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Daylighting Rule of Thumb for Room with Glazing Transmittance Variation

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Abstract: Since antiquity, architects have been using simple guides or easy to use calculation methods called rules of thumb for predicting daylighting performance inside buildings. These rules of thumb in daylighting continue to develop as new knowledge in science and technology evolves. In architectural practice, daylighting rules of thumb have often been expressed in terms of the percentages of window area to floor area. Such rules can be found in architectural literatures as well as in building regulations in various countries. The percentages of window glazing area to floor area suggested in the literatures and building codes often range from 10% to 35% depending on the specified visual tasks and the illumination characteristics desired. One of the most frequently cited daylighting rules of thumb is for 20% glazing to floor area allocated for habitable room or space. These rules of thumb are usually based on the standard clear glass with transmittance value of approximately 0.8 to 0.9. However, many recent buildings in tropical countries have glazing transmittance lower than this value for glare control and privacy purpose. In order to address this issue, daylighting simulations were conducted using AGi-32 to determine the effects of different glazing transmittances on indoor daylight performances and to modify existing rule of thumb. Based on the simulation data and analysis, a well-known daylighting rule of thumb by Littlefair is modified to cater for multiple glazing transmittances. This new rule of thumb presents an easy to use calculation to estimate daylight factor for interior based on glazing transmittance value.

Keywords **:** ***daylighting, glazing transmittance, rule of thumb***

I. INTRODUCTION AND BACKGROUND

The Cambridge Dictionary of English define 'rule of thumb' as a general and broadly accurate guide, method or principle of doing or measuring something derived from practice or experience rather than theory [1]. Therefore, a rule of thumb is a principle relatively free from rigorous or precise scientific reasoning and places emphasis on approximation and practical use. Architects and builders have been using rules of thumb to design day lit buildings since antiquity. This can be traced back in the early architectural treatises such as for an example, Vitruvius's Book VI of *De Architectura* (c. 80 - 20 BC) [2]. Daylighting rules of thumb are also promoted by an eminent scientist, R.G. Hopkinson, as easy guides for designers as long as the limits are clearly understood. Hopkinson and Kay (1969) quote numerous daylighting rules of thumb for buildings of various types in their book, *The Lighting of Buildings*. Daylighting rules of thumb are frequently expressed in the percentages of window area to floor area and usually refer to windows with clear or standard glazing. Questions can be raised in relation to this particular aspect. If windows with different glazing transmittances are utilized would the rules still reliable? Buildings especially in warm tropical climate usually have windows glazing of low transmittance values in order to avoid direct sunlight penetration and heat gain. This strategy has been applied on many commercial buildings and so-called sustainable buildings in tropical region. An example is the Diamond Building (Fig.1) in Putrajaya, Malaysia which has received Green Mark Platinum from the Singaporean LEED (Leadership in Energy and Environmental Design) association as reported by Kristensen [3]. Definitely, these buildings would not comply to standard daylighting rules of thumb associated to typical glazing transmittance as usually quoted in building regulations and numerous architectural textbooks.

Fig. 1. The award winning Diamond Building in Putrajaya, Malaysia

In the daylighting practice, rules of thumb for window area to floor area of between 20% to 30% have been promoted by Boyce [4], Building Research Station [5] and the Australian Standard [6]. These represent a category of the most quoted daylighting rules of thumb in architecture and building literatures.

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Studies conducted by Ne'eman, and Hopkinson in the 1970s came to a general conclusion that a ratio of 20-25% window area to floor area is satisfactory for most occupants [7]. The requirement for 20% window to floor area was also a common practice in order to fulfil the minimum 2% daylight factor or the desirable 5% average daylight factor inside classrooms as recommended by the British Standards Codes of Practice in 1945 [8].

Daylighting rules of thumb which assume glazing transmittance of 0.89 or approximately 0.9 actually represents typical sheet or plate of clear glass for window [9]. Window area to floor area ratios of 20-30% often refer to windows with a standard clear glazing and 80-90% transmittance value. In addition, most of daylighting rule of thumb recommendations made in literature are associated to cold and temperate regions. Windows in the warmer or tropical climates such as on buildings in Malaysia or South East Asia are more exposed to intense radiation and therefore have to rely upon tinted glazing to ward off direct sunlight and to minimise heat gain. This also means window glazing in these regions typically have lower transmittance values and lower percentage of glazing to floor area.

A past simulation study conducted using AGi-32 software for Sydney geographical location, demonstrated that 20% window area to floor area can achieve average daylight factor of approximately 5% for interiors [10]. This represents a cheerfully daylit interior condition as described by the Chartered Institution of Building Services Engineers (CIBSE). The study also involved modifying Littlefair's average daylight factor formula [11] as shown in equation (1) into a simpler equation or rule of thumb. The modified and simplified daylight factor formula or rule of thumb is shown in equation (2).

$$DF_{avg} = \frac{\tau_w A_g \theta}{A_s\left(1-R^2\right)} \qquad (1)$$

DF_{avg} average daylight factor
A_g window glazing area (m^2)
τ_w transmission of window glazing
θ sky angle measured at the centre of the window in degrees
A_s total area of the room surfaces ceiling, floor, walls and windows (m^2)
R the average reflectance. For fairly light colored rooms such as in the case studies, a value of 0.5 is normal

$$DF_{avg} \approx 27\,(A_g / A_f)\ \% \qquad (2)$$

DF_{avg} average daylight factor
A_g glazing area
A_f floor area

II. OBJECTIVES

The main objective of the current study is to verify the influence of various glass transmittances on a window area to floor area ratio rule of thumb in daylighting, namely the 20% window area to floor area rule. The current work also attempts to generate further daylighting rules of thumb which address various glazing transmittances.

III. METHODOLOGY

Simulations are carried out using the software AGi-32 as it has been found to be reliable and used before in similar works by Nik Ibrahim [12]. Two geographic locations are chosen for comparison; one in Kuala Lumpur, Malaysia (Latitude 5° North, Longitude -150° East) and the other in Sydney, Australia (Latitude -35° South, Longitude -150° East). These two regions represent hot humid and temperate climates. A standard exterior ground surface reflectance of approximately 20% was set as a default value in the simulation. This coincides with the surface reflectance of grass [13] or mild-grey colored surface [14] such as exposed concrete. Surface reflectance of 20% is also the default ground surface reflectance in AGi-32 software. Usually daylighting rules of thumb assume window glazing of standard glass transmittance value which is around 0.9 or 90%. The current study addresses variations from this standard transmittance value and how these could affect daylighting performance and rule of thumb.

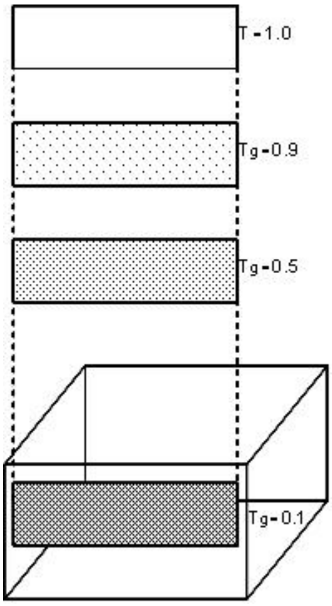

Fig. 2. Variations of glazing transmittance in the simulations

The experiment consists of rooms with glass transmittance variations ranging from 0.1 to 0.9 (Fig.2). An additional room with unglazed window is also included and represented by 100% or 1.0 window transmittance. The room series was simulated in order to determine the range of glazing transmittance which can be assumed in daylighting rules of thumb and to determine the effects of different glazing transmittance on daylighting performance. Each room in this typological series has similar 4.5 m x 4.5 m floor area and a full-width window conforming to a 20% window area to floor area rule. The ceiling height, window head height, sill height and the average interior surface reflectance were of standard values (0.8 for ceiling, 0.5 for walls and 0.2 for floor). This simulated medium size room with the allocated aperture to floor area ratio and interior surfaces reflectance also represents a typical cellular office room type.

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IV. RESULTS AND DISCUSSIONS

Comparison between different glazing transmittance in terms of daylighting performance and distributions is made possible by keeping constant window glazing area to floor area ratio, floor area and other room parameters. Glass area to floor area percentage of each room is kept constant at 20% representing a well-known daylighting rule of thumb. This simulation procedure is in keeping with the typological method frequently adopted in daylighting performance studies as elaborated in Nik Ibrahim & Kosman [15] and demonstrated in Nik Ibrahim, Hayman & Hyde [16].

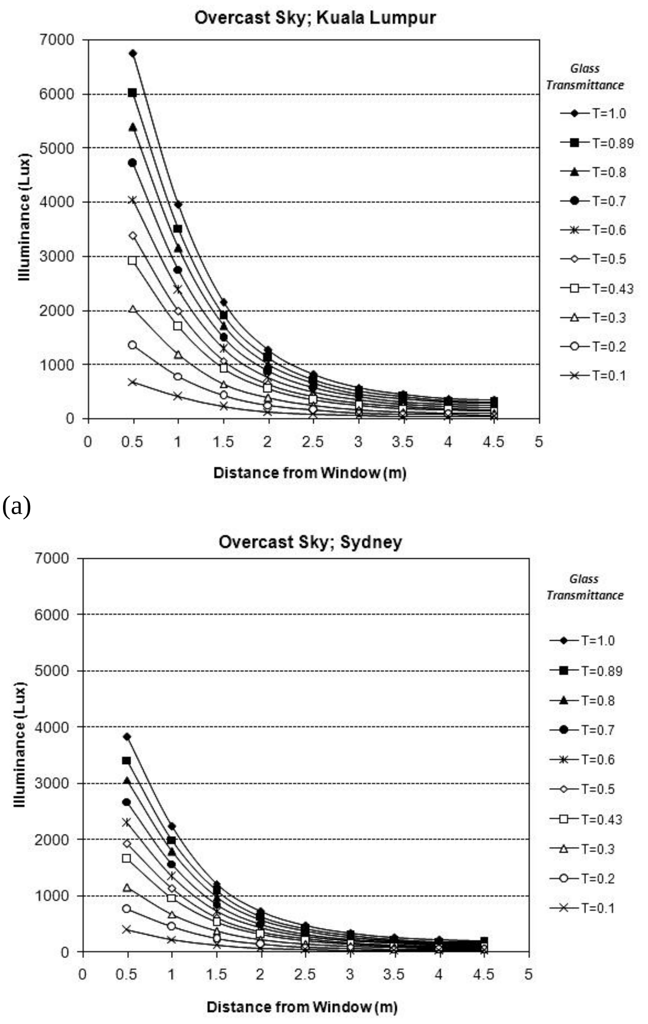

Fig. 3. Center line illuminance variations under different glazing transmittance

As shown in Fig. 3(a) and Fig. 3(b), center line illuminance variations between rooms with different glass transmittance were larger under an overcast sky in Kuala Lumpur than under an overcast sky in Sydney especially at the rear part of the interiors. Under an overcast sky, large illuminance variations between rooms occurred in the area close to a window but not towards the rear part of the interior due to the overcast sky dome being three times brighter at the zenith than at its horizon. Obviously, a similar size room in Kuala Lumpur with 20% window area to floor area gets higher illuminance than in Sydney.

In Fig. 4 and Fig. 5, interior average and minimum illuminance under overcast skies in Kuala Lumpur and Sydney increased linearly with the increase of window glazing transmittance value. From the graphs, in order to ensure an average illuminance of 500 lux (sufficiently daylit condition) and minimum illuminance of 100 lux under an overcast sky, the glass transmittance value should not be lower than 0.6 in Sydney and 0.34 in Kuala Lumpur. Lower glazing transmittance will not meet these average and minimum illuminance requirements.

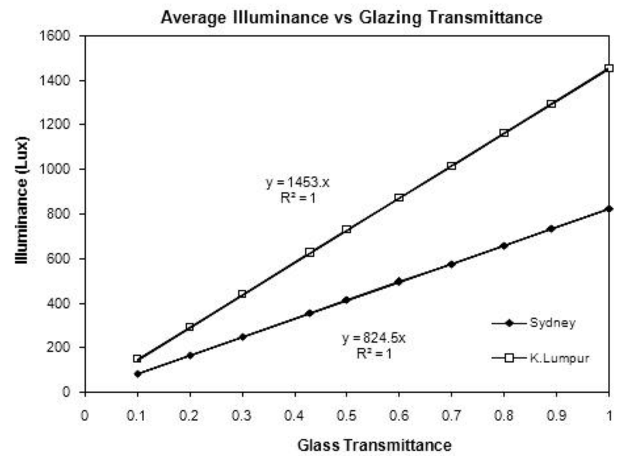

Fig. 4. Average illuminance versus glazing transmittance under an overcast sky in Kuala Lumpur and Sydney

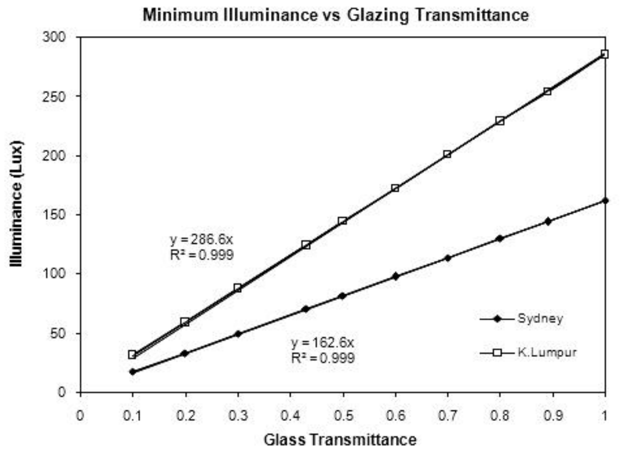

Fig. 5. Minimum illuminance versus glazing transmittance under an overcast sky in Kuala Lumpur and Sydney

However, for maintaining average illuminance of slightly more than 200 lux (average daylight factor of 2% or 'daylit appearance') glazing transmittance as low as 0.3 could still be tolerable in both regions.

The linear correlations between average illuminance of overcast sky and glazing transmittance in Fig. 4 can be represented by the simple equations (3) and (4).

$$E_{avg} = 1450\ \tau \quad (3)$$

(overcast sky in Kuala Lumpur)

$$E_{avg} = 825\ \tau \quad (4)$$

(overcast sky in Sydney)
E_{avg} average illuminance
τ glazing transmittance

The linear correlations between minimum illuminance of overcast sky and glass transmittance value as shown in Fig.5 can be represented by the simple equations (5) and (6).

$$E_{min} = 285\,\tau \qquad (5)$$

(overcast sky in Kuala Lumpur)

$$E_{min} = 160\,\tau \qquad (6)$$

(overcast sky in Kuala Lumpur)
E_{min} minimum illuminance
τ glazing transmittance

Average daylight factors insides the rooms with different window glazing transmittances are shown in Table I. Table I indicates that for this medium size room (4.5m x 4.5m) to maintain average daylight factor of 5% or 'cheerfully daylit' character, window glazing transmittance should be 0.7 and higher.

Table- I: Range of average illuminance and glazing transmittance values

Glazing Transmittance (ROT: A_w/A_f =20%)	Average Daylight Factor (%)
1.0	7- 8
0.89	6 - 7
0.8	5 - 6
0.7	4.5 - 5
0.5 - 0.6	3.5 - 4.5
0.4	3 - 3.5
0.3	2- 3
0.2	1 - 2
0.1	Less 1

A_w - window area (m^2); A_f - floor area (m^2)

Minimum daylight factors insides the rooms with different window glazing transmittances are shown in Table II. Table II indicates that for this room to maintain minimum daylight factor of 1% to 2%, window glazing transmittance should be 0.8 and higher.

Table- II: Range of average illuminance and glazing transmittance values

Glazing Transmittance (ROT: A_w/A_f =20%)	Minimum Daylight Factor (%)
1.0	1.5- 2.5
0.9	1 - 1.5
0.2 - 0.8	0.8 - 1
0	Less 0.8

A_w - window area (m^2); A_f - floor area (m^2)

The simulated rooms actually comply with three daylighting rules of thumb, namely the 20% window glazing area to floor area, the room limiting depth of twice window head height and the room limiting depth of 4.5m. As indicated in Table III, a minimum or rear interior illuminance of 100 lux under an overcast sky can be met with a glazing transmittance of 0.5 and above. In a model office study by Boyce [17], a glazing transmittance of approximately 0.2 was considered unacceptable by 50% of respondents while above 0.5 transmittances were regarded as highly acceptable. This finding seems to confirm Boyce's suggestion. As shown in Table I, this glazing transmittance value does not satisfy the average daylight factor of 5% or a 'cheerfully daylit' interior but can easily ensure 'daylit appearance' or daylight factor of above 2%.

Table- III: Rules of thumb and minimum illuminance under an overcast sky in Sydney and Kuala Lumpur

Rules of Thumb (ROT)	Glazing Transmittance	Minimum Illuminance (Overcast Sky in Sydney)	Minimum Illuminance (Overcast Sky in Kuala Lumpur)
A_w/A_f = 20% **Limiting Depth (H_{wh})** 2 x H_{wh} **Limiting Depth (m)** 4.5 m	0.5 - 0.7 0.8 - 0.89 1.0	100 - 140 lux 150 - 190 lux 200 + lux	180 - 250 lux 260 - 340 lux 350 + lux

A_w - window area (m^2); A_f - floor area (m^2); H_{wh}- window head height (m)

V. DAYLIGHTING RULES OF THUMB RELATED TO GLAZING TRANSMITTANCE

Further correlation is made between average daylight factors from the simulation and average daylight factor calculated by means of Littlefair's average daylight factor formula as shown in equation (1). The correlation in Fig. 6 can be represented by the following equation (7) which relates percentage of window or glazing area to room surface area together with glass transmittance variations. If standard interior room surfaces reflectance is assumed, it can be further transformed into equation (8).

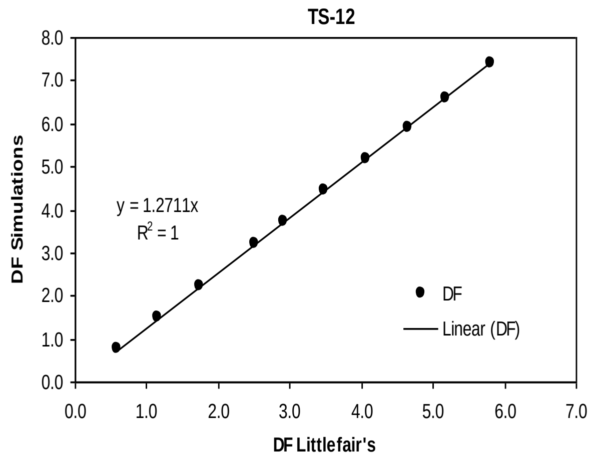

Fig. 6. Simulation average daylight factor vs. Littlefair average daylight factor

$$DF_{avg} = 1.27\left(\frac{\tau_w A_g \theta}{A_s(1-R^2)}\right)\% \qquad (7)$$

$$DF_{avg} = 150\left(\frac{A_g}{A_s}\right)\tau_w\,\% \qquad (8)$$

DF_{avg} average daylight factor
A_g glazing area

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A_s room surface area
τ_w glazing transmittance

Further correlation is made between average daylight factor from the simulation and calculated average daylight factor from modified Littlefair's formula in which case room surface area variable is substituted by floor area. The correlation is shown in Fig. 7 and can be described by the following equation (9).

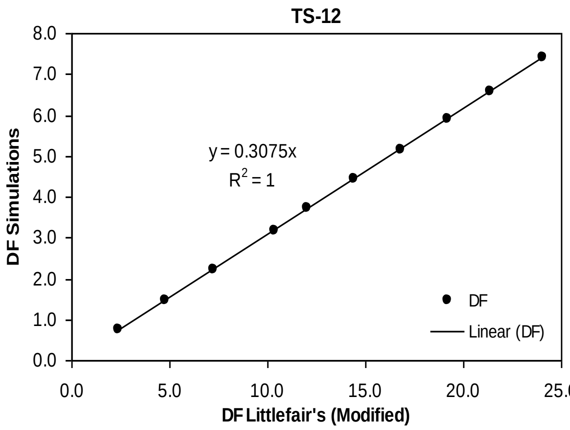

Fig. 7: Simulation average daylight factor vs. modified Littlefair average daylight factor

$$DF_{avg} = 0.308\left(\frac{\tau_w A_g \theta}{A_f(1-R^2)}\right)\% \qquad (9)$$

$$= 37\left(\frac{A_g}{A_f}\right)\tau_w\ \% \qquad (10)$$

DF_{avg} average daylight factor
A_g glazing area
A_f room floor area
τ_w glazing transmittance

The correlation in Fig. 7 can be represented by equation (10) if standard interior surface reflectance is used. However, for ease of memorizing, equation (11) can be adopted as a rule of thumb which address variation of glazing transmittance with association to glazing to floor area percentage.

$$DF_{avg} \approx 35\left(\frac{A_g}{A_f}\right)\tau_w\ \% \qquad (11)$$

In order to ensure daylight factor of 5% inside a room with 20% window area to floor area in both Kuala Lumpur and Sydney, glazing transmittance should not be less than 0.7. This finding also further elaborates a previous study by Mirrahimi, Surat, Nik Ibrahim, Che-Ani and Johar [18] which demonstrated the reliability of the window area to floor area rule.

VI. CONCLUSION

Daylighting rules of thumb expressed in terms of glazing area to floor area percentages available in various architectural literatures and building regulations can to be reformulated or modified in order to incorporate the impact of glazing transmittance values which are beyond the usual standard. This criterion is especially important in tropical and warm climate where tinted glazings of lower glazing transmittance values are used extensively on buildings in order to minimize sunlight penetration and heat gain. The simulation study conducted to address this issue although limited to a medium size room, demonstrates that window glazing with lower transmittance values in warmer region such as Kuala Lumpur can easily be accommodated into the existing rules which usually address only standard glazing transmittance. Through simulation data analysis, a new daylighting rule of thumb which addresses window glazing transmittance is formulated. In addition, this study also demonstrates that glass transmittance value for aperture in this tropical region should ideally be no lower than 0.5 or 50%.

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REFERENCES

1. Procter et al, *Cambridge International Dictionary of English*, Cambridge: Cambridge University Press, 1998.
2. I.D. Rowland, *Vitruvius: Ten Books on Architecture*, Cambridge: Cambridge University Press, 1999.
3. P. Kristensen, "Sustainable Buildings for the Future" in *FuturArc Forum*. Kuala Lumpur: IEN Consultants, 2008.
4. P.R. Boyce. *Human Factors in Lighting*, London: Applied Science Publishers, 1981.
5. B.S. Saini, *Building Environment: An Illustrated Analysis of Problems in Hot Dry Lands*, London: Angus & Robertson Pty Ltd., 1973.
6. Australian Standard. *Interior Lighting: General Principles and Recommendations (Part 1 / AS1680.1)*. New South Wales: Standard Association of Australia, 1990
7. E. Ne'eman and R.G. Hopkinson, "Critical Minimum Acceptable Window Size", in *Lighting Research and Technology*, 2(1), 1970, pp.17-27.
8. W. Wu and E. Ng, "A Review of the Development of Daylighting in Schools", *Lighting Research and Technology*, SAGE Publications, vol. 35, no. 2, 2003, pp. 111-124.
9. N.L. Nik Ibrahim, *Rules of Thumb in Daylighting Design* (M.Phil. Architecture thesis), New South Wales: The University of Sydney, 2002.
10. N.L. Nik Ibrahim, S. Hayman, and R. Hyde (2009). "Rule of Thumb for Daylighting of Rooms with External Obstructions" in *Architecture Science Review*, vol.52, no.2, 2009, pp. 150-159.
11. J.A. Lynes, "Chapter 3: Daylight and Energy", in S. Roaf and M. Hancock (eds.), *Energy Efficient Building: A Design Guide*, Oxford: Blackwell Scientific Publications, 1992.
12. N.L. Nik Ibrahim, *Daylighting Rule of Thumb and Typology* (PhD. Architecture thesis), New South Wales: The University of Sydney, 2009.
13. S.M.U., *Predicting Daylight as Interior Illumination*, Ohio: Libbey-Owen-Ford Glass, 1958.
14. D. Loe, *Lighting Guide 11: Surface Reflectance and Colour: Its Specification and Measurement for Designers*, London: The Society of Light & Lighting and the National Physical Laboratory, 2001.
15. N.L. Nik Ibrahim and K.A. Kosman. "Daylighting Rule of Thumb and Typology" in *Jurnal Alam Cipta: International Journal on Sustainable Tropical Design Research and Practice*, Universiti Putra Malaysia, vol.3, issue 1, 2009, pp. 25-33.
16. N.L. Nik Ibrahim, S. Hayman and R. Hyde, "Typological Approach to Daylighting Analysis" in *Architectural Science Review*, London: Earthscan Publishing, vol.54 (special issue), 2011, pp.141-147.
17. P.R. Boyce, *Human Factors in Lighting* (2nd ed.), New York: Taylor and Francis, 2003.

18. S. Mirrahimi, M. Surat, N.L. Nik Ibrahim, A.I. Che-Ani and S. Johar, "Optimal of Daylighting Performance with Shading Device via Computer Simulation for Office Building in Malaysia" in *Advances in Natural and Applied Sciences*, 2013 pp. 51-59.

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