International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463
Vol. 2 Issue 6, June-2013, pp: (1-6), Available online at: www.erpublications.com

Experimental study of Tubular Skylight and comparison with Artificial Lighting of standard ratings

Vanita Thakkar
Associate Professor, Mechanical Engineering Department
Babaria Institute of Technology, BITS Edu Campus, Vadodra, Mumbai

Abstract: Proper lighting system, an important aspect of comfort conditions in a shelter (residence/work-place), includes use of artificial light sources (e.g. lamps) and natural illumination of interiors from daylight. Lighting design of buildings hardly receives due importance. Day lighting (through windows) is often main source of light during daytime. Artificial lighting, mostly by electric lights, forms significant part of worldwide energy consumption. Lighting design applied to a built environment, "Architectural Lighting Design", is a science and an art. Comprehensive Lighting Design considers amount of functional light provided, energy consumed and aesthetic impact of lighting system. Tubular skylight, a simple device bringing sunlight to a building's interiors at places, not receiving daylight, shows good potential of use for energy conservation and ergonomics.

This paper presents results of experiments on performance of locally-fabricated Tubular Skylights of three different diameters, and comparison of illumination obtained with that obtained by bulbs of standard ratings.

Keywords: Tubular Skylight, Day lighting, Lighting Design.

Introduction

Lighting or illumination is the deliberate application of light to achieve some aesthetic or practical effect. It uses artificial light sources like lamps, as well as natural light sources like the daylight / sunlight. Proper lighting can enhance task performance and / or aesthetics, while there can be energy wastage and adverse health effects of poorly designed lighting. According to a Residential Appliance Saturation Study conducted in California, homes there use on average 1,200 kWh per year for lighting, 22% of their total annual electricity use (Kema-Zenergy et al, 2004). Indoor lighting is a form of fixture or furnishing, and a key part of interior design. Lighting can also be an intrinsic component of landscaping. Comprehensive Lighting Design requires consideration to the amount of functional light provided, the energy consumed as well as the aesthetic impact supplied by the lighting system. Some buildings, like surgical centers and sports facilities are primarily concerned with providing appropriate amount of light for the associated task, while some like warehouses and office buildings, with saving money through energy efficient lighting systems. Other buildings like theatres, restaurants, etc. are primarily concerned with enhancing appearance and emotional impact of architecture through lighting systems. Hence, it is important that the science of light production and luminary's photometrics are balanced with the artistic application of light as a medium in a given built environment. Artificial / Electrical day lighting systems should be ideally integrated with day lighting systems to evolve an optimum lighting system.

"Tubular Skylight" or "Solar Pipe" or "Light Tube" is the oldest and most widespread type of light tube used for day lighting. The concept is said to be originally developed by ancient Egyptians. The first commercial reflector systems were patented and marketed in the 1850s by Paul Emile Chappuis in London, utilizing various forms of angled mirror designs, which were in production upto 1943 [2]. Thereafter, the concept is said to have been rediscovered and patented in the 1980s [3]. Tubular Skylights show good potential of emerging as alternative products to conventional skylights to deliver daylight without the unwanted solar heat gains and cover areas not usually covered by windows and skylights.

Tubular Skylights consist of typically three parts : Collector – dome – to gather sunlight, pipe to channel the sunlight downward and ceiling diffuser to diffuse light to the indoor space. The collector is usually hemispheric and made up of clear glazing. It may include some devices to enhance the lighting output of the skylight, especially at low sun altitude angles. The pipe is usually made up of Aluminium sheet with highly reflective interior lining. The diffuser is hemispherical or flat with translucent (preferable for better light diffusion) or clear glazing (good light transmission, but poor diffusion, so lenses may be required to enhance diffusion). Fig. 1 shows a schematic representation of a Tubular Skylight.

This paper presents results of experiments on performance of locally-fabricated Tubular Skylights of three different diameters, and comparison of illumination obtained with that obtained by bulbs of standard ratings. It was found that at least for 4 hours a day, during working hours, steady, nearly maximum illumination is obtained by using tubular skylights. This ensures good energy saving along with healthy working conditions.

In view of such facts, many offices, industries and residences can adopt/have started adopting (at some places in India and many places in the USA, Australia and Europe) the use of tubular sky lights.

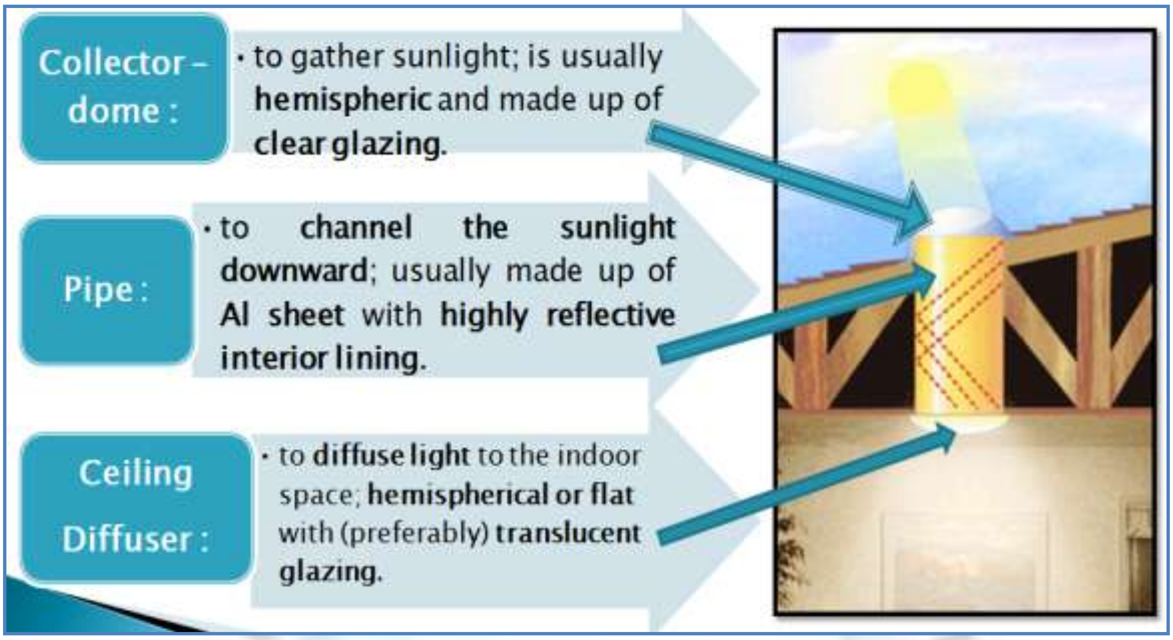


Fig. 1: Schematic Representation of Tubular Skylight

Literature Review

Prediction of performance of tubular skylights has always been a difficult task, although some tentative design guides have been proposed by researchers and some skylight manufacturers.

Laboratory and field measurements have been extensively used to predict the performance of tubular skylights in many countries like, USA, Canada, Australia, UK and other European countries (Allen, 1997 [4], Shao et al., 1998 [5]; Oakley et al., 2000 [6]; Salih et al., 2000 [7]; Carter, 2002 [8]; Zhang and Muneer, 2002 [9]; Jenkins and Muneer, 2003 [10]). Numerous theoretical models have also been attempted to address the transmission efficiency of the skylight (Zastrow and Wittwer, 1986 [11]; Swift and Smith, 1995 [12]; Edmonds et al., 1995 [13]). These models focused mainly on the pipe transmission efficiency, not including the collector and diffuser.

Under Indian conditions, detailed experiments on tubular skylights were done by R. R. Easow and S. C. Nagavkar at SPCE, Mumbai [14]. The study and experiments discussed in this paper were inspired by this article and the standard chamber for the experiments was made as per the specifications given in this article. They were conducted by four students of final year B. E. (Mech.) under the guidance of the author, as their project work for the final semester. The skylight was fabricated for 3 different diameters, the length kept constant, having a transparent dome and translucent diffuser. The interior of the chamber was kept matt white, unlike matt black kept in the experiment at SPEC to take into account conditions similar to those in day to day life. Also, the comparison of the illumination obtained using skylight to that obtained using bulbs of standard rating was done.

Experimental Set-up

The experimental set-up consists of:

A. **Chamber / Enclosure:**

The chamber for experimentation was of size : 6' x 6' x 6' – based on photometric considerations, made up of plywood sheets. It was painted with two coats of primer and followed by a coat of white paint. White drawing sheets were pasted on the interior of the enclosure to create an effect similar to that of white-washed walls. A circular hole of 11" diameter was made on the roof of the enclosure for fixing the tubular skylights. The enclosure was placed for experimentation in open space such that no shadows were cast on it throughout the day. Also, hinges are provided on the walls of the enclosure, to give it a "folding" kind of make, so that it can be assembled and dismantled as and when required. A fixed location was kept for the enclosure for the given experiment to maintain uniformity of location. Figure 2 shows the snap of the chamber / enclosure.

Fig. 2: Chamber / Enclosure for Experimentation

B. **Tubular Skylight Assembly**

It consists of three main components : The Dome – made up of transparent acrylic to transmit solar rays into the tube, Aluminium Tube, made up of Aluminium sheet 0.253m long, 1m wide and 0.3mm thick, with a glossy inner surface; and Diffuser – translucent, milky in colour of diameter 11". The same tube is used for different diameters. Holes are drilled on the Aluminium sheet to make it into a tube of needed size using bolts and nuts. Aluminium foil is used for preventing loss of sunrays from the dome at the places where joints are located. The whole assembly is placed at (almost) the centre of the roof of enclosure, such that fixing it for different sizes of skylights can be done properly.

Experiment and Study Procedure

For 3 days during the month of May, 2010 readings of illumination using the tubular skylight for three different diameters–11" ϕ on 4rd May, 10" ϕ on 5th May and 9" ϕ on 6th May, were recorded every hour, using a Lux-meter between 10:00 AM to 03:00PM. The readings were taken for illumination at the ground level and at 0.8m above the ground level, just below the skylight as well as at each corner of the enclosure, i.e. at 10 nodes – nodes 1 to 5 at 0.8m from the ground level and nodes 6 to 10 at ground level. For bulbs of 3 standard ratings, viz. 15W, 60W and 100W, similar readings were taken.

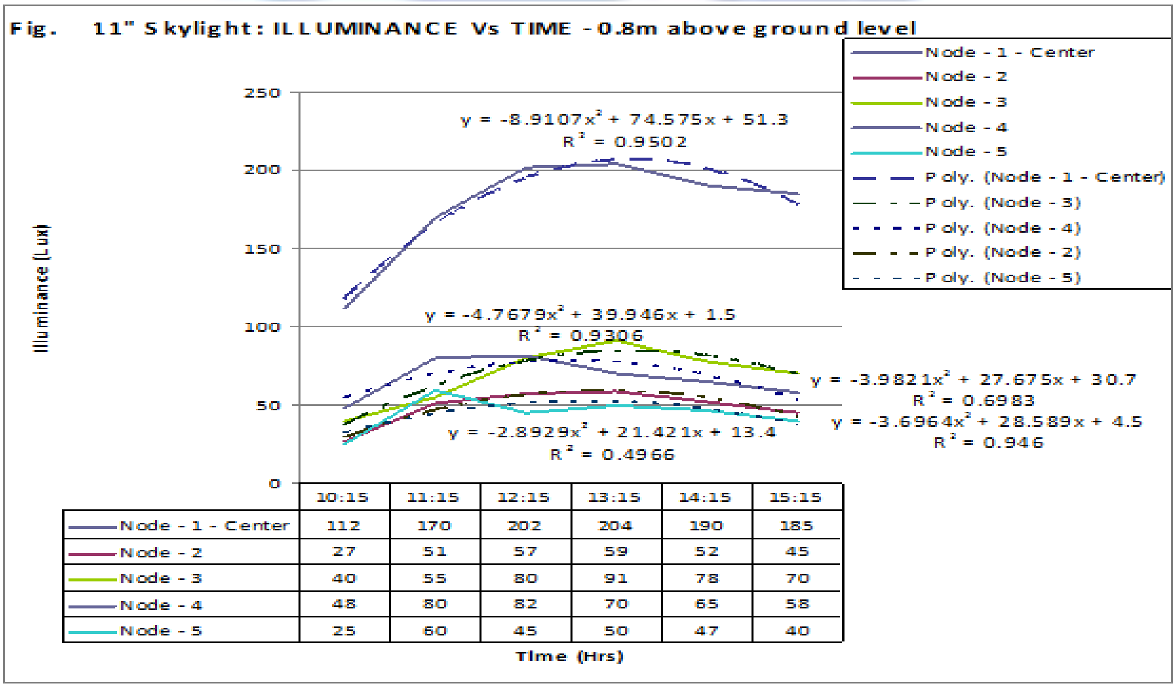
Average values of illumination at a given time were taken for skylights; graphs were plotted for Illumination obtained vs. Time and comparative study of the results obtained was done. Fig. 3 shows a view of the Tubular Skylight inside the enclosure.

Fig. 3: A view of the Tubular Skylight inside the enclosure

Results and Discussion

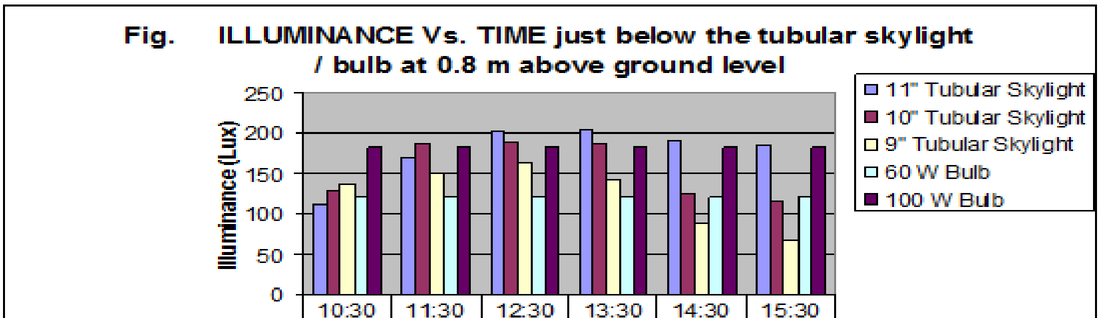
Fig. 4, 5 and 6 show some typical results plotted graphically to analyze the data collected during the experiments. Some important observations of the study are as follows :

- At both levels, 11” and 10” tubular skylights give illuminance better than a 60W bulb.
- The illumination at ground level is poorer than that obtained by a 100W bulb at all times. The diffusion of sunlight is not sufficient.
- The transmittance is better in the morning compared to that in the evening, especially for lower diameter (hence, higher aspect ratio) tubular skylights, e.g. the 9” tubular skylight gives 82 lux and 39 lux illuminance at nodes 1 and 6 respectively at 09:30 am when outside illuminance is around 42000 lux and 68 lux and 31 lux illuminance at nodes 1 and 6 respectively at 03:30 pm when the outside illuminance is 46200 lux.
- It has been found that use of solar light can be further optimized by installing a heliostat which tracks the movement of the sun, thereby directing sunlight into the tube at all times of the day as far as the surroundings’ limitations allow, possibly with additional mirrors or other reflective elements that influence the light path. The heliostat can be set to capture moonlight at night, as well [1]. But even under the present conditions, nearly the maximum value of illumination can be obtained for almost 4 hours a day, steadily – during working hours. This gives good scope for energy savings.
- Higher length and hence better aspect ratio would have given better results.
- The illumination levels obtained are sufficient / suitable for areas / tasks that require low or moderate illuminance levels like corridors / walkways (min. illuminance – 40 lux), change-rooms, loading bays and bulky storages (min. illuminance – 80 lux), waiting rooms, simple tasks – rough bench-work, general fabrication (min. illuminance – 160 lux) and moderately easy tasks which require min. illuminance of about 200 lux [15]. The illuminance obtained from 15W bulb was very low– maximum 12 lux and average illuminance at 0.8m above the ground level equal to 7 lux and at ground level equal to 5.4 lux. The readings were hence not taken into account for further analysis.
- The experimental set-up is prepared from locally available material and resources. The reflectance of actual white-washed wall and ceilings (typically 0.8) would be different from that of the white drawing sheets used to cover the interior of the chamber. Corresponding variations in the results will be there for white-washed walls and ceilings.
- Better data collection and hence, analysis can be done using sophisticated instrumentation for the experiments like, sensors for measuring illuminance, data loggers, etc.
- Also, experimenting over a longer time span with more variations in diameter and length of the tube would give more data and scope for analysis.



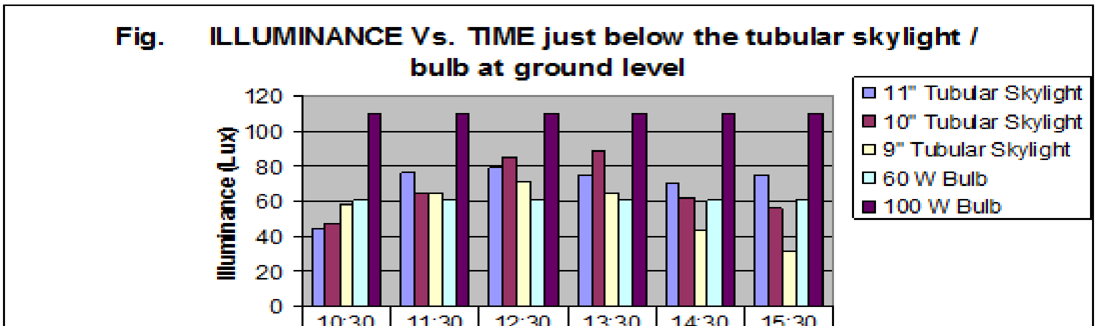
	10:15	11:15	12:15	13:15	14:15	15:15
Node - 1 - Center	112	170	202	204	190	185
Node - 2	27	51	57	59	52	45
Node - 3	40	55	80	91	78	70
Node - 4	48	80	82	70	65	58
Node - 5	25	60	45	50	47	40

Fig. 4: 11” Skylight : Illuminance Vs Time – 0.8m above ground level



	10:30	11:30	12:30	13:30	14:30	15:30
11" Tubular Skylight	112	170	202	204	190	185
10" Tubular Skylight	129	186	189	186	125	115
9" Tubular Skylight	137	150	163	142	88	68
60 W Bulb	120	120	120	120	120	120
100 W Bulb	182	182	182	182	182	182

Fig. 5: Illuminance Vs Time : Just below the skylight / bulb at 0.8 m above ground level



	10:30	11:30	12:30	13:30	14:30	15:30
11" Tubular Skylight	44	76	79	75	70	75
10" Tubular Skylight	47	65	85	88	62	56
9" Tubular Skylight	58	65	71	65	43	31
60 W Bulb	61	61	61	61	61	61
100 W Bulb	110	110	110	110	110	110

Fig. 6: Illuminance Vs Time : Just below the skylight / bulb at above ground level

Conclusions

The use of tubular skylights can result in energy savings as well as healthy conditions to stay / work in. In spite of the limitations of the experimental set-up, the results obtained are encouraging. Simple skylights were a regular passive feature for lighting and ventilation in the residences in the olden days. Tubular skylights have the advantage of practically no heat gain while getting the required visual comfort and illumination indoors. At least for 4 hours a day, during working hours, steady, nearly maximum illumination is obtained by using tubular skylights. This ensures good energy saving along with healthy working conditions. In view of such facts, many offices, industries and residences have started adopting the use of tubular sky lights. The initial cost and installation costs sound discouraging (around Rs.2500/- per skylight), but the advantage of zero operation and maintenance costs favour their usage.

References

[1]. “Light Tubes”, downloadable from : http://en.wikipedia.org/wiki/Light_tube
[2]. Science & Society Picture Library, “Advertisement for Chappuis’ patent reflectors, c 1851-1870” at: www.scienceandsociety.co.uk.
[3]. Downloadable from : http://www.solatube.com.au/corporate/about_history.php
[4]. Allen T., “Conventional and tubular skylights: An Evaluation of the daylighting systems at two ACT commercial buildings”, Proceedings of 22nd National Passive Solar Conference, Washington DC, pp. 97-129, 1997.

[5]. Shao, L., "Mirror light-pipes: Daylighting performance in real buildings, Lighting Research Technology", vol 30, no. 1, pp. 37-44, 1998.
[6]. Oakley G., Riffat S.B., and Shao L., "Daylight performance of lightpipes", Solar Energy 69(2), pp. 89-98, 2000.
[7]. Salih A., Shao L. and Riffat S., "Study of daylight and solar infrared transmitted through light pipes under UK climate", Proceedings of the CIBSE national conference, pp. 198-207, 2000.
[8]. Carter D.J., "The measured and predicted performance of passive solar light pipe systems", Lighting Research and Technology, 34(1), pp. 39-52, 2002.
[9]. Zhang X. and Muneer T., "A design guide for performance assessment of solar light-pipe", Lighting Research and Technology, 34(2), pp. 149-169, 2002.
[10]. Jenkins, D., Muneer, T., "Modelling light pipe performances – a natural daylighting solution"; Building and Environment 38, 2003, pp. 965-972.
[11]. Zastrow A. and Wittwer V., "Daylight with mirror light pipes and with fluorescent planar concentrators", SPIE vol. 692 Materials and optics for solar energy conversion and advanced lighting technology, pp. 227-234, 1986.
[12]. Swift, P.D., Smith, G.B., "Cylindrical mirror light pipes"; Solar Energy Materials and Solar Cells, 36, 1995, pp. 159-167.
[13]. Edmonds I.R., Moore G.I., Smith G.B., and Swift P.D., "Daylighting enhancement with light pipes coupled with laser-cut light-deflecting panels", Lighting Research and Technology, 27(1), pp. 27-35, 1995.
[14]. R. R. Easow and S. C. Nagavkar, "Investigation on Tubular Skylights and its Use for Indoor Lighting in the Indian Environment"; SESI Journal, 18, 2008, pp. 32-40.
[15]. Energy Efficiency Best Practice Guide Lighting : BP_Lighting_Manual.pdf, downloadable from : www.sustainability.vic.gov.au.