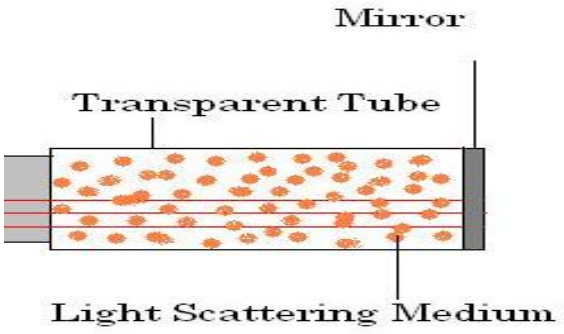

Fig 7:- A schematic view of the transparent tube.

Vertically held mirror

This is again a plane mirror and is kept vertical to reflect the major part straight back so that the reflected light may escape into the atmosphere. This may reduce the heating tendency of light. This may also add to illumination while on the backward path. This mirror may have an alternative of

using a metal in place of it. The metals are sometimes the very good reflectors of light. Although the cost of using this will be high but the arrangement will then be durable enough for a long period of sustainment.

Other components

The other components may include the flat plates that will be required to create a vacuum in the horizontal and vertical tubes. This may also help to retain the light scattering medium within the transparent part itself. The other components may include the arrangements to support the solar tubes within the room and outside of it. Further there shall be an arrangement to produce the illumination during the night time also. Such devices may be solar panels consisting of photo-voltaic cells, batteries, necessary wiring. A solar tube essentially consists of:-

1. A collector
2. A P.V.C. pipe
3. A glass tube
4. A plane reflecting glass
5. A reflector and
6. An external reflector made up of a no of small plane reflecting glass glued to a plane disc.

Fabrication of Solar Tube

The fabrication of solar tube includes the following important steps:-

1. Fabrication of PVC tubing and mirror systems.
2. Fabrication of transparent tubing and mirror systems.
3. Locating the collector.
4. Assembling the whole arrangement in one single location.

How the above steps were carried out is explained below:-

A PVC tube of diameter about 3.5 inches is taken. The length of tube is kept around 2.5 feet. The intensity of light reaching inside the room, to a large extent, depends upon the length of the tubing. The fall in intensity is considerable even when the length is not changed much. The tube is of very good quality PVC material so as to avoid distortion due to high temperature. The tube must be kept straight so that the large amount of light must reach inside the room. The tube is inserted with the shiny aluminium sheets so as to properly reflect the quality of light falling on the inside of the tube.

For this, the aluminium sheet of 36 gauge size is used. The sheet has been rolled to the proper diameter and then it is inserted into the tube. At one end of this tube which will be kept against the room is provided with an elbow. This elbow is coated with an aluminium foil used to wrap food items. The elbow contains a flat plane mirror inclined at an angle of 45^0 so as to deflect the incident light radiations into a linear beam of light. This beam of light is supposed to be almost straight and then travel through the tube. While on the other end of the tube (PVC pipes), a transparent tube is inserted to half of its length. The diameter of the transparent tube is almost 68 mm (external). The tube is closed at one end.

The PVC tube is supported by putting its one end into the hole drilled into the wall of the room. While the transparent tube projects out into the room with closed end into the room. The closed end of the transparent tube consists of a convex mirror glued to the base in such a way as to always face the light axially. The gluing has been done using clay. This will help in diverging the light thorough the transparent tube on to the reflector which will reflect the light on the large portion of the room. The reflector is mounted close to the wall on the transparent tube and a part is also inserted into the PVC pipe.

These systems were independently built and are assembled in such a way as to produce the required system. The arrangement of these is shown in the figure. The whole arrangement is so devised to illuminate the room made of plywood. The room is provided with a window to look into the room from the front whether the proper amount of light is leaking into the room or not.

Deviation from Proposed Arrangement

The proposed arrangement has been explained in the introductory part of the project report. However, during the fabrication of the project, it was not possible for us to produce the same arrangement as proposed at the time of the conception & definition phase. The objective was however not altered even after incorporating a number of changes. The following changes have been incorporated during the fabrication stage of the project. These are listed below-

1. Firstly the vertical tube was illuminated as due to its inclusion the transmission losses increased and the intensity of light available at the receiving end was not enough for proper illumination.
2. Secondly the size of the new system was reduced from 6.5ft to 2.5ft tubing due to the non assimilation of long vertical tube.
3. Next in hollow horizontal tube of PVC a transparent hollow glass tube closed at one end with an outer dia of 68mm was fitted in the horizontal tube for carrying light to outside.
4. Next instead of using a light scattering medium a convex glass was used in its place due to its ease of fabrication, costing, etc. The convex glass has aluminum coating on its convex side which serves as reflecting and scattering medium. This is used to orient the light at proper orientation. The additional useful feature of using glass tube is that its length can be varied easily (as it is free to slide in the horizontal tube).hence illumination can be adjusted by the user because illumination is a function of length.
5. The plane glass fitted at the end of light scattering medium in the proposed arrangement has been eliminated because convex glass has been used in its place as discussed above.
6. A reflector made of German of 12 inch outside diameter with its open end in front of lens was fitted on the glass tube. It receives light from convex aluminum coated glass and scattered light in all living space. Thus it helps in multiplication of scattering of light and offers better illumination throughout.

7. Lastly in order to reduce losses due to intensity of light transmitted very good reflecting thin aluminum sheets are used. These are rolled down to proper dimensions and fitted inside the horizontal tube throughout its length on the inside surface. They offer better transmission of light

IV. Testing

Light rays coming from sun are intercepted on parabolidal reflector which is manually tracked. The intensity of light reflected is varied by changing its orientation. The reflected light is allowed to fall on an inclined mirror positioned at an angle of 45 degree. The mirror intercepts the light and makes the light into parallel beam. This beam travels through horizontal glass tube placed inside a P.V.C. pipe axially and falls on convex mirror placed at the closed end of the tube. The light is reflected from the convex mirror and falls on the reflector, there by illuminating the plywood box. A window is made at the opposite face of reflector placed the box to view the intensity of light obtained. It is observed that about 30 %(approximately) of incident light was obtained. Furthermore, the intensity light can be varied by changing the length of the transparent glass tube as desired by the user.

Cost-effectiveness

Consider the cost analysis or cost effectiveness estimation for a community of 1000 families for about 5 years under the following assumptions:-

1. The sunlight is available during the complete daytime
2. The cost of electricity per unit is fixed.
3. The maintenance cost for the entire period is assumed constant.
4. The maintenance cost is taken to be equal to the installation cost.
5. There is no power cut for the stipulated period.

Total time for which sunlight is available = 10 hours per day
Energy consumed for enlightening 4 bulbs for this much time = 100 x 4 = 400 Watts of energy

Wastage of energy = 400 Joules/sec./day = 3,45,60,000 Joules

No. of electrical units = $(34560000/(3.6x10^6))x$ 1 KWh = 9.6 KWh/day

Now total electrical units for about 1 year with about 365 days = 9.6 x 365 = 3504 KWh/year

Cost of this for about a society with 1000 homes for a period of about 5 years (Rs. 3.50/- per unit)

C = 3504 x 5 x 1000 x 3.5 = Rs. 6,13,20,000/-

Cost of about 1000 solar tubes with installation for 5 years

C_1 = (1000 x 2000) + (5 x 300) x 1000 = Rs. 35,00,000

Total saving (in %) = ((61320000–3500000)/61320000) x 100 = 94.29 %

Thus this system will result in money saving of about 94.29% and may definitely be as per the eco-friendly concerns.

V. Advantages of Solar Tube

1. Avoids the over illumination since direct sunlight is not preferred at most of places. This reduces the various ill effects caused by the over illumination. Over-illumination**,** the presence of lighting intensity (ill-luminance) beyond that required for a specified activity has the disadvantages as firstly use of more artificial illumination than required is expensive and energy-intensive. This includes consideration both of the appropriate level of illumination when spaces are in use, and when they are unoccupied. Secondly clinical studies show that excessive levels of artificial light produce annoyance and health effects in a large fraction of the population. These effects may depend on the spectrum of the light as well as the overall brightness. The two disadvantages can be removed by the use of solar tube as it is inexpensive and clean. Moreover it is healthy as it uses naturally available solar light and thus has no ill effect on people.
2. It utilizes a non-conventional source of energy. This will help to energy consumption of a family at least for daytime.
3. It is an eco-friendly means of illumination.
4. It is comparatively cheaper with a payback period of about three years.
5. Over-illumination can contribute to light pollution, where stray light illuminates the outdoors or others' property, where it is unwanted. Over-illumination is a topic normally addressed in the process of building design, whereas light pollution is normally addressed by zoning regulations. So it helps in minimizing the light pollution.

VI. Applications of Solar Tube

1. It is used for lighting underground basements in buildings and mall as these are large and there is not proper space for sunlight to enter there.
2. It is used for illumination in multistory car parking's.
3. It is used for lighting libraries.
4. It may be used for lighting railway stations.
5. It may be installed in multistory offices for lighting them.
6. It may also be installed in hotels.

Conclusion

Today the main concern is on power generation by using eco-friendly non-conventional energy resources. India is on the back foot when it comes to generate power from these resources. We would have used electricity by converting the solar energy into that but this concept has always an associated efficiency which will always be less than one. Further the efficiency associated with the light transmission only is the highest. That is why we have directly used the sunlight to produce illuminating effect. Thus the system shall be a highly efficient one that would not otherwise be. This will reduce the power consumption, as already been

mentioned, for a complete day which is being spend on the enlightening the bulbs which consume the electricity produced from the conventional energy resources. This indeed will result in the power saving upto 88 percent on the economic standards. This is really a huge amount that can be saved when people opt to switch to this source of illumination. Further this will reduce the burden on the other power generation resources, mainly non-renewable energy resources. We hope that this will replace the conventional sources of illumination readily.

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