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A parametric approach for achieving optimum daylighting performance through solar screens in desert climates

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ABSTRACT

Daylighting provision gives a significant contribution to the enhancement of the indoor environment. However, in desert climates spaces are exposed to direct solar radiation, leading to a non-uniform daylight distribution and excessive heat gain. The literature proves that the use of a shading device may solve these problems. In this daylighting study, a parametric approach was implemented where all combinations of five screen parameters (window to wall ratio, louvers count, louvers tilt angle, screen depth ratio, and screen reflectivity) were computed. This generated 1600 different screen configurations based on the predefined range of each parameter. Two consecutive phases were performed in which the Illuminating Engineering Society (IES) metrics, Spatial Daylight Autonomy ($sDA_{300/50\%}$), Annual Sunlight Exposure ($ASE_{1000/250\ h}$), Daylight Availability as well as Annual Daylight Glare Probability (DGP), were examined. Diva-for-Rhino plug-in for Rhinoceros was used to interface Radiance and Daysim while Grasshopper plug-in for Rhinoceros was used to generate 1600 solar screen's configurations parametrically and to automate the simulation process. The simulated case study was a generic south-oriented classroom located in Cairo' desert in Egypt. A parallel computing procedure, by which multiple Radiance simulations can be run, was used to find optimal solutions. These solutions were characterized by maximum daylit area without excessive solar penetration. The general tendency of each parameter and the interaction between them was examined. Simulation results demonstrated the trend of converging solutions starting from 1:1 depth ratio with downward tilted angles. Finally, the influence of increasing screen reflectivity in enhancing daylighting performance was illustrated.

1. Introduction

Daylight in the indoor environment has a significant impact on occupant health and well-being [1]. In well-daylit classrooms, for example, studies showed a positive correlation between the user's performance and their health. A 14% increase in students' performance is found in daylit schools, and the rate of absenteeism is decreased by about 3.5 days per year [2]. Different studies have emphasized the influence of the surrounding context on the daylight availability and recommended taking it into consideration in order to secure adequate daylight exposure for the occupants [3]. The clear sky conditions that can be found in the desert climate can effectively contribute to the utilization of daylighting. However, this sky condition may cause visual discomfort or excessive heat gain; this is especially the case in a city like Cairo, which is characterized by having a sunny clear sky throughout the year [4]. Thus, utilizing a proper shading device on the glazed areas should be taken into consideration. One type of shading device that achieved a promising efficiency in the desert environment is the “Solar Screen” [5], which consisted of perforated panels fixed in front of the window [6]. Solar screens have been widely used in the Middle-East and South Asia for privacy concerns and shading provision. They can block direct sunlight while allowing the indirect light to diffuse into the space through ceiling reflections or solar shading [5,6]. A trend of their utilization in contemporary buildings has started to evolve.

In order to design a highly efficient solar screen, careful exploration of all screen design parameters is required. Accordingly, several studies were conducted to address these parameters. A study investigated different perforation ratios on both energy saving and daylighting autonomy through an experimental simulation. It was found that perforations ranging between 30% and 50% are the best for reaching a good compromise between thermal and daylighting requirements [7]. Other parameters such as the rotation angle and aspect ratio were also examined, proving that

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these two screen parameters significantly affected daylighting performance and solar radiation transmittance. The study concluded by reporting the effectiveness of screens with cell modules of horizontal length larger than that of vertical length [8].

In one study, the effectiveness of solar screens was studied through different screen configurations. Then, recommendations were given for each orientation regarding adding light shelves and changing rotation angle, screen height and aspect ratio [9]. In a more recent study, two screen parameters (axial rotation and aspect ratio) were explored in terms of their daylighting and energy performance. The criteria for selecting the screen was reported when the daylit area reached more than 70% of the room area. With this intention, five screen designs were analyzed. Results demonstrated that 18:1 (Horizontal: Vertical) aspect ratio together with non-rotated screens would be acceptable for both south and north directions [10]. In another research attempt to find the trade-off between daylighting performance and energy savings, different configurations of horizontal sun breakers were investigated [11]. The effect of their number, depth, and inclination angle was studied for a south oriented office space. End results have reached satisfactory balance for both daylighting and energy needs, achieving a 72% daylit area and a 34% reduction in energy loads. Another important factor affecting solar screen performance is reflectance. In a study that investigated the influence of this factor [12], light colored screens were recommended when more daylight diffusion is needed.

To conclude, it is clear that designing an efficient solar screen requires a careful exploration of all screen parameters. Based on the information gathered from the literature review, the use of solar screens to enhance daylighting performance has shown positive outcomes especially in desert climates. However, a limited number of studies have examined a large number of parameter variations at the same time. Usually, the results are described in a case by case fashion, instead of reporting the effect of each parameter as a sequence of outcomes that could be quickly transformed into alinear graph.

Hence, all possible combinations of screen parameters were computed in one list using an exhaustive search method [13] where we can make comparisons between solutions. Although this method was usually avoided due to its running time, this problem was overcome by using a parallel algorithm. This algorithm was specifically designed for this type of research, where hundreds or thousands of simulation runs are needed to obtain precise evaluation of each parameter. Thus, the workflow is made to fully utilize the maximum count of available CPU cores. This method allows the influence trend of the interacting parameters to be explicitly shown on the overall daylighting performance.

Furthermore, none of the previous publications applied the Illuminating Engineering Society (IES) approved daylighting method while evaluating the performance of solar screens. This method is concerned with two metrics: Spatial Daylight Autonomy (sDA300/50%), and Annual Sunlight Exposure (ASE1000/250 h). The first metric (sDA300/50%) represents the percentage of floor area having 300 lx of illuminance for at least 50% of the occupied hours (8 am–6 pm) throughout the year. A preferred minimum percentage of 75% of room area for spatial daylight autonomy is recommended. As for the second metric (ASE1000/250 h), it is defined as the percentage of floor area having 1000 lx of direct illuminance during occupied hours (8 am–6 pm) throughout the year for at least 250 h. A maximum percentage of 3% of floor area for Annual Sunlight Exposure (ASE1000/250 h) is preferred [14].

This study aims to provide an original contribution in:

1. Conducting a parametric study to examine 1600 different solar screen configurations.
2. Automating the simulation process using a parametric procedure.
3. Evaluating the annual illuminance results based on the IES approved daylighting metrics: Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE).
4. Analyzing the contribution of each parameter as well as the interactions between all screen parameters.
5. Identifying the near optimum solar screen configuration that could be utilized beyond the case study.
6. Identifying the optimal solar screen configuration for a south oriented classroom that achieved a remarkable daylighting perfromamce with 100% sDA without solar penetration.

Focusing on classrooms for the case study stems from the aim of enhancing the learning environment that eventually has a significant impact on both students and staff performance.

2. Methodology

A generic south oriented classroom located in the desert climate of Cairo, Egypt (30°6′N, 31°24′E, alt. 75 m) was selected for this study with no external obstruction. A typical classroom layout is daylight-illuminated from one side, located on the second floor with spatial dimensions 7 m∗5.5 m based on the design requirements set by the department of education in Egypt [19] as shown in Fig.1. The solar screen was parameterized according to a predefined process that associates its depth, count and rotation angle together. The parameters of the classroom and screen configurations are illustrated in Table 1.

A parallel algorithm was utilized in this parametric study to investigate the effect of a broad range of solar screen configurations on daylighting performance. The study was implemented in two consecutive phases that are described in detail in the following paragraphs. The first was concerned with daylighting adequacy; ensuring that the daylit area occupies 100% of the total room area, while protecting the space from excessive direct sunlight. Various alternatives were explored, and many satisfactory solutions were reached. Secondly, the case with the highest glare potential underwent glare analysis to ensure visual comfort inside the space.

2.1. Daylighting evaluation criteria

2.1.1. Phase one: SDA, ASE, and DA

In this study, the daylighting criteria used for evaluation are based on the approved method by Illuminating Engineering Society described in report number LM-83-12 [14]. These criteria are annual climate based metrics and consist of: Spatial Daylight Autonomy ($sDA_{300/50\%}$) and Annual Sunlight Exposure ($ASE_{1000/250\ h}$).

Spatial Daylight Autonomy ($sDA_{300/50\%}$) reports the percentage of the floor area in which the illuminance levels reach 300 lx for at least 50% during the 10 occupied hours (8 am–6 pm) throughout the year. $ASE_{1000/250\ h}$ measures the percentage of the floor area in which the illuminance levels reaches 1000 lx for at least 250 h during the occupied hours (8 am–6 pm) throughout the year [14]. Annual Sunlight Exposure gives an indication of the possibility of visual discomfort as a result of direct sunlight.

The preferable daylighting conditions set by IES Committee are as follows: (1) Spatial Daylight Autonomy (sDA300/50%) should be equal or more than 75% of the room area. (2) Annual Sunlight Exposure (ASE1000/250 h) should be less than 3%. However, more preferred acceptance criteria were employed in this study to determine if this is achievable. In this condition, Spatial Daylight Autonomy (sDA300/50%) has to cover 100% of the room area, while the Annual Sunlight Exposure (ASE1000/250 h) should be equal to 0% of the room area.