THE POTENTIAL USE OF LIGHT PIPE SYSTEM AS ILLUMINATION ELEMENT FOR ONE STOREY BUILDING IN MALAYSIA

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To Allah the Almighty

For my beloved mother, my husband and children

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ABSTRACT

Daylighting is an efficient and practical strategy for illuminating the interiors of buildings with natural light during the day. Natural light is extremely beneficial for energy conservation, the occupants' health and psychological well-being, and the environment. Light pipe system (LPS) is a lighting device that can capture sunlight from the rooftop and transmits into the low light area or into rooms with insufficient daylight. The purpose of this study was to determine the potential of a light pipe system for interior illumination in single storey building spaces in Malaysia. The physical experiment was conducted in a test room to determine the light pipe system's overall potential. Meanwhile, a computer simulation was used to determine the illuminance distribution of the LPS and artificial lighting in order to calculate energy savings. The simulation was conducted in three scenarios, (1) with one LPS, (2) with two LPS, and (3) with three LPS. The results indicate that the LPS performed admirably under intermediate sky and met the building's minimum illuminance (100 lux) requirements, as recommended by MS 1525:2014. Furthermore, the analysis of the daylight performance results was based on Work Plane Illuminance (WPI), the daylight penetration factor (DPF) and illuminance uniformity. The results illustrated that the LPS performance was reasonable , but the presence of clouds disrupted the capacity of the LPS to achieve the illuminance recommended. As a result, artificial lighting was used as a source of power. By combining a light pipe system with artificial lighting, it is possible to achieve an adequate level of illumination in a room while reducing electricity consumption. The simulation results indicate that using two LPS is more beneficial in a 15 m2 space than using one or three LPS. Using two LPS for the test room with the artificial lighting system and applying the dimming control, the reduction was up to 25 per cent per day, suggesting that 114 kWh could be saved annually. In parallel, the CO_2 emissions produced from the energy usage could be reduced to 80 kg per year. Both reductions would contribute to saving to the environment. This discovery provide useful information to building designers intending to implement LPS and this system will be widespread use of LPS in Malaysia.

ABSTRAK

Cahaya siang merupakan sumber pencahayaan semulajadi dalam bangunan yang efisen dan praktikal. Ia bermanfaat kepada penjimatan tenaga, kesihatan dan psikologi penghuni serta penjagaan alam sekitar. Sistem Paip Cahaya (LPS) merupakan sistem pencahayaan semulajadi yang dapat membawa cahaya siang daripada atas bumbung ke ruang dalaman bangunan, terutamanya ruang yang memperolehi cahaya siang yang rendah seperti ruang yang jauh daripada tingkap atau ruang yang terhalang dengan dinding sesekat. Tujuan kajian ini adalah untuk menentukan potensi LPS sebagai kaaedah pencahayaan semulajadi pada bangunan setingkat di Malaysia. Kajian fizikal secara eksperimen telah dijalankan di dalam bilik ujian. Manakala simulasi komputer dijalankan bagi menentukan corak pencahayaan daripada LPS dan lampu elektrik. Hasil simulasi ini digunakan untuk pengiraan penjimatan tenaga yang diperolehi dengan menggunakan LPS dan lampu elektrik. Simulasi dijalankan dalam tiga senario iaitu; (1) dengan satu LPS, (2) dengan dua LPS dan (3) dengan tiga LPS. Keputusan kajian menunjukkan LPS berupaya memenuhi keperluan minimum pencahayaan (100lux) sebagaimana yang dicadangkan dalam MS 1525 :2014. Selain itu, penilaian faktor penembusan cahaya (DPF) dan keseragaman pencahayaan (U_o) juga dapat dipenuhi oleh LPS ketika keadaan langit sederhana. Namun kehadiran awan telah mempengaruhi kapasiti cahaya. Menggabungkan LPS dan lampu elektrik adalah bagi mendapatkan tahap pencahayaan yang mencukupi dalam bangunan. Melalui simulasi komputer mendapati penggunaan dua LPS yang digabungkan dengan lampu elektrik adalah lebih sesuai untuk ruang 15m^2 berbanding dengan satu atau tiga LPS. Dengan menjadikan LPS sebagai sumber utama pencahayaan dan lampu elektrik sebagai sandaran, tenaga elektrik untuk tujuan pencahayaan dapat dijimatkan sebanyak 25% sehari dan mencecah 114kWh setahun. Disamping itu, pelepasan CO_2 juga dapat dikurangkan sebanyak 80kg setahun. Kajian ini dapat memberi maklumat kepada perekabentuk bangunan terhadap penggunaan LPS dan ia akan meluaskan penggunaan sistem ini di Malaysia.

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LIST OF SYMBOLS AND ABBREVIATIONS

A_r	-	Rayleigh scattering coefficient
E_d	-	Diffuse irradiance
E_{avg}	-	Average illuminance level
$E_{external}$	-	External illuminance
$E_{internal}$	-	Internal illuminance
E_{min}	-	Minimum illuminance level
$EC_{existing}$	-	Energy consumption of existing
$EC_{retrofing}$	-	Energy consumption of proposed system
E_g	-	Global irradiance
GWh	-	Gigawatt per hour
I_d	-	Diffuse irradiance
I_G	-	Global irradiance
klx	-	Kilo lux
kWh	-	Kilowatt per hour
lx	-	Lux
n	-	Duration of sunshine
NI	-	Number of lamp
no	-	Daylength
P	-	Power
R	-	Correlation coefficient
R^2	-	Coefficient of Determination
S	-	Sunshine duration
U_o	-	Illuminance uniformity
$U_{o\ max}$	-	Maximum illuminance uniformity
$U_{o\ min}$	-	Minimum illuminance uniformity
W	-	Watt
m	-	Optical air mass

α	-	Solar altitude
ACEM	-	Association of Consulting Engineers Malaysia
ALOS	-	Average Length of Stay
APEC	-	Asia pacific energy research centre
BC	-	Billing cost
BREEAM	-	Building research establishment environmental assessment method
CASBEE	-	Comprehensive Assessment System for Building Environmental Efficiency
CH_4	-	Methane
CIDB	-	Construction Industry and Development Board
CO_2	-	Carbon dioxide
CR	-	Cloud cover ratio
DF	-	Daylight factor
DPF	-	Daylight penetration factor
EC	-	Energy consumption
EE	-	Energy efficiency
EF	-	Emissions factor
ES	-	Energy saving
ET	-	Electricity tariff
GHG	-	Greenhouse gas
HOLIGILM	-	Hollow light guide interior illumination method
IESNA	-	The Illuminating Engineering Society of North America
LPS	-	Light pipe system
MS	-	Malaysian standard
N_2O	-	Nitrous oxide
NI	-	Nebulosity index
NOAA	-	National Oceanic and Atmospheric Administration
OH	-	Operating hour of the luminaire per year
PAM	-	Malaysian Institute of Architect
RE	-	Renewable energy
SCN	-	Suprachiasmatic nucleus
SF_6	-	Sulphur hexafluoride

UV	-	Ultra violet
WPI	-	Work plane illuminance

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CHAPTER 1

INTRODUCTION

1.1 Research background

Daylighting is the introduction of natural light to provide illumination in buildings during the daytime. It was the predominant source of light since the first built dwellings, even though oils lamps and gas lighting were invented thousands of years ago (Baker & Steemers, 2014). Due to their high fuel prices and environmental problems, oils and gas lamps do not make viable alternatives (Baker & Steemers, 2014; Mayhoub, 2011). The invention of electric lighting in the late 19th century rapidly replaced daylight in buildings due to its ability to keep the interior well-lighted and comfortable for the occupants. The development of electrical lighting transformed life in indoor environments by providing occupants with their lighting needs.

With the building sector and economic demand booming, people spend most of their lives in buildings such as offices, houses, factories, schools and supermarkets. For this reason, much energy consumption is associated with creating indoor environmental conditions that ensure the comfort of occupants. Besides that, the building envelope consequently became enclosed, fully air-conditioned and artificially lit. This situation has contributed to electrical lighting becoming the second most used type of electrical power consumption after air conditioning, and this rate is increasing every year. Although electrical lighting provides sufficient levels of illumination, it cannot provide the physiological benefits of natural light (Garcia-Hansen, 2006; Turan *et al.,* 2020). The use of electricity during the day not only contributes to electricity consumption but is also a waste of most natural light. Thus, it is not impossible that the peak demands for electrical lighting occur at the same time as the peak availability of daylight (Callow, 2003; Dortans *et al.,* 2020). Furthermore, with the increasing cost of electricity, people have become more environmentally responsible about reducing their electricity use (Ismail, 2007; Patil, Kaushik & Garg, 2018).

Daylighting is a passive strategy that can be implemented by architects and designers in building design. Recently, several studies have shown that incorporating daylight is a way to reduce energy consumption in buildings (Chen *et al*., 2014; Ihm, Nemri, & Krarti, 2009; Krarti, Erickson, & Hillman, 2005; Reffat & Ahmad, 2020; Srisamranrungruang & Hiyama, 2020; Yun *et al.*, 2012). These studies indicated that the need for artificial lighting in buildings can be reduced effectively, efficiently and sustainably through daylighting. It is possible to save as much as 27% and 10% of the energy usage as mentioned by Wagiman *et al*. (2021) and Zain-Ahmed *et al.* (2002) respectively. In addition, spaces illuminated by daylight give occupants the best colour rendering and most closely match human visual responses to provide high visual satisfaction (Edmonds & Pearce, 1999; Li & Lam, 2003; Osibona, Solomon, & Fecht, 2021).

As a way to reduce energy consumption in buildings, the incorporation of daylighting has increased over the last thirty years, along with the popularity of green building rating systems. In 1990, the Building Research Establishment Environmental Assessment Method (BREEAM) was first employed, since when the global application of green building appraisals has expanded. Assessment systems have been introduced and promoted by many countries, including Australia, with Green Star; Japan, with the Comprehensive Assessment System for Building Environmental Efficiency (CASBEE); Canada, with the Building and Environmental Performance Assessment Criteria (BEPAC) and the United States, with Leadership in Energy and Environmental Design (LEED).

In Malaysia, awareness of, and concern for, this issue has been growing within the government since the 2000s. The Construction Industry and Development Board (CIDB), a regulatory body entrusted with the responsibility for coordinating the needs of the Malaysian construction industry, has created an objective to promote green building projects. Besides that, the Malaysian Institute of Architects (PAM) and Association of Consulting Engineers Malaysia (ACEM) has introduced the Green Building Index (GBI) as a rating tool. The index is intended to promote sustainability in the built environment and enhances awareness of environmental issues and our collective responsibility to future generations among several parties. These include developers, architects, engineers, planners, designers, contractors and the public.

Malaysia experiences long sunshine hours during the daytime and sun is available throughout the year (Heng *et al.,* 2019; Munaaim *et al.,* 2014). Yet the conditions of the Malaysian sky are average or intermediate; in other words, the sky is not clear but not overcast (Zain-Ahmed *et al.,* 2002). These weather conditions are considered an advantage for daylighting. Therefore, the utilisation of innovative daylighting strategies could help in capturing daylight and delivering it into a building into which daylight cannot reach due to the building layout. This research examines the potential of using light pipes as innovative daylighting strategies in order to illuminate building interiors, which could be a contribution to sustainable solutions, i.e., the environment, society and economy could benefit.

1.2 Problem statement

The electricity demand in Malaysia is increasing every year due to increased population growth as well as economic growth. It rose from 110,119GWh in 2016, to 110567GWh in 2017 and 133,446GWh in 2018 (Suruhanjaya Tenaga, 2019). About 48% of the electricity generated is consumed by the building sector and by the year 2030, the consumption is expected to have increased by 50% (Hassan *et al.,* 2014). Artificial lighting contributes approximately 20% to 25% of the total building electricity consumption, for operational or aesthetic reasons (Tang & Chin, 2017; Zakaria *et al.*, 2013). More than 75% electricity generation in Malaysia dependant on fossil fuels compare to water power and renewable energy (Mohd Chachuli *et al.*, 2021; Worlddata, 2021). Due to that, CO_2 contributes the largest volume of gas emission resulting from the generation and this level is increasing day by day in develop and developing country such as Malaysia (Babatunde *et al.,* 2021; Ganandran *et al.*, 2014). CO_2 emissions have resulted in changes in temperature and also serious environmental issues related to the climate change. Nowadays, most countries around the world, making a significant effort to reduce CO_2 emissions percent. Malaysia on the other hand expected to reduce their percentage to 45% by 2030 (Ministry of Energy Green Technology and Water, 2017; Unit Perancang Ekonomi, 2021)

This has led designers to reconsider the use of daylight as an electric lighting substitute. Daylight is an essential resource that is readily available and its use is an effective and efficient sustainable approach that enhances visual comfort, energy

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APPENDIX E

LIST OF PUBLICATIONS

1. Aslila, A. K., Lokman Hakim, I., Narimah, K., & Mohd Jahaya, K. (2021). Monitoring of natural daylight by using light pipe system in building. *Malaysian Construction Research Journal*, 13(2), 32–42.[Scopus]

2. Aslila, A. K., Lokman Hakim, I., Narimah, K., Izudinshah, A. W., Masiri, K., Norhayati, N., & Mohd Shafiq, M. R. (2019). Improving the Performance of Light Pipe System Using Laser Cut Panel. *Journal of Physics: Conference Series*, 1150(1). [Scopus]

3. Aslila, A. K., Lokman Hakim, I., Narimah, K., & Masiri, K. (2016). Potential Of Light Pipes System In Malaysian Climate. *IOP Conference Series: Materials Science and Engineering*, 160, 012071 [Scopus]

VITA

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