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Sophisticated Light Shelf System in South Orientation in Hot Arid Zone

(A Parametric Study of Light Shelf System Performance of a Hypothetical Office Building in New Cairo Area)

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Abstract

In the framework of achieving advanced (sophisticated) light shelf system for deep office spaces in south in hot, arid zones, this study is based on the use of the parametric design approach in creating and investigating various combinations of the main design parameters of light shelf systems, in order to determine the design indicators and the key design elements that can help in developing and optimizing the performance of such daylight systems. Therefore a "819" study cases were created and tested in the previous phase of this study, as well as a "16" study cases have been tested in this study that produced from one hypothetical optimized parametric study case which was established by integrate the main design features of the best two case studies in the results of the previous study phase, in term of day lighting and energy consumption performance. This study has identified several basic designs and considerations for developing and optimizing the light shelf systems, in addition to the invention of two sophisticated design cases for deep office spaces with different ceiling heights (3.30 & 3.80 m.) in south in hot, arid zones (New Cairo area).

Keywords

Daylight system; light shelf; total annual energy consumption(TAEC); hot arid climates; sptial daylight atounomy(SDA); anuual sunlight expoure(ASE)

1. Introduction

The increasing problem of energy consumption in Egypt is contributing to the dependence on electrical power in the lighting systems in a large extent, especially in deep office spaces with one opened façade. Therefore, the need for sophisticated daylight systems become an essential factor in expand rely on the natural sources. In our previous researches, we have achieved an efficient light shelf system in South orientation, in addition to defining the key design parameters of such system. In this research, we examine how exploiting the efficiency of these key design parameters in optimizing the light shelf system performance. This will be accomplished by the parametric design by using Diva for Rhino- Grasshopper program.

2. Background

Many studies have recommended the need for focusing on the light shelf system performance in term of day lighting and thermal performance as well as saving energy. Also exploring the design variations of light shelf systems (Ayman, 2013).

The main benefit of using Parametric tools software is the highest ability of making modification of any parameters such as geometry shape and size without the need for recreating the entire model each modification.

(Yaik-Wah, 2013). Because a light shelf can function to block the direct sun and help increase day lighting levels deep within a room, there is a need to find a balance between how much light to block at the front of the room and how much light to direct into the rear of the room. To find such a balance, variables that could affect light shelf performance need to be carefully analyzed.

(Mayhoub,2017). Metal mirrors are available today offering several advantages since they have the form ability needed for curved light shelves together with excellent maintenance characteristics .

The above review of the literature reveals the increasing possibility of benefiting from the use of light shelf system in terms of improved day lighting.

3. Methodology

This study comes as a part of the completion of the study of the development of the performance of the light shelf systems. This study, based on the benefit of the outcome of what has been concluded in a previous study phase, especially the identification of design indicators and key design elements to develop the performance of light shelf systems. Based on this conclusion, a new hypothetical case study has been created as a base case for various experimental tests by using parametric design approach, in order to define the main design aspects of sophisticated light shelf systems. (Ahmed,Reham,Doha, 2017).by using CIE Standard.

4. Parametric Modeling

5. The proposed optimized designs alternative for parametric light shelf systems

Up to exploratory experiments (in the previous study phase), there were many cases that deserve advanced study in this research such as, cases (322) and (582) as they achieved good daylight performance with high sDA and low ASE (Table 1). These two cases have the most successful design specifications for external and internal light shelf systems, which guide the designer to merge those specifications for a new combined system that can help in optimizing daylight reflection and at the same time optimizing control the penetration of direct sun rays into the room space as a shading device.

Table 1. The light shelf cases achieved good day light performance on exploratory experimental stage.

Case No.	Orientation	Neighbor	Outer LS. Material	Outer LS. Angle	Inner LS. Material	Inner LS. Angle	Ceiling	sDA %	ASE %	TAEC %
322	South	N/A	G c 80	Horizontal	Silver mirror	-10	Tilted	78.5	8	163.4
582	South	N/A	G c 80	15	G c 80	Horizontal	Curved	77.5	8	161.5

Based on this design direction, one hypothetical parametric study case design (B) was developed as optimized basic study case which has the defined initial successful design specifications. Through implementing the parametric approach, a total of ”16” case studies are generated by all possible design combinations of the indicated design parameters. The hypothetical design cases will be tested and evaluated to monitor the development of the daylight performance and the optimal rate for each deigns case comparing with the results of the base design case.

6. Design specifications for parametric study case (B):

Up to the four defined optimizing directions in this study, the optimization design specifications for the hypothetical office room case study can be defined as follows (Table 2):
*Design specifications for study case (B): (Fig. 5.7)
1.Design addition; add additional one external GC 80 light shelf with a tilt angle of (15^o) (LS1) and additional one internal mirror light shelf with a tilt angle of (10^o) (LS3) (alternatively and in-combination) and Shutter of view window.
2.Design modification; the ceiling modification is to be curved in entire room space with room heights 3.30 and 3.8 m., and increase the height of the clerestory from 1.0 to 1.60 m.
3.Design integration; integrate two external light shelf types; (1) tilted light shelf with a tilt angle of (15^o), (2) horizontal light shelf combined with an internal light shelf with a tilt angle of (10^o). This new combination can help in optimizing daylight reflection and at the same time optimizing control the penetration of direct sun rays into the room space. In addition to integrate with other daylight systems improved daylight performance, but as simple such as shutters.

Table 2. The successful study cases of the exploratory test and the Design specifications for proposed hypothetical optimized case study (B).

Base case		The proposed optimized case study design (B)
The case study will be developed in the South without neighbor (case no. 322)	The case study will be developed in the South without neighbor (case no. 582)	
Figure 1	Figure 2	Figure 3

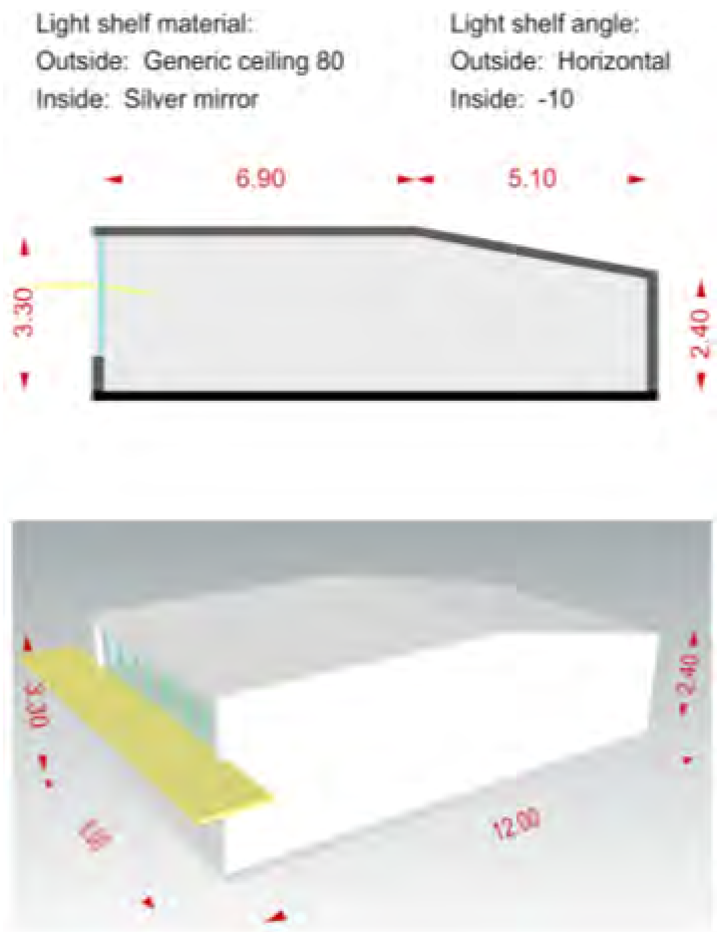


Figure 1.

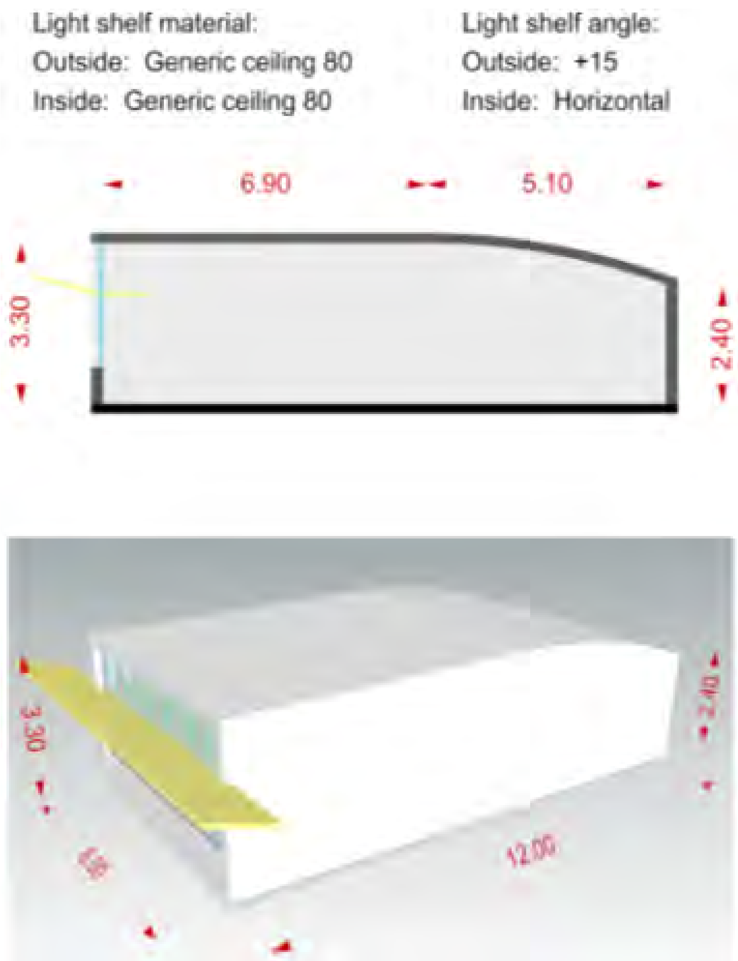


Figure 2.

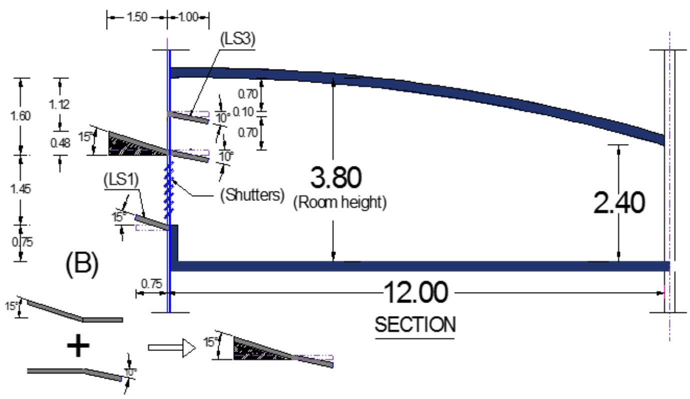


Figure 3.

7. Results and discussion

By analyzing of the simulation results (figure 4), especially the performance of the best study cases (No.0 & No 14), the following can be concluded;

• The optimized base case (No.0) provides the best light shelf system in case of the ceiling height of 3.30 M. (Table 3)

• Increasing the ceiling height to "3.80 m." lead to improve the performance of the light shelf system in term of maintaining the quantity and quality of daylight (sDA100%) meanwhile decreasing the exposure for annual direct sunlight (ASE) from 8% to 2%.

• This conclusion was made through the verification of the standard value of the performance of each design elements of the proposed parametric optimized base case (No.0) by comparing its results with the results of the best two study cases that have been achieved the best performance in the case of the ceiling of "3.30 m." height (study cases no. 4 & 6), and also in case of the ceiling of "3.80 m." height (study cases no. 14 & 15). (Table 4)

Case No.	Orientaion	Outer LS. Material	Outer LS. Angle	Inner LS. Material	Inner LS. Angle	Additional out LS Materials	Additional in LS Material	Ceiling	LS1	LS3	Shutters	Room Height	sDA 300/50% [% of Space Area]	ASE 250 h/1000 [% of Space Area]	Daylit	P.Daylit	Overlit	Total Annual Energy (KW/m2)	Annual Heating Load (KW/m2)	Annual Cooling Load (KW/m2)	Annual Electric Equipment Energy	Annual Lights Electric Energy (KW/m2)
0	S	GC 80	15&0	Mirror	-10	GC 80	Mirror	Curved	FALSE	FALSE	FALSE	3.3	100	8	60	0	40	149.06	115.72	5.4E-07	31.97	1.06
1	S	GC 80	**15&0**	Mirror	**-10**	GC 80	Mirror	**Curved**	TRUE	FALSE	FALSE	3.3	98	8	57	2	42	142.61	109.31	5.0E-07	31.97	1.33
2	S	GC 80	15&0	Mirror	-10	GC 80	Mirror	Curved	FALSE	TRUE	FALSE	3.3	98	7	64	2	33	144.43	110.87	5.8E-07	31.97	1.59
3	S	GC 80	**15&0**	Mirror	**-10**	GC 80	Mirror	**Curved**	TRUE	TRUE	FALSE	3.3	92	7	56	8	36	143.08	109.49	7.8E-07	31.97	1.61
4	S	GC 80	15&0	Mirror	-10	GC 80	Mirror	Curved	FALSE	FALSE	TRUE	3.3	79	1	42	21	37	144.43	110.88	4.9E-07	31.97	1.58
5	S	GC 80	**15&0**	Mirror	**-10**	GC 80	Mirror	**Curved**	TRUE	FALSE	TRUE	3.3	78	1	40	22	38	142.91	109.44	5.8E-07	31.97	1.49
6	S	GC 80	15&0	Mirror	-10	GC 80	Mirror	Curved	FALSE	TRUE	TRUE	3.3	72	0	48	28	24	144.28	110.82	4.9E-07	31.97	1.49
7	S	GC 80	**15&0**	Mirror	**-10**	GC 80	Mirror	**Curved**	TRUE	TRUE	TRUE	3.3	68	0	42	32	26	143.27	109.60	5.6E-07	31.97	1.70
8	S	GC 80	15&0	Mirror	-10	GC 80	Mirror	Curved	FALSE	FALSE	FALSE	3.8	100	16	46	0	54	162.19	128.68	9.1E-07	31.97	1.53
9	S	GC 80	**15&0**	Mirror	**-10**	GC 80	Mirror	**Curved**	TRUE	FALSE	FALSE	3.8	100	16	45	0	55	155.52	122.24	1.1E-06	31.97	1.30
10	S	GC 80	15&0	Mirror	-10	GC 80	Mirror	Curved	FALSE	TRUE	FALSE	3.8	100	9	52	0	48	161.85	128.53	8.2E-07	31.97	1.34
11	S	GC 80	**15&0**	Mirror	**-10**	GC 80	Mirror	**Curved**	TRUE	TRUE	FALSE	3.8	100	9	51	0	49	155.65	122.30	6.9E-07	31.97	1.38
12	S	GC 80	15&0	Mirror	-10	GC 80	Mirror	Curved	FALSE	FALSE	TRUE	3.8	100	10	49	0	51	161.86	128.54	8.1E-07	31.97	1.35
13	S	GC 80	**15&0**	Mirror	**-10**	GC 80	Mirror	**Curved**	TRUE	FALSE	TRUE	3.8	100	10	48	0	52	155.70	122.32	6.0E-07	31.97	1.40
14	S	GC 80	15&0	Mirror	-10	GC 80	Mirror	Curved	FALSE	TRUE	TRUE	3.8	100	2	64	0	36	139.04	105.61	2.9E-07	31.97	0.75
15	S	GC 80	**15&0**	Mirror	**-10**	GC 80	Mirror	**Curved**	TRUE	TRUE	TRUE	3.8	99	2	54	1	45	140.93	107.41	6.9E-07	31.97	1.05
		the best two light shelf system were identified																				
322	S	GC 80	Horizo	mirror	-10			Tilted					78.5	8	50	22	29	163.48	5.25	151.33	31.97	6.89
582	S	GC 80	15	Gc 80	Horizontal			Curved					87	12	57	13	30	162.64	5.34	150.77	31.97	6.53

Figure 4. Excel table illustrates the results analysis of 16 parametric which shows the performance's evaluation of each case design compared to the result of the optimized base case (No. 0). The sophisticated case design is also identified (No.14). Note: the results of the best two study cases that have been integrated into one design case (the optimized base case (No. 0)) are displayed at the bottom of the table.

Table 3. The results analysis of sophisticated cases

Sophisticated light shelf system	
Base case B (ceiling height = 3.30m)	Case no. 14 (ceiling height = 3.80m)
Figure 5	Figure 6
Achieved excellent results as it achieved 100% sDA , 8% ASE and 149.9 KW/m2TAEC. This leads to define the successful modified cases based on achieving ASE value of less than 8%, even if it has achieved less than 100% sDA.	Achieved 100% sDA, 2% ASE and 139.9 KW/m2TAEC. This light shelf system case study has achieved the best result among all the tested study cases, therefore it is recommended to be used in the South as a sophisticated light shelf system.
Figure 7	

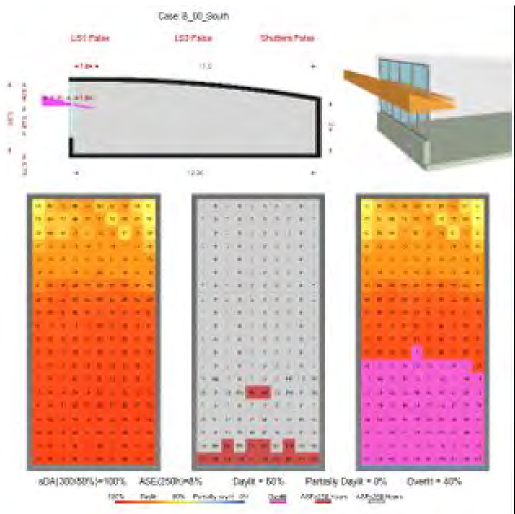
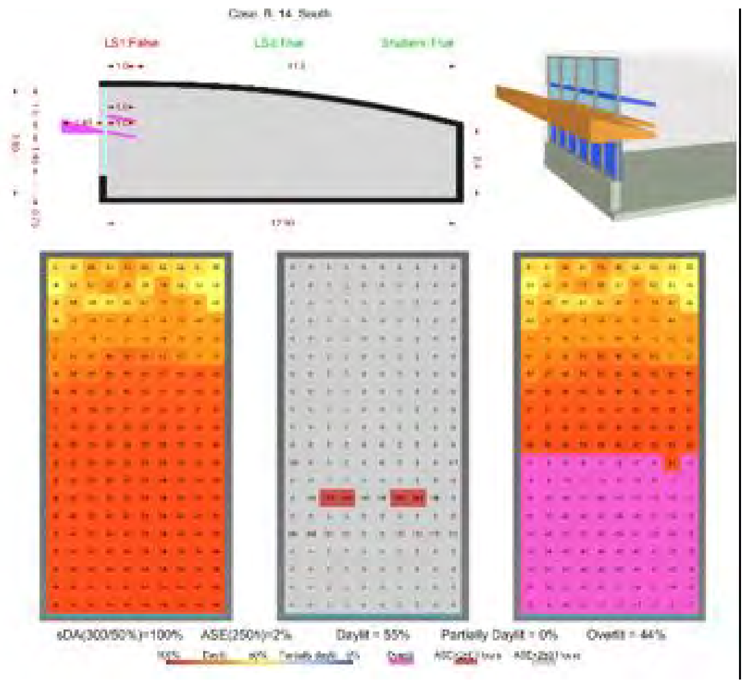


Figure 5.



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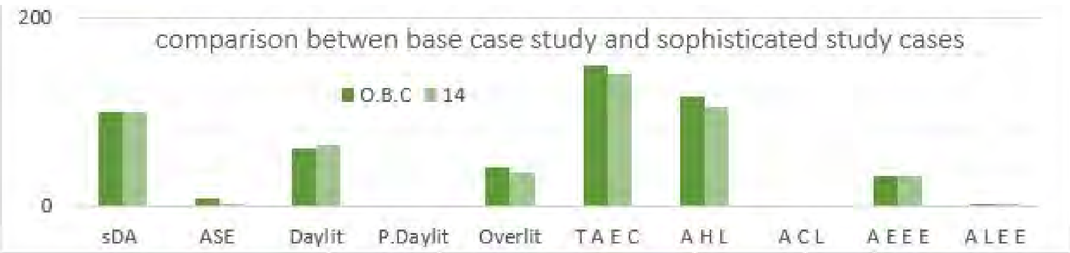

Figure 7.

Table 4. The results analysis of indicative cases to determine the performance of each element.

Study case no. 4	Study case no. 6
Figure 8	Figure 9
The result of study case"4" confirms the feasibility of adding shutters to the base case (No.0) with a ceiling height of 3.30, where it contributed to reducing ASE from 8% to 1%, but with a significant drop in the SDA value from 100% to 79%. So it is possible to integrate the base case with the shutters to reduce exposure to direct light, but in contrast, a large amount of light is lost and could be maintained.	The result of study case"6" confirms that it is useless adding an internal light shelf at the mid-height of the clerestory to integrate with the shutters, where it contributed in decreasing the SAD value significantly from 100% to 72% despite of reaching zero ASE.
Study case no. 15	Study case no. 14
Figure 10	Figure 11

Continued on next page

Table 4 continued

The result of study case "15" shows that despite the use of all elements of the design additions, this did not guarantee the efficiency of performance, but the effectiveness of the design combination, as the light shelf no. (1) (on the window sill with tilted angle -10) caused the reduction of the SDA value (quantity and quality of daylighting). The comparison of this study case with cases no. "4" and "6" shows the importance of increasing the height of the ceiling to 3.80m., which contributed to increase the efficiency of the light shelf no. (3) (which were added to the on mid-height of the clerestory as internal light shelf with tilted angle – 10) with shutters on the view window.	The result of study case "14" confirm that it is a sophisticated light shelf system and showed the feasibility of increasing the height of the ceiling from "3.30m." to "3.80m." with the proposed design additions (shutter on the view window and the internal light shelf in the middle of the clerestory). The light shelf design combination of this study case maintained the 100% SDA (quantity and quality of daylighting) of the base case with the reduction of the ASE (exposure to direct sunlight) from 8% to 2%, therefore it is recommended to be used in the South as a sophisticated light shelf system .

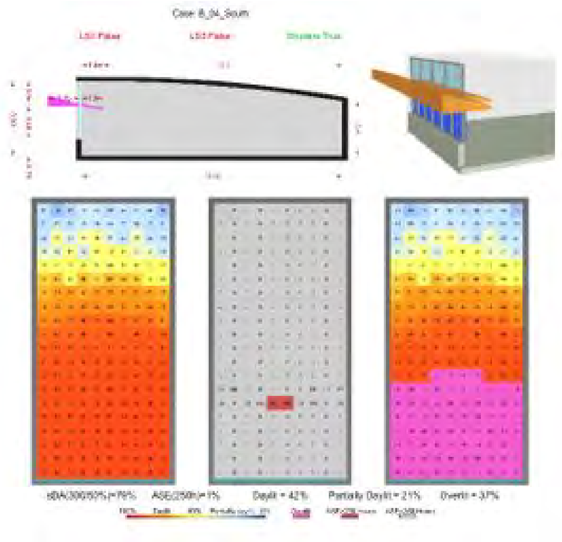

Figure 8.

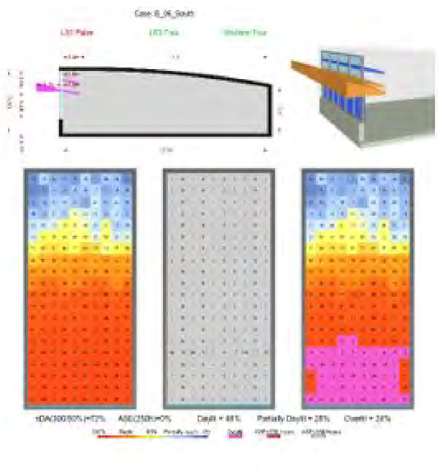

Figure 9.

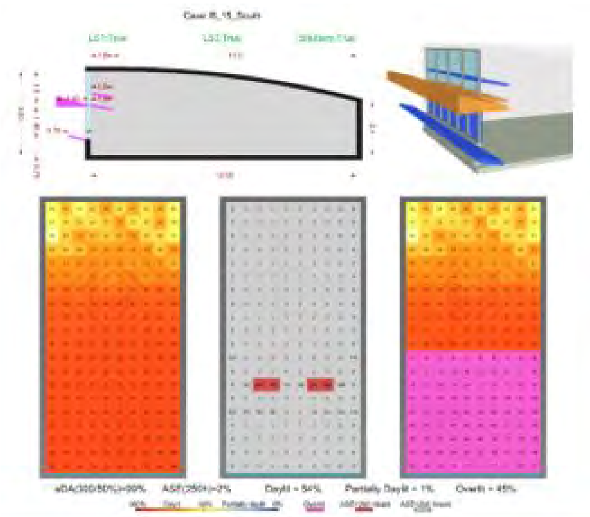

Figure 10.

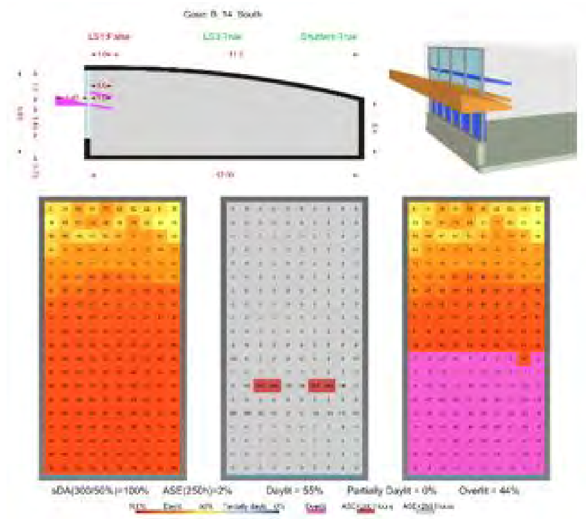

Figure 11.

8. Conclusions

The analysis of the simulation results of the proposed parametric study case (light shelf system in the south for deep office space in case of no neighbors), confirmed the followings;

1)The use of all design additional elements did not guarantee the efficiency of performance, but the design combination is the main key factor to enable the optimal performance effectiveness.

2)The importance of increasing the height of the ceiling to 3.80m., which contributed to the optimized performance of the light shelf system in term of maintaining the quantity and quality of daylight (sDA100%) meanwhile, decreasing the exposure for annual direct sunlight (ASE).

3)In the case of ceiling 3.30 m., the base case without modification or additions is the best design case for such ceiling height. The design combination of this case is based on the integration of two external light shelf types; (1) tilted light shelf with a tilt angle of (15o) and (2) horizontal light shelf, combined with an internal light shelf with a tilt angle of (10o). This light shelf system combination leads to:

a)Optimizing daylight reflection and at the same time optimizing and controling the penetration of direct sun rays into the room space as a shading device.

b)Reaching the maximum daylight quantity and quality of 100% sDA with the reduction of the exposure to direct sunlight (ASE) up to 8 % so as not to lose the amount of daylight against the limit of the exposure to direct sunlight.

4)In the case of the ceiling 3.80, the sophisticated design case (case no.14) which is the modified study case of the base case with ceiling modifications (curved in entire room space and increased heights to 3.80m.) and additional shutter of view window. The light shelf system of this case achieves the followings;
a)The maximum daylight quantity and quality of 100% sDA.
b)A great reduction of the exposure to direct sunlight (ASE) from 8% to 2%, therefore it is recommended to be used in the South as a sophisticated light shelf system for such ceiling height.

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