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MODELING OF VERTICAL LIGHT PIPES FOR DAYLIGHT ILLUMINATION OF INDOOR INDUSTRIAL BUILDINGS

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Abstract
The paper considers a daylight transport system model with light pipes, which provides the illumination of building production areas with natural daylight. The presence of natural light generates considerable physiological effect and affects the energy consumption in a building. The paper discusses correct application of a daylight pipe system based on the use of natural free energy sunlight sources. The advantage of a vertical light pipe application is that the daylight is delivered to the given space. The light pipe system is an effective method of daylight improvement in the existing buildings. The paper presents approaches to illumination modeling using light pipes for achievement of the desired lighting result. Practical examples of modeling for different types of light tubes are given.

Keywords
light pipe, daylight, illuminance, energy saving, light transportation

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The research was carried out in Instrumentation Department Laboratory. The simulation results can be applied for both practical design and teaching purposes.

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МОДЕЛИРОВАНИЕ ВЕРТИКАЛЬНЫХ СВЕТИЛЬНИКОВ ДЛЯ ДНЕВНОГО ОСВЕЩЕНИЯ ВНУТРЕННИХ ПОМЕЩЕНИЙ ПРОМЫШЛЕННЫХ ЗДАНИЙ

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Аннотация
Рассмотрена модель системы передачи света со световыми трубами, обеспечивающая естественное освещение производственных площадей зданий. Наличие естественного света создает значительный физиологический эффект и влияет на потребление энергии в здании. Обсуждается правильное применение системы труб дневного света, основанной на использовании естественных источников солнечного света. Преимущество использования вертикальной световой трубы заключается в том, что дневной свет доставляется в определенное пространство. Представлены подходы к моделированию освещения с использованием световодов для достижения желаемого светового результата. Приведены практические примеры моделирования для различного вида световых труб.

Ключевые слова
световая труба, дневной свет, освещенность, энергосбережение, передача света

Благодарности
Исследования выполнены в лаборатории приборостроения. Результаты могут найти применение как для целей практического проектирования, так и для обучения.

Introduction

In recent years, the consumption of daylight and energy in both existing and new buildings of construction industry has become an increasingly serious issue. The problem lies in analysis, assessment based on position, orientation, shading, climate, and materials used for commercial and residential buildings. Currently, homeowners and owners of commercial buildings also think about applying of natural light and lowering their annual electricity bill. Buildings can be cost effective by using a passive daylight system and capitalizing on a natural daylight system through light pipes [1]. The paper is focused more on the natural light usage adaptation and the daylight pipe presentation as the basic form of an in-building light source.

Modern architectural styles now highlight various passive and active daylight systems like [2] and [3]. Many foreign governments have provided funding for light pipe daylight systems even involving new strategies to examine the benefits. Permanently open windows cannot provide enough light to indoor lighting for indoor premises and forcefully people have to work with electric light.

Many adaptations of various strategies for gaining benefits of natural energy application by the use of light pipes are considered [4]. But the right and appropriate efforts can be possible only by involving engineers, architectures and also backyard designers' inventions of all kinds.

Windows fail to give significant light energy to the inside or middle parts of the building. The advantages of pipe daylight system application should be taken into account with regard to the electric lighting cost. The improvement of lighting level is an important factor for the workplace even if the placement of top light is a crucial factor [5]. The paper is focused on the innovative pipe light technology to achieve significant amount of natural light. The proposed approach provides vertical light pipe system that has more advantages for fixed three-floored building. Particularly, this is beneficial for buildings like factory and mill. Glare control is important for thermal comfort and possibilities of various kinds of pipes [6]. Energy saving is an important world problem and the demand of the present-day life [7].

Climate conditions and the daylight vary inside a building with regard to time, and color, and intensity is its indicator. Also the illuminance value varies during the day depending upon seasons. Even the shape, size and location of the building and the position of the window are critical.

Sunlight as a natural lighting provides positive impact to the human eyes. Innovative light pipe daylight system can reduce great electrical demands. Contribution of light pipe daylight system lies in the fact that people will turn off artificial lights. Due to light pipe technologies a significant amount of energy will be saved throughout the year during day hours.

Basically, half of the total energy bill costs depends on electric lighting considering any building. Proper window positioning also makes some reduction in electrical demand, that is why both light pipe and windows are of great importance for annually reduction of energy load. Ultraviolet rays that affect positively the human skin are more intensive during day hours. Poor daylight and poor ventilation lead to the feelings of tension and depression.

Light pipes of various size and shape are required to the building, and simulation techniques are applied for their calculation. The simulation output helps to judge on the required modification. All output results can be shown through the web based tools for time-saving. In practice, various CAD models are used aimed at taking prior knowledge of architectural design concepts and implementation of various design considerations for the gap of less daylighting.

Application of building model

Instead of expensive electric lighting used in the interior zones of the buildings, mills or warehouses, the adaptive reuse of natural daylight through the light pipe system can be the best solution for reducing electric bills.

Various buildings differ depending on the subdivided zones for flexibility space requirements. Some buildings have larger rooms according to the builder demands.

Daylight penetration through the windows is not enough to illuminate the large industrial areas. The light pipe application, where a light pipe is extended from the roof top, provides natural light in the daytime. The paper considers large areas where the effect of light pipe application is clearly visible.

The dimensions of the used windows are formulated in Table 1. All windows used throughout the project are of the same dimensions as mentioned in Table 1.

Different pipes with heights equal to 3 m and 6 m are considered. The location, timing and all other details are shown in Table 1 for simulation consideration.

Parameters

The attenuation parameter of the pipe can be obtained as [8]

$$T = R^{l\cdot\tan\theta/d_{\text{eff}}},$$

where R is the reflectance of the pipe surface; l is the pipe length; θ is the angle incidence of the light rays with the pipe, d_{eff} is the effective diameter of the pipe.

For a cylindrical straight light pipe with a diameter of D:

$$d_{\text{eff}} = \pi D/4.$$

Aspect ratio basically depends on the length and the diameter of the pipe. Aspect ratio is low when the length is small that means:

Table 1. Table label

Location	Time	Orientation	Factory Room Dimension, m	Type	Dimensions of window, m
Pune, Maharashtra, INDIA	August 16	North-South facing	36 × 13 × 2.8	Illuminance	1.43 × 1.5

aspect ratio = pipe length/pipe diameter.

Energy loss will be low if the aspect ratio is less.

Total light output Φ [9] depends on:

$$\Phi = (E \times A)/(UF \times M),$$

where A — area of the room; E — average horizontal illuminance on the working plane, lx; M — maintenance factor; UF — utilization factor.

The light output also depends heavily on the materials used, the pipe length, and the calculation time throughout the year with various climatic strategies. The paper presents the comparison of light pipes effectiveness in the daytime. Implementation of light pipe strategies is applicable for electric energy saving.

Design tools

Sketchup tool is used for factory model design and all the models are designed based on Sketchup CAD Tool. For computational speedup we use web based Lightstanza tool for each output result. Sketchup is considerable for easier architecture model design. Lightstanza is used for daylight calculation as it is very simple and web based. Sketches can be easily inserted into the Lightstanza environment and collaboration work can be also possible. Lightstanza reads easily the red, green, and blue reference values directly from materials used and that makes simple to obtain combined reflectance value.

The color of industry walls is considered as E02 that is ISO 105 standard[1]. It specifies the color of textiles. Spanish tile is chosen for the roof providing the natural beauty of the industrial building. The glass material used for the light tube is a translucent blue glass appropriate for transportation of daylight. The view qualities can be changed in the simulation process according to the required type of light. Various pipe length and diameter can also be taken into consideration. This study deals with the pipe diameter of 1 m and it remains invariant for the simulation throughout the paper. Corrugated shiny surfaces are considered for the industrial building facades. The design tool provides minimum time for daylight calculation.

[1] ISO 105-E02:1994 Textiles — Tests for colour fastness — Part E02:Colour fastness to sea water (IDT).

Simulation results

A large industrial factory room was taken as an example of simulation for judgment of the pipe model system potential.

Application of light pipe provides additionally thermal effect and complies with requirements for holes in the existing building models, and it is beneficial for three-floored building.

For building configuration shown in Fig. 1, *a*, the results are presented in Fig. 1, *b*, *c* and *d* for different timings. The results show clearly that at 12 a.m. the middle section of the building has got low-light-level conditions. With the use of low light pipe an illuminance increase is clearly visible as compared to all models related to1[2] a.m. time period.

Fig. 2, *a* shows 5 small pipes installed on the roof of the factory building with each pipe diameter of 1 m and the distance of 7 m between them. Fig. 2, *b*, c and *d* show the results for 10 a.m. in the morning, 12 a.m. and 3 p.m. in the afternoon, respectively. If the factory or the industrial building have two floors, three-meter pipes are used instead of small ones.

Fig. 3, *a* shows a factory building with 5 three-meter pipes and a diameter of 1 m for each one placed at a distance of 7 m apart from each other. Fig. 3, *b*, *c* and *d* represent results for three-meter pipes. If an industrial building is a three-floored, we implement six-meter pipe for the analysis.

The perfect results were reduced only when the environment conditions were cloudy. Various time zones

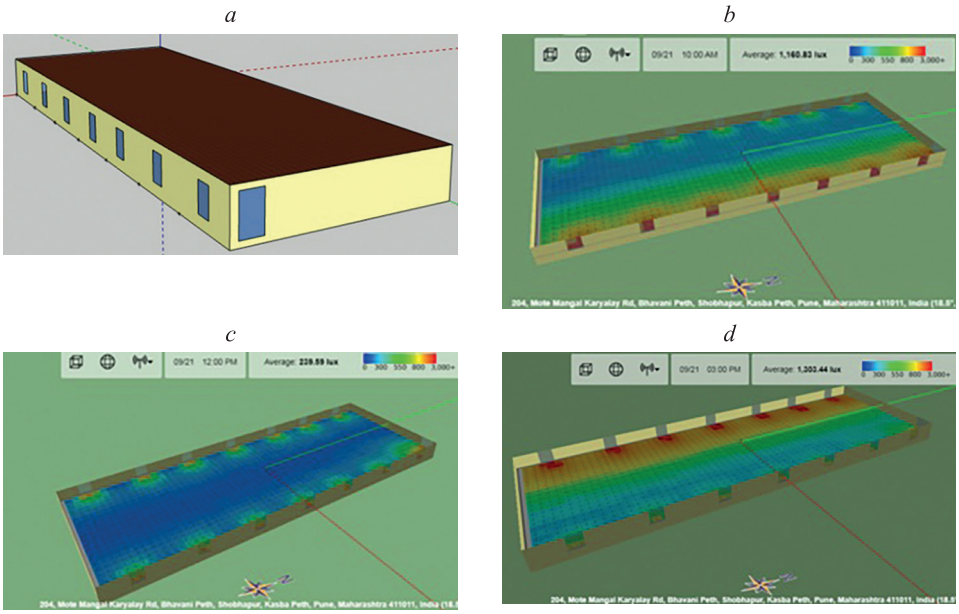

Fig. 1. Factory building (*a*); simulation without pipe application at: 10 a.m. (*b*); 12 a.m. (*c*); 3 p.m. (*d*)

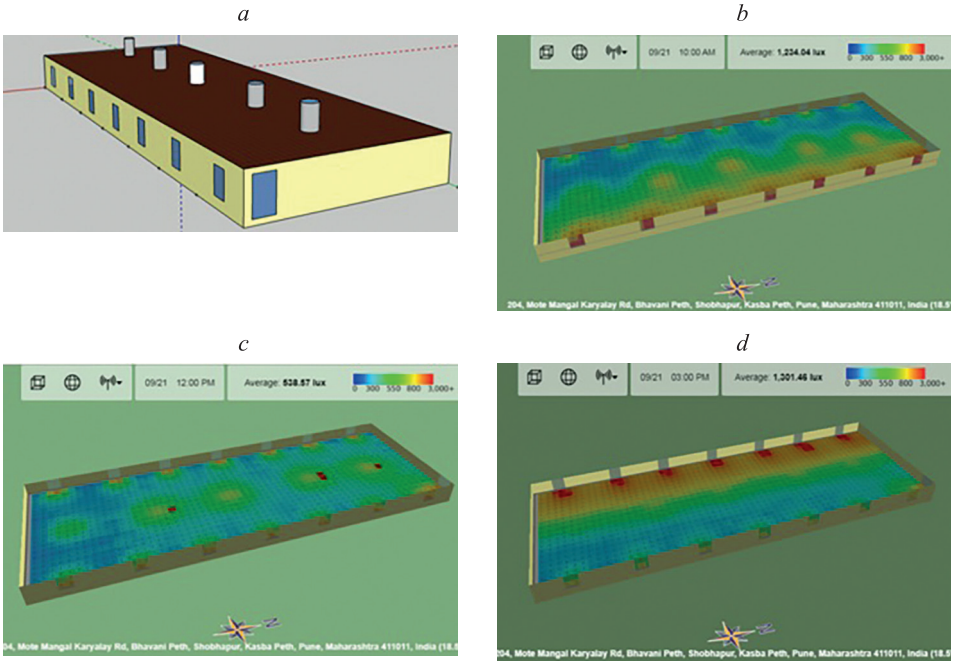

Fig. 2. Factory building with small pipes (*a*); simulation with small pipes at: 10 a.m. (*b*); 12 a.m. (*c*); 3 p.m. (*d*)

can be simulated easily by web based simulation tool throughout the year. The light pipe system has shown good potential result according to the opinion of many researchers [10]. Natural daylight can be darkened in the room [11]. Light pipe and light shelf are used for the best energy saving technologies [12] and are applicable for energy consumption to be reduced.

Fig. 4, *a* shows a factory building with six-meter high pipes and a diameter of 1 m each placed at 7 m apart from each other. Fig. 4, *b*, *c* and *d* represent the results for six-meter pipes at 10 a.m., 12 a.m. and 3 p.m., respectively.

There are various strategies for the illuminance and daylight factor determination at the workspace. The color, texture, material and change in orientation produce significant impact on the light level. Therefore, the study of various parameters gives valuable output, which helps to analyze the existing design or create new design for shopping malls, residential and industrial buildings with large saving of energy. Simulation introduces a new set of parametric study for specific solution of any problem.

Table 2 represents the illuminance value increase by using light pipe for specific height of the pipe. Early

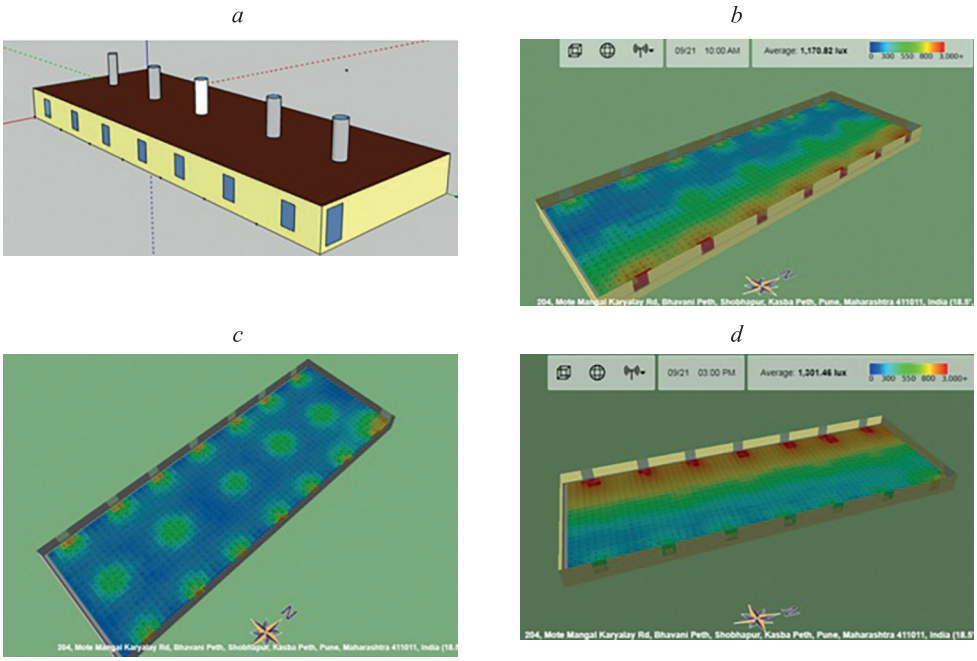

Fig. 3. Factory building with three-meter pipes (*a*); simulation with three-meter pipes at: 10 a.m. (*b*); 12 a.m. (*c*); 3 p.m. (*d*)

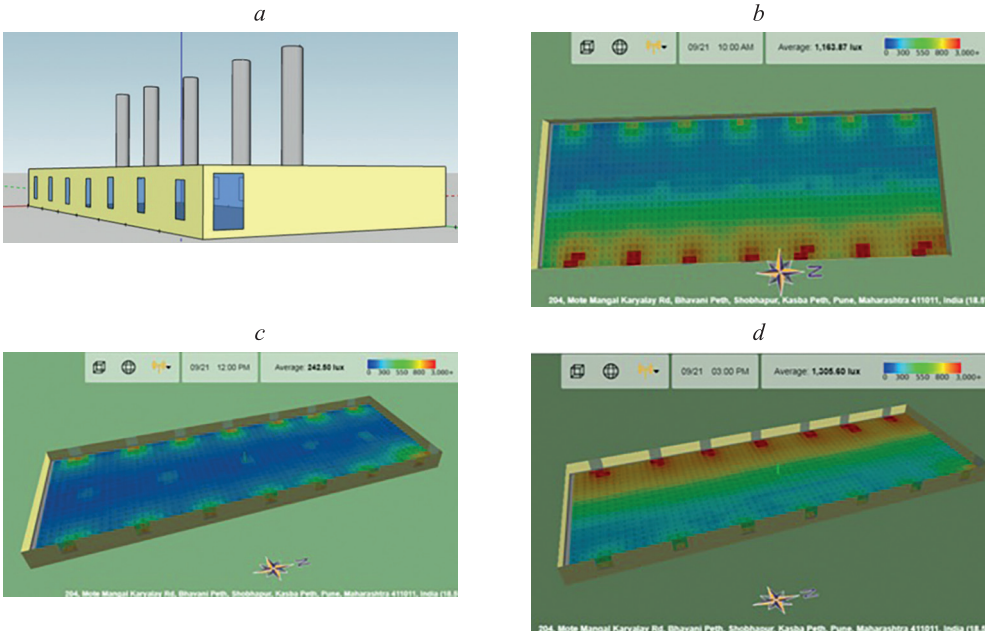

Fig. 4. Factory building with six-meter pipes (*a*); simulation with six-meter pipes at: 10 a.m. (*b*); 12 a.m. (*c*); 3 p.m. (*d*)

Table 2. Average illuminance in the middle of the factory, lx

Light pipe arrangement	Time		
	10 a.m.	12 a.m.	3 p.m.
No light pipe	300	150	450
With small height	600	400	550
With three-meter height	350	300	550
With six-meter height	280	250	550

decision can be possible by simulation for single roof or double roof depending upon the roof height.

The proposed idea of light pipe system provides the energy saving by the number of impacts reducing electrical light energy. Study and application of a light pipe is a vital and powerful element for providing significant amount of daylight for good luminous environment.

Conclusions

The study presents an attempt to discuss light pipe application in view of building location, roof type, windows location with regard to walls, roof harvesting potential of light, light shelf strategies and consideration of applied materials. Sustainable modification makes advantage in energy cost. Also modern control system can be useful for opening and closing the heads of light pipes depending on the thermal and comfort conditions of the room or the building. Preliminary research is highly valuable and gives advantages to the designers for the design process optimization. Designers also often overlook various new tools and take some integrated approaches for making the balance in the daylight illumination levels of all kinds.

The main intention of this paper is to demonstrate the effect of light pipe daylight system, which provides adequate light to the building indoor premises. It is realized by simulation through pipe system and it becomes an early design solution which makes benefits for the building designers. Implementation of light pipe system into the buildings will provide potential energy saving, and light pipe technologies will also make economic benefits.

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