INVESTIGATION OF THE EFFECTIVE PARAMETERS IN SQUARE UNIT BASED SHADING SYSTEMS; A SCOPE OF ACHIEVING BALANCE BETWEEN DAYLIGHT AND THERMAL PERFORMANCE

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ABSTRACT

The façade of the building is considered as one of the main contributors to the energy requirements of building spaces especially office spaces. Shading is one of the solar protection strategies that was used for long years in the past. Recently, utilizing shading devices increases as a solar protection provider in the hot arid climate in Cairo. Many publications reported the positive effect of square-based egg-crate shading devices on both daylighting performance and thermal performance. Different parameters as perforation ratio, depth and the grid size of egg-crate systems could affect the performance on achieving the optimum performance visually and thermally. Therefore, this research aims to carry out a deep investigation on the effect of these parameters of the egg-crate shading system in order to improve the performance of the shading system. Brute-force parametric simulation was conducted in the form of predefined algorithms using different proposed parameters in order to conclude the optimum solutions for the studied window to wall ratios. Grasshopper plugin for Rhinoceros was utilized for carrying out the parametric modelling process of all the different design configurations of the studied shading device. The study adopted a simulation process constructed on two sequential phases, which were carried out using DIVA for Rhino the interface for the widely used simulation engines Radiance, Daysim and EnergyPlus. Moreover, the simulation was derived based on the IES approved daylight metrics, particularly Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE). Results carried out the optimum composition associated with specific WWRs, which improves the distribution of daylight and complies with LEED v4 daylighting standards. Finally, analysing results of the study revealed many findings regarding the potential of using the egg-crate system and screening the effect of each parameter. Evaluation process of the study was carried out.

INTRODUCTION

Buildings all over the world consume large amounts of energy. These levels of consumption reach approximately 40% of the world's annual energy consumption (Alrubaih, M. S et.al. 2013)[1]. Many building components affect the energy consumption of the building as the façade design. Openings and glazed areas of the facade have an important and effective role in a building's energy consumption whether for heating, cooling or lighting. On one hand, newly constructed office buildings are characterized by the increasing ratio of glazing in their facades to enhance the access to daylight, solar gain and external view rarely considering local climate requirements, which results high energy consumption rates and visual discomfort in some cases as shown in Figure 1. (Freewan, A. 2014) [2]. On the other hand, daylighting is one of the space requirements that improves its quality, visual comfort and occupant pleasure. Specifically in office buildings, workspaces require daylight in order to enhance productivity (Hviid, C. A. et.al. 2008).[3] Achieving adequate daylighting requires using a complete daylighting system, which includes daylight apertures, glazing materials and shading device. Not only adequate daylighting is the approach to achieve comfort in the space, but also minimizing energy requirements through improving thermal comfort. Therefore, the shading system could take place to work on blocking sunrays before heating up a space. In other words, a shading element of the façade could be an effective approach in diminishing energy requirements of the buildings especially in a hot dry climate as Cairo.

Consequently, many building professionals introduced a solution by using interior shading controls with no considerations to the higher performance of the exterior shading systems. In other words, installing shading devices externally gives the capability of blocking direct sunrays before penetrating the space, which results higher thermal performance and diminish of the solar gains (Kim, G.et.al. 2012).[4]

Several articles supported using external shading devices in hot climates. Moreover, one article investigated the effect of diagonal fins, egg-crates and vertical fins concluding that an average of 5% reduction of energy is achieved. In another study that concerned about the different parameters of the shading device, it reported that annual energy savings of 20% could be achieved by experimenting different length and type of shading. Additionally, a study focused on the indoor air temperature improvement by comparing overhangs, louvers, and egg crates, reporting that egg crates shading devices yielded the largest reduction in the indoor air temperature and duration of discomfort (Al-Tamimi, N. A. et.al. 2011).[5]

On one hand, egg-crate shading devices achieved the highest energy consumption reduction in previous studies. On the other hand, facades in most of the cases are designed using architectural grids, which use a composition of horizontal and vertical structure elements that should be considered in the selection of the shading element to facilitate energy adapting implementation process especially in wide scale office buildings as shown in Figure 1.. In addition, the egg-crate shading is the shading type that follows the vertical and horizontal grids. In other words, the egg-crate shading system is composed of a lattice of perforated panels fixed externally. (Olgyay, A. et.al. 1976)[6]. This system is considered as a fixed solar control system, which was originally a traditional practice under different names in Japan, Spain, Southeast Asia and Middle East. (Harris, C. M. 2006) (Sherif, A. et.al.2012)[7] [8]

Furthermore, other investigations were conducted concerning the optimum aspect ratio of the shading system unit. The research recommended aspect ratio 1:1 in the case of south facing windows. In addition, several publications studied the effect of egg-crate shading systems on the indoor environment. First, investigations were carried out to find the range of perforations that sustain the balance between daylight and energy savings, however, brute-force simulation was not used it reported that 30% to 50% is the preferred range (Batool, A. et.al. 2014)[9].

In fact, office buildings require enhancing the view within protecting the space from direct solar gains. Consequently, higher perforation ratios would be required for fulfilling the user needs.

As a conclusion, several findings in the literature affected the aim and the objective of this research. First, it is clear that the literature revealed the usefulness and the positive effect of using egg crate shading systems. The egg-crate shading system were positively supported through the review to be capable of achieving energy reduction in the buildings consumption while reserving adequate daylighting levels. Second, it was found that the optimum aspect ratio for the system is 1:1. Therefore, the study focused on square based egg-crate systems. Third, selecting office buildings as the case study typology was a result of the high window to wall ratios used in this typology.

Moreover, achieving an optimum design for the shading system requires deep investigations through all the effective design parameters all-together. However, the literature concluded several useful results; no previous studies adopted a parametric brute force simulation process. In other words, most of the previous studies focused and studied the effect of a single parameter on the efficiency of the shading system. In combination, previous studies did not evaluate the adequacy of daylighting and visual comfort levels using the new approved Illuminating Engineering Society (IES) metrics. The IES approved two metric types; the Spatial Daylight Autonomy (sDA300/50%) and Annual Sunlight Exposure (ASE1000/250hr).

These findings induced the aim and objective of this study to explore several affecting parameters on the efficiency of the egg-crate shading system. Additionally, efficiency is defined as the optimum daylight adequacy achieved by the shading system coupled with the minimum energy requirements for the space in the local climate of Cairo. The research targeted office buildings typology as a reference for the study. Furthermore, the study addresses the potential of applying the shading system as a retrofitting strategy for existing office buildings. Therefore, it aims to provide stakeholders guiding recommendations for implementing the retrofitting process.

However, brute force simulations require high computing power and long simulation duration, brute force simulations were carried out to achieve the optimum configurations. Moreover, various iterations were proposed to investigate the studied parameters as; depth factor, perforation ratio and grid size of the shading lattice in an exhaustive parametric simulation process. Finally, results concluded several findings regarding the optimum configurations for each studied window to wall ratio.

Figure 1.1 Examples of office buildings located in Cairo. Source (Alico Egypt)

The research aims to investigate answers for the following questions:

- What is the optimum configuration for each studied WWR?
- What is the potential of using egg-crate shading system as an energy efficiency

retrofitting strategy in office buildings in Egypt?

- Is the energy efficiency retrofitting strategy worth to be carried out compared to energy savings?

METHODOLOGY

As a response to the aims and objectives of the research, the methodology of the research was developed. In order to understand the effect of each parameter individually and combined with other parameters, the research adopted a stepped pre-defined parametric process to execute the simulation.

As mentioned previously, the research aims to acquire the optimum balanced correlation between daylight adequacy and minimum energy requirements in the space. In other words, the role of the shading system is to block direct sunrays from penetrating the space and increasing the required cooling energy of the space. Hence, energy performance of the shading system is dependable on its performance through the daylight simulation. Therefore, the methodology reflected this sequence in the form of two consecutive phases that will be explained in detail. The first phase is concerned about visual comfort in the space by achieving adequate daylight levels compliant with the requirements of the office space. Consequently, cases that achieve adequate daylight levels need to be ordered through their energy consumption rates. Therefore, the second phase is concerned about using energy simulations through cooling, heating and lighting loads to order the successful cases from the previous phase.

The Evaluation criteria for the selection of the successful cases was based on meeting LEED v4 maximum requirements (USGBC)[10]. While as mentioned previously, the daylight adequacy was measured and visualized based on the Illumination Engineering Society (IES) approved daylight metrics: Spatial Daylight Autonomy (sDA 300/50%) and Annual Sunlight Exposure (ASE 1000/250hr). (IESNA, I. 2012)[11]. The required levels for daylight adequacy are (sDA 300/50%) value of 75% of the space and (ASE1000/250hr) of no more than 10%. (Heschong, L. et.al. 2012)[12]

Because of the findings in the literature, the simulation studied buildings with high WWRs ranging from 60% to 80%. Perforation ratios studied were a range from 50% to 90% as it provides enhancing the view. In addition, other studied parameters as depth factor, which is a ratio of the grid size of the shading element and the depth length were examined. In addition, all studied parameters were visualized in Table 4.

Particularly, the simulation was conducted on a south oriented office room of 4m x 6m x 3m as shown in Figure 1.2 and the specifications of used materials of the studied space are as illustrated in Table 1. Moreover, the model assumed the case of no obstructions for the simulation. The simulation was processed through an automated parametric process. In addition, it was conducted through the utilization of several linked softwares and simulation engines. In detail, the parametric modelling plugin Grasshopper for Rhinoceros 3D software was used to generate all the configurations of the different studied parameters. The parametric model was linked to the different simulation engines through DIVA for Rhino (L. Solemma. 2014)[13]. DIVA for Rhino was used to interface several simulation engines in the process for both phases of the methodology. DAYSIM and Radiance lighting simulation engines were utilized in the first phase of the research. While, the widely used energy simulation engine EnergyPlus was utilized in the second phase of the research.

Furthermore, 450 different configuration cases were modelled to study all the proposed parameters that were illustrated in Table 2. The simulation was conducted using the climatic data and hot arid conditions of the city of Cairo in Egypt. The settings for simulation of the two approved metrics sDA and ASE were illustrated in Table 3.

Table 1. Office space specifications

Dimensions	*4m x 6m x 3.2m*	
Area	*24m2*	
Orientation	*South*	
Materials Reflectivity of the Residential Space	*Walls*	*50%*
	Floor	*20%*
	Slab	*80%*
Occupancy	*8:00 am - 6:00 pm*	

Table 2. Parameters of the 1st phase of the Simulation

WWR	*60% to 80% (Step = 10%)*
Grid Size of the Screen	*0.2m to 0.6m (Step = 0.1m)*
Perforation Ratio	*50% to 90% (Step = 10%)*
Depth Factor	*0.3 to 1 of the Grid Size (Step = 0.1)*
Analysis Plane Height	*1 m*

Table 3. Radiance simulation parameters for [sDA and ASE metrics] respectively

Required Metric	*Ambient Bounces*	*Ambient Divisions*	*Ambient Sampling*	*Ambient Accuracy*	*Ambient Resolution*
sDA	6	1000	20	0.1	300
ASE	0	1000	20	0.1	300

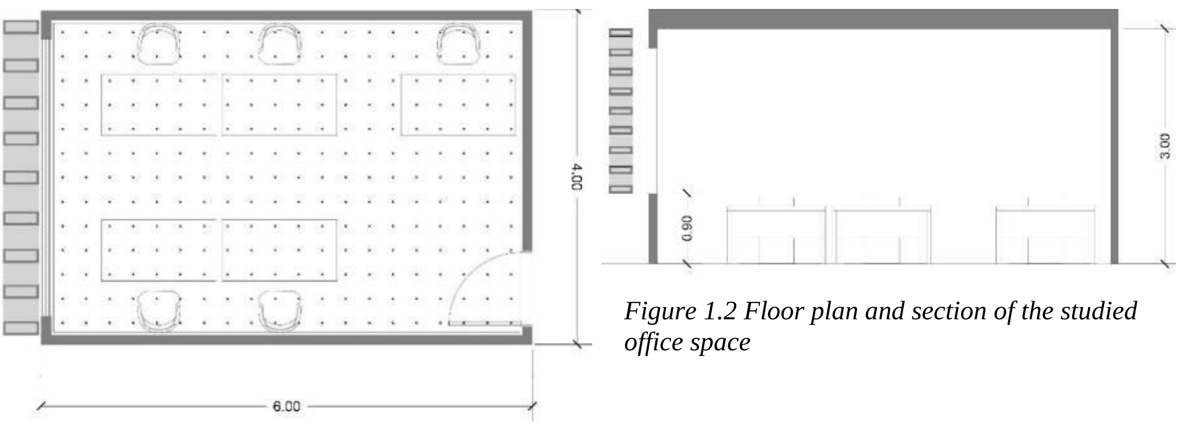
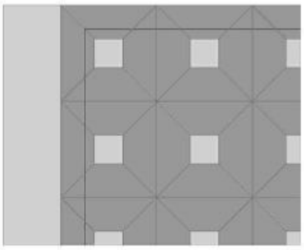
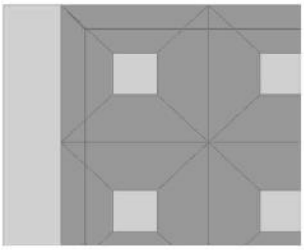
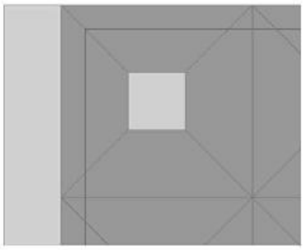
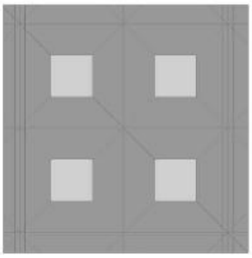
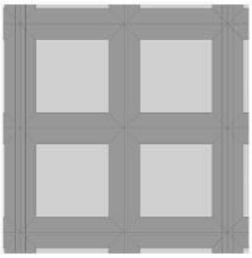
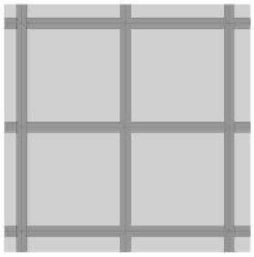
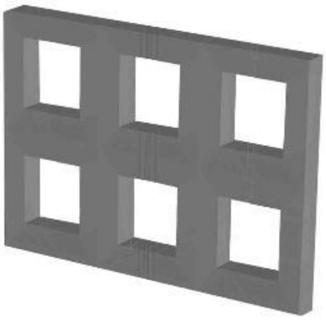
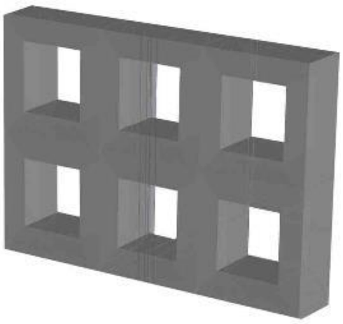


Figure 1.2 Floor plan and section of the studied office space

Table 4. Visualization of the parameters of the tested shading system

Grid Size of Screen			
Perforation Ratio			
Depth Factor			

DISCUSSION AND RESULT ANALYSIS

The following section displays and analyses the achieved results. The results are the outcome of brute force simulation that address all the studied parameters and their effect on the daylight adequacy and thermal performance on the office space.

Phase One

In this phase, results were screened and categorized to three categories referring to the studied window to wall ratio (WWR). In the following 3D bar charts all the configurations were displayed, numerical values of the achieved Spatial Daylight Autonomy (sDA 300/50%) and Annual Sunlight Exposure (ASE 1000/250hr) were labelled on each bar in the form of (ASE, sDA)

First, several findings were observed in the case of 60% WWR. The grid size parameter was found to be not highly effective on the sDA values within a constant perforation ratio.

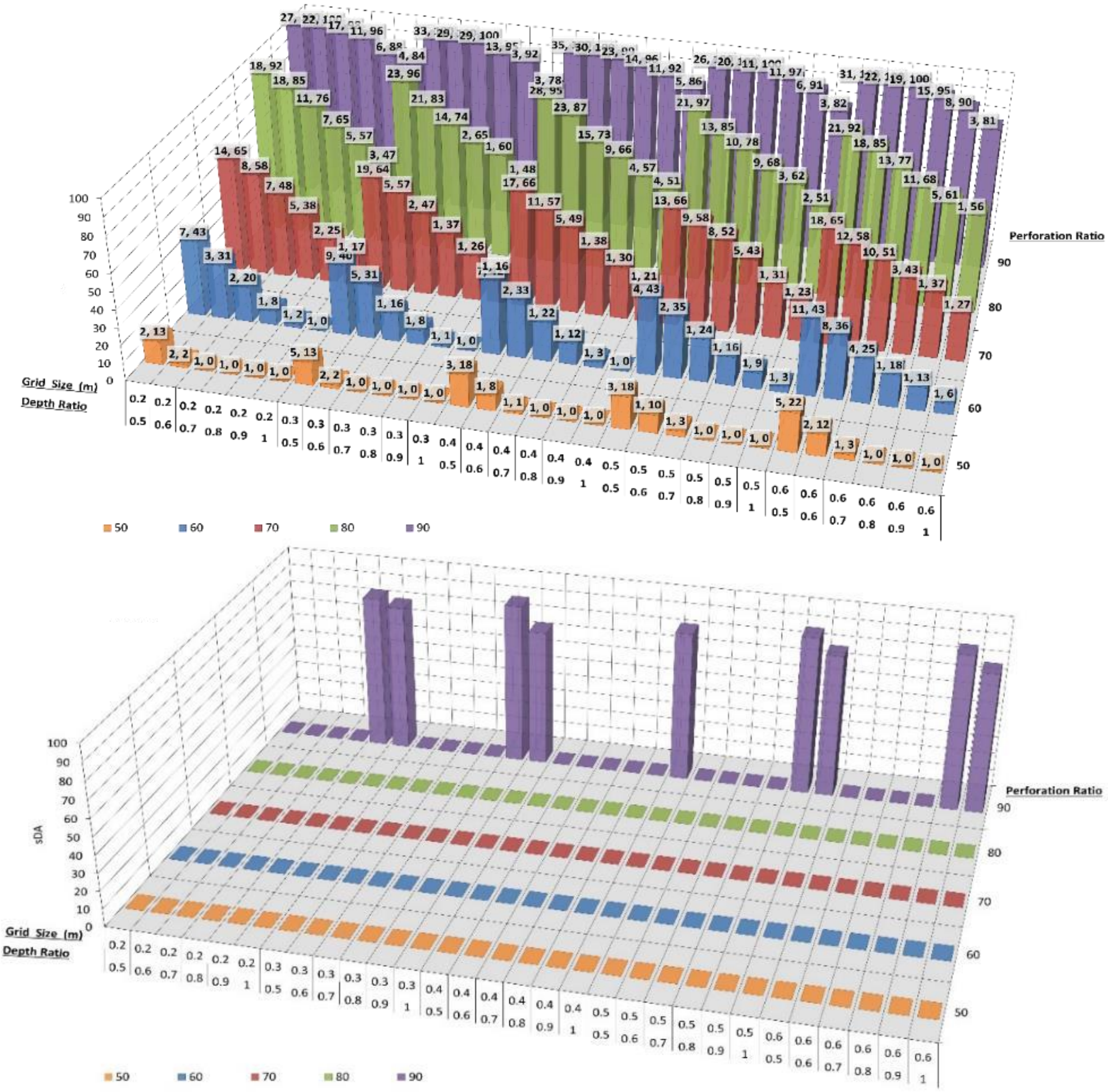


Figure 1.3. Results for 1st phase of the WWR 60%, all configurations upwards and successful configurations downwards.

In other words, the difference between the highest and lowest achieved sDA value is 9% with a constant perforation ratio 50% and a constant depth factor 0.5. While, perforation ratio parameter was highly effective on the sDA values. Between perforation ratios 50% - 60% and 60% - 70%, the sDA values increased dramatically by nearly 30%. Unlikely, less effectivity of perforation ratio parameter was found between perforation ratios 80% - 90% as values didn’t significantly increase. In conclusion, between ratios 80% - 90%, perforation ratio is not the effective parameter.

Conversely, the depth factor showed effectivity in most of the perforation ratios. To put it differently, the depth factor parameter was revealed the key parameter in determining the sDA value. However, the depth factor did not show the same effect in the case of perforation ratio 90%. Moreover, depth factor parameter was effective in achieving acceptable ASE values especially in high perforation ratios. Particularly in the case of perforation ratio 90%, the depth factor decreased the ASE value by 29% achieving the minimum ASE value of 3%.

In Figure 1.3, the successful cases achieving the maximum requirements of the LEED V4 were displayed. It was found that accepted sDA and ASE values were only found in the case of perforation ratio 90%. Particularly, the maximum achieved sDA value was 92%. In other words, 60% WWR requires a minimum 90% perforation ratio. In the same manner, the 70% WWR showed comparably similar performance. Correspondingly, sDA values increased by the increase of the WWR. Similarly, the depth factor was the effective parameter within the studied

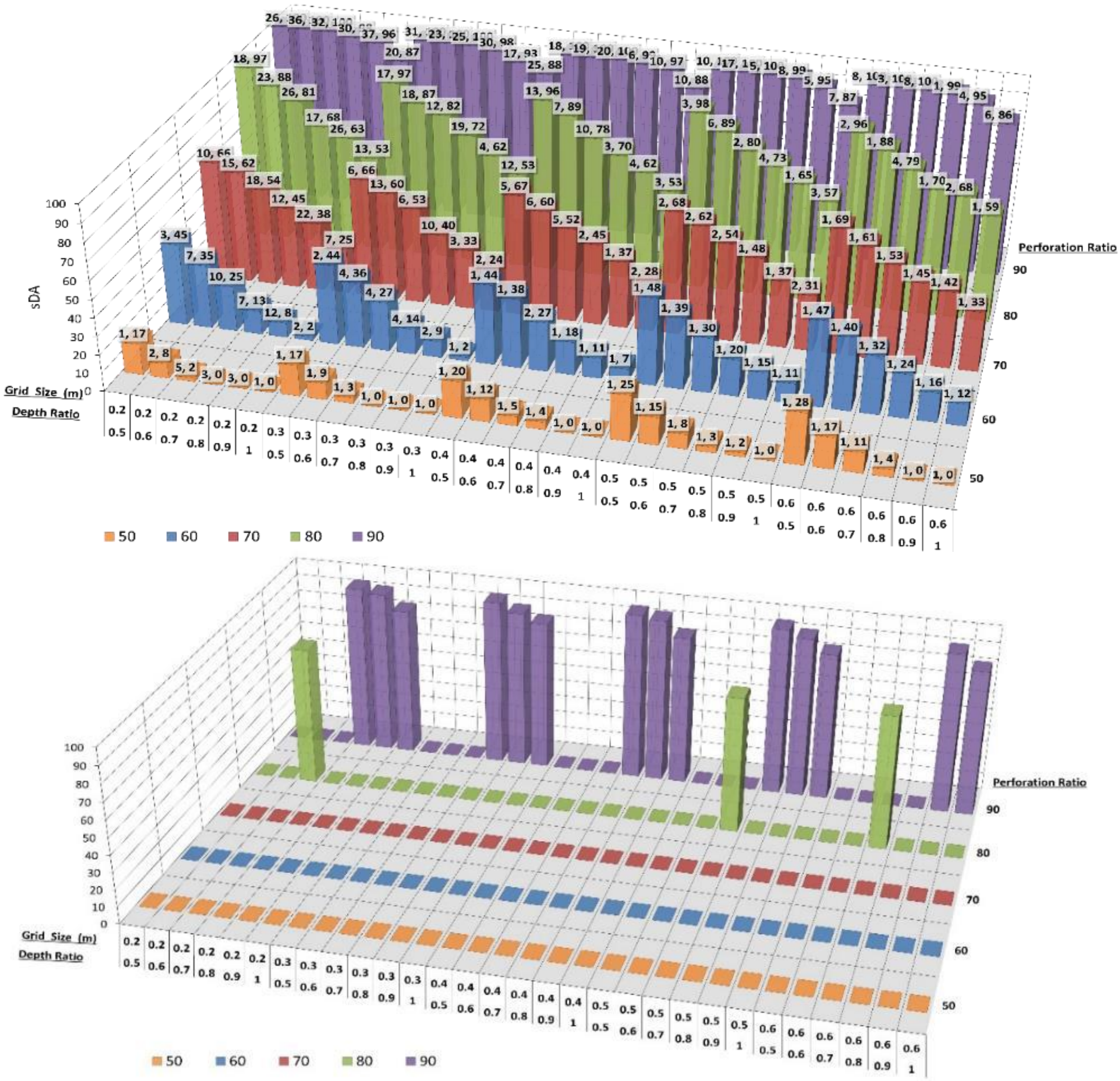


Figure 1.4. Results for 1st phase of the WWR 70%, all configurations upwards and successful configurations downwards.

parameters on sDA values. The effect of the depth factor was revealed in most of the perforation ratios except the 90% perforation ratio. Similarly, the grid size wasn't effective on the sDA values. Unlikely, the perforation ratio parameter was highly effective on the sDA values. Specifically, the increase of the perforation ratio increased the sDA values from 28% to 100% with a constant depth factor 0.5 and grid size 0.6m. Conversely, the perforation ratio was negatively effective on the ASE values as the values increased from 3% to 37% in the same configurations. According to Figure 1.4., the 70% WWR achieved higher number of successful cases. Moreover, the perforation ratio range of the successful cases increased to include perforation ratio of 80%. In detail, the highest sDA of the accepted configurations was 99%, while the minimum achieved ASE value was 1%. Comparatively similar was the performance of the 80% WWR. In other words, the WWR 80% followed the previous studied WWRs, but the increase of the WWR resulted slightly higher sDA values. Identically, the effect of the depth factor was sustained as a key parameter. Additionally, perforation ratio had higher effect on sDA. In the case of constant grid size of 0.2m and depth ratio 0.5, the increase of the perforation ratio resulted and increase in the sDA values from 22% to 100%. In contrast, the ASE values were negatively affected as they increased from 2% to 32% for the same configurations. In addition, , successful configurations for perforation ratio 80% increased. While, successful configurations perforation ratio 90% decreased. Generally, this could be explained that the increase of the WWR coupled with a high perforation ratio resulted higher ASE values out of the accepted range. It is clear from the previous that the depth factor parameter had a significant effect on daylight adequacy. For this reason, more understanding for the performance of this parameter was required. Therefore, the following line graphs were generated and displayed. As a result of the previous cases analysis, graphs were generated for the case of 80% WWR and 0.4m grid size. First, Figure 1.5 clarified the inverse relation between depth factor and sDA values. In other words, the depth factor negatively affects the sDA values, as values steadily decrease by the increase of the depth factor. However, the case of 90% perforation was slightly affected by the depth factor parameter. For this reason, all the cases of 90% perforation ratio acquired accepted sDA levels. Conversely, the number of the accepted configurations decreased for the 80% perforation ratio. Particularly, the accepted cases of 80% perforation ratio lay in the range of (0.9 – 1) depth factor. Second, the relation between the depth factor parameter and ASE values was studied. As can be seen, the depth factor has high impact in controlling ASE values. In high perforation ratios, the depth factor played a key role in reaching accepted ASE values. In other words, the case of 90% perforation ratio ASE values decreased dramatically by the increase of the depth factor, as the values fell down from 40% to 6%. Moreover, only the depth factor with the value of 1 achieved accepted ASE values. However, the case of 50% and 60% perforations had accepted cases in all the depth factors.

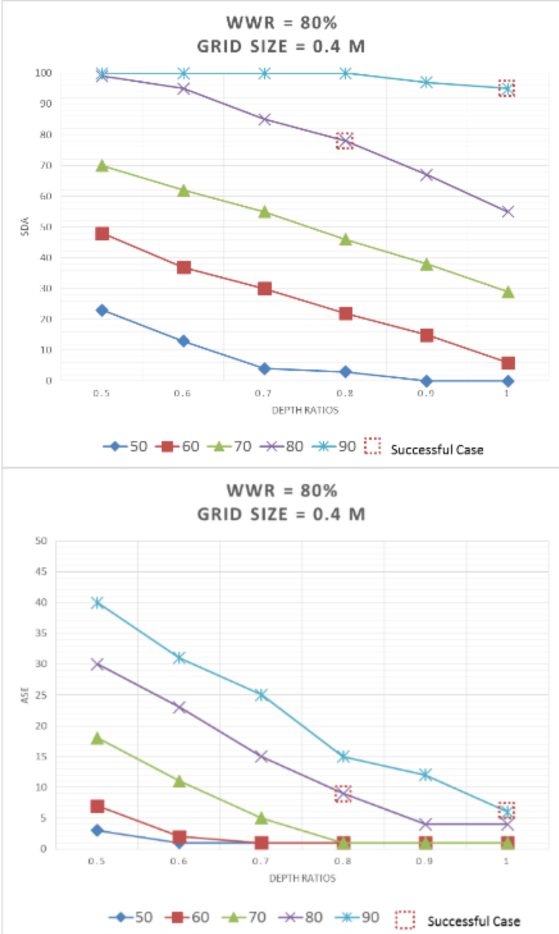


Figure 1.5. Relation between depth ratios and sDA, ASE values respectively.

Phase Two

The following section discusses and displays the results of the second phase of the research. After screening the results of phase one, configurations achieving adequate daylight levels will be evaluated and ordered according to their energy performance. The second phase took place to calculate the cooling, lighting electricity and heating loads of each configuration. The cases were classified into three categories according to their WWR. Furthermore, the results of all cases were summarized and illustrated in Table 5. Line graphs were generated to display the performance of all the simulated configurations. Besides, the reduction value that was achieved by the shading system was concluded. Thus, a simulation for a base case was conducted. First, it revealed that configuration 4 achieved the best energy performance in the 60% WWR. 70% perforation ratio coupled with grid size 0.2m and 0.9 depth factor. The configuration achieved savings around 69 kWh/m^2. The difference between the highest and lowest energy consumption values achieved is around 48 kWh/m^2. From the observation of the two cases, it appears that the effective daylight parameter that resulted the difference in the energy consumption levels is the ASE values. In detail, the highest energy consumption configuration achieved 7% ASE value.

In the case of 70% WWR, configuration 14 achieved the optimum energy performance that had a depth factor of 1 coupled with a perforation ratio of 0.9 and a grid size of 0.4m. Furthermore, the reduction acquired compared to the base case reached nearly 83kWh/m^2. Similarly, the effective daylight factor on energy consumption was the ASE. While in this case, the difference between the highest and lowest energy consumption increased to reach 72 kWh/m^2. Third, the successful configurations of 80% WWR were simulated for the energy requirements. Moreover, configuration 11 resulted the optimum energy loads for the space having depth factor with value of 1, grid size 0.5m and 90% perforation ratio. In the same manner, ASE values highly determined the energy consumption values. The difference between the highest and lowest energy consumption cases reached 57 kWh/m^2. Overall, successful and optimum cases were determined and revealed after the two consecutive phases of the simulation. Every WWR had configurations that achieve adequate daylighting levels that comply with LEED v4, while achieving the lowest energy consumption at the same time. In other words, it balances the requirements between daylight adequacies of the space and energy consumption of the space.

Table 5. Annual energy consumption of successful cases; WWR 60%, 70% and 80% respectively.

#	WWR	Grid Size	Perforation Ratio	Depth Ratio	sDA	ASE	Total Electricity (kWh/m2.)	Total Cooling (kWh/m2.)	Total Heating (kWh/m2.)	Total Annual Energy (kWh/m2.)
1		0.5	0.8	0.7	83	10	5.2	144.1	29.1	178.4
2		0.6	0.8	0.7	80	10	5.0	141.7	30.2	176.8
3		0.2	0.9	0.9	88	6	5.5	119.2	27.4	152.1
4		0.3	0.9	0.9	92	3	5.7	98.6	26.2	130.6
5		0.5	0.9	0.9	93	6	5.8	121.8	25.9	153.5
6	0.6	0.6	0.9	0.9	90	8	5.6	135.1	26.8	167.5
7		0.2	0.9	1	79	4	4.9	101.9	30.5	137.3
8		0.3	0.9	1	80	3	5.0	95.6	30.2	130.7
9		0.4	0.9	1	80	5	5.0	108.8	30.2	143.9
10		0.5	0.9	1	80	3	5.0	95.6	30.2	130.7
11		0.6	0.9	1	80	3	5.0	95.6	30.2	130.8
Reduction (kWh/sq.m)										68.7
1		0.2	0.8	0.7	77	4	4.8	101.2	31.3	137.4
2		0.5	0.8	0.7	83	7	5.2	123.7	29.1	157.9
3		0.2	0.9	0.8	97	6	6.0	123.8	24.9	154.7
4		0.3	0.9	0.8	98	10	6.1	156.5	24.6	187.2
5		0.4	0.9	0.8	98	10	6.1	156.5	24.6	187.2
6		0.5	0.9	0.8	100	10	6.2	158.1	24.1	188.5
7		0.2	0.9	0.9	95	5	5.9	115.0	25.4	146.3
8	0.7	0.3	0.9	0.9	96	8	6.0	139.0	25.1	170.2
9		0.4	0.9	0.9	94	5	5.9	114.5	25.7	146.1
10		0.5	0.9	0.9	96	7	6.0	131.2	25.1	162.3
11		0.6	0.9	0.9	97	8	6.0	139.7	24.9	170.6
12		0.2	0.9	1	85	3	5.3	96.9	28.4	130.6
13		0.3	0.9	1	85	8	5.3	131.8	28.4	165.5
14		0.4	0.9	1	88	1	5.5	83.1	27.4	116.0
15		0.5	0.9	1	88	4	5.5	104.8	27.4	137.7
16		0.6	0.9	1	88	6	5.5	119.3	27.4	152.2
Reduction (kWh/sq.m)										83.3
1		0.6	0.8	0.7	83	8	5.2	130.5	29.1	164.7
2		0.2	0.8	0.8	75	8	4.7	125.2	32.2	162.1
3		0.3	0.8	0.8	79	8	4.9	127.9	30.5	163.3
4		0.4	0.8	0.8	77	9	4.8	132.9	31.3	169.0
5		0.2	0.9	0.9	98	10	6.1	156.5	24.6	187.2
6	0.8	0.5	0.9	0.9	97	10	6.0	155.6	24.9	186.6
7		0.6	0.9	0.9	96	9	6.0	146.9	25.1	178.1
8		0.2	0.9	1	90	8	5.6	135.1	26.8	167.5
9		0.3	0.9	1	95	8	5.9	138.4	25.4	169.7
10		0.4	0.9	1	93	6	5.8	121.8	25.9	153.5
11		0.5	0.9	1	93	3	5.8	98.8	25.9	130.6
12		0.6	0.9	1	90	9	5.6	142.5	26.8	174.9
Reduction (kWh/sq.m)										68.7

SUMMARY AND CONCLUSIONS

This research addressed the problem of balancing daylight adequacy and energy performance in the studied space. The balanced relation was investigated through applying an egg-crate shading system. Conversely, previous literature addressed the efficiency of one side only; either daylight or energy requirements. Additionally, the research confirmed the findings of the previous literature that square-based egg-crate shading systems could positively enhance and improve the daylighting adequacy. While, the research took another step in the investigation by assessing the energy performance of the adequate daylight configurations. It can be noticed that egg-crate shading devices can be efficient in shielding and protecting windows from high solar radiations and in the same time, achieving accepted daylight levels. Moreover, the integration of the shading system with existing buildings is feasible. The study introduced a full guide for architects and engineers for a high range of depths and grid sizes in order to decide the feasible system for application. To put it differently, the tables that were concluded from the parametric simulation could be utilized as a guideline for environmental retrofitting office buildings. Additionally, high levels of daylight adequacy were achieved, as sDA levels of the accepted cases for all WWRs reached a range between (93 – 100) percent. Besides, ASE levels decreased by 50% in all the studied WWRs. On the other side, Energy consumption reductions for the studied space reached a range of (63-83) kWh/m^2.

Finally, additional research is recommended for examining the application of egg-crate in a physical model. Moreover, the research concerned about the retrofitting process of office spaces is required to understand the drawbacks. The potential of examining additional parameters is also recommended.

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