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Daylight performance of horizontal light pipe and shading systems in office room with bilateral opening

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Abstract. Daylighting implementation in the building can reduce building energy use. Previous research about Horizontal Light Pipe and shading systems in the Tropics examined daylighting strategies in a room with a unilateral opening, which receives daylight through a window in one wall. The bilateral openings from two adjacent side windows have the potential to improve daylight distribution and have yet to be discussed in previous research. This research evaluates the daylight level and distribution of HLP and shading systems in a room with a bilateral opening from two adjacent windows. The research method is experimental with simulation using IES-VE (Integrated Environment Solution-Virtual Environment) as a tool. The Daylight Factor (DF) and Uniformity Daylight Factor (UDF) of a room with bilateral openings from two adjacent windows were compared with a room with bilateral openings, HLP, and shading systems. The results indicate that integrating HLP and shading systems in an office room with two adjacent side windows decreases the average Daylight Factor (DF) by 48.74%, bringing the average DF fulfilling the recommended DF level for the office room. HLP and shading systems improve the Uniformity Daylight Factor and percentage of sensor points with DF 2-5%, as high as 56% and 67.38%, sequentially.

1. Introduction

Daylighting implementation in the building can reduce building energy use [1]. Daylighting can reduce the energy use for electric lighting [2] and reduce the peak power demand of buildings [3]. Proper daylighting strategies can contribute to a smaller air conditioning system [4].

For building users, daylight can improve productivity, workers' attention, cognitive performance, and alertness [5]. Daylight creates a look livelier and more attractive interior space. Building users also prefer good daylight in their working environment [6].

Deep-plan building design limits the area that can access daylight. Daylight illumination by a side window has a restriction, where the daylight level is reduced as the distance from the perimeter of the building increases. Without proper shading, a large glazing facade also admits direct solar radiation inside the building [7]. Those lead to non-uniform daylight distribution and glare problems.

A Horizontal Light Pipe (HLP) is an innovative daylighting system [8] that can distribute daylight into an area far from the side window. Considering the Tropics, the design significance is usually on avoiding overheating and glare by controlling the daylight level penetrating the building; HLP should be combined with shading systems [9,10]. In an office room with unilateral daylighting, combining HLP and shading systems can improve daylight performance inside the building by reducing the average daylight level and improving daylight uniformity [9].

Previous research about HLP primarily focused on improving HLP efficiency in receiving, transporting, and distributing daylight by several strategies such as HLP with static and tiltable reflectors [11], HLP with LCP [12], HLP with egg-crate reflectors [13]. Previous research about Horizontal Light Pipe and shading systems in the Tropics [9,10] also examined daylighting strategies in a room with a unilateral opening, which receives daylight through a window in one wall.

Configuration of office rooms in a building plan results in a room with unilateral opening and bilateral opening (figure 1). Previous studies about daylighting using HLP mainly focused on rooms with unilateral openings [9-13]. Previous research about HLP has not discussed the bilateral openings from two adjacent windows that can result in more uniform daylight distribution and less glare [14]. This research evaluates the daylight level and distribution of HLP and shading systems in a room with a bilateral opening from two adjacent windows.

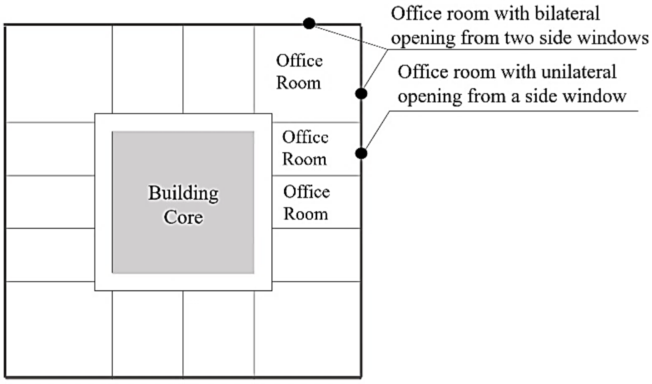


Figure 1. Configuration of the office room with a bilateral opening from two side windows in an office building

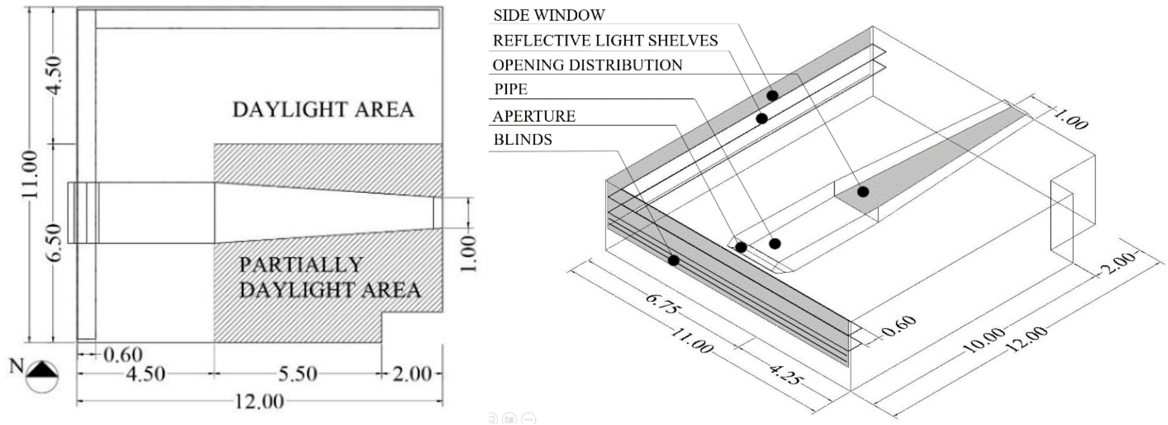
2. Methodology

2.1. Office Room with Bilateral Opening Implementing Horizontal Light Pipe and Shading Systems

The room studied is open plan office type, located at the corner of the building. The office room represents a deep plan office room with 12 m in length, 11 m in width, and 2.7 m in ceiling height. The office room has access to daylight from two adjacent side windows facing North and West. The window-to-wall ratio of the window facing North and the window facing West is 67%. The material properties of the ceiling, floor, and wall are tabulated in Table 1.

Horizontal Light Pipe as a light transport system complements daylight provided by the side windows [9]. Side windows provide full daylight to the work area 4.5 m from the building perimeter, and HLP distributes daylight at a partial daylight area of 4.5 m to 12 m from the building perimeter (figure 2). The aperture of HLP faces West, considering the best orientation of HLP in the Tropics, which is either West or East [15]. The aperture captures direct and diffuse sunlight through clear glass with a visible transmittance (VT) of 0.88. The transport element of HLP has a 12 m length and uses a reflective specular material in inner surfaces with a reflectivity of 0.90. The HLP distributes daylight through clear glass with a VT of 0.88.

The shading systems are composed of two internal reflective Light Shelves (LS) and blinds (figure 2). The internal LS has a 0.6 m width and reflectivity of 0.90 on its upper surface. The two internal LS were placed at 1.50 m and 2.1 m from the floor. The blinds have slats 45° closed and are placed at a height of 0.9 m to 1.5 m from the floor. A combination of internal LS and blinds is the optimum shading system in the Tropics [16].



(a) (b)

Figure 2. (a) Plan and (b) Perspective of an office room with bilateral opening integrating horizontal light pipe, light shelves, and blinds

2.2. Experimental with Simulation as a Tool

The research method is experimental, using simulation as a tool. IES-VE (Integrated Environment Solution-Virtual Environment) Radiance-IES is used to investigate the daylight performance of an office room with the bilateral opening from two adjacent side windows integrating HLP and shading systems. IES-VE has been validated in previous research about Horizontal Light Pipe [10] and shading systems [7] in the Tropics.

The material properties of the office room, HLP, light shelves, and blinds are shown in Table 1. The study location was Surabaya (7.38° S and 112.79°E), one of the cities in the Tropics. Horizontal illuminance sensor points are placed 1 m between each sensor and start at 0.5 m from the nearest wall.

The daylight performance of the base case, an office room with two adjacent side windows, is compared to the cases. Case 1 represents an office room with two adjacent side windows and HLP. Case 2 represents an office room with two adjacent side windows, light shelves, and blinds, while case 3 represents an office room with two adjacent side windows, HLP, light shelves, and blinds (figure 3).

Table 1. Material properties of the office room with a bilateral opening from two adjacent side window

	Components	Reflectance	Specularity	Roughness	Transmittance
Room	Wall	0.80	0.03	0.03	N/A
	Floor	0.43	0.04	0.03	N/A
	Ceiling	0.80	0.03	0.03	N/A
	Side window	N/A	N/A	N/A	0.88
Horizontal Light Pipe	Aperture	N/A	N/A	N/A	0.88
	Pipe	0.90	0.90	0.02	N/A
	Opening distribution	N/A	N/A	N/A	0.88
Reflective light shelves	Upper surface	0.90	0.90	0.02	N/A
Blinds	Slats	0.40	N/A	N/A	N/A

2.3. Daylight Performance Metrics

The daylight performance was analyzed using Daylight Factor and Uniformity Daylight Factor. Daylight Factor (DF) is defined as the ratio between the illuminance at a sensor point inside the room (Ei) to the external horizontal illuminance under CIE overcast sky condition (Eo) (equation 1) [4]. According to the British Council for Offices Guide, an average DF of 2-5% is recommended for an office workplace. An average DF of more than 5% indicated that the room is likely to have thermal problems (Brotas and Wilson in [4])

$$DF= \frac{Ei}{Eo} x100\% \quad (1)$$

Uniformity Daylight Factor (UDF) expresses the degree of homogeneity in lighting distribution. It is obtained by dividing the minimum DF value (DF min) by the average DF (DF avg) [17], as can be seen in equation 2. The minimum UDF for efficient working environments should be 0.4 [BREEAM in 17].

$$UDF= \frac{DF\ min}{DF\ avg} \quad (2)$$

Base Case	**Case 1**	**Case 2**	**Case 3**
Office room with two adjacent side windows	Office room with two adjacent side windows and HLP	Office room with two adjacent side windows and light shelves, blinds	Office room with two adjacent side windows. HLP, light shelves, blinds

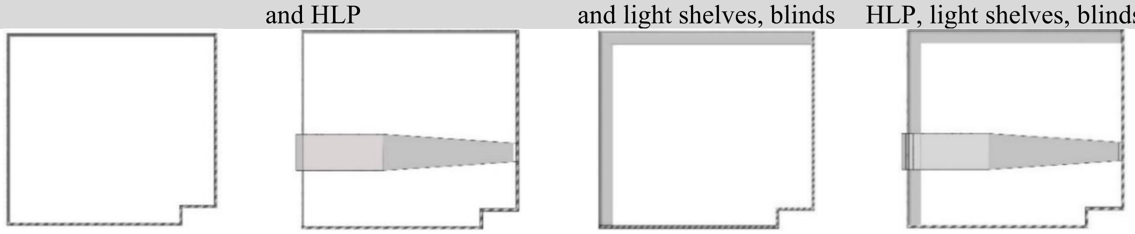


Figure 3. Experimental scheme

3. Results and Discussion

3.1. Daylight Factor Analysis

The results showed that the average DF of the base case, an office building with two adjacent side windows, was 7.55%, exceeding the recommended DF for the working area by 2-5% (table 2). Due to the intense daylight, a room with an average DF of more than 5% will likely encounter thermal problems (Brotas and Wilson in [4]). This result is aligned with previous research about side windows in the Tropics, which shows that without daylight control, an office building with a glazed façade has a high illuminance with uneven daylight distribution [7]. The percentage of sensor points with DF 2-5% in the base case was the lowest, as high as 37.04%.

The average DF of Case 1, as big as 6.93%, also exceeds the recommended DF for the working area by 2-5% (table 2). HLP integration in the room with a bilateral opening from two adjacent windows decreases the average DF by 8.2%. The decrement occurs because the HLP aperture gives shading for the sensor points at the area near the side window. These results are aligned with previous research [12] about the shading effect because of the HLP aperture protruding outside the building façade. The percentage of sensor points with DF values ranging from 2-5% reached 38% and improved by 2.8% compared to the base case.

The results indicated that the average DF of Case 2 reached 4.13% and was in the range of the recommended DF for the working area by 2-5%. The LS and blinds effectively reduced the average DF in a room with the bilateral opening from two adjacent side windows, reaching 45.3%. The percentage of sensor points with DF level 2-5% of case 2 were higher than the base case, that is, 54.6% and 37.04%, case 2 and base case, sequentially. Compared to the base case, the shading systems improved the percentage of sensor points with DF level 2-5%, as high as 47.4%.

The average DF of case 3 reached 3.87% and was in the range of the recommended DF for the working area by 2-5%. The DF minimum of an office room with two side windows with HLP and shading systems (case 3) was higher than a room with only windows and shading systems (case 2). A combination of HLP, LS, and blinds in a room with the bilateral opening from two adjacent side windows reduces the average DF by 48.74%.

The office room with two adjacent side windows, HLP, and shading systems had the highest percentage of sensor points with DF level 2-5%, as high as 62% (figure 4). The results indicated the effectiveness of shading systems in reducing the average DF and the maximum DF and improving the percentage of sensor points with a DF level of 2-5%.

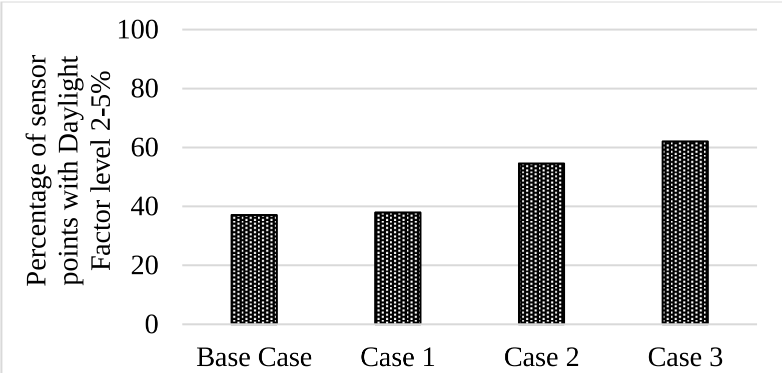
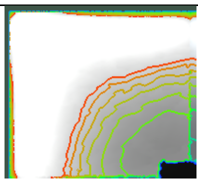
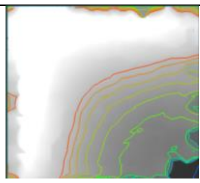
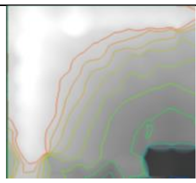
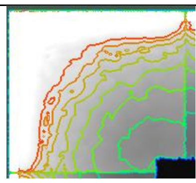


Figure 4. Percentage of sensor points with daylight factor level 2-5%

Table 2. Comparison of HLP, light shelves, and blinds impact on daylight performance

	Base Case	Case 1	Case 2	Case 3
				
DF maximum (%)	18.4	16.2	7.80	9.70
DF minimum (%)	1.90	1.80	1.00	1.50
Average DF (%)	7.55	6.93	4.13	3.87

3.2. Uniformity Daylight Factor Analysis

The results indicated that the base case and case 2 had the lowest UDF, as high as 0.25 and 0.24, sequentially. The office room with two adjacent side windows and HLP (case 1) had a UDF of 0.26, slightly higher than the base case and case 2. It was only an office room with two adjacent side windows equipped with HLP and shading systems with a UDF of 0.4, fulfilling the minimum UDF for achieving an efficient working environment (figure 5). The results showed the effectiveness of shading systems and HLP in improving the UDF in the room with a bilateral opening from two side windows.

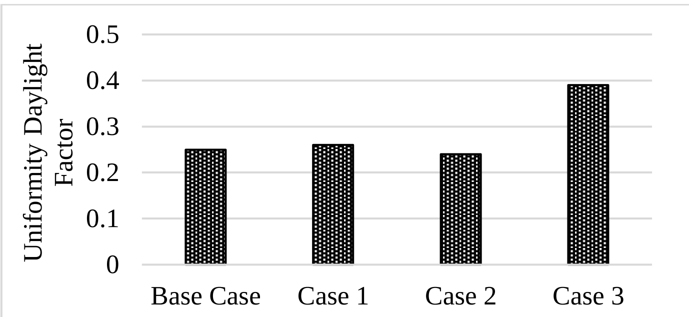


Figure 5. Uniformity daylight factor of office room with the bilateral opening from two adjacent side windows

4. Conclusion

Daylight level and distribution of office room with two adjacent side windows equipped with a Horizontal Light Pipe and shading systems were studied. The results indicated that integrating HLP and shading systems in an office room with two adjacent side windows decreased the average daylight factor by 48.74%, bringing the average DF to fulfill the recommended DF level for the office room. HLP and shading systems improved the Uniformity Daylight Factor and percentage of sensor points with DF 2-5% as high as 56% and 67.38%, sequentially.

The role of HLP and shading systems integration in an office room with the bilateral opening from two adjacent side windows in improving the daylight level and distribution is shown. Future lines of research could deepen the role of HLP and shading systems integration using dynamic daylight metrics and thermal and energy performance.

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