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Abstract

PREFACE

The School of Architecture, Planning and Policy Development, Institute of Technology Bandung, is pleased to present the Proceeding of HABITechno International Seminar, held in the Institute of Technology Bandung campus, Bandung, 11 November 2017. This is the third HABITechno seminar, and we plan to hold the seminar every two years.

From the 90s to recent times, discursion of housing and settlement development had been transformed in line with the growth of discussion in social and ecological issue. One of awareness towards this phenomenon is shown with development and urbanization theme which had been brought by HABITAT III in 2016 as commitments of change towards sustainable city development based on integration of social, economic, and environmental dimension. In general those commitments are: (1) Sustainable city development for achieving social inclusion and alleviating poverty; (2) Sustainable and inclusive city welfare for all; (3) Environmentally sustainable and resilient city development.

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Daylight performance of courtyard wall design at low-cost flat in the tropics

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Daylight performance of courtyard wall design at low-cost flat in the tropics

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Abstract. Courtyard in a low-cost flat in the tropics provides daylight but it is usually protected with a corridor to control the solar radiation. 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 room and control excessive light penetration at the corridor. Experiment with simulation as a tool was used as a research method. Illuminance value, Daylight Factor and uniformity ratio of the base case, a courtyard wall design in a typical low-cost flat in Surabaya (latitude 7º15'55''S) using louver and case, a proposed courtyard wall design using sloped light shelf were compared, simultaneously with daylighting standards. The results demonstrated that courtyard wall modification reduced excessive average illuminance on the corridor in the range of 41% to 57.1% and improved average illuminance in dwelling room in the range of 0.9% to 19.2%. The proposed courtyard wall also increased illuminance uniformity ratio in both corridor and dwelling room. In order to improve daylight quantity and quality, a courtyard wall with sloped light shelf can be applied on a low-cost flat in the tropics.

1. Introduction

The courtyard is one of daylight enhancing techniques to bring light into the interior, with the aim of reducing active zones [1]. Compared with a glazed atrium, a courtyard has higher light available [2]. Several benefits of courtyard application such as provides direct links to the outdoor environment [1], regulates daylight, air movement and thermal interaction with the outdoor environment [3]. The courtyard is also energy efficient for low-rise building, below 13 floors, in hot-humid climate [1].

Previous research about courtyard had conducted by Freewan [3], focused on optimizing the courtyard's daylight performance by modifying its wall geometries. A predictive method for calculating the Daylight Factor (DF) of square courtyards under overcast sky conditions was developed by Acosta et al. [4], while a comparative analysis of energy performance between a courtyard and central atrium in buildings was investigated by Aldawoud and Clark[1]. Soflaei et al. [5] studied the impact of courtyard design variants on shading performance of traditional courtyard houses in a hot-arid climate of Iran.

In warm-humid regions, effective prevention of solar heating of the building is important for providing comfort [6]. Exposed to solar radiation, courtyard is usually protected from both sun and rain with cloisters or verandas [2]. Courtyards in tropical climate also have porches to provide a comfortable area being shaded while at the same time receiving natural ventilation [7]. 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 [2].

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 [8] 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 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 [9]. 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 [10].

Previous researches about light shelf were focused on maximizing its daylighting performance by combining light shelf with a curved ceiling [11], combining light shelf with a horizontal light pipe [12] and using a dynamic internal light shelf without modifying external façade [13]. Claros and Soler, [14] investigated the influence of light shelf properties, i.e light shelf reflectance and model reflectance on daylight performance. 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 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 [15]. 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 centre 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 figure 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 [2].

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 [16], which was mounted at the upper part of the courtyard wall.

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. A radiance-based computer simulation which had been validated in previous research [13] was employed. Radiance is a daylighting simulation program that uses a ray-tracing methodology to predict daylight’s behavior in space accurately [17].

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, 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 ccourtyard 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 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 centre. 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 centre 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 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 and bed room. Located adjacent to the perimeter of the building, kitchen and bedroom were mainly daylighted by the side lighting. The courtyard provided daylight to the bathroom and living room through a top and bottom window in the living room and a top window at bathroom. Characteristics of the top and bottom window are described in table 2.

Daylight performance of courtyard wall at dwelling unit and corridor was measured on 21 June when the sun is lowest in the sky and the most critical time in the room facing North. Illuminance level, Daylight Factor (DF) and illuminance uniformity ratio of base and case then compared, simultaneously with daylighting standards.

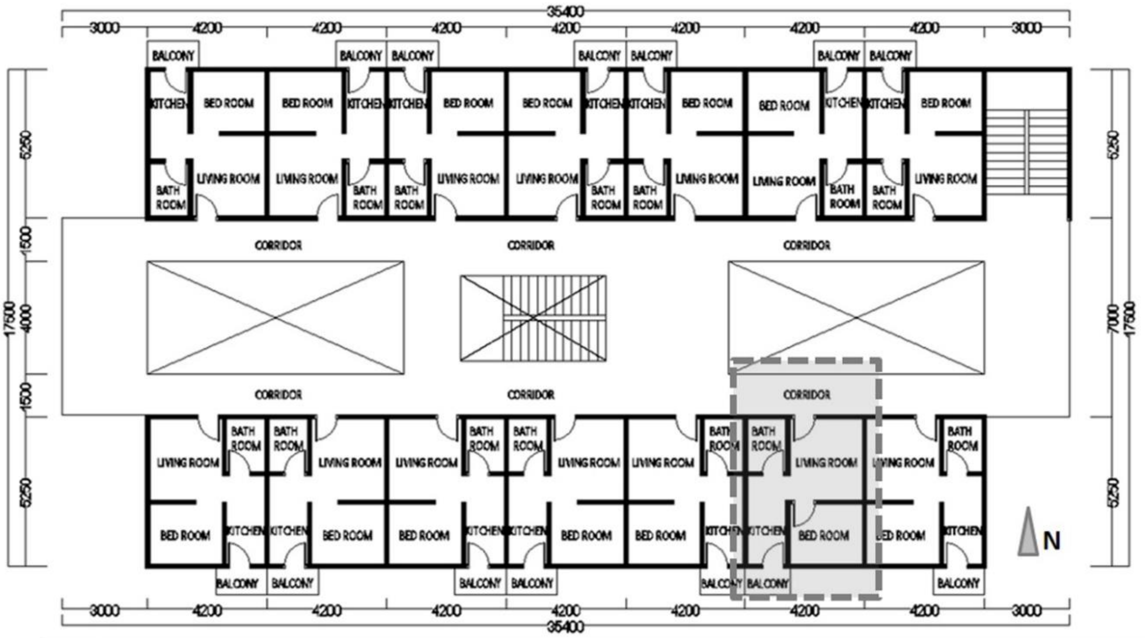


Figure 2. Location of dwelling unit and corridor studied on low cost flat

Table 1. Characteristics of dwelling unit, corridor and courtyard wall

Dwelling Unit		
Surface Reflectance	Wall	62.8% (light grey)
	Floor	67.5% (off-white)
	Ceiling	74.99% (beige)
	Door	85.53%
Windows facing courtyard	WWR	9.5%
	Lower part: translucent glass	Transmittance 75.2% (frosted glass)
	Upper part: clear glass	Transmittance 88.5% (clear glass)
Corridor and Courtyard Wall		
Surface reflectance	1 m wall	62.8% (light grey)
	Ceiling	74.99% (beige)
	Landscape at courtyard's floor	13.48% (RAL6007_Bottle_green)
	Louver	13.8 (dark grey)
	Light shelf	Upper surface: 97.5% (Galvanized metal LBNL) Covered glass: Clear glass 88.5% transmittance

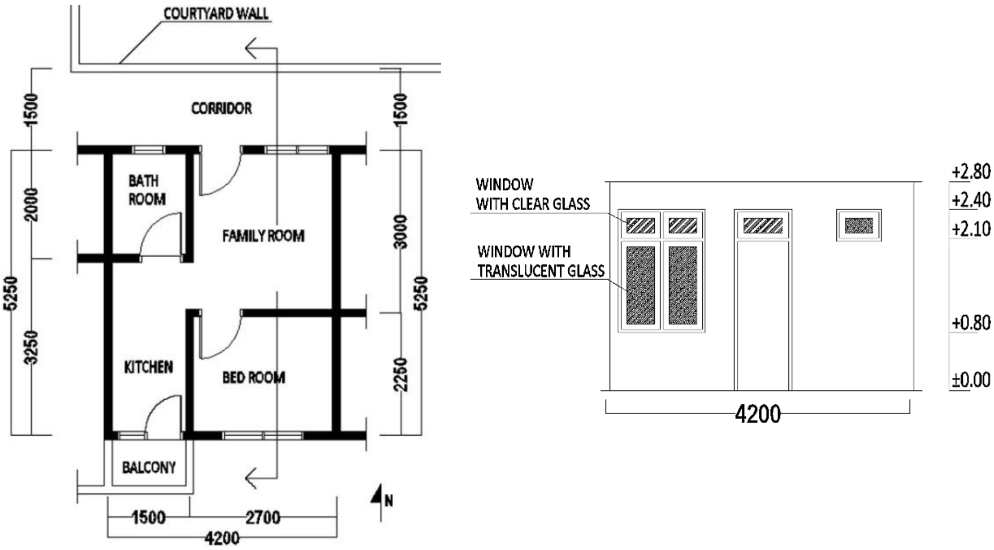


Figure 3. Plan and elevation of dwelling unit and corridor in low cost flat

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 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) [16]. 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 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.

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 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 [18]. 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 (figure 5). Those illuminance level had met illuminance target for a restroom, as big as 100-200 lux [18]. 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.

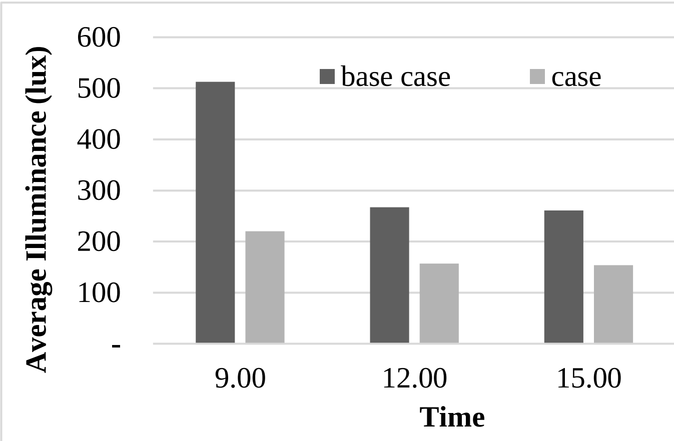
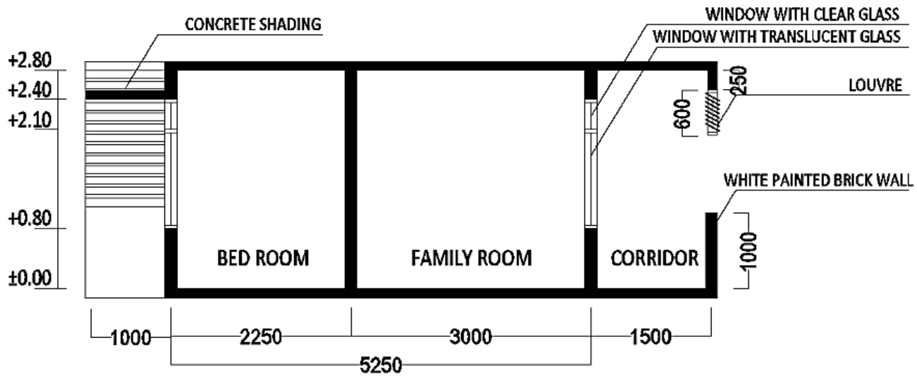
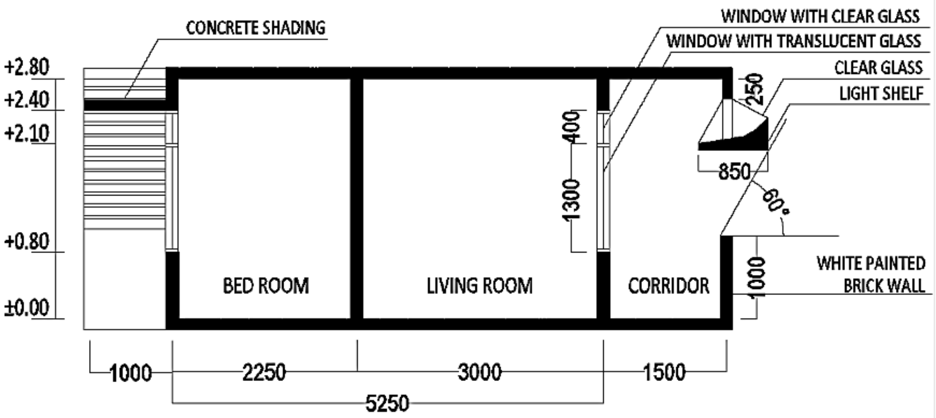


Figure 4. Average illuminance of base case and case on corridor

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 (figure 6).

Table 2. 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

An improvement of average illuminance level was 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. 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). 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.

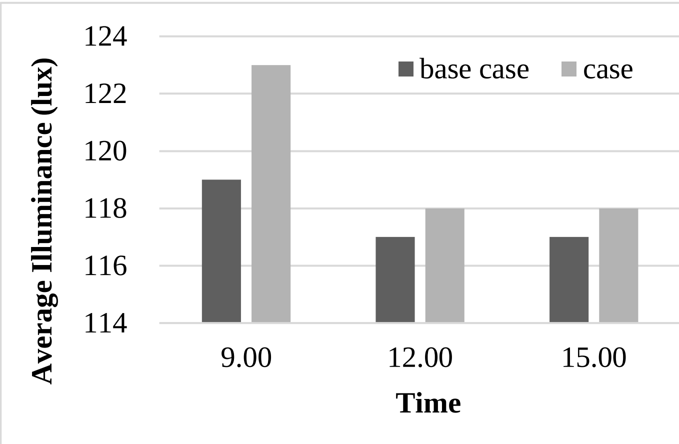


Figure 5. Average illuminance of base case and case on bath room of dwelling unit

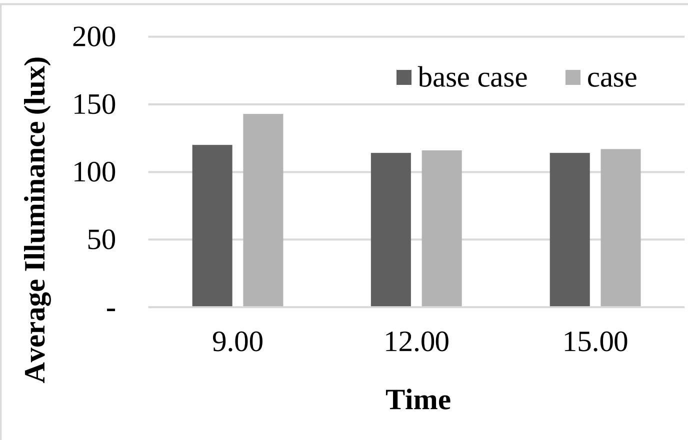


Figure 6. Average illuminance of base case and case on living room of dwelling unit

Figure 7 indicates the Daylight Factor (DF) profile at the centre 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 corridors (0.5% in Lechner [19]), 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 a living room, as big as 1% [19]. 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.

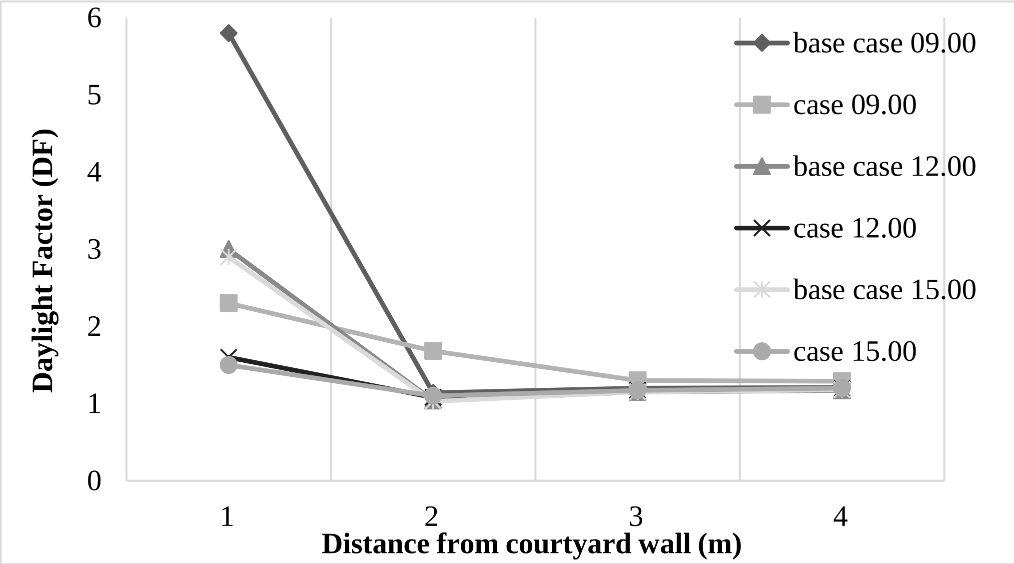


Figure 7. Daylight Factor (DF) profile on corridor and living room

4.2. Uniformity ratio

Table 3 summarizes the isolux plot, uniformity ratio of the base case and case. The existing base case recorded daylight uniformity ratio ranged from 0.32 to 0.50 at the 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 [18].

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 [18]. Those results are in a good agreement with Lim et al. 2012 [13].

Table 3 also shows that both base case and case had high uniformity ratio at 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.

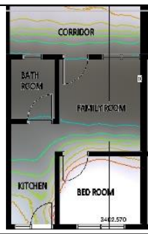
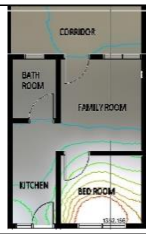
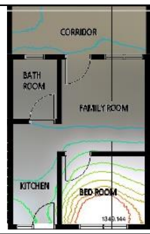
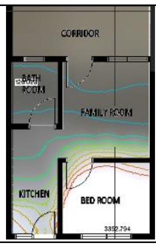
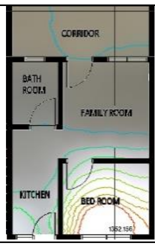
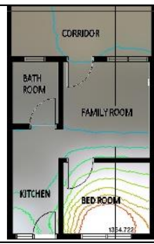
Modification of courtyard wall generated a higher uniformity ratio on living room than existing courtyard wall. An improvement of uniformity ratio by case was 2.4%, 1.2% and 3.5% at 09.00, 12.00 and 15.00 on 21 June.

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.

Table 3. Isolux plot, uniformity ratio of base case and case

		09.00	12.00	15.00
Base Case Courtyard wall consists of black-painted louver and 1 m white painted brick wall				
Uniformity ratio	corridor	0.32	0.50	0.47
	bath room	0.99	1.00	1.00
	living room	0.85	0.85	0.85
Case Courtyard wall consists of sloped light shelf and 1 m white painted brick wall				
Uniformity ratio	corridor	0.79	0.89	0.89
	bath room	0.99	1.00	1.00
	living room	0.87	0.86	0.88

6. Acknowledgements

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