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Daylight Harvesting System: A Review on Light Harvesting Technologies in Commercial Buildings

[1]R. R. Date,
rdate05@gmail.com

[2]S. M. Shamkuwar,

[3]K. S. Rambhad
kishorrambhad@gmail.com

Department of Mechanical Engineering, G. H. Raisoni College of Engineering, Nagpur- 440016, India

Abstract **- This article presents key energy use figures and explores the energy saving potential for day lighting in office buildings based on a review of relevant literature. The paper contains different ways in which the natural daylight can be made use of, thus reducing the use of artificial lighting. A comprehensive study regarding the day lighting and artificial lighting shows that Electric lighting accounts for 20% of the total primary energy consumed by commercial buildings in the U.S. Over the entire U.S. building sector, lighting accounts for more than 14% of the total primary energy consumed. Consequently, reducing lighting energy consumption presents a potential for considerable energy consumption reduction across the building sector. One effective approach to reduce the use of electric lighting is daylight harvesting. It is due to this reason that the use of daylight for daily illumination in place of artificial lighting also contributes for the concept of GREEN BUILDING, thus inhibiting higher economy of the country.**

Index terms- Green building, light tubes, tubular daylight devices, skylight, reflectance, daylighting

I. INTRODUCTION

Daylight harvesting systems, which automatically adjust lights in response to the amount of daylight in a space, can provide significant energy and demand savings. However, these systems are usually expensive to install, commission, and maintain. Also, they often do not perform as well as expected and are frequently deactivated by unhappy users

A successful daylight harvesting system requires two things: the controlled introduction of direct and reflected sunlight into a building and the reduction of the electric lighting load in response to the available daylight. In day lit spaces, the primary source of interior illumination during parts of the day is daylight, which has the potential of lowering building electricity consumption and reducing peak energy demand when paired with a lighting control system. Incorporation of day lighting technologies in both new buildings and renovations continues to increase, driven by energy standards, code requirements and building energy rating metrics.

Light tubes or light pipes are physical structures used for transporting or distributing natural or artificial light for the purpose of illumination, and are examples of optical waveguides. In their application to day lighting, they are also often called tubular day lighting devices, sun pipes, sun scopes, or daylight pipes. Light pipes may be divided into two broad categories: hollow structures that contain the light with a reflective lining, and transparent solids that contain the light by total internal reflection.

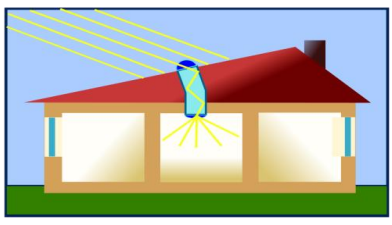

Figure1: Light Tube [1]

Basically, a **light pipe** or **light 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 equidistribution along the entire length or for controlled light leakage [1].

II. TYPES OF LIGHT TUBES

A. IR Light Pipes/IR Light Tube

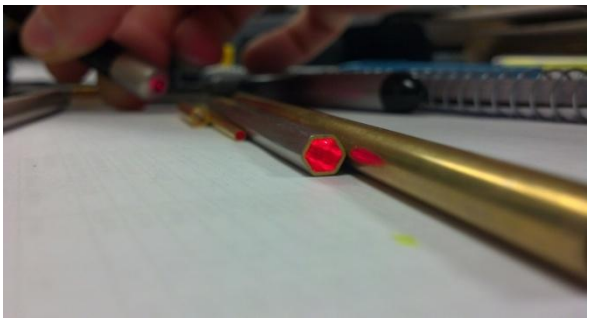

Figure 2: Hexagonal Light Tube Reflecting Laser Beam [1]

Only certain manufactures can custom design Infrared Light Pipes, Hollow Waveguides and Homogenizers. This is because these are tubes lined with a highly polished infrared reflective coating of Laser Gold, which can be applied thick enough to permit these tubes to be used in highly corrosive atmospheres. Laser Black can be applied to certain parts of light pipes to absorb IR light. This is done to limit IR light to only certain areas of the pipe.

While most light pipes are produced with a round cross-section, light pipes are not limited to this geometry. Square and hexagonal cross-sections are used in special applications. Hexagonal pipes tend to produce the most homogenized type of IR Light. The pipes do not need to be straight. Bends in the pipe have little effect on efficiency [1].

B. Light tube with reflective material

Also known as a "tubular skylight" or "tubular daylighting device", this is the oldest and most widespread type of light tube used for daylighting. The concept was originally developed by the ancient Egyptians. The first commercial reflector systems were patented and marketed in the 1850s by Paul Emile Chappuis in London, utilising various forms of angled mirror designs. Chappuis Ltd's reflectors were in continuous production until the factory was destroyed in 1943. The concept was rediscovered and patented in 1986 by Solatube International of Australia. This system has been marketed for widespread residential and commercial use. Other daylighting products are on the market under various generic names, such as "SunScope", "solar pipe", "light pipe", "light tube" and "tubular skylight" [1,2].

A tube lined with highly reflective 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 (in contrast to a periscope, for example), thus image distortions pose no problem and are in many ways encouraged due to the reduction of "directional" light.

The entrance point usually comprises a dome (cupola), which has the function of collecting and reflecting as much sunlight as possible into the tube. Many units also have directional "collectors", "reflectors" or even Fresnel lens devices that assist in collecting additional directional light down the tube.

A set-up in which a laser cut acrylic panel is arranged to redirect sunlight into a horizontally or vertically orientated mirrored pipe, combined with a light spreading system with a triangular arrangement of laser cut panels that spread the light into the room, was developed at the Queensland University of Technology in Brisbane. In 2003, Veronica Garcia Hansen, Ken Yeang, and Ian Edmonds were awarded the Far East Economic Review Innovation Award in bronze for this development.

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. To minimize losses, a high reflectivity of the tube lining is crucial; manufacturers claim reflectivities of their materials, in the visible range, of up to almost 99.5 percent [3].

Figure 3: One of three light pipes that transport natural daylight to the underground railway station Berlin Potsdamer Platz [16]

At the end point (the point of use), a diffuser spreads the light into the room.

To further optimize the use of solar light, a heliostat can be installed which tracks the movement of the sun, thereby directing sunlight into the light 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.

C. Optical fiber

Optical fibers are well known as fiberscopes for imaging applications and as light guides for a wide range of non-imaging applications. In the latter context, they can also be used for daylighting: a solar lighting system based on plastic optical fibers was in development at Oak Ridge National Laboratory in 2004; the system was installed at the American Museum of Science and Energy, Tennessee, USA, in 2005, and brought to market the same year by the company Sunlight Direct. However, this system was taken off the market in 2009.

Optical fibers are also used in the Bjork system sold by Parans Solar Lighting AB. The optic fibers in this system are made of PMMA (PolyMethylMethAcrylate) and sheathed with Megolon, a halogen-free thermoplastic resin. A system such as this, however, is quite expensive [4].

In view of the usually small diameter of the fibers, an efficient daylighting set-up requires a parabolic collector to track the sun and concentrate its light. Optical fibers intended for *light transport* need to propagate as much light as possible within the core; in contrast, optical fibers intended for *light distribution* are designed to let part of the light leak through their cladding [5].

D. Transparent hollow light guides

Figure 4: The Copper Box, venue for Handball at the 2012 Summer Olympics, made use of light tubes to reduce energy use [6]

A prism light guide was developed in 1981 by Lorne Whitehead, a physics professor at the University of British Columbia and has been used in solar lighting for both transport and distribution of light. A large solar pipe based on the same principle has been set up in a narrow courtyard of a 14-floor building of a Washington D.C. law firm in

2001, and a similar proposal has been made for London. A further system has been installed in Berlin.

The 3M company developed a system based on optical lighting film and developed the 3M light pipe, which is a light guide designed to distribute light uniformly over its length, with a thin film incorporating microscopic prisms, which has been marketed in connection with artificial light sources, e.g. sulfur lamps.

In contrast to an optical fiber which has a solid core, a prism light guide leads the light through air and is therefore referred to as hollow light guide.

The project ARTHELIO, partially funded by the European Commission, was an investigation in years 1998 to 2000 into a system for adaptive mixing of solar and artificial light, and which includes a sulfur lamp, a heliostat, and hollow light guides for light transport and distribution.

Disney has experimented in using 3D printing to print internal light guides for illuminated toys [6].

E. Fluorescence based system

In a system developed by Fluorosolar and the University of Technology, Sydney, two fluorescent polymer layers in a flat panel capture short wave sunlight, particularly ultraviolet light, generating red and green light, respectively, which is guided into the interior of a building. There, the red and green light is mixed with artificial blue light to yield white light, without infrared or ultraviolet. This system, which collects light without requiring mobile parts such as a heliostat or a parabolic collector, is intended to transfer light to any place within a building. By capturing ultraviolet the system can be especially effective on bright but overcast days; this since ultraviolet is diminished less by cloud cover than are the visible components of sunlight [7].

III. PROPERTIES AND APPLICATIONS

A. Solar and hybrid lighting systems

Solar light pipes, compared to conventional skylights and other windows, offer better heat insulation properties and more flexibility for use in inner rooms, but less visual contact with the external environment.

In the context of seasonal affective disorder, it may be worth consideration that an additional installation of light tubes increases the amount of natural daily light exposure. It could thus possibly contribute to residents´ or employees´ well-being while avoiding over-illumination effects.

Compared to artificial lights, light tubes have the advantage of providing natural light and of saving energy. The transmitted light varies over the day; should this not be desired, light tubes can be combined with artificial light in a hybrid set-up [8].

Some artificial light sources are marketed which have a spectrum similar to that of sunlight, at least in the human visible spectrum range, as well as low flicker. Their spectrum can be made to vary dynamically such as to mimick the changes of natural light over the day. Manufacturers and vendors of such light sources claim that their products can provide the same or similar health effects as natural light. When considered as alternatives to solar light pipes, such products may have lower installation costs but do consume energy during use; therefore they may well be more wasteful in terms of overall energy resources and costs.

On a more practical note, light tubes do not require electric installations or insulation, and are thus especially useful for indoor wet areas such as bathrooms and pools. From a more artistic point of view, recent developments, especially those pertaining to transparent light tubes, open new and interesting possibilities for architectural design [9].

B. Security applications

Due to the relatively small size and high light output of sun pipes, they have an ideal application to security oriented situations, such as prisons, police cells and other locations where restricted access is required. Being of a narrow diameter, and not largely affected by internal security grills, this provides daylight to areas without providing electrical connections or escape access, and without allowing objects to be passed into a secure area.

Figure 5: Taipei 101, the tallest and largest *green building* of LEED Platinum certification in the world since 2011 [10]

C. Green building

Green building (also known as green construction or sustainable building) refers to a structure and using process that is environmentally responsible and resource-efficient throughout a building's life-cycle: from siting to design, construction, operation, maintenance, renovation, and demolition. In other words, green building design involves finding the balance between homebuilding and the sustainable environment. This requires close cooperation of the design team, the architects, the engineers, and the client at all project stages. The Green Building practice expands and complements the classical building design concerns of economy, utility, durability, and comfort [10].

Leadership in Energy and Environmental Design (LEED) is a set of rating systems for the design, construction, operation, and maintenance of green buildings which was Developed by the U.S. Green Building Council.

Although new technologies are constantly being developed to complement current practices in creating greener structures, the common objective is that green buildings are designed to reduce the overall impact of the built environment on human health and the natural environment by:

- Efficiently using energy, water, and other resources
- Protecting occupant health and improving employee productivity
- Reducing waste, pollution and environmental degradation

A similar concept is natural building, which is usually on a smaller scale and tends to focus on the use of natural materials that are available locally. Other related topics include sustainable design and green architecture. Sustainability may be defined as meeting the needs of present generations without compromising the ability of future generations to meet their needs. Although some green building programs don't address the issue of the retrofitting existing homes, others do, especially through public schemes for energy efficient refurbishment. Green construction principles can easily be applied to retrofit work as well as new construction.

A 2009 report by the U.S. General Services Administration found 12 sustainably designed buildings cost less to operate and have excellent energy performance. In addition, occupants were more satisfied with the overall building than those in typical commercial buildings [11].

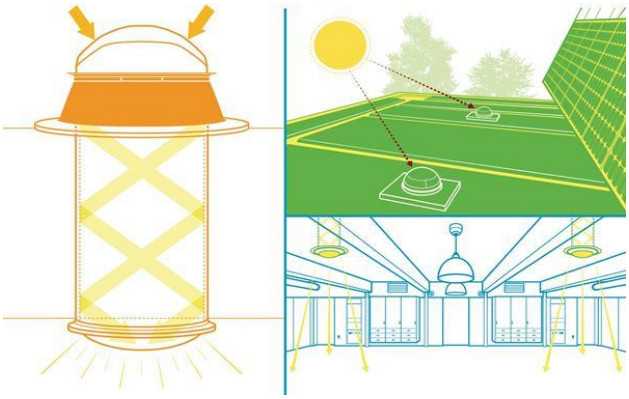

Figure 6: Tubular daylighting devices (TDDs) present a way to collect, transport, distribute, and control daylighting [14]

IV. TUBULAR DAYLIGHT DEVICES (TDDs)

A tubular daylighting device (TDD), also known as a light tube, is installed at the roof level and transmits light to a focused area of the interior. These somewhat resemble recessed ceiling light fixtures when viewed from inside the interior. They allow minimal heat transfer, as opposed to traditional skylights, because they have less surface area. TDDs harvest daylight through a roof-mounted dome with diameters ranging from about 10 inches for residential applications to 22 inches for commercial buildings. Made from acrylic or polycarbonate formulated to block ultraviolet rays, the dome captures and redirects light rays into an aluminum tubing system that resembles ductwork [12].

Tubular daylighting devices use modern technology to transmit visible light through opaque walls and roofs. The tube itself is a passive component consisting of either a simple reflective interior coating or a light conducting fiber optic bundle. It is frequently capped with a transparent, roof-mounted dome 'light collector' and terminated with a diffuser assembly that admits the daylight into interior spaces and distributes the available light energy evenly (or else efficiently if the use of the lit space is reasonably fixed, and the user desired one or more 'bright-spots').

Tubular daylighting devices are often used in residential settings to add natural light.

The use of tubular daylighting devices in commercial applications is known as daylighting. Daylighting falls under the larger umbrella of sustainable or green building.

The tubular daylighting device was invented by Solatube International in 1993 and is used to provide daylighting to residential and commercial buildings, contributing to sustainability from a lighting standpoint and reducing the carbon footprint. Other manufacturers of TDDs include Velux/Sun Tunnel, ODL, Natural Light and US Sunlight [13].

Windows and skylights have opened our rooms to sunlight, but heat gain, glare, and occasional water infiltration tagged along. The modern-day tubular daylighting device (TDD), invented in the mid-1980s, presented a way to collect, transport, distribute, and—perhaps most importantly—control daylighting using advanced technology in material science and physics [14].

Light tube is a transparent round tube that is used to transport natural light. The light tube, which is lined with highly reflective material, leads the light rays through the rooms, starting from an entrance point located on its roof. The entrance point comprises a dome, which has the function of collecting and reflecting as much sunlight as possible into the tube. They have directional ‘collectors’, ‘reflectors’ that assist in collecting and directing light down the tube [15].

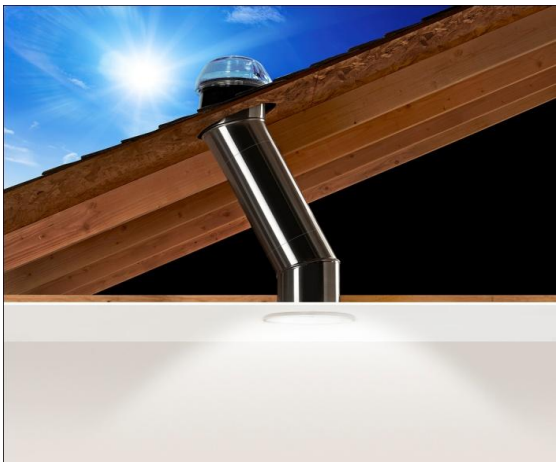

Figure 7: Solatube Daylighting Systems harvest sunlight at the roof level and transmit it through a highly reflective tube into interior spaces at the ceiling level [12]

V. CONCLUSION

In this paper, an attempt was made to explore various available methods to make use of the natural daylight which is available to us free of cost. Out of the many methods discussed above, the Tubular Daylight Devices are found to be more effective. Besides brightening illumination, they also serve us with numerous additional benefits such as daylighting consistency, better quality of light output, energy efficiency, affordability, ease of installation, versatility and finally the ease of maintenance.

This paper will help the researchers to understand the following:

i. Different methods of using the natural daylight
ii. Ways to harvest the daylighting
iii. Most appropriate method of daylighting, as per the requirements

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