INTERNATIONAL JOINT-CONFERENCE

SENVAR-iNTA-AVAN 2015

# PROCEEDINGS

24-26 November 2015

Faculty of Built Environment
Universiti Teknologi Malaysia
Johor, Malaysia

WISDOM OF THE TROPICS
PAST, PRESENT & FUTURE

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# PREFACE

*Bismillahirrahmanirrahim*

All praise to Allah s.w.t the Most Gracious and the Merciful for giving all His Rahmah and Barakah to complete the International Joint Conference proceedings of SENVAR-iNTA-AVAN (SiA2015) jointly organised by Institut Sultan Iskandar (ISI) - Centre For The Study of Built Environment in The Malay World (KALAM) of Universiti Teknologi Malaysia - Graduate School For International Development & Cooperation (IDEC) of Hiroshima University - Center for Advanced Studies in Architecture (CASA) of National University of Singapore, and supported by Universiti Teknologi Malaysia (UTM), Hiroshima University (HU) from November 24 to 26, 2015 in Universiti Teknologi Malaysia, Johor Bahru, Malaysia.

The theme for SiA2015 Conference is “Wisdom of the Tropics: Past, Present & Future”. SiA2015 conference brings together an international community of experts to discuss the state-of-the-art, new research results, perspectives of future developments, and innovative applications relevant to sustainable building design, vernacular architecture, tropical architecture, urban planning, climate change, green technology, socio-economic and sustainable habitat.

More than 200 scholars and researchers from different background and countries were invited to submit their papers, and of these, about 100 people submitted their full papers. These reviewers represent 10 different countries, which provided a broad set of perspectives to the research arena. I would like to thank all these reviewers for their time and effort in reviewing the papers. Without this commitment it would not be possible for the proceedings to be published. The quality of the accepted papers are attributed to the authors and also to the reviewers who have guided the necessary improvement.

Enough thanks cannot be expressed to our distinguish key note speakers Architect Kengo Kuma, Architect Razin Mahmood making themselves available and all other participants, sponsors, supporters, volunteers and media for all their valuable contributions in the conference. Also, special thank you to the Vice Chancellor UTM Prof. Datuk Ir. Dr. Wahid Omar, Director of The Centre of Built Environment in the Malay World or Pusat Kajian Alam Bina Dunia Melayu (KALAM) Associate Professor Dr.Raja Nafida binti Shahminan, Research Fellow from Graduate School for Internatioanl Development and Cooperation (IDEC) Hiroshima University Associate Professor Dr. Tetsu Kubota, Director of CASA (Centre for Advanced Studies in Architecture) National University of Singapore Associate Assistant Professor Dr. Widodo Johannes, Deputy Director of Institut Sultan Iskandar Associate Professor Dr. Syed Ahmad Iskandar bin Syed Ariffin and all the organizing committee members that have worked so hard to ensure that this conference and the publication of the proceeding a great success. The SiA2015 conference and proceedings are a credit to contribution of a large group of people and thus we should be proud of the outcome.

Best Regards,

Chair,
Prof Dr Mohd Hamdan Ahmad
SiA2015 Conference
20 November 2015

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ST 5 SUSTAINABLE HABITAT & SOCIO-ECONOMIC

ST 6 CLIMATE CHANGE

# Collaboration of Two Optical Daylighting Systems at Office Building in the Tropics

Feny Elsiana[1], Frans Soehartono[2] and Luciana Kristanto[3]

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Intensive use of air conditioning encourages building's plan to be deep with a minimum surface to volume ratio. Modern air conditioned office building in the tropics are also applied external shading on windows or highly reflective glazing to minimize radiant heat gain. Those lead to the presence of areas that have insufficient daylight level at the work plane. Horizontal Light Pipe (HLP) is one of optical daylighting system that can guide daylight to these areas. Considering that distributing daylight evenly throughout room is important besides providing sufficient daylight level, a shading system, Reflective Louvre (RL) is applied. RL plays role in reducing daylight level at areas near to window and improving daylight uniformity inside room. The research's aim is to evaluate and explain daylight quantity and distribution of HLP and RL at office space in the tropics. Experiment with physical model 1:10 was used as the research method. Illuminance was measured using HOBO U12/12 data logger, on a real sky condition. Comparison of illuminance, daylight ratio and uniformity ratio resulted by Base Case and HLP&RL Case, a typical office building with sidelighting and an office building with HLP and RL application sequentially, simultaneously with daylighting standards were conducted. Results showed that office room with HLP and RL application had a higher average illuminance and daylight ratio than Base Case. HLP and RL introduced consistently average illuminance between 400-900 lux, improved illuminance level at deep area of room as 160-290% and decreased illuminance level at area close to window as 8-60%. This combination created high uniformity ratio inside room, as high as 0.33-0.71. At most time, those illuminance value and uniformity ratio had fulfilled office's daylighting standards.

Keywords: daylighting performance; horizontal light pipe; reflective louvre

## Introduction

According to Chirarattananon et al., (2000), daylighting has good potential for application in the tropics, where the sky is luminous. For daylighting purpose, multi storey buildings should have a shallow plan, and increase the ratio of surface to building's volume (Moore, 1993). However, intensive use of air conditioning encourages building's plan to be deep, as expressed by Lomas (2007) with a minimum surface to volume ratio to reduce heat load from building envelope and air conditioning equipment (Givoni, 1998). According to Edmonds and Greenup (2002), modern air conditioned office building are also applied external shading on its windows or highly reflective glazing with severe internal shading to minimize radiant heat gain. Those lead to the presence of areas that have insufficient daylight level, especially at deep area of the building. Daylight level at building in the tropics are typically several times lower than commonly achieved in European and North American buildings (Edmonds and Greenup, 2002). Sufficient daylight level, the first issue, is needed to achieve energy saving through daylighting in the tropics.

The second issue is related with daylight distribution. Besides providing sufficient daylight level, distributing daylight evenly throughout room is also important. According to CIBSE (1999), improvement in daylight level is not effective if daylight quality is low, including uniformly daylight distribution. This research raises two daylighting systems, Horizontal Light Pipe (HLP) and Reflective Louvre (RL) that can deliver daylight to deep areas of the building and increase uniformity ratio inside space sequentially.

Horizontal Light Pipe is one of optical daylighting system (Martin, 2002) which is designed to complement sidelighting, especially for the space in the deep area of the building (Beltran et al., 1997). According to Canziani et al., (2004), HLP collects, redirects and in some cases, concentrates or collimates the incident luminous flux with aperture situated at building facade; transports daylight inwards the building through pipe and distribute it into the deep area of the rooms via distribution opening.

Previous researches on HLP were conducted by Chirarattananon et al., (2000) by constructing 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. Development of few methods to improve light pipe's performance were conducted by Hien and Chirarattananon (2007) through tilt able mirror; Scartezzini, Courret (2002) through anidolic ceiling and Hansen et al., (2001) through Laser Cut Panel. Beltran et al., (1997) studied four type of HLP on office room. HLP type C, which gained the best daylighting performance from previous study then was developed together with Mogo (2007) and Uppadhyaya (2008). The effect of HLP branching on daylighting performance was also studied by Elsiana et al., (2014).

Those researches showed HLP's reliability as one of daylighting systems that can illuminate deep area of the building. HLP's prototype in this research was referred to Beltran and Uppadhyaya's HLP (2008). Several adjustments were done in this study, including reflector's tilt design to reach the same efficiency in tropical area, aperture's orientation to the West for HLP in the tropics, and utilization of mirror acrylic as specular reflective material.

Louvre is included in shading system and designed to block direct sun and admit diffuse light (Martin, 2002). According to Hashemi (2014), Reflective Louvre (RL) reduces average daylight in the room, but potentially decreases the need for artificial lighting by improving daylight distribution in the building. Louvre is composed of multiple horizontal, vertical or sloping slats of various shapes and different surface finishes (Freewan et al., 2009). They are used to partially or completely obstruct sun's rays and can be oriented to any direction and latitude.

Previous researches on RL showed its reliability in improving daylight distribution and reducing the need of electric lighting. Those researches including static optical louver by Konis and Lee (2015), semi-silvered reflective louver by Leung et al., (2013), automated reflective louvre system by Hashemi (2014), and interaction between louvers and ceiling by Freewan et al., (2009). Daylight level and daylight distribution at office space in the tropics, which were generated by collaboration of two daylighting systems, HLP and RL, were described in this paper.

**Collaboration of Horizontal Light Pipe and Reflective Louvre at Office Room in the Tropics**

Several adjustment of Beltran and Uppadhyaya's HLP prototype were done in this study, including reflector's tilt design for Surabaya (latitude 7°14'24"S), aperture's orientation to the West for HLP in the tropics, and utilization of mirror acrylic at HLP's interior. Surabaya is located at tropical area and has partially cloudy sky condition (Lauber, 2005).

In general, light pipe had trapezoidal section in plan view and elevation. The rear of the light pipe was 0.60 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. Was placed on tropical climate, HLP's aperture orientation has been directed to East or West, according to Chirarattananon et al., (2000) that for tropical location, aperture of light pipe faces either East or West to utilize the sunlight in the morning or in the afternoon. Single clear glass with Visible Transmittance 88% covered HLP's aperture which was oriented to the West in this study.

Pipe, a rectilinear duct with optical properties suitable for deliver sunlight into room (Canziani et al., 2004) had 0.6 m in height and used mirror acrylic (85% specular reflectivity) on its inner surface. This pipe was equipped with reflector that had adjusted to sun's altitude at 12:00, 14.00 and 16.00 at research location, Surabaya, Indonesia (latitude 7°14'24"S). Adjustment of reflector's tilt angle was done to reach the same efficiency in tropical area (Fig 1). Surabaya sun's altitude data was collected using Ecotect 2011 software. Overall length of light pipe was 9 m.

Distribution element consists of diffuser, a natural light spreader into the room, and had Visible Transmittance (VT) of 88%. Diffuser was placed on partially daylight area, at a distance of 4.5 m from sidelighting.

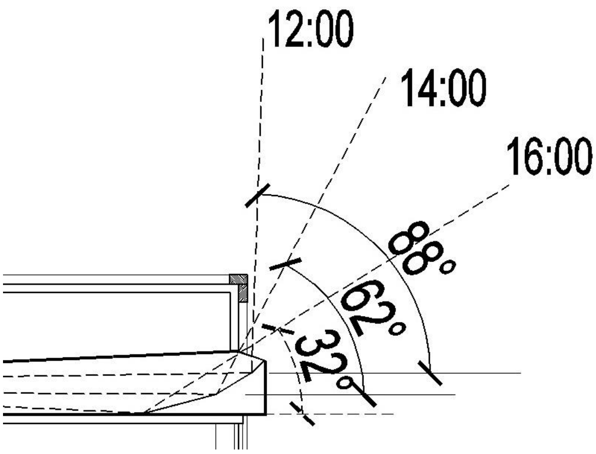



**Figure 1: Reflector's tilt adjustment toward sun's altitude at Surabaya (latitude 7°14'24"S)**

Reflective louvre had 6 m in length and 0.3 m in width. The upper surface was covered with mirror acrylic to reflect sunlight. Each slat was installed with equally distance between one another. Horizontal position of RL was considered to make the results of this study comparable with other passive daylight guiding system, according to Leung et al., (2013).

Experiments were conducted on open plan office room in the tropics. This room had 6m in width and 9m in length, assumed consist of 9 workers (according to Meel et al., 2010) who had area of 6m$^2$ per person. The office had 2.75m in ceiling height and 4.2m in floor to floor height, synthesized from office's floor to floor height consideration of typical high rise office building in Asia of Kohn and Katz (2002).

Office space had a sidelighting on west wall, 6m in width and 1.95m in height. Highly reflective glass was used for sidelighting, with Visible Transmittance (VT) 0.14, representing a modern air conditioned office space in the tropics to minimise radiant heat gain. Interior reflectance of wall, ceiling and floor are 0.66, 0.74 and 0.43 sequentially.

## Method

To study HLP and RL's daylighting performance, experimental with physical scaled model was used. Two models 1:10, reflecting Base Case and HLP&RL Case were developed. Experiment was conducted by comparing work plane illuminance and uniformity ratio of Base Case and HLP&RL Case, a typical office building with sidelighting and an office building with HLP and RL application sequentially (Figure 2-5). Those illuminance and uniformity ratio were also compared with daylighting standards.

Office room's wall and floor were constructed using GRC (glass reinforced cement), painted in its interior wall. Surface reflectance of wall, ceiling and floor were 0.66, 0.74 and 0.43 sequentially. Visible Transmittance (VT) of sidelighting, a clear glass with reflective film was 14%, representing high reflective glass in modern air-conditioned office building in the tropics.

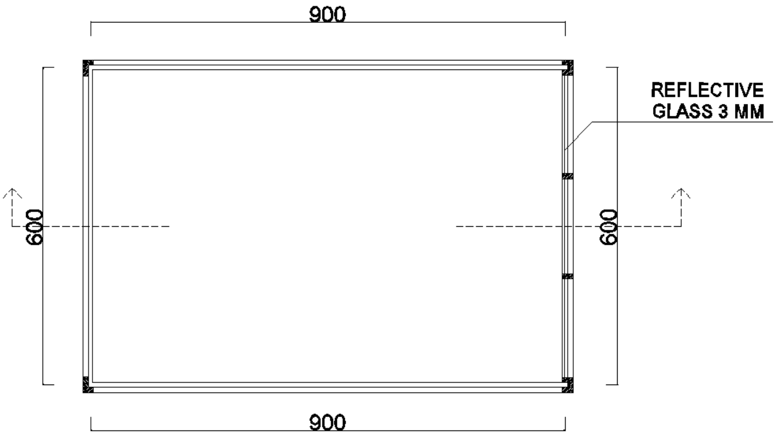



**Figure 2: Plan of typical office space with sidelighting**

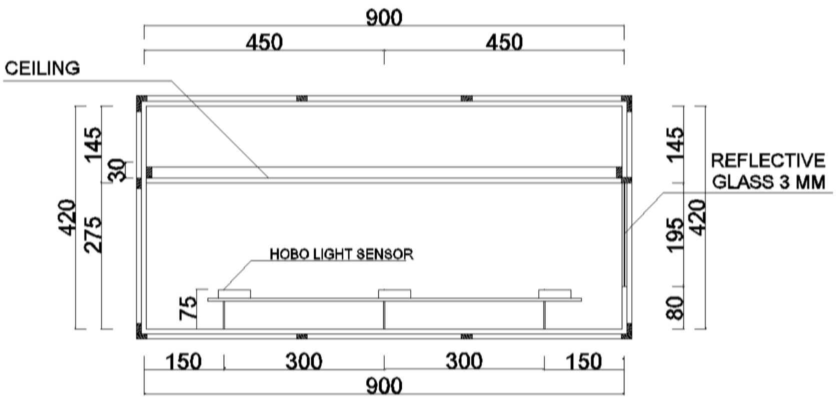



**Figure 3. Section of typical office space with sidelighting**

HLP was constructed using plywood and placed inside plenum area of office space model. HLP's interior surfaces were covered using mirror acrylic to deliver sunlight into room. Plywood was also used to construct RL, which was coated with mirror acrylic at its upper surface.

Illuminance was measured using HOBO U12/12 data logger, on a real sky condition of Surabaya (partially cloudy). Six sensors were located on 0.75 m above floor in each model. According to the manufacturer's technical datasheets, the sensors were appropriate for relative daylight measurements. Light meter was used to measure outdoor horizontal illuminance. All experimental setup was placed on the roof top of seven-stories building at Petra Christian University.

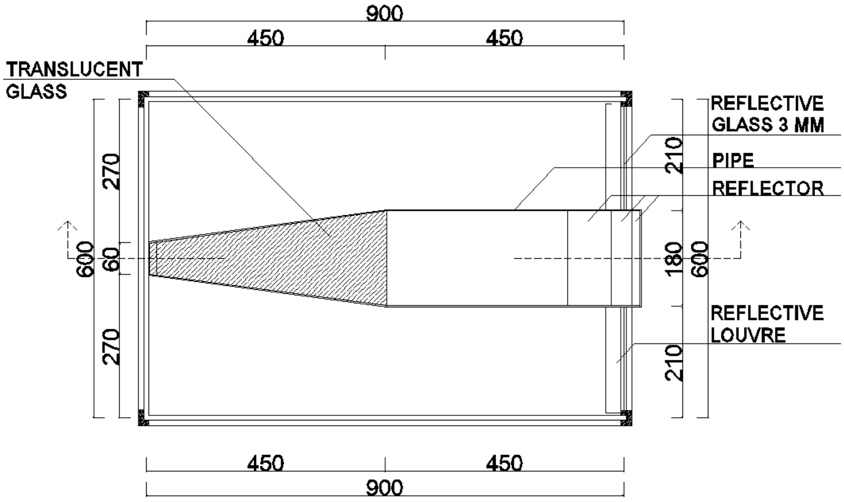



**Figure 4: Office Space with HLP and reflective louvre's plan**

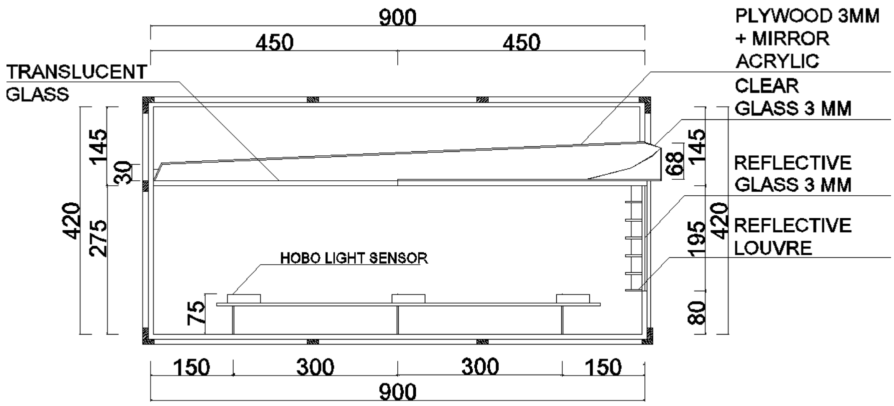



**Figure 5: Office Space with HLP and reflective louvre's section**

## Results and Discussion

This section described measurement results and analysed the daylighting performance of HLP and RL application in office room. Daylighting performance analysis was conducted by comparing work plane illuminance, daylight ratio and uniformity ratio of Base Case and HLP&RL Case, simultaneously with daylighting standards. Recommended Lighting Levels by CIE (International Commission on Illumination) in Heerwagen (2004), recommended Daylight Factor (DF) by Longmore in Heerwagen (2004) and uniformity ratio on working space according to The Society of Light and Lighting in Hashemi (2014) were used as daylighting standards.

*Illuminance and Daylight Ratio*

In general, HLP and RL application in office room had a good daylighting performance. Combination of two daylighting systems, HLP and RL generated average illuminance by 426 lux, 817 lux and 929 lux at 12:00, 14:00 and 16:00 sequentially. Those results were fulfilled recommended lighting levels for simple visual task (300-750 lux) at 12:00 and normal visual task (500-100 lux) at 14:00 and 16:00. These facts reinforced Beltran et al., (1997)'s statement about HLP's function as a complement of sidelighting and expanded validity of that theory on combination other daylighting system, reflective louvre.

**Table 1: Comparison of average work plane illuminance and daylight ratio of Base Case and HLP&RL Case**

| | Time | Average work plane illuminance (lux) | Average daylight ratio (%) |
|---|---|---|---|
| Base Case | 12:00 | 435 | 0.47 |
| | 14:00 | 738 | 1.00 |
| | 16:00 | 463 | 2.74 |
| HLP&RL Case | 12:00 | 426 | 0.46 |
| | 14:00 | 817 | 1.11 |
| | 16:00 | 929 | 5.51 |

Compared with recommended Daylight Factor (DF) by Heerwagen (2004), except 12:00, average daylight ratio resulted by HLP and RL were above minimum DF in buildings for general offices (1-2%). At 12:00, average daylight ratio of both Base Case and HLP&RL Case were under minimum DF in buildings for general offices.

Observation of illuminance value on overall measurement points inside office space showed that Base Case had illluminance value under 300 lux as big as 67%, 33% and 50% at 12:00, 14:00 and 16:00, sequentially (Figure 6). Those points were at deep area of the room, at the distance further than 4.5m from sidelighting. Different results appeared on HLP&RL Case, where there were no illuminance value under 300 lux at 12:00 and 16:00. Only 17% of measurement points inside HLP&RL Case had illuminance values under 300 lux. Those points were at deep area of the room, near side wall.

The results of physical test also showed that application of HLP and RL improved office space's average illuminance value (Figure 7). Combination of HLP and RL generated higher average illuminance than typical office space with sidelighting only; except in high sun altitude (12:00). At 14:00, improvement of average illuminance resulted by HLP and RL application was 11%, from 738 lux into

817 lux, Base Case and HLP&RL Case sequentially. Highest improvement of average illuminance occurred at 16:00, as big as 101%, from 463 lux into 929 lux, Base Case and HLP&RL Case sequentially. Small reduction of average illuminance occurred at 12:00, as big as 2%, from 435 lux into 426 lux, Base Case and HLP&RL Case sequentially. At high altitude angle (12:00), RL's role in decreasing average illuminance in space appeared most.

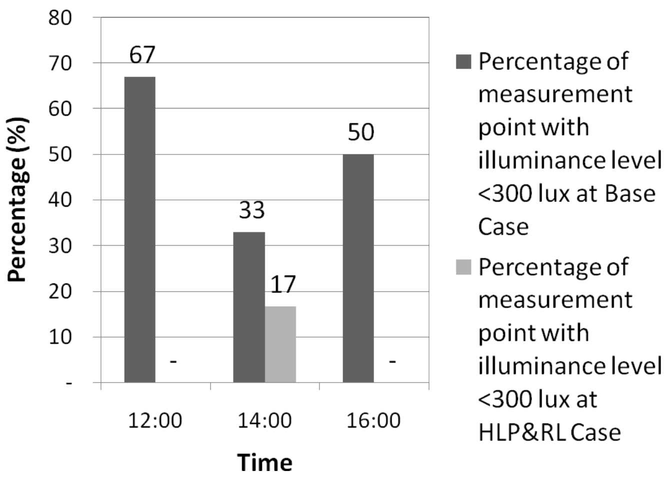



**Figure 6: Percentage of measurement point with illuminance level below 300 lux**

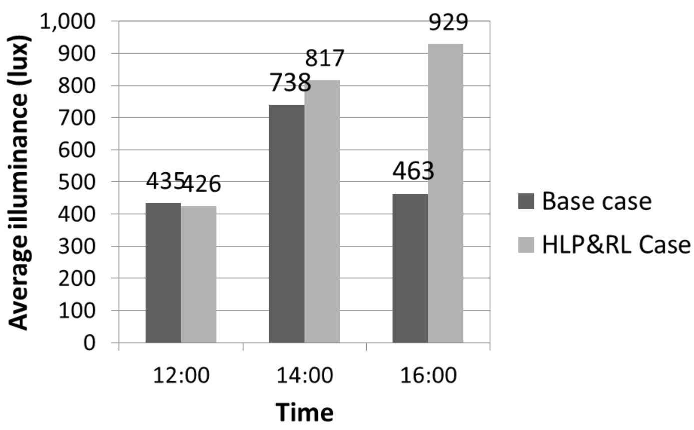



**Figure 7: Average illuminance comparison between Base Case and HLP&RL Case**

Further analysis about RL's role in decreasing daylight level was done by comparing illuminance level of Base Case and HLP&RL Case, at area close to sidelighting. At 12:00, illuminance level at the distance 1.5 m from sidelighting in HLP&RL Case was lower than Base Case. Reduction of illuminance level was 60%, from 848 lux into 343 lux, Base Case and HLP&RL Case sequentially (Figure 8). The same tendency were occurred at other time of measurement, with decrement of illuminance value as big as 21% and 8%, at 14:00 and 16:00 sequentially (Figure 9 and 10). Those results reinforced statement of Gago et al., (2015) on reflective louvre's role in decreasing illuminance level at area close to sidelighting.

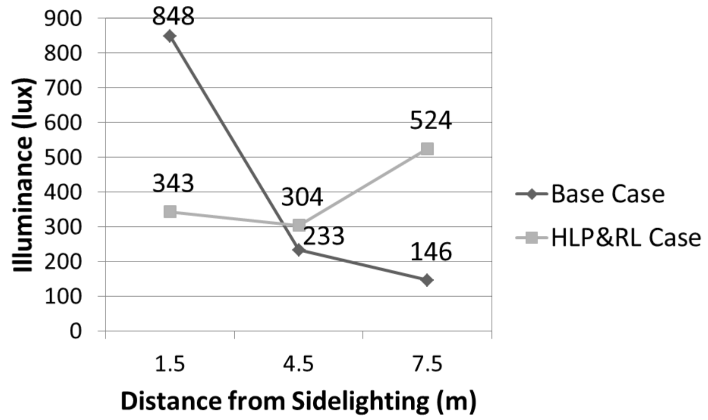



**Figure 8: Iluminance level of Base Case and HLP&RL Case at room section (measurement at 30 July 2015, 12:00, exterior horizontal illuminance 92.620 lux)**

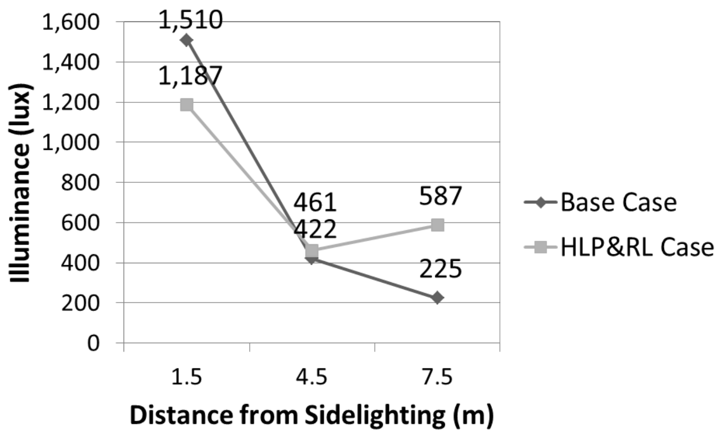



**Figure 9: Iluminance level of Base Case and HLP&RL Case at room section (measurement at 30 July 2015, 14:00, exterior horizontal illuminance 73.630 lux)**

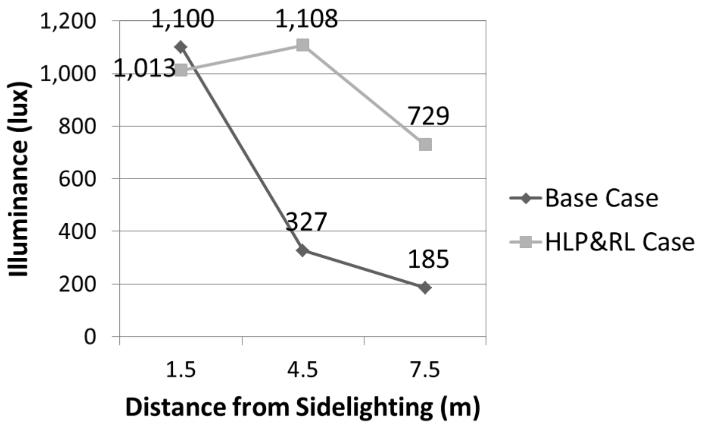


**Figure 10: Illuminance level of Base Case and HLP&RL Case at room section (measurement at 30 July 2015, 16:00, exterior horizontal illuminance 16.860 lux)**

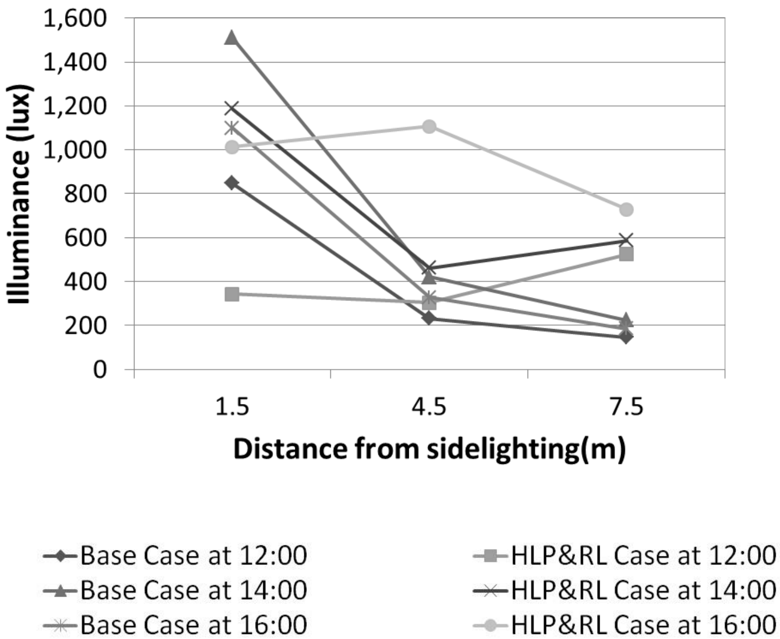



**Figure 11: Pattern of work plane illuminance at office room's section**

Illuminance level at the distance 7.5 m from sidelighting (deep area of room), generated by HLP and RL application was higher than office space with sidelighting only. Improvement of illuminance level reached 259% at 12:00, from 146 lux into 524 lux, Base Case and HLP&RL Case sequentially (Figure 8). The same pattern occurred at 14:00 and 16:00, with improvement of illuminance level as big as 161% and 294%, at 14:00 and 16:00 sequentially (Figure 9 and 10).

Highest decrement of illuminance value resulted by HLP and RL application, at area near to sidelighting occurred at highest sun's altitude (at 12:00). Highest improvement of illuminance level resulted by HLP and RL application, at deep area of the office room occurred at lowest sun's altitude (16:00). Illuminance from sidelighting dropped off for the area further from sidelighting, but that from the HLP and RL increased towards the interior of the room, under HLP's distribution opening (Figure 11).

*Daylight Distribution*

Daylight distribution analysis was conducted by comparing work plane illuminance (WPI) uniformity ratio of Base Case and HLP&RL Case, simultaneously with recommendation of uniformity ratio on working space to maximize daylighting utilization, according to The Society of Light and Lighting in Hashemi (2014). WPI uniformity ratio was gained using formula in Lim et al., (2012), where higher uniformity ratio indicated better daylight distribution.

$$\text{WPI Uniformity Ratio} = \text{minimum WPI/ average WPI} \qquad (1)$$

Where, WPI is work plane illuminance (lux)

Measurement results showed that HLP and RL application improved WPI uniformity ratio. At 12:00, WPI uniformity ratio increased as big as 209%, from 0.23 into 0.71, Base Case and HLP&RL Case sequentially. At 14:00, WPI uniformity ratio also improved as 83%, from 0.18 into 0.33, Base Case and HLP&RL Case sequentially. Similar condition also occurred at 16:00, with improvement of WPI uniformity ratio 90%, from 0.21 into 0.40, Base Case and HLP&RL Case sequentially (Figure 12).

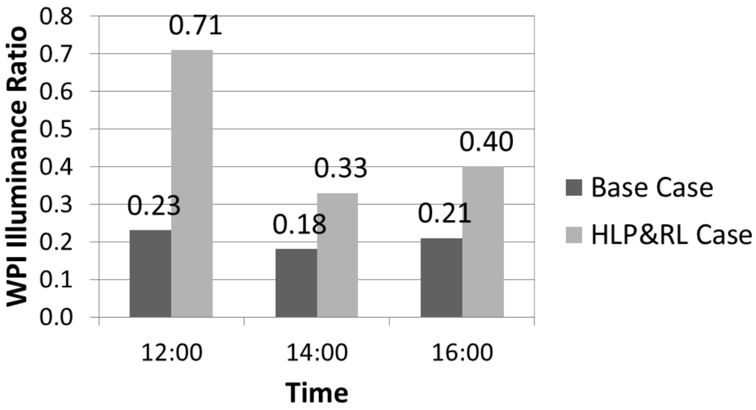



**Figure 12: Comparison of WPI Uniformity Ratio of Base Case and HLP&RL Case**

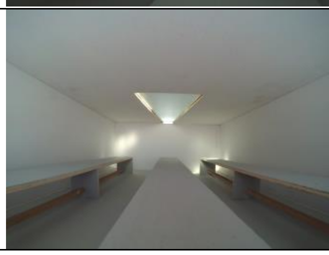
| **Base Case (a)** | **HLP&RL Case (b)** |
|---|---|
|  |  |
|  |  |

**Figure 13: Photo Images at 12:00 (a) Typical Office Room with sidelighting and (b) Office Room with HLP and Reflective Louvre on July, 30**

Highest WPI uniformity ratio generated by HLP and RL application in office room occurred at 12:00, as big as 0.71 (Figure 12). Lowest WPI uniformity ratio occurred at 14:00, as big as 0.33. Those WPI uniformity ratio were in recommendation range of uniformity ratio on working space to maximize daylighting utilization (30-50%). These results showed that combination of two daylighting system, HLP and RL, generated uniformly daylight distribution inside office room. Improvement of illuminance level at the area far from sidelighting by HLP, collaborated with reduction of illuminance level at area near from sidelighting by RL generated uniformly daylight distribution inside overall office space.

Figure 13 shows interior photo images of HLP and RL application inside office space at 12:00. When RL is used as combination with HLP, the illumination over the back wall and ceiling was higher, given the appearance of brighter space.

## Conclusion

Application of Horizontal Light Pipe (HLP) and Reflective Louvre (RL) presented in this study had demonstrated their potential to increase daylight level of office space at the tropics. HLP and RL could introduce consistently average illuminance between 400-900 lux, and illuminance level at 500-700 lux at 7.5m from window wall. RL introduced lower light level at the area near to sidelighting than Base Case. Decrement of illuminance level resulted by RL at the area 1.5m from sidelighting reached 8-60%. HLP generated higher daylight level at the area far from sidelighting than Base Case. Improvement of illuminance level at the distance 7.5m from sidelighting were 160-290%.

HLP and RL application distributed daylight more uniform than typical office space with sidelighting only. WPI uniformity ratio generated by HLP and RL are 0.71, 0.33 and 0.40 at 12:00, 14:00 and 16:00. Improvement of WPI uniformity ratio were 83-209%.

Further research, focusing on qualitative assessment about HLP and RL application in office space is needed. Evaluation of energy saving achieved by HLP and RL, optimization HLP and RL’s geometry can also be elaborated on next research, adapting with the sun’s altitude angle and different opening orientation.

## Acknowledgements

The authors of this paper would like to thank Architecture Department, Petra Christian University, Surabaya for financial supporting and valuable contributions throughout the model development and measurement processes of Horizontal Light

Pipe and Reflective Louvre application in office room.

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