OPTIMIZATION OF THE WORKING PLANE FOR DAYLIGHT USE IN WINTERS THROUGH THE SOUTH FAÇADE WITH OVERHANG WIDTH VARIATION IN MID WESTERN INDIA

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Abstract
For the past few years daylight design of buildings that is one of the essential techniques of passive solar architecture has gained much attention. This contribution tries to depict the quantitative performance of illuminance on the working plane through a computer model, which was developed using established sky luminance and interior illuminance models. Computations have been performed through a window on the South façade with overhang width variation in winter at Indore. Daylight contours of both direct and diffuse illuminance have been plotted. Optimized position of the working plane for illuminance on various tasks has been determined with optimum overhang width.

Keywords: Sunlight, Skylight, Daylight, luminous efficacy, illuminance

Introduction
It has been established that work productivity of humans increase if the working plane is day lit. The concept of daylight design of buildings is not new as our historical buildings exhibit excellent design elements. In the modern context of daylight design by incorporating prediction techniques through mathematical models a reduction in energy costs can be achieved.

The first research work on daylight was attempted by Moon & Spencer [1] and on other than overcast or clear skies i.e. for ‘average skies’ by Littlefair [2] and ‘intermediate’ skies by Nakamura et al [3]. Perez et al [4] developed the ‘all weather’ model using three parameters of sky clearness, sky brightness and the zenith angle based on the global and direct irradiance measurements. Recently S. Darula and R. Kittler [5] presented new method of sky luminance estimation based on luminance gradation and indicatrix function, which was chosen to predict the sky luminance at Indore.

Table 1: Hourly horizontal irradiance for December month at Indore, W/m\(^2\)

<table>
<thead>
<tr>
<th>Month</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec. (global radiation)</td>
<td>0</td>
<td>47</td>
<td>225</td>
<td>418</td>
<td>590</td>
<td>710</td>
<td>753</td>
<td>71</td>
<td>418</td>
<td>225</td>
<td>47</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Dec. diffuse radiation</td>
<td>0</td>
<td>29</td>
<td>104</td>
<td>136</td>
<td>131</td>
<td>126</td>
<td>126</td>
<td>126</td>
<td>131</td>
<td>136</td>
<td>104</td>
<td>47</td>
<td>0</td>
</tr>
</tbody>
</table>

Mathematical modeling for illuminance distribution inside a room

The horizontal illuminance of the daylight entering in a room has three components: the beam illuminance \(E_{b,r}\), the diffuse illuminance \(E_{d,r}\), and the reflected illuminance \(E_{r,r}\). In this paper for calculation purposes the reflected illuminance was not considered.

Beam illuminance: To calculate the interior horizontal beam illuminance \(E_{b,r}\) of the daylight, equation (1) has been used.

\[
E_{b,r} = \tau_w (\theta_i) E_b
\]

where \(\theta_i\) is the angle of incidence and \(\tau_w (\theta_i)\) is the light transmittance through the window.

To calculate the light transmittance of the window, equation (2) has been used.

\[
\tau_w (\theta_i) = 0.118 \tau_w (0) \cos \theta_i (1 + \sin^3 \theta_i)
\]

where \(\tau_w (0)\) is the light transmittance of window with the 0 angle of incidence.

The outdoor horizontal beam illuminance \(E_b\) is calculated from the outdoor horizontal beam irradiance \(G_b\).
where $K_b$ (lm/W) is the luminous efficacy of the beam radiation calculated through [9,10].

To find out whether the sun is visible to the point of reference, first the solar altitude $\alpha_s$ and solar azimuth angle $\gamma_s$ are calculated and then the altitude and azimuth angles of the edges of the window seen by the observer $O$ inside the room are calculated.

The sun is visible to the observer $O$ if:

$$\theta_1 < \alpha_s < \theta_2$$

and $\gamma_1 < \gamma_p < \gamma_2$

where $\gamma_p = \gamma_s - \gamma_w$

where $\gamma_w$ is the azimuth of the normal to the window in radians.

and $\theta_i$ is the altitude angle of the lower edge of the window relative to the observer $O$.

(Radians)

$$E_d = \frac{\tau_o L}{2} \left( \tan^{-1}\left( \frac{w_l}{z} \right) - \frac{z}{\sqrt{w_h^2 + z^2}} \tan^{-1}\left( \frac{w_l}{\sqrt{w_h^2 + z^2}} \right) \right)$$

where $w_l$ is the length of the window in meters and $w_h$ is the height of the window in meters as shown in figure.

A general case of equation (18) is given by (Vartiainen & al., 2000) [11]

$$E_d = \frac{\tau_o L}{2} \left( \frac{z}{\sqrt{h_o^2 + z^2}} \tan^{-1}\left( \frac{w_x + w_y - x_o}{\sqrt{h_o^2 + z^2}} \right) + \tan^{-1}\left( \frac{x_o - w_i}{\sqrt{h_o^2 + z^2}} \right) \right)$$

where $w_x$ is the distance between the left edge of the window and left wall in meters.

$x_o$ is the distance between the point of observation $O$ and the left wall in meters.

$h_o$ is the height of point $O$ from the window sill in meters.

$z$ is the distance of the point $O$ from window in meters.

**Daylight prediction with an overhang**

A mathematical model was developed for the estimation of internal illuminance if an overhang as placed on the window.

If an overhang is placed on the window the sky seen through the window would decrease.

Figure 3 illustrates the methodology adopted.
Fig. 2: The shaded and sunlight area of fenestration for interior Illuminance determination

Let $H$ be the total height from the top of the window to the floor, $h_{sh}$ be the portion in shadow, $h_{sun}$ be the portion in sun. Let $P_v$ be the overhang length and $Z$ be the distance of point of observance from the plane of the window.

From similar triangles A and B

$$\frac{P_v}{Z} = \frac{h_{sh}^2 + P_v^2}{\sqrt{h_{sun}^2 + z^2}} \quad \text{and} \quad H = h_{sh} + h_{sun}$$

(6)

Solving and rearranging we get

$$h_{sun} = \frac{H}{1 + \frac{P_v}{z}}$$

(7)

Results and discussion

Room size and Input data

For a typical window of dimensions $2.0 \text{m} \times 1.2 \text{m}$, area $2.4 \text{ m}^2$, the hourly interior illuminance at desk level was estimated for December average day 4 hours before and after noon (8:00hrs through 16:00 hrs for a typical office room of size $6.0 \text{m} \times 4.5 \text{m} \times 3.0 \text{m}$, desk level was fixed at 0.6375m and the sill height was fixed at 0.75m the solar radiation data was taken from [12]. As the interior horizontal illuminance decreases rapidly with the distance from the window therefore it is not sufficient to estimate the daylight availability at a single point in the room so it was decided that the room be divided into grids of $20\text{cm} \times 30 \text{cm}$ resulting in 450 grid points in the interior. Further for calculation accuracy the window was divided into $10 \times 10$ patches resulting in 100 grid points on the window. The normal light transmittance of window was fixed at 0.85.

Daylight contours with no overhang width variation

Composite time averaged contours were plotted for sunlight and skylight from 8am to 4pm, which are, depicted in figures 3 and 4.

Fig. 3: Composite time averaged contours of sunlight with no overhang

It can be interpreted from the above graph that the maximum accessibility of the sunlight is up to the depth of $2.5\text{m}$ grid $(13, S1), (13, S15)$ which is of the order of $1000 \text{ lx}$ so the working plane could be after $2.5\text{m}$ from the window plane. In the mornings and evenings the average illuminance is higher as compared to afternoon because more beam component enters the room during morning and evening hours.

Fig. 4: Composite time averaged contours of skylight with no overhang
It is evident that for an office building where positioning the working plane 3.6m away from the South facing window plane can fulfill the lighting requirement of 300-500lx, grid (18, S1), (18, S15).

**Daylight contours with overhang width variation**

For the aforesaid window the overhang width was varied from 0.3m to 0.9m with 0.3 m increments and again the composite time averaged contours were plotted for sunlight and skylight from 8am to 4pm, which is depicted in figures 5 to 10.

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**Fig. 5:** Composite time averaged contours of sunlight with 0.3m overhang width

**Fig. 6:** Composite time averaged contours of sunlight with 0.6m overhang width

**Fig. 7:** Composite time averaged contours of sunlight with 0.9m overhang width

**Fig. 8:** Composite time averaged contours of skylight with 0.3m overhang width
With increase in overhang width the sunlight is reduced which is evident from figures 3-7. It can be seen that the decrease in illuminance contours during mornings and evenings is 20cms for an overhang of 0.3 m as compared to no overhang which increases to 40cms with an overhang of 0.6m as compared to 0.3m and reduces to 20cms for an overhang width of 0.9m as compared to 0.6m overhang. Further between 11am to 1 pm the decrement is 20cms from 0.3m to 0.6m and there is no appreciable shift from 0.6m to 0.9m-overhang width. Hence it can be inferred that the optimum overhang width should be in between 0.3 and 0.6m. It can be envisaged from figures 5 and 9 that overhang has no appreciable effect on diffuse illuminance farthest of the window since the optimum value of 300-500lx is still in the grid (17, S1), (17, S15) 3.4m away from the South facing window plane. However the effect on skylight reduction can be seen nearer to the window.

Comparing figures, it is evident that an overhang width has no significant effect on the diffuse light where the desired lighting requirement is needed in the room therefore choice of 0.45m overhang width is beneficial as far as cost is concerned.

Having determined the overhang width the position of working plane for different tasks was determined. Table 2 [3] shows the requirement of illuminance level for different tasks.

Table 2: Illuminance level requirements for different tasks

<table>
<thead>
<tr>
<th>Location</th>
<th>Illuminance levels (lx)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Library/classroom</td>
<td>300</td>
</tr>
<tr>
<td>General office</td>
<td>500</td>
</tr>
<tr>
<td>Work bench</td>
<td>500</td>
</tr>
<tr>
<td>Drawing office</td>
<td>500-750</td>
</tr>
<tr>
<td>High precision tasks</td>
<td>1500</td>
</tr>
</tbody>
</table>

The requirement of 300lx for a library, 500 lx for general office building, 700 lx for drawing area and 1500 lx for high precision task can be achieved at a distance of 4.6m grid (S1, 23), 3.8m grid (S1, 19), 3.4m grid (S1, 17), 2.4m grid (S1, 12) respectively from the window plane and the necessary requirement of illuminance after this distance can be augmented by artificial light. Further the placement of desk can be either on the east grid (8, S15) or west grid (8, S1) facing as far as day lighting is concerned.
Conclusions

The optimum illuminance level on work plane for common tasks have been determined through a window placed on South façade at Indore of width to height (w/h) ratio of 1.66 and area 17.7 % of the façade area with overhang width variation. The optimal overhang width at the orientation has been also determined. It has been observed that an overhang width of 0.45m would be optimum for both daylight and cost considerations. It was also seen that the effect of overhang width on skylight and sunlight is more prominent nearer to the window plane and after a distance of 2.4m and farther visual comfort for various tasks can be achieved. For the aforesaid overhang width, length of the working plane from the window plane to breadth of the room (l/b) ratio of the placement of task area should be 1.02, 0.84, 0.75, 0.53 respectively for library, general office, drawing office, high precision task areas respectively. The areas under visual comfort were found to be 20.7 m$^2$, 17.1 m$^2$, 15.3 m$^2$, 10.8 m$^2$ respectively which is of the order of 76.6%, 63.3%, 56.6%, 40% of the room area respectively provided the areas where the illuminance falls less than the required number, and are supplemented with artificial light.

References