Parametric Studies on Window-To-Wall Ratio for Day lighting Optimisation in High-Rise Office Buildings in Kuala Lumpur, Malaysia

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The use of daylight in non-residential buildings has become an important strategy to improve environmental quality and energy efficiency by minimising artificial lighting requirements and thus reducing the cooling load. These can be achieved by a good and proper configuration of the fenestrations. They can control the amount and distribution of natural lighting entering a space as a pleasant daylight strategy. There are some Passive Design factors which architects should consider, namely: fenestrations, climate conditions, orientations, and shading devices. This paper studies the impact of Window-to-Wall Ratio (WWR) as one of the passive design strategies to optimise day lighting in high-rise office buildings in Kuala Lumpur as a recommendation for building designers to use it at the early stages of design. This study was carried out by simulations on IES-VE software by using RADIANCE program for calculation of the daylight distribution due to WWR on daily basis during office hours. An investigation on the optimum amount of window size has been done by studying an office room model with 6m × 6m × 4m dimension. WWR was considered from 20% to 50% at 5% interval in two types of expanding method of window namely vertical and horizontal. The simulations were performed in two sky conditions (Sunny sky and standard CIE overcast sky) on different dates, times and orientation. The primary findings of this study found that 25% WWR is the best in vertical expanding as well as 35% WWR have more suitable daylight in horizontal expanding in sunny sky for a hypothetical office room.

Keywords: *Daylight, Window-to-Wall Ratio (WWR), Office building, CIE overcast sky, IES-VE, Simulation, Daylight Factor*

Terminology:

WWR	: Window-to-wall ratio
Vertical expanded window	: Width of the Window remains constant, the height is varied
Horizontal expanded window	: Height of the Window remains constant, the width is varied
SAZ	: Suitable Area Zone with approperiate daylight
DF	: Daylight Factor
LT	: Light to Thermal ratio

1. INTRODUCTION

Many architectural design features of a building such as the position and size of the windows affect the indoor climate (Givoni, 1998). The design of fenestration and the choice of glass seem to be the point in the design process with the largest direct impact on future energy performance of buildings and the point where a complex group of aesthetics and performance issues come together. Attempts have been directed at exploring the behaviour of a building affected with solar radiation through fenestration.(Sekhar & Toon, 1998).

Day lighting is one of the major functions of windows. The design of the window determines the distribution of daylight to a space. Windows which are solely selected for their architectural design attributes may perform satisfactorily in many cases (IEA, 2000). Day lighting is one of the most significant sections in passive design strategies that building designers and architects consider about. Since 2000 there has been a growing concern and knowledge with regard to design and built energy efficiency building by government and policy or decision maker in Malaysia (Lim, Kandar, Ahmad, Ossen, & Abdullah, 2012).

Additionally, day lighting approaches and architectural design procedures complement each other. Daylight not only replaces artificial lighting, reducing lighting energy use, but also has an impact on both heating and cooling loads (IEA, 2000). The application of daylight is one of the most essential factors which needs to be taken into consideration in the design of buildings (Li, Wong, Tsang, & Cheung, 2006) cited in (Ihm, Nemri, & Krarti, 2009). The significance of daylight is not only because of energy conservation but also due to visual comfort, health, lighting quality, and human performance (Ko, Elnimeiri, & Clark, 2008). If appropriately applied, daylight will enhance human visual response, motivation and higher levels of task performance thereby resulting in higher productivity in work (Manav, 2007) as quoted in (Andersen et al., 2008). Occupant priority for natural instead of electric light lies also in the quality of light, its colour rendering ability, in addition to its variability along with its changeability (Boyce, 1998). It should be stated that all surveyed office buildings in Malaysia were dependent upon electrical lighting though there is adequate exterior daylight availability in the tropical region. (Kandar et al., 2011)

Daylight provides high illuminance and allows excellent colour identification and colour rendering. These two properties indicate providing the condition for good vision by daylight. On the other hand, daylight can also produce high luminance reflections on display screens and solar glare discomfort, both of which interfere with good vision. Hence, the impact of daylight on the performance of tasks relies on the delivery of daylight. All such factors need to be considered in day lighting design for buildings (IEA, 2000).

A window system must address the range of a building's outdoor conditions to perform the variety of inside requirements. The position and sizing of windows are among the most influential attributes of architectural design for daylight. Since the design of windows has an obvious impact on the potential daylight and thermal performance of adjacent spaces, it has to be monitored very carefully (IEA, 2000).

The LT (Light-Thermal) approach enhanced for typical climates in the European Union, makes it possible to estimate energy consumption for cooling, lighting, and heating process as a role of glazing ratio (Baker & Steemers, 2000). One more thing is that appropriate application of daylight in buildings is a challenging task. Daylight is highly dynamic in its intensity, spatial distribution and direction (Altomonte, 2008). It has daily and seasonal plus spatial variation which makes it a challenging task to apply for illumination of inside spaces (IEA, 2000). Tall and narrow windows provide deeper day lighting zone and superior open view but high glare if they face south, east or west and are more likely to create light/dark contrast. In the same area, the wider window at high level gives more daylight illumination and higher minimum daylight factor. Yet it should be mentioned that building designers usually suggest the second one due to lower level of glaring light and also priority of the occupants for the broader opening (Chungloo, Limmeechokchai, & Chungpaibulpatana, 2001). In the meantime, it is worth stating that there are also several previous researches illustrating that through utilizing suitable daylight at the perimeter zone, the consumption of electrical energy can decline up to 30-40% because of lighting influence and created cooling load extracted out of artificial lighting system (Ibrahim & Zain-Ahmed, 2007; Ko et al., 2008). Day lighting which is considered as an approach for passive energy efficiency is far more pertinent in tropical countries such as Malaysia because of its long hours of sun shine throughout the entire year in addition to the enormous daylight luminous in Malaysia. This characteristic could meet most of the luminance internal demand within a day that could direct in considerable proportion of energy saving (Ibrahim & Zain-Ahmed, 2007).

What is more, daylight has usually been known as a useful source of energy savings in buildings. Currently, interest has been increased with regard to incorporation of daylight in architecture of building designs in order to save energy consumption of buildings. Artificial lighting is one of the major electricity-consuming items in many non-domestic buildings. A majority of previously- performed reports have demonstrated that proper lighting controls integrated with day lighting have a strong potential for the reduction of energy request in non-domestic building by effective exploitation of daylight (Li, Lam, & Wong, 2005).

Furthermore, it could be stated that designers should prefer day lighting not only for its positive influences on human well being, comfort, and performance but also the reduction of harmful impacts of our growing request for lighting including energy savings and greenhouse gas emission. On the other hand daylight is dynamic in nature and its intensity, direction and spectrum changes as the location, time and weather conditions change. These are the reasons why designers are required to investigate, predict, monitor and assess daylight in all types of buildings. At the same time, day lighting is a significant factor in modern architecture in the creation of a pleasant visual environment. Daylight is considered as the best source of light for excellent colour rendering and its quality is that kind of light that is the most close match with human visual reaction (Li & Lam, 2003).

Hot-humid region is one of the most difficult climate conditions for architectural design because of a high percentage of relative humidity and high temperatures going farther than the ASHRAE comfort limit for the majority of the year (Al-Tamimi, Fadzil, & Harun, 2011; Hyde, 2008). Protection of the building façade against the overheating and sun glare in a tropical country like Malaysia while the appropriate day lighting is obtained is the biggest challenge architects are confronting in the window design. (Zain-Ahmed, Sopian, Zainol Abidin, & Othman, 2002) have studied the impact of window geometry on daylight and their finding shows that the 25% is the optimum window to wall ratio (WWR). The objective of this study is to find the optimum WWR in different sky condition and orientation in Malaysia.

2. RESEARCH METHODOLOGY

The method applied in this study is simulation by using relevant software. The simulations were conducted in Radiance software of Integrated Environmental Solution-Virtual Environment (IES-VE) on a model that presents an office room. Simulation runs were carried out for Kuala Lumpur location (3.12º N, 101.55º E and 120º E), for three times a day at 10 am, 1 pm and 4 pm on 21th March ,June, September, and December due to its sun path and with two models facing north and south. According to the sun path diagram in Malaysia, sun position will change every half a year in the north and south side periodically. Also, because of the dynamic nature of the Malaysia sky, day lighting conditions can change rapidly in a short time. Therefore, each model was simulated under two different skies: the standard CIE overcast sky and sunny sky. Figure 1 shows the sun path of the Kuala Lumpur.

2.1 Model Description

A sample room was used as an office room with external dimensions of 6m in width, 6 m in depth and 4m in height, located in 12th floor of a hypothetical 25 storey building (Figure 2&3).

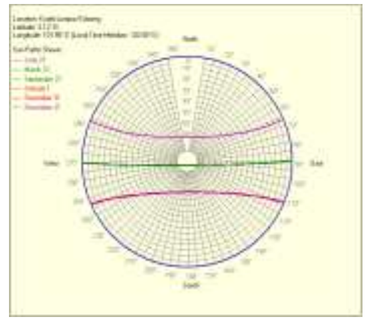

Figure 1: Sun path of the Kuala Lumpur (source: IES-VE)

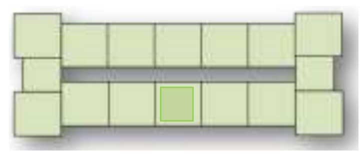

Figure 2: Typical floor plan of hypothetical high rise office building

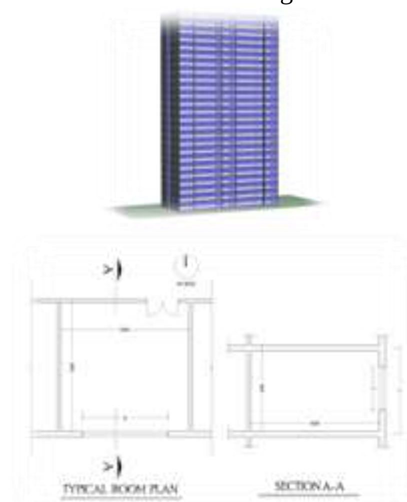

Figure 3: General 3D view of a 25 storey office building modelled in IES, & typical office room plan

To find the optimum WWR, two kinds of range were applied to window size including vertical expanded and horizontal expanded that varied from 20% to 50% which assumed as base size for comparison and the maximum possible size of window as well for this office room (Figure 4).

WWR	20%	25%	30%	35%	40%	45%	50%
Vertical expanded	6 × 0.80	6 × 1.00	6 × 1.20	6 × 1.40	6 × 1.60	6 × 1.80	6 × 2.00
Horizontal expanded	2 × 2.40	2 × 3.00	2 × 3.60	2 × 4.20	2 × 4.80	2 × 5.40	2 × 6.00

Figure 4: Two expanding method applied in this study

The windows were assumed with no shading device as well as with 85% visible transmittance glazing type and light colour internal surface. For both vertical and horizontal expanded types window sill height was considered identically 1m from the floor. As it can be seen in Figure 4 the first group (vertical expanded) was started by a window with 6m wide and 0.80m high and it was ended by a window with 6m wide and 2m high. As well as for the second group, horizontal expanded, it was started and ended by the windows with dimension of 2.4m x 2m and 6m x 2m respectively. In the other words, in the first group, the window width is fixed value as 6m, and in the second, the window height is fixed by 2m.

2.2 Evaluation Method

A comparison between simulation results helped with finding of how the changes of WWR influence the day lighting appearance under different sky condition, orientation, time over a day and time over a year. To find optimum WWR in different conditions two indexes were applied including Suitable Area Zone (SAZ) according absolute LUX and Daylight Factor. In each simulation results SAZ (absolute Lux) stand to percentage of area where had a proper internal daylit between 300 and 2000 Lux (as recommended average illuminance levels in MS1525) in both sunny and CIE overcast sky. In daylight evaluation according to Malaysian Standard a daylight factor between 2% and 6% for working plane is considered as a suitable daylight (MS1525, 2007). As an example figure 5 depict the brightness distribution in the room and suitable area zone (SAZ) by colour value (green) in two indices of absolute Lux and DF.

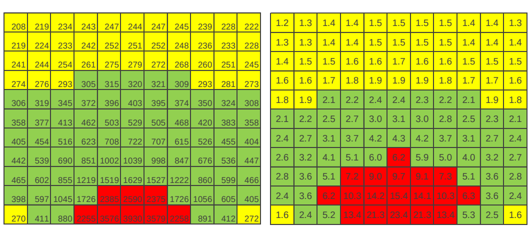

Figure 5: SAZ value by colour (green) in two method of Lux (left) and DF (right)

These numbers show the grid point of the simulation output that were analysed by transferring to excel program to determine actual Lux values and DF. Also, the figure 6 illustrates inside illuminance distribution level by another feature of the simulation output as colour rendering.

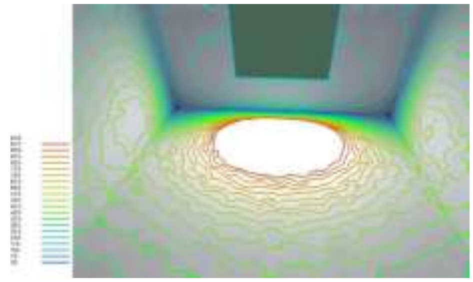

Figure 6: Inside brightness level by colour rendering

In this study SAZ (DF) stand to percentage of occupied area where their daylight factor were between 2% to 6%. Since daylight factor calculated by Equation (1) is considered in overcast sky only, in this study the DFI is simulated in only CIE overcast sky.

$$Daylight\ Factor\ (DF) = \frac{Internal\ illuminance}{External\ illuminance} \times 100 \qquad (1)$$

3. RESULTS AND DISCUSSIONS

3.1 Daylight evaluation of horizontal expanded WWR

The results obtained from 210 simulation runs were analysed in Microsoft Excel. Simulation runs were classified in two main groups in terms of expanding direction namely vertical expanded and horizontal expanded. Table 1 demonstrates the result of various WWR of the horizontal expanded. As it was pointed out the models were simulated in two different orientations, including south and north and each direction was simulated in 2 main months of June and December for these directions.

As shown in Table 1 for horizontal expanded WWR, based on SAZ (absolute Lux), the maximum percentage in sunny sky is for 30% WWR which is 70.9% while the maximum percentage in over cast sky with 87.6% belongs to 25% WWR. Also based on SAZ (DF) in table 2, the best WWR is for 25% in overcast sky that is in agreement with previous study done by Zain-Ahmed (Kandar et al., 2011; Zain-Ahmed et al., 2002).

Table 1: SAZ value in horizontal expanded in sunny and cloudy sky, different orientation and different date

Sky	WWR%	Orientation	Date	Suitable Grid point No.	Suitable Area Zone (m2)	SAZ (%)	Ave SAZ % (Orientation)	Ave SAZ % (WWR)
Sunny	2 * 2.40 - 20%	North	June	104	26.00	86.0	61.2	58.7
			Dec.	44	11.00	36.4		
		South	June	55	13.75	45.5	56.2	
			Dec.	81	20.25	66.9		
	2 * 3.00 - 25%	North	June	89	22.25	73.6	67.8	61.2
			Dec.	75	18.75	62.0		
		South	June	80	20.00	66.1	54.5	
			Dec.	52	13.00	43.0		
	2 * 3.60 - 30%	North	June	68	17.00	56.2	77.3	70.9
			Dec.	119	29.75	98.3		
		South	June	121	30.25	100.0	64.5	
			Dec.	35	8.75	28.9		
	2 * 4.20 - 35%	North	June	54	13.50	44.6	72.3	63.4
			Dec.	121	30.25	100.0		
		South	June	121	30.25	100.0	54.5	
			Dec.	11	2.75	9.1		
	2 * 4.80 - 40%	North	June	40	10.00	33.1	66.5	58.7
			Dec.	121	30.25	100.0		
		South	June	121	30.25	100.0	50.8	
			Dec.	2	0.50	1.7		
	2 * 5.40 - 45%	North	June	28	7.00	23.1	61.6	55.8
			Dec.	121	30.25	100.0		
		South	June	121	30.25	100.0	50.0	
			Dec.	0	0.00	0.0		
	2 * 6.00 - 50%	North	June	12	3.00	9.9	55.0	52.5
			Dec.	121	30.25	100.0		
		South	June	121	30.25	100.0	50.0	
			Dec.	0	0.00	0.0		

Sky	WWR%	Orientation	Date	Suitable Grid point No.	Suitable Area Zone (m2)	SAZ (%)	Ave SAZ % (Orientation)	Ave SAZ % (WWR)
Cloudy	2 * 2.40 - 20%	North	June	103	25.75	85.1	82.2	79.5
			Dec.	96	24.00	79.3		
		South	June	99	24.75	81.8	76.9	
			Dec.	87	21.75	71.9		
	2 * 3.00 - 25%	North	June	106	26.50	87.6	87.6	87.6
			Dec.	106	26.50	87.6		
		South	June	106	26.50	87.6	87.6	
			Dec.	106	26.50	87.6		
	2 * 3.60 - 30%	North	June	102	25.50	84.3	84.3	84.3
			Dec.	102	25.50	84.3		
		South	June	102	25.50	84.3	84.3	
			Dec.	102	25.50	84.3		
	2 * 4.20 - 35%	North	June	96	24.00	79.3	79.3	79.3
			Dec.	96	24.00	79.3		
		South	June	96	24.00	79.3	79.3	
			Dec.	96	24.00	79.3		
	2 * 4.80 - 40%	North	June	90	22.50	74.4	74.4	74.4
			Dec.	90	22.50	74.4		
		South	June	90	22.50	74.4	74.4	
			Dec.	90	22.50	74.4		
	2 * 5.40 - 45%	North	June	84	21.00	69.4	71.1	71.3
			Dec.	88	22.00	72.7		
		South	June	85	21.25	70.2	71.5	
			Dec.	88	22.00	72.7		
	2 * 6.00 - 50%	North	June	81	20.25	66.9	67.8	67.8
			Dec.	83	20.75	68.6		
		South	June	81	20.25	66.9	67.8	
			Dec.	83	20.75	68.6		

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Table 2: SAZ value in horizontal expanded in cloudy sky by DF (2-6)

Daylight Factor (2-6) - High-Window - Cloudy Sky			
WWR%	Orientation	SAZ (%)	Ave SAZ % (WWR)
20%	North	49.2	48.6
	South	47.9	
25%	North	73.6	71.1
	South	68.6	
30%	North	62.8	62.8
	South	62.8	
35%	North	56.6	57.2
	South	57.9	
40%	North	50.4	50.4
	South	50.4	
45%	North	45.5	45.5
	South	45.5	
50%	North	44.6	45.0
	South	45.5	

3.2 Daylight evaluation of vertical expanded WWR

Table 3 represents the SAZ (absolute LUX) in two sky conditions for vertical expanded WWR. This table demonstrates the SAZ value (absolute LUX) in different orientations and months in cloudy and sunny sky. As Table 3 shows the best WWR in terms of SAZ (Absolute Lux) is for 35% in sunny sky and the maximum percentage of SAZ (Absolute lux) in CIE overcast sky belongs to 35% WWR as well.

Also, based on the result of daylight factor in this group the maximum percentage of SAZ is 63.6% for WWR 35%. As it is cleared the WWR 35% is the best option for vertical expanded window in two sky conditions and both Absolute Lux and Daylight Factor.

Table 3: Summary of the results for two forms of window expanded in different sky and SAZ assessment

sky		HORIZONTAL EXPAND			VERTICAL EXPAND		
		Sunny sky	CIE Overcast sky	CIE Overcast sky	Sunny sky	CIE Overcast sky	CIE Overcast sky
index		SAZ (AL) %	SAZ (AL) %	SAZ (DF) %	SAZ (AL) %	SAZ (AL) %	SAZ (DF) %
WWR	20%	58.7	79.5	48.6	59.9	45.5	27.3
WWR	25%	61.2	87.6	71.1	61	53.7	36.2
WWR	30%	70.9	84.3	62.8	59	60.6	49.3
WWR	35%	63.4	79.3	57.2	70.7	81.8	63.6
WWR	40%	58.7	74.4	50.4	62.4	73.6	54.5
WWR	45%	55.8	71.3	45.5	57.9	72.7	49.9
WWR	50%	52.5	67.8	45	52.5	67.8	45

Window to Wall Ratio (WWR), Suitable Area Zone (SAZ), Daylight Factor (DF), Absolute Lux (AL)

These results have been demonstrated in Figure 7 for comparing the two WWR expansion forms.

Table 4: SAZ value in vertical expanded in sunny and cloudy sky, different orientation and different date

Sky	WWR%	Orientation	Date	Suitable Grid point No.	Suitable Area Zone (m2)	SAZ (%)	Ave SAZ % (Orientation)	Ave SAZ % (WWR)
Sunny	20%	North	June	108	27.00	89.3	62.8	59.9
			Dec.	44	11.00	36.4		
		South	June	44	11.00	36.4	57.0	
			Dec.	94	23.50	77.7		
	25%	North	June	97	24.25	80.2	62.8	61.0
			Dec.	55	13.75	45.5		
		South	June	66	16.50	54.5	59.1	
			Dec.	77	19.25	63.6		
	30%	North	June	77	19.25	63.6	63.6	59.9
			Dec.	77	19.25	63.6		
		South	June	81	20.25	66.9	56.2	
			Dec.	55	13.75	45.5		
	35%	North	June	66	16.50	54.5	77.3	70.7
			Dec.	121	30.25	100.0		
		South	June	121	30.25	100.0	64.0	
			Dec.	34	8.50	28.1		
	40%	North	June	52	13.00	43.0	71.5	62.4
			Dec.	121	30.25	100.0		
		South	June	121	30.25	100.0	53.3	
			Dec.	8	2.00	6.6		
	45%	North	June	37	9.25	30.6	65.3	57.9
			Dec.	121	30.25	100.0		
		South	June	121	30.25	100.0	50.4	
			Dec.	1	0.25	0.8		
	50%	North	June	12	3.00	9.9	55.0	52.5
			Dec.	121	30.25	100.0		
		South	June	121	30.25	100.0	50.0	
			Dec.	0	0.00	0.0		

Sky	WWR%	Orientation	Date	Suitable Grid point No.	Suitable Area Zone (m2)	SAZ (%)	Ave SAZ % (Orientation)	Ave SAZ % (WWR)
Cloudy	20%	North	June	55	13.75	45.5	45.5	45.5
			Dec.	55	13.75	45.5		
		South	June	55	13.75	45.5	45.5	
			Dec.	55	13.75	45.5		
	25%	North	June	68	17.00	56.2	54.1	53.7
			Dec.	63	15.75	52.1		
		South	June	67	16.75	55.4	53.3	
			Dec.	62	15.50	51.2		
	30%	North	June	99	24.75	81.8	81.8	80.6
			Dec.	99	24.75	81.8		
		South	June	97	24.25	80.2	79.3	
			Dec.	95	23.75	78.5		
	35%	North	June	99	24.75	81.8	81.8	81.8
			Dec.	99	24.75	81.8		
		South	June	99	24.75	81.8	81.8	
			Dec.	99	24.75	81.8		
	40%	North	June	88	22.00	72.7	73.6	73.6
			Dec.	90	22.50	74.4		
		South	June	88	22.00	72.7	73.6	
			Dec.	90	22.50	74.4		
	45%	North	June	88	22.00	72.7	72.7	72.7
			Dec.	88	22.00	72.7		
		South	June	88	22.00	72.7	72.7	
			Dec.	88	22.00	72.7		
	50%	North	June	81	20.25	66.9	67.8	67.8
			Dec.	83	20.75	68.6		
		South	June	81	20.25	66.9	67.8	
			Dec.	83	20.75	68.6		

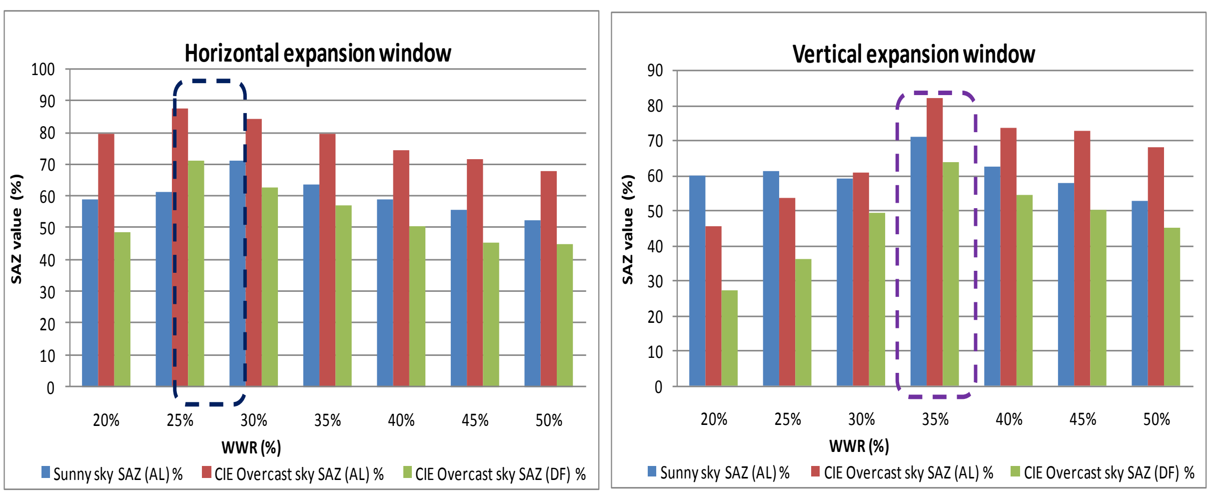

Figure 7: Two WWR expansion form in different sky and different SAZ assessment

Moreover, table 5 shows the final brief results. Based on this table it is clear the WWR 35% in vertical expanded and WWR 25% in horizontal expanded are the best options.

3.3 Daylight evaluation in different sky conditions

To find the difference between daylight behaviour in various sky conditions, Figure 8 illustrates SAZ (absolute Lux) in various expanding types of WWR in two sky conditions including sunny and CIE overcast sky. As it is clarified in Figure 8, in sunny sky 35% and 30% WWR are the best in vertical expanded and horizontal respectively. While in CIE overcast sky the best WWR stand for 35% and 25% in vertical and horizontal expanding respectively. In addition an interesting result was found that in the CIE overcast sky all the horizontal expanded windows played better roles in terms of SAZ in comparison with vertical expanded windows.

Table 5: Appropriate WWR in two window expansion forms

Sky	Vertical expanded (wide win.)	Horizontal expanded (high win.)
Sunny (300-2000) lux	35%	30%
Cloudy (300-2000) lux	35%	25%
Cloudy DF (2-6) %	35%	25%
Result	35%	25%

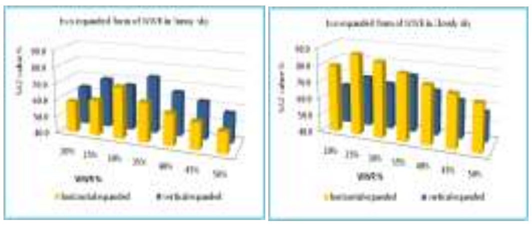

Figure 8: Comparison of the SAZ values in various WWR in two sky conditions

4. CONCLUSIONS

In order to determine the WWR in high-rise office building, this paper has been studied in two aspects included different sky condition (cloudy and sunny), and various windows expanded method (vertical and horizontal) in different orientations by simulation approach. The results can be seen as an annual average of two critical months (June and December) based on sun path diagram of Kuala Lumpur for sunny sky in unshaded window condition. All windows have a constant window sill height. A window with maximum possible size (50%) assumed as base window, that one of dimensions reduced in every step for comparison between two kinds of window expansion. This method indicates the effect of window form expansion on window design which architects should consider it in early design stages.
According to the above studies of daylight evaluation of an office area in various WWR, the following options can be concluded:

- The best WWR for an office room in CIE overcast sky is 25% in horizontal expanding window which is the representative of a 3 m wide and 2 m high window; while in vertical expanding WWR 35% is the best option.
- In sunny sky the best WWR is 35% in vertical expanded window, which is a 6m in width and 1.40 m in height; while WWR 30% is the best option for horizontal expanding.
- In sunny sky most of the vertical expanded windows based on SAZ (Lux) had a better daylight while in overcast sky all the horizontal expanding window achieved the higher SAZ (Lux) than the vertical expanding windows.
- In the overcast sky according SAZ (DF) the best WWR is 25% in horizontal expanding; while in vertical expanding it is 35%.

These results revealed that between horizontal expanded windows and vertical expanded windows which have equal SAZ value, the horizontal expanded ones have smaller size (area). Therefore, this kind of windows meets less solar heat gain in sunny hours.

It is notable that in this study the height of the office room has been assumed as 4 m. However, in case of different height of the room and also different window expansion methods, other results will possibly obtain in future studies.

5. REFERENCES

Al-Tamimi, Nedhal Ahmed M., Fadzil, Sharifah Fairuz Syed, & Harun, Wan Mariah Wan. (2011). The Effects of Orientation, Ventilation, and Varied WWR on the Thermal Performance of Residential Rooms in the Tropics. *Journal of Sustainable Development, Vol. 4*(No. 2).

Altomonte, S. . (2008). Daylight for Energy Savings and Psycho-Physiological Well-Being in Sustainable Built Environments. *sustainable Development*.

Andersen, M., Kleindienst, S., Yi, L., Lee, J., Bodart, M., & Cutler, B. (2008). An intuitive day lighting performance analysis and optimization approach. *Building Research & Information, 36* (6).

Baker, N., & Steemers, K. . (2000). *Energy and Environment in Architecture*. London: E & FN Spon.

Boyce, Peter. (1998). *Why Daylight?* Paper presented at the Proceedings Daylight 98, International Conference on Day lighting Technologies for Energy Efficiency in Buildings, Ottawa, Ontario, Canada.

Chungloo, S., Limmeechokchai, B., & Chungpaibulpatana, S. (2001). *Energy Efficient Design of Side-Window for Day lighting Application in Thailand*. Paper

presented at the Seventh International IBPSA Conference, Rio de Janeiro, Brazil.
Givoni, B. (1998). *Climate Consideration in Building and Urban Design*. New York: Van Nostrand Reinhold.
Hyde, Richard. (2008). *Bioclimatic Housing: innovative designs for warm climates*. London: Earthscan.
Ibrahim, Norhati, & Zain-Ahmed, Azni. (2007). *Daylight availability in an office interior due to various fenestration options*. Paper presented at the 2nd PALENC Conference and 28th AIVC Conference on Building Low Energy Cooling and Advanced Ventilation Technologies in the 21st Century, Crete island, Greece.
IEA, International Energy Agency. (2000). *Daylight in buildings, a source book on day lighting systems and components*: Berkeley, CA: The Lawrence Berkeley National Laboratory.
Ihm, Pyonchan, Nemri, Abderrezek, & Krarti, Moncef. (2009). Estimation of lighting energy savings from day lighting. *Building and Environment, 44*(3), 509-514.
Kandar, Mohd Zin, Sulaiman, Mohd Sabere, Rashid, Yong Razidah, Ossen, Dilshan Remaz, Abdullah, Aminatuzuhariah M, Wah, Lim Yaik, & Nikpour, Mansour. (2011). Investigating Daylight Quality In Malaysian Government Office Buildings Through Daylight Factor and Surface Luminance. *Engineering and Technology 59*.
Ko, Dong-Hwan, Elnimeiri, Mahjoub, & Clark, Raymond J. (2008). Assessment and Prediction of Ddaylight Performance in High-Rise Office Buildings. 953–976.
Li, Danny H. W., Lam, J. C., & Wong, S. L. (2005). Day lighting and its effects on peak load determination. *Energy, 30*(10), 1817-1831.
Li, Danny H. W., & Lam, Joseph C. (2003). An investigation of day lighting performance and energy saving in a daylit corridor. *Energy and Buildings 35*, 365-373.
Li, Danny H. W., Wong, S. L., Tsang, C. L., & Cheung, Gary H. W. (2006). A study of the day lighting performance and energy use in heavily obstructed residential buildings via computer simulation techniques. *Energy and Buildings, 38*(11), 1343-1348.
Lim, Yaik-Wah, Kandar, Mohd Zin, Ahmad, Mohd Hamdan, Ossen, Dilshan Remaz, & Abdullah, Aminatuzuhariah Megat. (2012). Building façade design for day lighting quality in typical government office building. *Building and Environment, 57*(0), 194-204. doi: 10.1016/j.buildenv.2012.04.015
Manav, Banu. (2007). An experimental study on the appraisal of the visual environment at offices in relation to colour temperature and illuminance. *Building and Environment, 42*(2), 979-983.
MS1525, (Malaysian Standard). (2007). *Code of Practice on Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings*. Malaysia.
Sekhar, S. C., & Toon, Kenneth Lim Cher. (1998). On the study of energy performance and life cycle cost of smart window *Energy and Buildings 28*, 307-316
Zain-Ahmed, A., Sopian, K., Zainol Abidin, Z., & Othman, M. Y. H. (2002). The availability of daylight from tropical skies--a case study of Malaysia. *Renewable Energy, 25*(1), 21-30.