INVESTIGATING OF THE LIGHT SHELF SYSTEM PERFORMANCE IN THE MAIN FOUR GEOGRAPHICAL DIRECTIONS IN HOT ARID ZONE
(A case study of a hypothetical office building in New Cairo area)

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ABSTRACT

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 and visual performance. This requires more studies to be conducted in order to explore the factual possibility of benefiting from the effective use of light shelf and quality in hot arid climate. Therefore, this paper performs investigation into using different light shelf positions for the four main geographical directions. This system will be evaluated from the point of view of its impact and influence on special daylight autonomy (sDA) 300/50% [% of Space Area]), Annual sunlight Exposer (ASE 250 h/1000 [% of Space Area]), daylight availability (partially daylight, daylight and over lit), and Total Annual Energy consumption (tAEC [KW/m2]). The study performed a parametric analysis using DIVA for Rhino (grasshopper) simulation tool on a hypothetical office building in New Cairo area. The study outcome proved that light shelf can be an effective daylighting system to improve lighting environments without any negative effect on energy consumption, especially by using that kind of combined light shelf (internal and external). The results show that the performance rate in descending order was in the south, then west and east while it is not futile of use horizontal light shelf in the north direction. Therefore, on this basis this search recommends developing a parametric design for light shelf systems.

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 with consistent presence of direct sunlight; this causes a critical penetration for solar rays into built spaces, that creates a non-uniform daylight distribution and high solar heat gain, which in turn affects both visual and thermal comfort. Solar control systems such as light shelf could improve the daylight performance in the building's interior of these climates. The light shelves are typically placed above the eye level and can be internal and/or external; the internal portion was designed to block direct sunlight from the window area above the shelf, while the exterior portion shades the surface area closer to the window (1-2). On this basis the main objective of the use of light shelf system is to maximize harvesting daylight, while uniformly diffusing the direct sun rays, in order to reduce artificial lighting and saving energy consumption. This underlines the need for careful design of light shelf, in order to achieve a balanced performance between its role as a barrier and as a reflector of light with taking into account the accompanying energy performance. Therefor this study presents an investigation of the performance of various light shelf types installed in the main four geographical directions, and will be described and evaluated in terms of its impact and influence on special daylight autonomy (sDA 300/50% [% of Space Area]), Annual sunlight Exposure (ASE 250 h/ 1000 [% of Space]), daylight availability (partially daylight, daylight and over lit) and Total Annual Energy consumption (tAEC [KW/m2]) through daylighting simulations (3-4).

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2- BACCKGROUND

Many studies have recommended the need for focusing on the effect of light shelves on daylight, thermal performance and energy consumption rate and also evaluating the light shelf performance for the different orientation and obstruction scenarios.

Mahmoud Gad El-Hak, 2014, proved through a research that a combination of redirecting systems (light shelves) and a shading system (solar screen). And a second system, free form "gills surface", to provide acceptable daylighting performance, proved that the first system, of a screen with 90% perforation and 50° VSA combined with a 120 cm, 10° rotated light shelf, was the best solution. [5]

Hanan Sabry et al., 2012, conducted a research on the configuration of an externally fixed perfo-rated solar screen and an externally fixed light shelf. For the four main orientations. Daylighting performance was simulated and the result demonstrated the usefulness of combining several techniques in order to achieve better daylight performance. The combined solar screen and light shelf configuration was the best option in enhancing daylight availability and distribution [6].

The above review of literature reveals that light shelves was the best option in the Egyptian desert climate. This research will contribute to increasing the benefits from the use of light shelves in terms of improved natural lighting and will take into account the positive energy performance (total consumed energy) in the four main orientations.

3- METHODOLOGY

This paper is part of an ongoing research that aims to optimize light shelf daylighting performance in office spaces in New Cairo district (Hot Arid Climates), in order to achieve the optimized performance in term of visual and thermal comfort. Investigation was performed in the four major orientations (N, S, E, and W). This paper methodlogy is based on a comparative analysis of daylighting and energy consumption performance for a hypothetical deep office space, with various light shelf positions for the four orientations. This makes a total of 16 tests study cases for the study analysis.

To identify the performance characteristics of the light shelf in each tested design case, four main values have been measured. They are special daylight autonomy sDA, Annual sunlight Exposure ASE, daylight availability DA and total annual energy consumption TAEC. The simulation results are presented, discussed, and recommendations for better retrofitting solution are proposed.

PERFORMANCE METRICS

There are two main performance metrics are used in this study they are as followings;

3-1- Daylight Autonomy (sDA) and Annual Sun Exposure (ASE):

These two metrics are: Spatial Daylight Autonomy (sDA) and Annual Sun Exposure (ASE) metrics, which together form a clear picture of daylight performance that can help architects, make good design decisions. sDA describes how much space receives sufficient daylighting, 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) and increase the cooling loads. In LEED v4 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 [7].

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

A hypothetical first story room with dimensions 6m x 9m x 3m (width, length & height) is examined with constant window ratios, the sensor point at a grid of 60 cm (Fig. 1, & Table 1).

Table 1- Dimensions and properties of the tested office space

Space Dimensions and Materials		
Floor level		one level
Space dimensions (m)		6m x 9m x 3m
Walls	Reflectance	50%
	Material	Medium Colored Internal-walls Off-White
Ceiling	Reflectance	80%
	Material	White Colored Ceiling
Floor	Reflectance	20%
	Material	generic floor
Window(1) Dimensions and Materials		
Width(m)	6.00m	
Sill(m)	.90m	
Lintel(m)	2.10m	
Glazing	Double glazing clear (VT=80%)	
Clear story(2) Dimensions and Materials		
Width(m)	6m	
Sill(m)	2.20m	
Lintel(m)	3m	
Glazing	Double glazing clear (VT=80%)	
Light Shelf Dimensions and Materials		
External light shelf depth	1.20 m	
Internal light shelf depth	1.20 m	
External light shelf rotation angle	0	
Reflectance& Material	High-Refl_80%	

The times of the year that represent the occupied daylight hours of the studied room space were chosen from 8:00 AM until 6 sunset times. The reference plane on which daylight performance was simulated contained measuring points in a grid of 0.6m * 0.6m, at a working plane of height 0.75 m. 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". [8]

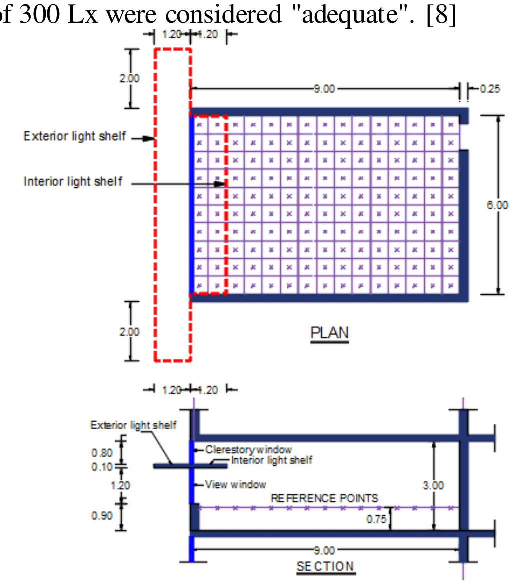


Figure 1- Hypothetical office building room plan and section is 300 lux, on which daylight autonomy

5- THE RESULT ANALYSIS

The evaluation method assesses the quantity sDA, quality ASE of daylight and the amount of energy saved inside the office space. The results are presented and analyzed by comparing the measured three values of the tested cases, and the result analysis are presented in 3parts as follows:

5-1- The first part:

This part focuses on the analysis of the results that show the effect of changing four main direction on the performance of each type of light shelf, in addition to the base case (without light shelf). This part evaluates how the performance of each light shelf design case could change with the change of geographical orientation of the tested room (Table2).

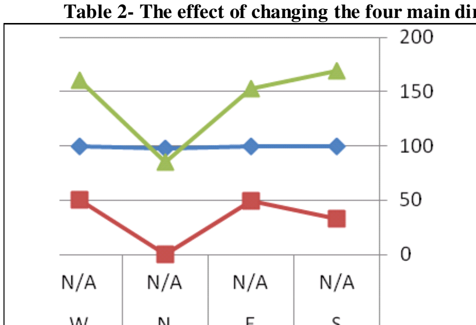
In Table 2/a, the SDA, ASE and TAEC Performance curve for the base case (without light shelf), table 3/a, shows the equal effect of the four geographic direction on the SDA values. The diagram also shows that the Performance rate for ASE was in a descending order for the North orientation, South then the East and West that were equal, whereas the descending order for TAEC was for the north oriention, East, West and then the South, which means that the total energy consumption is not only correlated with ASE.

In Table 2/b, the SDA, ASE and TAEC Performance curve for external light shelf. The results, showed that the dependence on the external light shelf did not produce the required results for the four orientations. It did not increase the SDa value and reduced the ASE value by a small percentage.

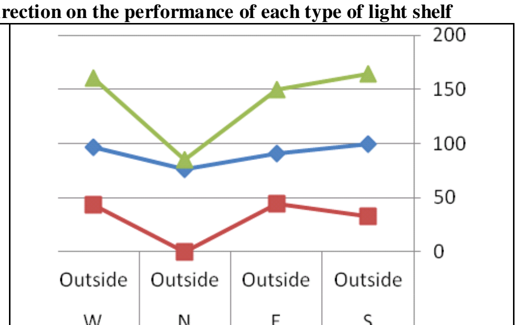
In Table 2/c, the ADA, ASE and TAEC Performance curve for both side light shelf. The results showed that dependence on the combined of external and internal light shelf type has achieved the best performance in the South, East and West, in terms of reducing ASE value, thus, the combination of light shelves was not useful in the North

In Table 2/d, the SDA, ASE and TAEC Performance curve for internal light shelf. The results showed that the reliance on the internal light shelf has an effective role in the South, East and West, as it contributed significantly to reduce the ASE value and it was useless in the North.

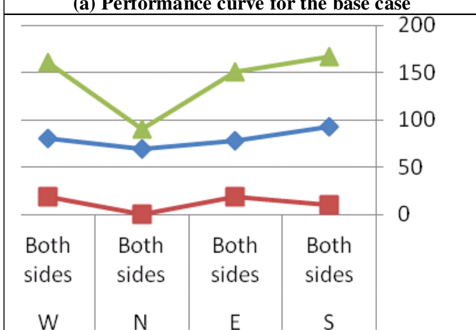
Table 2- The effect of changing the four main direction on the performance of each type of light shelf



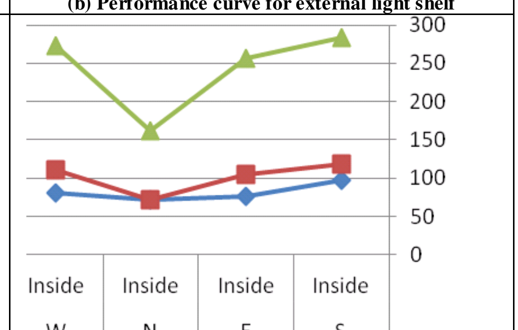
(a) Performance curve for the base case



(b) Performance curve for external light shelf



(c) Performance curve for both side light shelf



(d) Performance curve for internal light shelf

sDA 300/50% [% of Space Area]
Total Annual Energy (KW/m2)
ASE 250 h/1000 [% of Space Area]

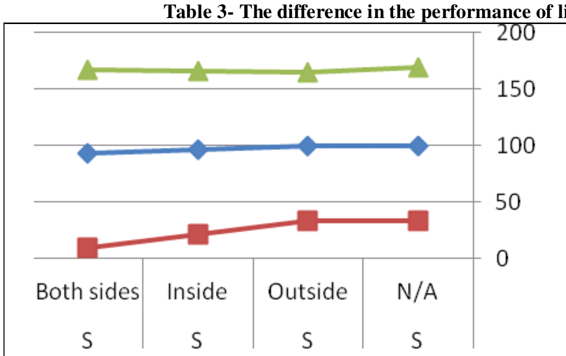
5-2- The second part:

This part focuses on the analysis of the results showing the difference in the performance of light shelf types in each four main orientations as shown in Table 3.

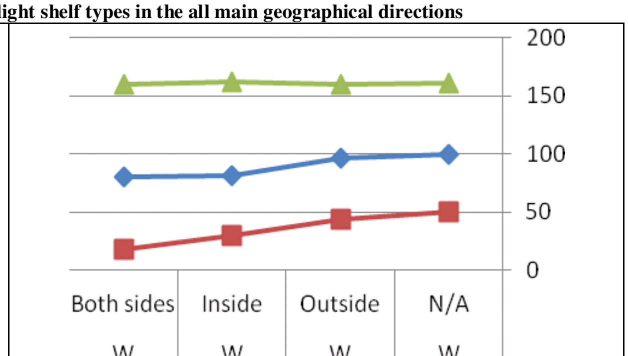
In Tables 3/a, 3/b and 3/c (South, West and East orientations), the ASE performance curve shows that when applying both side light shelves, they were the most successful design cases for the three orientations compared to the other designs as well as the base case. The SDA performance curves showed a slight negative effect for both side light, but still within the framework of the accepted value of SDA (300/50% of Space). The diagrams show that the convergent impact for all design cases in these orientations in terms of TAEC. The diagrams also show the positive relationship between SDA and ASE performance curve and the descending order of the performance rate for the four design cases as shown in table (4) of the base case.

In Table 3/D, in north direction, the diagram shows that the increased energy consumption rate in all light shelf design cases occurred because the SDA values were decreased. The zero values for ASE emphasizes that the northern façade does not need a light shelf for the three assumed positions. However it is noted that the external light shelf was the best composition, since it has the least effect on the SDA value, but it has to be modified.

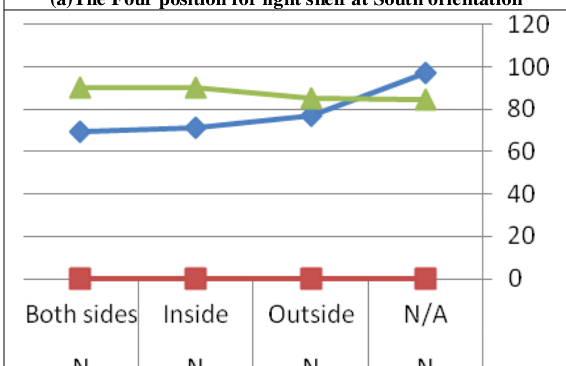
Table 3- The difference in the performance of light shelf types in the all main geographical directions



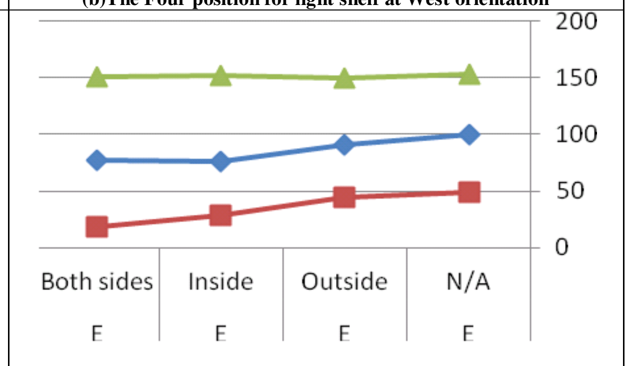
(a)The Four position for light shelf at South orientation



(b)The Four position for light shelf at West orientation



(D)The Four position for light shelf at North orientation



(c)The Four position for light shelf at East orientation

sDA 300/50% [% of Space Area]
Total Annual Energy (KW/m2)
ASE 250 h/1000 [% of Space Area]

Table (3): The difference in the performance of light shelf types in the all main geographical directions

5-3- The third part

The third part focuses on the analysis of the results to verify the performance of light shelf types and the factual benefit from the use of light shelf in terms of helping to improve the performance of optical and visual environment and cutting down the total energy consumption for the four orientations.

As for SDA, values in all the three cases were less than the SDA values in the base case (without light shelf) but still within the framework of the accepted value of SDA (300 lux 50%).

As for ASE, it showed positive impact for all light shelf design cases, since the ASE values were less than the base design values, especially in both side light shelf design cases accompanied by the maximum reduction of energy consumption for all the three orientations specially in the south direction where the value of (ASE = 9.3) which fulfilled the required ASE standard value. And does not exceed the 10% (Table 4, Figs. 2). How-ever, the ASE values for all light shelf cases has been approaching the required values, and in order to fulfill the desired value this will require reliance on light shelf geometry so as to take the full advantage of using light shelf composition that increases exposure to the high luminance area near the sky zenith. This means more experimentation needs to be conducted in this regard.

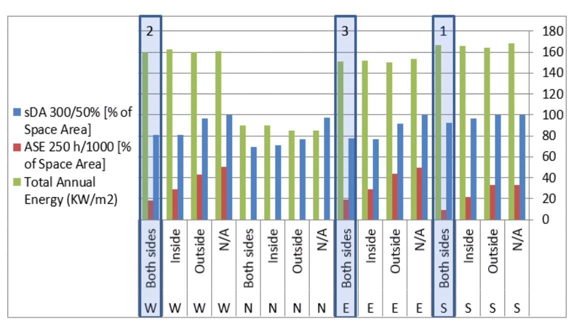


Figure 2- the comparison between the performance of both side light shelf type in the four main orientations

Table 4- The measured values for Special daylight autonomy (SDA), Annual sunlight Exposure (ASE) and total energy consumption (TEC) in the four main orientations for each light shelf design case.

Cases (without Neighbor)	south			east			north			west		
	SDA	ASE	TAE	SDA	ASE	TAE	SDA	ASE	TAE	SDA	ASE	TAE
normal	100	33.3	168.7	100	49.3	153.1	97.3	0	84.8	100	50	160.7
Outside	100	33.3	164.5	91.3	44	150.1	76.7	0	85.3	96.7	43.3	160
Inside	96.7	21.3	166.1	76.7	28.7	151.9	71.3	0	89.9	81.3	29.3	162.4
Both side	92.7	9.3	166.3	77.3	18.7	151.3	69.3	0	90.1	80.7	18	160.4

Table 5, present the measured visual values that show the efficient functioning of both side light shelves in all directions, especially in the south direction where the lowest value for over lit has been fulfilled in addition to the best daylight uniformity (SDA, ASE).

The energy performance results for all cases (as shown in Table 5) proved that the light shelves did not cause any increase in the cooling and heating loads, but contributed to the reduction of these loads, this is contrary to what is commonly known about the impact of light shelf. And this confirms that reliance on both side light shelves in hot arid zone areas does not cause a problem but it is one of the most appropriate solutions for light shelf system.

Table 5, presents the results of a detailed classification of the total energy consumed in the four of graphical directions with the use of the different design cases for the light shelves. Such results confirm that the use of light shelves in the various designs contribute to the decrease of the total energy consumption, this is due to reducing the heating and cooling loads, even at a low rate.

The loads of electricity has increased, even at a low rate for the same light shelves design cases, compared to its status in the base case (without light shelf). This is what has caused such energy performance, although the light shelf offers great opportunities in increasing natural light for interior spaces. But it could be the cause of complete darkness and prevention of light for same areas inside the space. This verifies the need for the design of light shelves in order to achieve a balance regarding its role as a barrier and as a reflector of light. It may be the underestimation of the value of SDA which is causing the lack of harmony of daylight that leads to the dependence on electric lighting, which emphasizes the need for more modification to increase efficiency as a reflector.

Table 5- Energy performance of the light shelf which shows the results of detailed classification of the total energy consumed for all 16 tested design cases.

Orientation	Light shelf	Annual Heating Load (KW/m2)	Annual Cooling Load (KW/m2)	Annual Electricity Load (KW/m2)	Total Annual Energy (KW/m2)
S	Normal	5.7	160.5	2.4	168.7
S	Outside	5.6	155.4	3.3	164.4
S	Inside	5.6	156.2	4.2	166.1
S	Both sides	5.6	156.3	4.3	166.3
E	Normal	5.2	145.7	2.1	153.1
E	Outside	5.1	141.4	3.5	150.1
E	Inside	5.1	142.2	4.5	151.9
E	Both sides	5.1	141.9	4.1	151.3
N	Normal	7.6	73.4	3.7	84.8
N	Outside	7.5	72.5	5.2	85.3
N	Inside	7.4	74.5	7.8	89.9
N	Both sides	7.4	74.6	8.0	90.1
W	Normal	6.9	150.8	2.9	160.7
W	Outside	6.7	147.5	5.7	160.0
W	Inside	6.7	148.6	7.0	162.4
W	Both sides	6.7	147.7	5.9	160.4

6- CONCLUSION

The study results have proved the efficiency of light shelf systems in hot arid zone areas, but special care has to be delivered regarding the design in order to improve the daylight performance within large spaces with deep depths as open administrative spaces in addition to reducing the energy consumption. Also, the light shelf system did not contribute to the increase in heating energy.

In South, West and East, the external light shelf reflects light more than the internal light shelf does. But it does not prevent all direct Solar rays, whereas the combination of both external and internal light shelves leads to significant contribution to the uniform distribution of light with the best saving in energy consumption as it does not cause in this case any loss or heat gain as was common before.

We can use light shelf system in any orientation under overcast sky conditions, but as for clear sky conditions, the South orientation is the best orientation for using horizontal light shelves, as the performance efficiency achieved was 72%. While, when it is applied in other orientations the performance efficiency that was achieved in Western orientation was 64% and in the Eastern was 62%, thus it must be carefully designed in order that it could control glare. While there is no use in using light shelf in north orientation, especially the horizontal ribs. The eastern and western orientation, light shelves allows the passage of direct solar rays that cause a glare problem, and, therefore, necessitates increasing the depth of light shelf and working on light shelf geometry variables as well as the rest of system elements in the future studies.

The results of this study showed the benefit of the use of the light shelf systems in improving the optical environment by relying only on the basic components of the system which makes us expect better performance when integrating the light shelf system into other systems, such as solar screens, which can produce a more suitable and successful light shelf system with in hot arid zone conditions, and it is recommended by this study for future studies.

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