A PARAMETRIC STUDY OF LIGHT SHELF SYSTEM PERFORMANCE FOR SOUTH ORIENTION IN HOT ARID ZONE
(A case study of a hypothetical office building in New Cairo area)

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ABSTRACT

In this daylighting study, a parametric approach was implemented, where all possible combinations of the various design parameters for the two design elements of the light shelf system (light shelf and room specifications) were computed. This generated a total of "819" cases that were tested exploring experimental hypothetical deep office room, facing South orientation with no external obstruction. The experimental tests of the parametric light shelf system have been executed through using Diva-for-Rhino (Grasshopper). The performance results were performed according to 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), in addition to the metric value for total Annual Energy consumption (tAEC).

The result analysis of the most successful tested study cases that have contributed design indicators for optimizing the performance of light shelf design parameters. In order to extent and maximize the positive influence of each design parameter within the design combinations that have proved successful. The selected successful tested case studies are the alternatives designs of light shelf systems for deep office spaces in new Cairo area, as models for applying light shelf system in the south direction in areas of hot climates under clear sky conditions. Among defined successful study cases, specific study cases will be selected as eligible samples for development, which by optimizing the performance of all their design parameters; be able to define the design aspects of advanced design cases of parametric light shelf systems for deep office spaces with optimum overall performance facing South orientation. This will be followed by subsequent future studies in the context of the trend towards defining the main design aspects, characteristics and executive specifications of sophisticated light shelf design systems in all main four major orientations.

Key words: light shelf; clear sky desert environment; hot arid climates; special daylight autonomy; Annual sunlight Exposure and energy consumption.

1- INTRODUCTION

Hot arid climates, are characterized by clear sunny sky most of the year. Such climates are known for their futility to use light shelves, especially in terms of energy consumption. This requires more studies to be conducted in order to explore the factual possibility of benefiting from the effective use of light shelves. Consequently, it is necessary to expand the study for all the design possibilities of the light shelf systems in order to explore the factual possibility of benefiting from the use of light shelves, and the optimal performance can be reached. Therefore, this study aimed at using the methodology of parametric design to expand and investigate various designs alternatives for light shelf systems, which increases

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the chance of reaching optimal design case of these systems. This study will be focusing on studying light shelf systems in deep South-oriented spaces only.

2- BACCKGROUND

Many studies have recommended the need for focusing on the light shelf systems performance in terms of daylighting and thermal performance as well on saving energy. Also exploring the design variations of light shelf systems by using parametric design.

Hanan Sabry, et al, 2006, Light shelves could locate inside or outside or on both sides of a building facade. Internal light shelf blocks less daylight, and it usually redirects less daylight into buildings [1].

Andersen, M, et al, 2008, External light shelves could redirect more daylight and work as overhang devices. However, external light shelves are not able to block all direct sun light. Combined light shelves could utilize the advantages of both and provide the most evenly distributed illumination [2].

Freewan A., et al, 2008, tested a room with a fixed light shelf and compared the four different ceiling geometries: flat ceiling, curved ceiling, chamfered and sloped ceiling on their effect of daylight performance of the test room. A conclusion is that ceiling slope could greatly affect the light shelf performance and a specifically designed curved ceiling could improve the light shelf performance by increase the daylight availability and uniformity of the test room [3].

The above review of the literature reveals the increasing possibility of benefiting from the use of light shelf system in terms of improved daylighting especially by using parametric tools software.

3-PERFORMANCE METRICS

There are a number of performance metrics are used in this study as follows;

3-1- DAYLIGHT AUTONOMY (SDA)

Two metrics in LEED v4 are codified for evaluating daylight autonomy design, which allow a daylight space to be evaluated for a one-year period using two different performance parameters: sufficiency of daylight luminance and the potential risk of excessive sunlight penetration. These two metrics are: Spatial Daylight Autonomy (sDA) and Annual Sun Exposure (ASE) metrics, which together form a clear picture of daylight performance. sDA describes how much space receives sufficient daylight, which, for office building spaces, must achieve (sDA 300 lux / 50% of the annual occupied hours) for at least 55-75% of the floor area. sDA has no upper limit on luminance levels, and, therefore, ASE is used to describe how much space receives too much direct sunlight which can cause visual discomfort (glare) or increase the cooling loads.

ASE measures the percentage of floor area that receives at least 1000 lux for at least 250 occupied hours per year that must not exceed 10% of floor area [4, 5].

3-2- TOTAL ANNUAL ENERGY CONSUMPTION (TAEC)

This criterion is presented in the comparison results between the base case, and each design combination in terms of the total annual energy consumption.

TAE will be used as verifying criteria in terms of achieving the reduction of TAE for the proposed design case.

4- CASE STUDY DESIGN PARAMETERS (ROOM AND LIGHT SHELF)

4-1- DESIGN OF HYPOTHETICAL OFFICE MODULE

The hypothetical office room designed with dimensions 6m x 12 m x 3.30m (width, length & height) which represent a large and a deep office space in a large multi-story Building. The selected length (12m) can accommodate at least eight open plan workplaces, while the selected width is 6 m in order to reduce the effect of inter-reflection from the walls on the light sensors located inside the model. The sensor points at a grid of 60 cm. at a working plane of height 0.75 m. The times of the year that represent the occupied daylight hours of the studied room space, were chosen from 8:00 AM until 6.00 PM sunset times. The tested room lies in the first floor from the street level, examined with constant window ratios. Figure (1) presents the various Dimensions and properties of the tested office space. Measurements that were found equal or higher than the recommended minimum luminance value for an office building room space of 300 Lx were considered "adequate" [6].

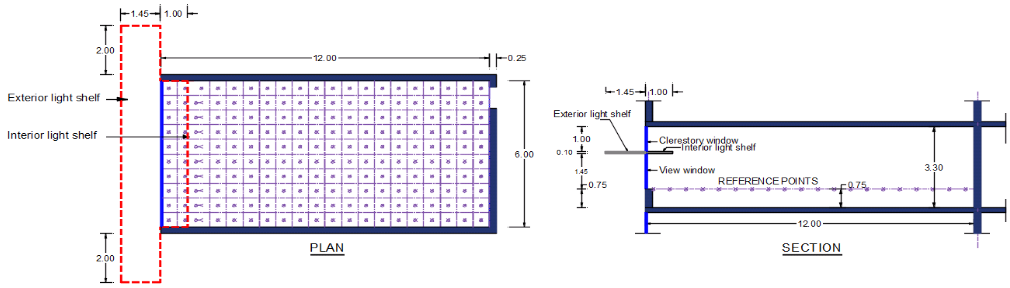


Figure (1): Hypothetical office building room plan and section is 300 lux, on which daylight autonomy

4-2-Light shelf system's parameters specifications

In this study, the variable parameters of light shelf system include a number of office space room parameters (ceiling tilt angle and curvature angle), and a numbers of light shelf parameters (position, tilt and curvature angle and material). The variable parameters specifications were defined (Table 1).

TABLE (1) DIMENSIONS AND PROPERTIES OF THE TESTED OFFICE SPACE AND DEFINE THE VARIABLES AND CONSTANT PARAMETERS

Dimensions and properties of the tested office space			Total Number for cases	Variable Type
Space Dimensions and Materials				
Floor level		one level	1	Constant
Room orientation		South	1	Constant
Space dimensions (m)		6m x 12m x 3.30 m	1	Constant
Walls	Reflectance	50%	1	Constant
	Material	Medium Colored Internal-walls Off-White	1	Constant
Ceiling	Reflectance	80%	1	Constant
	Material	White Colored Ceiling	1	Constant
	rotation angle	0,10 from half ceiling	2	Variables
	curvature angle	0,10 from half ceiling	2	Variables
Floor	Reflectance	20%	1	Constant
	Material	generic floor	1	Constant
Window(1) Dimensions and Materials	Width(m)	6 m	1	Constant
	Sill(m)	.75 m	1	Constant
	Lintel(m)	2.20 m	1	Constant
	glazing	Double glazing clear (VT=80%)	1	Constant
Clear story(2) Dimensions and Materials	Width(m)	6m	1	Constant
	Sill(m)	2.30 m	1	Constant
	Lintel(m)	3.30 m	1	Constant
	glazing	Double glazing clear (VT=80%)	1	Constant
Light Shelf Dimensions ,angle ,curvature and Materials				
Light shelf position		External, Internal, External and Internal together	4	Variables
External light shelf depth		1.45 m	1	Constant
Internal light shelf depth		1 m	1	Constant
Internal light shelf height from finish floor level		2.20	1	Constant
External light shelf height from ground level		5.90	1	Constant
External and Internal light shelf width		6 m	1	Constant
External and Internal light shelf thickness		,10 m	1	Constant
External light shelf rotation angle		0 , 15 , 35	3	Variables
Internal light shelf rotation angle		0 , -10	2	Variables
External light shelf curvature angle		0 , 15 , 35	3	Variables
Internal light shelf curvature angle		0 , -10	2	Variables
External and Internal light shelf Material		Generic ceiling 80, Silver mirror, Transparent glass and Translucent Panel	4	Variables
Reflectance& Material		High-Refl_80%	1	Constant

5- DATA ANALYSIS METHODS

A total of 819 cases were tested using one hypothetical deep office room for south orientations with different combinations of light shelf system.

The study performed a parametric analysis using DIVA for Rhino (grasshopper) simulation tool and the results are presented and analyzed in this study.

The data analysis in this study considers achieving two main goals; firstly, define the nature and the effect range of each design parameter in term of optimizing the daylighting performance and saving energy in order to help the designer to identify the effectual combination of light shelf design parameters. Secondly, define special design indicators for developing the performance of the defined design key parameters that have major and basic effect on daylight performance in order to identify the alternative design aspects of varies sophisticated light shelf systems.

6- AUTOMATING THE SIMULATION PROCESS

The automation of the simulation process was developed by closing the loop between the modeling and analysis environment. The workflow starts with running a daylight and energy simulation for various combinations of all design parameters. The results have been evaluated with reference to the LEED and IES standards to evaluate the performance for each design combination. The cases that can be considered as successful cases in term of some of performance criteria but yet to be developed in order to meet all the success criteria. Those cases will be modified in a new loop process. The optimization relies on developing the key design parameters that have the main influences on the system performance. The optimazation process will continue on runing till achieving all the performance objectives of the daylight performance optimization, as shown in figure (2).

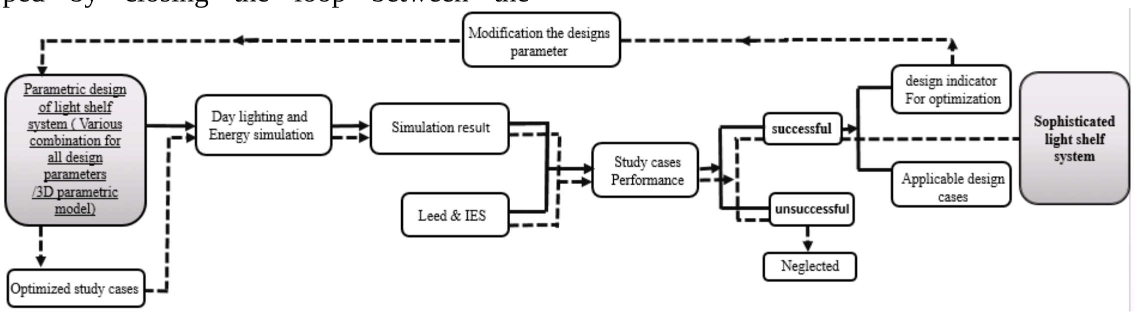


Figure (2): The study workflow

7- THE RESULT ANALYSIS

7-1- Define the successful study cases and their design characteristics

In the southward orientation, there were a large number of successful study cases that have been achieved. A total of 82 cases were identified as successful from a total of 819 study cases have been tested, (Fig. 3). The basic case in south orientation has achieved 80.5% sDA 300, 50% and 27.5% ASE1000, 250h., therefore the tested cases that have achieved more than 70% sDA and less than 27.5% ASE, have been identified as applicable successful cases. Among those defined as successful study cases, specific study cases will be selected as eligible samples for development in order to achieve optimal performance.

Up to exploratory experiments results, it was found that the most successful cases in south direction are cases no. 321, 322 and 582.

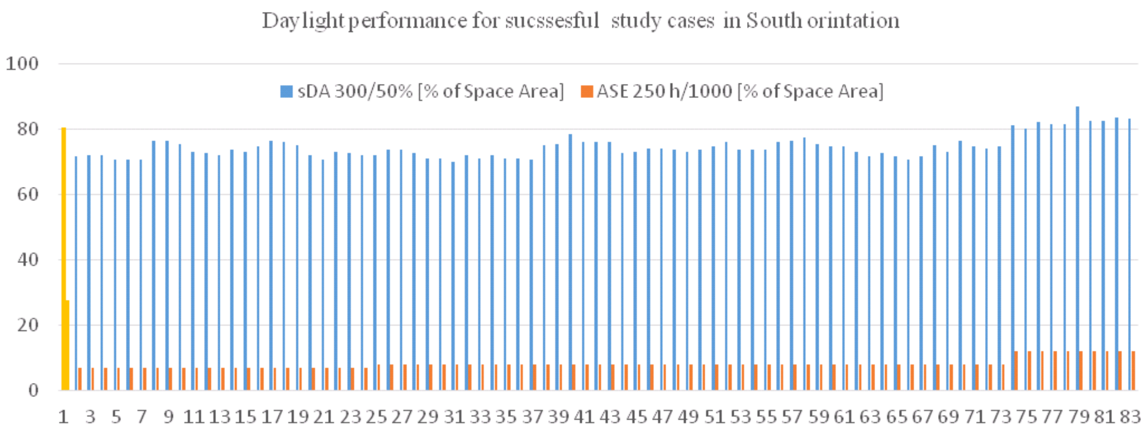


Figure (3): Chart shows the daylight performance for all successful study cases compare to base cases in south orientation

7-2-Result analysis of the selected successful study case samples in the South

The performance of each selected samples of the successful cases can be concluded as following:

- Sample cases no. 321:

The performance of this case was that the horizontal external Generic Ceiling 80 light shelf combined with the horizontal internal silver mirror or Generic Ceiling 80 light shelf with both tilt and curved ceiling by angel of -10° are the most effective parameters aspects in term of achieving the best sDA and ASE improving. Table (3) shows the performance rustles of this case as following:

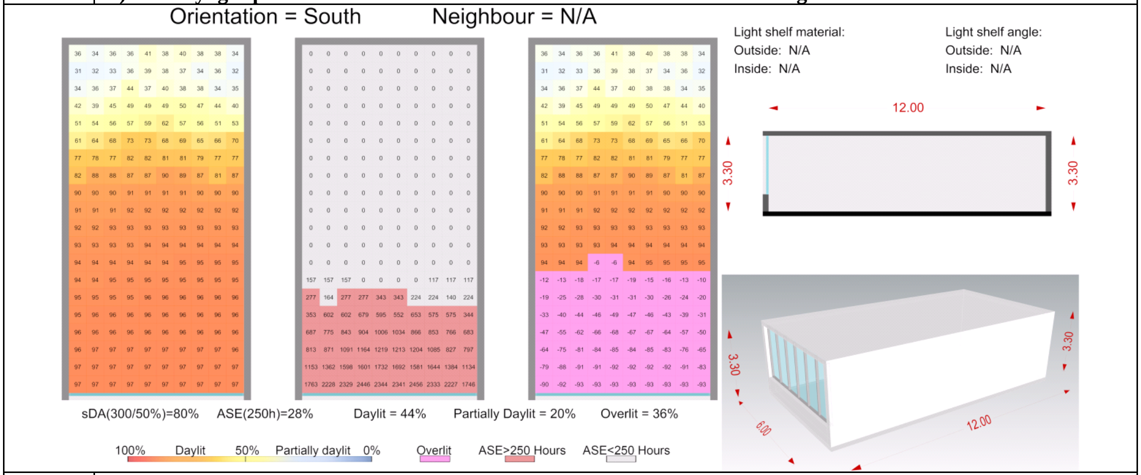
* The graph shows that there are performance enhancements for the selected Samples of the successful cases with ratio of 20.5% for ASE comparing to the base case, while maintaining the sDA quality.

* The first chart shows the daylight performance enhancement ratio, for the selected samples of the successful cases with a ratio of 20.5% for ASE comparing to the basic case performance.

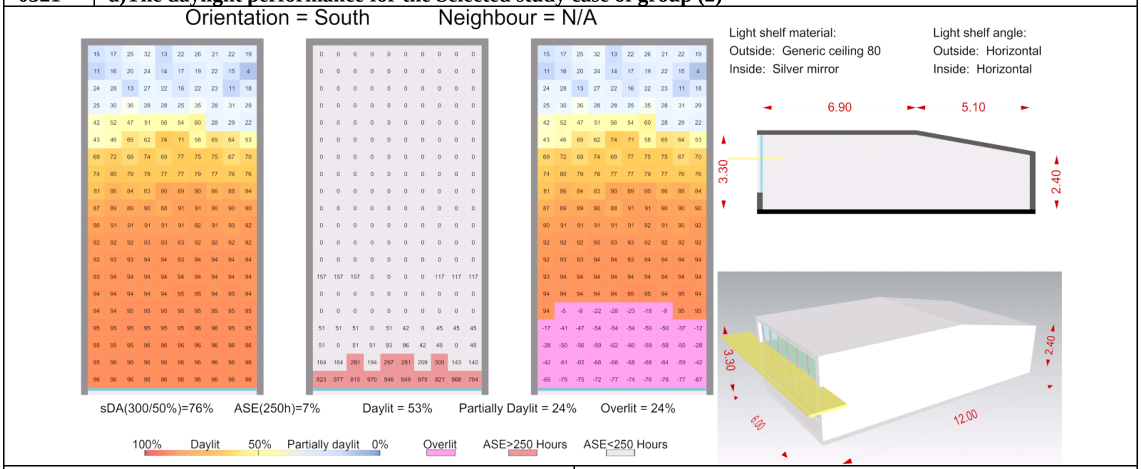
* The second chart shows a decrease in saving energy performance, due to the slight reduction in sDA value.

Table 3- Rustle analysis for study case no. (321).

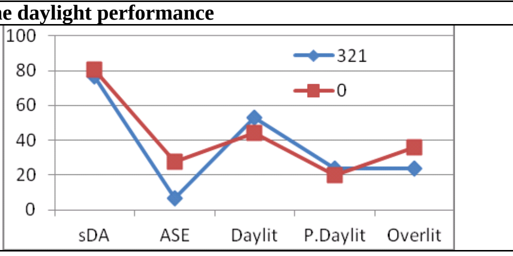
0000 | **a) The daylight performance for base case for South orientation without neighbor**



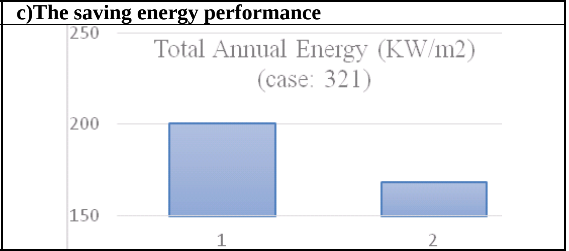
0321 | **a)The daylight performance for the Selected study case of group (2)**



b)The daylight performance



c)The saving energy performance



9- CONCLUSION

The study analysis has achieved two main goals; firstly, it defined successful applicable design models of light shelf systems for deep office spaces south oriented. Secondly, define the effect range of each design parameters in term of daylighting and saving energy performance.

The most important contribution to the analysis of the most successful study cases is the determination of design indicators to optimize the performance of light shelf systems for deep office spaces in the south direction. These design indicators includes the identification of key design parameters that have major and basic effect on daylight performance, as well as their most appropriate and effective design specifications, which provides researchers and designers with a design basis for more alternatives of varies sophisticated systems of light shelf. The identified design indicators are as follows;

1- The combined external and internal light shelf design case is the most successful design parameters for position of light shelves, whereas the combination of both external and internal light shelves leads to significant contribution to the uniform distribution of daylight with the best saving in energy consumption.

2- A horizontal flat light shelf performs well to block out direct sunlight as shading and reflect it as daylight system in the south.

3- The use of horizontal ceiling is not preferable compare to tilted and curved ceiling.

4- The best material for external light shelf is G.C. 80 and the best material for internal light shelf is silver mirror that have higher illuminance level at the back of the room.

Based on the defined design indicators, this study recommend with develop various proposed parametric light shelf systems in further future studies.

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