POTENTIAL OF LIGHTPIPES SYSTEM IN MALAYSIAN CLIMATE

Aslila Abd Kadir¹, Lokman Hakim Ismail², Narimah Kasim³ and Masiri Kaamin¹

¹ Department of Civil Engineering, Centre For Diploma Studies, Universiti Tun Hussein Onn Malaysia, Malaysia.

² Department of Design Engineering And Architecture, Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, Malaysia.

³ Department of Construction Management, Faculty of Technology Management and Business, Universiti Tun Hussein Onn Malaysia, Malaysia.

E-mail: aslila@uthm.edu.my

Abstract. Light-pipes system are simple structures that allow the transmission of daylight from the outside to the inside of a room. It is a practical application in many buildings where daylight cannot reach due to building design and limited façade to placing windows. Since roof is the element directly exposed to the sunlight, light pipes system could be introduced. This paper examines the illumination levels obtained using light pipes system under Malaysia climate conditions. A light-pipe system that was installed in a test room located in Batu Pahat. Indoor illuminance distributions and concurrent outdoor illuminance were monitored at a 30 minutes interval for 5 days. The results indicated that the amount of daylight penetrated into the building are varied with less than 150lux in the early morning and late evening, and maximum at over 350lux in the noon and early afternoon. The average internal illuminance levels offer by light pipe system met the MS 1525:2007 recommendation for application in Malaysian buildings. These findings indicated that the light pipe system has a potential as a tool for introducing daylight indoors in Malaysia.

Keyword: natural lighting, light pipes system, indoor illumination

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 their lives in building such as offices, houses, factories, schools and supermarket. There is challenges to architect in enhancing daylight illumination into the internal spaces of the building. Therefore electric lamps rapidly replaced daylight with their ability to meet new requirements in building sector and economic demands. In spite of the artificial lighting provides sufficient levels of illumination for visual tasks, it cannot provide physiological benefits of natural
light [1]. Utilizing electric lamps during daytime will contribute to electrical consumption and also greatest abundance of natural lighting.

Due to increasing electricity rates, people nowadays are more responsive to the environment [2]. Therefore, people are looking for ways to reduce building consumption of electricity consequently led to return to the natural resource of lighting. Daylighting is an effective and efficient sustainable approach to reduce the need for artificial lighting in buildings. Moreover, illuminating indoor area using natural light is one of the principle in green building index in reducing the dependency on electricity for illumination. In additional, The Malaysian Standard 1525:2007 has outlined illuminance levels recommendations for various tasks and applications in a building [3]. Table 1 shows the recommended average illuminance levels for Malaysian building.

**Table 1.** Recommended Average Illuminance Levels [3].

| Task                        | Illuminance [lx] | Example of Applications                          |
|-----------------------------|------------------|--------------------------------------------------|
| Lighting for infrequently used area | 20               | Minimum service                                  |
|                              | 100              | Interior walkway and carpark                     |
|                              | 100              | Hotel bedroom                                   |
|                              | 100              | Lift interior                                   |
|                              | 100              | Corridor, passageways, stairs                    |
|                              | 150              | Escalator, travelator                            |
|                              | 100              | Entrance and exit                               |
|                              | 100              | Staff changing room, locker and cleaner room, lavatories, stores |
|                              | 100              | Entrance hall, lobbies, waiting room            |
|                              | 300              | Inquiry desk                                    |
|                              | 200              | Gate house                                       |
| Lighting for working area    | 200              | Infrequent reading and writing                   |
|                              | 300-400          | General offices, shops and stores, reading and writing |
|                              | 300-400          | Drawing office                                   |
|                              | 150              | Restroom                                         |
|                              | 200              | Restaurant, canteen, cafeteria                   |
|                              | 150              | Kitchen                                          |
|                              | 150              | Lounge                                           |
|                              | 150              | Bathroom                                         |
|                              | 100              | Toilet                                           |
|                              | 100              | Bedroom                                          |
|                              | 200-500          | Classroom, library                              |
|                              | 200-750          | Shop/Supermarket/Department store                |
|                              | 300              | Museum and gallery                               |
| Localised lighting for exacting task | 500             | Proof reading                                    |
|                              | 1000             | Exacting drawing                                |
|                              | 2000             | Detailed and precise work                        |

Introduction of natural daylighting system in buildings has many advantages and benefits, with range from the aesthetic to physiological and economic. Spaces illuminated by daylight will provide occupants with a high satisfaction of visual and thermal comfort along with low energy consumption for lighting, heating and cooling [4]. Daylight illumination can come directly from the sun, light diffused through the atmosphere and light reflected from external surfaces. Side lighting from windows is the prominent architectural aspect in building design. Besides lighting purposes, windows offer ventilation, view and fresh air. These may provide relaxation and inspiration to occupants. However, the illuminance levels from windows decrease rapidly with distance from the window. Therefore, the area away from window may tend to look gloomy and required supplementary artificial lighting. Thus, top lighting strategies could be introduces to illuminate building interiors where sunlight cannot reach due to building plan or layout. This strategies also can provide satisfactory illuminance and more efficient than window [5].
Nowadays, there are an innovation in directing daylight into the interior of building using light pipe or light tube[6]. Light pipe systems are linear devices that channel daylight into the core of a building[7]. Figure 1 shows the typical of light pipe system. The light pipe systems comprise of a collector, a light tube and a diffuser. A collector is usually located at roof level and is made of clear domed light to accept sunlight from the whole sky hemisphere. Light tube acts as a light transport that will guide the light into the room to be daylighted. The tube with highly reflective internal surfaces, like aluminium sheet with reflectance of about 95–99%, increases the efficiency [8].

![Figure 1. Schematic of Typical Light Pipe [9]](image)

The performance of light pipe system as natural daylighting system has been reported in a number of studies[9]–[13]. These studies have verified the efficiency of light pipe system as a light source in a building. An experimental study carried out by [9] reported that light pipes are proficient devices for introducing daylight into buildings. Surveys on 13 buildings have found that light-pipe systems could provide 25% –50% of the workplane illuminance and tend to reduce lighting energy consumption [14]. In another study revealed that interior illuminance on the working plane could vary depends on sky condition [12]. This study was supported by [13] through the prediction model, where there are strong associations between the daylighting performance of the light-pipe and local climate conditions. Malaysia is a tropical country with climatic features are classified as hot-humid tropics with uniform temperature, high humidity, copious rainfall, light winds, and abundant sunshine. Malaysian sky condition are classified as an intermediate sky, which is neither clear nor overcast [15]. Due to that, the illuminance can vary drastically, since the cloud cover cuts off a substantial amount of sunlight. The illuminance can vary from 20,000 lx during cloud cover to 100,000 lx when the sunlight is not obstructed by the cloud [16]. Therefore the purpose of this study is to evaluate the daylight amount penetrate into the building using light-pipe system in Malaysian climate via full scale measurement.

2. Methodology
To investigate the daylight amount of this system, a model test bed with dimensions of 3m (W) X 3m (L) X 3m (H-Ceiling) was built at 5 3’N latitude, 100 3’E longitude in Batu Pahat, Johor, Malaysia (Figure 2). To achieve total darkness and to obtain accurate results, all opening was lined with hardboard to prevent light penetration to the test area. Typical cement rendering screed was chosen as floor finish, and a set of white plaster boards were used as ceiling.
A straight light-pipe has been mounted on the roof (Figure 3a). The cylindrical light-pipe was 1.2m long with a diameter of 0.3m (Figure 3b). The tube was fabricate using mirrored finished material easily available in Malaysian market. The top of the light-pipe was fitted with a clear acrylic dome and a flat polycarbonate diffuser was attached to the lower opening of the light-pipe (Figure 3c & Figure 3d).
Illuminance level monitoring was conducted from 8:00 am to 6:00pm 5 Feb 2015 to 16 February 2015. The study selected five days without any rain for the analysis[17]. Extech Digital Light Meter 401025 were used to measure internal and external illuminance levels. All internal illuminance were taken at work plane height 800mm from the floor level. The external and internal illuminance data were measured at 30 minutes intervals.

3. Results

3.1. External illuminance distribution
Figure 4 shows the distributions of external illuminances measured during the monitoring period. From the figure show that daily reading formed a bell-shaped curved. Each day the maximum level are varied.

The reading on Day 1 show that unstable reading due to the sky mostly covered by cloud. In the noon the illuminance reading was only 37,000 lux. The highest reading was recorded at one o’clock with 73,000 lux, while at 1.30 pm the illuminance was dropped to 28,000 lux. This is due to inconsistent cloud formation. However the illuminance increased to 41,000 lux and 44,000 lux at 2.30 pm and 3.00 pm respectively. From 3.30 pm to 6.00 pm gradually decreased due to sunset. The reading for Day 2 until Day 5 are more stable compared to Day 1. In the noon, illuminance was recorded around 109,000 lux to 113,000 lux. The highest illuminance was recorded 127500 lux on Day 3, at 1.00pm. In the evening, gradually the illuminance descended to below 20,000lux at 6.00 pm when the sun going down.

Since Malaysian sky type was categorized under intermediate sky, cloud formation mostly blocking the daylight from reaching the ground. Therefore non-uniform illuminance were occurred. This record shows on Day 3 at 11.00 am with 105,700 lux, fell to 25,000 lux at 11.30 am and increased again to 111700 lux at 12 noon when the sunlight not obstructed by cloud.

Figure 4. External Illuminance Distribution

3.2. Internal illuminance distribution
Figure 5 shows the distribution of internal illuminances over the monitoring period. The figure indicates that the internal illuminances recorded were distributed evenly except on Day 1. The graph shows that the internal illuminance was less than 150 lux in the early morning and late evening, and maximum at over 350 lux in the noon early and early afternoon. Since sky mostly covered by cloud on Day 1, it was influencing the internal illuminance distribution. The highest illuminance level on Day 1...
was only 320 lux at 1.00 pm, since at the same time 680 lux, 701 lux, 664 lux and 543 lux on Day 2,
Day 3, Day 4 and Day 5 respectively. Starting from 10 am, internal illuminance was met minimum
requirement in MS 1525:2007 with 153 lux at Day 1, 129 lux Day 2 and 189 lux on Day 3. However,
due to inconsistent cloud formation, there is little penetration of light on Day 4 and Day 5 with only 70
lux and 85 lux. Thus, the penetration of light was increased at 12 noon. In the afternoon, the
penetration of light was decreased gradually due to nature of sky.

![Internal Illuminance Distribution](image)

**Figure 5. Internal Illuminance Distribution**

4. Discussion and Finding

This paper evaluates the daylight amount offer by a light-pipe system used under the Malaysian
climate conditions through measurements of internal and concurrent external illuminances of a
windowless experiment room in which the light-pipe system was installed. Figure 6 illustrates the
distribution between internal and external illuminance levels. From the figure shows that the external
illuminance was influential the penetration of light in the building. The internal illuminance was
gradually increase in the morning associated with an increasing of solar latitude. In this study found
that the peak external daylight availability in noon time was exceed 100klx. These results are in line
with those of previous studies on tropical daylighting. Field measurement conducted by [15]
demonstrated that external illuminance during peak hours exceeded 100klx in Shah Alam and 140klx
in Bangi. The study by [18] proved that tropical daylight availability can exceed 100klx at noon time
by employing Perez daylight model to calculate external illuminance in Kota Kinabalu. External
illuminance level of 130klx at noon time were recorded in Johor Bahru by [19].

Another important finding was associations between climate and the performance of the light-pipe
system. The performance of light pipe system varied due to the sky conditions. However, the average
illuminance offered by light pipes shows the potential of this system for bringing a considerable
natural light to indoor. The average illuminance of 100 lx over a period from 10.30 am to 4.00 pm for
sunny day. These results are in accordance with Malaysian Standard (MS) 1525:2007. Recommended
illuminance level for infrequently used area such as corridor, entrance or lobbies are 100 lx to 200 lx.
For working area such as office, kitchen and classroom recommended illuminance level are 300 lx to
500 lx.
5. Conclusion
In conclusion, this study has indicated that external illuminance was influencing the performance of light pipe systems. With average internal illuminance values ranging from 100lx to 550lx over a period from 10.30am to 4.00pm, this system could be an effective tool for introducing natural daylight into the interior of buildings. This study shows that light pipe systems using materials easily available in the Malaysian market can fulfill the internal illuminance recommended by MS 1525:2007. However, this study has not considered the effects of diameter and length of the pipes. Further monitoring activities will evaluate the effects of varying the lengths 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.

6. Acknowledgement
The research described in this paper was funded by the 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.

References
[1] V. Garcia-Hansen, “Innovative Daylighting Systems For Deep-Plan Commercial Buildings,” Queensland University of Technology, 2006.
[2] L. H. Ismail, “No Title,” 2007.
[3] Department of Standards Malaysia, “Malaysian Standard MS 1525:2007 Code of Practice on Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings,” 2007.
[4] C. F. Reinhart and J. Wienold, “The Daylighting Dashboard - A Simulation-Based Design
Analysis for Daylit Spaces,” *Build. Environ.*, vol. 46, no. 2, pp. 386–396, 2011.

[5] S. Treado, G. Gillette, and T. Kusuda, “Daylighting with Windows, Skylights, and Clerestories,” *Energy Build.*, vol. 6, no. 4, pp. 319–330, 1984.

[6] M. Paroncini, B. Calcagni, and F. Corvaro, “Monitoring of a Light-Pipe System,” *Sol. Energy*, vol. 81, pp. 1180–1186, 2007.

[7] D. J. Carter and M. Al Marwae, “User Attitudes Toward Tubular Daylight Guidance Systems,” *Light. Res. Technol.*, vol. 41, no. 1, pp. 71–88, Mar. 2009.

[8] X. Zhang, T. Muneer, and J. Kubie, “A Design Guide for Performance Assessment of Solar Light-Pipes,” *Light. Res. Technol.*, vol. 34, no. 2, pp. 149–169, Jun. 2002.

[9] G. Oakley, S. Riffat, and L. Shao, “Daylight Performance of Lightpipes,” *Sol. Energy*, vol. 69, no. 2, pp. 89–98, Jan. 2000.

[10] D. J. Carter, “Developments in Tubular Daylight Guidance Systems,” *Build. Res. Inf.*, vol. 32, no. 3, pp. 220–234, May 2004.

[11] M. A. Marwae and D. J. Carter, “A Field Study of Tubular Daylight Guidance Installations,” *Light. Res. Technol.*, vol. 38, no. 3, pp. 241–258, Sep. 2006.

[12] J. Mohelnikova, “Tubular Light Guide Evaluation,” *Build. Environ.*, vol. 44, no. 10, pp. 2193–2200, Oct. 2009.

[13] J. Y. Shin, G. Y. Yun, and J. T. Kim, “Evaluation of Daylighting Effectiveness and Energy Saving Potentials of Light-Pipe Systems in Buildings,” *Indoor Built Environ.*, vol. 21, no. 1, pp. 129–136, Sep. 2011.

[14] M. Al-Marwae and D. J. Carter, “Tubular guidance systems for daylight: Achieved and predicted installation performances,” *Appl. Energy*, vol. 83, no. 7, pp. 774–788, Jul. 2006.

[15] A. Zain-Ahmed, K. Sopian, M. Y. Othman, A. A. Sayigh, and P. Surendran, “Daylighting As a Passive Solar Design Strategy in Tropical Buildings: A Case Study of Malaysia,” *Energy Convers. Manag.*, vol. 43, pp. 1725–1736, 2002.

[16] Y.-W. Lim and M. H. Ahmad, “The Effects of Direct Sunlight on Light Shelf Performance Under Tropical Sky,” *Indoor Built Environ.*, May 2014.

[17] M. A. C. Munaaim, K. M. Al-Obaidi, M. R. Ismail, and A. M. Abdul Rahman, “Potential of Fibre Optic Daylighting Systems in Tropical Malaysia,” *Indoor Built Environ.*, Sep. 2014.

[18] H. Djamila, C. C. Ming, and S. Kumaresan, “Estimation of exterior vertical daylight for the humid tropic of Kota Kinabalu city in East Malaysia,” *Renew. Energy*, vol. 36, no. 1, pp. 9–15, Jan. 2011.

[19] Y.-W. Lim, M. Z. Kandar, M. H. Ahmad, D. R. Ossen, and A. M. Abdullah, “Building façade design for daylighting quality in typical government office building,” *Build. Environ.*, vol. 57, pp. 194–204, Nov. 2012.