Improving the Performance of Light Pipe System Using Laser Cut Panel

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Abstract. Light pipe systems (LPS) are simple devices that allow the transmission of daylight into interiors of buildings. It is a convenient concept for illumination of windowless parts of buildings. The light performance of this is highly dependent on the solar altitude due to the small inlet aperture. Placing the laser-cut panel (LCP) at the entrance aperture in light pipe system, will increase the light performance during low solar angle. This paper presents the results of light performance a 400mm diameter light pipe integrated with a laser-cut panel at entrance aperture as collector. For that reason, this research adopted an experimental approach to compare the light pipe performance via 1:10 scale model. Two scale models were built. LCP in the form of pyramids was fitted at the entrance aperture of light pipe in different tilted angle 40° and 47.5°. The system has been monitored 30 minutes interval with lux meter to evaluate the improvement light performance on a working plane for 6 days under good sky condition. The results of this experiment shows that LCP with 40° tilted angle performed better than 47.5° tilted angle. The light pipe with LCP as collector the minimum recommended illuminance by Malaysian Standard (MS) 1525:2007 can be achieved as early at 8am.

1. Introduction

Daylighting is an introduction natural light to provide illumination in building during day time. It was the only source of light since the beginning of the built dwelling. With modern lifestyle nowadays, people spend most of their lives in building such as offices, houses, factories, schools and supermarket. The daylight strategy has to be designed to simultaneously reflect the needs of the users and the requirements of the building. There are challenges to architect in enhancing daylight illumination into the internal spaces for buildings with limited façade to placing windows. Since a roof is the element directly exposed to the sunlight, light pipes system could be introduced.
Light pipe systems are linear devices that channel daylight into the core of a building [1]. The performance of a light pipe system as natural daylighting system has been reported in a number of studies [2]–[6]. Malaysia as a tropical country received about 7 hours per day of sunshine has been potential to introducing light pipe system as a tool in an indoor daylight system [7]. However, this study found that daylight performance at early morning and late evening are low. To overcome these shortcomings, placing the laser cut panel (LCP) as a collector at the entrance aperture in light pipe system, will increase the light performance during low solar angle [8], [9]. Figure 1 is a comparison of light pipe system with and without LCP. Figure 1 (a) shows that when low angle light passing through a clear dome its transmitted by multiple reflection. Whereas figure 1(b) shows how a LCP redirects light more axially along the light pipe.

![Figure 1. Daylight transmission with and without LCP [8]](image)

Laser-cut panel is parallel laser cutting in transparent acrylic panel, which provides powerful deflection of off-normal light [10]. Figure 2 illustrates the concept of the LCP, tilted at a particular angle, indicating as to how low angle light are redirected straight down for which the design parameters are the tilt angle, depth (D) and the width (W). Study by [11] found that LCP panel tilted at 20\(^0\) and facing the sun altitude under 60\(^0\) has increased on average by about 100% of light performance. He also concludes in his study that LCP in the form of pyramids is the best design for improving light performance. Furthermore, study by [12] with varying tilt angle of the LCP found that light pipes with a LCP at the entrance aperture improved the illumination inside an integrating box.

According to Malaysian Standard (MS) 1525:2007, recommended illuminance levels for infrequently used area such as corridor, entrance or lobbies are 100 lx to 200 lx and for working area such as office, kitchen and classroom recommended illuminance levels are 300 lx to 500 lx. From previous study done by [7] the optimal duration offered by the light pipes system is between 10am to 4pm. In the early morning and late evening the internal illuminance does not meet the requirement. The purpose of this study is to investigate the light performance of light pipe system using LCP as a collector in Malaysian climate. For that reason, a field work by utilizing scaled model has been done.
2. Methodology

To investigate the daylight performance of this system, two models were constructed using plywood with scale of 1:10 with dimensions of 400mm x 400mm x 430mm. These models were represented a typical room. The indoor of the models finished with white paint. For easy access to placing lux meter into the models, top of the panels was made removable. 40mm diameter straight light-pipe has been mounted at the centre of the top panel to represent the light pipe system. The pipe was fabricated using mirrored finished material easily available in Malaysian market. LCP in different tilted angle 40° (figure 3) and 47.5° (figure 4) were fitted at the entrance aperture with pyramid configuration (figure 5). The models were windowless design, in order to get the absolute illuminance transmitted by the light pipe.

![Figure 2. Light deflected down by tilting the laser cut panel [9]](image)

**Figure 2.** Light deflected down by tilting the laser cut panel [9]

**Figure 3.** Pyramid Laser Cut Panel (LCP) collector with 40° tilt

**Figure 4.** Pyramid Laser Cut Panel (LCP) collector with 47.5° tilt

The measurement was conducted at an opened area in Universiti Tun Hussein Onn Malaysia. Illuminance level monitoring was conducted on 24 October 2016 to 8 November 2016, from 8:00 am to 6:00pm at 30 minutes intervals. The study selected six days without any rain for the analysis [13]. Extech 401025 Digital Light Meters were used to measure internal and external illuminance levels. The sensors were placed at the centre of the models (figure 6). The models were placed on the table to
provide a typical desk level (figure 7). Both models were tested concurrently in this experiment. In order to investigate the daylight performance, measurement for light pipe without pyramid collector were also taken.

![Figure 5. Pyramid LCP collector placed at entrance aperture of LPS](image1)

![Figure 6. Lux sensor place at centre of the model](image2)

![Figure 7. Both windowless models were placed on the table to provide a typical desk level and data observation concurrently](image3)

3. Result and discussion

As mentioned in the literature review, LCP in the form of pyramids is the best design in improving light performance. Therefore, this experiment was to investigate the light performance of light pipe system using LCP in a form of pyramid as a collector in Malaysian climate. Figure 8 presents the average distribution of internal illuminances over the monitoring period for 40\(^{\circ}\) tilted angle. Overall, the reading formed a bell-shaped curved due to dependent of light performance on the solar altitude. Starting from 8 am the illuminance was increased until noon and while times goes, the illuminance was decreased till late evening. The highest internal illuminance was recorded at one o’clock with 728 lux and 576lux for pipe without collector and 40\(^{\circ}\) tilted LCP respectively. While, at low solar angle, the graph shows that the internal illuminance was only 64lux in the early morning and 65lux in late evening for pipe without LCP collector. Interestingly, the internal illuminance level was increased when using LCP as a collector, the internal illuminance was increase to 110lux from 65 lux.

Next, figure 9 shows the results for a 47.5\(^{\circ}\) tilted angle. The results denote that LCP with 47.5\(^{\circ}\) tilted angle also exhibiting incremented internal illuminance level at lower solar angle. The
illuminance was increased from 103 lux to 129 lux in the early morning and 104 lux to 115 lux in the late evening. The highest internal illuminance offered by this angle was 555 lux at one o’clock.

![Figure 8. Light pipes with LCP 40° tilted angle](image1)

![Figure 9. Light pipes with LCP 47.5° tilted angle](image2)

This investigation through measurements of internal illuminances of a windowless scale model reveals that LCP in pyramid configuration can improved the illumination inside the models in Malaysian climate. Figure 10 shows the comparison light performance for light pipe system with LCP in different tilted angle. Overall, the internal illuminance was gradually increase in the morning associated with an increasing of solar latitude and reaches the peaks at noon around 12pm to 1pm. Starting from 2 pm, the illuminance was decreased until late evening.

This study found that using LCP with tilted angle 40°, there was an increase of 71% lighting at 8am. Meanwhile, for the 45.7° tilted angle, the increase was 46%. At 9 pm, although the light performance is better, but the percentage improvement has decreased. It was only 31% and 15% for
LCP tilted angle 40\textdegree{} and 47.5\textdegree{} respectively. This study found that the higher the solar altitude, the effectiveness of LCP is less. Starting from 11am, light pipe system without pyramid collector was performed better than LCP.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure10.png}
\caption{Comparison light performance for light pipe system using LCP in different tilted angle}
\end{figure}

4. Conclusion
In this paper has presented an empirical study of daylighting performance of light pipe system fitted with LCP under Malaysian climate using physical scaled model measurement. The investigation has compared the performance of two LCP collectors in different tilted angle, 40\textdegree{} and 45.7\textdegree{}. The results of this investigation show that LCP collector with 40\textdegree{} tilted angle can improve the light by 71\% in the morning. As early as 8 am, the minimum internal illuminance has been reached by using light pipe system with LCP collector. It is an effective tool for improve the daylight performance of light pipe system in low solar altitude. This study shows that light pipe system with LCP collector can fulfil the internal illuminance recommended by MS 1525:2007.

However, this study has not considered the effects of diameter and length of pipe. Further monitoring activities will evaluate the effects of varying tilted angle and diameters of light-pipes and test room dimensions will be carried out. It is hoped that the findings will contribute significantly to the widespread use of the light-pipe system in Malaysia, thus enhancing the occupant’s well-being and health and contributing to the energy efficiency of buildings.

5. Acknowledgement
The research described in this paper was funded by Ministry of Higher Education Malaysia (MOHE) through Research Acculturation Grant Scheme (RAGS), VOT R064. The authors wish to thank the Centre For Diploma Studies, University Tun Hussein Onn Malaysia for providing a platform to carry out this research.
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