The influence of latitude variations on daylighting rule of thumb effectiveness

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ABSTRACT: Rule of thumb in daylighting is often regarded as a universal principle which can be applied in any geographical location. For example the 20% to 25% window area to floor area ratio is a well known daylighting rule of thumb proposed by various researchers in Europe and in the United States. However, very few researchers have provided testimony to the applicability of this rule in other regions. A previous daylighting simulation work using Lumen Micro 8 has testified to the validity of this rule of thumb in Sydney, Australia. The current simulations carried out using AGi-32 lighting software cover latitudes deviations away from Sydney to include those closer to the Equator and the South Pole. The daylighting simulations also address variations in window area to floor area ratios. The limitations of the window area to floor area ratio rule of thumb in other latitudes are thus identified.

Conference theme: Architectural
Keywords: daylighting, latitude variations, rule of thumb, simulations

INTRODUCTION

R.G. Hopkinson (1964, p. 3), an eminent illumination scientist has suggested that adequate daylight factor of not less than 2% can be obtained with window area to floor area ratio of approximately 20% to 25%. This rule of thumb has also been prescribed for classrooms by E.R. Robson, the architect for the London School Board in the 19th century (Wu & Ng, 2002; Wu & Ng, 2003). This rule of thumb has a long history and is implicit in the work of classical architects such as Palladio (1979), Morris (1971) and Gwilt (1982). Their daylighting principles although expressed in different terms can be condensed into this simple rule (Nik Ibrahim, 2002). A question is raised whether this rule is suitable outside the regions where the rule was originally prescribed - for example in other latitudes. In this work, daylighting simulations were carried out on different latitude angles to test the rule validity.

OBJECTIVES

The main objective of the lighting simulations carried out is to test whether the 20% to 25% window to floor area daylighting rule of thumb can be applied for rooms located on different latitude angles. The simulations also seek to determine the limiting latitude angle where the rule can be applied.

METHODOLOGY
The experiments consist of two groups of daylighting simulations. The first group comprises of rooms with 20% window area to floor area located on different latitudes. The second group involves rooms of different sizes with varying window area to floor area percentages. The first simulation group consists of rooms with 100 m² floor area and located on varying latitudes in southern hemisphere, ranging from 5° to 65°. As the longitude angle is fixed at 150° East, these latitudes variations can be regarded as deviations from Sydney (-35° South; -150° East). All rooms in this simulation group conform to a daylighting rule of thumb 20% window area to floor area ratio and has a standard ceiling height and an average interior surface reflectance of 0.5. The objective of the first simulation group is to test the validity of this rule under different latitudes. The second simulation group consists of rooms with varying floor areas ranging from 9m² to 225m² and window area to floor area ratios ranging from 10% to 50%. The rooms, located in Sydney and Kuala Lumpur, have standard ceiling height and average interior surface reflectance. The objective of the second simulation group is to test the range of window area to floor area ratios which are sufficient for daylighting. The independent variables and dependent variables of both simulation groups are shown in Fig. 2.

Daylighting simulations were conducted using a lighting software, AGI-32 which has been validated against CIE Technical Report (CIE 171:2006) - Test Cases to Assess the Accuracy of Lighting Computer Programs (Dau Design & Consulting, 2007).

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**THE 1st GROUP OF DAYLIGHTING SIMULATIONS**

The illuminance performances of the first simulation group are shown in the following graphs.

**Figure 3a: Centreline illuminance of Typological Series 22 under an overcast sky (latitude angles in degrees).**
In Fig. 3a, Fig. 3b and Fig. 3c, centreline illuminance and illuminance distributions on the workplanes decreased as the rooms were located on higher latitude angles. The illuminance range between a room’s front and rear was larger under an overcast sky than under a clear sky. However, centreline illuminance variations between different rooms were greater under a clear sky than an overcast sky and this was even apparent at the back of rooms.

Figure 4: (i) Average illuminance versus latitude angles and (ii) Minimum illuminance versus latitude angles.
Average illuminance decreased linearly with higher latitude angles as shown in Fig. 4(i). From Table 1, ‘cheerfully daylit’ conditions or 5% average daylight factor (average illuminance of approximately 560 lux under the simulation overcast sky) can be achieved inside rooms located on latitude angle not more than 40°. This seems to suggest that the 25% window to floor area is applicable in area with the latitude angle of 40° and lower. Under a clear sky, average interior illuminance of not less than 500 lux can be maintained within latitude angles (θ_L) not exceeding 55°.

Table 1: Average illuminance and the latitude angles.

<table>
<thead>
<tr>
<th>South Latitude Angles (ROT A_w/A_f = 20 %)</th>
<th>Average Illuminance (Lux)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overcast Sky</td>
<td>Clear Sky</td>
</tr>
<tr>
<td>05° - 10°</td>
<td>05° - 30°</td>
</tr>
<tr>
<td>15° - 25°</td>
<td>35° - 40°</td>
</tr>
<tr>
<td>30° - 35°</td>
<td>45° - 50°</td>
</tr>
<tr>
<td>40°</td>
<td>55°</td>
</tr>
<tr>
<td>45° - 50°</td>
<td>60°</td>
</tr>
<tr>
<td>55°</td>
<td>-</td>
</tr>
</tbody>
</table>

For average illuminance of not less than 500 lux:

θ_L ≤ 40° (overcast sky)  
θ_L ≤ 55° (clear sky)

Where,

θ_L - latitude angle (in degrees)

The linear correlations in Fig. 4 (i) can be represented by the following simple equations or rules of thumb.

\[ E_{avg} \approx 1200 - 18 \theta_L \text{ (overcast sky)} \]  
\[ E_{avg} \approx 1600 - 20 \theta_L \text{ (clear sky)} \]

Where,

\[ E_{avg} \] - average illuminance (lux)

As shown in Fig. 4 (ii), minimum illuminance also decreased linearly with higher latitude angles. Minimum illuminance was approximately two times larger under a clear sky than an overcast sky. In Table 2, minimum illuminance of 100 lux and above under an overcast sky can only be attained inside rooms located at lower latitudes of 25° and below. Therefore, large rooms such as those in the simulations with 25% window area to floor area ratio, can only fulfill minimum illuminance requirement at lower latitude angles.

Table 2: Minimum illuminance and south latitude angles.

<table>
<thead>
<tr>
<th>South Latitude Angles (ROT A_w/A_f = 20 %)</th>
<th>Minimum Illuminance (Lux)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overcast Sky</td>
<td>Clear Sky</td>
</tr>
<tr>
<td>-</td>
<td>05° - 25°</td>
</tr>
<tr>
<td>-</td>
<td>30° - 45°</td>
</tr>
<tr>
<td>05° - 25°</td>
<td>50° - 60°</td>
</tr>
</tbody>
</table>

For minimum illuminance of not less than 100 lux:

θ_L ≤ 25° (overcast sky)  
θ_L ≤ 60° (clear sky)

Where,

\[ E_{min} \] - minimum illuminance (lux)

\[ E_{min} \approx 160 - 2 \theta_L \text{ (overcast sky)} \]  
\[ E_{min} \approx 430 - 5 \theta_L \text{ (clear sky)} \]

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From the simulations, identical rooms at different latitudes obtained similar average daylight factor under an overcast sky. However, average illuminance levels inside these rooms were different at different latitudes. Therefore, if 2% average daylight factor can provide sufficient average illuminance level for a task in one location it may not necessarily be sufficient for another location at different latitude angle. Inversely, average ‘daylight factor’ under a clear sky is different in different latitude angles.

Daylighting equation proposed by Littlefair (1996) as shown below is frequently used for calculating average daylight factor for interiors. As all rooms in these latitudes have similar daylight factor under an overcast sky, Littlefair’s equation is modified to provide a ‘daylight factor’ rule under a clear sky for different latitudes. Littlefair’s daylight factor formula is divided by $90^\circ - \theta_L$ and then multiplied by 10 ($\theta_L$ is latitude angle in degrees). The correlations between daylight factors derived from this calculation and those obtained from the simulations are shown in Fig.5 (i).

$$DF_{avg} = \frac{\tau_w A_g \theta}{A_s (1 - R^2)} \times 10$$

Where,

- $DF_{avg}$: average daylight factor
- $A_g$: window glazing area ($m^2$)
- $\tau_w$: transmission of window glazing (in this case 0.9)
- $\theta$: sky angle measured at the center of the window in degrees
- $A_s$: total area of the room surfaces: ceiling, floor, walls and windows ($m^2$)
- $R$: the average reflectance (in this case, 0.5).

The linear correlations in Fig. 5 (i) can be represented by the following equations.

$$DF_{avg(c)} = 0.1994 \left( \frac{\tau_w A_g \theta}{A_s (1 - R^2)} \right) \times \frac{10}{90^\circ - \theta_L} \quad (R^2 = 0.8256)$$

$$= 215 \left( \frac{A_g}{A_s} \right) \left( \frac{1}{90^\circ - \theta_L} \right) \quad \%$$

(10)

If $A_s$ is substituted with $A_f$ [as shown in Fig. 5 (ii)], then the following equation can be generated,

$$DF_{avg(c)} = 0.6736 \left( \frac{\tau_w A_g \theta}{A_f (1 - R^2)} \right) \times \frac{10}{90^\circ - \theta_L} \quad (R^2 = 0.8256)$$

$$= 727 \left( \frac{A_g}{A_f} \right) \left( \frac{1}{90^\circ - \theta_L} \right) \quad \%$$

(11)
As the rooms conforms to the 25% window area to floor area ratio ($A_g/A_f$), equation (11) can be simplified into the following rule.

\[
\text{DF avg(c)} \approx 180 \left( \frac{1}{90^\circ - \theta_L} \right) \% \quad (12)
\]

**THE 2\textsuperscript{nd} GROUP OF DAYLIGHTING SIMULATIONS**

The 2\textsuperscript{nd} simulation group was carried out for two geographical location, that of Sydney, Australia (-35°S, -150°E) and Kuala Lumpur, Malaysia (2.6°N, -102°E). This also constitutes a latitude angle range of between 0° to 35°. The correlations between average illuminance (under overcast and clear skies) and window area to floor area percentage in Sydney and Kuala Lumpur are shown in Fig. 6 and can be represented by the following equations.

(i) 

\[ E_{avg} \approx 3400 \frac{A_g}{A_f} \quad \text{(overcast sky, Sydney)} \quad (13) \]

(ii) 

\[ E_{avg} \approx 6000 \frac{A_g}{A_f} \quad \text{(overcast sky, Kuala Lumpur)} \quad (14) \]

\[ E_{avg} \approx 2900 \frac{A_g}{A_f} + 450 \quad \text{(clear sky, Sydney)} \quad (15) \]

\[ E_{avg} \approx 4400 \frac{A_g}{A_f} + 650 \quad \text{(clear sky, Kuala Lumpur)} \quad (16) \]

Based on Fig. 6 (i) and (ii), if the average illuminance over 1000 lux under an overcast sky is considered too bright, then window with glazing ratio to floor area above 15% in Kuala Lumpur might need some form of shading. This might not be so crucial in Sydney with a window area to floor area ratio of up to approximately 30%. This finding seems to question the integrity of the 20% to 25% window area to floor area rule.

From the equations (13 and 14), average illuminance under an overcast sky is approximately 1.8 times larger under an overcast sky and 1.5 times larger under a clear sky inside rooms in Kuala Lumpur than those with similar parameters in Sydney. However as shown in Fig. 7, the daylight factor equation or rule of thumb for both geographical locations is similar.

The correlations in Fig. 7(i) and (ii), can be represented by the following simple rule. This coincides with a rule of thumb proposed in a previous article (Nik Ibrahim, et al., 2008).
DF_{avg} = 30 \left( \frac{A_w}{A_f} \right) \% (Sydney and Kuala Lumpur) (17)

Figure 7: Average Daylight Factor vs. Window Area to Floor Area Percentage for (i) Sydney and (ii) Kuala Lumpur.

This limited analysis indicates that in both regions with different latitude angles the daylight factor rule of thumb, $DF_{avg} = 30\left(\frac{A_w}{A_f}\right)\%$, is applicable. However, one has to remember that a room in Kuala Lumpur can yield higher average illuminance. For example, a room with a standard interior surface reflectance and window glazing transmittance, with a 25% window area to floor area ratio can provide an approximately 2% daylight factor in both Sydney and Kuala Lumpur. However, the illuminances on external horizontal planes under overcast skies are 11,156 lux in Sydney and 19,662 lux in Kuala Lumpur (Nik Ibrahim, et al., 2009), therefore, average illuminances inside the rooms in the two geographical locations are 187 lux and 330 lux respectively. Therefore, the average daylight factor may be adequate to provide ‘daylit appearance’ in both Kuala Lumpur and Sydney but it may not fulfill similar task illuminance requirement.

By contrast, the ratio of interior illuminance to exterior illuminance on the horizontal plane under a clear sky is not similar in Sydney and Kuala Lumpur due to different sun positions and sky luminance distributions. Therefore, a similar room in these two different regions cannot bear similar average clear sky ‘daylight factors’ and thus cannot rely on a similar rule under a clear sky. Under an overcast sky, all rooms demonstrate a similar value of daylight factor but under a clear sky, rooms located on higher latitudes obtain a lower ‘daylight factor’.

CONCLUSIONS

In summary, latitude angle plays an important role in determining the applicability of window area to floor area ratio rule of thumb. This demonstrates the limitation of daylight factor recommendation and rule of thumb proposed in a particular region such as the one by Hopkinson. As a general rule based upon rooms with 25% window area to floor area ratio, average illuminance of not less than 500 lux under an overcast sky can be obtained if latitude angle does not exceed 40°. For these rooms category, average illuminance under an overcast sky is approximately equivalent to $6(200-3\theta_L)$. As daylight factor in different geographical latitudes yields different average illuminance levels, the 20-25% window area to floor area rule as proposed by Hopkinson and others in temperate regions might be too bright for the Tropics. In addition, a simple ‘daylight factor’ rule is proposed for rooms with 25% window area to floor area ratio in different latitudes under a clear sky. Clear sky ‘daylight factor’ is approximately 180 times the inverse of $90°-\theta_L$. This rule is applicable only if the room’s window is facing away from a direct sun.

REFERENCES


