EVALUATING THE ENERGY PERFORMANCE OF EXTERNAL PERFORATED SOLAR SCREENS: EFFECT OF SCREEN ROTATION AND ASPECT RATIO

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ABSTRACT

External solar screens fixed in front of windows were traditionally used to conserve the cooling energy loads, achieve privacy, shading and daylighting control of buildings in hot climates. Modern perforated wooden solar screens with square or rectangular perforations, and fins perpendicular to screen surface similar to miniature egg-crate sun breakers were tested to investigate the effect of screens rotation on their energy performance.

This paper addresses the combined effect of changing screen rotation angle and aspect ratio on the annual cooling, heating and lighting energy loads. EnergyPlus simulation software was used in conducting series of experiments for a typical residential building.

Conclusions stated that rotating the slats of screen with squared perforation, had no significant effect on energy use. However, for screens with aspect ratios of vertical: horizontal=1:2, 1:4, 1:8 and 1:12, rotation of screens horizontal slats up and down affected the energy savings by up to 16%. Rotating the screen slats up to 30° downwards enhanced the screen energy performance

INTRODUCTION

Window solar gain considerably affects building energy consumption and peak cooling loads. Shading of windows reduces such loads and controls solar gain. The development of historical shading tools such as solar screens to more scientific and advanced forms can help in achieving the modern goals of sustainability and energy conservation, as well as high standard quality of life. Modern perforated wooden solar screens with square or rectangular perforations, and fins perpendicular to screen surface similar to miniature egg-crate sun breakers were tested to investigate the effect of screens rotation on their energy performance.

The paper builds on previous publications by the authors that addressed the energy performance of perforated wooden solar screens. In a previous publication, screen configurations in terms of depth and perforation ration that result in most significant savings were identified. These screens had a depth: perforation ratio of 1:1 with an 80% perforation percentage in the West and North orientations, and a 90% perforation percentage in the East and South orientations. The near optimum range extended from the 0.75 to 1.25 depth ratio, with perforation ratio between 80% and 90% in all orientations. In the West orientation, the highest energy saving was 30% (Sherif et al., 2012). In another related study, the influence of changing the perforation percentage of external perforated solar screens on the thermal performance of desert buildings was examined using the EnergyPlus simulation software. It was found that thermal loads dropped rapidly when screens with high perforation ratios were used. Screens with an 85% perforation rate provided significant energy savings. Reduction of perforation below this rate reduced thermal loads insignificantly. Reduction of the cooling energy was attributed to the substantial decrease in the transmitted solar energy and window heat gain energy (Sherif et al., 2010).

The rotation angle of other shading devices such as louvers ed in several publicaitions. External horizontal and vertical louvers were examined in several locations. TRNSYS software was used in performing the simulation runs, while EES was used in creating the model geometry. Results showed that louvers decreased energy consumption significantly and achieved thermal comfort especially in countries with high intensity solar radiation such as Cairo, Madrid and Lisbon. For countries with cold climatic conditions such as London, mechanical louvers can be rolled up in winter to decrease the heating loads and rolled down to decrease the cooling loads in summer (Palmero-Marrero and Oliveira, 2010).

External fixed horizontal shading devices of different slat lengths and tilts were tested using TRNSYS simulation in four cities in Italy. It was found that optimizing the louvers design decreased the cooling loads in summer achieving significant savings in the annual energy loads. Moreover, Louvers design varied in different locations and weather conditions (Datta, 2001).

The daylighting aspects of solar screens were analyzed in several publications. The effectiveness of solar screens axial rotation on daylighting performance was studied. It was found that for all orientations, as the rotation angle increased, the daylighting increased linearly. Screens rotation angle varied according to the change of orientation, season and time especially in the south and north orientations, where rotation angle from 0° to 30°

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influence was found to be significant in summer. However, for East orientation, the rotation angle influence was found to be significant in winter (Sabry, 2011).The effect of size of the solar screen gaps on reflected sunlight through screens was studied. Daylighting was found to be lower in rounded screens having larger cell diameters. This was attributed to the ratio of openings to solid parts of the screen panels. Screen reflectance was also investigated. It was found that light colored screens increase the average daylighting factor percentage by 17% compared to the dark coloured screens (Aljofi, 2005). Moreover, the average illuminance levels resulting from use of solar screens on windows of a designed living room were measured for different window orientations over a range of day times in different seasons. The resultant quantity of room daylighting was investigated and recommendations for minimum screen perforation were presented. Conclusions were drawn stating the adequacy of these solar screens in terms of luminance values in different orientations, seasons and times (Sherif et al., 2010). Solar screen perforation openings aspect ratio was studied, where the illuminance levels in the clear sky condition location of El Sadat City (30.2˚N - 30.2˚E) was demonstrated. It was found that for South and North orientations, illuminance levels resulting from changing the solar screen opening proportions till 1:6 increased significantly compared to the base case. However, from 1:6 to 1:32 proportions the daylighting performance was slightly enhanced. For East orientation, an increasing trend in daylighting performance was observed by increasing the proportions till 1:12 ratio. Similar results were achieved in the West orientation. Therefore, for all orientations, 1:6 and 1:5 proportions can provide a satisfactory balance between energy efficiency and daylighting (Sherif et al., 2011).

Solar screens of circular openings design and analysis were examined algorithmically by using a generic optimization procedure to control daylighting levels. Altering the openings arrangement of a couple of solar screens generated desirable light and shadow patterns (Lockyear, 2010).

SIMULATION SETUP

Experimentation was conducted using the EnergyPlus simulation software, where the Design Builder application was used as an interface and modeling tool. The architectural parameters were selected according to the principal features of a typical dwelling lounge. Simulations were carried out using the subtropical environment of Kharga Oasis, Egypt, located in the African Sahara. Specific “base case” input parameters were assumed so as to be opening-tuned in order to focus on the thermal effect of using the tested screens. These were detailed in table (1).

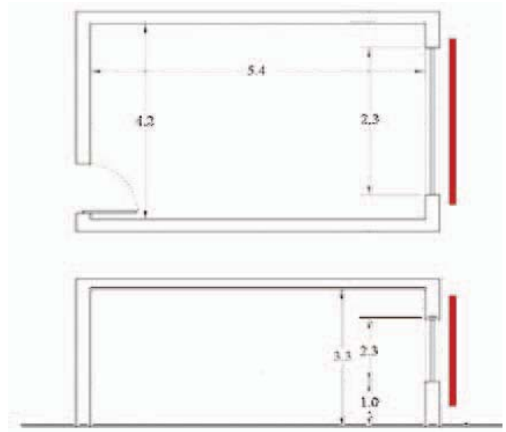

Figure 1 Design space plan and cross section.

The base case is a dwelling lounge isolated from the external environmental thermal changes by assuming that all surfaces, other than the external tested wall, were adiabatic. Thus, three walls, floor and roof were assumed adiabatic. The fourth wall was defined as a 350 mm thick double brick insulated cavity wall with a U- value of 0.475 W/m² –k that carried a window at its center. A split-unit type air-conditioning system was assumed. The heating and cooling set points were 23 ˚C, while the set backs were 25°C. The heating supply air temperature was 35 ˚C. The cooling supply air temperature was 12 ˚C. The minimum fresh air requirements were set to 10.0 l/s-person. Artificial lighting was set to be dynamically controlled by sensors according to daylighting adequacy. A daylighting control was set up with an illuminance set point of 300 lux at the centre of the dwelling lounge. The internal occupants’ load was accounted for, while the energy consumption of appliances was not considered (Figure 1).

Table 1 Dimensions and parameters of the tested dwelling lounge, window and solar screen.

DWELLING LOUNGE SPACE PARAMETERS	
Floor level	Zero level
Wall Thickness	0.35 m
WINDOW PARAMETERS	
Dimensions	2.30 m * 1.20 m
Sill Height	1.0 m
WWR	20%
Material	generic double clear glazed separated by 13mm air gap
Light Transmission	0.75
SOLAR SCREEN PARAMETERS	
Dimensions	2.70 m * 1.80 m
Perforation	80%
Material	Dark brown matt painted Oakwood
Position	50mm from the window
	0.7m height from ground
Shape	Orthogonal grid of rectangular section bars
Perforation Rate	80%
Slats Rotation Angles	Ranging from 0˚ to 60˚

SOLAR SCREEN PARAMETERS

Rotation of the screen slats affects the energy use. This effect varies when changing screen aspect ratios. Accordingly, the combined effect of changing the screen aspect ratio and rotation of screens horizontal slats up and down with varying degrees was examined for each orientation. The search for optimum louver angles ranged from θ = 0˚ to 60˚ for screens with aspect ratios of vertical: horizontal=1:1, 1:2, 1:4, 1:8 and 1:12. The results were compared with the base case of zero angle rotation. Figure 2 illustrates the investigated rotation angles of horizontal screen slats upwards and downwards.

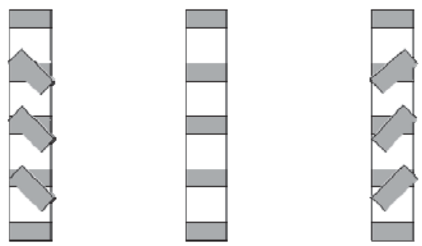

Figure 2 Screen horizontal slats tilt angles.

Moreover, the effect of rotating the screen itself, while changing the screen perforation aspect ratio was examined for the southern orientation. The search for optimum screen rotation angle ranged from θ = 0˚ to 90˚ clockwise and anticlockwise for screens with aspect ratios of vertical: horizontal= 1:1, 1:2 and 1:4 (Figure 3). The results were analyzed and discussed in comparison with the base case of zero angle rotation.

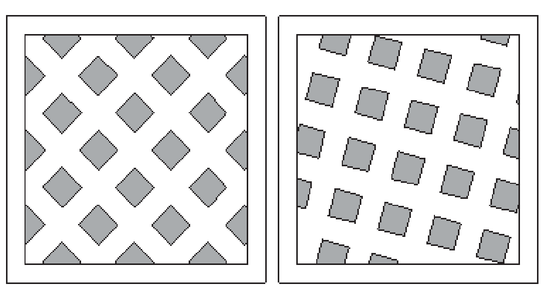

Figure 3 Screen rotation angle.

RESULTS AND DISCUSSION

<u>Solar screen with an aspect ratio of V: H=1:1</u>

For external solar screens with orthogonal grid of square section bars and high perforation ratio of 80 and optimal aspect ratio of V: H=1:1, rotating the screen slats didn't affect the screen energy performance, where a wide range of screen tilt angles from 15° upwards to 30° downwards had no effect on energy savings. However, rotating the slats other than that can deteriorate the energy losses up to 18% (Tables 2 and 3).

Table 2 Energy Saving percentages due to changing screen slats tilt angles downwards angles for solar screens with an aspect ratio of V: H=1:1.

DIRECTION	DOWN				
Tilt Angle	5	15	30	45	60
South	-1%	-1%	-1%	-17%	-18%
West	-1%	0%	0%	-17%	-17%
East	-1%	0%	0%	-16%	-17%
North	-1%	-1%	-2%	-18%	-18%

Table 3 Energy savings percentages due to changing screen slats tilt angles upwards angles for solar screens with an aspect ratio of V: H=1:1.

DIRECTION	UP				
Tilt Angle	5	15	30	45	60
South	-1%	-1%	-4%	-9%	-11%
West	-1%	-3%	-6%	-9%	-10%
East	-1%	-2%	-6%	-8%	-9%
North	-1%	0%	-3%	-3%	-4%

The total energy loads increased with the increase of screen slats roation angle downwards. This could be attributed to the fact that as the screen rotation angle increased, the daylighting decreased resulting in a more use of artificial lighting. On the other hand, rotaion of screen slats upwards up to 30° enhanced the daylighting leading to a slight decrease in the lighting electricity and the total energy loads. However, rotating the slats more than 30° upwards lead to a considerable decrease in daylighting and accordingly an increase in the lighting and total energy loads (Figures 4, 5 and 6).

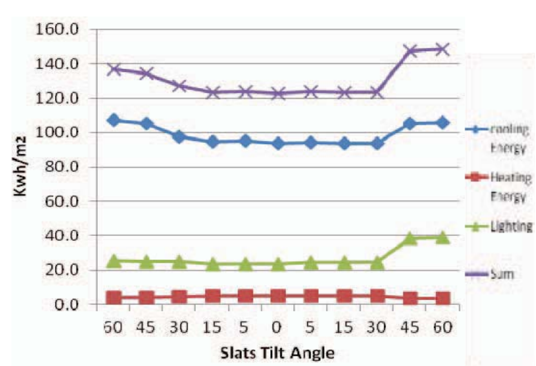

Figure 4 Energy consumption for solar screens with aspect ratio of V: H=1:1 for slats tilt angles from 0° to 60° upwards and downwards- South.

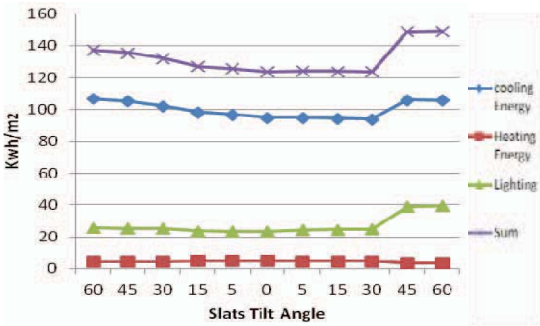

Figure 5 Energy consumption for solar screens with aspect ratio of V: H=1:1 for slats tilt angles from 0° to 60° upwards and downwards – West.

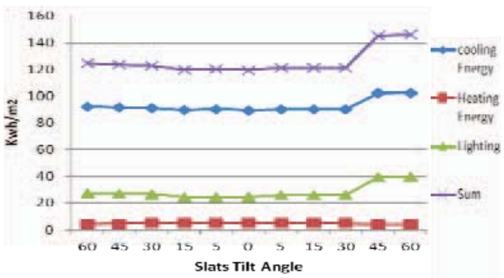

Figure 6 Energy consumption for solar screens with aspect ratio of V: H=1:1 for slats tilt angles from 0° to 60° upwards and downwards – North.

<u>Solar screen with an aspect ratio of V: H=1:2</u>

Unlike screen with previous aspect ratio, rotating the screen slats upwards for the solar screen having an aspect ratio of V: H=1: 2 enhanced the screen energy performance significantly. The total energy savings in comparison with the base case of screen with zero rotation reached 13, 14 and 16% when the screen slats were rotated upwards by 5° and 15° for the West, South and North orientations respectively. This increase in energy savings could be due to the significant improvement in daylighting that resulted in the decrease in lighting electricity and the total energy loads. Increasing the tilt angle to 30° slightly decreased these savings to 10%. However, Increasing the tilt angle upwards to 45° and 60° gave a drastic loss in energy by 7% and 9% respectively due to lack of daylighting that led to the increase in lighting electricity and consequently the cooling loads. This is attributed to the increase of the lighting loads that consequently resulted in extra heat gain dissipated by electrical lamps (Figures 7, 8 and 9).

On the other hand, rotating the slats tilt angle downwards gave a negative impact up to 9% losses in energy compared to the base case due to the increase in the lighting and cooling loads. Near optimum range extended from 5° to 30° upwards. However, rotating the slats downwards more than 30° upwards gave a negative impact (Tables 4 and 5).

Table 4 Energy Saving percentages due to changing screen slats tilt angles downwards angles for solar screens with an aspect ratio of V: H=1:2.

DIRECTION	DOWN				
Tilt Angle	5	15	30	45	60
South	-3%	-4%	-6%	-7%	-8%
West	-3%	-4%	-5%	-6%	-7%
East	-3%	-4%	-5%	-7%	-7%
North	-2%	-3%	-4%	-6%	-6%

Table 5 Energy savings percentages due to changing screen slats tilt angles upwards angles for solar screens with an aspect ratio of V: H=1:2.

DIRECTION	UP				
Tilt Angle	5	15	30	45	60
South	13%	13%	10%	-7%	-9%
West	13%	13%	8%	-6%	-8%
East	14%	14%	9%	-7%	-9%
North	14%	16%	12%	-5%	-6%

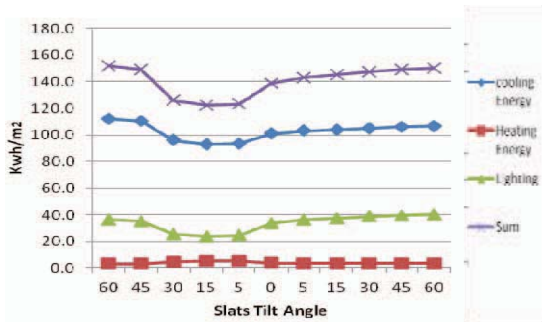

Figure 7 Energy consumption for solar screens with aspect ratio of V: H=1:2 for slats tilt angles from 0° to 60° upwards and downwards –South.

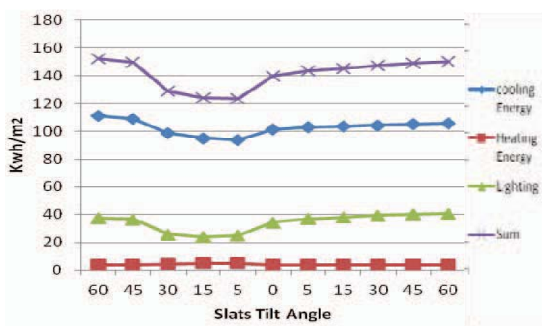

Figure 8 Energy consumption for solar screens with aspect ratio of V: H=1:2 for slats tilt angles from 0° to 60° upwards and downwards – West.

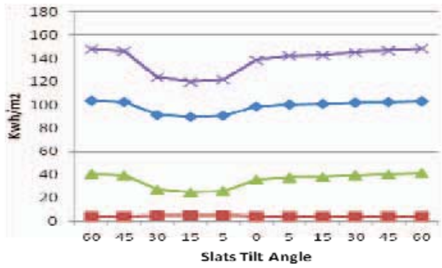

Figure 9 Energy consumption for solar screens with aspect ratio of V: H=1:2 for slats tilt angles from 0° to 60° upwards and downwards – North.

<u>Solar screen with an aspect ratio of V: H=1:12</u>

Tables 6 and 7 illustrate the annual energy savings for alternative solar screens. In the South, when the screen slats were rotated downwards by 15° and 30°, the energy savings in comparison with the base case reached only 1%. Increasing the tilt angle to 45° and 60° gave a drastic loss in energy by 11% and 13% respectively due to lack of daylighting that lead to the increase in lighting electricity and consequently the cooling loads (Figure 6). On the other hand, rotating the slats upwards gave a negative impact due to the significant increase in the cooling loads. When the screen slats are rotated upwards, energy savings were reduced by 2 to 16%.

Table 6 Energy Saving percentages due to changing screen slats tilt angles downwards angles for solar screens with an aspect ratio of V: H=1:12.

DIRECTION	DOWN				
Tilt Angle	5	15	30	45	60
South	0%	1%	1%	-11%	-13%
West	1%	3%	5%	-7%	-8%
East	0%	2%	3%	-9%	-10%
North	-1%	-1%	0%	-14%	-16%

Table 7 Energy saving percentages due to changing screen slats tilt angles upwards angles for solar screens with an aspect ratio of V: H=1:12.

DIRECTION	UP				
Tilt Angle	5	15	30	45	60
South	-2%	-4%	-12%	-17%	-16%
West	-2%	-6%	-11%	-13%	-10%
East	-2%	-5%	-10%	-12%	-10%
North	-1%	-1%	-4%	-4%	-4%

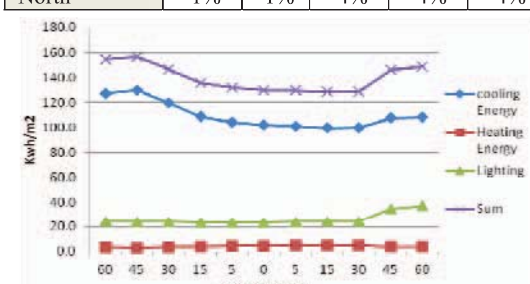

Figure 10 Energy consumption for solar screens with aspect ratio of V: H=1:12 for slats tilt angles from 0° to 60° upwards and downwards – South.

In the West orientation, rotating the screen horizontal slats downwards led to significant energy savings up to 5% with 30° rotation. Increasing the tilt angle to 60° gave a drastic loss in energy by 8% due to lack of daylighting (Figure 11). On the other hand, rotating the slats upwards gave a negative impact due to the significant increase in the cooling loads. When the screen slats are rotated upwards, energy savings are reduced by 2 to 13%. East facades gave a similar trend with maximum savings reaching 3%. The best performance was achieved with slats rotated 30° downwards.

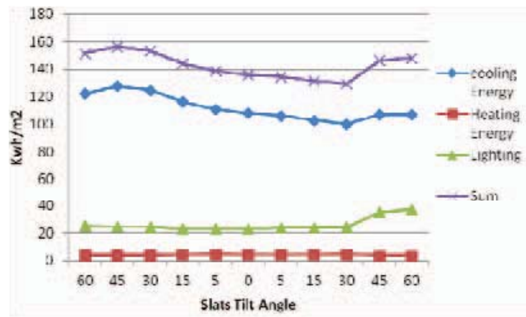

Figure 11 Energy consumption for solar screens with aspect ratio of V: H=1:12 for slats tilt angles from 0° to 60° upwards and downwards – West.

In the North, rotating the screen slats either upwards or downwards led to a negative effect compared to the base case. Rotating the slats upwards created losses (up to 4%) which is less destructive than downward rotation (up to 16%) (Figure 12). Accordingly, screen slats shouldn't be rotated in the northern façade when using screens with perforation aspect ratio of V: H =1:12.

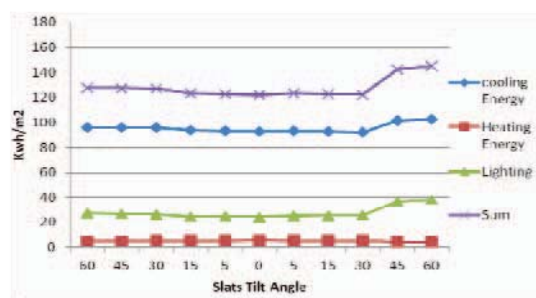

Figure 12 Energy consumption for solar screens with aspect ratio of V: H=1:12 for slats tilt angles from 0° to 60° upwards and downwards – North.

<u>Solar screens with aspect ratios of V: H=1:8 and 1:4</u>

A similar behavior was noticed by changing the screen aspect ratio from V: H of 1:12 to V: H of 1:8 or 1:4 with lower energy saving percentages, especially in the South orientation (Tables 8, 9, 10 and 11).

Table 8 Energy saving percentages due to changing screen slats tilt angles downwards angles for solar screens with an aspect ratio of V: H=1:8.

DIRECTION	DOWN				
Tilt Angle	5	15	30	45	60
South	0%	0%	0%	-12%	-14%
West	1%	3%	5%	-8%	-9%
East	0%	2%	3%	-9%	-11%
North	-1%	-1%	0%	-14%	-16%

Table 9 Energy saving percentages due to changing screen slats tilt angles upwards angles for solar screens with an aspect ratio of V: H=1:8.

DIRECTION	UP				
Tilt Angle	5	15	30	45	60
South	-1%	-4%	-10%	-17%	-15%
West	-2%	-5%	-11%	-12%	-10%
East	-2%	-5%	-10%	-11%	-10%
North	0%	-1%	-4%	-4%	-4%

Table 10 Energy Saving percentages due to changing screen slats tilt angles downwards angles for solar screens with an aspect ratio of V: H=1:4.

DIRECTION	DOWN				
Tilt Angle	5	15	30	45	60
South	-1%	0%	0%	-13%	-15%
West	0%	2%	3%	-10%	-12%
East	0%	2%	3%	-11%	-13%
North	-1%	-1%	-1%	-15%	-17%

Table 11 Energy saving percentages due to changing screen slats tilt angles upwards angles for solar screens with an aspect ratio of V: H=1:4.

DIRECTION	UP				
Tilt Angle	5	15	30	45	60
South	-1%	-2%	-8%	-15%	-14%
West	-2%	-5%	-10%	-12%	-11%
East	-2%	-5%	-11%	-13%	-11%
North	-1%	-1%	-4%	-4%	-12%

<u>Effect of rotating the screen parallel to the window</u>

The effect of rotating the whole screen in the southern orientation for screens with aspect ratios of vertical: horizontal= 1:1, 1:2 and 1:4 on the building energy performance was investigated. The rotation angle ranged from θ = 0˚ to 90˚ clockwise and anticlockwise to identify the optimum rotation of each aspect ratio (Figure 13).

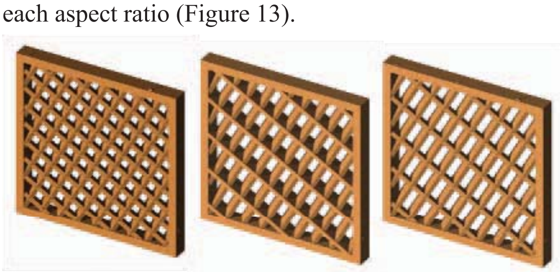

Figure 13 Screen rotation angle with aspect ratios of V: H=1:1, V: H=1:2 and V: H=1:4 respectively.

Table 12 Energy saving percentages due to changing screen rotation angle clockwise for a solar screen with an aspect ratio of V: H=1:1.

ROTATION ANGLE	5	15	30	45	60	90
ENERGY LOSSES %	1.2	1.4	1.4	2.8	2.1	0

Table 13 Energy saving percentages due to changing screen rotation angle anticlockwise for a solar screen with an aspect ratio of V: H=1:1.

ROTATION ANGLE	5	15	30	45	60	90
ENERGY LOSSES %	1.5	1.6	1.1	3	2.4	0

Table 14 Energy saving percentages due to changing screen rotation angle clockwise for a solar screen with an aspect ratio of V: H=1:2.

ROTATION ANGLE	5	15	30	45	60	90
ENERGY LOSSES %	0.7	1.5	1.6	1.5	2.4	3.1

Table 15 Energy saving percentages due to changing screen rotation angle anticlockwise for a solar screen with an aspect ratio of V: H=1:2.

ROTATION ANGLE	5	15	30	45	60	90
ENERGY LOSSES %	1	1.8	1.8	1.8	2.7	3.1

Table 16 Energy saving percentages due to changing screen rotation angle clockwise for a solar screen with an aspect ratio of V: H=1:4.

ROTATION ANGLE	5	15	30	45	60	90
ENERGY LOSSES %	1	1.5	1.5	1.7	1.6	3.3

Table 17 Energy saving percentages due to changing screen rotation angle anticlockwise for a solar screen with an aspect ratio of V: H=1:4.

ROTATION ANGLE	5	15	30	45	60	90
ENERGY LOSSES %	0.9	1.7	2.3	2.9	3.1	3.3

For the screen with an aspect ratio of squared perforations and V: H=1:1, rotating the screen to 45° led to increasing the losses in energy savings up to 2.8% (Tables 12 and 13). For the screens with aspect ratios of V: H=1:2 and V: H=1:4, rotating the screen clockwise led to increasing the losses in energy up to 3.3% at 90° rotation angle. In other words, when the horizontal openings rotate 90° till they become vertical. This complies with previous results found in the literature that demonstrated the significance of using horizontal perforations in reducing the energy loads for the South orientation (Tables 14, 15, 16 and 17).

CONCLUSION

External solar screens are typically used to reduce the energy loads of buildings. The revival of modern angled types of perforated wooden solar screens can lead to significant energy savings. This paper investigated rotating the solar screen either itself or its slats to search for optimum louver angles ranging from 0˚ to 60˚ up and downwards in different orientations.

For the screen with squared perforation and optimal depth ratio of 1, rotating the screen slats had an insignificant effect on screen energy performance. However, for screens with aspect ratios of vertical: horizontal=1:2, 1:4, 1:8 and 1:12, the combined effect of changing the screen aspect ratio and rotation of screens horizontal slats up and down affected the energy savings by up to 16%. Rotating the screen slats up to 30° downwards enhanced the screen energy performance. However, exceeding 30° gave a negative effect due to lack of daylighting that led to the increase in the lighting loads. On the other hand, rotating the slats upwards deteriorated the energy performance significantly.

Furthermore, the effect of rotating the whole screen in the same plane parallel to the window, while changing the screen perforation aspect ratio was investigated. Rotating the screen decreased the energy savings up to 3% at 90° rotation angle (vertical perforation). Accordingly, screens of square and horizontal perforations perform better than screens with vertical perforations.

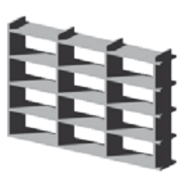	
screen of 0° rotation angle	Screen of 90 ° rotation angle

Figure 13 Recommended screen with 0° rotation angle vs. Screen of 90 ° rotation angle *that should be avoided in the South.*

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