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Determination of Sun-rays Factor of Solar Breakers in Humid Tropical Climates

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Abstract: This study presents a quantitative assessment of sun-breaker effects and determines the necessary conditions for an opening sun-break. Horizontal and vertical sun-breaker models were presented. For horizontal model, the sun-rays factors were determined as function of the width of the mask. The results showed optimization of mask to be considered for horizontal sun-breaker. For vertical model, sun-rays factors were also determined as function of ratio and angle of opening for vertical sun-breaking. Parameter efficiency was defined and calculated to evaluate the utility and the quality of sun-breaker. The model of Bird-Hulström was used to calculate radiance components.

Key words: Sun-breaker, sun-rays factor, thermal comfort, buildings, envelope

INTRODUCTION

In the context of lasting development, thermal comfort in buildings is obtained through adapted design devices. In order to control the heating, daylighting and cooling abilities of structures, several investigations have been made either on the envelope (Vijayalakshmi *et al*., 2006; Sharifah and Sheau-Jiunn, 2004; Littlefair, 2001; Saraka, 1999; Mills, 1997), or integrating devices (Greenup and Edmonds, 2004; Abd El-Wahab *et al*., 2003; Mwaniki, 1998).

Among the measures taken by designers to limit the solar rays capturing, sun-breakers in humid tropical regions are the oldest and the most current method for openings and screens for opaque surfaces. But if these devices are current and their effects obvious, however they are less known quantitatively and they are hardly expressed by meaningful factors.

We present in this study a quantitative assessment of these effects and the conditions for an effective opening sun-breaking.

MATERIALS AND METHODS

We consider masks that form part of the architecture of the building and that present some vertical plan shifts of awnings or roof-canopy.

We study simple horizontal sun-breaker, or roof-canopy, suitable for North or South orientations and vertical sun-breaker generally made of numerous vertical blades, adapted to East and West orientations.

This study requires direct, diffuse and global solar radiance determination. It describes the factor in relation with the weakening of the natural lighting for the different types of sun-breakers. The model of Bird-Hulström (Saraka, 1999) is used to calculate radiances. Three components of radiance have been considered: Φ_D, directly from sun; $R_{d\beta}$, from the ground; $\Phi_{d\beta}$, from the sky.

Horizontal sun-breaker model description: Horizontal sun-breaker (Fig. 1) may shade the direct radiance and partly obscure the view of diffuse sky. So with a constant width l of mask, the diffuse illuminance reaching a point of the opening with elementary height of Δy, is given by the relation:

$$\Phi_{dm} = \left(\frac{4\Phi_d}{\pi}\right) \cdot \sum_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \left(\frac{\mathrm{Arctan}\left(\frac{\Delta y}{1}\cos\varphi\right)}{2} + \frac{\sin\left(2 \cdot \mathrm{Arctan}\left(\frac{\Delta y}{1}\cos\varphi\right)\right)}{4} \right) \qquad (1)$$

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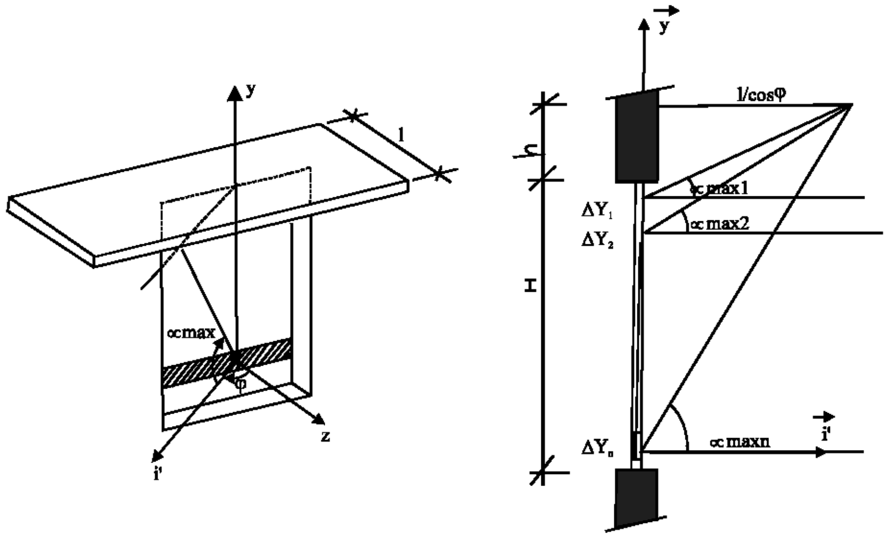

Fig. 1: Profile diagram for diffuse sun-rays factor

where, Φ_d is the diffuse radiance reaching the point of the opening without mask. α and φ are, respectively the height and azimuth of the considered direction.

Without mask α varies between 0 and $\pi/2$, whereas with the mask the values α and φ are, respectively

$$0 \le \alpha \le \alpha_{max} \text{ and } -\frac{\pi}{2} \le \varphi \le \frac{\pi}{2}$$

sun-rays factor f_e defined as $f_e = \phi_{dm}/\phi_d$ depend on Δy. Thus, the average diffuse sun-rays factor f_d is determined.

Similarly, considering the received direct irradiation by the opening (Fig. 2) lasting all day, the direct sun-rays factor is expressed as:

$$f_D = \frac{\sum_{n=0}^{24} H_{sn} \cdot E_n}{E_j \cdot H} \qquad (2)$$

where, H_{sn} is the height of a part of the opening receiving a direct irradiation E_n and E_j the direct irradiation received during all day by the collector or the opening without the horizontal mask.

H_{sn} is determined by the relation below:

$$Hsn = H + h - \left(\frac{1}{\cos(\eta - \xi)}\right) \mathrm{Tan}(\gamma) \qquad (3)$$

γ is solar altitude and η is solar azimuth. H is the height of the opening and h is the distance between the upper side of the opening and the mask. ξ is the orientation of the opening with regard to northern hemisphere and l is the width of the mask.

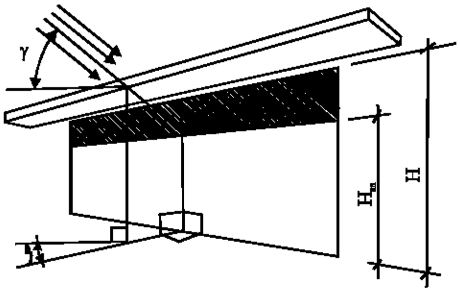

Fig. 2: Configuration for direct sun-rays factor

Final sun-rays factor (mean) of horizontal sun-breaker is defined as:

$$f_{gh} = \frac{f_d \Phi_{d\beta} + R_{d\beta} + f_D \Phi_D}{\Phi_{d\beta} + R_{d\beta} + \Phi_D} \qquad (4)$$

Vertical sun-breaker model description: In the case of vertical mask (Fig. 3), the incident flux is the one of the diffuse solar radiance coming from the sky and ground (Tregenza, 1995).

The vertical mask is characterized by an angle of opening noted as ω and a ratio of opening r given below:

$$r = \frac{L_2}{L_g} \qquad (5)$$

$$0 \le r \le 1 \text{ and } 0 \le \omega \le 90°$$

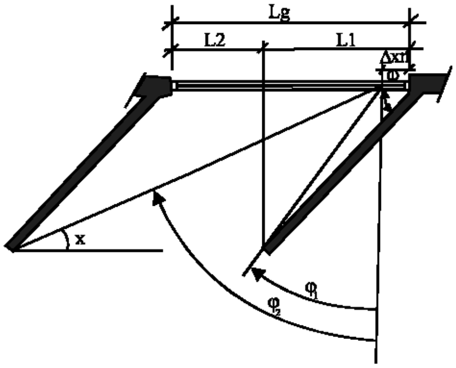

Fig. 3: configuration of vertical sun-breaker

The corresponding sun-rays factor f_e and the average diffuse sun-rays factor f_d were determined as previously. with

$$\Phi_{dm} = \left(\frac{\Phi_d}{2}\right) \cdot \left(\text{Sin}\varphi_2 - \text{Sin}\varphi_1\right) \tag{6}$$

$$0 \le \alpha \le \frac{\pi}{2} \text{ and } \varphi_1 \le \varphi \le \varphi_2$$

$$\text{Tan}\,\varphi_1 = \frac{L_1 - \Delta xn}{L_1 \text{Tan}\omega} \tag{7}$$

$$\text{Tan}\,\chi = \frac{L_1 \text{Tan}\,\omega}{2L_1 + L_2 - \Delta xn} \tag{8}$$

$$\varphi_2 = \frac{\pi}{2} - \chi$$

Considering the direct irradiation received by the opening (Fig. 4) lasting all day, the direct sun-rays factor is:

$$f_D = \frac{\sum_{n=0}^{24} L_{vn} \cdot E_n}{E_j \cdot L_g} \tag{9}$$

with

$$L_{vn} = L_2 - L_m$$

$$L_m = \frac{L_1 \text{Tan}\,\omega}{\text{Tan}\,\eta} \tag{10}$$

L_{vn} is the width of a part of the opening receiving a direct irradiation E_n depending on solar azimuth. L_g is the width of the opening and E_j is direct irradiation received by the opening during a day without vertical mask.

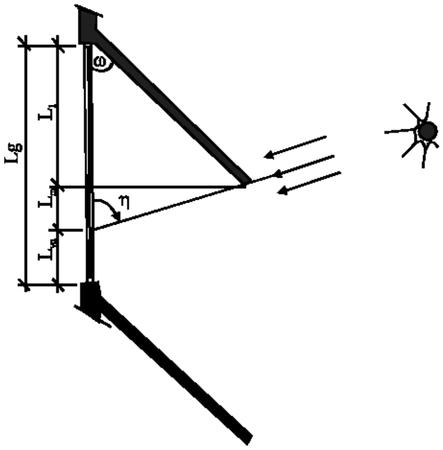

Fig. 4: Configuration for direct sun-rays for vertical mask

Final sun-rays factor (mean) of vertical sun-breaker is defined as:

$$f_{gv} = \frac{f_d\left(\Phi_{d\beta} + R_{d\beta}\right) + f_D \Phi_D}{\Phi_{d\beta} + R_{d\beta} + \Phi_D} \tag{11}$$

Criteria quality of a sun-breaker: For appreciating the utility and the quality of sun-breaker, a parameter efficiency E_f is defined as

$$E_f = \frac{f_l}{f_g} \tag{12}$$

As natural lighting depends on the diffuse radiance whereas the thermal incidental energy is due to the global radiance, f_l and f_g are given below:

$$f_l = \frac{\Phi_{dm}}{\Phi_d} \tag{13}$$

$$f_g = \frac{G_{\beta m}}{G_\beta} \tag{14}$$

Φ_{dm} and $G_{\beta m}$ are, respectively the diffuse and the global mean daily radiance with mask, f_l is the factor of daylighting and f_g is the global sun-rays mean factor due to the mask (horizontal or vertical).

For a surface S of window, the quality of natural lighting is defined by e_{bs} whereas the received thermal energy is expressed by e_{th}.

Thus, the ratio e_{bs}/e_{th} is proportional to ratio $\phi d/G\beta$ with E_f as proportional coefficient:

$$\frac{e_{bs}}{e_{th}} = E_f \frac{\Phi_d}{G_\beta} \tag{15}$$

RESULTS

The most current dimensions used for measurements of opening are 1.30 m height for normal windows, 0.50 m height for windows and 2.30 m height for door-windows or bay glazed.

The results with 1.30 m height for windows are presented here.

Results of horizontal sun-breaker model: Figure 5 and 6 show, respectively the sun-rays factor and the efficiency as a function of width of the mask. The sun-rays factor decreased significantly and became practically constant when the width of the mask was about 1.30 m in June for all latitudes. For the same period, an increasing of efficiency was observed starting from one. The efficiency remained constant as the width of mask equaled or was above 1.30 m. Therefore, the use of mask became absolutely necessary for the north facade during this period. Similar observations have been reported by Mills (1997) using sky view factor.

So, in June and December, the following optimization values shown in Table 1 were proposed as appropriate dimensions for North or South openings according to the north latitudes.

For the other periods, sun-rays factors were almost identical and slightly varied. The Efficiency values in these cases were approximately equal to one. These results could be due to the North facade receiving practically the diffuse radiance. It means that the use of mask is not necessary at these periods.

Results of vertical sun-breaker model: The effects of the vertical sun-breaker model were studied for openings oriented to the East or the West, 0.4 as ratio. Figure 7 and 8 show, respectively the sun-rays factor

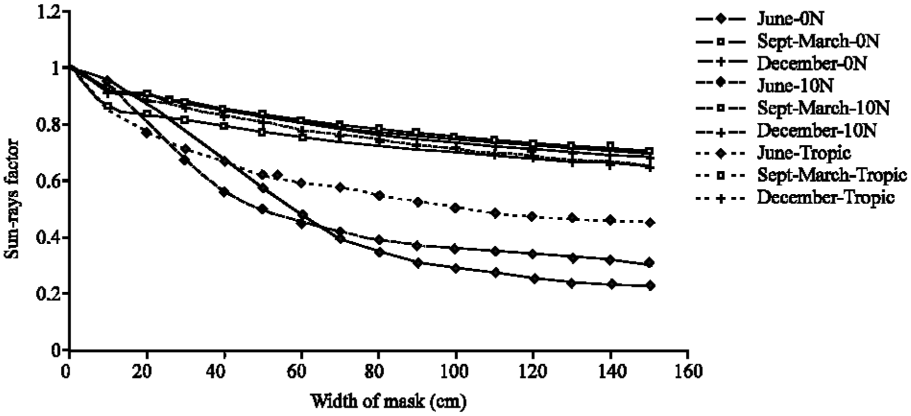

Fig. 5: Sun-rays factor as function of horizontal mask width

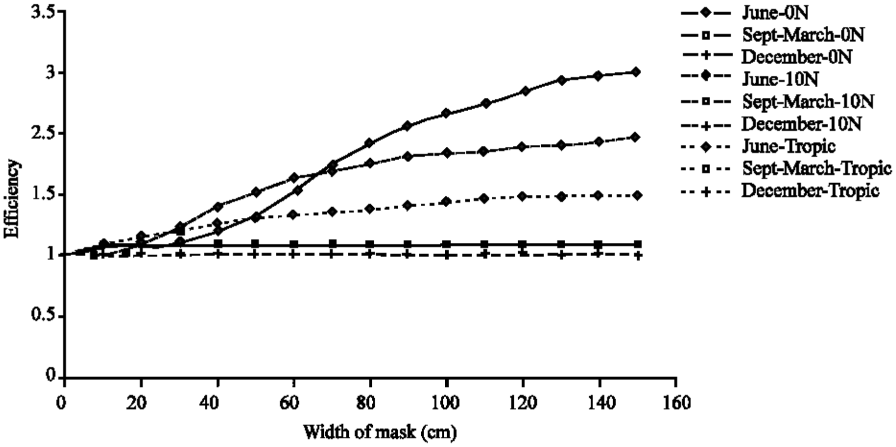

Fig. 6: Efficiency as function of horizontal mask width

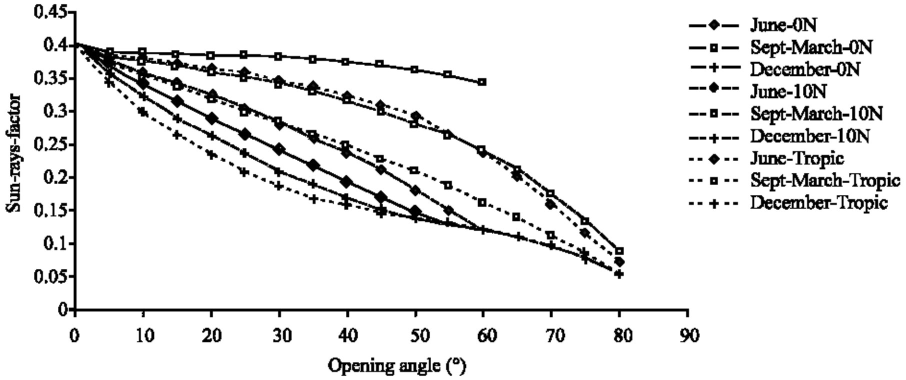

Fig. 7: Sun-rays factor as function of opening angle of vertical mask

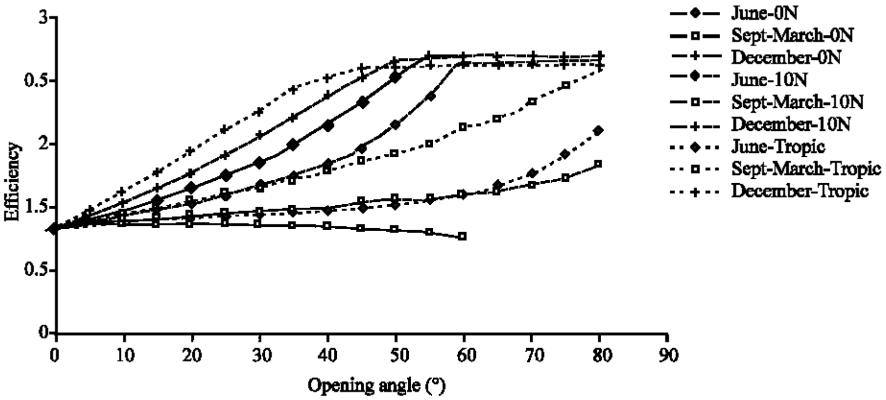

Fig. 8: Efficiency as function of opening angle of vertical mask

Table 1: Optimization of horizontal mask widths

Latitude (°)	Width of mask (m)	Sun-rays factor (%)	Efficiency
0	1.30	30	2.9
10	1.00	35	2.0-2.2
23°26'	1.20-1.30	42-47	1.5-1.53

Table 2: Optimization of vertical mask

Latitude (°)	Ratio (r)	Opening angle ω (°)	Sun-rays factor	Efficiency
0	0.2-0.4	35-55	0.1-0.15	2.6
10	0.2-0.4	35-60	0.1-0.13	2.6
23°26'	0.2	65-75	0.08-0.09	2.6

and the efficiency as function of opening angle. Sun-rays factor decreased whereas an increasing of efficiency was observed. The efficiency remained constant starting from about 55° opening angle especially in December period. It means that vertical sun-breaker presents a great interest to limit solar entrance. Therefore, for efficiency values equal or lower then one, the solar entrance reduction can be obtained with high efficiency by merely decreasing the surface of opening. Thus, the use of mask is not necessary. For different ratio of opening, an asymptote effect was observed in June and December. Therefore the values indicated in Table 2 are well suited for these periods.

CONCLUSIONS

The main aim of this study is to determine the conditions for which an opening sun-breaker presents a specific interest. Two models of sun-breaker were investigated. For horizontal model, the sun-rays factors were determined. Results showed optimization of width of mask to be considered by designers for horizontal sun-breaker adapted for both north and south orientations. In the case of vertical sun-breaker model, sun-rays factors were also determined as function of ratio and angle of opening suitable for East or West orientations. Parameter efficiency was defined and calculated to assess the utility and the quality of sun-breaker.

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