

DAYLIGHTING PERFORMANCE OF HORIZONTAL LIGHT PIPE BRANCHING ON OPEN PLAN OFFICE SPACE

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ABSTRACT

For daylighting purpose, office buildings should have a shallow plan and increase the ratio of surface to building's volume. However, intensive use of air-conditioning drives office building's plan to be deep with a minimum surface to volume ratio. This leads to the presence of areas that have insufficient daylight level at the work plane. Considering limitations of some daylighting methods in distributing daylight to these areas, Horizontal Light Pipe (HLP) was selected. The aim of this research was to evaluate and explain the effect of HLP branching on daylight quantity and distribution inside open plan office space. Experimental with simulation as a tool was used as the research method. HLP branching's uniformity ratio, illuminance and Daylight Factor were compared with unbranching HLP, simultaneously with daylighting standards. Results showed that office space with HLP-L branching had higher daylight level than HLP-T branching, 296 lux and 295 lux, HLP-L and HLP-T, respectively. However, HLP-T branching distributed daylight more evenly than HLP-L branching, with uniformity ratio as 1.49:1 and 1.50:1, HLP-T and HLP-L, respectively. Both of them met the illuminance target value and uniformity at work plane. Light's deflection and improvement amount of opening distribution decreased average illuminance and Daylight Factor up to 3.59%. Those also decreased uniformity of daylight inside the space.

Keywords: Daylighting performance; open plan office space; horizontal light pipe; branching.

INTRODUCTION

According to Boubekri (2008), daylighting application in office building provides several advantages, such as energy saving, health and psychological benefits. Daylighting reduces overall building's energy consumption, including energy used for air conditioning and minimizes energy peak demand (Ander, 1995). This reduction is significant, considering that energy used for electric lighting in office building reaches 40% of overall energy consumption (Lechner, 2009). Besides energy saving, daylight helps fulfill user's psychological needs through inherent and unique qualities that are not easy to imitate artificially (Boubekri, 2008). According to Ander (1995), daylighting can fulfill human needs of view and increase user's productivity. Daylight is also one of the most effective antidepressants available and enable building's user to maintain a well-balanced circadian rhythm (Boubekri, 2008).

For daylighting purpose, according to Moore (1993), multi storey buildings should have a shallow plan and increase the ratio of surface to building's volume. However, with the intensive use of air-conditioning, building's plan has a tendency to be deep, as expressed by Lomas (2007), with minimum surface to volume ratio in order to reduce heat load from building envelope and load on the air conditioning equipment (Givoni, 1998). This leads to the

presence of areas that have insufficient daylight level at the work plane. On a square building plan without atrium, 4.5 m perimeter area from sidelighting are full daylight zone, the rest are no daylight zone (Lechner, 2009).

Considering the limitations of some daylighting methods (skylight, sidelighting, light shelves and vertical light pipe) in distributing daylight to these areas (Hien and Chirarattananon, 2007), Horizontal Light Pipe (HLP) is selected. According to Chirarattananon et al., (2000), light pipe transports light which enters to the intended exit in the ceiling at the interior of the building. According to Beltran et al., (1997), HLP is designed to supplement daylight from sidelighting and illuminate the deep area of the building. Using light pipe system, daylight level can be increased and energy consumption over the day can be reduced significantly.

Previous research on Horizontal Light Pipe was conducted by Chirarattananon et al., (2000) by developing a model based on light pipe's general configuration at plenum in a test room and comparing the calculation results with results from physical measurements. Beltran et al., (1997) then investigated four types of HLP on office room. Utilization of few methods to improve light pipe's daylighting performance was studied by Hien and Chirarattananon (2007) through tiltable mirror; Scartezzini and Courret (2001) through anidolic ceiling and Garcia Hansen et

al., (2001) trough Laser Cut Panel. Daylight and energy performance of HLP equipped with a flat captation system was investigated by Canziani *et al.*, (2004). Those researches showed HLP’s reliability as one of the advanced optical daylighting system which can illuminate deep areas of the room.

Daylighting performance of HLP branching became a topic in this research. HLP’s prototype which was branched on this study was based on light pipe C, developed by Beltran *et al.*, (1997). HLP was applied on an open plan office space at Surabaya (latitude 7°15’55”). The effect of HLP branching on daylight level and distribution through open plan office space was investigated.

HORIZONTAL LIGHT PIPE BRANCHING ON OPEN PLAN OFFICE SPACE

Horizontal Light Pipe Branching

Light Pipe C prototype, developed by Beltran *et al.*, (1997), was used in this research. Placed on tropical climate, light pipe’s aperture orientation had been directed to East-West, according to Chirarattananon *et al.*, (2000). In general, light pipe had a trapezoidal section in plan and section. The rear of the light pipe was 0.9 m in width. Aperture, an external planar closing element that collect, redirect sunlight in order to optimize the direction of the incoming solar rays as the solar position varies (Canziani *et al.*, 2004), had 0.6 m in height and 1.80 m in width. Aperture, which was oriented to the West, was covered by single clear glass that has visible transmittance of 88%.

A pipe, a rectilinear duct with optical properties suitable for delivering sunlight into the room (Canziani *et al.*, 2004) had 0.6 m in height and used 95% specular reflective film on its inner surface. This pipe was equipped with a central reflector which had compound reflective film (88%) on its surface and side reflector which had highly reflective specular film (95%) on its surface. The length of light pipe was 8 m, in accordance with the depth of the room.

Distribution element consisted of a diffuser, a natural light spreader into the space under the pipe, which had transmittance of 88%. Diffuser was placed on the partially daylight area, at a distance of 4.5 m from sidelighting.

HLP’s branching was equipped with “tapping off” mirror and followed by reducing HLP’s size, as described by Szokolay (2004). HLP’s branching was varied in L and T shape (Table 1). Design elements of HLP branching consists of opening distribution’s distance from the aperture and the number of distribution opening.

Open Plan Office Space

Experiments were conducted on open plan office space. The dimension of open plan office space was 8 m x 24 m, consisted of 32 workers (according to Meel *et al.*, 2010) who have an area of 6 m² per person. Office space was placed on an office building (Fig 1) which had central core and single zone circulation. Width of the office building was 24 m, according to Bailey (1990) that width of office building with single zone and central core was 16-24 m.

Open plan office space was placed on the west side of the building, consisted of 139.5 m² full daylight area and 52.5 m² partially daylight area. Floor to floor height of office space was 4.2 m, based on Kohn and Katz (2002), that floor to floor height of typical high rise office building in Asia was 4-4.2 m. Ceiling height of the office was 2.75 m, synthesized from office floor to floor height consideration of Kohn and Katz (2002).

Sidelighting along three wall sides (North, West and South orientation), 40 m width and 1.95 m in height, was located in open plan office space. Highly reflective glass was used for sidelighting, with Visible Transmittance of 0.22. Interior reflectance of ceiling, wall and floor were 85%, 70% and 40%, respectively (based on Rea in Egan and Olgyay, 2002)

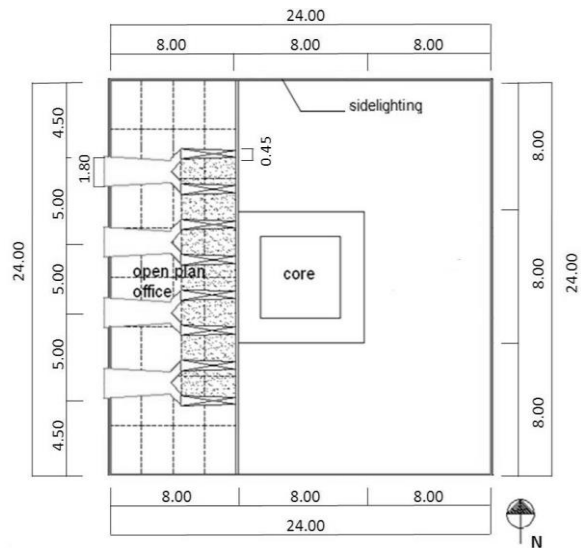


Figure 1. Office Building Plan with HLP Branching Application

Description:

- daylight zone
- partially daylight zone
- opening distribution
- Horizontal Light Pipe
- Mirror

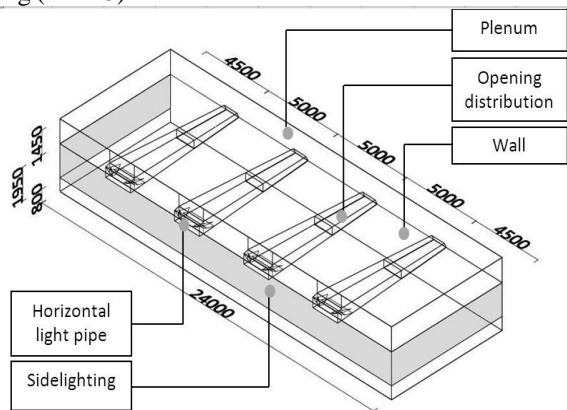
METHODOLOGY

To study the effect of HLP branching on daylight level and distribution through office space, experimental method with simulation as a tool was used. With the same amount, HLP in open plan office space was branched with “L” type, where one of opening distribution distributed daylight directly from aperture and pipe, while another distributed daylight from light pipe deflection. “T” type HLP branching was a condition where all of distribution opening distributed daylight from light pipe deflection (Table 1). Both of HLP branching were applied at open plan office space, where HLP worked as a complement to sidelighting.

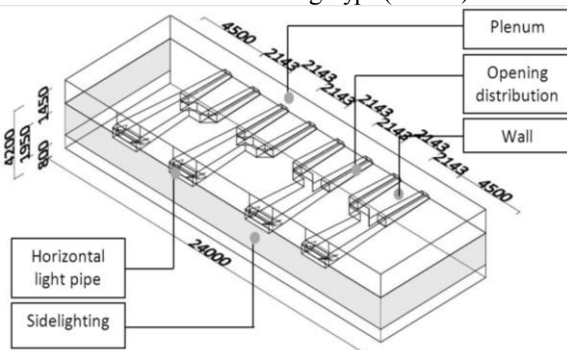
Base case, an open plan office space with unbranched HLP was compared with case, an open plan office space with HLP branching. Experimental scheme can be observed in Table 1. Comparison of light deflection’s amount, and opening distribution’s amount between the base case and case can be viewed in Table 2, while materials that were used in the simulation can be seen in Table 3.

Table 1. Experimental Scheme

Base Case
Unbranched HLP at open plan office space with sidelighting (HLP-O)



Case
Case 1. HLP with “L” Branching Type (HLP-L)



Case 2. HLP with “T” Branching Type (HLP-T)

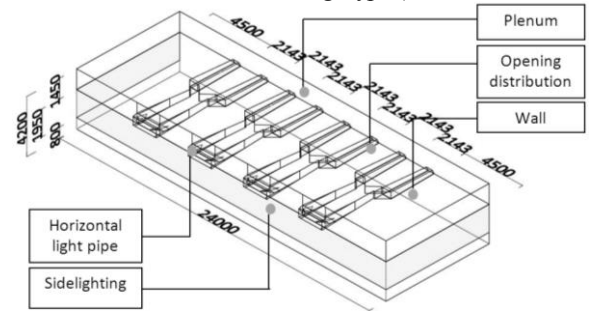
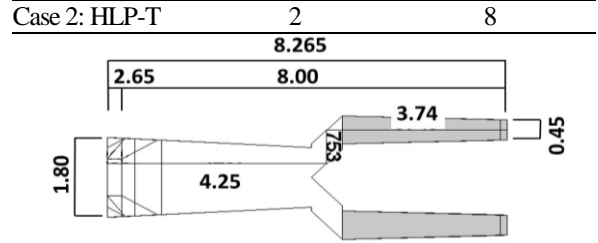
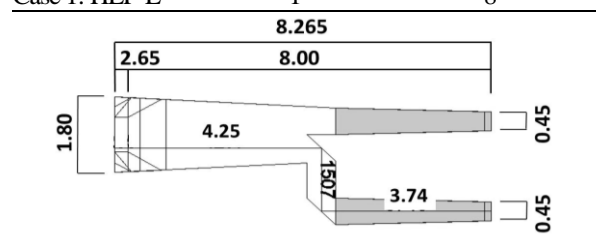
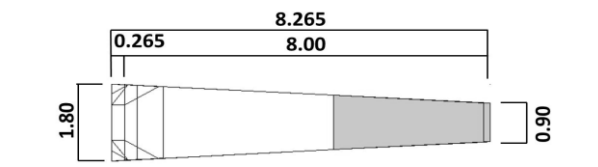


Table 2. Comparison of HLP’s Amount of Light Deflection and Opening Distribution between Base Case and Case

	Amount of Light Deflection	Amount of Opening Distribution
Base Case: HLP-O	0	4
Case 1: HLP-L	1	8
Case 2: HLP-T	2	8



HLP branching’s daylighting performance was studied using the Radiance simulation software. Radiance was a daylighting simulation program that used ray-tracing methodology to predict daylight’s behavior in space accurately (Canziani et al., 2004). Radiance was used by Canziani et al., (2004) in predicting the daylighting performance of a flat cap-tation light pipe and Courret et al., (1998) in investigating anidolic light-duct’s daylighting performance.

Climate data of Surabaya (7°15’55” South Latitude and 112°44’33” East Longitude) with over-cast sky condition was used in this study. According to Chirarattanon et al., (2000), HLP’s supplementary illuminance was significant when skylight illuminance from the sidelighting was low; therefore simulation time was set on June 21 at 09.00.

Table 3. Open Plan Office Space and Horizontal Light Pipe's Material

		Transmittance (%)	Reflectance (%)	Specularity (%)	Theoretically
Floor	RAL 7005_mouse grey	0	40.34	0	40% (20-40%, according to Rea in Egan and Olgyay, 2002)
Wall	Beige paint	0	71	0	70% (50-70%, according to Rea in Egan and Olgyay, 2002)
Ceiling	white	0	85.77	0	85% ($\geq 80\%$, according to Rea in Egan and Olgyay, 2002)
Sidelighting Aperture	Bronze reflective 3 mm clear laminate	22	24	-	<i>Reflective glazing</i> , VT 24% transmittance 88% (Beltran et al., 1997)
Distribution opening	DuPont 3 mm clear laminate	88	8.3	-	transmittance 88% (Beltran et al., 1997)
Pipe	DuPont Galvanized-metal LBNL	0	97.5	80	95% <i>specular relective film</i> (Beltran et al., 1997)
Mirror	Galvanized-metal LBNL	0	97.5	80	Flat mirror, shiny surface, 100% specular reflection (Lam, 1986)
Reflector	Aluminium LBNL	0	88.6	80	Compound reflective film, highly reflective (88%) (Beltran et al., 1997)

RESULT

Daylighting performance analysis was conducted by comparing illuminance, Daylight Factor and uniformity ratio of the base case and case, simultaneously with daylighting standards. Illuminance Target Value from Steffy (2008), Daylight Factor standard for quality B (fine work, accurately work which is not intensively continuous) from SNI (Standar Nasional Indonesia) 03-2396-2001 (2001) and illuminance uniformity on work plane from Steffy (2008) were used as daylighting standards.

According to Steffy (2008), illuminance target value for:

- Working spaces where simple visual task are performed: 150 lux (between 135-165 lux, considering that calculations within 10 percent of target values are considered acceptable)
- Performance of high contrast visual task: 300 lux (between 270-330 lux, considering that calculations within 10 percent of target values are considered acceptable)

Illuminance uniformity on work space, as mentioned by Steffy (2008), should be 3:1 and 6:1, average to minimum and maximum to minimum sequentially.

Illuminance Level and Daylight Factor

In general, HLP branching application as complement to sidelighting at open plan office space had a good daylighting performance. This office could serve as a work space with simple visual task, as well as a work space with high contrast visual task (typical). HLP branching had average illuminance level as big as 296 lux and 295 lux for HLP-L and

HLP-T, respectively. Both of them had fulfilled illuminance target value with simple and high contrast visual task, as can be seen in Table 4. These facts reinforced Beltran et al., (1997)'s theory about HLP's function as a complement to sidelighting and also expanded validity of that theory on HLP branching.

Table 4. Comparison of Average Work Plane Illuminance with Illuminance Target

	Average work plane illuminance	Illuminance Target (Steffy, 2008)	
		Simple Visual Task, work situation (135-165 lux)	High Contrast Visual Task, work situation (270-330 lux)
Base Case (HLP-O)	306	√	√
Case 1 (HLP-L)	296	√	√
Case 2 (HLP-T)	295	√	√

Description:

√ : Fulfilled

X : Unfulfilled

Figure 2-4 show Daylight Factor (DF) value resulted by HLP-O, HLP-T and HLP-L. At main measuring point (TUU1), side measuring point 1 (TUS1) and side measuring point 2 (TUS2), HLP-L and HLP-T generated DF as big as 3.1%, 5.9% and 3.6%, respectively. Those DF had fulfilled Daylight Factor standard for quality B (fine work, accurately work which is not intensively continuous) as minimal 2.8%, 1.12% and 1.4% on main measuring point (TUU1), side measuring point 1 (TUS1) and side measuring point 2 (TUS2), respectively.

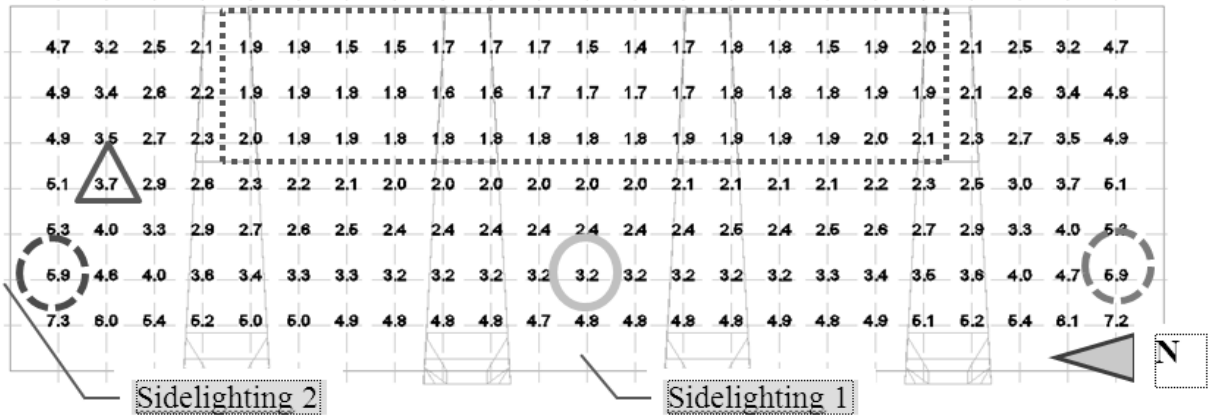


Figure 2. Daylight Factor Value on Open Plan Office Space with Unbranched HLP application (HLP-O)

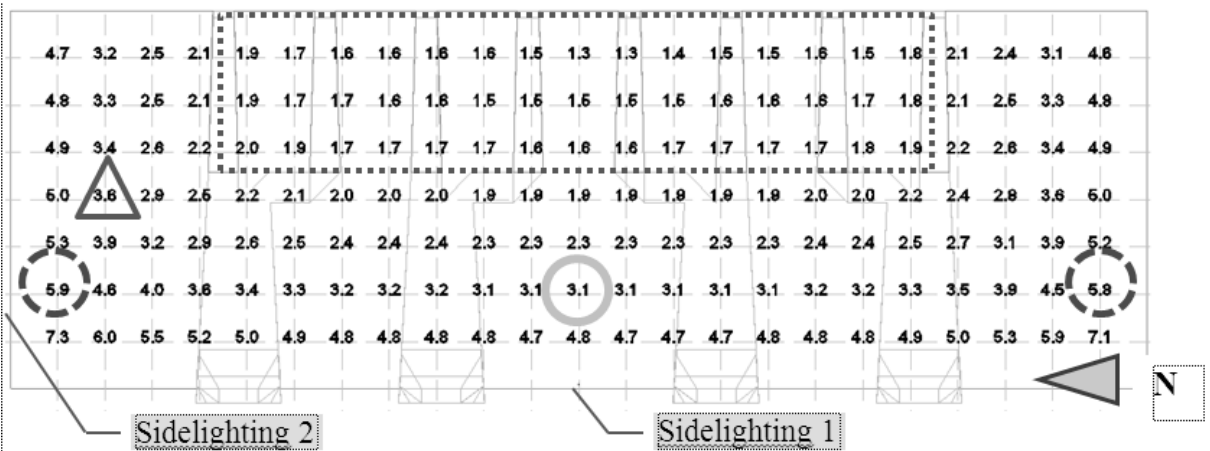


Figure 3. Daylight Factor Value on Open Plan Office Space with HLP L Branching Application (HLP-L)

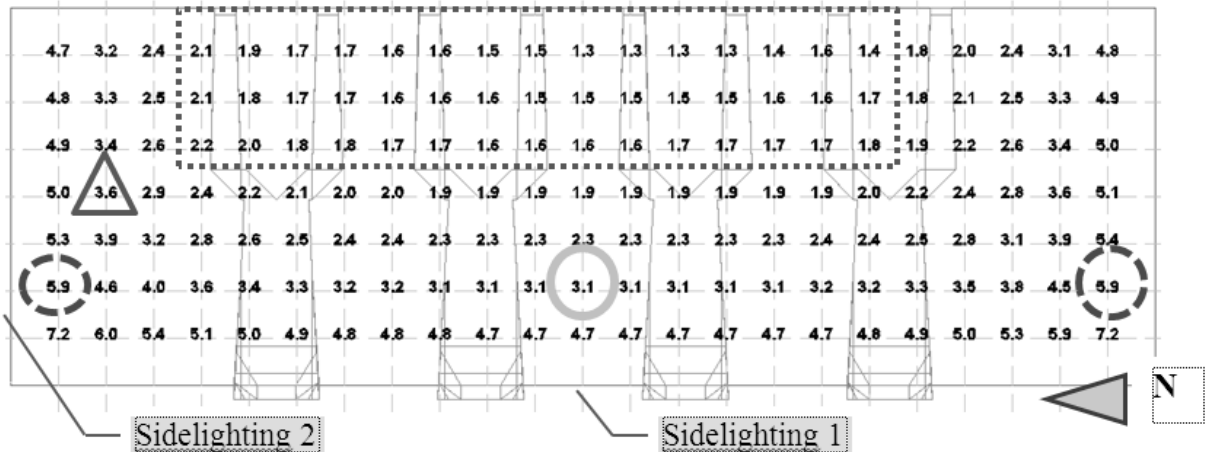






Figure 4. Daylight Factor Value on Open Plan Office Space with HLP T Branching Application (HLP-T)

Description:

-  = TUU 1, main measuring point at a distance of $1/3 d_1$ (2.67 m)
-  = TUS 1, side measuring point at a distance of 0.5 m from side wall, parallel to TUU1
-  = TUU 2, supplementary main measuring point at a distance of $1/3 d_2$, where $d_1=d_2$ (2.67 m)
-  = Partially Daylight Area
- d_1 = distance between sidelighting 1 and interior wall

Uniformity Ratio

HLP branching had high illuminance uniformity ratio on overall area of office space, as big as 2.2:1 and 5.5:1, average to minimum and maximum to minimum, respectively. Those ratios had fulfilled illuminance uniformity target by Steffy (2008).

HLP branching also had high illuminance uniformity ratio in the partially daylight area, where the opening distribution of HLP was placed. Illuminance uniformity ratio, neither average to minimum nor maximum to minimum in the base case and case had fulfilled uniformity target on work plane (Table 5). Those results were appropriate to the theory expressed by Beltran *et al.*, (1997) about HLP's placement to illuminate the space uniformly, and expanded validity of that theory on HLP branching.

Table 5. Comparison of Uniformity Ratio on (a) Overall Area and (b) Partially Daylight Area with Work Plane Uniformity Target

(a)				
Uniformity Ratio on Overall Area				
Average to Minimum		Maximum to Minimum		
Condition	Target	Condition	Target	
	(max 3:1)		(max 6:1)	
HLP-O	2.1: 1	√	5.1: 1	√
HLP-L	2.2: 1	√	5.5: 1	√
HLP-T	2.2: 1	√	5.5: 1	√

(b)				
Uniformity Ratio on Partially Daylight Area				
Average to Minimum		Maximum to Minimum		
Condition	Target	Condition	Target	
	(max 3:1)		(max 6:1)	
HLP-O	1.24:1	√	1.45:1	√
HLP-L	1.24:1	√	1.50:1	√
HLP-T	1.24:1	√	1.49:1	√

Description:
 √ : Fulfilled
 X : Unfulfilled

DISCUSSION

Further analysis then conducted, focusing on the effect of HLP branching design aspects, such as the deflection of light and amount of opening distribution on average illuminance, Daylight Factor and uniformity ratio in space.

Deflection of Light

Deflection of light reduced average illuminance level and Daylight Factor (DF) inside space, as big as 3.27% and 3.59%, HLP-L with one deflection of light and HLP-T with two deflections of light, respectively (Figure 5). This trend was also seen in Figure 6, which described illuminance level profile in the middle of space. The highest illuminance level at a distance of 7 m from sidelighting was generated by

HLP-O, which had no deflection of light, as big as 171 lux. At the same distance, HLP-L and HLP-T, with one and two deflections of light had a lower illuminance level than HLP-O. Illuminance level generated by HLP-L and HLP-T were 163 lux and 161 lux, HLP-L and HLP-T, respectively.

Figure 7a showed that HLP-O (base case), which has no deflection of light, distributed daylight more evenly than HLP-L and HLP-T (case) which had deflection of light. Deflection of light reduced neither average illuminance nor minimum illuminance inside space. When average and minimum illuminance were compared with maximum illuminance, higher uniformity ratio value was resulted. Both cases (HLP-T and HLP-L) resulted the same illuminance uniformity ratio inside space.

On partially daylight area, deflection of light did not significantly effects illuminance uniformity ratio. Uniformity ratio was more influenced by how two opening distributions distributed daylight. HLP-T, whose two opening distributions had the same way in distribute daylight, distributed that light more evenly than HLP-L, whose two opening distributions had different way in distribute daylight. Illuminance uniformity ratio, average to minimum, which were resulted by HLP-T and HLP-L are 1.49:1 and 1.5:1 sequentially (Fig 7b).

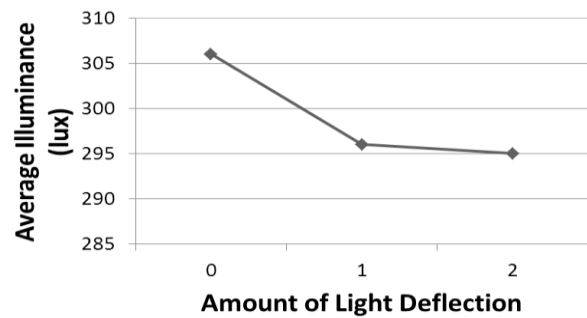
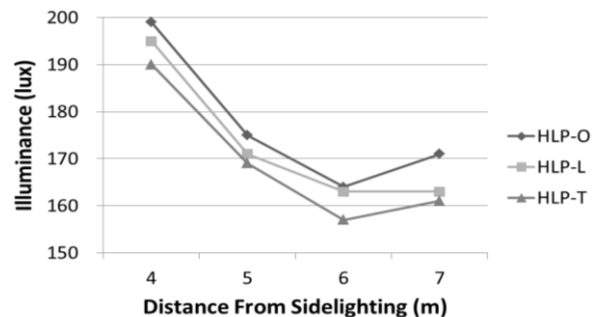
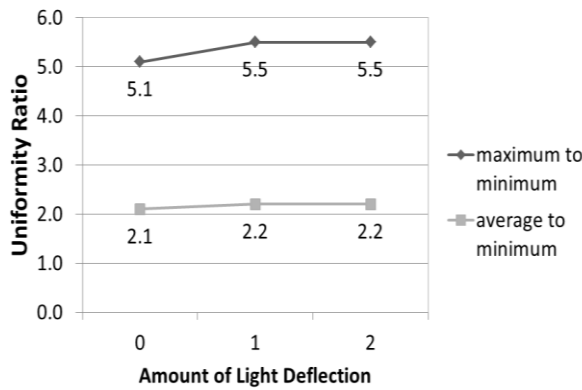


Figure 5. The Effect of Light Deflection on Average Illuminance in Open Plan Office

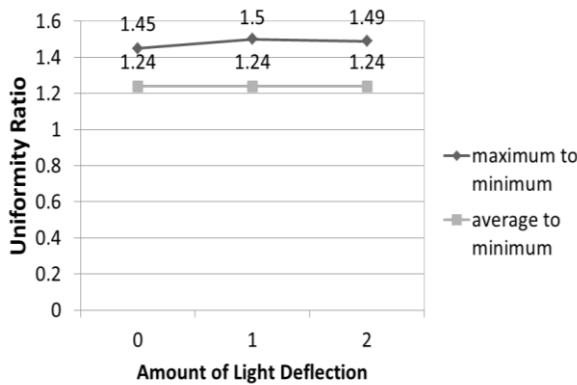


Description:
 HLP-O: no deflection of light
 HLP-L: one deflections of light
 HLP-T: two deflections of light

Figure 6. Illuminance Level Profile in The Middle of the Space



(a)



(b)

Figure 7. The Effect of Amount of Light Deflection on Uniformity Ratio in (a) Overall Area and (b) Partially Daylight Area

Amount of Opening Distribution

Increasing the number of opening distribution, from 4 to 8, reduced average illuminance level and Daylight Factor (DF) in space, but improved uniformity ratio value. HLP with 4 and 8 opening distributions had an average illuminance as big as 306 lux and 295 lux, respectively (Figure 8) and uniformity ratio maximum to minimum as big as 5.1:1 and 5.5:1, respectively (Figure 9).

With the same amount of daylight source (4 apertures), dividing one opening distribution into two by light pipe deflection caused decrement on average illuminance inside office space. HLP with fewer number of opening distributions, but did not have deflection of light had a higher average illuminance.

In line with the theory expressed by Beltran et al., (1997), back walls had an important role in the illumination of the space. Figure 10 showed the illuminance distribution on east wall which were resulted by HLP.

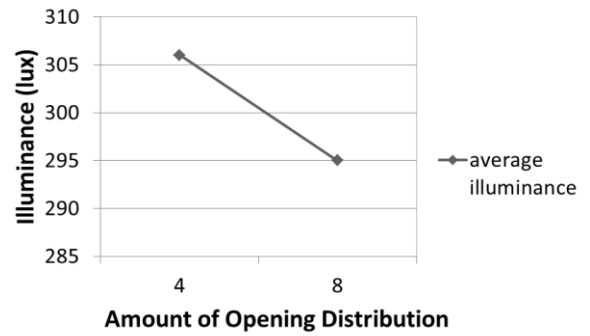


Figure 8. The Effect of Opening Distribution's Amount on Average Illuminance Level

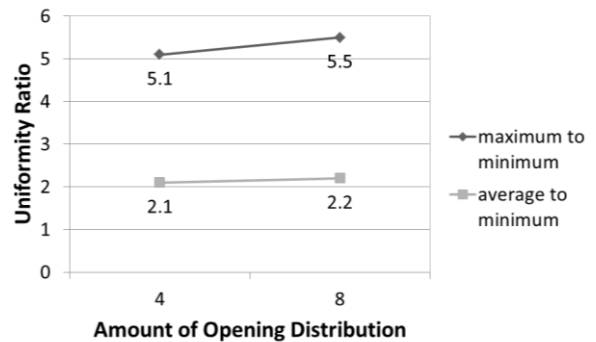


Figure 9. The Effect of Opening Distribution Amount on Uniformity Ratio in Overall Area

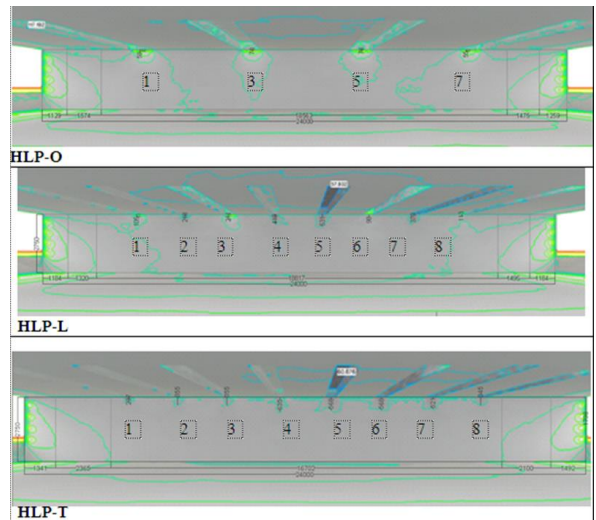


Figure 10. Illuminance Distribution Pattern of Horizontal Light Pipe on East Wall

CONCLUSION

The results showed that open plan office space with HLP-L branching had a higher daylight level than HLP-T branching type, 296 lux and 295 lux, HLP-L and HLP-T, respectively. However, HLP-T distributed daylight more evenly than HLP-L bran-

ching type, with a uniformity ratio as 1.49:1 and 1.50:1, HLP-T and HLP-L, respectively. Both of them had met illuminance target value and uniformity at work plane. Light deflection and addition amount of opening distribution decreased average illuminance level and Daylight Factor (DF) up to 3.59%. Those also reduced uniformity of daylight inside the space.

Development of HLP prototype for tropical area can be done on the next research. The influence of space design elements on HLP's daylighting performance can also be elaborated. For open plan office planning, HLP can be applied without any branching, with aperture width, the rear of the pipe width and HLP length as big as 1.80 m, 0.90 m, and 8.27 m, respectively.

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