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THE EFFECTS OF DAYLIGHT FLUCTUATION AND ILLUMINANCE LEVEL IN OFFICE BUILDING

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Abstract

Daylighting is concerned with the lead causes of energy consumption where greenest building assessments is based on the daylight quality. Most of the measurements of daylight performance and quality are based on illuminances in office spaces. Daylight and illuminance should not be neglected in adapting the appropriate brightness as this is an important criterion in rating building performance. Impact of illuminance level in office buildings is not critically examined to support the visual performance of occupants. The objectives of this study are to investigate the level of illuminance and fluctuations of daylight on occupancy for the office spaces and to identify whether the minimum level of illuminance affect occupants' visual comfort in optimum performance zone. The research methodology applied in this work is divided into three parts that are survey on the occupant's perception, the visual test and simulation. The results demonstrate the density of occupancy of 50% and below in a space of 300 lux achieved the daylight performance with R squared of 0.8385. While the ideal WWR for single office space should be within below 40% in achieving the optimum performance zone with 2700 mm distance from window. The new approach on daylighting performance and quality analysis that is based on occupant density is to define the direction of designing a space with acceptable illuminance level and improving the daylight metric for performance zone.

Keywords: Occupant density, daylight fluctuation, illuminance level, performance zone.

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1. Introduction

Daylight utilisation in buildings highlight the need of consuming the electricity in building. Furthermore, the greatest challenge on building energy index has been demonstrated in green buildings criteria to achieve the 10th- 12th Malaysia Plan. This embraces a new energy-efficient strategy with passive design without compromising human comfort. Arabi, Husini, and Kandar, (2012) highlighted the current sustainable design that features the criteria on energy efficiency which significant to occupant's comfort. Visual comfort is defined as the perceptual performance by occupants where there is a complex perception through human's senses (Araji, 2008). Apparently, the effort to support the perceptual performance is based on the brightness in a space while the accessibility of direct daylight from side window will generate people's satisfaction in the working environment (Husini, Arabi, & Kandar, 2011). The method to demonstrate the desired daylight is based on visual test which derive the actual ranges acceptable illuminance level by occupants. However, to employ the daylight in internal spaces, Aminu (2015) enhanced the optimal size of a window for diffuse daylight and direct daylight were between 25 % to 40%. This was supported by Husini (2016), there were relation between daylight penetration and window to wall ratio to achieve the acceptable illuminance level based on the density of occupants. The acceptable illuminance level will adapt a better occupant's satisfaction and visual comfort in interior spaces as this is applied to describe a new visual comfort concept with a long period of prediction by Jakubiec and Reinhart (2016).

2. Problem Statement

Previous designers have overestimated the relation between the daylight availability, and the visual comfort and user perception. This user perception character is considered as a primary data to create a sense of place (Ja'afar, Usman, Sulaiman, Husini, & Arabi, 2014). This may influence the physical condition on the varies of window size and people's satisfaction. The current recommended illuminance level is not achieved the desired illuminance levels during occupancy in the post evaluation. Furthermore, the unstable fluctuation of illuminance level may affect the inconsistency of visual comfort (Husini, Yazit, Arabi, Ismail, & Jaafar, 2018). It is found that the preferred illuminance level in office building is still ponder and further improvement on the implementation on passive design strategy still required. Most of the interior spaces are not successfully maintained its brightness and this will lead to the decision whether to adapt a higher or lower required illuminance level in the office (Husini, 2016).

2.1. Issues on illuminance level

Currently, a minimum of illuminance level of 300 lux was decided at the schematic design phase while in actual condition, the preferred illuminance level was not achieved when there was daylight fluctuation and reduction of the illuminance level during post occupancy evaluation (Husini, 2016). The current standard guideline in designing a space only emphasise the minimum glazing factors of 2% when there were 75% occupied areas in a space (Wang, 2009). Meanwhile, the illuminance level in the current standard MS 1525; 2007 only concentrated during electric lighting is used. Lighting quality for indoor

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lighting is inserted in Malaysian Standard 1525:2007 and the recommended average illuminance level is referring to Table 1.

Table 01. Illuminance Level (Department of Standards Malaysia, 2007)

Guideline	Task	Illuminance (Lux)	Guideline
Malaysia Standard 1525	Lighting for working interior	300-400 (General Office)	Malaysia Standard 1525
Chartered Institution of Building Services Engineers (CIBSE)	Lux for interiors where visual tasks do not require perception of detail, e.g., foyers and entrances.	200	Chartered Institution of Building Services Engineers (CIBSE)
	For interiors where visual tasks are moderately easy, e.g., libraries, sports and assembly halls, teaching spaces, and lecture theatres.	300	

Lim (2011) found the recommended illuminance levels of daylight factor (DF) was within 1.5% to gain the effective of daylit office spaces and this is considered a high percentage for Malaysia Furthermore, the current standard lighting quality do not emphasise the uniformity, value and luminance ratio.

2.2. Issues on fluctuation of illuminance level

Currently, the lighting systems are dissatisfied where lighting apparently derived from the glare condition and daylight penetration from window (Leder, Newsham, Veitch, Mancini, & Charles, 2016). The deep issues and further investigation on fluctuation of illuminance in daylight is required and these changes of illumination variarion resulted the different perception to mood and performance in the building (Husini et al., 2018). Fluctuation is defined as changes that can occur when there is increasing light and decreasing light. The study from Laura, Fragliasso, and Riccio (2018), the percentage of daylight fluctuation comprised in the range +/- 5% but when the weather changes from a sky condition, the fluctuation happened about 50% or even higher.

3. Research Questions

- What is the acceptable range of illuminance level for office's occupants in daylighting condition?
- What is the relationship between fluctuation of illuminance level and visual performance in the performance zone?
- Is there any relation between fluctuation in daylighting and occupancy in a room?

4. Purpose of the Study

The objectives of this research are to determine the illuminance level and daylight fluctuations for the office spaces based on occupant density and to examine whether the minimum illuminance level affect occupants' visual comfort in optimum performance zone.

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5. Research Methods

The study comprises of two scenarios; investigate the relationship between the acceptable illuminance and daylight fluctuation. Lastly, to evaluate the efficiency of daylight performance zone in performing the task. The case study was conducted in Building B07 Faculty Architecture Building, Universiti Teknologi Malaysia, Skudai, Johor which was selected to investigate the performance zone while the visual test and daylight fluctuation were conducted in the office buildings of Malaysian Japan International Institute Technology, Kuala Lumpur and TIMA office Building. Since that the reliability of computer simulation increased in recent years and the use of scaled models by daylighting experts' decreases (Reinhart & Fitz, 2006), this research uses computer simulation to evaluate the daylight performance zone.

5.1. Case Study

The case study on performance zone using reading task was conducted in Building B07 Faculty Architecture Building, Universiti Teknologi Malaysia. This is to investigate the optimum zone to perform visual task. The location of the selected room is on the fourth floor of block B07 with the dimension of 11600mm x 3700mm and a floor area of 43m^2 as shown in Figure 1.

(a) Floor plan

(b) Floor plan with seating arrangement

(c) Case study building: interior and exterior view.

Figure 01. Case study building.

Source: Aminu, (2015)

From the case study, the illuminance level for BO7 office building only achieved 200 lux and considered did not meet the MS 1525: 2014. Anyway, it was noticed the office occupants expressed their satisfaction with the lux level at working plan illuminance even the building was unable to achieve

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MS1525:2014 with the minimum requirement of 300 lux for general office. Aminu (2015) mentioned in his investigations on the optimal performance zone had the similar result from Saidin, Ibrahim, and Sopian (2013) as the office occupants' in Malaysia showed the acceptable range of illuminance level was at the range of 200 lux – 250 lux.

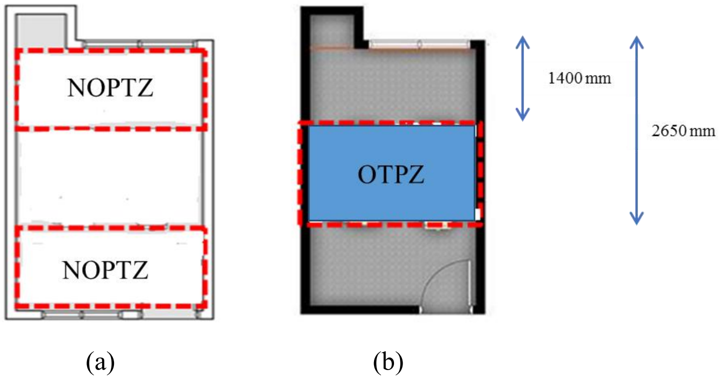

Figure 02. (a) Non-Optimal Task Performance Zone (NOTPZ); (b) The distance of Optimal Task Performance Zone (OPTZ).
Source: Aminu (2015)

The Figure 2; (a) explains the Non-Optimal Task Performance Zone (NOTPZ) as identified from the case study while the Figure 2; (b) shows Optimal Task Performance Zone (OTPZ). According to Aminu (2015), to identify the OTPZ was based on 1.5d where d is regarded as the height from the finish floor level to the height of window. For the space in Figure 4, the calculation is 1.5 x 1100mm which is equal to 2925mm in the window-to-wall-ratio of 25%. The window-to-wall-ratio of 45%, is to 3975mm (1.5 x 2650mm). It is summarised that at the distance of 2650mm from window is considered as the optimal Task Performance Zone. This distance in stated configuration is used for simulation base-model by using IESVE software.

5.2. Visual test

Starting from the measured data on the reading task performance, visual test was performed in the two selected office buildings that were Malaysian Japan International Institute Technology, Kuala Lumpur and TIMA office Buildings (Figure 3). In the second session, 20 workers were asked to answer three questions on identification of letters within twenty minutes. This visual test is to analyse the feedback from the occupants in order to gain the acceptable illuminance level in working environment. Results will describe in mean of the daylight fluctuation condition that focus only the highest score and the lowest score. This visual test was conducted to determine text quality metrics and examine the visual comfort where similar method done by Roufs and Boschman (1997).

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(a) (b)

Figure 03. Selected office buildings: (a) Malaysian Japan International Institute Technology; (b) Tun Ismail Mohamad Ali Office Building.

5.3. Simulation

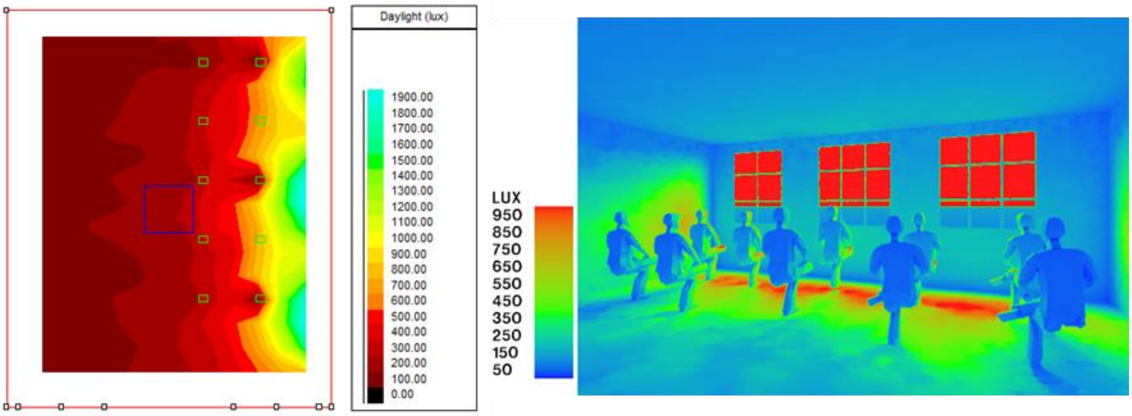

Figure 04. Daylighting mapping and false colour.

Daylight calculation on illuminance fluctuation was obtained through computer simulation by using Integrated Environmental Solution Virtual Environment (IESVE). The technique is to enhance the daylighting mapping and false colour during fluctuation in Figure 4. This software is a tool to analyse the building performance for sustainable building design. From the model of 5 types of rooms with different sizes (Table 2), this will capture the accurate illuminance level, time, numbers of occupants and daylight fluctuation. The three selected spaces which regard as a base model; Malaysian Japan International Institute Technology and Kuala Lumpur, TIMA office building and Building B07 Faculty Architecture Building were known as type Room C.

Table 02. Models of 5 rooms.

OFFICE ROOM A Linear/shallow layout	OFFICE ROOM B Linear/shallow layout	OFFICE ROOM C Linear/shallow layout	OFFICE ROOM D Deep/narrow layout	OFFICE ROOM E Deep/narrow layout
$128m^2$	$96m^2$	$64m^2$	$128m^2$	$96m^2$

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6. Findings

The results presented the acceptable illuminance level in two office buildings was lower than the required in Malaysian Standard MS1525: 2007. The data gathered the results of preferred ranges of illuminance level and visual test that was between 280 lux to 399 lux. The occupants in TIMA's office preferred higher ranges of 401–600 lux while 25% performed well the visual test in the ranged of 280-550 lux. From Table 3, 45% of the occupants achieved the lowest marks in the experimental room ranged of 600-800 lux.

Table 03. The Llluminance Level and Performance Level in Daylighting Condition Through Survey.

Office	Preferred illuminance level		Visual test in real illuminance level			
			Highest Score		Lowest Score	
	Illuminance level (lux) in the room offices	Percentage (%) of subjects (achieved highest score)	Performed Illuminance level (lux)	Percentage (%) of subjects (achieved high score)	Performed Illuminance level (lux)	Percentage (%) of subjects (achieved low score)
Menara TIMA	401 lux and more (401 lux – 600 lux)	32%	280-550 lux	25%	600-800 lux	45%
MJIIT Building	300-450 lux	47%	401-600 lux	50%	280-399 lux	50%

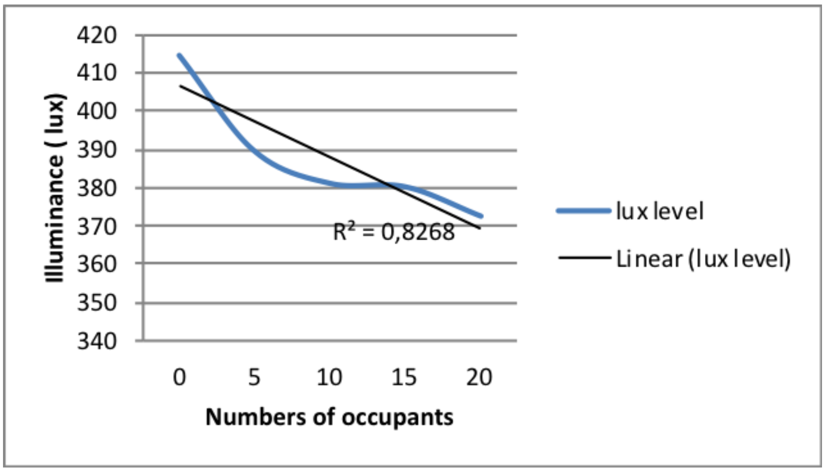

Figure 05. Simulation on Fluctuation of illuminance for base model.

Figure 5 presented the illuminance fluctuation that occurred in MJIIT office building based on the statistical analysis that was the coefficient of determination (R^2 value). The R squared value of 0.8268 shows the illuminance fluctuation and numbers of occupants were both correlated from simulation result. The room was gradually inserted with occupants until maximum numbers to achieve the acceptable illuminance level in optimal task performance zone. Figure 6 shows the 50% occupant in a room change

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the illuminance of more than 26%. The reduction of illuminance level occurred in the daylight zone from 4025 mm to 2750 mm when 75% of the occupant density increased. However, 25% of the occupancy was considered the maximum and the acceptable illuminance level maintained in the daylight zone ranged between 280 lux to 399 lux.

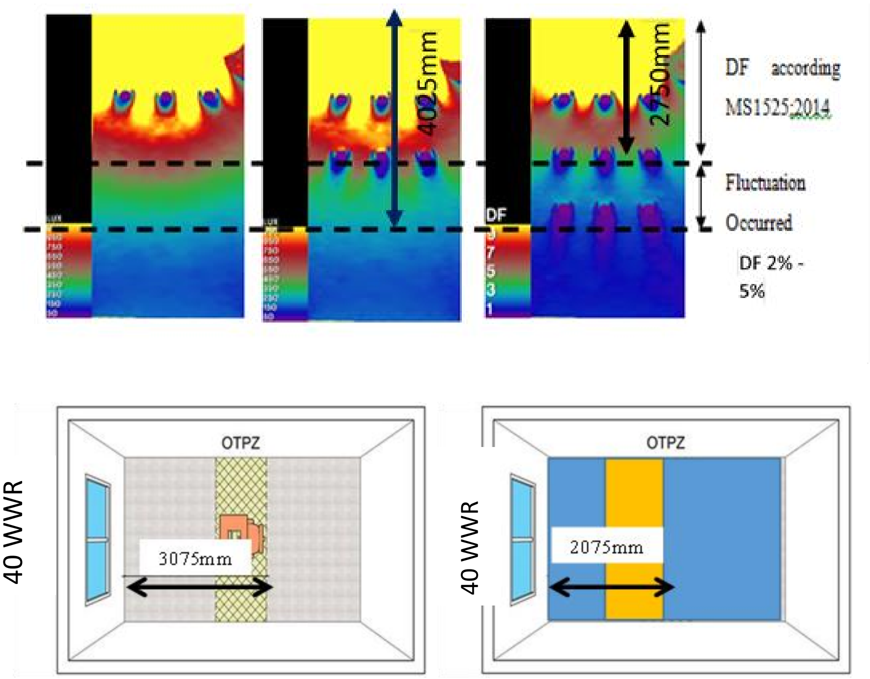

Figure 06. Daylight zone and distance from window.

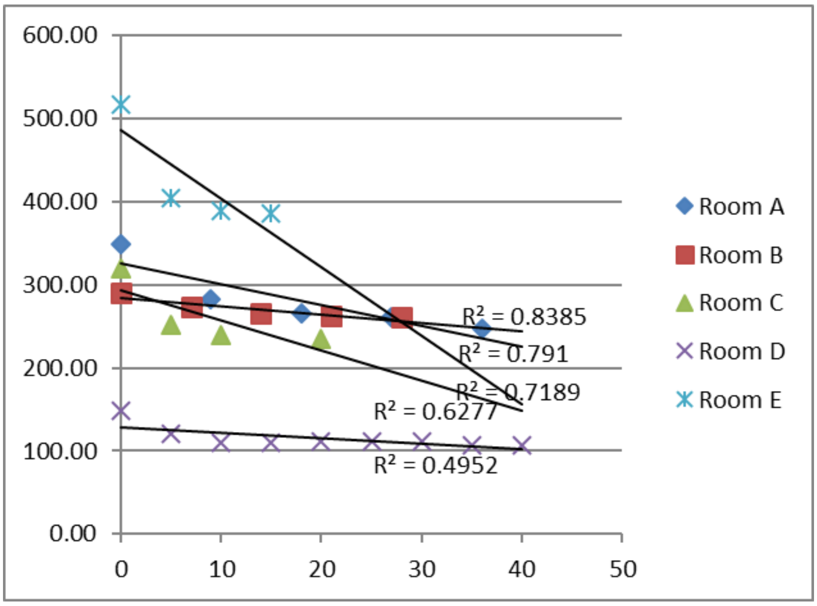

Figure 07. R Squared for 5 types of rooms.

The results identified the daylight calculation and fluctuation in 5 types of rooms which these were accordance with the standard office areas in Malaysia. These findings (Figure 7) described the significance of fluctuation in the rooms when the numbers of occupants were gradually increased. where R- squared for

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Office Room A (0.791), Office Room B (0.8385), Office Room C (0.6277), Office Room D (0.4952) and Office Room E (0.7189). In overall, the R-squared data is in the agreement to conclude that there is relationship between fluctuation and number of subjects in the rooms.

7. Conclusion

This work exactly demonstrates the need of the designers to consider the acceptable illuminance level of the ranges between 280 lux to 330 lux and the occupancy density increased from 25% to 50% in a room while the fluctuation of illuminance level is less than 26%. The illuminance fluctuation in daylighting are proven based on simulation which the Malaysia Standard of illuminance level (300 lux -400 lux) only can be maintained when WWR of 70% and the numbers of occupancy is less than 50 % in the daylight zone. The optimal task performance zone is depending on the maximum percentage of occupancy. It is reasonable to assume this is the optimal performance zone with the distance range from 0mm to 2075mm with the maximum percentage of occupancy in a room. The daylight fluctuations show there is relationship between the occupant density based on numbers of occupants and fluctuation in illuminance level. The factors that influenced the light fluctuation were identified. Occupant density, distance, window to wall ratio and room layout were significantly correlate to this analysis.

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