Effect of various bending angles on a passive light pipe for eco-daylighting systems

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Effect of various bending angles on a passive light pipe for eco-daylighting systems

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Abstract. Daylighting systems is one of alternative to reduce a high energy consumption that caused by artificial lighting. However the use of passive light pipes in daylighting systems with various bending angles may affect the efficiency of light transfer from the sunlight to the room. Thus this paper is proposed to study the effect of various bending angles on a light pipe. Three bending angles of light pipe, which are 0°, 30° and 45°, were analyzed through the experimental works. A test bed room was constructed in order to simulate daylighting in a room. The results were then visualized in graphs based on the efficiency by considering the maximum average internal illuminance achieved by each light pipe. From the results, it shows that when the bending angle increases, the average internal illuminance decreases. And the highest average internal illuminance was achieved by 0° light pipe.

Keywords: daylighting, light pipe, bending angles, external illuminance, internal illuminance.

1. Introduction

Energy consumption is increasing rapidly in Malaysia from year to year[1]. Artificial lighting is one of the main factor of this high energy consumption which leading to high electricity as well. Building constitutes approximately 30-45% of the global energy demand with statistic result shows that 25-35% is constituted by lighting in office building[2]. Daylighting, the use of natural light for illumination of basic daily activities is used as an sustainable approach in alternative lighting system to reduce the use of artificial lighting effectively and efficiently[3]. Daylight is known as the primary natural light source which is applicable during daytime for indoor illuminance purpose as well as a visual connection between indoor and outdoor[4, 5].

Light pipe which is also known as light tube has becoming well-known result in an increase amount usage of light pipe system[3]. It is commonly used in daylighting technology which is made up by collector, light pipe and diffuser. A collector is used to collect daylight from outdoor which will be reflected in the light pipe consisting of aluminum with reflectance of about 95-99% to be diffused through the diffuser as indoor illuminance for basic daily indoor usage[5].

The use of light pipe has several advantages over the use of windows although both are using daylight which is renewable for illuminance purpose. For typical office workspace, the value of illuminance is in the range of 250 – 500lux [6]. However, the illuminance level will decrease when work plane is far away from window [5]. Light pipe will be able to solve this problem as well as applied to deep plan building or room without window. Therefore the purpose of this study is to observe and analyze the effect of bending angles of light pipe to the value of internal illuminance. The performance of daylight system is measured through the maximum value of internal illuminance.

2. Daylight Observation for Malaysia's Climate

Daylight observation on climate was conducted at Campus Pauh Putra, Unversiti Malaysia Perlis (UniMAP), Perlis, Malaysia for four months from September 2016 until December 2016. The data were collected at hourly interval from 8.00 am to 5.00 pm for external illuminance, altitude and azimuth to simulate the working office hours. External illuminance was collected by using light meter. A compass bearing board was constructed for the measurement of azimuth and altitude as shown in エラー! 参照元が見つかりません。. Azimuth is measured from the north direction along the horizon while altitude is calculated by using Pythagorean Theorem equation as shown in Equation 1 which is the inverse tan of length of shadow formed by object over the original length of object.

$$tan\,\alpha = \frac{l_o}{l_x} \tag{1}$$

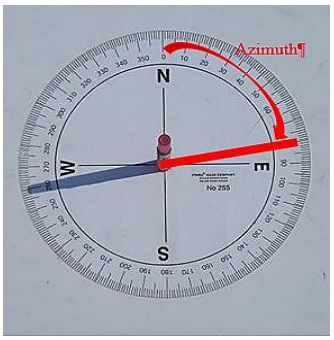

Figure 1: A compass bearing board

Figure and Figure 3 show the average external illuminance obtained from 8.00 am to 5.00 pm and altitude versus azimuth for four months, respectively. The highest average external illuminance of 94,100lux was achieved at 12.00 pm in October and lowest average external illuminance is 14,606lux 5.00 pm in November. This high average external illuminance has exceeded the required indoor illuminance which represent that Malaysia has a potential for using light pipe in daylighting system.

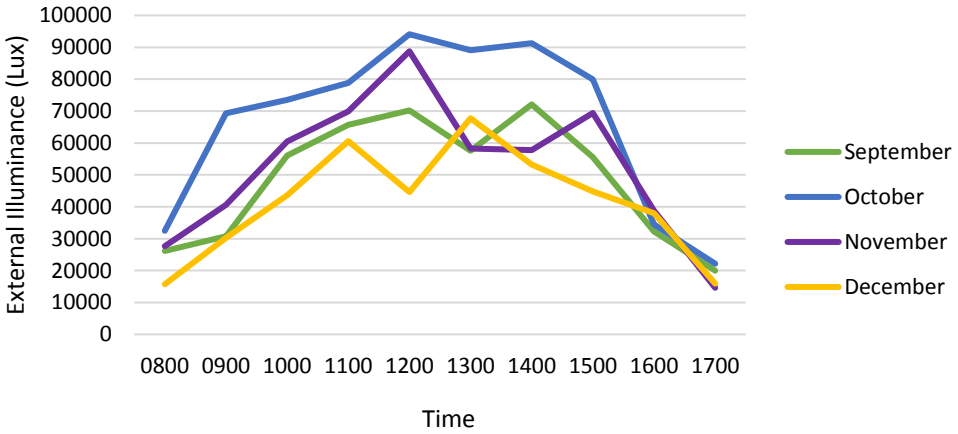

Figure 2: Average external illuminance versus time

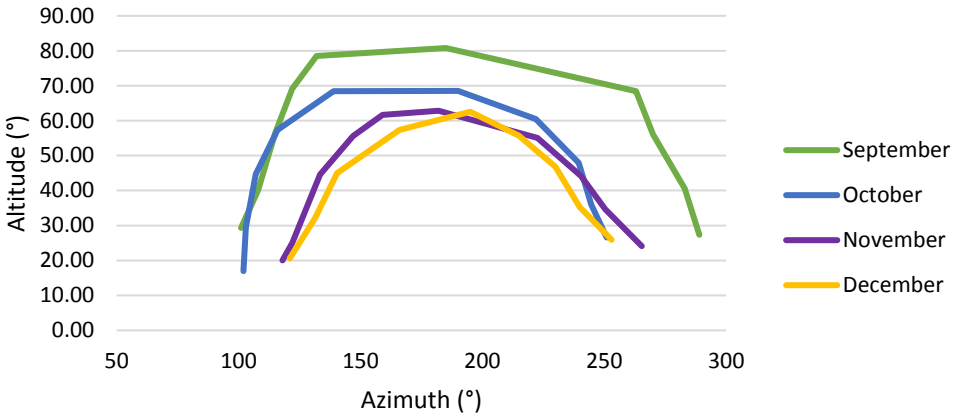

Figure 3: Altitude versus azimuth

3. Experimental setup

A test bed room with dimension of 1.8m (L) × 0.9m (W) × 2.4m (H) was constructed as in Figure 4. It was made of plywood. A door hinge was attached at one side to enable opening of the house for placement of light meter with data logger as well as for the installation of the light pipe during experimental works.

Figure 4: Test bed room for experimental works

Monodraught Sunpipe with bending angles of 0°, 30° and 45° were installed to the test bed room for each of the experimental work as shown in エラー! 参照元が見つかりません。. The experiments were conducted for five days from 8.00 am to 5.00 pm. Both the external and internal illuminance was recorded at hourly interval.

(a) (b) (c)

Figure 5: Actual light pipe with bending angles (a) 0°, (b) 30° and (c) 45°

The efficiency of the light pipe is calculated in percentage by using the maximum average internal illuminance over external illuminance as shown in Equation 2.

$$efficiency = \frac{Maximum\ average\ internal\ illuminance}{External\ Illuminance} \times 100\% \quad (2)$$

4. Results and Discussions

The experimental data was collected for five days from 8.00 am to 5.00 pm for each of the bending angle configuration. The result was plotted by using the average external illuminance and average internal illuminance. Figure 6 - 8 show the average external illuminance and average internal illuminance for each light pipe with bending angles of 0°, 30° and 45°, respectively. The internal illuminance have the similar trend for all light pipes which is low in early morning and late afternoon while higher in the midday. This signifies that the maximum internal illuminance can be achieved when the sun angles is aligned with the angle of light pipe.

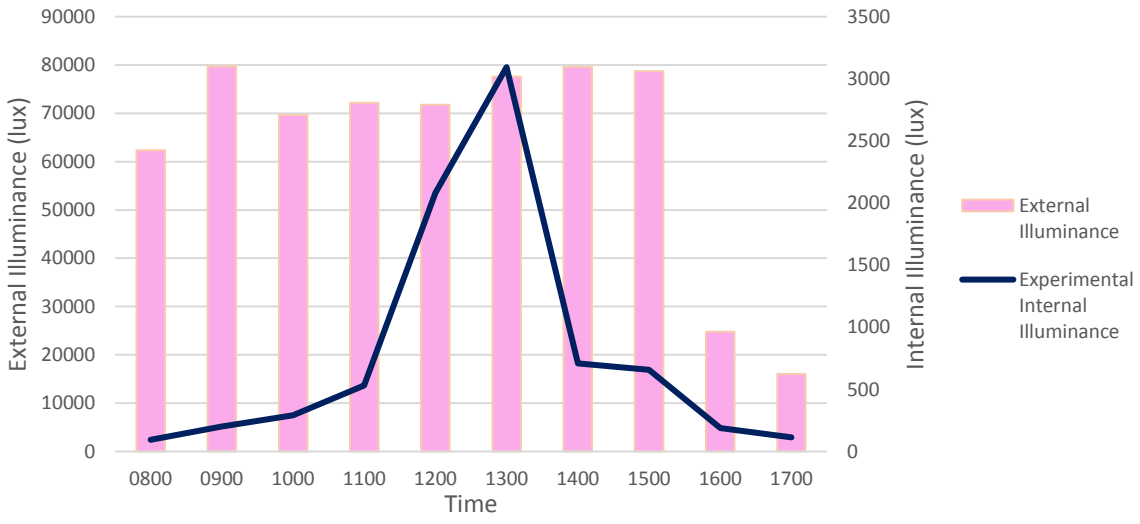

Figure 6: Average external illuminance and average internal illuminance over time for 0° light pipe

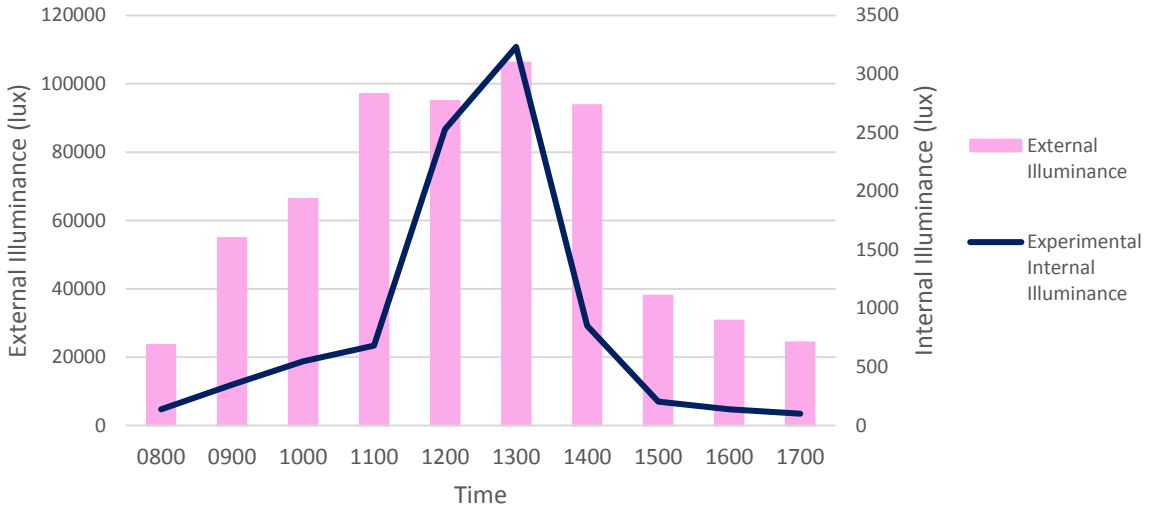

Figure 7: Average external illuminance and average internal illuminance over time for 30° light pipe

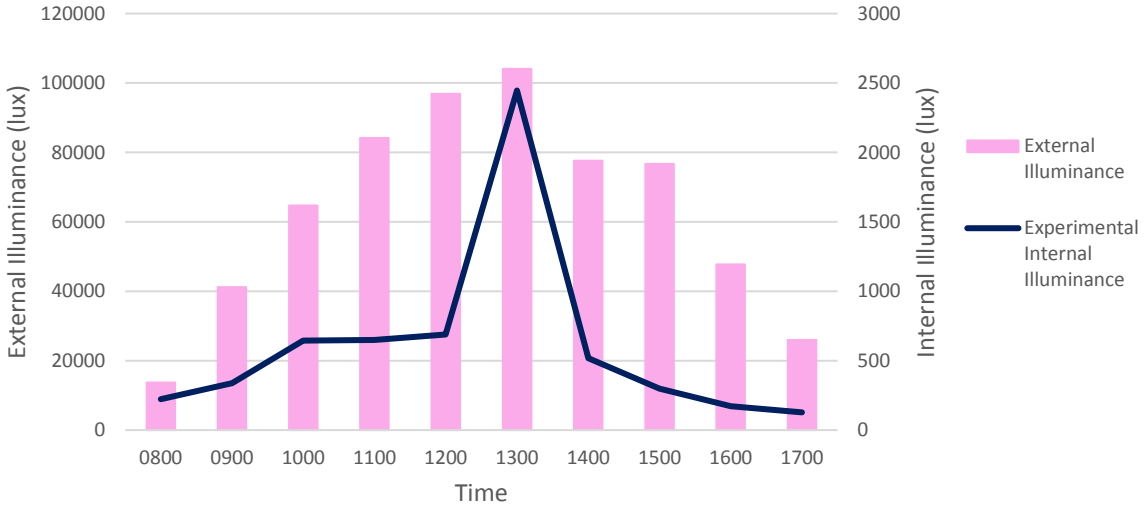

Figure 8: Average external illuminance and average internal illuminance over time for 45° light pipe

From the results, the average optimum lux value for all bending angles of light pipe was achieved at 1.00 pm. This average optimum internal illuminance was used to calculate the efficiency of each light pipe between both experimental and simulation works. The light pipe with 0° bending angle which is also known as the straight light pipe has the highest efficiency at 4.0%. It is followed by bending angle of 30° and 45° with efficiency of 3.0% and 2.4%, respectively. This shows that 0° bending angle light pipe have the least loss of daylight during the transmission from outdoor to indoor.

5. Conclusion

This study shows that the external illuminance obtained in Perlis, Malaysia is feasible for the application of an eco-daylighting system. Most of internal illuminance obtained for each hour exceeds the 250lux which is the minimum value for a typical office workspace. It is also observed that the bending angle will affect the internal illuminance. The value of internal illuminance will decrease with the increment of bending angle. The best performance in term of efficiency is achieved by light pipe with 0° bending angle which is known as straight light pipe with maximum average internal illuminance around 3000 lux and efficiency of 4.0%. This is due to the shape itself does not have any bending which result in more successful equivalent reflection.

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