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HABITechno International Seminar – Ecoregion As a Verb of Settlement Technology and Development 1 Daylight Performance of Courtyard Wall Design at Low-Cost Flat in the Tropics Feny ELSIANA 1, Anik JUNIWATI 1, and Lilianny S. ARIFIN 1 1Petra Christian University ABSTRACT The use of courtyard in low-cost flat provides daylight, air movement and direct connection to the outdoor environment. Exposed to solar radiation, courtyard in the tropics is usually protected with cloister, veranda or corridor. Surrounded by a shaded corridor, daylight level of the adjacent dwelling rooms around the courtyard are reduced. Modification of courtyard wall by integrating a sloped light shelf is proposed to improve the daylight level on dwelling unit and control excessive light penetration at the corridor. The

aim of this research is **to evaluate and** investigate **the** daylight performance **of** 1

courtyard wall design using sloped light shelf at a low-cost flat in the tropics. Experiment

with simulation as a tool was used as a **research method.** 1

Illuminance value,

Daylight Factor and uniformity ratio of the base case, 1

a courtyard wall design in a typical low- cost flat in Surabaya (latitude 7º15'55''S) and case, a proposed courtyard wall design were compared, simultaneously with daylighting standards. Existing courtyard wall design consists of 1m white-painted wall at the bottom and a black-painted horizontal louver at the upper part. A combination of 1 m white-painted wall and the sloped light shelf was studied as the case. The results demonstrated that modification of courtyard wall could reduce excessive average illuminance on the corridor in the range of 41% to 57.1% and improve average illuminance in dwelling room in the range of 0.9% to 19.2%. The proposed courtyard wall could also improve illuminance uniformity ratio as big as 78% to 147% in the corridor and 1.2% to 3.5% in the living room. In order to improve daylight quantity and quality, a courtyard wall consists of a sloped light shelf at the upper part and 1m white-painted wall at the bottom can be applied on a low-cost flat in the tropics. Keywords: daylight performance, courtyard wall, low-cost flat, light shelf, tropics 1. INTRODUCTION The courtyard is one of

daylight enhancing techniques to bring light into the interior, 12

with the aim of reducing active zones (Aldawoud and Clark 2008). Compared with a glazed atrium, a courtyard has higher light available (Baker and Steemers 2002). Several benefits of courtyard application such as provides direct links to the outdoor environment (Aldawoud and Clark 2008), regulates

daylight, air movement and thermal interaction with the outdoor environment (Freewan 2011). **The** 10

courtyard is also energy efficient for low-rise building, below 13 floors, in hot-humid climate (Aldawoud and Clark 2008). Previous research about courtyard had conducted by Freewan (2011), focused on optimizing the courtyard's daylight performance by modifying its wall geometries. A

predictive method for calculating the Daylight Factor 7

(DF)

of square courtyards under overcast sky conditions 7

was developed by Acosta et al. (2014), while a

comparative analysis of energy performance between a **courtyard and** central **atrium in buildings** 8

was investigated by Aldawoud and Clark (2008).

Soflaei et al. (2017) studied **the impact of courtyard design variants on shading performance** 5

of traditional courtyard houses in a **hot-arid climate of Iran.** 5

In warm-humid regions, effective prevention of solar heating of the building is important for providing comfort (Givoni, 1998). Exposed to solar radiation, courtyard is usually protected from both sun and rain with cloisters or verandas (Baker and Steemers, 2002). Courtyards in tropical climate also have porches to

provide a comfortable area being shaded while at the same time receiving natural ventilation 6

(Taleghani, 2014). This protection from sun and rain also found in many low-cost flats at Surabaya, at the form of corridor with louvre around courtyard. Surrounded by a shaded corridor, daylight level of the adjacent rooms around the courtyard are reduced. The surrounding walls will be in shadow and will not act as diffuse sources of daylight (Baker and Steemers 2002). Modification of courtyard wall by integrating an advanced daylighting system that can block direct sun and admit diffuse light, at the same time redirect daylight into the dwelling area was proposed. A light shelf, a shading system (Kischkoweit-Lopin 2002) that can act both as a shading device and a light guiding into the depth of the room was selected.

A light shelf is one of **a** daylighting system **designed to** enhance **daylight** 17

penetration into buildings. It

can be mounted at the upper part of a typical window to provide solar shading and glare control to occupants near **to the window while allowing daylight into the room** 4

(Wong 2017). Commonly in the form of horizontal or inclined projection attached to a window with a highly reflective surface, light shelf reflects sunlight to

the ceiling and from there to the back of the room (Warrier **and** 3

Raphael 2017). Previous researches about light shelf were focused on maximizing its daylighting performance by combining light shelf with a curved ceiling (Freewan 2010), combining light shelf with a horizontal light pipe (Beltrán and Uppadhyaya 2008) and using a dynamic internal light shelf without modifying external façade (Lim et al. 2012).

Claros and Soler 2002 **investigated the influence of light shelf** 13

properties, i.e

light shelf reflectance **and model reflectance on** daylight **performance.** 19

Those researches showed light shelf's ability in providing shading while allowing daylight into the rear part of the room. Different from previous research, the light shelf in this research is integrated on a low- cost flat's courtyard wall that has

a distance of 1 **.5 m from the window** 15

of dwelling units. Integration of light shelf on the courtyard wall is expected to reduce the daylight level in 1.5 m wide corridor area and enhance daylight level in the dwelling unit area adjacent to the courtyard. The proposed light shelf had employed sloped reflector at its upper surface which was designed for Surabaya (latitude 7º15'55''S). The optimum angle of the reflector was determined based on the required angles of the incident and reflected solar rays. The effect of proposed courtyard wall design on daylight performance was investigated in this study. Daylight level and uniformity of courtyard wall were evaluated not only on the dwelling unit but also on the corridor. Corridor in a low-cost flat is not only functioned as circulation area but also as a place where frequent social interaction between occupants occurred. Corridor occupation on low-cost flat also happened as a form of the household adaptation in order to expand their unit apartments so that their space requirement can be met (Kisnarini 2015). Daylight adequacy and uniformity on both dwelling unit and corridor are important to achieve. 2. COURTYARD WALL DESIGN OF LOW COST FLATS Several low-cost flats in Surabaya that utilize courtyard as their daylighting method are located at Grudo, Jambangan, and Siwalankerto (Figure 1). They have a fully enclosed courtyard that placed at the center of the building. Commonly consists of four stories and is designed in twin blocks, the low-cost flat building has two rows of dwelling units with corridors facing the courtyard. The width of the corridor is 1.5 m. Courtyard wall design of existing low-cost flats in Surabaya consists of a white-painted brick wall at the bottom and horizontal louver at the top. The brick wall has 1 m in height while the louver has 0.6 m in width. The louvers are painted black and some of them are added with plantations (Figure 1). The adjacent dwelling unit located 1.5 m from courtyard wall was shaded by corridor and louver (Figure 2 and 3). Utilization of courtyard as a secondary daylight source on dwelling units is limited as the surrounding walls will be in shadow and will not act as diffuse sources of daylight (Baker and Steemers 2002). Courtyard wall modification was proposed to improve the daylight performance in corridor and dwelling unit. Proposed courtyard wall design utilize light shelf, a horizontal shading and redirecting devices (Egan and Olgyay 2002), which was mounted at the upper part of the courtyard wall. (a) (b) (c) Figure 1. Courtyard wall design in low-cost flats at (a) Jambangan (b) Grudo and (c) Siwalankerto The light shelf had totally 0.85 m in width, consists of 0.35 m internal and 0.50 m external light shelf (Case in Table 1). It had a sloped reflector which was developed by considering sun position of a specific location, i.e. Surabaya (latitude 7º15'55''S). The optimum angle of the reflector was determined based on the required angles of the incident and reflected solar rays. The reflector composed of a sloped and segmented surface to redirect sunlight with changing of solar altitudes (Case in Table 1). The material of the reflector was a highly reflective film (97.5%). In order to protect from dirt, the reflector was sealed and closed with clear glass on its both sides. 3. METHODOLOGY To investigate the impact of courtyard's wall design on daylight level and distribution in corridor and dwelling unit at low-cost flat, experiment

with simulation as a tool was used as research method. 1

A radiance-based computer simulation which had been validated in previous research (Lim et al. 2012) was employed. Radiance is

a daylighting simulation program that uses a **ray-tracing methodology to predict daylight's behavior in space accurately (Canziani et al. 2004).** 1

A typical low-cost flat with fully enclosed courtyard, surrounded by single loaded corridor was studied. Illuminance value,

Daylight Factor (DF) **and uniformity ratio of the base case,** 1

a courtyard wall design in a typical low-cost flat in Surabaya (latitude 7º15'55''S) and case, a proposed courtyard wall design were compared, simultaneously with daylighting standards (Table 1). Existing courtyard wall design consists of 1m white- painted wall at the bottom and a black- painted horizontal louver at the upper part. A combination of 1 m white-painted wall and the sloped light shelf was studied as the case.

As a shading device, the light shelf was designed for a vertical shade angle of 60°, **and had both internal and external** part. **The** 3

light shelf had 0.85 m in width, and was installed along the upper part of courtyard wall. A highly reflective material covered its top surface, with reflectance value as big as 97.5%. The typical low-cost flat consisted of four stories and were designed in twin blocks. Its linear facades were orientated facing North and South. The building had two courtyards at its center. Each courtyard had 4 m in width and 9 m in length (Figure 2). Those courtyards were separated by a stair and corridor located at the center of the building. Each building floor had totally seven dwelling units and had floor-to-floor height of 3 m. Figure 2 shows the position of the dwelling unit and corridor investigated in this research. Located

on the West side of the building, the 16

unit had 4.2 m in width and 5.25 m in length. Ceiling height of the dwelling unit and corridor were 2.85 m. Figure 3 describes the elevation and plan of dwelling unit and corridor on low-cost flat studied. The dwelling unit had four rooms, those were bath room, living room, kitchen Figure 2. Location of dwelling unit and corridor studied on low cost flat Table 1. Experimental Scheme Base Case Courtyard wall consisted of black-painted louver and 1 m white-painted brick wall Case Courtyard wall consists of a sloped light shelf and 1 m white-painted brick wall and bed room. Located adjacent to the perimeter of the building, kitchen and Table 2. Characteristics of dwelling unit, bedroom were mainly daylighted by the corridor and courtyard wall sidelighting. The courtyard provided Dwelling Unit daylight to the bathroom and living room Surface Wall 62.8% (light gray) through a top and bottom window in the Reflectance Floor 67.5% (off-white) living room and a top window at bathroom. Ceiling 74.99% (beige) Characteristics of the top and bottom Door 85.53% Windows WWR 9.5% window are described in Table 2. facing Lower part: Transmittance 75.2% Daylight performance of courtyard wall at courtyard translucent (frosted glass) glass dwelling unit and corridor was measured on Upper part: Transmittance 88.5% 21 June

when the sun is lowest in the sky 18

and clear glass (clear glass) the most critical time in the room facing Corridor and Courtryard Wall North. Illuminance level, Daylight Factor Surface 1 m wall 62.8% (light gray) (DF) and illuminance uniformity ratio of base reflectance Ceiling 74.99% (beige) Landscape at 13.48% and case then compared, simultaneously courtyard's (RAL6007_Bottle_green) with daylighting standards. floor Louver 13.8 (dark gray) Light shelf Upper surface: 97.5% (Galvanized metal LBNL) Covered glass: Clear glass 88.5% transmittance Figure 3. Elevation and plan of dwelling unit and corridor in low cost flat 4. RESULTS AND DISCUSSION 4.1. Illuminance Level and Daylight Factor on Corridor and Dwelling Unit Figure 4 shows the daylight

performance results of the existing courtyard wall (base **case) and modification of the** 11

courtyard wall (case) at the corridor. The results showed that the base case, an existing courtyard wall consisted of 0.6 m louver and 1 m white- painted brick wall introduced high average illuminance level on the corridor. Average illuminance level on the corridor of the base case reached 513 lux, 267 lux and 261 lux at 21 June 9.00, 12.00 and 15.00, sequentially. Those average illuminance level were exceeded the IESNA recommended illuminance value for corridor where visual tasks are only occasionally performed (100- 200 lux) in Egan and Olgyay (2002). High average illuminance level at corridor indicated that the louver could not shade well the corridor, especially at low sun altitude (at 9.00). Different result occurred at the case, a courtyard wall consisted of a sloped light shelf at its top and 1 m white-painted brick wall at its bottom. Average illuminance level resulted by the case were lower than base case, as big as 220 lux, 157

lux and 154 **lux at** 09 **.00,** 12 **.00 and** 15 **.00, sequentially. Those** average illuminance value **were** 2

in the range of IESNA recommended illuminance value for corridor where visual tasks are only occasionally performed (100-200lux), except at 21 June 09.00. Lower average illuminance value of case compared to the base case indicated the role of a sloped light shelf in providing shading and reducing the excess illuminance level at the adjacent area, that is the corridor. Reduction of average illuminance level generated by a sloped light shelf reached 57.1%, 41.2% and 41% at 09.00, 12.00 and 15.00, sequentially. Average Illuminance (lux) 600 base case case 400 200 - 9.00 12.00 15.00 Time Figure 4. Average illuminance of base case and case on corridor Figure 5 indicates the average illuminance of base case and case at dwelling unit. Analyses were mainly focused on two rooms inside dwelling unit that are adjacent to the courtyard, i.e. bathroom and living room. Bed room and kitchen area are also simulated but excluded in analysis considering both rooms receive daylight mostly from sidelighting facing South, not the

courtyard. The results showed that the base case 14

generated low average illuminance level on the bathroom. Average illuminance level resulted by base case on bath room was 119 lux, 117 lux, and 117 lux at 9.00, 12.00 and 15.00 on 21 June. Those illuminance level had met illuminance target for a bathroom, as big as 100-200 lux (Steffy 2008). Low illuminance value was caused by a small proportion of bathroom window (WWR 5.9%) and the use of translucent glass (VT

0.75) on the window to maintain privacy. Modification of courtyard wall by integrating a sloped light shelf (case) increased average illuminance inside bathroom. Slightly improvement of average illuminance on bathroom occurred, as big as 3.4%, 0.9% and 0.9% at 09.00, 12.00 and 15.00 on 21 June, sequentially. Average illuminance of the case on bathroom was 123 lux, 118

lux and 118 **lux at** 09 **.00,** 12 **.00 and** 15 **.00** on 21 June, **sequentially** 2

(Figure 5). Those illuminance level had met illuminance target for a restroom, as big as 100-200 lux (Steffy 2008). This result showed the role of light shelf in increasing daylight level on the rear part of the room, at the distance of 1.5 m from courtyard wall. 124 Average Illuminance (lux) 122 base case case 120 118 116 114 9.00 12.00 15.00 Time Figure 5. Average Illuminance of Base Case and Case on Bath Room of Dwelling Unit The results also showed that the base case yielded low average illuminance level on the living room. Average illuminance level of the base case on the living room was 120 lux, 118

lux and 114 **lux at** 9 **.00,** 12 **.00 and** 15 **.00** on 21 June, **sequentially** 2

(Figure 6). An improvement of average illuminance level achieved in case. Average illuminance of the case on the living room was 143 lux, 116

lux and 117 **lux at** 9 **.00,** 12 **.00 and** 15 **.00** on 21 June, **sequentially.** 2

This fact indicated that the biggest improvement of daylight level occurred at low angle sun (09.00), as big as 19.2%. Slightly improvement of daylight level occurred at high angle sun (12.00), as big as 1.8%. Improvement of daylight level at low angle sun at 15.00 were 2.6%. The low improvement of daylight level at 15.00 was caused by the presence of an obstruction, i.e the west side of low-cost building. Those average illuminance value of both base case and case had met the

illuminance target value for a living room **where simple visual** tasks **are performed** (100-200 **lux).** 1

Considering that diverse activities took place at the living room, from a simple visual task (entertaining, playing, TV-watching) and an increase of visual task (ironing, studying), the improvement of daylight level by integrating a sloped light shelf is important. 200 Average Illuminance (lux) 150 base case case 100 50 - 9.00 12.00 15.00 Time Figure 6. Average Illuminance of Base Case and Case on Living room of Dwelling Unit Figure 7 indicates the Daylight Factor (DF) profile at the center of the corridor and living room. The case introduced lower DF value on the corridor than the base case. DF value of base case ranged from 2.9 to 5.8%, while the case ranged from 1.5 to 2.3%. DF value reduction on the corridor at the distance 1 m from courtyard wall reached 60.3%, 46.7% and 48.3% at 09.00, 12.00 and 15.00, respectively. These results showed that the sloped light shelf provided shading and reduced the excess daylight level at the area near the courtyard wall. Although all DF value for

both base case and case were above the **minimum DF for** 2

corridors (0.5% in Lechner 2009), but DF value of the base case, as big as 5.8% at 09.00 was over lit (above 5% which exceed the maximum 5% for avoiding glare and overheating). Figure 7 also indicates that the case generated a higher DF value on the living room, at the distance of 2-4 m from courtyard wall than the base case. DF value of the base case ranged from 1.03 to 1.21% while the case ranged from 1.08 to 1.68%. The highest improvement of DF value by case reached 47.4% at low angle sun (09.00). All DF value

of both base case and case were above the **minimum DF for** 2

a living room, as big as 1% (Lechner 2009). Considering that diverse activities took place at the living room, from a simple visual task and an increase of visual task, the improvement of daylight level is useful. 6 5 Daylight Factor (DF) 4 3 2 1 0 4.2. Uniformity Ratio Table 3 summarizes the isolux plot,

uniformity ratio of the **base case and case.** The existing **base** 2

case recorded daylight uniformity ratio ranged from 0. 32 **to 0.** 50 at **the** 9

corridor. Only at high sun altitude (12.00), daylight uniformity ratio of the base case had met the uniformity standard for corridor where a visual task was only occasionally performed, as big as 0.5 (Steffy 2008). Modification of courtyard wall gave significant improvement on daylight uniformity, especially in the corridor. Uniformity ratio of the case on corridor was range from 0.79 to 0.89. Improvement of daylight uniformity ratio on the corridor by case reached 147%, 78% and 89.4% at 09.00, 12.00 and 15.00 on 21 June, sequentially. This improvement occurred because the light shelf shaded the corridor then decreased high daylight level near the courtyard (Table 3). Daylight uniformity ratio of the case had met the target uniformity ratio for corridor (Steffy 2008). Those results are in a good agreement with Lim et al. 2012 Table 3 also shows that both base case and case had high uniformity ratio at room base case 09.00 case 09.00 Corridor Living Room base case 12.00 case 12.00 base case 15.00 case 15.00 1 Distance From Courtyard Wall (m) 2 3 4 Figure 7. Daylight Factor (DF) profile on corridor and living room adjacent to courtyard, i.e bathroom and living room. Uniformity ratio of base case and case on bathroom was 0.99, 1.00 and 1.00 at 09.00, 12.00 and 15.00 on 21 June. Modification of courtyard wall generated a higher uniformity ratio on living room than existing courtyard wall. An improvement of uniformity ratio by case was 2.4%, 1.2% and 3.5% at 09.00, 12.00 and 15.00 on 21 June. 5. CONCLUSIONS The results demonstrated that modification of courtyard wall by replacing an existing a black-painted louver with a sloped light shelf at the upper part could provide an improvement in the daylight quality and quantity. The proposed courtyard wall could reduce excessive average illuminance on the area near to courtyard, i.e corridor, in the range of 41% to 57.1%. The proposed courtyard wall using 8.5 m light shelf also increase average illuminance level in dwelling room at the distance of 1.5m from courtyard wall. Improvement of average illuminance level in those spaces ranged between 1.8 to 19.2% on living room and 0.9% to 3.4% on bathroom. The proposed courtyard wall design also had higher illuminance uniformity ratio on the area near the courtyard (corridor) and dwelling room at the distance 1.5 m from courtyard than existing base case. Improvement on illuminance uniformity ratio of the case reached 78% to 147% on the corridor and 1.2% to 3.5% on the living room. In order to improve daylight quantity and quality, a courtyard wall consists of a sloped light shelf at the upper part and 1m white-painted brick wall at the bottom can be applied on a low-cost flat in the tropics. 6. ACKNOWLEDGMENTS This research is funded by LPPM Petra Christian University through a research grant 01/G-RESEARCH/LPPM-UKP/XII/2016. Table 3. Isolux plot,

Uniformity Ratio of Base Case and Case Base **Case** Courtyard Wall consists **of** 2

black- painted louver and 1 m white painted brick wall 09.00 12.00 15.00 Uniformity corridor 0.32 0.50 0.47 ratio bath room 0.99 1.00 1.00 Case Courtyard Wall consists of Sloped Light Shelf and 1 m white painted brick wall living room 0.85 0.85 0.85 Uniformity corridor 0.79 0.89 0.89 ratio bath room 0.99 1.00 1.00 living room 0.87 0.86 0.88 7. REFERENCES Acosta, I., Navarro, J., &Sendra, J. J. (2014). Lighting design in courtyards: Predictive method of daylight factors under overcast sky conditions. Renewable Energy, 71, 243–254. Aldawoud, A., & Clark, R. (2008). Comparative analysis of energy performance between courtyard and atrium in buildings. Energy and Buildings, 40(3), 209–214. Baker, Nick and Steemers, Koen. (2002). Daylight Design of Buildings: A Handbook for Architects and Engineers. James &James (Science Publishers) Ltd. London. Beltrán, L. O., and Uppadhyaya, K. (2008). Displacing Electric Lighting with Optical Daylighting Systems. 25th Conference on Passive and Low Energy Architecture, (October), 20–25. Retrieved from http://plea-arch.org/ARCHIVE/2008 Canziani, R., Peron, F., & Rossi, G. (2004). Daylight and energy performances of a new type of light pipe. Energy and Buildings, 36(11), 1163–1176. Claros, S.T. and Soler, A. (2002). Indoor daylight climate–influence of light shelf and model reflectance on light shelf performance in Madrid for hours with unit sunshine fraction. Building and Environment, 37, 587–598. Egan, M. David and Olgyay, Victor W. (2002). Architectural Lighting, Second Edition, McGraw-Hill Company, New York. Freewan, Ahmed A. (2011). Modifying Courtyard Wall Geometries to Optimize the

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