THE DYNAMICS OF DAYLIGHTING AT A RESIDENTIAL COLLEGE BUILDING WITH THE INTERNAL COURTYARD ARRANGEMENT

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Abstract
Dayasari residential college building was designed with the internal courtyard that allows for numerous implementations of bioclimatic design strategies, especially on daylighting. The field measurement was conducted at eight unoccupied student rooms, selected as samples to represent ten scenarios and orientations that concerned with the level of radiation and penetration of sunlight. This study reveals the contribution of the internal courtyard in the residential college which allows the daylight penetration at the corridor areas and interior of the rooms through the transom over the entrance door, up to ten hours daily. Different amounts of daylight were measured in specific room scenarios to suggest on the most comfortable indoor living space. The recorded mean value for indoor varied from 37 to 286 lux, while in the corridor area 192 to 3,848 lux. However, the use of the large overhangs over the windows, wall openings in the room and trees with large canopy in the landscape setting should critically justify when the adequacy of daylight was drastically reduced in certain rooms.

Keywords: *Bioclimatic design, Illuminance, Internal courtyard, Residential college building*

INTRODUCTION

Daylighting is a technique that brings natural daylight into a building, through openings so that the day's natural light provides effective internal lighting (Fontoynont et al., 2004). Daylight is the total light from the sky dome which is affected by attenuation, due to the absorption and scattering in the atmosphere and it consists of direct (or beam), diffused and ground-reflected components (Zain-Ahmed et al., 2002a). The daylighting was introduced in building designs before the second half of the twentieth century when most of the buildings during that time have more windows than walls, high ceilings with high windows, also E-, U-, O- and H-shaped floor plans in providing daylighting (Lechner, 2009). In equatorial regions where the climate is hot and humid, most of the traditional buildings are constructed with wide awning or verandas shading the large windows which can be opened during most of the year, or specifically throughout the day and night for ventilation (Edmonds and Greenup, 2002).

The daylighting studies involve a great number of cross-disciplined design factors intertwined between the site planning, architecture, interior design, lighting design, electrical engineering and mechanical engineering (Phelan, 2002). All these factors have to integrate with occupants' characteristics, owner's operating requirements, task lighting requirements and the daily and seasonal solar cycles. There are three major developments that contribute to interests on the aspect of daylighting in building designs namely; the impact of light on human health, the growing influence of green building rating schemes and progress at lower cost, along with reliable, integrated control technologies to provide the responsiveness needed for comfort and energy savings (Reinhart and Selkowitz, 2006; Franzetti et al., 2004).

The right application of daylighting in buildings can reduce electricity usage for room illumination by more than 50% (Lechner, 2009; Ihm et al., 2009), while Zain-Ahmed et al. (2002b) proved that the adaptation of daylighting as passive solar design strategy in tropical buildings can help to conserve up to 10% of the energy used. By using computer simulation approaches, Li et al. (2005) have found that the application of daylighting can reduce the maximum cooling plant load and building electrical demand for the base case model by 5 and 9.3%, respectively. Lowering the usage of electric lighting in buildings, it can reduce the energy demand for cooling requirements resulted from the internal load from the artificial light (Leslie, 2003). The incandescent lamps introduce about six times more heat than daylighting and fluorescent lamps introduce about two times more heat than daylighting (Lechner, 2009). The electricity from an incandescent lamp heats up a wire filament causing it to glow and emit the light, where 90% of the energy produced is heat, not light (Mahlia et al., 2005). According to Leslie (2003), capturing day light in the buildings is capable to;

- improve the human performance and well-being through daylighting's impact on their aesthetics, vision, and photobiology, where experimental work indicates that the suppression of melatonin, the hormone responsible for regulating the body's internal clock or circadian rhythm is influenced by the exposure to light levels typical of daylight.
- possibly improve productivity, increase job satisfaction or reduce absenteeism.
- create interesting lighting effects that modulate throughout the day and year, while also providing a broad electromagnetic spectrum with excellent colour rendering.
- allow buildings to be lit at higher levels than those with electric lighting alone. This will allow people to continue working on certain given tasks during power shortages or breakdown.

The effectiveness of daylighting depends on several factors, including the building architectural features (shape, window area, glazing type), the building locations (Ihm et al., 2009), the surrounding climate and the requirements of lighting for specific purposes (Kischkoweit-Lopin, 2002). In the window design, it can include the size, location, orientation, external condition and the use of light diffusers which directly control the light level, daylight qualities and internal luminance (Jughans, 2008). Thus, improving the visual comfort while reducing the heat gain caused by light penetration (Yeang, 2008), can be conclusive in four daylighting strategies, as mentioned by Omer (2008),

- Penetration : collection of natural light inside the building,
- Distribution : homogeneous spreading of light into the space focusing,
- Protect : reducing, by external shading devices, the sun ray penetration into the building,
- Control : control light penetration using movable screens to avoid discomfort.

For multi-storey buildings, the most appropriate zones for active human activities should be located within the daylight zone, typically about 5m deep from the window wall or the top floor of a building with skylight (Leslie, 2003). Additionally, the critically visual tasks need to be placed near the building parameter, and light colour interior surfaces should be used towards reducing the luminance contrast between the windows and surrounding surfaces while increasing the visual comfort.

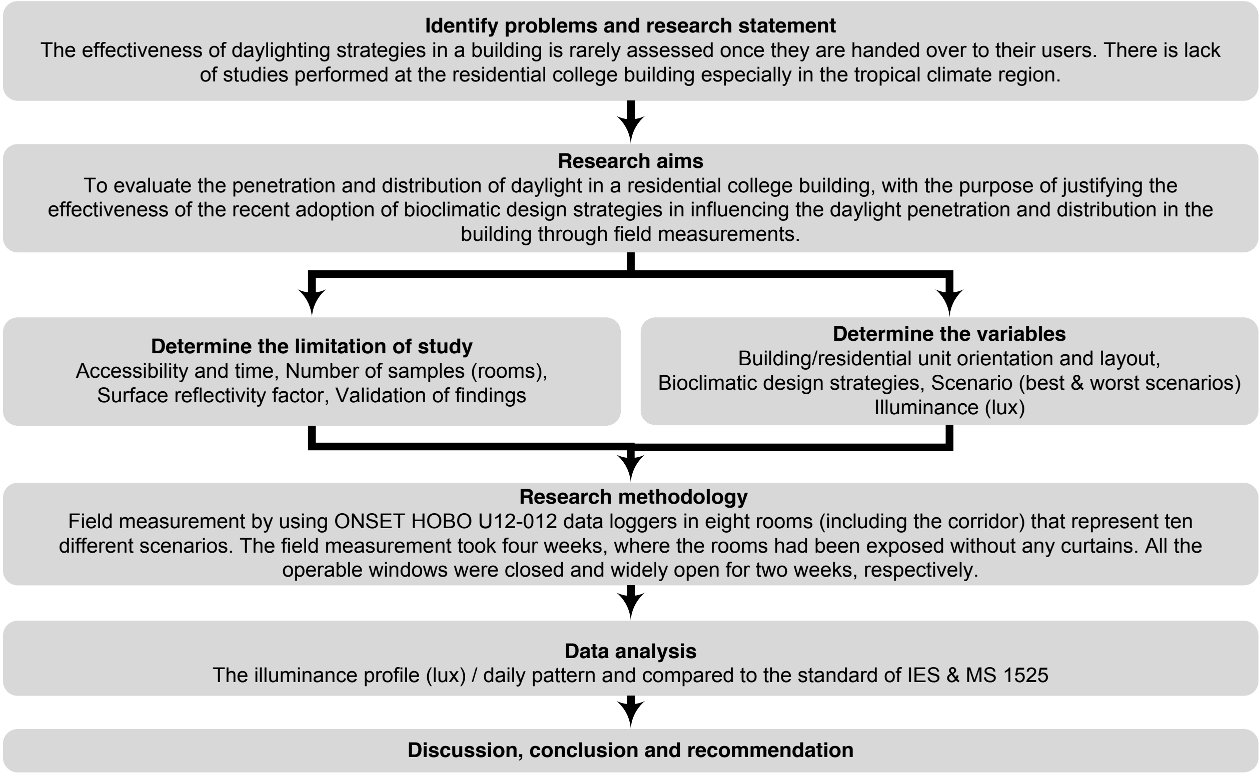
Therefore, the opening size of a window is the most important aspect that affects the penetration of daylighting in the building. The solar gains as the window to wall ratio (WWR) increase while the peak gains occur in the southwest-facing windows (Zain-Ahmed et al., 2002a). The optimum window opening for daylighting in Malaysia is 25% WWR, where the illuminance levels in a room do not reach 500 lux before 8.30 a.m. and after 4.30 p.m. for distances less than 1.75m from the window (Ibrahim and Zain-Ahmed, 2006). Nevertheless, there is no guidance for the maximum size of the opening when other practical requirements such as sun control, security and privacy should also be considered (Aynsley, 1999).

The daylighting is not only an energy efficient technology but also an architectural discipline that improves the performance of the building and occupants. Daylighting stands in prominence as the major factor in occupants' perceptions and acceptance of spaces in buildings. Successful energy saving through daylighting can only be realised when the building and system design support broader occupants' needs for comfortable and healthy indoor environments (Reinhart and Selkowitz, 2006). Unfortunately, the effectiveness of implemented bioclimatic design strategies, particularly daylighting in a building is rarely assessed once they are handed over to their users. There is lack of studies performed at the residential college building especially in the tropical climate region, as compared to the office or commercial buildings in the temperate climate region. Even worse, the designers often design with dreams far away from realistic situations when they fail to understand the features of the local climatic zone and living style (Maheswaran & Zi, 2007). The buildings normally do not fit the ecological and cultural contexts and do not answer to programmatic, practical and functional needs (Al-Kodmany, 2014). Thus, this study aims to evaluate the penetration and distribution of daylight in a residential college building, with the purpose of justifying the effectiveness of the recent adoption of bioclimatic design strategies in influencing the daylight penetration and distribution in the building through field measurements. Indirectly, this indicates the adequacy of daylight in achieving comfortable space as a habitat indoor environment, as prescribed by international and local standards. The selected residential college is an old building located in Kuala Lumpur, which is designed with an internal courtyard and numerous adaptations of bioclimatic design strategies, particularly on daylighting.

RESEARCH METHODOLOGY

The research has been conducted at a multi-residential building, which provides accommodation for university students and which is commonly referred as 'residential college' or 'hostel' in Malaysia. Concerning safety issues which limit the accessibility to the residential block, the field measurement was done for a very short period of time at a selected location, as determined by the residential college administration. The research approach is shown in the following research structure in Figure 1.

The field measurement was conducted in eight unoccupied student rooms, which are regarded to be the most excellent rooms in representing ten scenarios concerned with the level of radiation and penetration of sunlight into the student rooms. There are five best scenarios, which were labelled as 'B', and five contrary scenarios which were described as the worst scenarios and labelled as 'W'. All the ten identified scenarios are based on climatic design theories according to the previous studies, particularly in the tropical region (Lechner, 2009; Jughans, 2008; Yeang, 2008; Ahmad, 2008; Hyde, 2000; Davis et al., 2006; Konya and Vandenberg, 2011; Aynsley, 2007; Monteiro and Alucci; 2009); they are extensively explained in Table 1. Initially, two from eight selected rooms had been chosen to represent two different scenarios. The findings from each selected room will give a general evaluation of daylight penetration and distribution based on the identified scenario (Jamaludin et al., 2012). Theoretically, the worse or better conditions were expected in the room with the combination of two or more scenarios.



Identify problems and research statement
The effectiveness of daylighting strategies in a building is rarely assessed once they are handed over to their users. There is lack of studies performed at the residential college building especially in the tropical climate region.

Research aims
To evaluate the penetration and distribution of daylight in a residential college building, with the purpose of justifying the effectiveness of the recent adoption of bioclimatic design strategies in influencing the daylight penetration and distribution in the building through field measurements.

Determine the limitation of study
Accessibility and time, Number of samples (rooms), Surface reflectivity factor, Validation of findings

Determine the variables
Building/residential unit orientation and layout, Bioclimatic design strategies, Scenario (best & worst scenarios) Illuminance (lux)

Research methodology
Field measurement by using ONSET HOBO U12-012 data loggers in eight rooms (including the corridor) that represent ten different scenarios. The field measurement took four weeks, where the rooms had been exposed without any curtains. All the operable windows were closed and widely open for two weeks, respectively.

Data analysis
The illuminance profile (lux) / daily pattern and compared to the standard of IES & MS 1525

Discussion, conclusion and recommendation

Figure 1. Research structure

Table 1: The 10 identified scenarios.

Scenario		Description
B1	North orientation	Receiving reflected heat radiation and penetration either from the west or east. Meanwhile, it is not influenced by direct heat radiation and penetration by man-made surface either on top or on the ground.
W1	East orientation	Receiving direct heat radiation and penetration from the east. Meanwhile, it is not affected by direct heat radiation and penetration of man-made surface either on top or on the ground.
B2	South orientation	Receiving reflected heat radiation and penetration either from the west or east. Meanwhile, it is not influenced with direct heat radiation and penetration by man-made surface either on top or the ground.
W2	West orientation	Receiving direct heat radiation and penetration from the west, while, not affected by direct heat radiation and penetration of man-made surface either on top or on the ground.
B3	Avoid direct contact with man-made surfaces on the top	Not receiving direct heat radiation and penetration from man-made surfaces on the top, i.e. roof, wall etc. and with north-south building orientation.
W3	Direct contact with man-made surfaces on the top	Receiving direct heat radiation and penetration from man-made surfaces on the top solely, i.e. roof, wall etc. and with north-south building orientation.
B4	Avoid direct contact with man-made surfaces on the ground	Not receiving direct heat radiation and penetration from man-made surfaces on the ground, i.e. tarmac, court etc. As well as, direct heat radiation and penetration neither from the east nor the west.
W4	Direct contact with man-made surfaces on the ground	Receiving direct heat radiation and penetration from man-made surfaces on the ground solely, i.e. tarmac, court etc., while not affected by directing heat radiation and penetration either from the east or west.
B5	Shaded	Shaded by landscape or trees or adjacent buildings and with north-south building orientation. Not affected somehow by direct heat radiation and penetration of man-made surface either from the top or on the ground.
W5	Exposed	Exposed to open spaces and with north-south building orientation. Not affected somehow by direct heat radiation and penetration man-made surface either from the top or ground.

For example, higher mean illuminance values in the exposed room with the west or east orientation imply that the room receives direct daylight penetration. On the other hand, lower mean illuminance values would be obtained in shaded rooms with the north or south orientation.

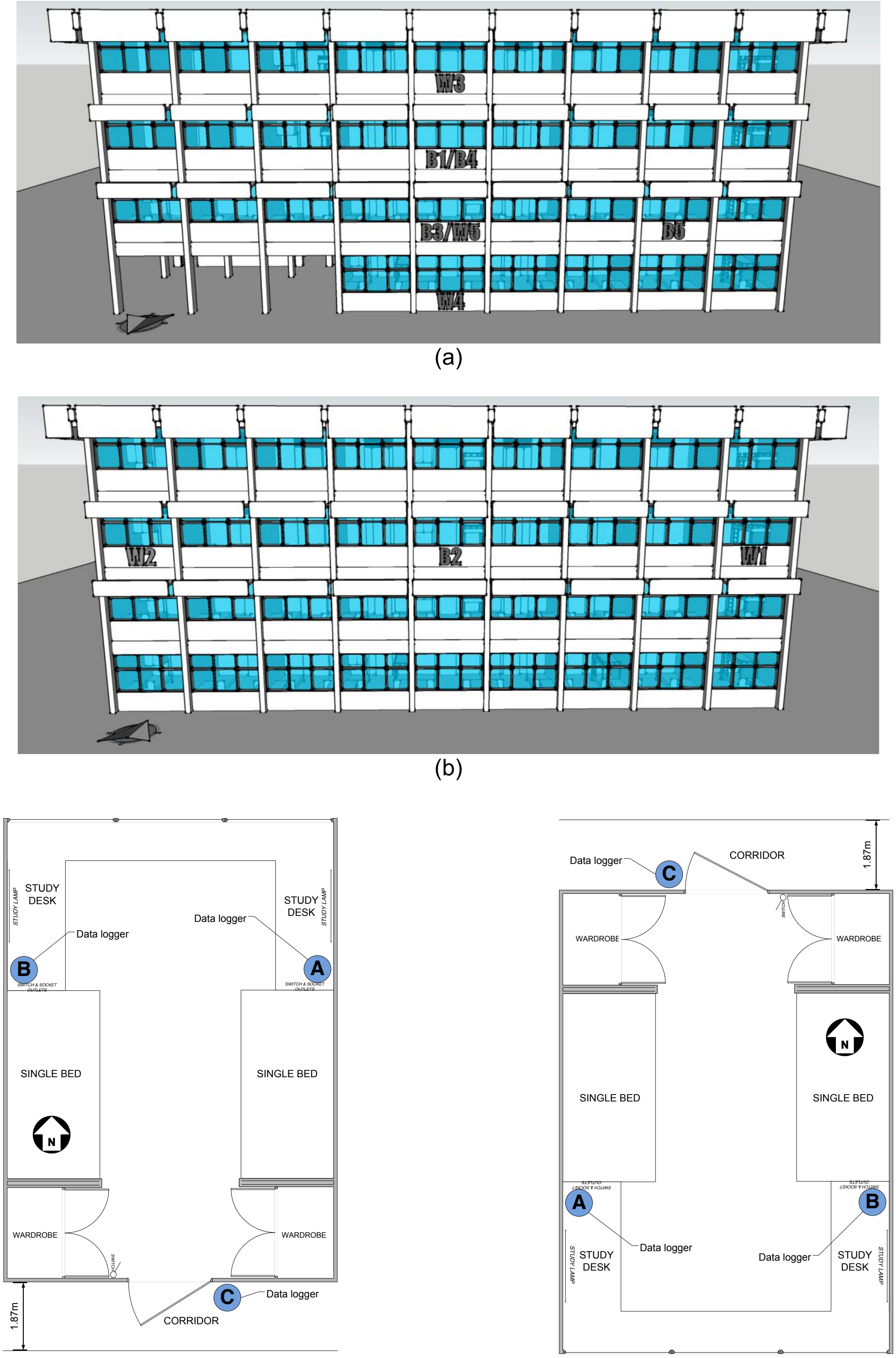
The study done by Chaiwiwatworakul and Chirarattananon (2013) on a double-pane window with enclosed horizontal slats for daylighting in buildings in the tropics was adapted to restructure the research methodological approaches on data collection. ONSET HOBO U12-012 data loggers for indoor measurements were fixed on both sides of the walls to find out the distribution level of daylight (lumens/ft^2 or lux) in the room (Hua et al., 2011). These data loggers were fixed on the room's core area for main activity; which is on the study desk at 1.10m above the floor (Kim and Kim, 2007; Jovanić at al., 2014). As adapted from a study done by Li and Lam (2003) on an investigation of daylighting performance and energy saving in a daylit corridor, ONSET HOBO U12-012 data logger was also fixed outside the selected rooms for the examination of the level of daylight outside the room, specifically in the corridor area. The location field measurement and all three data loggers are shown in Figure 2.

The measurement was done in four weeks, where the rooms had been exposed without any curtains. In the first two weeks, all the operable windows were closed, while in another two weeks all operable windows were widely opened. This is to find out the effects of facade design and building orientation in providing daylighting into the room in ten different scenarios, as the user's adjustment on the internal shading is subjective and unable to be generalised (Lim et al., 2012). The plastic net with 1.5cm^2 of mesh size with 0.5 to 0.6 of light transmittance has been fixed for the safety of data loggers during the opening of all operable windows. According to Ahmad (2008), Malaysia's climatic conditions are uniform throughout the year with only little seasonal variation and constant sunshine hours. In contrast, there are very distinguishable difference between the minimum and maximum daily temperature due to the day and night factor. Thus, the measurement was covered in a 24-hour period with one-hour interval between measurements (Dahlan et al., 2009). According to Li and Tsang (2005), data measurement is regarded as the most effective and accurate method of setting up reliable databases.

All the collected data were initially analysed by using the Hoboware pro software. In order to assess the level of daylighting in the building, the illuminance data were compared with the international and local illumination standards. The standards which are established by the Illuminating Engineering Society (IES) and Standards and Industrial Research Institute of Malaysia (SIRIM) with Malaysia Standard 1525 (MS 1525), were used in view of the most stringent standards (Department of Standards Malaysia, 2007; IES, 2011). The MS 1525 is the code of practice on energy efficiency and the use of renewable energy for non-residential buildings. Listed by the IES, the minimum of 100 lux is applied to circulation areas, corridor being one example. Meanwhile, 150 lux is for the living room in general, 400 lux for casual reading and 100 lux for the bedroom as referred to MS 1525. In addition, statistical computer software package was used for further statistical analyses that include a descriptive analysis, to find out the difference of the mean and maximum illuminance values between the indoor and outdoor.

BUILDING DESCRIPTION

The Dayasari Residential College (Dayasari RC) was established in 1966 with 18,212.51m^2 of the total floor area and leads other residential colleges in the University of Malaya campus in terms of its implementation of bioclimatic designs, especially when it comes to allowance for the best utilisation of daylighting (Jamaludin et al., 2012). This residential college is a low-rise and naturally-ventilated building and can accommodate up to 847 residents at one time. The building's orientation to sun path is north-south, which directly reduces the glare and thermal effect that can be collected inside the rooms. Only service areas such as toilets, bathrooms, stores, staircases and balconies are located at a west-east orientation.



(a)

(b)

(c)

(d)

Figure 2. (a) (b) Location of field measurement, (c) Location of three data loggers for scenarios B1, B3, B4, B5, W3, W4 and W5, (d) Location of three data loggers for scenarios B2, W1 and W2.

The building layout is based on a courtyard arrangement that allows for the transom on top of the entrance door and wall to fully function, in providing daylight in the room, at least in theory. The typical room's floor area and volume are 16.35m^2 and 45.78m^3, respectively. With the open staircase area and a corridor that face the internal courtyard, the lamps do not need to be switched on during daytime as compared to other buildings with a linear arrangement of building layout (Jamaludin et al., 2011). As a consequence, Dayasari RC has to contain amongst the lowest Energy Efficiency Index (34.52 kWh/m^2/year) compared to the other residential colleges which are in the range of 40 to 125 kWh/m^2/year (Jamaludin et al., 2013). Based on the energy audit done by Jamaludin et al. (2013), the uses of electrical lamps at the Dayasari RC depend on the location and purpose. Generally, it is 12 hours in the corridor and in the toilets (from 7 p.m. to 7 a.m.), 6 hours in the room (from 6 p.m. to 12 a.m.) and 4 hours for study lamp (from 8 p.m. to 12 a.m.) daily. The typical elevation and floor plan of Dayasari RC are presented in Figure 3.

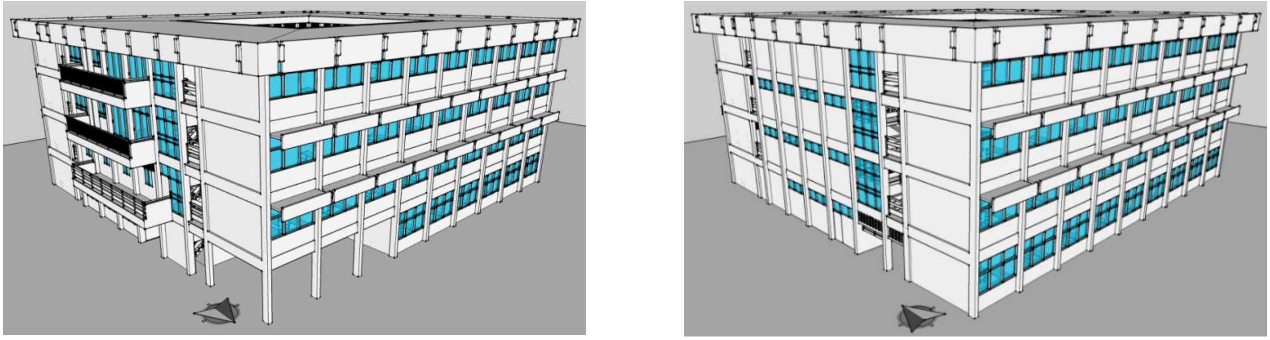
In light of the enclosure and facade design, Dayasari RC was designed with two special features; glare protection and adjustable/fixed opening options. There are two types of single glazed windows; namely the centre pivot and awning, which are a standard float and tinted glass with 0.56-0.60 of the visible transmittance. The Window to Wall Ratio (WWR) is fairly big, 0.66, while the window area is 6.41m^2. Subsequently, the operable window area is only 4.20m^2 with 0.43 of operable WWR. To date, the WWR is not efficient, as the ASHRAE 90.1 Standards Committee voted the current 0.24<WWR<0.40 for low-rise buildings (US Glass News Network, 2012). The WWR is the ratio of vertical fenestration area to gross exterior wall area and higher ratio can result in excessive daylight into the building (Yeang, 2008). The measured ratio of window to floor area is 39%, which is more than the prescribed rule of thumb for daylight design in Architecture's Data used by Neufert and Neufert (2012). The WWR in the range of 10 to 12.5% is recommended, while 10 to 25% was suggested by Gutherie (2010). There are large concrete overhangs along the window in each room; excluding the ground floor, in giving a significant shadow effect to the rooms. These overhangs are painted with white coated on the bottom surface and uncoated on the upper surface with 0.85-0.95 of the solar reflectance. The combination of the internal courtyard, transom on top of the entrance door and two types of single glazed window create cross-flow / two sided ventilation that encourages air circulation in the room. The implementation of bioclimatic design strategies at Dayasari RC are visualised in Figure 4.

Finally, there are about 61:39 ratio of soft and hard landscape areas with 0.607 of Biotope Area Factor (BAF); the proportion of green space to the entire development area. The Dayasari RC is surrounded by a highly diverse vegetated area as it is next to the foothill of Rimba Ilmu, the university's tropical botanical garden. Most trees are well matured with their canopies covering the ground that provides wonderful shading effects to the residential building (Jamaludin et al., 2011).

RESULTS

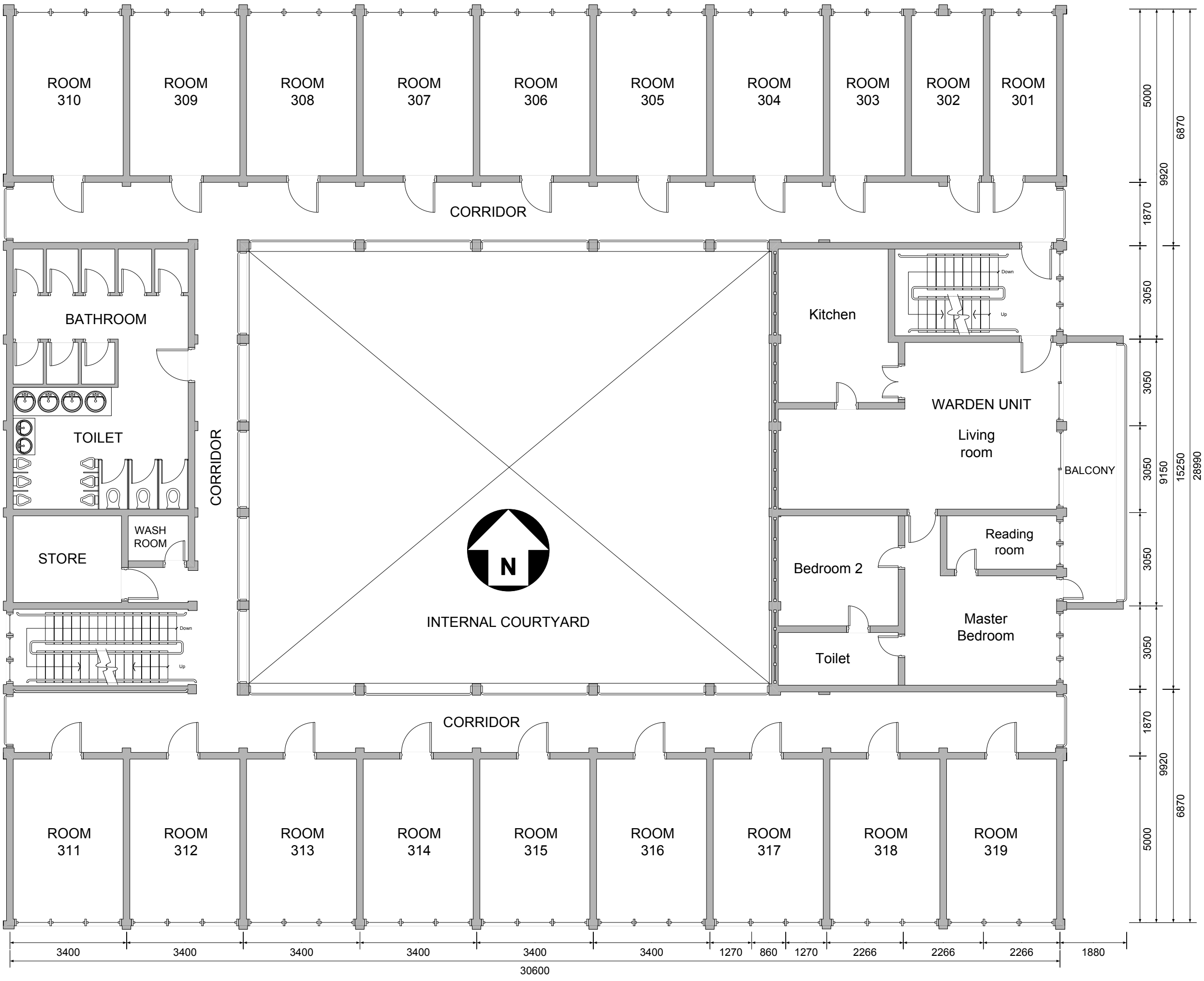
The illuminance profile of all eight rooms that represents ten different scenarios, in order to evaluate the penetration and distribution of daylight at a residential college building with the internal courtyard arrangement, is drawn in Figure 5. The profile shows in the form of daily pattern and compares the minimum requirements of the IES and MS 1525. The mean and maximum illuminance values (lux) for each room and corridor are presented in Table 2.

The adequacies of daylight in all selected rooms as presented in Figure 5, fulfil the minimum requirement of the IES for corridor (100 lux), along with MS 1525 for the living room (150 lux) and bedroom (100 lux). The availability of daylight was varied from 8 a.m. to 7 p.m. with regard to the scenarios represented.



Front isometric elevation

Rear isometric elevation



Floor plan

Figure 3. Typical elevation and floor plan of the Dayasari RC building.

(a) (d) (b) (e) (c) (f)

Figure 4. Implementation of bioclimatic design strategies at Dayasari RC, (a) Internal courtyard in the middle of residential building, (b) Transom/fixed opening over the doorway of the room, (c) The wall opening in the room - creates a wind pressure, (d) Open staircase area, (e) two types of single glazed window with standard float and tinted glass, centre pivot and awning, (f) Glare protection and adjustable natural ventilation options.

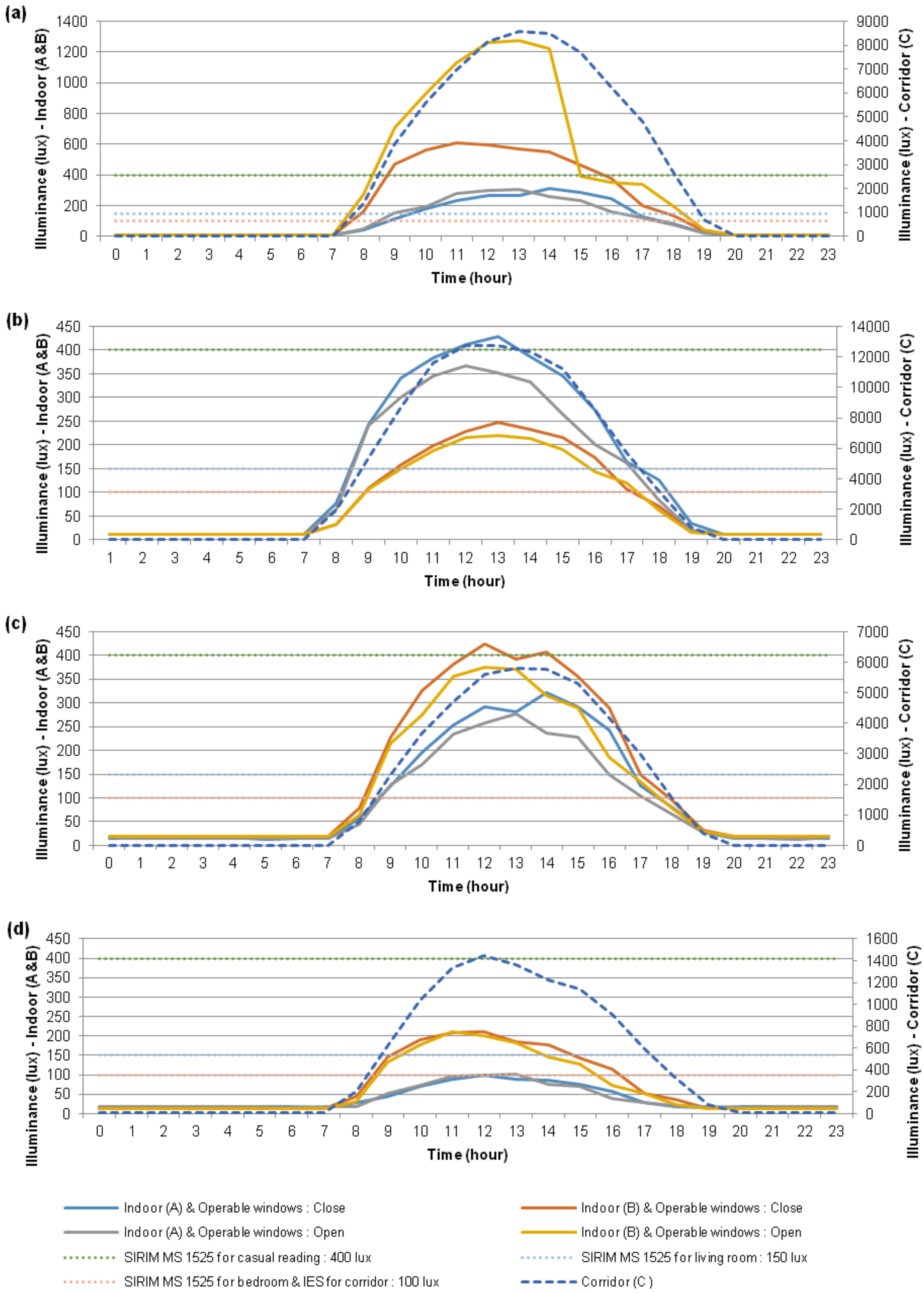


Figure 5. The illuminance profile (lux) / daily pattern as compared to the standard of IES and MS 1525, (a) Scenario B1 and B4, (b) Scenario B2, (c) Scenario B3 and W5, (d) Scenario B5

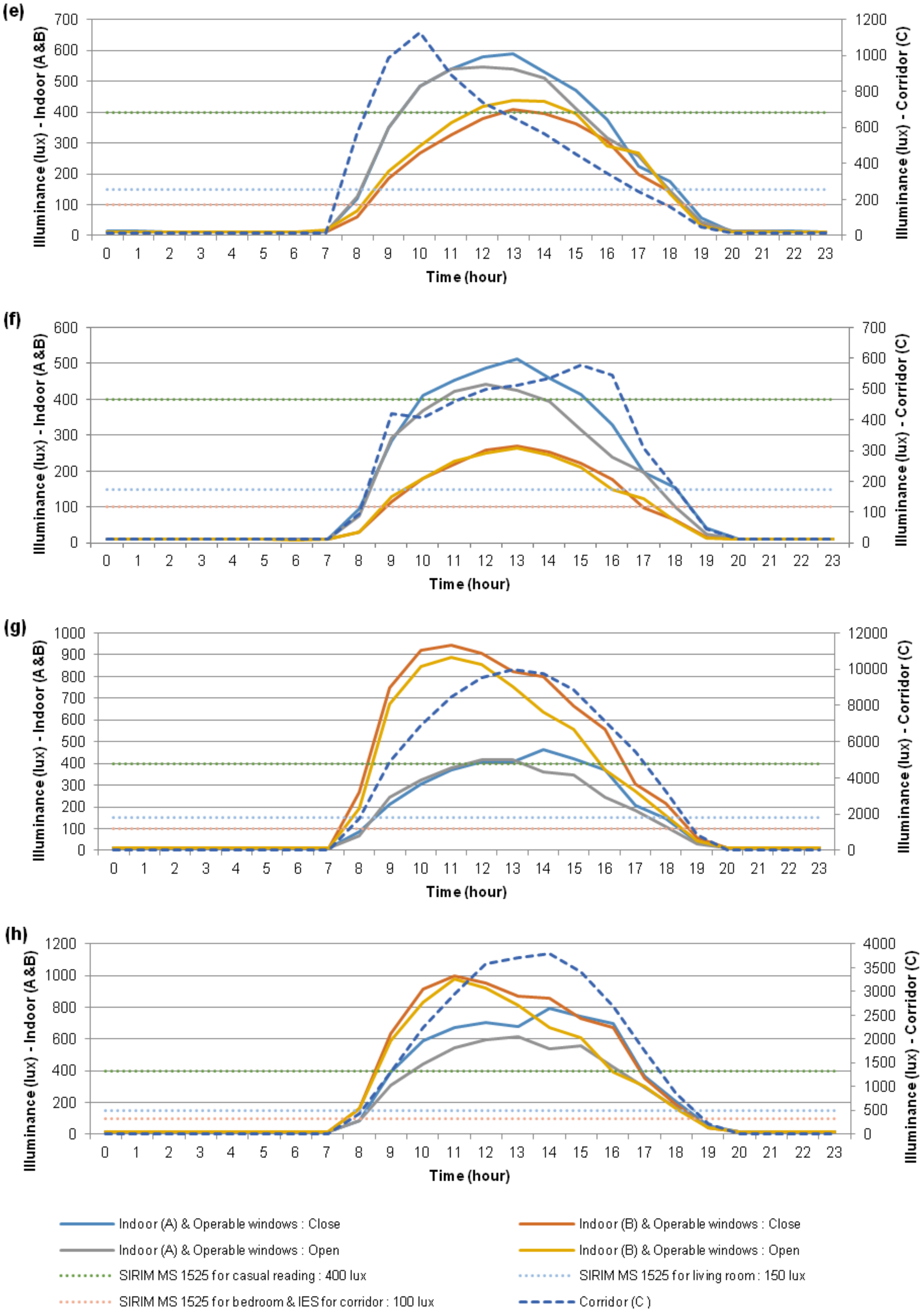


Figure 5. continued, (e) Scenario W1, (f) Scenario W2, (g) Scenario W3, (h) Scenario W4.

Table 2: The mean and maximum illuminance values (lux) in the room and corridor according to the level of the floor.

Level & Room No.	Scenario		Location		
			Indoor A	Indoor B	Corridor
Level 4, 406	W3	Direct contact with man-made surfaces on the top	139 lux Max: 682 lux	278 lux Max: 1,644 lux	3,120 lux Max: 14,179 lux
Level 3, 306	B1 & B4	North orientation & Avoid direct contact with man-made surfaces on the ground	91 lux Max: 453 lux	187 lux Max: 966 lux	2,647 lux Max: 12,933 lux
Level 3, 319	W1	East orientation	185 lux Max: 721 lux	136 lux Max: 643 lux	282 lux Max: 3,189 lux
Level 3, 315	B2	South orientation	127 lux Max: 509 lux	76 lux Max: 359 lx	3,848 lux Max: 18,893 lux
Level 3, 311	W2	West orientation	151 lux Max: 635 lux	82 lux Max: 398 lux	192 lux Max: 1,133 lux
Level 2, 208	B5	Shaded	37 lux Max: 162 lux	65 lux Max: 304 lux	422 lux Max: 1,943 lux
Level 2, 205	B3 & W5	Avoid direct contact with man-made surfaces on the top/ Exposed	93 lux Max: 461 lux	128 lux Max: 580 lux	1,750 lux Max: 8,794 lux
Level 1, 102	W4	Direct contact with man-made surfaces on the ground	221 lux Max: 1,131 lux	286 lux Max: 1,407 lux	1,097 lux Max: 5,452 lux

Referring to Table 2, the mean illuminance values in the room varied from 37 lux to 286 lux, while in the corridor area the values were between 192 lux and 3,848 lux. Comparatively, higher mean illuminance values were recorded in the corridor as compared to the rooms exceeding 3,120 lux. The selected rooms which represented the worst scenarios recorded higher mean illuminance values with the margin 6 to 150 lux, as compared to the rooms that represented the best scenarios. However, a different situation was recognised for Indoor B between scenario W1 (east orientation) and scenario B1 (north orientation). The mean illuminance value for B1 was 51 lux higher than W1. Overall, the highest mean illuminance values for both Indoor A and B were recorded in the room that represented scenario W4 (direct contact with man-made surfaces on the ground). The highest maximum illuminance values for Indoor A and B were recorded in the rooms which represented scenario W4 (direct contact with man-made surfaces on the ground) with 1,131 lux and W3 (Direct contact with man-made surfaces on the top) with 1,644 lux, respectively. As located at the middle of building, the corridor of the room which represented scenario B2 (south orientation) showed the highest mean and maximum illuminance values with 3,848 lux and 18,893 lux, respectively.

DISCUSSION

Higher mean illuminance values were recorded in the corridor to compare the rooms (Table 2). The adequacies of daylight with regard to the minimum requirement of the IES for corridor; 100 lux, were from 8 a.m. to 7 p.m. (Figure 5). Thus, this reduces the electricity usage for artificial lighting in the corridor area. As presented in Figure 5(f), the availability of daylight at the corridor of the room, which is representative of scenario W2 (west orientation) was limited from 8 a.m. to 6 p.m. although this room is orientated to the west and supposedly receives the most sun in the mid-afternoon (Al-Obaidi and Woods, 2006). This is due to the shading effect of the large tree canopy as adjacent to the ‘Rimba Ilmu’ area. In order to improve the daylight illumination in a shaded corridor area, optical systems can be adapted as alternative design strategies by redirecting daylight to areas which are further from the internal courtyard (Kischkoweit-Lopin, 2002). The success of these optical systems includes the following traits; angle selective glazing, light guiding shades, vertical and horizontal light pipes, switchable glazing and angle selective skylight, all of which have been proven relatively in small buildings by Edmonds and Greenup (2002).

According to Yeang (2008) and Zain-Ahmed (2009), these systems designed and effectively transported the daylight to block direct sun, direct source of glare and thermal discomfort.

Different illuminance values were recorded even within the same room, which can be well visualised in Table 2 and Figure 5. The side of the room's wall facing to the east had received more daylight due to the sun path. There were different times and periods of daylight availability with regard to the minimum requirement of MS 1525 for casual reading; 400lux in the rooms. Prolonged period was recorded in the room that represents scenario W3 (direct contact with man-made surfaces on the top). The duration reached up to 9 hours, starting from 8 a.m. to 5 p.m. daily [Figure 5(g)]. The duration and the amount of daylight received gradually decreased from the top to the second floor. This is more obvious on the second floor with 6 hours of duration [Figure 5(c)]. However, the duration of daylight received on the first/ground floor increased up to 8 hours in the room which represents scenario W4 (direct contact with man-made surfaces on the ground) [Figure 5(h)]. The mean and maximum illuminance values were much higher as compared to the values for the room on the top floor, where the values at the both sides of the walls being slightly similar (Table 2). The same results were also discovered as compared to the room that represents a contrasting scenario B4 (avoid direct contact with man-made surfaces on the ground) [Figure 5(a)]. These are due to the fact that there are no overhangs over the windows and due to the reflection of solar radiation on the concrete paving (Lechner, 2009).

As an intermediate room, the adequacy of daylight in the room that represents scenario B2 (south orientation) had fulfilled the minimum requirement of MS 1525 for casual reading [Figure 5(b)]. Apparently, it was only limited to four hours from 10 a.m. to 2 p.m., even when there was a high value of light intensity in the corridor area which was exceeding 18,000 lux (Table 2).The corridor area is directly facing the internal courtyard. Referring to the rooms representing scenario W1 (east orientation) and W2 (west orientation) which are located on the same floor, these two corner rooms received higher amounts of daylight for longer durations; that is up to eight hours [Figure 5(e)& (f)]. Meanwhile, only 1,000 lux to 3,000 lux were recorded in the corridors of both corner rooms, as a result of not facing the internal courtyard area (Table 2). These substantial differences occur due to the wide overhangs over the windows all along the floor. The presence of the opening wall to encourage wind pressure inside the room has limited the function of transom over the doorway to provide the penetration of daylight from the internal courtyard into the intermediate room. The artificial lighting is needed to deal with the shadows inside, which are caused by the overwhelmingly efficient solar protection and shades (David et al., 2011). Therefore, the use of wide overhangs all along the floor and the opening wall inside the room should critically be analysed, especially for the intermediate room. The efficiency of solar shades must be considered both for thermal and visual points of view, plus good solar shade typically excludes all direct sun and much of the indirect light from the sky as well (David et al., 2011). An appropriate sun shading device for the window is necessary to reject the undesirable amount of solar radiation but at the same time, it lets the desirable amount of solar radiation to penetrate the aperture for daylighting purpose (Chung et al., 2010). In addition, the indoor space should be kept open as frequently as possible by reducing the number of walls, as well as daylight penetration, to encourage air circulation inside the room (Tantasavasdi at al., 2001).

Located on the same floor, there is an intermediate room that represents two different scenarios; B1 (north orientation) and B4 (avoiding direct contact with man-made surfaces on the ground) [Figure 5(a)]. Theoretically, the illuminance value is slightly similar to the room that represents scenario B2 (south orientation) [Figure 5(b)]. Apparently, a higher mean and maximum illuminance value with longer duration of daylight availability had been recorded, that is up to eight hours. Meanwhile, at the corridor area, the value is slightly lower with the same duration of daylight availability. Different conditions of the area facing the room are hypothesised as the justification for this situation. There is a green area with trees at the south, while a multipurpose open area is located at the north of the residential building.

The presence of a landscape with green trees influences the surrounding environment as compared to the open sky (Monteiro and Alucci, 2009).

The amount of daylight in the room which represents scenario B5 (shaded by landscape or trees or adjacent buildings with north-south building orientation) was less than the minimum requirement of MS 1525 for casual reading [Figure 5(d)]. As shaded by trees with large canopy, the maximum value of daylight was only 304 lux (Table 2). The contribution of the green landscape in providing better environment is undeniable. The tree canopy has a significant filtration capability which contributes to the reduction of terrestrial radiation, cooling the ground surfaces by capturing more latent heat, reducing air temperature by promoting more evapotranspiration, and effectively improving the outdoor thermal comfort, especially in open spaces of the tropical climate region (Hyde, 2000; Monteiro and Alucci, 2009; Shahidan et al., 2010). Unfortunately, too much shade will evade the effectiveness of daylighting in the building. Thus, in optimising the utilisation of landscape and the trees to improve the condition of the room through shading effects, the visual comfort should not be sacrificed as well. Relatively, the illuminance in the room which represents the opposing scenario; W5 (exposed to open space with north-south building orientation) is much better [Figure 5(c)].The adequacies of daylight with regard to the minimum requirement of MS 1525 for casual reading; 400 lux, was from 10 a.m. to 4 p.m. with the maximum exceeding 500 lux. This room was also representative of scenario B3 (avoiding direct contact with man-made surfaces on the top) and as parallel with the opposing scenario which has been discussed earlier, the values of light intensity at W3 were found to be much higher with a longer period of time that meet the requirements of MS 1525 for casual reading.

According to the contradiction between the usages of some bioclimatic design strategies, the green landscape has more negative impact on the adequacy of daylight in the room, as compared to the overhangs along the windows and wall opening in the windows. In the room E 208, which happens to be shaded by a tree with large canopies, it has recorded low illuminance values. The maximum value was only 304 lux and not exceeding the minimum requirement of MS 1525 for casual reading. In turn, the illuminance values in the intermediate rooms with wide overhangs over the windows all along the floor were much higher with the maximum illuminance value 966 lux. The adequacy of daylight with regard to the minimum requirement of MS 1525 for casual reading was beyond 4 hours daily. The wall opening has less negative impact on the adequacy of daylight in the room. Some of the rooms studied recorded higher illuminance values, exceeding 1,000 lux and fulfilled the minimum requirement for casual reading for more than 6 hours daily. This negative impact was only discovered on selected rooms, depending on their location and orientation.

Overall, the adequacies of daylight in all selected rooms have fulfilled the minimum requirement of MS 1525 for the living room (150 lux) and bedroom (100 lux) most of the daytime. Then, there are the constant minimum values in the rooms and the corridors due to the corridor and street lamps located in close proximity to one another in the selected rooms. The corridor and street lamps are switched on from 7 p.m. to 7 a.m. daily.

With the opening of operable windows, the iluminance values were slightly reduced as revealed in Figure 5.The usage of plastic net with 1.5 cm of mesh size for security reason during the measurement has influenced the adequacy of daylight in the room. However, there were no differences in the room on the ground floor that can represent scenario W4 (direct contact with man-made surfaces on the ground) [Figure 5(h)]. The plastic net was not used in this room as the window grill was already fixed with 4 cm of mesh size iron net prior to this measurement. Therefore, the use of the window grill or net for security purposes should be well planned beforehand, to avoid the reduction of daylight level, as well as to promote natural ventilation in the room (Aynsley, 2007).

CONCLUSION

The application of bioclimatic design strategies based on an internal courtyard arrangement at a residential college building in a region with tropical climate is able to provide a comfortable room with less electricity usage, particularly for the lighting purposes.

According to the illuminance profile (lux) / daily pattern, the daylight is available at 7 a.m. until 7 p.m. daily and reaches the peak between 12 p.m. and 1 p.m. due to the location of the rooms. There are different amounts of daylight in the room in the residential college building with the internal courtyard arrangement, even within the same room. The side of the room's wall facing to the east had evidently received more daylight due to the sun path, in the range of 23-51% as compared to the west. The daylight availability in terms of the duration and amount is gradually reduced by lowering the floor levels, and is considerably increased at the ground floor due to the absence of overhangs over the windows and the reflection of solar radiation. These findings are based on the measurement that was conducted in eight unoccupied student rooms, which are regarded as the most excellent rooms in representing ten scenarios due to limited access to the residential block based on safety issues.

The residential college building design, which is based on the internal courtyard of the building arrangement and well adapted to other bioclimatic design strategies, has been found to be able to provide a comfortable room as a living space and a bedroom. This type of building design and strategies; specifically transom/fixed opening over the doorway of the room, open staircase area, two types of single glazed window with standard float and tinted glass, glare protection and adjustable natural ventilation options, should widely be implemented either for refurbishment or as new designs of any residential college building. The internal courtyard provides the adequacy of daylight at the corridor, which is up to ten hours daily. Thus, electricity usage for lighting in the building is reduced, especially in the tropical climate region that receives 12 hours of daylight every day and all year round. However, further improvements are needed when the minimal daylight is required for the study room; especially for casual reading, we remember that the daylight is only limited for a certain duration of time. This involves a critical evaluation on the design and the usage of overhangs over the windows by considering the room location and orientation. Also, the wall opening in the room theoretically creates wind pressure only with the presence of high air velocity while denying the distribution of daylight entirely. Additionally, the optimal landscape designs for daylighting in buildings should take into account the tree height, crown shape and distance to the buildings.

In order to evaluate the penetration and distribution of daylight in a systematic and rigorous manner, future research should include more rooms and not only limited to a certain area and period. Referring to this study; which emphasizes on a multi-level residential college building with an internal courtyard of building layout and single external wall, all the intermediate and corner rooms on each floor should be included in this evaluation. The service areas such as the bathroom, toilet, store and staircase areas are also considered essential to be examined. Additionally, the surface reflectivity factor should be highly considered as well. Thus, the effectiveness of bioclimatic design strategies in influencing the daylight penetration and distribution in the building can be determined precisely. The validation of findings from the field measurement can be done by using computer simulation.

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REFERENCES

Ahmad, S. A. (2008). Kuala Lumpur: A hot humid climate. In R. Hyde (Eds.), Bioclimatic housing: Innovative designs for warm climates (pp. 269-293). UK: Earthscan.

Al-Kodmany, K. (2014). Green towers and iconic design: Cases from three continents. *ArchNet-International Journal of Architectural Research, 8*(1), 11-28.

Al-Obaidi, M. A. A. H., & Woods, P. (2006). Investigations on effect of the orientation on thermal comfort in terraced housing in Malaysia. *International Journal of Low Carbon Technologies, 1*(2), 167-176. doi: 10.1093/ijlct/1.2.167

Aynsley, R. (1999). Low energy architecture for humid tropical climates, World Renewable Energy Congress, Kuala Lumpur, 8-11 June 1999. pp. 333-339.

Aynsley, R. (2007). Natural ventilation in passive design. *BEDP Environment Design Guide, Tec 2*, 1-11.

Chaiwiwatworakul, P., & Chirarattananon, S. (2013). A double-pane window with enclosed horizontal slats for daylighting in buildings in the tropics. *Energy and Buildings, 62*, 27-36. doi:10.1016/j.enbuild.2013.02.027

Chung, T., Kwok, C., & Mardaljevic, J. (2010). A study on daylight distribution and the associated heat gain of a typical flat in Hong Kong commercial buildings. *Journal of Light & Visual Environment, 34*(2), 105-110. doi: 10.2150/jlve.34.105

Dahlan, N. D., Jones, P. J., Alexander, D. K., Salleh, E., & Alias, J. (2009). Evidence base prioritisation of indoor comfort perceptions in Malaysian multi-storey hostels. *Built and Environment, 44*(10), 2158-2165. doi:10.1016/j.buildenv.2009.03.010

David, M., Donn, M., Garde, F., & Lenoir, A. (2011). Assessment of the thermal and visual efficiency of solar shades. *Building and Environment, 46*(7), 1489-1496. doi: 10.1016/j.buildenv.2011.01.022

Davis, M. P., Ghazali, M., & Nordin, N. A. (2006). Thermal comfort honeycomb housing: The affordable alternative to terrace housing. Malaysia: Institute of Advance Technology, UPM.

Department of Standards Malaysia. (2007). MS 1527:2007 - Code of practice on energy efficiency and use of renewable energy for non-residential buildings. Malaysia: Department of Standards Malaysia.

Edmonds, I. R., & Greenup, P. J. (2002). Daylighting in the tropics. *Solar Energy, 73*(2), 111-121. doi: 10.1016/S0038-092X(02)00039-7

Fontoynont, M., Tsangrassoulis, A., & Synnefa, A. (2004). SynthLight handbook. France: European Commission.

Franzetti, C., Fraisse, G., & Achard, G. (2004). Influence of the coupling between daylight and artificial lighting on thermal loads in office buildings. *Energy and Buildings, 36*(2), 117-126. doi: 10.1016/j.enbuild.2003.10.005

Gutherie, P. (2010). The architect's portable handbook: First step rules of thumb for building design, 4th ed. New York: McGraw-Hill.

Hua, Y., Oswald, A., & Yang, X. (2011). Effectiveness of daylighting design and occupant visual satisfaction in a LEED Gold laboratory building. *Building and Environment, 46*(1), 54-64. doi: 10.1016/j.buildenv.2010.06.016

Hyde, R. (2000). Climate responsive design: A study of buildings in moderate and hot humid climates. New York: E&FN Spon.

Ibrahim, N., & Zain-Ahmed, A. (2006). A simple prediction tool for energy savings due to daylighting in Malaysia. *Journal Science & Technology Vision, 2*(1), 25-29.

Ihm, P., Nemri, A., & Krarti, M. (2009). Estimation of lighting energy savings from daylighting. *Building and Environment, 44*(3), 509-514. doi: 10.1016/j.buildenv.2008.04.016

Illuminating Engineering Society. (2011). The lighting handbook – Reference and Application, 10th ed. US: IES.

Jamaludin, A. A., Inangda, N., Ariffin, A. R. M., & Hussein, H. (2012). Energy performance: A comparison of four different multi-residential building designs and forms in the equatorial region. *International Journal of Renewable Energy Resources, 2*, 13-22.

Jamaludin, A. A., Inangda, N., Ariffin, A. R. M., & Hussein, H. (2011). Energy performance of three residential college buildings in University of Malaya campus, Kuala Lumpur. *Journal of Design and Built Environment, 9*, 59-73.

Jamaludin, A. A., Mahmood, N. Z., Keumala, N., Ariffin, A. R. M., & Hussein, H. (2013). Energy audit and prospective energy conservation: Studies at residential college buildings in a tropical region. *Facilities 31*(3/4), 158-172. doi: 10.1108/02632771311299430

Jovanić, A., Pejić, P., Djorić-Veljković, S., Karamarković, J., & Djelić, M. (2014). Importance of building orientation in determining daylighting quality in student dorm rooms: Physical and simulated daylighting parameters' values compared to subjective survey results. *Energy and Buildings, 77*, 158-170. doi:10.1016/j.enbuild.2014.03.048

Jughans, L. (2008). Design, elements and strategies: Daylighting. In R. Hyde (Eds.), Bioclimatic housing: Innovative designs for warm climates (pp. 345-365). UK: Earthscan.

Kim, S., & Kim, J. (2007). The impact of daylight fluctuation on a daylight dimming control system in a small office. *Energy and Buildings, 39*(8), 935-944. doi:10.1016/j.enbuild.2006.10.009

Kischkoweit-Lopin, M. (2002). An overview of daylighting systems. *Solar Energy, 73*(2), 77-82. doi: 10.1016/S0038-092X(02)00036-1

Konya, A. & Vandenberg, M. (2011). Design primer for hot climates. UK: Archimedia Press Limited.

Lechner, N. (2009). Heating, cooling, lighting: Sustainable design methods for architects, 3rd ed. New Jersey: John Wiley & Sons.

Leslie, R. P. (2003). Capturing the daylight dividend in buildings: why and how?, *Building and Environment, 38*(2), 381-385. doi: 10.1016/S0360-1323(02)00118-X

Li, D. H. W., & Lam, J. C. (2003). An investigation of daylighting performance and energy saving in a daylit corridor. *Energy and Buildings, 35*(4), 365-373. doi:10.1016/S0378-7788(02)00107-X

Li, D. H. W., & Tsang, E. K. W. (2005). An analysis of measured and simulated daylight illuminance and lighting savings in a daylit corridor. *Building and Environment, 40*(7), 973-982. doi:10.1016/j.buildenv.2004.09.007

Li, D. H. W., Lam, J. C., & Wong, S. L. (2005). Day lighting and its effects on peak load determination. *Energy, 30*(10), 1817-1831. doi: 10.1016/j.energy.2004.09.009

Lim, Y., Kandar, M. Z., Ahmad, M. H., Ossen, D. R., & Abdullah, A. M. (2012). Building façade design for daylighting quality in typical government office building. *Building and Environment, 57*, 194-204. doi:10.1016/j.buildenv.2012.04.015

Maheswaran, U., & Zi, A. G. (2007). Daylighting and energy performance of post millenium condominiums in Singapore. *ArchNet-International Journal of Architectural Research, 1*(1), 26-35.

Mahlia, T. M. I., Said, M. F. M., Masjuki, H. H., & Tamjis, M. R. (2005). Cost-benefit analysis and emission reduction of lighting retrofits in residential sector. *Energy and Buildings, 37*(6), 573-578. doi: 10.1016/j.enbuild.2004.08.009

Monteiro, L. M., & Alucci, M. P. (2009). The impact of vegetation on outdoor thermal comfort in urban spaces, http://www.ide.titech.ac.jp/~icuc7/extended_abstracts/pdf/375911-3-090514092945-005.pdf, Access Date, 4/12/2014.

Neufert, E., & Neufert, P. (2012). Neufert Architects' Data, 4th ed. UK: John Wiley & Sons.

Omer, A. M. (2008). Renewable building energy systems and passive human comfort solutions. *Renewable and Sustainable Energy Reviews, 12*(6), 1562-1587. doi: 10.1016/j.rser.2006.07.010

Phelan, J. P. E. (2002). Commissioning lighting control systems for daylighting applications, http://resources.cacx.org/library/holdings/178.pdf, Access Date, 4/12/2014.

Reinhart, C., and Selkowitz, S. (2006). Daylighting - Light, form and people. *Energy and Buildings, 38*(7), 715-717. doi: 10.1016/j.enbuild.2006.03.005

Shahidan, M. F., Shariff, M. K. M., Jones, P., Salleh, E., & Abdullah, A. M. (2010). A comparison of *Mesua ferrea* L. and *Hura crepitans* L. for shade creation and radiation modification in improving thermal comfort. *Landscape and Urban Planning, 97*(3), 168-181. doi: 10.1016/j.landurbplan.2010.05.008

Tantasavasdi, C., Srebric, J., & Chen, Q. (2001). Natural ventilation design for houses in Thailand. *Energy and Buildings, 33*(8), 815-824. doi: 10.1016/S0378-7788(01)00073-1

US Glass News Network. (2012). ASHRAE 90.1, with 40 percent window to wall ratio, approved for final publication from http://www.usgnn.com/newsASHRAE20120130.htm, 2012.

Yeang, K. (2008). Ecodesign: A manual for ecological design. London, UK: John Wiley & Son Ltd.

Zain-Ahmed, A. (2009). Climate change, green technology and sustainable buildings. Selangor, Malaysia: University Publication Centre, UiTM.

Zain-Ahmed, A., Sopian, K., Abidin, Z. Z., & Othman, M. Y. H. (2002b). The availability of daylight from tropical skies–a case study of Malaysia. *Renewable Energy, 25*(1), 21-30. doi: 10.1016/S0960-1481(00)00209-3

Zain-Ahmed, A., Sopian, K., Othman, M. Y. H., Sayigh, A. A. M., & Surendran, P. N. (2002a). Daylighting as a passive solar design in tropical buildings: a case study of Malaysia. *Energy Conversion and Management, 43*(13), 1725-1736. doi: 10.1016/S0196-8904(01)00007-3

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