ABSTRACT

Daylighting is an effective sustainable development strategy in improving the qualities for visual comfort, productivities and health. The increasing use of daylighting system can offer better savings in electricity usage, up to 20–30% of total building energy consumption. This paper reviews the current daylighting strategies incorporated to a building. The development of a highly efficient reflective and refractive materials have made the redirection of daylighting into areas of buildings far away from the façade. Light pipe system is one invention that transports daylight efficiently from outdoor into rear part of a room. Its does not only provide sufficient luminance into the room but also improve the internal environment without generating excessive heat. Light pipe system is a practical application in many buildings whether in deep plan building or link building. In conclusion, Malaysia as a country which experiences a hot tropical climate throughout the year is relevant to adopt this strategies.

Keywords: daylighting, energy consumption, luminance, light pipe system, sustainable.

1. INTRODUCTION

Daylighting is a method to illuminate building interiors with natural light without artificial lighting in daytime. Side lighting from windows is commonly used to allow daylight to enter into the buildings. Besides that, daylighting also can enter into building from top lighting such as skylight or clerestory window especially for buildings with limited façade. Nowadays, there are technology in harnessing daylight and transporting it into building interior by using highly reflective materials known as light pipe system. It is the simplest daylight system which allows daylight to enter into the interior spaces where windows restricted. With proper introducing of daylighting system, it will help in reducing energy consumption and has positive physiological effects on building occupants. Moreover, this approach is one of the aspects in green building certification due to its potential that can improve energy effiency and the quality indoor environment [1]. Therefore, this paper reviews the potential of light pipe system as a daylighting approach in Malaysian buildings.

2. DAYLIGHTING OPTIMIZATION

In recent years, with an increasing awareness of sustainable development, daylight has been seen as an effective means of saving energy and reducing the environmental impact. Previous studies have confirmed the benefits to users satisfaction and well-being.

2.1 Benefits of Daylighting

Recently, large body of knowledge showing general preferences for daylight as a light source in buildings because of the benefits it offers. Space 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 [2].

(a) *Human well-being*

Daylight can deliver high intensity of light emitted into the interior of building together with a spectral composition that ensures favorable perception of color. Indirectly, it will provide spatial meaningful, interesting and dynamic visual. Daylight also allows people feel to the same connection with the environment and can influence physiological responses such as the regulation of diurnal cycle of body activities and improve health conditions in working environments [3].

(b) *Productivity and performance*

Good daylighting does not just offer high illuminance into a building interior, but also increase the productivity of the occupants. Space illuminate with adequate daylight will provide an environment that is more attractive and more pleasant atmosphere until the end of the day. By replacing artificial light with daylight it will increase 15% productivity and decreased 15% absenteeism [4]. Indirectly individual improvement productivity increases from 0.45% to 15% when a better quality of daylighting is introduced into the building [3]. Daylighting also influences students performance and health in schools [5]. There is a high relationship between classroom condition with student test scores. Students with the most daylighting in their classrooms progressed 20% to 26% faster when compared to students in classroom with no window [6].

(c) *Energy consumption*

By introducing daylighting strategies, its potentially reduce the needs of artificial lighting up to 20-30% electricity usage [7]. In addition, at least 10% of energy savings can be achieved by using daylight strategies [8]. The daylight offers high luminous efficacy compared to majority of artificial lighting as per Table 1. Therefore less heat will be dissipated into the building. Indirectly, its will reduce cooling loads and the potential for smaller heating, ventilating and air-conditioning (HVAC). In another study, found that daylight lowers the cooling requirements of a building up to 15% [9].

<table>
<thead>
<tr>
<th>Source</th>
<th>Luminous efficacy (lm/w)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daylight</td>
<td></td>
</tr>
<tr>
<td>Sunlight</td>
<td>70 – 105</td>
</tr>
<tr>
<td>Clear blue skylight</td>
<td>130</td>
</tr>
<tr>
<td>Overcast skylight</td>
<td>110</td>
</tr>
<tr>
<td>Global skylight</td>
<td>105</td>
</tr>
<tr>
<td>Artificial light</td>
<td></td>
</tr>
<tr>
<td>Incandescent bulb</td>
<td>15</td>
</tr>
<tr>
<td>Compact fluorescent</td>
<td>57 – 72</td>
</tr>
<tr>
<td>T5 linear fluorescent</td>
<td>70 – 100</td>
</tr>
</tbody>
</table>

2.2 *Daylighting Strategies for Building*

Daylight illumination can come directly from the sun, light diffused through the atmosphere and light reflected from external surfaces. Side and top lighting are convetional methods in illuminating building. Side lighting from windows is the prominent architectural aspect in building design. In addition to 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 as shown in Figure 1. By introducing large window areas to allow more daylight into a space is not a good idea, because these strategies may allow excessive heat gains or losses which increases the air-conditioning cooling or heating load and consequently the energy consumption [11].
Eventhough window offer good view, its also increases the level of noise, glare or contributes to the distraction of the occupants. Previous studies of [12] showed that the students learning progress is reduced with the distraction from outside activity. Thus, people tend to use window blinds, curtain and artificial lighting in controlling the glare, distraction and privacy [13]. Thus, this behaviour indirectly increased the energy consumption, when people switch on lighting during daytime. Therefore the peak demands for electrical lighting occurs at the same time as peak availability of daylight [14].

Figure 1: Sidelighting Strategies (Tregenza, P. et al. 2011)

For building with limited façade such as terrace or link building, top lighting can be the most effective approach for illuminating the interior. Since roof is the element directly exposed to the sunlight, top lighting can provide satisfactory illuminance and more efficient than through window [15]. Skylight, sawtooth apertures and monitor apertures are the conventional top lighting strategies that can be incorporated to the building as shown in Figure 2.

Figure 2: Toplighting Strategies (Architectural Energy Corporation)

Nowadays, there are an innovation in directing daylight into the interior of building using light pipe or light tube [16], [17]. Light pipes perform the same function as other skylight strategies, the only different is the way daylight is transported into internal spaces by using highly reflective tube. This system is also known as solar pipe, tubular daylight guidance system or mirror pipe. Compared to conventional skylights and windows, a light pipe offers better heat insulation properties and are more flexible [18]. Figure 3 shows the distribution of illuminance offers from window and light pipes.
3. LIGHT PIPE SYSTEM

Light pipe systems are linear devices that channel daylight into the core of a building [20]. This system brings daylight into deep of a building without producing extreme warmth [7], [21]. Figure 4 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 [21].

High efficiency reflection is the principle in light pipe system. Hence, the use of elbow or bend will result in light loss. In a review done by [22] mentioned that, each elbow may loss 8% of light. Studies by [21] on 330mm diameter on elbows and straight pipe showed that straight pipe performed better than elbows due to light loss. The light loss in straight pipe with elbows will be higher than the straight pipe without elbows [23]. With a simpler installation, this system is suitable to install in new buildings or retrofitted to buildings.

Light pipe technology actually has commercially exploited over the past fifteen years [3]. Recently, light pipe systems are commercially available in market such as Monodraught, Solatube, Skydome, light ways etc. At mid-2000, more than 2000 light pipe systems had been installed throughout the United Kingdom in comparison to about only 50 in the year 1997 [24]. However, it is not yet popular in Malaysia.
3.1 Performance of Light Pipe System

The performance of light pipe system as natural daylighting system has been reported in a number of studies [1], [7], [21], [25]–[27]. These studies have verified the efficiency of light pipe system as a light source in a building. An experimental study carried out by [7] reported that light pipes are proficient devices for introducing daylight into buildings. Surveys conducted by [28] on 13 buildings have found that light-pipe systems could provide 25%–50% of the workplane illuminance and tend to reduce lighting energy consumption. In another study [27] revealed that interior illuminance on the working plane could vary depends on sky condition. Figure 5 shows the intercorrelations between indoor illuminance and sky condition. This study was supported by [1] through the prediction model, where there are strong associations between the daylighting performance of the light-pipe and local climate conditions (i.e., solar altitude, sky clearness index, and external illuminance).

Figure 5 : Illuminance Measurements in the Windowless Corridor (Mohelnikova, 2009)

3.2 Challenges of Light Pipe System Utilization

Although previous studies show positive performance of light pipe system, but there are several challenges that caused it are not popular. The challenges can come in terms of cost, maintenance and the awareness of users.

(a) High initial cost
There are cost association in maximising daylight illumination in building [29]. The installation of light pipe systems were substantially cost higher compared to the electric systems and conventional window. The initial cost will be increased due to implementation of advanced technology in order to collect more amount of daylight [30]. However, light pipe system is an inexpensive method compared to other innovative daylighting system. Moreover, the light pipe system provides sufficient daylight in the clear sky condition and provides a significant amount of light.

(b) Maintenance
To ensure the quality of illuminance, maintenance program should be applied to the system. Dirt and dust can reduce the efficiency of the systems, hence it require regular cleaning. The replacement of affected component due to optical distortions or possibility of broken or degraded components. the maintenance of light pipe system may a problem and more inaccessible than the conventional lighting [25].
(c) **User awareness**

Users’ awareness on the use of daylight is essential for widespread its use. Studies conducted by [25], recognizing that the human factor as a key determinant of delaying implementation of the technology to be more widely. Reducing electricity bill is not enough to convince the user due to light pipe system with high initial cost. By providing information about the benefits in term of visual environment, well-being impact and productivity improvements can increase user awareness of this system.

### 3.3 Potential Utilization of Light Pipe System

Although there are challenges in using light pipe system, on the other hand it has been successful in several types of building. Light pipe systems are now being installed for office, industrial and health-care buildings in many parts of the world [28]. Due to [31], in their studies found that light pipe system gives the best electric savings for locations near the equator.

Malaysia as a tropical country located at about $3^\circ$N the equator, with approximate latitude $1^\circ$ to $6^\circ$45’N and longitude $99^\circ$36’E to $104^\circ$24’E. The climatic features of Malaysia are classified as hot-humid tropics with uniform temperature, high humidity, copious rainfall, light winds, and abundant sunshine [32]. According to [33] the sky condition in Malaysia is average or intermediate, which means that it is neither clear nor overcast (85.6% is predominantly intermediate, 14.0% overcast and 0% blue). Therefore, in a tropical daylighting study, intermediate sky shall be employed [34].

Daylight data is important that need to be taken into account in designing buildings using daylight. Moreover, the quality of the external illuminance will affect the performance of daylight system. For Malaysia daylight availability, a research done by [33] showed that the illuminance exceeds 80,000 lx at noon during March when solar irradiation is the highest and reaches 60,000 lx even during December when solar irradiation is less intense (Figure 6).

![Figure 6: Daylight Availability in Subang (Zain-Ahmed et al., 2002)](image)

From the above mentioned climate condition, it shows that there can be a high potential for using light pipe system as a daylight system in Malaysia. A study on light pipe system conducted by [35] produced a conversion factor for predicting light pipe performances under the tropical Malaysian sky conditions using scale model. Figure 7 shows the high illuminance level during daytime where light pipe can be incorporated to building.
4.0 Conclusion

This paper presents an overview of light pipe system as an effective daylighting system to building. The overview emphasized not only the studies of theory and performance of light pipe, but also some overview of Malaysian climate in optimising daylighting using light pipe system. In addition, this paper also discusses the common challenges in using light pipe as a daylighting system. With the advantages offered by light pipe system, it has the potential to be widely used in Malaysian buildings.

REFERENCES


[34] Lim, Y., Ahmad, M. H. and Ossen, D. R. 2013. Internal Shading For Efficient Tropical Daylighting in Malaysian Contemporary High-Rise Open Plan Office. Indoor and Built Environment.