Light, daylighting and fluctuation of illuminance level in office buildings

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Light, daylighting and fluctuation of illuminance level in office buildings

Elina Mohd Husini[1], Raja Nur Syaheeza Raja Md Yazit[1], Fadli Arabi[1], Wan Norisma Wan Ismail[1] and Nor Haslina Jaafar[2]

[1] Architecture Department, Faculty of Engineering and Built Environment, Universiti Sains Islam Malaysia, Nilai, 71800, Negeri Sembilan, MALAYSIA
[2] Architecture Department, Faculty of Built and Environment, Universiti Kebangsaan, Bangi, MALAYSIA

elina@usim.edu.my

Abstract. Illuminance in spaces is important criteria in rating building performance. These also a strategy to develop some passive design criteria to meet the occupant visual comfort. The aim of this study is to investigate the fluctuation of the illuminance level and the impact of daylighting in an optimum performance zone. This study also investigates the effects of occupant density whether affect the illuminance level in two selected office buildings. Qualitative survey has been conducted on the occupant's perception toward visual comfort and obtaining the comparison on the glare effect by using IESVE computer simulation while visual test has been conducted involving selected workers. The maximum occupant density and physical conditions; window to wall ratio of 25%, 40% and 70% of typical office space were identified by using IESVE simulation. Findings from experiment of visual performance and daylighting simulation showed more than 50% occupancy in typical office room with 70% of WWR affected the extend of the daylight zone and the acceptable of illuminance level is not achieved. There high contract between 50% of the occupancy in a room is also changed the illuminance level of more than 26%. The findings contribute towards the improvement of an acceptable visual comfort ranges and design recommendations for optimum performance zone in a single office space in Malaysia.

1. Introduction

When most of the buildings were found to over illuminate or lack of illumination, it shows the designer should identify the significant parameter in lighting design during schematic layout till occupancy. This consideration and awareness can meet the acceptable illuminance level for occupants during performing the task less work for retrofitting such as de-lamping artificial lighting. Therefore, complaint by occupants on lighting distraction and too bright the illuminance level shows fluctuation of illuminance level occurs frequently in indoor spaces. In addition, these may reduce visual comfort and performance. Furthermore, the fluctuation of daylight illuminance level which affects the acceptable indoor daylighting level is not highlighted in any visual comfort issue where it significantly changes the quantity of daylight levels. This unpredictable change in illuminance level happens more severely when the room is fully occupied, and it is also reported that dimming control systems may be affected due to this condition. Clarification is needed on whether lighting guidelines have over- or underestimate the preferred amount of light. Factors that influence illuminance changes in offices are not identified during

the measurement of quantity of illuminance level. The occupants are not aware of the illuminance change, and this illuminance variation may contribute to visual discomfort and visual annoyance. (Lee et al., 2012). This may also influence by physical condition as such as window size and people's preferences and satisfaction. Husini (2011), described the preferred illuminance level was related to occupant's satisfaction in daylighting condition. Meanwhile the current recommended settings of lighting have not yet reached the needed levels for occupants and optimum performance zone. A range of illuminance levels need to be furthered since it was detected unstable due to fluctuation of illuminance level. Until today there is no annual metric exists to access visual satisfaction in daylight environment and less work applying this metrics in daylight interiors (Rubiño et al., 1994; Jakubiec and Reinhart, 2012). In this paper, an investigation of fluctuation of the illuminance level and optimum occupancy in daylight zone is presented followed by a description on the fluctuation effect in minimum window-to-wall ratio. In this discussion section, only the range of the acceptable with the optimum window-to- wall ratio which meets the acceptable illuminance level is explored within the context of visual comfort methodologies. A review of the principle of light to human and the exploration of the ancient science of light from the previous Islamic scholars is explored in this study.

2. Principal of light, optic and visual performance

'Light' refers to the wave length that emphasis on the electromagnetic spectrum, which includes visible light, as well as light with wavelengths that we cannot see such as: radio waves, microwaves, infrared, ultraviolet, X-rays, and gamma rays. Light is the key ingredient which highlights the application in physics, environmental sciences pharmacology, engineering and industrialized design. The environmental implementation on light, daylighting and visual performance are strongly connected concept. These explorations on the overall atmosphere of the inner environment of the building is interpreted in a various transformation of architecture that started from early discovery of light. In the history of light, Ibn al-Haythm who is widely known as the Arab Scientist had demonstrated the experiment of light and he concluded that vision would only take place when a light ray which comes from a luminous source or was reflected from such a source before it entered the eye. His discoveries are truly extraordinary when he experimented to prove that we see because light from objects travels in a straight line into our eyes.

Further to the study on light, the illuminance is also an important part. Based on Ziai (2013) and Aminrazari (2014), the Shihab al-Din Yahya al-Suhrawardi, in his Kitab hikmat al-ishraq explained that Ishraq is commonly used to refer to the internal illumination and Illuminationism was exploring the ancient "science of lights" ('ilm al-anwar). It is described that the light and luminous in respect of degrees of intensity. It also provides luminosity, give shape to the forms and these make the entity 'visible and known. The light may cause the perceptual performance and visual comfort by occupants which causes the visual where there is a complex perception through human's senses. (Araji, 2008). This can adapt the wide range of brightness. Elzeyadi (2002) found that visual comfortable environment depends on vision perception, space configuration and corresponding to different activities. The eye receives light and sends signals to be processed by the brain through optical components (Araji, 2008). The role of lighting designers and architects necessitates balancing lighting conditions for optimal visual comfort in daylighting design. Several standards and guidelines in Malaysia are only considered when the electric lighting is used. Lighting quality as outlined in Malaysian Standard 1525:2014 is referring to this code of lighting practice to provide sufficient indoor lighting is at the range of 300 lux.

2.1. Illuminance, absorption, fluctuation and occupancy.

The light we see affects our perceived ideas of brightness. This light or amount of light reaching the eyes of the observer are considered luminance (IESNA Handbook, 2000). In this study, the illuminance level is focused on working plane illuminance and its impact on visual performance. The connection of the light and human occurred when there was light can be detected by the reflections of skin. The light

that is not reflected at the surface, but penetrates the material body, will be scattered and selectively absorbed at wavelengths which provide the characteristic object color through body reflection. The incident of light (95%) entering the skin is mainly absorbed and scatters within two skin layers (body reflectance). (Storring et al., (2001). The theory of absorption by Lambert's Law explained that the basic principal of how absorption affects the light through some wavelengths while transmitting others. While the later theory based on Beer's Law elaborates on how the intensity of light decreases exponentially with depth in the material. Beer's Law states that a similar amount of absorbing material may also absorb an equal fraction of light. In this study, the concept of absorption is a focus where, in the transmission of light, an object can absorb part of the light and when this material absorbs some wavelength, it may transmit the light back by converting it into heat. Lighting represents almost 20% of global electricity consumption. The belief on light and work performance has also been studied by Hughes and Mc Nelis, (1978) and their studies have proved that illuminance affects task performance. Fluctuations in illuminance are identified through the impact from external and internal illumination. These fluctuations in illuminance will enhance the impact of indoor visibility and lighting systems. Light fluctuation affected the occupants when the room had a normal ambience of light, but the actual illuminance fluctuated over time and the desired illuminance could not be maintained as required. Fluctuation is known as brightness fluctuation, in which both the increasing light and decreasing light may determine different perceptions of lighting change. When they tested reading-based tasks using field measurements of fluctuation ranges or illuminance variation, their research showed a change in visual annoyance and visual comfort, resulting in a negative mood and lowered performance in the office. The factors that affect the fluctuation were mainly from the lighting from outdoor, sky condition and the window design. Boubekri, (1991) investigated the impact of window size and sun patches, finding that there was no significance from the latter to occupants' emotions, but that sunlight penetration through windows affects feelings. The consideration on guidelines and recommendation for daylighting and visual comfort is based on Universal Building Bye Law (UBBL) requires minimum Window to Floor Ratio (WFR) of 10 % for designing a space in a building. However, UBBL does not further outline any requirement for daylighting. (Yakubu, 2015). Another focus in the effect of absorption of light is the human occupancy in the space. Occupant density is defined as an ideally calculated in an office when the room is occupied. The indoor illuminance has a relationship with occupancy patterns when there are changes of illuminance level due to the crowding effect; this means that more occupants in a room will result in different energy consumption characteristics in different scales of office buildings. In short, a higher level of energy consumption occurs when the number of occupant's changes. The study from Elina (2016), concluded that when the number of occupants increases, the coefficient of variability decreases, and the lighting schedule was more regular.

3. Methodology

3.1. Experiment for visual test and computer simulation.

There are two phases in this study: (i) Experiment on visual test performance, and (ii) computer simulation. In the first phase is to analyze the experiment based on visual test on selected buildings; Malaysian-Japan International Institute of Technology, Universiti Teknologi Malaysia (MJIIT), Menara Tima and Midvalley office building. The final phase is conducted by using computer software; Integrated Environment Solution Virtual Environment (IESVE) software. A triangulation of the results concludes the research.

3.2. Experiment 1; Visual Test.

The purpose of conducting the visual test is to analyze the subjects' responses to capture the acceptable illuminance level in a space. The results were based on highest score and the lowest score which described in mean score. The test was referred to Roufs and Boschman (1997) who applied a visual test to determine text quality metrics for visual display units. The setting of the room was decided according

to the need for a visual quality aspect in a room which provided comfort for a reading task. The different occupancy patterns are according to the office ergonometric. This is to analyze visual comfort as a product of number of occupants and daylight distribution from the window and identify the ranges of preferred illuminance level and performance level achievement. A similar technique was applied by Wang, (2009) to capture sunlight patch in daylight zone.

3.3. Computer simulation; IESVE software

In this research, computer simulation was used to investigate the fluctuation in daylight illuminance with varying occupancy patterns. The computer simulation experiment in this study uses the IESVE software. Through the analysis of computer simulation, various designs such as room geometries, window-to-wall ratios, occupant density, and distance to window are considered as design variables. This will be a base setup for computer simulation using Integrated Environmental Solution Virtual Environment (IESVE) with different configuration of rooms such as linear room and deep room with varies of occupancy from 25%, 50% to 70% in window-to-wall-ratio of 70% (Figure 1). 70% of window –to-wall-ratio is considered as maximum opening which will provide stable daylit in indoor space.

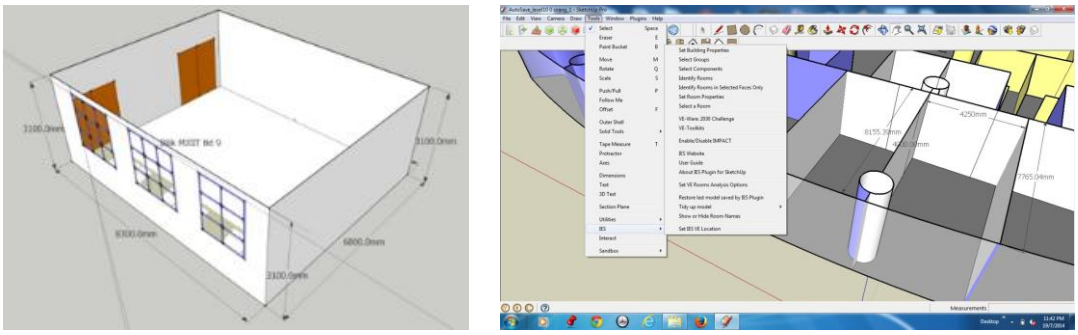

Figure 1. Simulation using IESVE Software in Selected Office Space

4. Results and discussion

4.1 Visual Test Result.

Table 1. Comparison of scores and speed and ranges of illuminance level

	Range of Acceptable illuminance level (in daylighting)	**Percentage Score (%)**	**The Fastest Speed (Time)**
TIMA Office	300-350 Lux	25% (2min – 3 min)	1min 35 sec – 1 min 45 sec
MIDVALLEY Office	401-499 Lux	25% (1 min 46 sec- 2 min)	1min 46 sec- 2min
MJIIT Office	401-599 Lux	50% (2 min 01 sec – 2 min 15 sec	1 min 16 sec-1 min 30 sec

The comparison of score and speed in visual test among three office buildings are shown in Table 1. It shows that 50% of occupants in the MJIIT Office Building were in the top group, with a speed between 2:01 and 2:15. This is followed by TIMA Office Building, which placed 25% of the subjects in the top group for scores in the visual test, which was conducted in the illuminance range of 300-350 lux. Midvalley office resulted in 25% of the subjects scoring in the lowest percentage, with illuminance levels of 401-499 lux. It is therefore shown that there was a correlation between visual performance and acceptable ranges of illuminance level

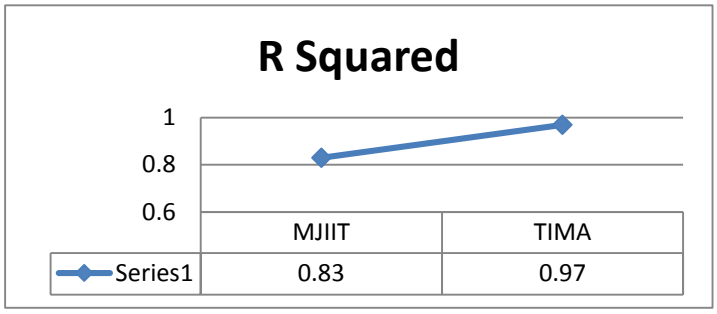

Figure 2. Percentage of Occupant and Scores of MJIIT Office Building

Figure 2 shows how the fluctuation of illuminance was significant, with a strong result of $R^2 = 0.83$ for Malaysian Japan International Institute Technology (MJIIT) and $R^2 = 0.97$ for Tun Ismail Mohamad Ali Office Building (TIMA). The illuminance level was reduced when occupancy was increased. When the maximum number of subjects occupied the daylight zone, the percentage of fluctuation increased and these fluctuations happened.

4.2 Simulation Result

The simulation using IESVE software shows the daylight zone with minimum distance from window. The room was inserted with maximum number of occupant to identify the minimum distance to achieve acceptable illuminance level and which zone provides optimal task performance even there is fluctuation of illuminance. Figure 3 shows the 50% of the occupancy in a room changed the illuminance level of more than 26%. It means when this empty room showed 300 lux at the distance of 3075mm but when it was occupied by 50% of the room, the illuminance level fluctuated to 222 lux. The distance of daylight zone was also reduced from 4025mm to 2750mm when 50% to 75% occupancy in the room. This shows that 25% of the occupancy was considered the maximum occupancy in the room where the daylight zone can maintain the acceptable illuminance level of 300 lux. (Refer to Table 2).

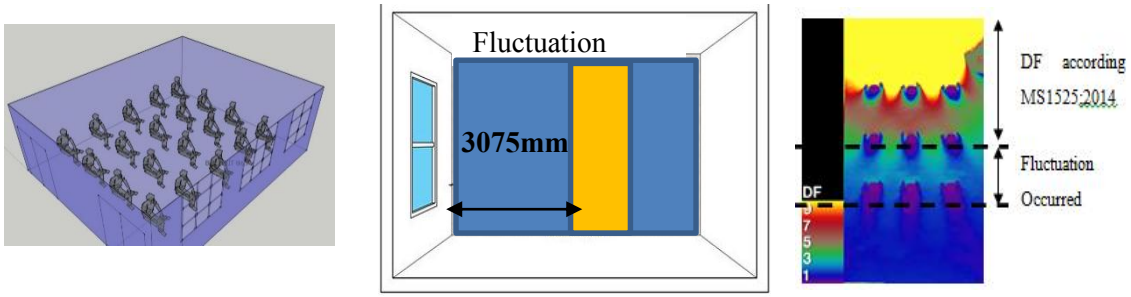

Figure 3. Daylight Zone and Distance

Table 2. Distance within daylight zone and acceptable illuminance range

Percentage of Occupancy	Daylight zone within acceptable illuminance range (distance)	Average illuminance level (lux)
0% occupancy	2.75 – 4.25 meters	406
25% occupancy	2075- 3075 mm	313
50% occupancy	2075 – 3000 mm	246.5
75% occupancy	2075– 3000 mm	125.6

Simulated the distance of daylight zone which was 3075mm from window with 70% window-to wall ratio was reduced to 2075mm distance from window in maximum percentage of occupancy. (-Refer Figure 3). The reduction will give the impact towards lighting decision and energy consumption. Besides that, the visual discomfort can be reduced.

5. Conclusion

This work concludes that the designer and architect need to organize the occupancy density by reducing or increasing the occupancy numbers from 25% to 50% in a room which can reduce the fluctuation by about less than 26% with the minimum daylight factor of 2% (250 lux). The fluctuation in daylighting was significantly detected from the experiment. It was also shown that the quantity of illuminance level, fluctuation and occupancy affected visual quality. The change pattern of average illuminance level at daylight zone was gradually decreased at certain occupancy.

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