PARAMETRIC ANALYSIS OF SOLAR SHADING PARAMETERS IN INTERMEDIATE ORIENTATIONS LOCATED IN DESERT CLIMATES
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ABSTRACT
Improving daylighting performance for offices provides positive effects on well-being, productivity and energy savings. High exposure to direct solar radiation in desert climates has been addressed in the literature by the use of shading devices. A study of the effect of four parameters (screen rotation, depth and tilt, window-to-wall ratio) on daylighting of a generic office in the deserts of Cairo, Egypt was carried out in two intermediate orientations (SE and NE) through a parametric simulation approach using Rhino 3D, Grasshopper, SpeedSim-for-DIVA and Diva-for-Rhino. The newly approved IES metrics were used to evaluate the 1120 iterations with an exhaustive method. The use of mainly horizontal shading, downward tilting shades, high window-to-wall ratio (WWR), and large screen depths were suggested.

INTRODUCTION
Daylight has many advantages to building performance and the occupants’ well-being, this has been proven in a number of studies.

In term of energy savings, a significant portion of the total electricity consumption in offices goes to artificial lighting, ranging from 20 to 60% (Bodart & De Herde, 2002). Studies show that energy savings were possible through integrating daylighting with artificial lighting, by a reduction in artificial lighting consumption, ranging from 50 to 80%, as well as a reduction in internal loads, both summing up to about 40 to 50% of energy (Bodart & De Herde, 2002).

In term of the occupants’ well-being, surveys show that the use of daylight is strongly preferred in office environments, with preference proportions varying from 65 to 95%, particularly due to the beliefs of improved well-being (Abdou, 1997; Galasiu & Veitch, 2006). In addition, Researchers have shown that natural lighting has a positive impact on human performance in work environments (Abdou, 1997), thus optimizing human resource cost which is greater than the cost burdens of artificial light consumption (Bodart & De Herde, 2002). Higher illumination levels, which are achieved with natural daylight, show an improvement in task performance with a rise in productivity levels up to 16% (Edwards & Torcellini, 2002), an increase in alertness and a decrease in accidents and hazards, reducing them by half (Abdou, 1997). There is much literature to demonstrate better well-being due to natural lighting represented in regulation of circadian rhythm, mood-boosting, lower stress levels, higher concentration and alertness levels in addition to increased work satisfaction (Andersen, 2015). Additionally, a reduction of sickness and unhealthy symptoms has been witnessed including a decrease in common workplace problems such as headaches, eyestrain and SAD, as well as lower blood pressure (Edwards & Torcellini, 2002). These factors combined lead to a reduction in absenteeism, sick leave and turnover (Abdou, 1997; Edwards & Torcellini, 2002), with percentages reaching 15%, 25% and 200% respectively (Edwards & Torcellini, 2002).

Lighting quality was shown to have a large effect on the workers’ space perception: lighting changes acting act as competitive and motivational tools for workers when perceived as a hierarchical status upgrade (Abdou, 1997), and providing feelings of pleasure through the added spaciousness of the room (Galasiu & Veitch, 2006).

However, providing natural daylighting in offices by the use big glazed areas is not a preferential solution in hot climate areas (Ahmed Sherif et al., 2012). The excessive penetration of sunlight can cause massive heat gain, glare and direct sunlight exposure. The use of louvers as a passive design technique help in reducing the cooling loads ensuring energy savings without compromising daylighting (A. Sherif et al., 2012). A simulation performed in the city of Cairo showed that the use of the shading devices reduced energy consumption by 60% (Palmero-Marrero & Oliveira, 2010). Therefore, many researches in similar climates have been conducted in order to carefully study the different louvers parameters, and their effects on daylighting and energy performance.

A study in Jordan examined three louver parameter changes: louver width, tilting angle along with the changing in the ceiling geometry configuration to explore their effect on the daylight performance (Freewan et al., 2009). Another study in Amman aimed to find a shading device configuration that provided maximum daylighting with minimum heat gain with an office space as case study. Three louvers cases were studied: vertical louvers, horizontal ones and horizontal louvers with a 45 degree tilt (Alzoubi & Al-Zoubi, 2010).

The effectiveness of solar screens in hot arid climates was also explored in several researches. The first
research examined the main orientations with different axial rotation for the perforated screens (A. H. Sherif et al., 2012). In a second research, a second parameter (opening aspect ratio) was studied, in addition to the axial rotation. The study concluded that the horizontal aspect ratios provide better performance than the vertical ratios and that the second parameter (the aspect ratio) was more effective than the axial orientation (Sherif et al., 2012). Moreover, the effect of the screen depth was also examined in addition to perforation ratio in another study. It was proven that the best solar screen configuration could provide energy savings of up to 30% in south and west orientations (A. Sherif et al., 2012).

The previous researches examined and proved the relevance of designing for improved daylighting performance for offices, and the positive effect of using shading devices to improve it, especially in hot arid climates. However, all of these studies were centred on south orientation and a very limited number considered the main four orientations, while no studies investigated the intermediate orientations. Extending a previous research, where optimum daylighting performance was intended through the simulation of 1600 screen configurations (Wagdy & Fathy, 2015), the novel contribution of this study to the daylighting research can be summarized in the following points:

- Determining the optimum louver configuration for an office with acceptable daylighting conditions for intermediate orientations.
- Using the newly IES approved daylighting method to evaluate the daylighting performance: Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE).
- Examining 560 different solar screen configurations for 2 intermediate orientations (South-East and North-East) with 1120 iterations using an exhaustive search method.

METHODOLOGY
The aim of this study was to provide designers with a detailed analysis of a solar screen shading system in intermediate orientations to help them make informed decisions about shading device parameters that create an optimum, naturally lit environment that maximizes the workers’ productivity and well-being while minimizing energy use. A detailed explanation of the implementation process and strategy for conducting this study involves elaborating on the daylighting evaluation criteria, the case study office plan configuration, and the shading device structure ending with the simulation techniques.

Daylighting Evaluation Criteria
Three complementary daylighting metrics were used in this study: Spatial Daylight Autonomy (sDA300/50%), Annual Sunlight Exposure (ASE1000/250hr) and Daylight Availability (DA); basing this choice on the newly approved method by the Illuminating Engineering Society (IES) (IESNA, 2012). A preferred minimum percentage of 75% of room area for Spatial Daylight Autonomy (sDA300/50%) is recommended by IES, defined as the percentage of floor area, for at least 50% during occupied hours (8am-6pm), in which 300 lux of illuminance is reached throughout the year (IESNA, 2012). A maximum percentage of 3% of room area for Annual Sunlight Exposure (ASE1000/250hr) is preferred as well, and defined as the percentage of floor area, for at least 250 hours during occupied hours (8am-6pm), in which 1000 lux of direct illuminance is reached throughout the year (IESNA, 2012).

Case Study Office Plan Configuration
A generic office plan configuration, located in the second floor, was adopted for this study with spatial dimensions of 4.5m by 6m, day-lit from one side. The climatic zone under study was that of Cairo, Egypt, in a desert environment with no obstruction. Two intermediate orientations were investigated South-East (SE) and North-East (NE), which can represent the four intermediate orientations because of the symmetrical nature of the solar hemisphere.

Shading Device Structure
The louver was defined by three parameters: the tilt-up angle, the depth and the rotation angle with a range of variables generating multiple configurations. These parameters were investigated through integrating Rhino 3D, a 3D modelling software along with its parametric plug-in Grasshopper to produce the modelling alternative for simulation (Rutten, 2014; Wagdy, 2013). Table 1 indicates the simulation constants and parameters for the office and shading device configurations.

Table 1
Simulations Constants and Parameters
OFFICE CONFIGURATION

<table>
<thead>
<tr>
<th>Area</th>
<th>25m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orientation</td>
<td>South-East</td>
</tr>
<tr>
<td>North-East</td>
<td></td>
</tr>
<tr>
<td>Window-to-Wall</td>
<td>Ratio (WWR)</td>
</tr>
<tr>
<td>20%, 40%, 60%, 80%</td>
<td></td>
</tr>
</tbody>
</table>

MATERIALS AND REFLECTANCE

| Walls | 55% |
| Ceiling | 80% |
| Floor | 20% |
| Window | 80% VT |

SHADING LOUVER CONFIGURATION

| Louver Spacing | 1 meter |
| Tilt-Up Angle | [-20º, -10º, 0º, 10º, 20º] |
| Louver Depth | [0.75, 1, 1.5, 1.5] |
| Louver Rotation Angle | [0º, 15º, 30º, 45º, 60º, 75º, 90º] |

Figure 2 shows the range of configurations created parametrically with Grasshopper.

Table 2

<table>
<thead>
<tr>
<th>Daylight Evaluation Metrics</th>
<th>Ambient Bounces</th>
<th>Ambient Divisions</th>
<th>Direct Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>sDA &amp; DA</td>
<td>6</td>
<td>1000</td>
<td>0</td>
</tr>
<tr>
<td>ASE</td>
<td>0</td>
<td>1000</td>
<td>0</td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSION

Using an exhaustive method for this study (examining the effect of four solar shading device parameters in two different orientations), allowed us to analyse in detail, the impact of each variable individually and their overall integrated impact on the daylighting performance. This section explains the findings of this study for the change in sDA and ASE with reference to changes in screen rotations, depths, tilt angles and Window-to-Wall Ratios (WWRs).

Firstly, the screen rotation impact and preferred angles differed for the SE and NE orientations, with a common positive effect for the horizontal configuration. The larger portion of the impact was observed in the ASE values, relative to the sDA. Figure 3 and 4 show the effect of the 7 screen rotation and 4 depth alternatives on the ASE and sDA, for a 60% WWR and no tilt angle, for the SE and NE orientations respectively. sDA and ASE are represented by solid and dashed lines respectively. The dot positions indicate the conditions at which both sDA and ASE conditions were met. In the SE orientation, the daylighting performance improved as the rotation moved towards a horizontal position (0º). Accordingly, 0º and 15º were the angles with the best daylighting impact, despite the fact that no iteration for these conditions fulfilled the accepted criteria, due to the high direct solar radiation (ASE values) even with high screen depth ratio of 1.5m as shown in Figure 3.

On the other hand, for the NE orientation, both the horizontal and vertical configurations reached positive results. For all depth conditions, the ASE values decreased moving from the 45º angle towards both horizontal (0º) and vertical (90º). The latter resulted in a number of iterations ranging within the accepted conditions, with slightly higher sDA for the horizontal case (0º) as shown in Figure 4.
Secondly, the lower screen depths showed higher sDA and ASE while the determining factor for daylighting acceptance was based on the ASE, because of its shown higher impact. The screen depths that allowed for an acceptable lighting performance were in iterations with 1.5 and 1.25 meters for all orientations, while the NE orientations had some accepted iterations with 0.75 and 1-meter screen depths. The latter can be explained by the lower vertical solar angle in the northern orientation, requiring larger depth values to obstruct direct sun radiation.

Thirdly, the change in tilt angles showed a relatively significant impact on both sDA and ASE. The larger changes were observed for the SE orientation due to the higher vertical sun angles, which create positions at which the shading elements are moving towards an almost parallel or near perpendicular position to the sunrays, accentuating their effect. Figure 5 and 6 show the ASE and sDA graphs after being affected by the introduction of a -20° tilt angle to the shading device, for a 60% WWR, for the SE and NE orientations respectively.

The iterations with negative tilt angle values increased significantly the direct solar penetration for the preferred screen rotations accordingly resulting in no accepted solutions for both orientations with the exception of very few accepted iterations with -10° tilt angle in the NE orientation. Figure 7 and 8 show the effect of a +20° tilt angle for a 60% WWR, for the SE and NE orientations respectively. The positive tilt angle positions were on the other hand beneficial to
the daylighting performance, reducing ASE values and thus reaching the accepted ranges for both ASE and sDA.

In the NE orientation, the case of the vertical orientation was interesting as improvements were noticeable for both horizontal and vertical screen orientations, with better results in the vertical position. The lower sun vertical angles can explain the success of the tilting on the vertically oriented shading since they can accordingly manage to block a large amount of radiation.

The last investigated parameter was the window to wall ratio (WWR), which also had a significant impact on the acceptance or rejection of iterations. The accepted solutions were non-existent for a WWR of 20%, and represented only about 7.5% for a WWR of 40%. The small openings did not allow sufficient lighting to come inside the room and thus did not fulfill the sDA requirements. Accordingly, the 60% and 80% WWR represented the only accepted solutions.

In addition to the individual influences of the four parameters, the study of the integration of these together provides a wider comprehension of the complexity of shading design parameters. Figure 9 and 10 denote the sDA (9) and ASE (10) for all iterations in values, gradient circle colours as well as identify the iterations achieving both sDA and ASE conditions by filled circles for the SE orientation. Each configuration, its location within tabular matrix identifies the value of its four parameters, and the number indicates the sDA (9) and ASE (10) values under these conditions, more clearly visually displayed by the circle’s stoke colour and filled circles for cases that achieves both metric standards. For the SE orientation, it can be noted that sDA requirement was fulfilled for all cases with WWR of 60% and 80%, and for the majority of the cases with 40% WWR, adding up to 404 cases out of 560 (72%). Only 15 of these achieved the ASE condition. This observation reflects the relatively higher daylighting issue being with the direct solar penetration. The accepted iterations for sDA and ASE could be found in screen rotations ranging from 0 to 30º, screen depths of 1.25 and 1.5 meters and tilt angles of 10º and 20º.

The study of the same parameters on the two orientations showed differences in the sDA and ASE patterns. Figure 11 and 12 denote the sDA (11) and ASE (12) for all iterations in values, gradient circle colours as well as identify the iterations achieving both sDA, and ASE conditions by filled circles for the NE orientation. Almost all cases with WWR of 60% and 80% achieved sDA conditions, while 40% WWR, unlike the SE orientation, was not sufficient for daylight. The iterations achieving adequate ASE values were significantly higher than the SE orientation, making the sDA and ASE of equal position in relative importance concerning solving daylighting problems. The accepted iterations for sDA and ASE could be found in screen rotations ranging of 0º, 15º, 75º and 90º, which show the effectiveness of both horizontal and vertical shading elements in that orientation. All screen depths had passing iterations with greater success with the larger end as well as downward tilting angles although two iterations achieved the conditions with a -10º tilt.
CONCLUSION

Previous studies have shown that horizontal perforated solar screens have superior daylighting performance, especially for southern façade. This research was conducted because there is a lack of quantitative research on their performance over the intermediate orientations such as North East and South East. This paper not only addressed how each screen parameter affects daylighting performance, but also showed the effect based on all possible combinations between these parameters.

The use of an exhaustive method, studying 1120 cases through parallel simulation, provided greater opportunities for in-depth study of individual parameter influences as well as their integrated effect on daylighting performance in an office setting with desert climate for intermediate orientations. Table 3 shows the 67 iterations that fulfilled the daylighting conditions for both sDA and ASE and their corresponding parameters.

Based on the findings and analysis of the results, the effectiveness of using horizontal shading for intermediate orientations was shown to be higher than other angles. Contrary to the traditional thinking that promotes the use of vertical devices for these orientations, it was only effective in the northeast and correspondingly northwest as well. In-between angles for screen rotations did not show a significant impact, with the exception of 15º in the southeast orientation. The use of downward tilting shades (20º), high WWR (60 and 80%), and large screen depths (1.25 and 1.5) are recommended for all intermediate orientations. This study was limited geographically, functionally and spatially in order to constraint the impact on daylighting metrics to the four parameters under study. Although a tailoring of design solutions should be driven from integrated contextual constraints, this study provides a well-grounded intuition and strong understanding of individual as well as integrated design parameter impacts. Further studies could consider the effect of these parameters on daylighting distribution, glare and energy consumption.

REFERENCES


