Integration of HLP and Shading Systems in Office Building in the Tropics

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Integration of Horizontal Light Pipe and Shading System in Office Building in the Tropics

Abstract

Many high-rise office buildings in the tropics have a full-glazed façade and a deep open-plan space. Without any external shading, the office space has a non-uniform daylight distribution and glare problem. A deep open-plan space design also causes insufficient daylight levels in the area distant from the building perimeter. Previous studies about Horizontal Light Pipe (HLP) mainly focused on system improvement in capturing, transporting, and distributing daylight at the deep space of the building. Integration of HLP as a light transport system that can deliver daylight deeper into building interiors and shading systems consist of Light Shelf (LS), blinds that can redirect and reduce the excessive daylight level near the side window are proposed and studied. The research objective is to explain the daylight performance of the integration of HLP and shading systems. The research method is experimental with Radiance-based simulation as a tool. Surabaya (latitude 7.38° S and longitude 112.79° E), a typical city in the Tropics, was chosen for the simulation. Daylight level, daylight distribution, and Daylight Glare Probability (DGP) of office space with East faced side window are compared with office space with HLP and shading systems. The results showed that the integration of HLP and shading systems increased the average illuminance level in the area distant from the side window reached 135% and reduced the average illuminance level in the area near to the side window reached 55%. HLP and shading systems also increase the daylight distribution inside space and slightly improve the DGP but still in the range of imperceptible for building users.

Keywords: blinds; daylight performance; light shelf; horizontal light pipe; tropics

1. Introduction

The daylight use in buildings brings several benefits, including energy efficiency, the improvement of occupant's health, and productivity [1, 2]. Properly designed, daylighting can reduce building energy use for artificial lighting and overall energy use [3]. Daylight is also one of the most effective antidepressants available [4]. The human eye functions best when it takes in the full spectrum of light provided by daylight [5]. Daylight is the best light source for good color rendering [2]. Building occupants prefer daylight compared to artificial light [6]. Daylighting also improves occupant productivity in their workplaces [7].

The potential use of daylight in the Tropics is high. The tropical area receives high intensity of sunlight throughout the day [8] and has a long period of its illumination during daytime [9]. The illuminance in the Tropics can reach 80,000 lx during the brightest months and exceed 60,000 lx during the cloudy months [10]. The sky condition in the Tropics is also predominantly intermediate and dynamic, where the cloud formation changes in seconds [11].

Glazed buildings are predominant and constructed all over the world in different climates and latitudes [12,13]. Curtain wall construction with a full glazed or partially glazed is also commonly used in office buildings in Indonesia. Without any external shading devices, a large, glazed office building has a non-uniform daylight distribution and glare problem [11]. The daylight level at the area near the window perimeter is excessive and in contrast, is low at the area distant from the building perimeter and will require electric lighting [14]. A shading system is needed to block direct sunlight while admitting diffuse light and redirect sunlight into a deeper area of the building.

The deep-plan building design is popular among commercial buildings to maximize the rentable floor area [15]. Using a side window as the light source, a deep-plan building has an inadequate daylight level in the area distant from the building perimeter. Side window admits light with a strong directionality, which reduces as the distance from the building perimeter increases. Enlarging the window size to improve the daylight level at a deep area is ineffective [16]. A core daylighting system is needed to provide daylight in areas distances from the building perimeter [1].

Horizontal Light Pipe (HLP) is a core daylighting system that can deliver daylight to a deep area of the building. As a light transport system, HLP can collect, redirect daylight through an aperture at building façade, transport daylight using a pipe, and distribute daylight into deep area using an opening distribution [17]. Previous research mainly focused on improving the daylight performance of HLP. The strategies including the use of mirror systems [18], trapezoidal form in plan and reflectors [19, 20], the use of Laser Cut Panels [21, 22]. Other strategies to improve the daylight performance are a flat capitation system and an active reflector [17], egg-crate reflector at the opening distribution [23]. Those previous research showed the reliability of HLP in improving daylight levels and uniformity in the area distant from the building perimeter. A previous study about the application of HLP in an office building in the Tropics also showed that a shading system is needed to reduce the excessive daylight level at the area near the side window [24].

Two widely used shading system to control glare are Venetian blinds and light shelves (LS) [2]. LS and blinds are categorized as shading systems that employ direct sunlight and can be applied in all climate [25]. A light shelf (LS) is a horizontal or inclined plane placed on an opening above the eye level [26]. LS may be external or internal one or both and can control and redirect daylight through its reflection using the upper surfaces [27]. In general, blinds are not potential for daylight utilization but useful in reducing luminance contrast [28]. LS can improve the daylight uniformity and reflect daylight into a deeper area of the building but increased the luminance contrast [28]. The integration of LS and partial Venetian blinds can improve the work plane illuminance and luminance ratio [28].

Previous research about Horizontal Light Pipe mainly focused on the improvement of its performance in capturing, transporting, and distributing daylight. Considering that daylighting design in the Tropics should avoid excessive sunlight by restricting daylight levels transmitting the building [16], the HLP application as a complement to the side window in the Tropics should integrate a shading system to improve its daylight performance. Integration of Horizontal Light Pipe (HLP) that can deliver daylight into deep space of the building and shading systems consist of Light Shelf (LS), blinds that can redirect and reduce the excessive daylight level near the side window are proposed and studied as an integrative daylight system in the Tropics.

The purpose of the research is to evaluate the daylight performance of the integration of HLP and shading systems. The research location is Surabaya (latitude 7.38° S and longitude 112.79° E), one of the cities in Indonesia that has a tropical climate. Experiment with Radiance based simulation, IES-VE (Integrated Environment Solution-Virtual Environment) as a tool is employed as a research method. Glare probability, daylight level, and daylight distribution of the system are studied.

2. Integration of Horizontal Light Pipe and Shading Systems

2.1. Horizontal Light Pipe

Horizontal Light Pipe (HLP) can collect, transfer, and distribute daylight to a deep floor plan building [29]. HLP has three main components: aperture, pipe, and opening distribution. Aperture can collect, redirect, in some cases concentrate or collimate the incident light [17]. The pipe transport daylight into the building, while the opening distribution transmits the daylight inside the room. HLP can complement the daylight provided by a side window and can be the primary source of daylight at 4.6 to 9.1 m from the side window [19].

HLP aperture collects and redirects daylight through a passive or active collector. There are two classifications of passive collectors: a light redirection or a light-concentrating [30]. Light redirection collectors including Laser Cut Panels [21,22], mirror system [18], reflectors [19,20] while light-concentrating collectors including anidolic collectors [9,24]. In the Tropics, HLP orientation is East or West [22, 31]. HLP receives daylight only from half of the hemisphere in front of it [18].

The pipe transports the daylight into the building, depending on the optical property of its material. The pipe can transport light through multiple specular reflections in mirror light pipe, total internal reflection in the hollow and solid pipe, or by convergences in the lens system [30]. The length of mirror HLP varies, from 5.75 m [18] to 20m [22].

Opening distribution is designed to provide uniform daylight in a room without any glare. To transmit daylight, opening distribution material can be a high visible transmittance such as transparent or translucent glazing [18], a Laser Cut Panels to deflect the sunlight into the room [21, 22], or diffused glass [17]. The light distribution system determines the nature and quality of light output [30].

2.2. Light shelves and blinds

Light shelf and Venetian blinds are two widely used devices to control glare [2]. A light shelf is one of the shading systems that primarily using direct sunlight [25]. A light shelf can provide shading and can redirect sunlight to the ceiling and improve daylight uniformity [26]. Venetian blinds are one of the shading systems that can block direct sunlight but admit the diffuse skylight [25]. Blinds are not potential for daylight utilization but effective in decreasing luminance contrast [28].

Several criteria for the choice of blinds are its ability in glare protection, uniform illumination, energy-saving potential for artificial lighting [25]. Several criteria for the selection of light shelves are its ability to provide a view outside, a light guiding into a deeper area of the building, uniform illumination, saving potential for artificial lighting [25]. Both light shelves and blinds are suitable for all climates [25] and can be applied in the Tropics [11, 28].

In the Tropics, the use of a shading system is important since the emphasis of daylighting design is usually avoiding excessive sunlight by limiting the daylight amount entering the building [16]. The use of A combination of light shelf and blind is the most effective internal shading design for a high-rise office building in the Tropics [28]. The optimum LS depth to achieve a uniform daylight distribution in the Tropics is 600 mm [28]. A combination of LS (2 planes, at the distance of 0.6 between one another) and partial Venetian blinds that have slats 45° closed is an internal shading for optimum daylight performance for an East-facing side window in the Tropics [28].

2.3. Integration of Horizontal Light Pipe and Shading systems

The use of HLP improves daylight levels and uniformity in the area distant from the building perimeter. A previous study about the application of HLP in an office building in the Tropics showed that a shading system is needed to reduce the excessive daylight level at the area near the side window [24]. In this research, the integration of light shelves and blinds as a shading system and HLP as the light-transport system in the East facing side window are studied.

Figure 1 shows the integration of HLP and LS, blinds in an office room in the Tropics. A passive light redirection HLP is studied. The aperture is equipped with passive reflectors that have adjusted with the sun incident angle at the research location in the Tropics. The mirror light pipe transports light by multiple specular reflections and distributes daylight through an opening distribution 4.5 m to 10 m from the side window. Integration of LS (2 planes, at the distance of 0.6 between one another) and partial Venetian blinds that have slats 45° closed [28] is used in combination with HLP.

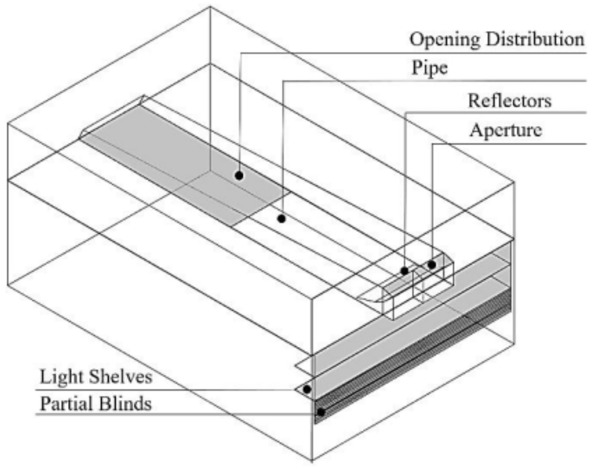


Figure 1. Integration of Horizontal Light Pipe and Shading systems

3. Methodology

Previous studies about the daylight performance of HLP employed several methods, including experimental with a physical model, mathematical models, and simulation. The experiment with a physical model is used in several previous studies [20, 22] and with a full-scale model [31]. Mathematical modeling is employed by [15, 18]. The experimental method with simulation is employed in evaluating the daylight performance of HLP [9, 17, 21, 24]. Computer simulation programs have abilities involving lots of design parameters and complex models [29]. The simulation results also have a good match with measurement [32], showing the reliability of the computer software.

The research method is experimental with simulation as a tool. A radiance-based simulation software, IES-VE (Integrated Environment Solution-Virtual Environment), is employed in this study to simulate the daylight performance of HLP, light shelf, and blinds. IES-VE uses ray-tracing techniques and can include detailed complex geometry and material types. The reliability of IES-VE in simulating daylight performances for various sky conditions and design variables has been validated in several previous research [9, 11, 24, 33, 34].

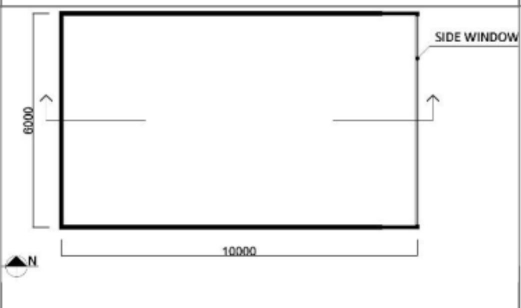
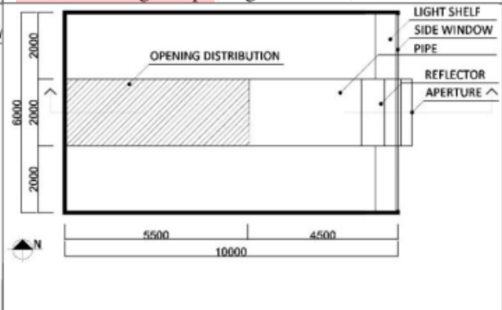
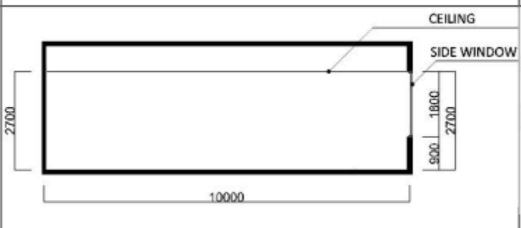
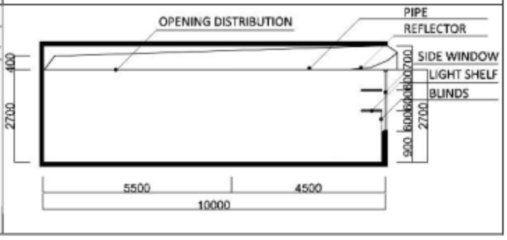
The study location is Surabaya (latitude 7.38° S and longitude 112.79° E) that represents a typical city in the Tropics. Intermediate sky condition is selected in simulation, corresponding to intermediate sky condition in the Tropics, means nor overcast or clear [10]. The climate data of Juanda International Airport, the closest area from the research location, are used in the simulation.

Daylight level, daylight distribution, and Daylight Glare Probability (DGP) of office space with East faced side window (base case) and office space with HLP and shading systems (the case), were compared. The width of the office space was 6 m, and the ceiling height is 2.70 m. The room depth is 10 m, represent a deep-plan office space. The office space has a side window with WWR (Window to Wall Ratio) 17.4 oriented to the East. The side window had 1.8 m in height and 5.8 m in width. The material of the window glazing was clear glass with a Visible Transmittance (VT) of 0.763. Table 1 shows the configuration of the base case and case. Table 2 shows the material used in the simulation.

HLP and light shelves, partial blinds were installed at the same room geometry, represented the case. The width and length of HLP were 2 m and 10.4 m, respectively. Was in the plenum area, the HLP had 0.7

m in height. The light pipe had a trapezoidal section in elevation and had 0.4 m in rear part height. A 90% specular reflective film was covered the internal surfaces of the light pipe to redirect sunlight. The hollow mirrored HLP had a static reflector that had an inclination angle in accordance with the sun altitude in Surabaya (Table 1). HLP aperture was oriented to the East, corresponding to the best orientation of HLP with light redirection collector in the Tropics to East or West [15, 31]. The aperture and distribution opening were covered with a clear glass that had a Visible Transmittance of 0.85 (Table 2).

Table 1. The base case and case configuration

	Base Case Office space with East facing side window	**Case** Office space with East facing side window and Horizontal Light Pipe, Light shelves, blinds
Plan		
Section		

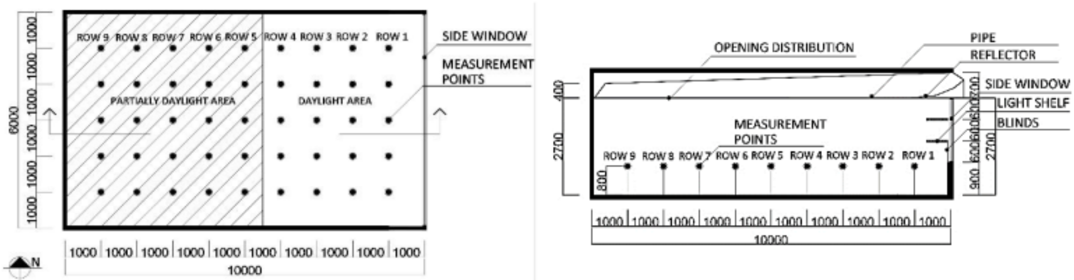
The shading systems consist of two light shelves (LS) and partial blinds. The geometry of LS and partial blinds were adopted from previous research [28] as an effective internal shading in the Tropics for East-oriented window. LS was installed at 2.1 m and 1.5 m above the floor, respectively. The depth of both LS was 0.6 m and had a reflective material on its upper surface. The blind slats had an inclined angle of 45° to cut down the luminance from the side window. Partial blinds were placed at 0.9 to 1.4 m above the office floor.

Figure 2 shows the position of measurement points inside office space. In this experiment, measurement points were placed at 0.80 m above the floor in a grid of 1 m. Analysis of Daylight Glare Probability was then conducted with a camera view facing the window from the center point of the office space. The camera height was 1.15 m above the floor, following the user's eye level height in sitting position. The simulation time is 21 March, 21 June, and 21 December at 09:00, 12:00, and 15:00.

The office room was divided into two zones: daylight area, at 0-4.5 m from East facing window, and partially daylight area, at 4.5-10 m from East facing window (Figure 2). Measurement points at row 1 to 4 were located in the daylight area, while measurement points at row 5 to 9 were placed in a partial daylight area. By dividing the office room into two zones, the impact of HLP and shading systems integration was evaluated.

Table 2. The properties of the material used in the simulation

Building Component	Material	Properties			
		Specularity	Roughness	Reflectance	Visible Transmittance
Office space					
Glazing	Clear glazing	-	-	-	0.763
Floor	Tile Gray	0.040	0.030	0.437	-
Wall		0.030	0.020	0.630	-
Ceiling		0.00	0.00	0.80	-
Light Pipe					
Pipe internal surfaces	Sheet steel	0.900	0.020	0.801	-
Aperture	Clear glazing	-	-	-	0.850
Opening distribution	Clear glazing	-	-	-	0.850
Blinds Shading coefficient 0.2		-	-	0.40	-
Light shelf					
Upper reflective surfaces	Sheet steel	0.900	0.020	0.801	-
Surfaces		0.030	0.020	0.630	-



(a) (b)

Figure 2. Measurement points on (a) plan (b) section

4. Results and Discussion

The daylight performance of HLP and shading system integration was evaluated using four daylighting metrics: Illuminance level, Daylight Factor (DF), uniformity ratio, and Daylight Glare Probability. The daylight level analysis involving illuminance level and daylight factor. Illuminance target for a workspace that performs a visual task of high contrast or large size is 300 lx [35]. DF was used to determine the daylight performance of HLP, light shelf, and blinds under the overcast sky condition. A recommended average DF of 1.5-2.5% for ordinary seeing tasks such as reading, easy office work, and the filling was used [2].

Uniformity ratio was employed for daylight distribution analysis, while the Daylight Glare Probability was employed for glare analysis. The uniformity ratio is related to the qualitative aspect of daylighting and represents the ratio between minimum illuminance and the average illuminance levels within a room [36]. The work plane illuminance should have a uniformity ratio for a minimum of 0.8 [2]. DGP is a percentage of users disturbed by one or some daylight glare sources [37]. DGP under 0.35 corresponds to an imperceptible glare by building users [37].

4.1 Daylight Level Analysis

Figure 3 shows the average horizontal work plane illuminance levels for the daylight area (measurement points at row 1-4), partially daylight area (measurement points at row 5-9), and overall area (measurement points at row 1-9) obtained from simulation. Considering that the recommended illumination level for office space is 300 lx with paper-based and computer tasks (Steffy, 2008), both the base case and case provided an average illuminance level of more than 300 lx only at 09:00, when the East facing window receive direct illumination from the sun. The average illuminance level of the office room with East facing window was in the range of 349 lx-688 lx, while the average illuminance level of the office room with HLP and shading systems was in the range of 305 lx-369 lx.

For the East facing window, the average illuminance level at the overall area reached the highest in the morning (09:00), lower at noon, and slightly increase in the afternoon (15:00) (Figure 3). The results also showed that on 21 March, both two cases had the highest average illuminance level in the overall office room. On 21 March 09:00, the mean illuminance level for an office room with the East facing window was 688 lux, while for an office room with HLP and shading systems was 369 lux. In accordance with the previous study of Djamila et al., 2011 [38], in the Tropics, the East facing window received the highest illuminance level on 21 March, and the diffused illuminance became the main daylighting source from noon until the afternoon.

The results also showed that the average illuminance level in partially daylight area (measurement points at row 5-9) reached the highest in the morning (09:00), lower at noon, and slightly increase in the afternoon. In this area, HLP is the main daylight source [19]. Oriented to the East, the highest average illuminance level reached 131 lux on 21 March 09:00. These trends are in accordance with the study of Chirarattananon et al., 2009 [18] about East facing HLP with static reflector.

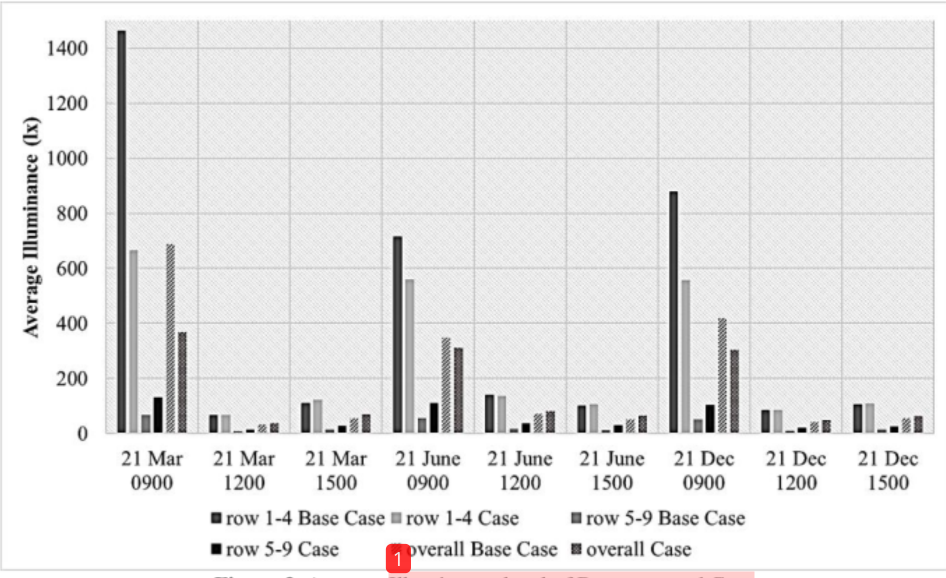


Figure 3. Average Illuminance level of Base case and Case

HLP and shading system integration decreased the average illuminance level at the overall area (measurement points at row 1-9) of office space. Figure 4 shows the percentage of average illuminance level decrement in overall office area after the integration of HLP and shading systems. The highest decrement as big as 46% occurred on 21 Mar 09:00. When the East facing side window receives direct sunlight, the role of the shading system in reducing the excessive illuminance level at the area near the side window is significant.

The integration of HLP, LS, and blinds decreased the average illuminance level in the daylight area when the East-oriented side window was facing the sun. The average illuminance level at daylight area decreased 55%, 22%, and 37% on 21 March 09:00, 21 June 09:00, and 21 December 09:00, respectively. At 12:00 and 15:00 when the side window was not received direct sunlight, integration of HLP and shading systems slightly increased the average illuminance level at daylight area in the range of 0.45% to 11%. In the daylight area, the role of the shading system in decreasing the average illuminance level is significant, especially when the sun position is in front of the East-facing window (at 09:00).

HLP and shading system integration increased the average illuminance level at partially daylight area at all measurement times. The average illuminance level improvement was in the range of 79% to 135%. Figure 4 shows that the highest average illuminance level improvement occurred on 21 June 15:00, while the lowest improvement occurred on 21 December 15:00. In the partially daylight area, the role of HLP in increasing the average illuminance level was significant in all simulation time. Although the HLP received daylight only from half of the hemisphere in front of it [18], the improvement of average illuminance level at partially daylight area when the sun position was not in front of the side window was still high.

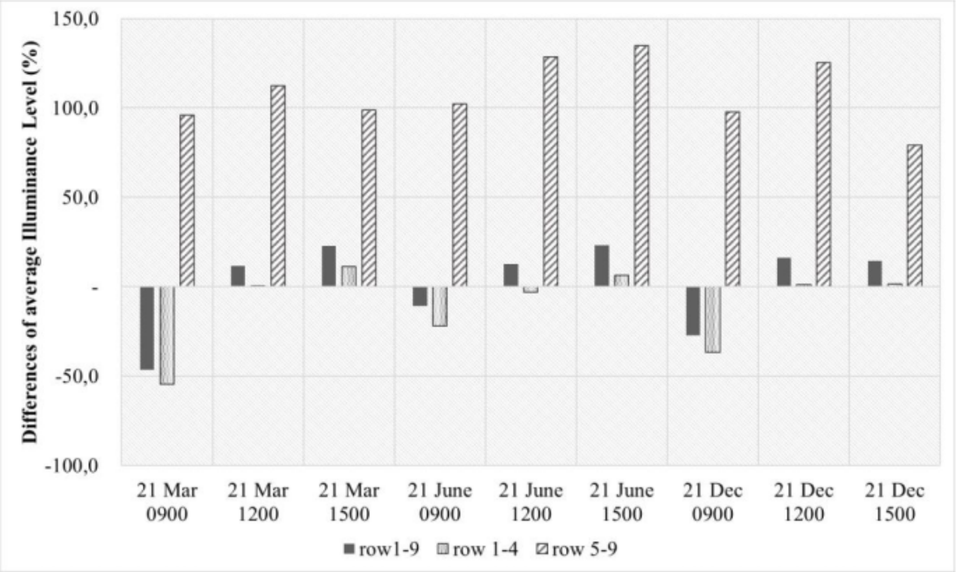


Figure 4. Percentage of average illuminance level improvement and decrement after integration HLP and shading systems

Figure 5 shows the trend of the average illuminance level at measurement points at 09:00. Integration of HLP and shading systems decreased the excessive daylight level at the area near the East facing window, while improved the daylight level at the area distant from the East facing window. Under the opening distribution of HLP (measurement points at row 5-9), integration of HLP and shading systems increased the illuminance level 52-203% on 21 March, 83-125% on 21 June, and 59-131% on 21 December. At the area near the East facing window (measurement points at row 1-2), integration of HLP and shading systems reduced the illuminance level reached 48-73%. At measurement points in row 3 and 4, the integration of HLP and shading systems also improved the daylight level, reached 42-62%. The improvement of daylight level at measurement points row 3-4 m from the East facing window showed the role of Light Shelf in bringing light deeper into the building.

Further analysis then focused on the simulation time when direct illumination from the sun reached the side window (at 09:00). Figure 6 shows the percentage of the room daylight area more than 300 lx on 21 March, 21 June, and 21 December 09:00. The daylight simulation results showed that the percentage of the room daylight area more than 300 lx in the base case were in the range of 22% to 31%. The percentage of the room daylight area more than 300 lx in the case were in the range of 33%-42%.

HLP and shading systems integration improved the percentage of the room daylight area more than 300 lx. The highest improvement of the percentage of the room daylight area more than 300 lx occurred on 21 December, 21 March, and 21 June 09:00 reached 70.3%, 35.7%, and 15.2%, respectively. The integration of the HLP and shading system decreased the average illuminance level at the overall area of office space but increased the percentage of the room daylight area more than 300 lx.

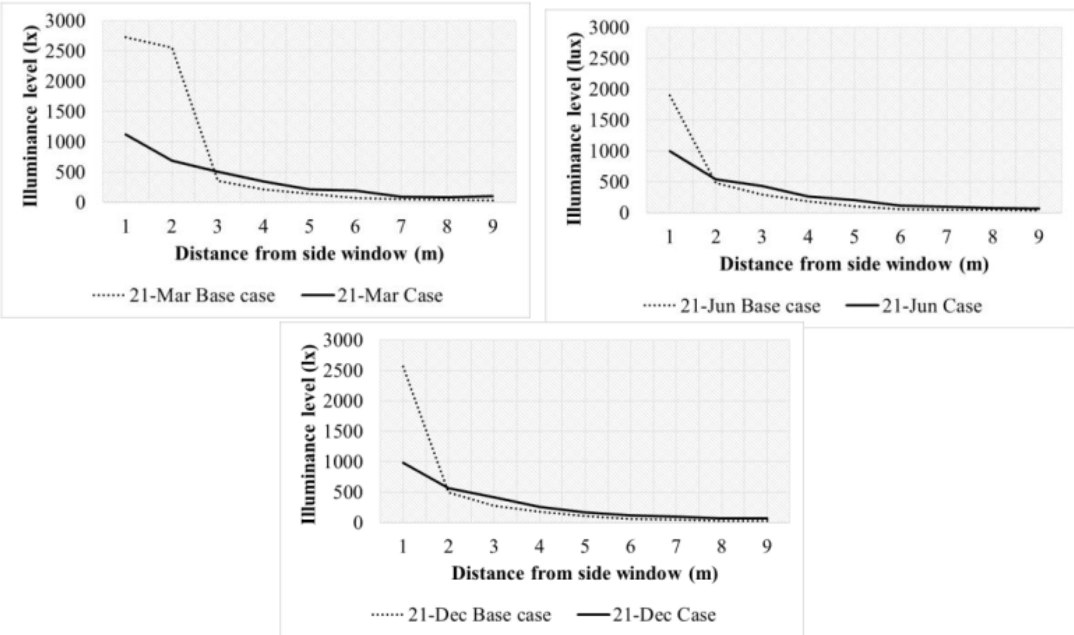


Figure 5. Average illuminance level profile at measurement points for 21 March, 21 June and 21 December 0900

Table 3 shows the comparison of the average DF level between the base case and the case. Under overcast sky condition, the simulation results showed that HLP and shading systems integration improved the average DF inside office space reached 79%. Integration of HLP and shading system also decreased the average DF level at the area near the side window (measurement points row 1-4) as big as 5% and improved the average DF at the partially daylight area (measurement points row 5-9) as big as 120%. These results indicated the role of shading systems in decreasing the excessive DF level at the area near the East facing window and the role of HLP in increasing the DF level in the deep area of the office room

DF point analyses for the base case and the case also showed that HLP and shading system integration improved the percentage of measurement points achieving the DF level more than 1.5-2.5%. The percentage of measurement points achieving the DF level more than 1.5-2.5% was 22% and 27% for base case and case, respectively.

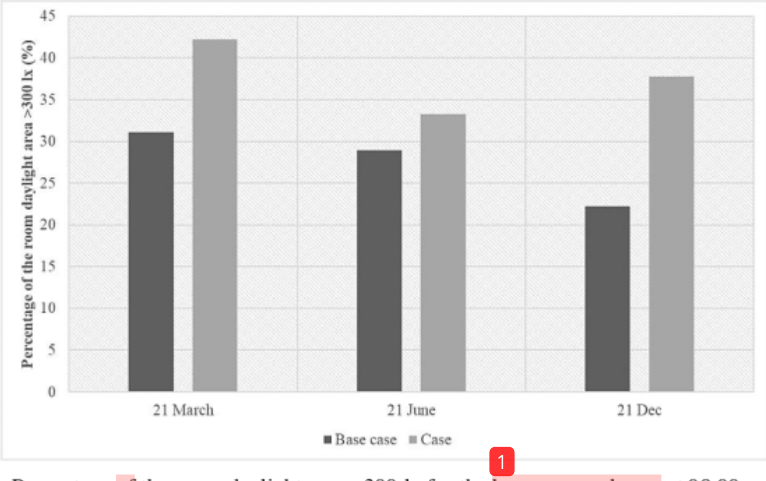
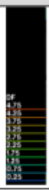
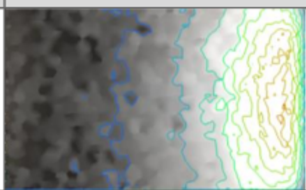
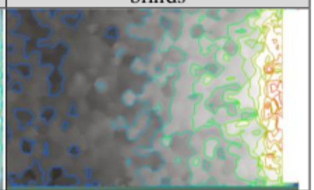


Figure 6. Percentage of the room daylight area> 300 lx for the base case and case at 09:00

Table 3. Comparison of Daylight Factor between base case and case

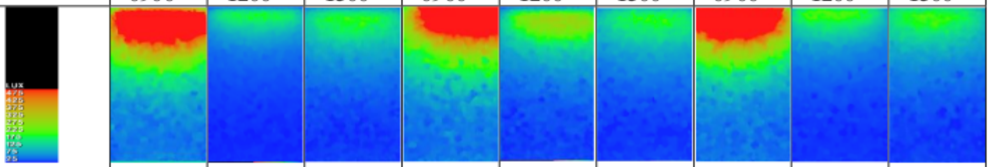
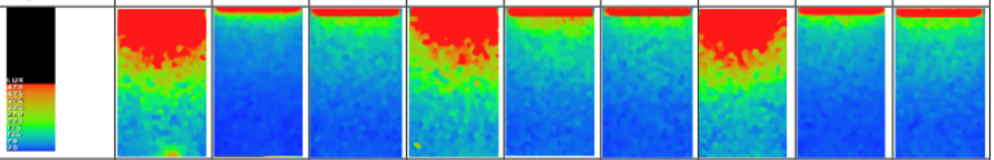
		Base Case Office with East facing side window	**Case** Office space with East facing side window and Horizontal Light Pipe, Light shelves, blinds
Simulated Daylight Factor			
Percentage of points achieving DF range (%)	<1.5	77.8	73.3
	1.5-2.5	22.2	26.7
Daylight Factor (%)	Minimum	0.1	0.2
	Maximum	4.1	3.5
	Row 1-4	1.94	1.85
	Row 5-9	0.20	0.44
	Average	0.97	1.74
Percentage changes in DF level	Minimum		100
	Maximum		-15
	Row 1-4		-5
	Row 5-9		120
	Average		79

4.2 Daylight Distribution Analysis

Table 4 showed the daylight distribution analysis of the base case and case under intermediate sky condition. The results showed that the base case and case had a uniformity ratio below 0.8, but there was a significant improvement of uniformity ratio by HLP and shading systems integration. The uniformity ratio improvement was in the range of 143% to 800% (Figure 7). The uniformity ratio improvement in most critical times at the East facing window was 267%, 800%, and 210% for 21 March, 21 June, and 21 December 09:00, respectively. At 12:00 and 15:00, the improvement of the uniformity ratio was in the range of 143% to 363% (Figure 7).

Illuminance distribution of HLP and shading system integration (Table 4) also showed the role of LS in distributing daylight further into the office room. HLP distributed daylight at the deep area of the office room (Table 4), especially when the HLP aperture received direct sunlight at 09:00. HLP improved the minimum daylight level located in the area distant from the East facing window, while the shading systems decreased the excessive daylight level at the area near the building perimeter. The combination of those daylighting systems improved the uniformity ratio in the overall office room, by increasing the minimum daylight level and lowering the average daylight level.

Table 4. Daylight distribution analysis of base case and case

		21 March 0900	**21 March 1200**	**21 March 1500**	**21 June 0900**	**21 June 1200**	**21 June 1500**	**21 Dec 0900**	**21 Dec 1200**	**21 Dec 1500**
Base case										
	Average Illuminance (lx)	688	34	57	349	72	52	420	43	55
	Uniformity Ratio	0.04	0.06	0.05	0.01	0.06	0.06	0.05	0.07	0.07
Case										
	Average Illuminance (lx)	369	38	70	311	81	64	305	50	63
	Uniformity Ratio	0.16	0.16	0.13	0.13	0.26	0.26	0.15	0.20	0.22

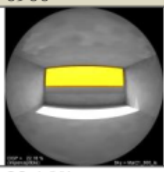
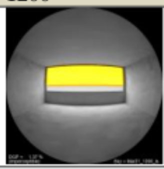
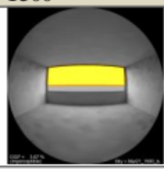
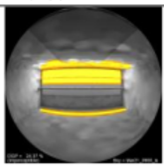
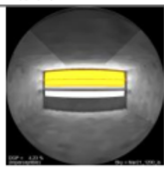
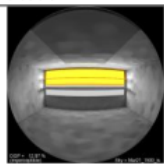
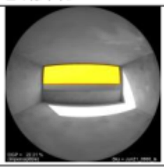
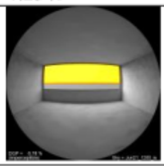
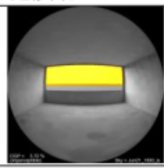
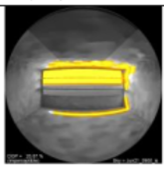
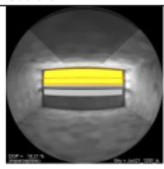
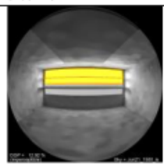
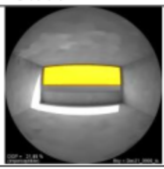
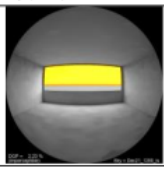
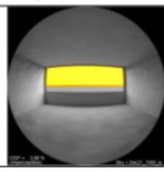
4.3 Glare Analysis

Table 5 shows the simulation results of Daylight Glare Probability (DGP) for base case and case. In general, the results showed that LS and blinds reduced the direct sunlight patches and reflected the sunlight into the ceiling area. The ability of LS and blinds in reducing the sunlight patches to avoid glare on the horizontal work plane is in agreement with the results of Lim et al., 2012 [28].

The simulation results showed that both two cases had DGP under 0.35, which corresponds to an imperceptible glare by building users. Office space with HLP and shading system had a higher DGP than office space with an East facing window only. The highest DGP in the base case was 22.21%, while in the case was 25.07%. The highest DGP for base case and case occurred on 21 June 09:00 when the East faced side window received direct sunlight.

Integration of HLP and shading system resulted in a higher DGP, but still in the range of imperceptible by building user. Table 5 also shows the reflected light on the ceiling by LS, which had a reflective material on its upper surface. Application of LS and blinds decreased illuminance level near the East facing window but slightly increased the Daylight Glare Probability. The trend occurs since the area near the East facing window was shaded by LS and blinds, but the wall and ceiling area obtained more daylight reflected by the reflective upper surface of LS.

Table 5. The Daylight Glare Probability of Base Case and Case

Date		**Simulation Time**		
		0900	**1200**	**1500**
21 March	**Base Case** Office with East facing side window			
	DGP	22.16%	1.37%	3.67%
	Case Office space with East facing side window and Horizontal Light Pipe, Light shelves, blinds			
	DGP	24.37%	4.23%	12.97%
21 June	**Base Case** Office with East facing side window			
		22.21%	6.78%	3.72%
	Case Office space with East facing side window and Horizontal Light Pipe, Light shelves, blinds			
		25.07%	19.21%	12.92%
21 December	**Base Case** Office with East facing side window			
		21.89%	2.23%	3.98%

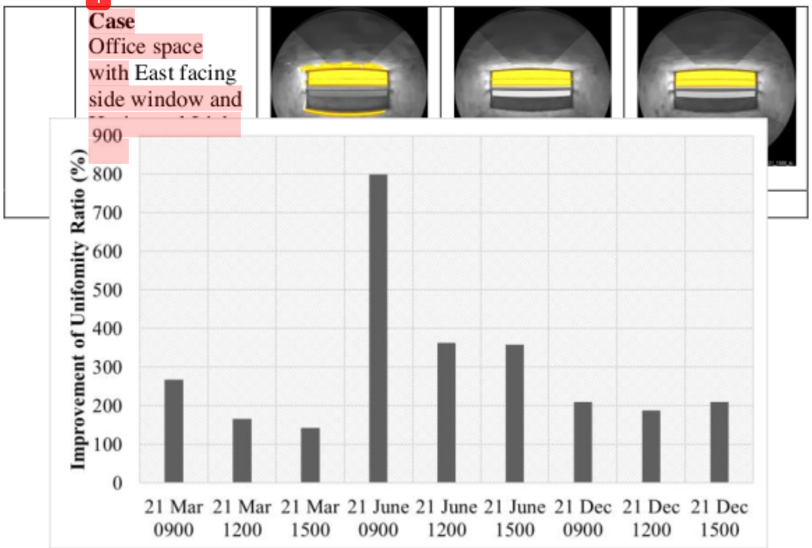


Figure 7. Improvement of Uniformity Ratio by integration HLP and shading systems

5. Conclusion

The results showed that the integration of Horizontal Light Pipe (HLP) as a light transport system and light shelf (LS) and blinds as shading systems decreased the average illuminance level in the overall area of office space but increased the percentage of the room daylight area more than 300 lx. Under intermediate sky condition, both two cases provided an average illuminance level of more than 300 lx and met the illuminance target for a workspace that performs a visual task of high contrast or large size at 09:00, when the East facing window received direct illumination from the sun. At that time, the base case had an average illuminance level of 349 lx-688 lx, while the case had an average illuminance level of 305 lx-369 lx.

The role of shading systems in decreasing the excessive daylight level at the area near the perimeter window and HLP in increasing the daylight level at an area distant from the perimeter window was significant when the East facing window received direct sunlight (09:00). At that time, HLP and shading system integration increased the average illuminance level at partially daylight area, reached 135%, and decreased the average illuminance level at the area near the side window, reached 55%. Although the HLP received daylight only from half of the hemisphere in front of it, the improvement of average illuminance level at partially daylight area when the sun position was not in front of the side window was still high.

Under overcast sky condition, HLP and shading systems integration improved the average Daylight Factor inside office space reached 79%. HLP and shading system integration also decreased the average DF at the area near the perimeter window (measurement points at row 1-4) as big as 5% and improved the average DF at the area distant from the perimeter window (measurement points at row 5-9) as big as 120%.

The uniformity ratio of both cases was below 0.8, but there was a significant improvement of uniformity ratio by HLP and shading systems integration, in the range of 143% to 800%. The combination of those daylighting systems increased the uniformity ratio in the office room by increasing the minimum daylight level and lowering the average daylight level. HLP and shading system integration resulted in a higher Daylight Glare Probability, but still in the range of imperceptible by building users.

The office depth in this research was 10 m, representing a deep-plan office room in the Tropics. Further studies involving different room geometry will be investigating. Analysis of HLP and shading systems daylight performance in different window orientations will also be evaluating, while still considering the HLP orientation in the Tropics to the East or West.

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