

# METHOD OF ASSESSING THE REDUCTION OF SOLAR HEAT ON WINDOW SURFACE SHADED BY CONTINUOUS VERTICALLY SLANTED SHADING DEVICES

Tran Ngoc Chan<sup>a</sup>, Pham Thi Hai Ha<sup>b,\*</sup>, Pham Van Luong<sup>a</sup>, Nguyen Thi Khanh Phuong<sup>b</sup>

<sup>a</sup>*Faculty of Environmental Engineering, National University of Civil Engineering,  
55 Giai Phong road, Hai Ba Trung district, Hanoi, Vietnam*

<sup>b</sup>*Faculty of Architecture and Planning, National University of Civil Engineering,  
55 Giai Phong road, Hai Ba Trung district, Hanoi, Vietnam*

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## Abstract

The research discusses calibration of the method used to calculate solar heat transfer through shaded windows with continuous vertical slanted shading devices (below is abbreviated as “vertical slanted fins”) with any slant angle  $\theta$  through a radiation reduction coefficient -  $K_{br}$ . In order to evaluate the reduction of solar heat on window surface shaded by shading devices, a designated coefficient  $\beta$  of solar heat gain reduction through glazed windows should be established. It is the ratio of the transmitted amount of solar heat (including direct and diffuse radiation) through windows with shading device  $Q_K$  to those without solar shading device  $Q_{K0}$ . The study also introduces two in-house software programs. These programs help calculating solar heat gain and coefficient  $\beta$  for vertically slanted fins with any slant angle  $\theta$  for 16 window orientations. The results of this study will be applied to the implementation of the Vietnamese national code QCVN 09:2017/BXD towards energy efficiency in buildings.

**Keywords:** sun-shading device; solar protection; vertically slanted shading device; software program for vertically slanted shading device.

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## 1. Introduction

In hot-and-humid tropical countries like Vietnam, intensity of solar radiation in summer is often extreme. An investigation conducted by the Ministry of Construction (MoC) and International Finance Corporation (IFC) [1] showed that air-conditioning systems dealing with this heat account for 40-55% of energy consumption in civil buildings in Vietnam. Proportionally, such energy consumption has a close link to the total heat transmission into buildings, which is mostly caused by glazed windows [2]. The heat transmitted through glazed windows into the room is caused by two factors: the difference in air temperature between indoor and outdoor space and solar radiation rays transmitted into the room (after absorption and reflection processes). However, heat transferred into the room due to difference in air temperature between the indoor and outdoor space is not affected by sun-shading devices.

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\*Corresponding author. E-mail address: [hapth@nuce.edu.vn](mailto:hapth@nuce.edu.vn) (Ha, P. T. H.)

Therefore, to reduce heat from the outdoor environment, only the reduction of solar radiation by glass is considered. Hence, external shading elements are crucial to reducing sun penetration through windows; a well-designed shading system may help to reduce up to 80% of energy consumption amount secured by means of active cooling of buildings [3]. One of the most common systems for the windows with non-cardinal orientations is the continuous vertical slanted fins.

In Russia, shading for windows had not been considered in technical standards of construction. Until 1978, when Dang and Bogoslovskiy proposed a new method of calculating solar heat (direct and diffuse radiation) for installed horizontal and vertical shading devices [4, 5], the shading effect was first considered, followed by other research projects in Russia that also set up new standards and handbooks [6, 7]. Though the efficiency of shading is totally dependent on horizontal and vertical projection angles ( $\beta$  and  $\gamma$  in Table 4 [7]), we still yet unable to calculate the efficiency in case of angles exceeding  $60^\circ$ .

In the United States and Europe, formula calculating the amount of solar heat transferred through the windows were established with two simplest types: horizontal and vertical shading devices that are perpendicular to the attached wall (2017 ASHRAE Handbook – Fundamentals [3] and ISO 52016-1:2017 [8]). In Malaysia, the Standard MS 1525:2014 [9] provided data and ways to find the shading coefficients of three types of external shading devices: horizontal projection, vertical projection and egg-crate shading structures (all perpendicular to the attached wall) with eight window orientations. The Code on Envelope performance for buildings in Singapore [10] also provided tables with Effective Shading Coefficients of three types of external shading devices (continuous horizontal projection, continuous vertical fins array and egg-crate shading structure) with eight window orientations. The tables of Effective Shading Coefficients in the document [10] were represented by horizontal and vertical shadow angles with application angle intervals of  $10^\circ$ . It is, again, impossible to calculate when angles exceed  $50^\circ$ . Furthermore, the handbook [3] and all standards [8–10] did not consider the efficiency of diffuse radiation reduction by shading devices. The energy simulation software programs for buildings, which integrates EnergyPlus or DOE-2, all apply the algorithm approach of ASHRAE handbook and ISO standard. Some studies in recent years [11–23] have mentioned only common external shading devices – continuous horizontal projection, continuous parallel vertical projection, overhang and egg-crate structures (all perpendicular to the mounting wall) – to assess their influence on the cooling load of buildings.

To solve these problems, this study aims to improvise the method to calculate the amount of solar heat transferred through the windows which are shaded by continuous vertically slanted fins. The method will be able to calculate with any angle oblique  $\theta$  while still considering the efficiency of diffuse radiation reduction of the shading devices. To conveniently evaluate the shading effect of external shading devices different times of a day, a designated coefficient  $\beta$  was established. It is the ratio between the transferred amount of solar heat through windows with shading device  $Q_K$  to that without shading device  $Q_{Ko}$ ; lower  $\beta$  would lead to higher energy performance of external shading elements. And based on the proposed calculation method, two in-house software programs have been developed to calculate  $\beta$  with any slant angle  $\theta$  of the vertically slanted fins for 16 different window orientations.

## 2. Materials and methods

### 2.1. Principle of calculation

The modification of the method to calculate the coefficient  $\beta$  considering the reduction diffuse radiation of shading devices ( $K_{br}$ ) is illustrated in the flow-chart below (Fig. 1).

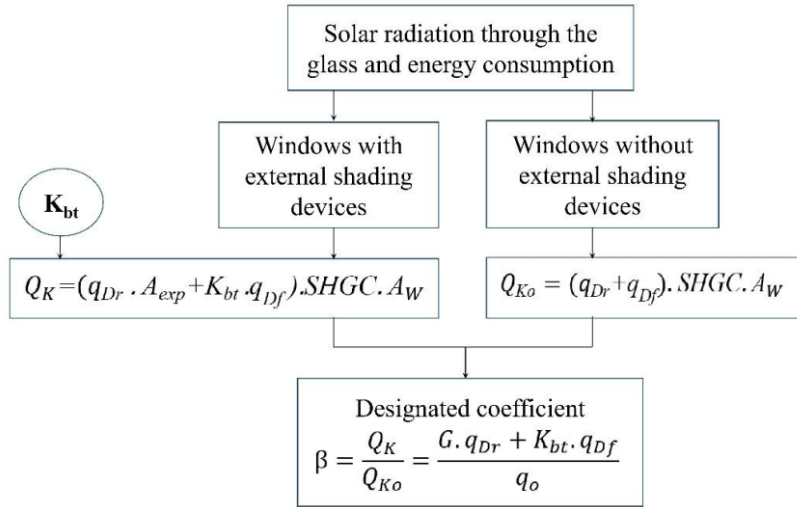


Figure 1. The research flow-chart

#### a. Principle of algorithm

The calculation of all types of sun shading devices is based on the projection of the sunbeam, which passes over the point B of the sun shading OABC area and touches point M (illustrated in Fig. 2).

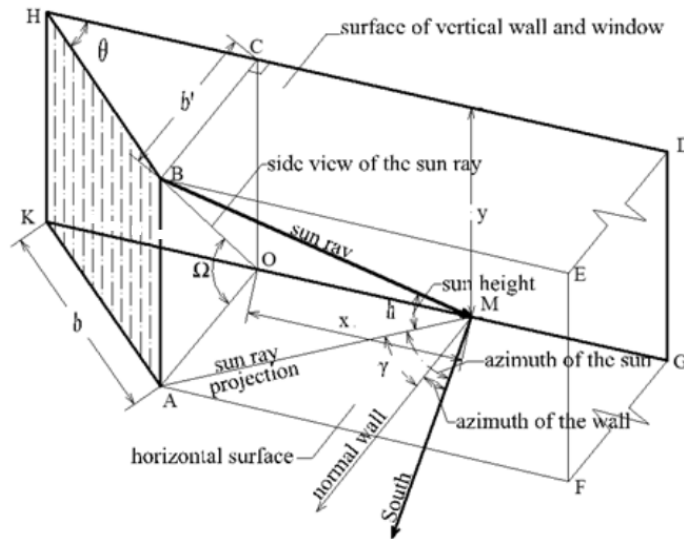


Figure 2. The projection and touch point M of the sunbeam on the window or wall surface in Fig. 2: CDGO - window, ABHK - continuous vertically slanted slabs

The  $x$  and  $y$  coordinates of the point M (of the sunbeam) on the window/wall surface could be determined with the following formulas [3]:

$$\tan \Omega = \frac{\tan h}{\cos \gamma} \quad (1)$$

$$x = b' \tan \gamma \quad (2)$$

$$y = b' \tan \Omega \quad (3)$$

For the vertically slanted shading device ABHK with width  $b$  and slant angle  $\theta$ , as well as with an edge AB, the  $x, y$  coordinates of the point M of a sunbeam could also be defined by the above mentioned formula (2) with the addition (illustrated in Fig. 2):

$$x = b' \tan \gamma = b \sin \theta \tan \gamma \quad (4)$$

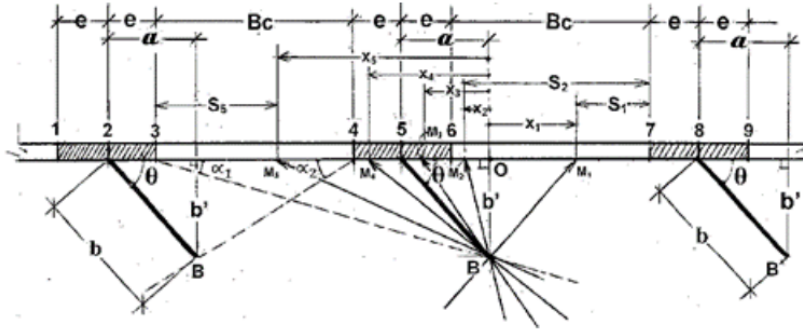


Figure 3. The projection of the horizontal section of the wall and windows with vertical slanted fins at a specific slant angle  $\theta$

In Fig. 3:  $\theta$  is the slant angle of the shading device and the wall surface can take the following values:  $\theta < 90^\circ$ ,  $\theta = 90^\circ$  or  $\theta > 90^\circ$ ;  $a = b \cos \theta$  ( $a > 0$  when  $\theta < 90^\circ$ ;  $a = 0$  when  $\theta = 90^\circ$  and  $a < 0$  when  $\theta > 90^\circ$ );  $M_1, M_2, \dots, M_5$  are touch points of a sunbeam passing through point B;  $x_1, x_2, \dots, x_5$  are abscissa of the point  $M_i$  from the point O,  $m$  (at position  $M_i$  on the right side of point O –  $x_i > 0$ ; opposite side  $-x_i < 0$ );  $S_1, S_2, \dots, S_5$  are the widths of window parts irradiated by sunbeam corresponding to the points  $M_i, m$ .

#### b. Calculation of the exposure coefficient G

When the sun shines on the walls and windows with shading devices, a part of the window surface is exposed by both direct and diffuse radiation. The rest of the window area (the shaded area) is only exposed to diffuse radiation. The exposure coefficient  $G$  can be calculated as follows:

$$G = \frac{A_{exp}}{A_w} \quad (5)$$

From the relative positions of points O and  $M_i$  in Fig. 3, the following formula is applied to calculate width  $S$ :

$$S = Bc + e + k(x + a) \quad (6)$$

The calculation conditions are listed in Table 1.

Notes of formula (6):

- If the value of  $S$  is negative, let  $S = 0$  and the irradiation coefficient  $G = 0 \rightarrow$  the glazed window is entirely shaded;
- If the value of  $S$  is obtained  $Bc$ , let  $S = Bc$  and the irradiation coefficient  $G = 1 \rightarrow$  the glazed window is entirely exposed.

Table 1. Conditions for calculating the coefficient  $k$  in the formula (6)

Slant angle $\theta$	Conditions	Coefficient $k$ in the formula (6)
$\theta < 90^\circ$	$x > 0$	$k = -1$
or $\theta = 90^\circ$	$x < 0$	$k = +1$
$\theta < 90^\circ$	$k = -1$	
	$x < 0$	$k = +1$
$\theta > 90^\circ$	$x > 0$ and $x >  a  + e$	$k = -1$
	$0 < x <  a  - e$	$k = +1$

c. Coefficient of decreasing diffuse radiation over shaded window surface -  $K_{bt}$

From Fig. 3, respective angles  $\alpha_1$  and  $\alpha_2$  are identified by shading devices and edges of the window. These angles represent the limited sky view from windows caused by vertically slanted shades. When  $\theta = 90^\circ$ ,  $\alpha_1 = \alpha_2$ ; the coefficient  $K_{bt}$  depends on  $\alpha = \alpha_1 = \alpha_2$ . From [6], a regression equation  $K_{bt} = f(\alpha)$  was derived for continuous vertical shading devices where  $\theta = 90^\circ$ . The equation is shown as follows:

$$K_{bt} = 2.10^{-5}\alpha^2 - 0.007\alpha + 0.992; \quad \text{with} \quad R^2 = 0.999 \quad (7)$$

where  $\alpha$  is measured in degrees.

For vertically oblique shading devices with any value of  $\theta$ , (Fig. 2):

$$\alpha_1 = \arctan\left(\frac{b \sin \theta}{Bc + e + b \cos \theta}\right) \quad (8)$$

$$\alpha_2 = \arctan\left(\frac{b \sin \theta}{Bc + e - b \cos \theta}\right) \quad (9)$$

Considering  $K_1 = f(\alpha_1)$  and  $K_2 = f(\alpha_2)$  by using the formula (7), the average value of  $K_{bt}$  for slanted shading devices can be calculated, as shown in Fig. 3:

$$K_{bt} = \frac{K_1 + K_2}{2} \quad (10)$$

d. Coefficient of solar heat decreases by shaded windows  $-\beta$

The amount of heat penetrating into the room through the glazed windows of a certain exposure area without any shading device ( $Q_{Ko}$ ) is calculated by the following formula:

$$Q_{Ko} = (q_{Dr} + q_{Df}) \cdot SHGC \cdot A_W \quad (11)$$

The amount of solar heat transferred through windows with shades,  $Q_K$ , is calculated using the two following terms: the area exposed to direct solar radiation  $q_{Dr}$  ( $A_{exp}$ ), and the area total area of the window ( $A_W$ ). Without shading devices, the window is exposed to diffuse radiation  $q_{Df}$ . The existence of shading devices helps reducing that exposure ( $q_{Df}$ ) by coefficient  $K_{bt}$ . Therefore, the solar heat penetrated through the window in case of shading devices can be calculated as follows:

$$Q_K = (q_{Dr}A_{exp} + K_{bt}q_{Df}) \cdot SHGC \cdot A_W \quad (12)$$

A designated coefficient  $\beta$  for the ratio of  $Q_K$  and  $Q_{Ko}$ , as the coefficient of heat gain reduction of solar radiation through the glazed windows, can be calculated with the formula (5):

Since the coefficient of radiation decreased due to the shading effect, it can be derived as follows:

$$\beta = \frac{Q_K}{Q_{Ko}} = \frac{Gq_{Dr} + K_{bt}q_{Df}}{q_{Dr} + q_{Df}} = \frac{q_K}{q_o} \quad (13)$$

All of the values  $q_o, q_{Dr}, q_{Df}$  were calculated using the ASHRAE method [3] for various regions in Vietnam. Expression (12) can be rewritten as the following for  $Q_K$  (note: if there is no sun-shading device,  $\beta = 1$ ):

$$Q_K = (q_{Dr} + q_{Df}) \cdot SHGC \cdot \beta \cdot A_w \quad (14)$$

## 2.2. Development of two in-house software programs

The main purpose of the calculation of solar heat penetrated through windows with shading devices is to calculate the coefficients  $G$  and  $\beta$  hourly in daytime, in each month of the year at a specific location. Two in-house software programs were developed to help calculating of coefficients  $G$  and  $\beta$  for vertical slanted fins with any slant angle  $\theta$  for a total of 16 window orientations.

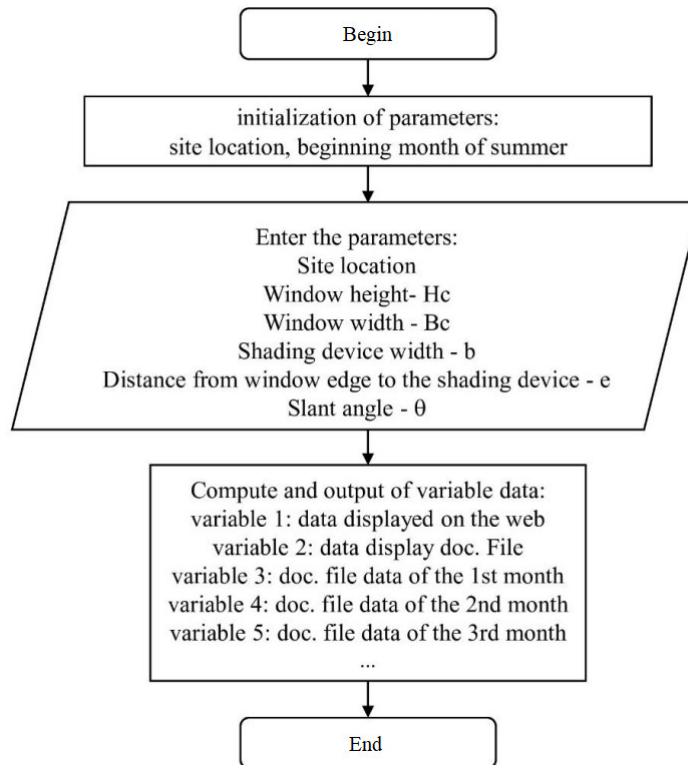


Figure 4. The flowchart of the algorithm

The first program was developed with ASP.net and .Net codes for the calculation of coefficient  $\beta$ . The result is the average value of cumulative  $\beta$  in sixteen cases of window orientations over three representative months in hot seasons. The application also allows the calculation of hourly value of  $\beta$  in these 16 cases for additional analysis on cooling load. The generated files are saved in .docx format.

The second software visualized the shading effects on the façade. It would display the shading elements at different times of a day and provide corresponding values of  $K_{bt}$ ,  $G$  and  $\beta$ . It was developed with DOS-operated TURBO-PASCAL that could be run on Windows OS thanks to DOSBOX. The flowchart of the developed software programs is shown in Fig. 4.

### 3. Results and discussion

The two developed in-house software programs could quickly and accurately calculate the coefficients  $G$  and  $\beta$  when designing the continuous vertically slanted fins with any slant angle  $\theta$ , for a total of 16 window orientations.

Case study: The continuous vertically slanted fins were set for windows with a width of  $B_c = 2.6$  m; shading device width  $b = 1.25$  m; distance from the side edge of the window to the bottom of the shading device  $e = 0.25$  m; slant angles  $\theta$  are respectively  $60^\circ$ ,  $90^\circ$  and  $120^\circ$ ; window orientation: Southwest. Location: Hanoi, Time: on typical day of July.

Using in-house software No. 1: For Hanoi, generated mean values of  $\beta$  over three hot summer months (June to August). This case study was applied for pre-assumed dimensions of windows on eight West-oriented facades with continuous vertically slanted fins (other orientations were not considered since only SW-facing facade was mentioned in the case study). Values of  $G$  and  $\beta$  in July for  $\theta = 60^\circ$  are illustrated in Tables 2 and 3, respectively.

Table 2. Generated mean values of  $\beta$

Parameters	$\beta_{av}$							
	S	SWS	SW	WWS	W	WWN	WN	NWN
$B_c = 2.60$ m; $H = \text{any value}$ ; $b = 1.25$ m; $e = 0.25$ m; $\theta = 60^\circ$	0.742	0.531	0.525	0.688	0.814	0.914	0.923	0.742
$k(L = 0)$	0	2	0	0	1	4	12	0
$m(L = 1)$	35	34	21	19	21	21	21	22
$s(0 < L < 1)$	4	3	18	20	17	14	6	17
$u(\cos d > 0)$	8	21	20	20	18	19	19	18
$v(\cos d \leq 0)$	31	18	19	19	21	20	20	21

where:  $\gamma_1 = 17.30^\circ$ ;  $\gamma_2 = 25.94^\circ$ ;  $K_{bt} = 0.85$ ;  $k(L = 0)$  - taking into account the entire Sun exposition of windows;  $m(L = 1)$  - taking into account the full protection against the Sun thanks to either shading elements or no incidents;  $s(0 < L < 1)$  - taking into account the partial Sun exposition;  $u(\cos d > 0)$  - taking into account the incidents on wall;  $v$  - taking into account that there is no incidents on wall; S - South; SWS - South West South; SW - South West; WWS - West West South; W - West; WWN - West West North; WN - West North; NWN - North West North.

The values of  $G$  and  $\beta$  in July in Hanoi generated by continuous vertically slanted fins applied on eight west-oriented facades (only West-ward orientation is mentioned in the problem and considered) are presented in Table 3.

Table 3. Values of  $G$  and  $\beta$ 

Hours	$G/\beta$							
	S	SWS	SW	WWS	W	WWN	WN	NWN
6	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850
7	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850
8	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850
9	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850
10	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850
11	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850
12	0.856/ 0.851	1.000/ 0.859	0.920/ 0.854	0.331/ 0.837	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850	0.000/ 0.850
13	0.000/ 0.850	0.000/ 0.469	0.425/ 0.598	0.675/ 0.736	0.849/ 0.849	1.000/ 0.948	0.934/ 0.901	0.378/ 0.629
14	0.000/ 0.850	0.000/ 0.370	<b>0.366/ 0.506</b>	0.643/ 0.693	0.822/ 0.829	0.990/ 0.957	0.982/ 0.947	0.523/ 0.638
15	0.000/ 0.850	0.000/ 0.334	0.307/ 0.439	0.612/ 0.661	0.798/ 0.808	0.965/ 0.943	1.000/ 0.968	0.625/ 0.685
16	0.000/ 0.850	0.000/ 0.333	0.234/ 0.370	0.578/ 0.628	0.773/ 0.787	0.939/ 0.924	1.000/ 0.972	0.712/ 0.743
17	0.000/ 0.850	0.000/ 0.373	0.136/ 0.287	0.537/ 0.591	0.745/ 0.762	0.911/ 0.901	1.000/ 0.975	0.793/ 0.804
18	0.000/ 0.850	0.000/ 0.519	0.000/ 0.181	0.483/ 0.545	0.710/ 0.732	0.879/ 0.874	1.000/ 0.976	0.871/ 0.868
$u (\cos d > 0)$	1	7	7	7	6	6	6	6
Average	0.856/ 0.850	0.143/ 0.643	0.341/ 0.641	0.551/ 0.753	0.783/ 0.825	0.947/ 0.885	0.986/ 0.899	0.651/ 0.794

Notes:

- For the row of average values, the left value represents the mean of  $G$  during insolation hours on the vertical surface of given orientation while the right one is the daily mean of  $\beta$ . Bolded texts in Table 3 match the results generated by application 2 that is shown in Fig. 5(a);

- Based on the daily average value of coefficient  $\beta$  (last row of Table 3), the window with solar shading device of  $\theta = 60^\circ$  and given dimensions produces best solar shading efficiency on SW



window orientation (with  $\beta_{av} = 0.641$  - the lowest in comparison with those in other orientations in the Western hemisphere);

- Following the symmetrical principle of solar radiation along the North-South axis at around 12 am (midday), the window-solar shading device system of  $\theta = 120^\circ$  will also produce similar efficiency at 10 am in SE orientation with  $G = 0.366$  and  $\beta = 0.506$ , with the same value of  $\beta_{av} = 0.641$  - the lowest in comparison with those on other orientations in Eastern hemisphere (except North orientation).

Using in-house software program No. 2: the outcomes are drawings of the projections as shown in the horizontal section of the wall and the window with the position of the projections of the sunbeam

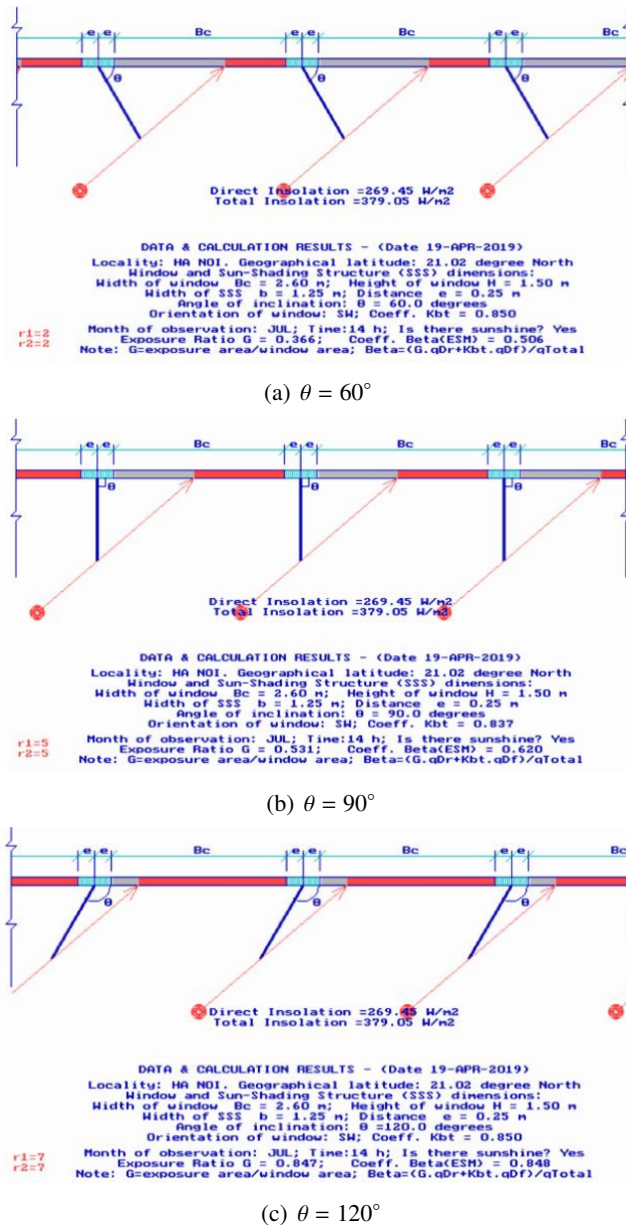


Figure 5. Shadows of vertically slanted fins with slant angle  $\theta$  on the surface of the window facing Southwest orientation at 14 h in July in Hanoi

at each hour of the day and all the relevant data for calculation. For vertical south-west walls oriented in Hanoi in July, solar insolation takes place from 12 h to 18 h. The results of calculations (at 14 h only) are displayed in Fig. 5.

Similar to the mentioned case study above, calculating can be made for vertical walls oriented towards Southwest, in Moscow ( $56^\circ$  N) in July, with solar insolation takes place from 11 h to 19 h. Fig. 6 below displays the results of calculations (at 14 h for comparison purpose).

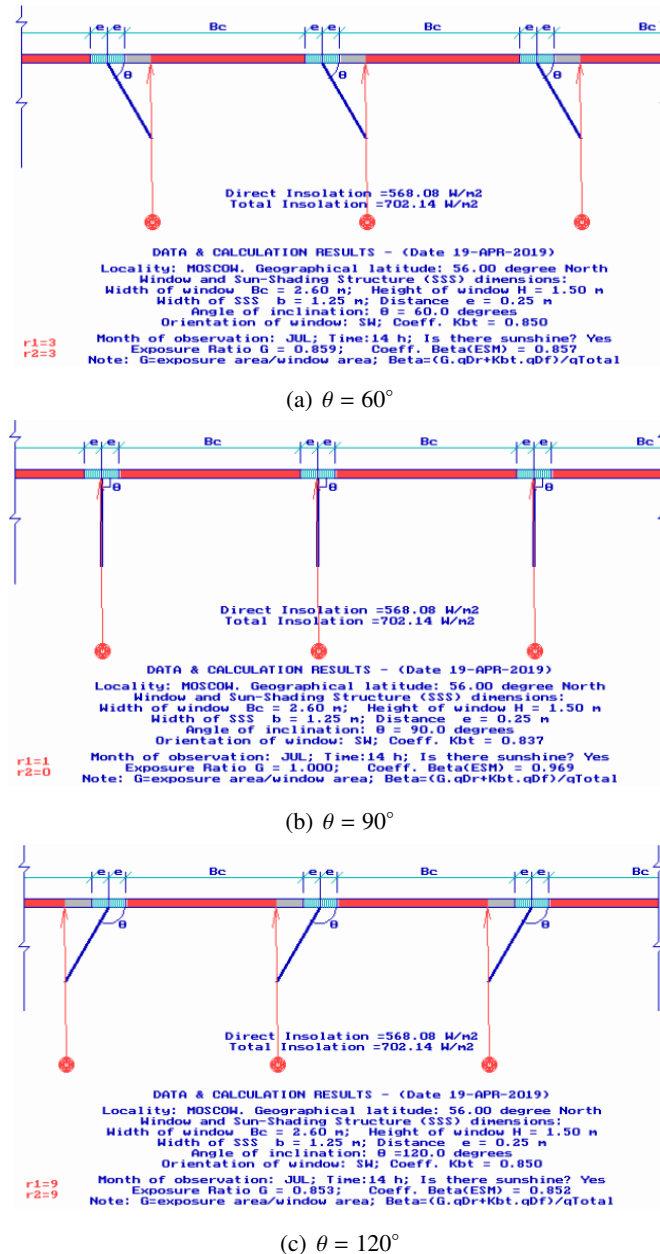


Figure 6. Shadows of vertical slanted fins with angle  $\theta$  on the surface of the window facing Southwest orientation at 14 h in July in Moscow

Using the proposed calculation method, the effect of vertical shading devices standing at different

angles was evaluated for Hanoi and Moscow through the coefficient of radiation decreased by solar shading device  $\beta$ . From the data calculations shown in Fig. 5 and Fig. 6, it is possible to compare the efficiency of sunshading at different values of the angle  $\theta$  (Tables 4, 5 and 6).

Table 4. Intensity of solar radiation irradiated on the window surface with and without shading devices at 14 h in July on Southwest orientation in Hanoi and Moscow

No.	Slant angle ( $\theta$ )	Intensity of solar radiation (illustrated in Fig. 5 and Fig. 6, at 14:00h)					
		Hanoi (21°N)			Moscow (56°N)		
		$q_0$ (W/m <sup>2</sup> )	$q_K$ (W/m <sup>2</sup> )		$q_0$ (W/m <sup>2</sup> )	$q_K$ (W/m <sup>2</sup> )	
			without $K_{bt}$	with $K_{bt}$		without $K_{bt}$	with $K_{bt}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	60	379.05	208.48	191.80	702.14	622.10	601.73
2	90	379.05	252.83	235.01	702.14	702.14	680.37
3	120	379.05	337.73	321.43	702.14	618.59	598.22

Table 5. The result of calculations for windows with the shading devices at 14 h July on the South-West orientation in Hanoi (21.02°N) – (illustrated in Fig. 5)

No.	Slant angle ( $\theta$ )	Parameter					
		$G$	$G_{av}$	$\beta$		$\beta_{av}$	
				without $K_{bt}$	with $K_{bt}$	without $K_{bt}$	with $K_{bt}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	60	0.366	0.341	0.550	0.506	0.740	0.641
2	90	0.531	0.421	0.667	0.620	0.787	0.680
3	120	0.847	0.683	0.891	0.848	0.900	0.802

Table 6. The result of calculations for windows with the shading devices at 14 h July towards the South-West orientation in Moscow (56°N) – (illustrated in Fig. 6)

No.	Slant angle ( $\theta$ )	Parameter					
		$G$	$G_{av}$	$\beta$		$\beta_{av}$	
				without $K_{bt}$	with $K_{bt}$	without $K_{bt}$	with $K_{bt}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	60	0.859	0.560	0.886	0.857	0.820	0.744
2	90	1.000	0.583	1.000	0.969	0.839	0.755
3	120	0.853	0.621	0.881	0.852	0.861	0.784

From Table 5, for the certain conditions, the shading devices prove to achieve more efficiency at the lower values of  $\theta$ . This method and program of calculation can be applied to most locations in

the world. For example, for windows and shading devices of the same sizes but located in Moscow (Russia) -  $56^{\circ}\text{N}$ , the result of the calculations can also be summarized as follows (Table 6).

The differences between the Table 5 and Table 6 are: for Hanoi (Table 5), the order of oblique angles  $\theta$  from the most to the worst efficient is respectively:  $\theta = 60^{\circ}$ ;  $\theta = 90^{\circ}$ ;  $\theta = 120^{\circ}$ ; for Moscow (Table 6), the above order is correct only for the instantaneous values in the columns (4) and (6).

Columns (3) to (8) in Table 4 display the results of  $q_o$  and  $q_K$  at 14 h in July in Hanoi and Moscow. Columns (5) and (7) in Table 5 and Table 6 display the results of the instantaneous coefficient  $\beta$  and the average  $\beta_{av}$  values when the efficiency of diffuse radiation diminished by shading devices ( $K_{bt}$ ) is not considered ( $K_{bt} = 1$ ). The  $\beta_{av}$  value considering the efficiency of diffuse radiation diminished by shading devices in column (8) is less than the  $\beta_{av}$  value in column (7) – from 0.076 to 0.084 for Moscow, and from 0.072 to 0.099 for Hanoi. This means that the amount of solar heat transferred through the glass window considering the efficiency of diffuse radiation diminished by shading devices may differ from the current calculation method of ASHRAE handbook and ISO standard at about 8.9 to 10% for Moscow and from 10.8–13.6% for Hanoi.

#### 4. Conclusions

Through the study, we have calibrated the method for assessing the efficiency of reducing the solar heat transmitted through the glazed window shaded by vertically slanted shading devices with any slant angle for 16 window orientations while still considering the reduction of diffuse radiation. An algorithm and two in-house software programs were also built to help automatically and accurately calculate the values. The results of this study could help finding the most appropriate angle and dimension of vertically slanted shading devices to minimize heat transmission into a room through shaded windows while designing.

However, the current assessment method uses weather data by theoretical calculations; actual measurement of radiation values on the facades to verify the error of the proposed method has not been made. In the next studies, we will evaluate the proposed theory with site measuring.

This method can process long-term climatic data of any location from weather stations or satellites that contains the solar radiation data. Therefore, it can be used in most region in the world.

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## Appendix A.

### Nomenclature

- $M$  the touch points of a sunbeam  
 $O$  the origin point of the coordinate system  
 $x$  coordinate of the point  $M$  from the point  $O$ , m

$y$	coordinate of the point M from the point O, m
$b'$	the width of projection of slant shading device on the vertical surface, perpendicular to the wall, m
$h$	the height of the sun, degrees
$\gamma$	the azimuth of the sun to wall, degrees
$\Omega$	angle of the lateral projection of the sunbeam, degrees
$\theta$	the slant angle of the shading device – the angle between the panel shading device and the window surface; the window is closer to the right of the sun shading device, degrees; ( $0^\circ < \theta < 180^\circ$ )
$\alpha$	angles formed by a panel shading device over the window with a horizontal surface, degrees
$\beta$	the coefficient of radiation decreased by solar shading device
$\beta_{av}$	average coefficient of radiation decreased by solar shading device all day
$b$	the width of solar shading device, m
$a$	width of the projection of the solar shading device on the wall surface, m
$e$	distance from the side edge of the window to the bottom of the shading device, m
$B_c$	width of the window, m
$S$	widths of window parts irradiated by sunbeam corresponding to the contact points $M_i$ , m
$G$	the exposure coefficient, i.e portion of window surface is irradiated by solar radiation
$G_{av}$	average value of exposure coefficient during insolation hours of the day
$A_{exp}$	area of exposed glass, $m^2$
$A_W$	area of window glass, $m^2$
$k$	coefficient in the formula (6), dependent on the different conditions
$K_{bt}$	the coefficient of diminishing diffuse radiation on window surface by solar shading device
$q_{Dr}$	intensity of direct solar radiation, irradiating on the window surface, $W/m^2$
$q_{Df}$	intensity of diffuse solar radiation, irradiating on the window surface, $W/m^2$
$q_o$	total solar radiation intensity, irradiating on the window surface, $W/m^2$
$q_K$	total solar radiation intensity, irradiating on the window surface with solar shading device, $W/m^2$
$Q_K$	the transferred amount of solar heat through windows with solar shading device, W
$Q_{Ko}$	the amount of heat penetrating into the room through the glazing without solar shading device, W
SHGC	solar heat gain coefficient