Assessment of Window Blind Operation to Understand Occupants' Behavior towards the Use of Daylight in a Green Office Building in Putrajaya, Malaysia

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Abstract— **The utilization of daylight to ensure a good indoor visual environment and to increase occupants' productivity is one of the key features of a green office building. However, the daylight performance can be affected due to improper positioning of window blinds by the occupants. In many cases, window blinds in Malaysian office buildings are fully lowered most of the time and artificial lights are switched on during daytime, which result in high electricity consumptions. Window blinds can greatly affect the penetration of daylight but their operations in the tropical regions are rarely considered in the calculation of daylight performance in buildings. Therefore, this paper aims to examine the operation of window blinds in green office buildings in Malaysia. The main objective is to find out how frequently the office occupants change the position of their window blinds and how the blind positions are correlated with different orientations, sky conditions, time and floor levels. As such, a Gold-certified green office building in Putrajaya was selected as a case study. Time-lapse photography was conducted on a daily basis in March and July 2017 to record the positions of the window blinds under different sky conditions. The recorded images were carefully processed for coding and subsequently, Anova and Pearson Correlation tests were conducted for statistical analysis. A questionnaire survey was also carried out among the occupants to investigate the frequency of, and the reasons behind, their blind adjustments. Results from the photographic analysis show that window blind occlusion values changed significantly with the orientation, sky conditions and floor levels. Additionally, the window blind occlusion was strongly correlated with orientation and floor levels but not with time. The survey revealed that majority of the participants rarely adjusted their window blinds and, in most cases, these blinds were adjusted due to excessive brightness or glare coming from the sun. The findings suggest that the occupants of the studied office building do not make any effort to change the position of their window blinds throughout the period of the field measurements. It is hoped that the results would trigger the necessity of considering occupants' use of window blinds in the calculation of daylight performance in order to provide a better visual environment in office buildings.**

Keywords— Blind control, occupant behavior, daylight, green office building.

I. Introduction

In order to cope with the increasing amount of energy consumption, a plethora of rating tools have been developed all over the world to assess the sustainability performance of buildings [1]. In Malaysia, the initiative was taken by the Malaysian Institute of Architects (PAM) and the Association of Consulting Engineers Malaysia (ACEM) in 2009 to develop an environmental rating tool known as the Green Building Index (GBI) [1], [2]. As of 15 February 2018, there were a total of 442 GBI-certified buildings, 50% of which were non-residential buildings [3]. These green buildings are meant to have an ideal visual environment for the occupants and should have certain features that can fully utilize the available daylight so that the buildings' electricity consumption can be reduced.

However, today, the proper use of daylight in office buildings in Malaysia is a concerning issue. A recent survey by Lim et al. [4] found that many existing high-rise office buildings in Malaysia are not properly utilizing the available daylight due to inappropriate façade designs. Occupants of these office buildings also do not operate their window blinds frequently during the daytime, and most of the time, the artificial lightings are turned on. Even though a proper use of internal shading devices can save up to 30% of electricity consumption in office buildings [5], typical Building Energy Intensity (BEI) of office buildings in Malaysia is in the range 200-250 kWh/m^2/year [6]–[8], which is higher than the maximum BEI stated in the MS1525:2014. Occupants' use of window blinds can greatly affect the penetration of daylight inside the office buildings, yet they have been overlooked during the calculation of the daylight performance of these buildings such as the calculation of daylight factor (DF), useful daylight illuminance (UDI), daylight glare index (DGI), daylight glare probability (DGP), visual comfort probability (VCP) and so on. Therefore, this paper aims to investigate the window blind operation by the occupants of a GBI Gold-certified office building in Putrajaya, Malaysia.

II. Climatic Conditions of Malaysia

Malaysia is located near the equator with a geographic coordinates lie between 1º to 7º north and from longitude 100º to 119.5º east [9]. The main two parts of this country include, the Peninsular Malaysia in the west and Sabah and Sarawak in the east. Having situated in the tropical region, this country experiences a hot-humid climatic condition throughout the year. The main climatic conditions of this country are:

- An average temperature of 23º C to 33ºC throughout the year. This temperature rarely goes below 22º C and above 34º C, as shown in Fig. 1 [10].
- This country receives around 400- 600 MJ/m^2 of solar radiation every month which is shown in Fig. 2 [11].
- The monsoon occurs two times in a year- the Northeast monsoon and the Southwest monsoon. The Northeast monsoon occurs during November to March with average wind speeds of 15 to 50 km/hr. The Southwest monsoon is usually seen between June and September having average wind speed of 25 km/hr [9].
- The sky condition remains overcast most of the time during Northeast monsoon. It is rare to have a completely clear sky during drought season [12].
- Malaysia has a sky with an average cloud coverage of 6-7 Oktas and 85.6% of the time, the sky condition is intermediate, where the rest 14% of the time is overcast [13], [14].

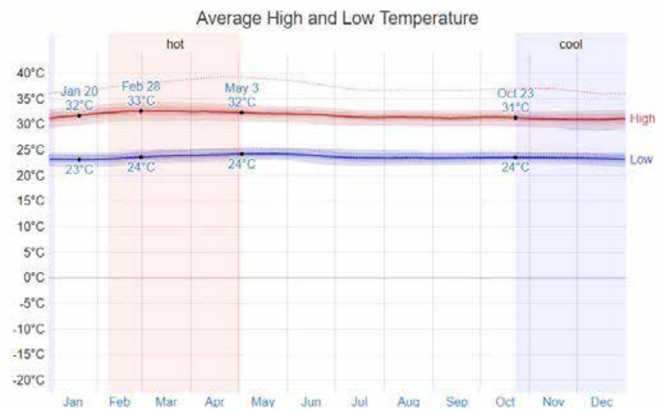

Fig. 1. Average temperature of Malaysia
Source: [10]

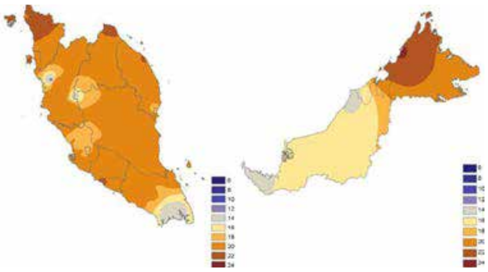

Fig. 2. Average solar radiation in Malaysia
Source: [11]

III. Sun Positions and Daylight Conditions in Malaysia

Due to the geographical positioning of Malaysia, the sun altitude angle does not differ much throughout the year. Malaysia receives an average solar radiation of 4000-5000 Wh/m^2 every day [11]. The months of November till January experience the lowest sun altitude angle of 65° to 60° in the South orientation and 68° to 71° of sun altitude angle in North orientation during the month of June [15]. The North facing windows receive direct solar radiation from 22nd September till 20th March and solar radiation is received by the South facing windows for the rest of the months. Daylight condition is critical during the month of March as maximum amount of solar radiation is received during this month [13], [16]. The sun comes over the equator during the month of March and September; hence, direct solar radiation is received by the northeast, northwest, southeast and southwest facing windows. The sun goes furthest from the equator during the months of June and December. Therefore, windows in East and West orientations get the maximum amount of solar radiation.

IV. Daylighting in Malaysian Office Buildings

Daylighting is a fundamental requirement in building and interior designs. The modern concept of daylighting design is not only to provide sufficient level of daylight, but also to address detail features such as shading devices; size of and spacing between windows; materials used for glazing; as well as the finishing and reflectance of interior space [17]. Tropical regions like Malaysia have sufficient daylight that can be utilized in office buildings for energy conservation and improvement of occupant productivity [4], [18]. However, many office buildings in Malaysia have poor daylight performance either due to façade design flaws or improper blind usage by the occupants. A study carried out by Kandar et al. [19] on five government office buildings in Malaysia found that all these office buildings are fully dependent on artificial lightings although there is sufficient daylight available. Lim and Mohd Hamdan [20] surveyed 13 existing high-rise office buildings in Malaysia and came to the conclusion that these buildings do not optimize the use of daylight and their occupants prefer to lower down their window blinds most of the time to avoid excessive glare from the sun. Occupants' control of window blinds can vitally affect the daylight performance inside the office buildings. Although many studies have been undertaken in Europe, USA, Canada and Korea to observe occupants' behavior towards their use of window blinds [21]–[33], there are still few behavioral studies that have been conducted in the tropical regions with hot-humid climatic conditions. As stated by Lim et al. [4], "lots of efforts needed to further develop the knowledge of tropical daylighting and future research can be done on the impact of human behavior on tropical daylighting." This paper has tried to fill this gap and can be regarded as an interim result of the first author's current research activities in the area.

V. Methodology

A. Case study building description

This study was conducted in Menara Putrajaya Holdings (PjH), an office building located in Putrajaya, Malaysia that has received the GBI Gold rating (Fig. 3). Completed in 2012, Menara PjH was the first commercial green building in the main commercial boulevard in Precinct 2, Putrajaya. This 12-storey building includes two 4-storey courtyard buildings as a podium and a tower comprising of 8 floors. Covering a total gross floor area of 575,721 square feet, this building has a unique shading system including aluminum spandrel panels and vertical aluminum fins on the podium facades. The North and South facing facades of the tower building are designed with high performance glass and aluminum spandrel curtain walls while the East and West oriented facades are equipped with high performance glass and aluminum framed fritted glass fins in to have a controlled solar radiation (Fig. 4). Dimmable artificial lighting technology is used inside the building which is centrally controlled by the Building Management System (BMS). The windows of this building are assembled with white colored manually controlled roller blinds (Fig. 5). The use of Semi-Opaque blinds enables visual privacy for the office occupants; hence, allows sufficient daylight to stream through the windows.

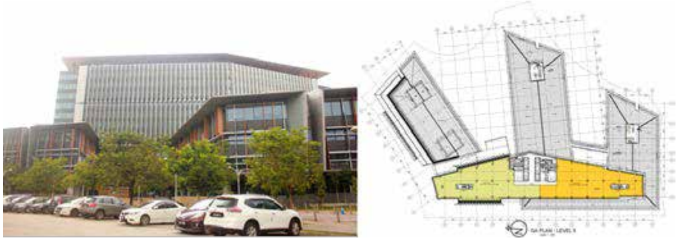

Fig. 3. Floor plan and Eastern view of Menara PjH.

Fig. 4. Multiple external shading system of Menara PjH.

Fig. 5. Window blinds and artificial lighting of Menara PjH.

B. Field measurements

The field measurements involved time-lapse photography to record the window blind positions from inside the building and a questionnaire survey to understand the occupants' satisfaction level with the indoor visual environment. The study considered the following four factors: time of the day, building orientations, floor levels and sky conditions. Window blinds located on all four orientations (north, south, east and west) were recorded at 9am, 12pm and 4:30pm in two separate sessions. The first session was done from 15th till 31st of March 2017, during which Malaysia typically receives extreme solar radiation [34]. The second session was from 21st until 28th of July 2017. A total number of 248 window blinds were recorded during each session. Table I gives an overview of the field measurements conducted.

TABLE I. Overview of the Field Measurements

Date	Floor levels	Orientation				No. of window blinds
15th- 31st March 2017	Level 1	North	-	East	West	30 nos
	Level 4	North	South	East	West	110 nos
	Level 11	North	South	East	West	108 nos
21st- 28th July 2017	Level 1	North	-	East	West	30 nos
	Level 4	North	South	East	West	110 nos
	Level 11	North	South	East	West	108 nos

C. Photographic data analysis

The post-processing of the recorded images of window blinds were conducted after the field measurements were completed. A total number of 14,136 blinds were carefully resized and rated to obtain the "blind occlusion index." Blind occlusion index is the percentage of an occluded blind [24]. For example, if the blind occlusion index is 70%, it means the blind is 70% lowered at a specific time. There are some well-established and globally accepted window blind rating system available for blind movement analysis [24], [27], [29]–[31], [35]. Each window blind is assigned with a number ranging from 0 to 10 (0 = fully opened and 10 = fully closed) and coded with a name representing their number, orientation and floor level (Fig. 6). The sky condition was also recorded at the same time of time-lapse photography and it was categorized as sunny, partly cloudy or overcast sky condition. Subsequently, ANOVA and Pearson Correlation tests were performed on the complete data sets including the four factors (i.e. time of the day, building orientations, floor levels and sky conditions) for both sessions of the field measurements.

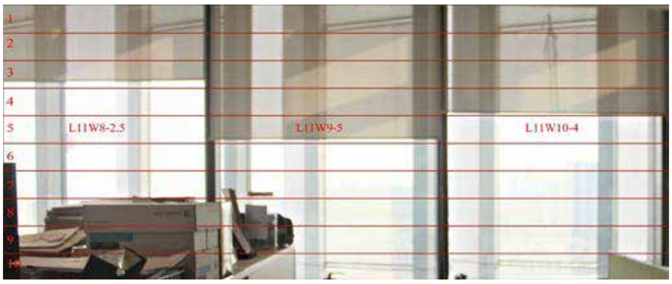

Fig. 6. Estimation of blind position for occlusion index

D. Questionnaire survey

Hard copies of questionnaire survey were distributed during the second session of field measurements in order to find out how frequently the occupants operate their window blinds and the reasons that encourage them to adjust their window blinds. Out of 180 distributed questionnaire forms, 107 were returned for further analysis.

VI. RESULTS

A. Window blind positions

Results of the ANOVA test on data from the first session indicated that blind occlusion index changed significant with the building orientations, floor levels and sky conditions ($p < 0.05$). The interaction between orientations and floor levels also had higher F-value for the average blind occlusion index (Table II). Pearson Correlation test also showed that window blind occlusion was strongly correlated with the building orientations and floor levels but not with time and sky conditions, which is shown in Table III.

TABLE II. ANOVA TEST ON DATA FROM THE FIRST SESSION

Source	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	87	1.053	40.272	.000	.911
Intercept	1	22995.498	879095.710	.000	1.000
Time	2	.065	2.498	.084	.014
Orientation	3	4.259	162.810	.000*	.589
Floor level	2	10.587	404.712	.000*	.704
Sky condition	2	.279	10.659	.000*	.059
Time X Orientation	6	.006	.244	.961	.004
Time X Floor level	4	.000	.007	1.000	.000
Time X Sky condition	3	.035	1.347	.259	.012
Orientation X Floor level	5	6.862	262.329	.000*	.794
Orientation X Sky condition	6	.017	.649	.691	.011
Floor level X Sky condition	4	.029	1.109	.352	.013

*The means are significantly different at the level of less than 0.05

TABLE III. PEARSON CORRELATION TEST ON DATA FROM THE FIRST SESSION

		Time	Orientation	Floor level	Sky condition
Average bling occlusion index	Pearson Correlation	.018	-.207**	-.157**	-.032
	Sig. (2-tailed)	.709	.000	.001	.509
	N	429	429	429	429

**. Correlation is significant at the 0.01 level (2-tailed).

With regard to data from the second session, the ANOVA test conducted revealed that window blind occlusion values were statistically significant with the building orientations and floor levels; and the interaction between orientations and floor levels ($p < 0.05$). But interestingly, Pearson Correlation test showed that window blind occlusions were only correlated with orientations, but not with the time of the day, floor levels and sky conditions. Table IV and Table V show the results of ANOVA and Pearson Correlation tests respectively.

TABLE IV. ANOVA TEST ON DATA FROM THE SECOND SESSION

Source	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	87	.508	33.145	.000	.963
Intercept	1	13371.266	872399.357	.000	1.000
Time	2	.004	.233	.793	.004
Orientation	3	2.252	146.961	.000*	.800
Floor level	2	3.581	233.661	.000*	.809
Sky condition	2	.007	.427	.653	.008
Time X Orientation	6	.006	.405	.875	.022
Time X Floor level	4	.005	.334	.854	.012
Time X Sky condition	3	.003	.197	.898	.005
Orientation X Floor level	5	5.130	334.672	.000*	.938
Orientation X Sky condition	6	.019	1.209	.307	.062
Floor level X Sky condition	4	.009	.596	.666	.021

*The means are significantly different at the level of less than 0.05

TABLE V. PEARSON CORRELATION TEST ON DATA FROM THE SECOND SESSION

		Time	Orientation	Floor level	Sky condition
Average bling occlusion index	Pearson Correlation	.013	-.346**	-.029	-.009
	Sig. (2-tailed)	.852	.000	.681	.898
	N	198	198	198	198

**. Correlation is significant at the 0.01 level (2-tailed).

B. Questionnaire survey

The questionnaire survey revealed that 81.1% of the surveyed participants rarely adjusted their window blinds, 11.1% of which said they operated their window blinds once a day and 7.8% only occasionally. The frequent distribution of blind adjustment by the occupants is presented in Fig. 7.

In terms of reasons for operating their window blinds, more than 28% of the participants said they adjusted their window blinds to reduce the glare or brightness coming from sun, whereas, 22.1% of them operated their window blinds to have an outside view. 19.7% and 10.6% of the participants claimed that they adjusted their window blinds in order to increase the daylight level and to reduce heat from the sun respectively. Table VI describes the reasons behind the blind adjustments.

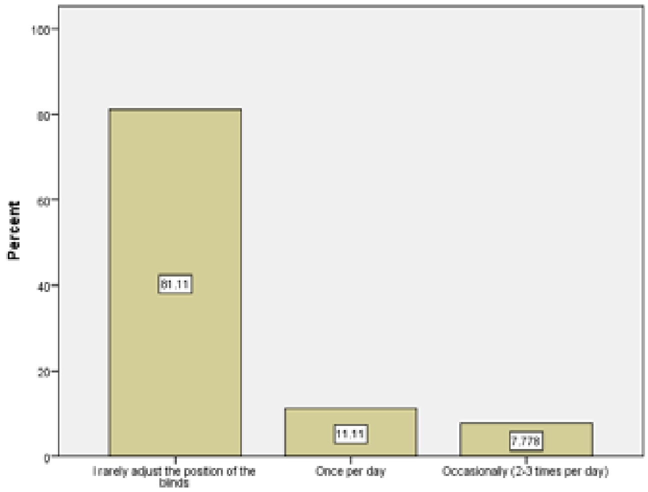

Fig. 7. Frequent distribution of blind adjustment by occupants

TABLE VI. FREQUENT DISTRIBUTION OF OCCUPANTS' REASONS BEHIND BLIND ADJUSTMENT

		Responses	
		N	Percent
Reason for blind adjustment	To increase daylight level	41	19.7%
	To reduce glare or brightness from daylight	60	28.8%
	To feel the warmth of the sun	14	6.7%
	To reduce heat from the sun	22	10.6%
	To have an outside view	46	22.1%
	To increase visual privacy	8	3.8%
	To increase room spaciousness	7	3.4%
	To reduce visual stimulus	6	2.9%
	Other	4	1.9%

VII. DISCUSSION AND CONCLUSION

This study has investigated the occupants' window blind usage pattern in a green office building. The results demonstrate that window blind occlusion values are highly dependent on the building orientations and floor levels and sometimes on the sky conditions. But the results from both ANOVA and Pearson Correlation tests have found that there is no correlation between window blind occlusion and time, which means occupants of the study building did not change their window blinds frequently throughout the period of field measurements. The questionnaire survey also indicates that the occupants of the study office building rarely adjust their window blinds and the main reason for operating the window blind is excessive brightness or glare coming from the sun. This suggests that once occupants experience glare at their workplace, they partially or fully close their blinds and rarely reopen them. The studied office building has daylight sensors installed to help automatically switch the artificial lights off when daylight level outside is sufficient. This would help reducing the building's lighting energy. However, this may not have been achieved because almost all window blinds are partially or fully lowered causing the artificial lights to remain on even during periods of full sunlight.

As mentioned earlier, many office buildings in Malaysia are experiencing poor daylight conditions and high rate of energy consumption because of the improper blind operation by the occupants. Yet, window blind operations are being overlooked during the initial calculation of daylight performance of these office buildings. It is expected that this study would create urgency among the designers, researchers and authorities to consider window blind operation during the process of calculating a building's daylight performance in order to have a productive visual environment inside the building. Further similar studies involving more green buildings in the tropics are recommended to provide a deeper and clearer understanding of occupants' behavior.

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