DAYLIGHTING FOR PRIVACY: EVALUATING EXTERNAL PERFORATED SOLAR SCREENS IN DESERT CLEAR SKY CONDITIONS

Ahmed Sherif[1], Hanan Sabry[2] and Tarek Rakha[1]

[1]The American University in Cairo, Egypt.
[2]Ain Shams University, Egypt.

Deserts are endowed with clear skies. However, these favorable conditions are not utilized for daylighting in Egypt, Saudi Arabia and similar countries due to reasons of privacy. A traditional solution that provides discretion is the "Mashrabeya", a wooden patterned shading device. This paper reports on outcomes of the first stage of a research that aims at the development of solar screens that resembles the "Mashrabeya". A series of experiments were performed in which different screen perforation percentages were applied. Conclusions were drawn stating the adequacy of these solar screens in terms of illuminance values in different orientation, seasons and time.

Keywords: desert, clear sky, solar screen, daylighting performance, privacy.

INTRODUCTION

The desert climate is identified by its sunny and clear sky condition, providing an excellent setting for optimum daylighting performance. However, in Egypt, Saudi Arabia and similar countries, penetration of solar radiation is generally not desired due to thermal comfort considerations. One of the shading systems used to diffuse daylight and reduce solar radiation indoors is a Solar Screen, which is an external perforated panel that is fixed in front of a window [1]. It resembles a traditional solution named "Mashrabeya", which is described as a wooden lattice of cylinders connected with spherical joints. It is used as a shading device to screen unglazed openings and provides privacy, which is a socio-cultural need present in the culture of communities in the Arab region [2].

Most relevant research on similar concepts for solar screens included "Rawshan" screens, which confirmed the natural trend expected in daylighting experimentations, where higher perforation percentages are expected to produce a relatively higher daylighting performance concentrated towards the center of the space tested near the window [3]. Another research introduced a computer model for predicting daylighting performance in complex parallel shading systems, which consisted of multiple slats that excluded direct solar radiation whilst permitting daylight penetration [4]. Lindelöf described a fast daylighting model suitable for embedded controllers for a given room geometry, including position and tilt of venetian blinds, and the sun's position. This model was validated on a Radiance software model, and a "toy" controller that uses this model has been shown capable of keeping the horizontal work plane illuminance close to a given set point [5]. In a pilot study of the use of shading systems, it appeared that office workers participating in the research were consistent in the way they used their installed devices according to its kind. It was found that remotely controlled black venetian blinds were used three times more often than manually controlled fabric blinds. In addition to that, most of the time users adjusted the tilt of the slats of the venetian blinds downwards, towards the external ground [6]. Those studies emphasized the need to understand the process of daylight transmission through complex devices that are similar to Solar Screens.

Reviewed literature concerned with shading systems were more oriented towards shading devices in general, with special concentration on louvers configuration and geometry. This paper reports on the outcomes of an investigation that studies the influence of perforation percentages of the solar screen on daylighting performance of a typical residential living room. The aim is to develop perforation percentage configurations for external solar screens that provide adequate daylighting performance.

EXPERIMENTATION APPROACH

Experimentation was conducted using simulation software Radiance, which has been widely validated by different researchers [6, 7]. The research is built on having an indoor space with a number of assumed fixed experimentation parameters. The architectural design parameters (Table 1) have been chosen with the principal features of a residential living room. Al Sadat City, Egypt was chosen as the geographic location to suite the properties of a desert environment, especially the sky condition. The simulated living space and tested Solar Screen are presented in Figure 1 and Figure 2.

This paper investigates the effect of changing solar screen perforation percentages on illuminance values in the tested indoor space. Measurements that were found lower than 200 lux were identified as "inadequate" for the function of the tested residential living room [8]. These results defined minimum perforation percentages at the three tested zones. Comparative analysis was drawn to identify various potentials and limitations.

Table 1. Tested architectural space design parameters.

Geographic Location: El Sadat City, Egypt		
Latitude		30.22.11
Longitude		30.29.26
Sky Condition		Clear sky with sunshine
Indoor Space Parameters		
Floor level		Zero level
Dimensions		4.20 m * 5.40 m * 3.30 m
Internal Surfaces		
Walls	Reflectance	68%
	Material	Medium off-white color
Ceiling	Reflectance	85.7%
	Material	White color paint
Floor	Reflectance	31.7%
	Material	Medium colored wooden
Window Parameters		
Dimensions		2.30 m * 1.20 m
VLT		85%
Solar Screen and Sun Breaker Parameters		
Screen Dimensions		2.8m*1.8m
Sun Breaker Dimensions		2.8m*0.40m
Sun Breaker		10%
Reflectance		68%
Material	Wood Medium off-white color Paint	

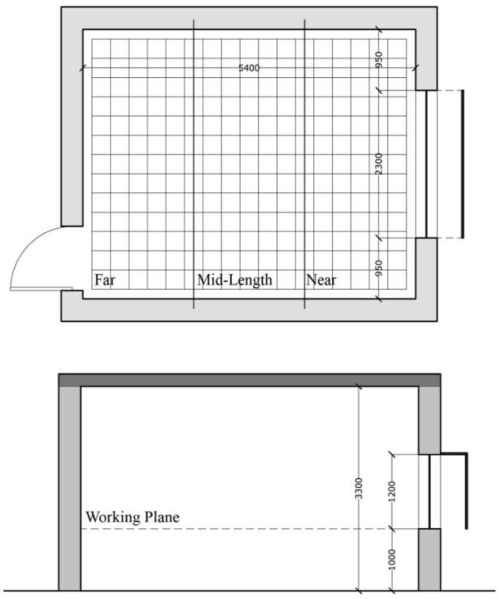

Fig. 1. Assumed design parameters of the analyzed indoor space.

Simulation runs were analyzed to comprehend daylighting performance according to its relationship to three tested zones and different orientations, which is explained next in the research methodology.

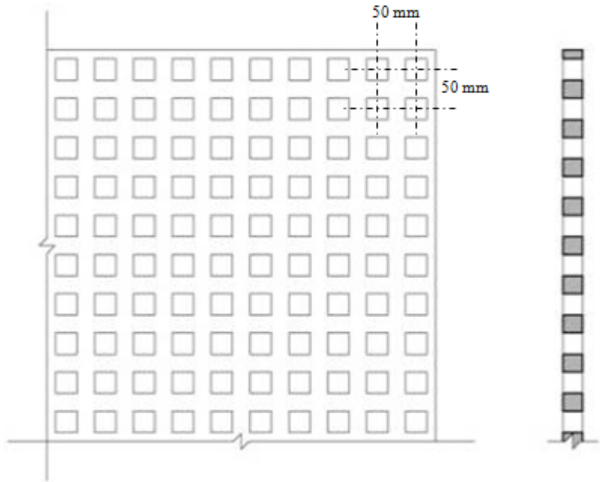

Fig. 2. Example Solar Screen 30% Elevation and Section

Research Methodology

Three zones were analyzed, the first zone is located near the window (the near zone), second zone at mid length of the indoor space (the mid length zone) and third zone is near the rear wall (the far zone). Each zone contained 84 measuring points in a grid of 0.3m *0.3m at working plane of height 1 m. Averages of each zone were calculated separately, excluding any direct sun penetration above 5000 lux from the average calculations. Simulation results were tabulated according to the relationship between tested perforation percentages (10-90%) with different orientations (N, NE, E, SE, S, SW, W and NW) and different seasons (spring, summer, autumn and winter) with different times (9:00, 12:00, and 15:00). Those results are presented and analyzed to be concluded with recommended minimum perforation percentages.

SIMULATION RESULTS

Simulation runs were analyzed to comprehend daylighting performance according to its relationship to the three tested zones and different orientations.

Tested Zones

At the three tested zones, perforation percentages were directly proportional to illuminance values, with a significant response in the near zone. Linear performance slope values vary depending on orientation and time of the day, with the near zone always at a higher slope with higher illuminance values. Perforation percentages that satisfy required illuminance in the near zone start from as low as 10%, mid-length zone from 40% and the far zone from 50% in different settings. Two examples were chosen to show linear performance of Solar Screens in Figure 5, one representing direct solar penetration (East-Winter-9:00AM) and the other representing diffused / reflected natural light (North-Spring/Autumn-12:00 Noon).

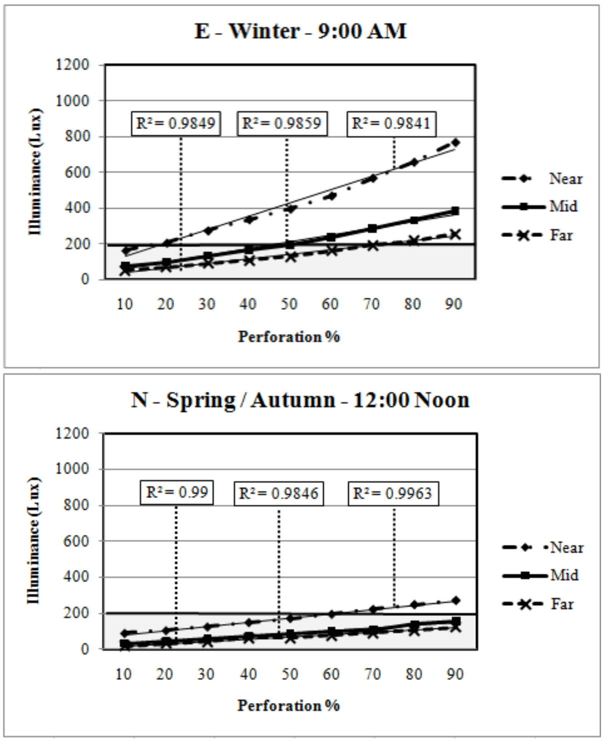

Fig. 3. Solar screen perforation percentage against illuminance values showing linear performance.

Orientations

According to the time of day and season, each orientation had a different daylighting performance. Certain orientations have almost the same daylighting performance that is often found inadequate (e.g. all orientations except E, SE and S in winter at 9:00). Other orientations have a different effective and adequate behavior in certain perforation percentages (e.g. NW, W, SW, in summer at 15:00).

In the South orientation, daylighting performance is found to be adequate in almost all seasons and at all three tested zones at certain perforation percentages (Figure 4), except for summer at the far zone at 9:00 and 3:00. However, in the North orientation, there is a significant decrease in illuminance values (e.g. 50% perforation in winter gives an average of 60% less illuminance in the three tested zones in comparison to the south orientation at the same conditions). Consequently, daylighting performance was found inadequate in almost all seasons in the mid-length and far zones. Conversely, the near zone needs high perforation percentages to provide minimal daylighting needs, not less than 80% in winter, spring and autumn, and 60% in summer. In the East and West orientation, change in daylighting performance is considerably affected by the time of the day. East at 9:00 and West at 15:00, illuminance values were found adequate in most cases. However, at other times, performance differs and is similar to the North orientation in regards to behavior in the three tested zones.

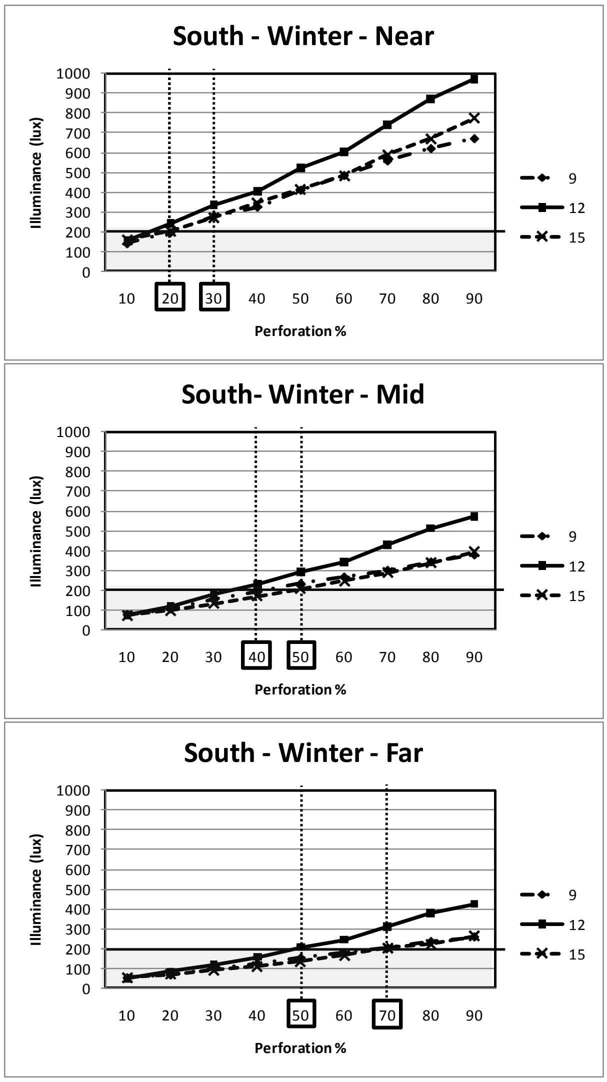

Fig. 4. Illuminance against perforation % for the Winter season, with a highlight on the suitable perforation for the tested times in the South orientation.

DISCUSSION

The resultant quantity of room daylighting was investigated in each of the previously mentioned cases and recommendations for minimum screen perforation are presented in Table 2, showing minimum screen perforation percentage in all three zones in regards to orientation, season and time. This minimum percentage could be as low as 10% (e.g. Spring/Autumn – 9AM – S at the near zone), and could reach 90% with no other lower percentages suitable for adequate performance (e.g. Spring/Autumn – 12 Noon – SE at the far zone). In order to utilize the table in designing solar screens for suitable performance in all three zones, perforation percentages that satisfy requirements of adequacy in the far zone has to be the ones used (e.g. Summer – 15PM – NW, 70% Perforation). Dark cells that contain no numbers indicate that a solar screen would be found inadequate in that situation.

Table 2. Showing minimum screen perforation percentage in all three zones in regards to orientation, season and time. Lighter shade indicates a low perforation percentage, and darker shades indicate a high perforation percentage.

Near	21st Dec - Winter			21st Mar - Spring			21st Jun - Summer			21st Sep - Autumn		
	9	12	15	9	12	15	9	12	15	9	12	15
N		80		80	70	80	50	40	60	70	70	70
NE	80	80		10	60	80	20	40	70	10	60	80
E	20	70		30	50	80	20	40	70	20	60	80
SE	30	20	90	20	30	10	20	30	70	20	20	60
S	30	20	20	10	30	10	60	30	60	20	30	10
SW		20	20	60	30	20	70	30	20	50	30	20
W		70	30	80	60	20	70	40	20	80	60	20
NW		80		80	70	10	70	40	30	80	70	10

Mid	21st Dec - Winter			21st Mar - Spring			21st Jun - Summer			21st Sep - Autumn		
	9	12	15	9	12	15	9	12	15	9	12	15
N								90				
NE				60			50	90		60		
E	60			40			40	90		40		
SE	40	50		40	60		50	80		40	60	
S	50	40	50	50	50	60		70		50	50	60
SW		50	40		60	40		80	60		60	40
W			50			40		90	50			40
NW						60		80	50			60

Far	21st Dec - Winter			21st Mar - Spring			21st Jun - Summer			21st Sep - Autumn		
	9	12	15	9	12	15	9	12	15	9	12	15
N												
NE							80					
E	80			60			60			70		
SE	50	70		60	90		80			60	90	
S	70	50	70	90	70	90		90		80	80	90
SW		70	50		80	60			80		80	60
W			80			60			70			60
NW						90			70			90

Experiments conducted on the perforation percentages of Solar Screens gave a variety in their daylighting performance, fulfilling requirements of the majority of tested cases. Quantitative daylighting analysis of the Solar Screen satisfies more 83% of the tested cases in the near zone and 53% in the mid-length zone, while the far zone suites 40% of the cases. This will call for designing different perforation percentages in the same screen as well as combining various daylighting techniques to achieve satisfactory results in all three zones.

In the South orientation, East at 9:00 and West at 15:00, illuminance values were found adequate in most cases. This creates opportunities of integration for thermal comfort needs, as solar radiation can be controlled at minimal perforation percentages that give both adequate daylighting and minimal thermal infiltration. However, in the North orientation, there is a significant decrease in illuminance values. This is due to the absence of direct solar penetration in the space, which makes the screen have more of a dimming effect rather than a tool for solar control. If the screen is to be used for privacy measures, integration with daylighting techniques should be considered.

CONCLUSION

A series of experiments were performed on a solar control device named "Solar Screen", in which different screen perforation percentages were applied. Daylighting performance was analyzed for a designed living room indoor space where average illuminance levels of three zones in the room were measured for different window orientations, during different times of the day, and in different seasons. The resultant quantity of room daylighting was investigated in each of these cases and recommendations for minimum screen perforation were presented.

In order to achieve the visual privacy provided by the screen and at the same time maintain adequate natural daylighting levels at specific situations that do not satisfy required illuminance, different techniques combined with the solar screen should be investigated (such as higher screen reflectivity values, change of screen parameters, use of light shelves , etc…).

Further research will be orientated towards the study of qualitative issues in regards to perforations. This should draw conclusions on maximum screen percentages that would provide suitable daylighting performance but at the same time avoid glare.

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