Journal of Solar Energy Research (JSER)

Journal homepage: www.jser.ut.ac.ir

Optimization of office building window lighting in Ahvaz

Zeinab Zabi[1], Mohsen Bina [2, *]

[1] MA student in Architecture, Department of Architecture, Faculty of Architecture and Urban Planing, Jundi-shapur University of Technology, Dezful, Iran.

[2] Assistant Professor, Department of Architecture, Faculty of Architecture and Urban Planing, Jundi-shapur University of Technology, Dezful, Iran

Received: 2020.10.29
Accepted: 2021.03.30

Abstract

True and proper employment of daylight illumination is one of the principles of building design. Daylight has a dynamic nature which helps the designers to achieve suitable space quality. To employ the potentials of daylight, the proper model must be similar to light properties from the nature prospective. This study is aimed at investigation and explanation of an optimum dynamic lighting system to equip office building windows in order to deepen, balance and control the received light. For this purpose, physical variables including the floor height, the ratio of the occupied surface by window to the total surrounding surface (Window area or window-to-wall ratio (WWR)) and the dimensions of the reference office room were modelled in the Rhino software. The lighting of the reference room in Ahvaz climate was simulated by Grasshopper, Ladybug, Honeybee and Honeybee-plus plugins in the Rhino software, and the lightness parameters were analyzed based on the LEEDV4 standard. According to the results and software outputs, design strategies were proposed to overcome lighting defects by a dynamic lighting system, and their performance and effectiveness on improvement of office space lighting were investigated by the software. It was found that an optical niche with optimized dimensions and angle, and its installation on a window with optimum proportions in the office room studied leads to deeper light penetration into the room. The employment of movable window canopy with retractable plates containing sun location-sensitive sensors during whole daytime and critical days was found to control the glare phenomenon caused by the entrance of natural light and contributed to a space in the visual ease region.

Keywords: dynamic lighting system, light shelf, daylight, optimization, side lightning parameters.

1. Introduction

Employment of natural light in the buildings has been considered in all eras, so that the orientation of the buildings was chosen based on proper lighting and employment of natural light as an important and basic source and a designation priority, affecting the whole design. In some architecture styles and especially the green architecture, it is emphasized on employment of natural parameters for reducing energy consumption and as a result, reducing offence to the nature. One of the aspects of green design is to employ daylight in the building as a reproduciblesource. Benefit from illumination quality is a feature dependent on the climate. It is crucial to consider the climate and geographical location of the building to take advantage of the daylight illumination. Climate characteristics of the region such as the extent and angle of radiation, cloudy or clear sky and etc. affect the employment of light. Hence, international and national lighting standards must be localized based on geographical location and climate of the environment around building to achieve the highest daylight quality. Correspondence and lighting proportions of the building with background are important from both lighting quality development and energy stabilization points of view. Despite the progresses in the science of construction technology in the contemporary era, the crucial element of proper window for efficient light penetration in the artificial complex environment is neglected. The window affects the spatial quality of building by relating the inside space with the outside environment and allowing observation of landscape and also ventilation, as well as providing a radiation transfer bed and employment of sunlight. This can reduce both energy consumption and environmental hazards and also contributes to physical and mental health of humans along with higher efficiency.

In this article, according to the effect of natural light on the performance of individuals in the workplace as well as energy consumption reduction, a dynamic lighting system was simulated and analyzed to provide visual ease.

A considerable portion of building maintenance costs is devoted to the required energy for lightness facilities and equipment. Many countries around the world have progressed towards the zero-energy building concept to control their energy consumption. Combining the daylight illumination along with artificial light is one of the methods employed in these buildings for energy saving. In this regard, in order to achieve visual ease in the buildings, international ranking designs introducing standard values for environmental performance have been created. The global LEEDV4 standard is one of the most important standards in this field, which includes four areas in the field of lightness such as stable sites, energy and atmosphere, quality of internal environment and innovation in design. In the chapter for quality of internal environment, the regulations and criteria of innovative designs for controlling the daylight systems has been discussed.

Receiving accurate environmental information from the users of each space for exact performing of duties and related activities is in direct relationship with the extent of proper light. In other words, the visual ease of individuals is endangered by decrease or increase of light. To calculate the lightness indices, annual weathering conditions of each place are employed for momentary, hourly, daily, monthly and annual evaluations. These evaluations are usually determined by comparing the real conditions of the internal space with optimum predefined ranges or thresholds and as a function of the activities of the residents of that internal environment. Generally, two static and dynamic evaluations are assumed for evaluation of daylight illumination in buildings.

The static indices evaluate the daylight factor (DF), light uniformity (UO) and illuminance (LUX). The evaluation basis of these indices for lightness analysis is the uniform sky. According to the variable qualitative and quantitative nature of daylight, static evaluation is accompanied with numerous restrictions and defects in calculation of the internal natural light. On the other hand, the dynamic method is used for daylight evaluation via considering the quantitative and qualitative fluctuations of daylight in a certain period of year or during the whole year, and applying the climate and geographical location data. Dynamic indices include daylight autonomy index (DA), spatial daylight autonomy index (sDA), useful daylight illuminance (UDI) and spatial useful daylight illuminance (sUDI).

In investigation of visual ease, the important effective subject of glare is usually discussed along with the illuminance analysis. There are numerous indices for glare analysis including ASE and DGP. In the LEEDV4 standard, the indices ASE and sDA are employed for measuring glare and illuminance, respectively.

sDA is an illuminance evaluation unit which determines the percentage of the internal work space area with access to adequate natural illuminance. According to the suggestion given by the illuminating engineers society (IES), in order to provide adequate illuminance at each point of the work place surface, the horizontal illumination threshold has been defined as 300 Lux for at least 50% of the occupied hours (working hours between 8 A.M. and 6 P.M.) which is represented as sDA 300/50%

ASE index is an illuminance evaluation unit which obtains the possibility of visual problems caused by annoying glare in work environments, and is defined as the percentage of working area which receives direct daylight illumination for more than a certain number of hours. This limit has been proposed to be 250 hours by IES.

An illuminance of 1000 Lux which is only receivable by direct daylight illumination and not the sky illuminance at that point, has been defined by IES as the minimum illumination, and is represented as ASE1000/250h [1]

In building performance evaluation methods such as LEEDV4 which is one of the most strictly and accurate standards for evaluating energy and performance of buildings, sDA and ASE indices have been employed as comprehensive indices for evaluation of illumination and glare (Table 1).

Table 1. Defined values for sDA and ASE indices in the LEEDV4 standard

Lighting status	Acceptable range	Indicator
Inadequate daylight	Less than 50%	(sDA)
Suitable daylight	Larger than 50%	
Lack of comfort (glare)	More than 10%	(ASE)
Comfort (no glare)	Less than 10%	

Many researches have been performed on employment of daylight illumination in buildings. Various researches have investigated strategies for absorbance, control and adjustment of daylight illumination. Since this study is devoted to the design of dynamic lighting systems, researches somehow related to various sections of dynamic lighting systems are investigated. Light shelf is an important part of the dynamic lighting system. According to the numerous researches conducted on the performance of light shelf, they must be combined with performance components of windows such as canopy, movable panels, solar louvres and etc., to achieve better performance. The collection of these components and light shelf constitutes the dynamic lighting system. Therefore, the researches focused on performance, proportions, dimension, angles, optimal localization and supplementary components for performance of light shelf are considered here.

First studies in relation with the nature of light shelf were performed in 1950 in several hospitals with deep plans to investigate the performance of light shelf in daylight transfer. One of these hospitals was the Larkfield hospital in Scotland. The model of this hospital was designed by Littlefair who demonstrated that the daylight factor is decreased by light shelf, although becoming more uniform[2]. In 1986, Benton researched on the performance of light shelf in Lawrence Berkeley laboratory. He studied for a year on a building in San Francisco with actual dimensions and light shelf at both northern and southern sides. The results revealed that shelf or light shelf can attribute to an average illumination of almost 200 Lux in the center of space along with a distance of 13 m from both northern and southern windows [3]. In 1997, Soler and Pilar in Madrid, Spain, investigated the effectiveness of light shelf by developing a model in the scale of 1:10 to understand the dependency of space lightness to the presence and absence of light shelf. This experiment which lasted for a year, revealed that there is no dependency among the studied variables in the case of a cloudy sky. Oppositely, in the clear sky, the illumination was enhanced by increment in the sun height angle and decrement in the angle of sun facing direction from sunrise until noon [4].

A transparent curved design in light shelf was studied by Eckerlin and Atre. This design utilizes a unique curved, translucentinterior light shelf, working in combination with a highly reflective ceiling in the classroom spaces. While preventing glare, this strategy diffuses daylight in a very uniform manner and assists in reflecting daylight deeper into the classroom spaces. The daylighting glazing area is reduced by 40% compared to that used in past daylighting applications. Whole building energy analysis results indicate a 50% lighting energy reduction, a 10% cooling energy reduction, and a 11% total building energy reduction through daylighting (about 60% of the total square footage of the building is daylight), as compared to a code compliant base case without daylighting [5]. Brotas and Rusovan investigated the performance of this system at different climates. They concluded that the performance of light shelf in cloudy climates such as England is not effective and proper [6]. In another study in North Carolina, a length of 1.83 m was considered suitable for internal light shelf and 0.92 m for external light shelf. In this research, light shelf located half inside and half outside building as well as perpendicular to the window were investigated. Moreover, increment in the ceiling height resulted in better internal illumination, while using partitions led to lower illumination. the optimum performance of the light shelf was observed at a ceiling height of 3.40 to 3.65 m [7]

In a study performed in Greece by Antonio and Mirersi, the climate and latitude of the place were employed and an 80cm external light shelf with an angle of 20° was introduced to be effective at most times [8].Claros and Soler investigated the effect of light shelf' material on the level of illumination in the external space. This study was performed on four categories of colorless, white, methacrylate- and mirror- coated aluminum light shelf. The shelf coated with methacrylate was found to be the most effective choice for higher light penetration and optimum performance in the middle months of year, while shelf coated with mirror were the best for the first and last months of year. In addition, the light shelf coated with colorless aluminum showed the least effect on the performance of light shelf [9]

Daum revealed that the energy consumption is 50% reduced by employing dynamic movable light shelf compared to the static light shelf systems [10] . Rafael compared the three cases of fixed shelf, fixed internal and movable external shelf, and movable internal and external shelf by the PGSL algorithm, and found that energy consumption is reduced by 12% in the third case compared to the first one [11].Perez et al, introduced a combined system of light shelf composed of light shelf and louvres, called FLS, and revealed its effectiveness on reduction of glare and creation of a uniform space [12].

The effect of an optimum combination of flexible horizontal and vertical canopies and selectively covered light shelf in hot and dry office buildings was investigated by Abboushi and Belal Khalid(2013), they covered light shelf with selective reflective covers and introduced it as a new class of light shelf (SRL) [13].Maria Konstantoglou and ArisTsangrassoulis (2016) studied dynamic systems of shading and lighting. According to their findings, energy savings with automatically controlled blinds depend on the type of control strategy and their connection to dimmable electric lighting systems. Even though control strategies enhance energy performance and occupants' comfort, their level of complexity highly affects their efficiency and therefore influences their performance [14].Antonis Kontadakis et al, (2017) studied the sunlight redirection system that uses a number of movable mirrors, installed on a light shelf and capable of tracking the sun. Reflected sunlight is projected towards a specified, fixed target area on the ceiling. The results indicate an increase of 99%, in the daylighting levels in the secondary (non-daylight) area during the summer solstice and a reduction of 21%, during the winter solstice, when compared to an unshaded, unobstructed reference case. If a case with a shading system(i.e. external static blinds) is used as a reference case, the proposed system increases the daily illuminance values during both solstices by 152% (summer) and 12.5% (winter). Unfortunately, there is a slight increase (<5%) in daily primary energy consumption. Simulations were performed using Radiance and EnergyPlus while the data needed as input, was created with a new algorithm capable of producing 3D models of the proposed system together with the reflected sunpatch geometry on the ceiling [15].Also this researcher and her colleagues in 2018 reviewed the researches performed on light shelf in the last three decades, evaluated various types and emphasized on the application of light shelf in improving the lighting performance via various materials and geometries [16].

In another study, Tbadkani et al, (2018) studied the illumination, glare control and achievement of visual ease standards. Their study reports on developing an innovative approach for the parametric analysis of daylighting and visual comfort, through a sun responsive shading system. The objective is estimating the annual daylight metrics and indoor glare discomfort. To this end, a review of the literature was carried out on three key concepts: smart facades, visual comfort, and parametric design, in order to develop a dynamic pattern of an oriental system for enhancing the daylight and visual performance. Afterwards, two geometrical components (Rosette modules and louvers) were applied, using Grasshopper plug-in for Rhino and daylighting plug-in DIVA, to investigate the indoor daylight quality through different geometrical and physical properties. This resulted in generating 6480 design variants, when several variables (rotation, distance to facade, time hours, transmittance properties and colors) that affect incoming daylight as well as visual comfort performance in a single office space in the hot-arid climate of Tehran were taken into account. Interactive correlations between the overall performance of kinetic patterns and visual performance were investigated through an optimization process. Analyses showed that the proposed approach is capable of significantly improving the shading flexibility to control daylight metrics and glare, via a full potential adaptive pattern to achieve the maximum visual comfort level based on LEEDv4 certificate [17].Several comparative researches performed in the past years are summarized in Table 2.

Table 2. Several comparative researches conducted in the past years

Analysis	Comparison of systems
Light pipe and light shelf can transfer the light properly by an almost identical performance in the southern side of building with 30° Azimuth angle in sunny days and a distance of 4.6 to 9.1m from the window [18]	Skylight, light pipe, light shelf
Light shelf can perform better in creation of visual ease compared to various canopies [19].	Light shelf and 3 types of canopy
Identical from glare control perspective, 4 hours per day for light shelf and 7 hours per day for light pipe during a year from the light transfer point of view [20]	Light shelf and light pipe
Light shelf acts more effectively in glare control and creation of uniformity and light penetration into the depth, compared to the manual shutter [21]	Manual shutter and light shelf
Light shelf is more effective than the Anidolic system in glare control, creation of uniformity and light penetration into the depth [22]	Light shelf and Anidolic system
Optical niche reveals a better performance for thermal and visual ease compared to the other systems [23]	Light shelf, various canopies, shutter
The best performance among these four systems is related to the optical niche [24]	MLG/ LS/ LCP/ LRB

Materials and methods

The studies in this method were performed by simulating an office room in the city of Ahvaz, and a geographical coordinate between 49 degrees and 11 minutes' eastern longitude to 31 degrees and 50 minutes' northern latitude, and also a hot and dry climate (Figure 1).

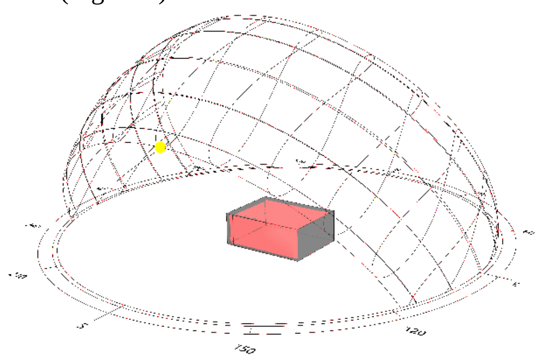


Figure 1. Sun diagram of the Ahvaz city.

In order to investigate the performance of the dynamic lighting system, the height, width, side view length and the ratio of the window area to the area of the wall it is located at (WWR), for the reference room, were chosen as 3m, 8m, 4m and 65%, respectively, based on the dimensions proposed by the Reinhart reference room.

The reflection coefficients of inside walls' materials, floor, ceiling and buildings around the room were considered as 60%, 30%, 80% and 10%, respectively. Visible light transmission coefficient for the glass of the room window was selected as 70%. According to the standard for work table, the height of the work plate was determined to be 80cm from the floor. In order to analyze lighting, as shown in Figure 2, several sensors were installed on the work plate with 25cm longitudinal and transverse distance at a height of 80cm from the floor. The data were calculated at these points and tested based on this height.

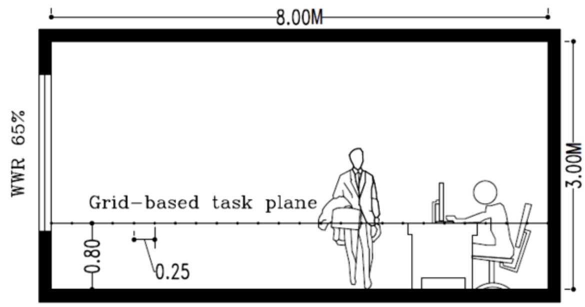


Figure 2. Dimensions of the reference room.

The 2phasic method was used in this research to analyze the lightness of the model. Total data of annual lightness are obtained based on this method. Annual matrices of the objective functions were then extracted and applied to optimize and achieve the best model of lighting system. The 2phasic method is based on simulating the direct and indirect lights radiated on the internal surface of the room from sky according to two independent factors. The first factor is the light directly entered into the space from the sky and reflections of the surrounding environment (S), while the second factor is the visual characteristics of the space and features of the sensors installed on the work plate (Cdc) (Figure 3).

$$E = Cdc \times S \qquad \text{(Equation 1)}$$

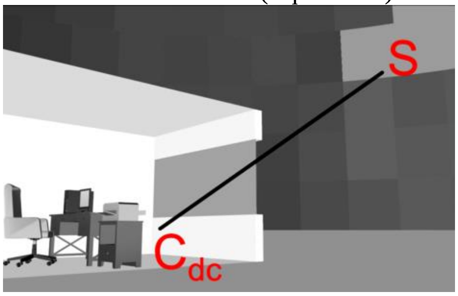


Figure 3. Effective factors in the 2phasic method[25]

Results & Discussion

This research is aimed at reducing the ASE function to less than 10% and increasing the sDA function to more than 50%. According to the defined values for the reference room in this study, the model algorithm was written and its annual matrices (ASE, sDA) were extracted as an epw file, using the weathering data of the Ahvaz city, and shown in Figure 4 and Digrams 1, 2, 3 and 4.

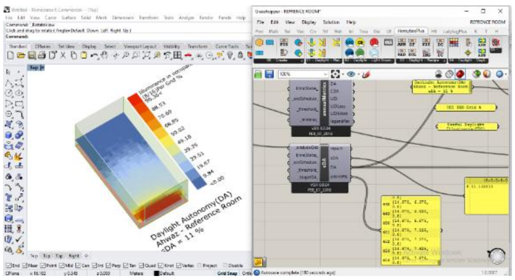


Figure 4. Simulation of the reference room in Rhino software and Grasshopper plugin.

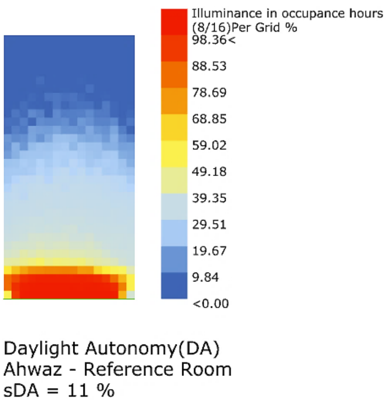


Diagram 1. Points receiving natural light.

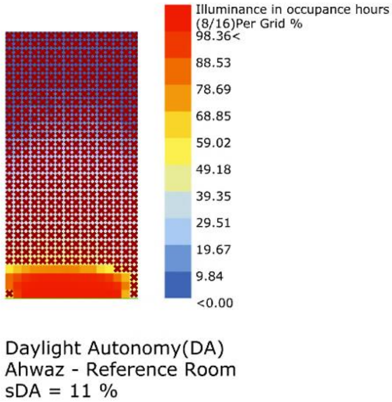


Diagram 2. Critical points not receiving natural light.

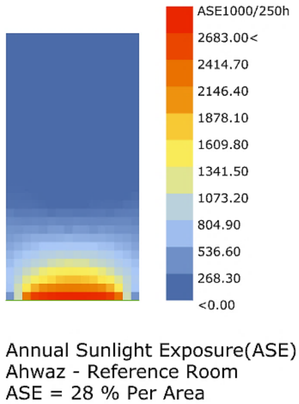


Diagram 3. AES diagram.

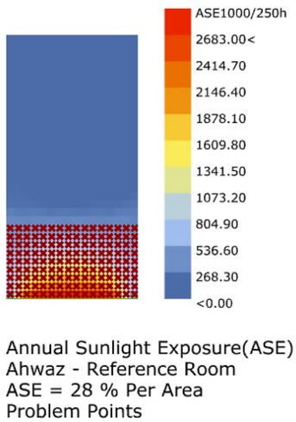


Diagram 4. Critical points.

According to the LEEDV4 standard, the lighting of the reference room was found to be inproper and out of the visual ease range due to the unplacement of the objective functions (ASE, sDA) in the defined range (ASE < 10% and sDA > 50%). Therefore, according to the data given in Table 3, the reference room with these lighting conditions does not correspond to the LEEDV4 standard.

Table 3. Comparison between lightness analysis results of the reference room and LEEDV4

ASE	sDA	Title
ASE< 10%	sDA >50%	LEED V4
28% (+18%)	11%(-39%)	Reference room

The strategies to obtain LEED license are designed and proposed to achieve the three following goals:

1. To receive and increase the penetration depth of lightness at the surface of internal work space for at least 50% of the occupied hours (working hours between 8 A.M. and 6 P.M.) and a horizontal lightness threshold of 300 Lux (sDA 300/ 50%).
2. To control the lightness level in the range below 10% for a working level of 250 hours from occupation of space (8 A.M. to 6 P.M.) for a value of 1000 Lux direct sunlight (10%-ASE1000/250hr).
3. To control the glare in the visual ease range (DGP<0.35).

In order to enhance the penetration depth of light, an external shelf of 0.3, 0.6 and 0.9 m dimensions with 0, 15 and 30° angles, along with an internal shelf of 0.3, 0.6 and 0.9 m dimensions and various heights of 0.3, 0.6 and 0.9 m from the floor were investigated and the most proper choice was extracted via simulation by software. As can be seen in Figure 5, the reflection surface of the external shelf mirror and the height of light shelf from floor were chosen as 90% and 2.1 m, respectively.

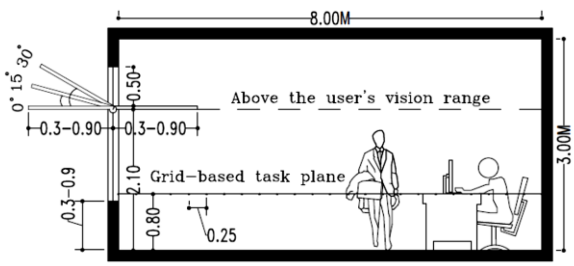


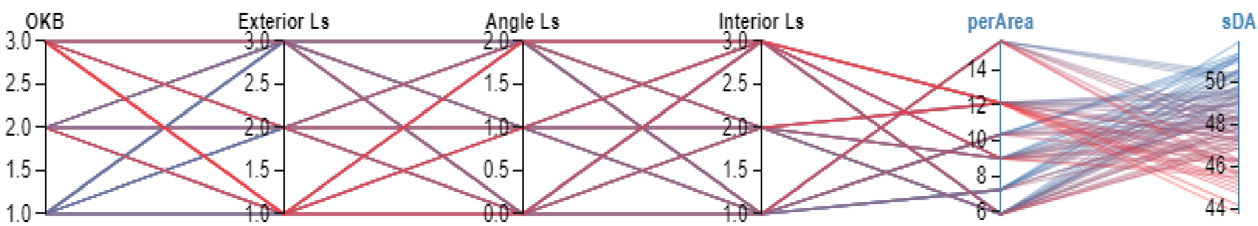
Figure 5. Initial strategies of the design

Variables relating the lighting system were modelled in the Rhino software and the Grasshopper plugin in Honeybee-plus. All possible states for the four variables and the two objective functions were investigated by the Colibri component which donducts a comprehensive investigation of variables based on the objective functions. According to the the laws of probabilities, as shown in Table 4, there are 81 possible cases for this number of variables.

Table 4. Variables and objective functions.

Objective functions	Algorithm values	Values and number of states	Variables
sDA>50% perArea (ASE)<10%	Y= 0.3 (1,2,3)	Y= 0.3,0.6,0.9	OKB
	Y= 0.3 (1,2,3)	Y= 0.3,0.6,0.9	Exterior Ls
	Y= 0.3 (1,2,3)	Y= 0.3,0.6,0.9	Interior Ls
	Y= 50 (0,1,2)	Y= 0,15,30	Angle Ls

Excel file and images produced by various states investigated by the Colibri component were loaded into Design Explorer2 (Diagram 5).



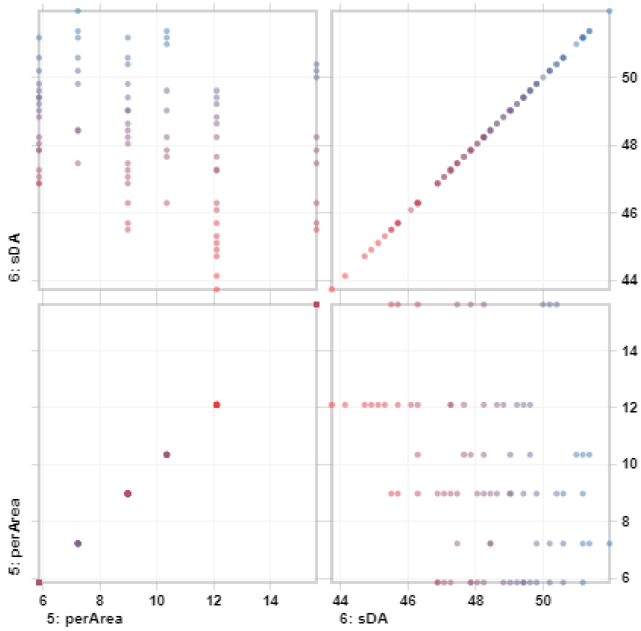


Diagram 5. Various states of the variables and objective functions.

Some output DC diagrams of the Colibri component were randomely selected among the 81 possible cases and represented in Diagram 6.

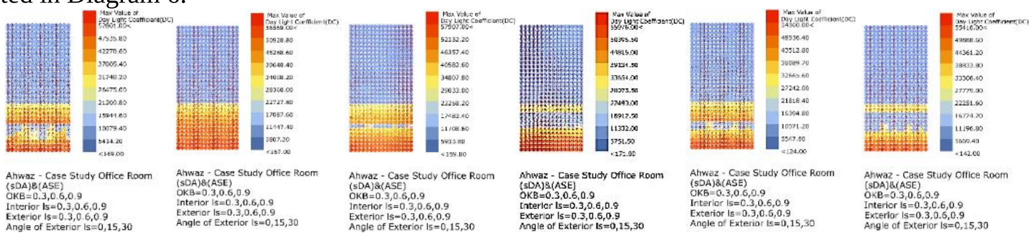


Diagram 6. DC diagrams of the various states of variables.

As mentioned earlier, a total number of 81 cases were given by Colibri based on four variables and two objective functions, among which 11 cases were successfully validated as optimum cases (ASE=10%, sDA > 50%) and represented in Table 5.

Table 5. Optimum states.

OKB	Exterior Ls	Angle Ls	Interior Ls	perArea(ASE)	sDA
1	3	0	1	7.23	51.95
2	3	0	1	7.23	50.20
1	3	1	1	7.23	51.17
1	3	2	1	7.23	51.36
2	3	2	1	7.23	50.58
1	2	0	2	8.98	50.58
1	3	0	2	5.85	51.17
1	2	1	2	8.98	50.39
1	3	1	2	5.85	50.58
1	2	2	2	8.98	51.17
1	3	2	2	5.85	50.20

All cases shown in Table 5 are optimum and proper for the performance of light shelf. However, comparing all optimum cases, the most optimum case for performance of light shelf in lighting system for the city of Ahvaz with iys weathering data is the case in which the distance between window bottom to floor, protrusion length of the external light shelf, protrusion length of internal light shelf and the angle of external shelf are equal to 0.3m, 0.9m, 0.3m and 0°, respectively (Diagram 7,8,9 and Table 6,7,8).

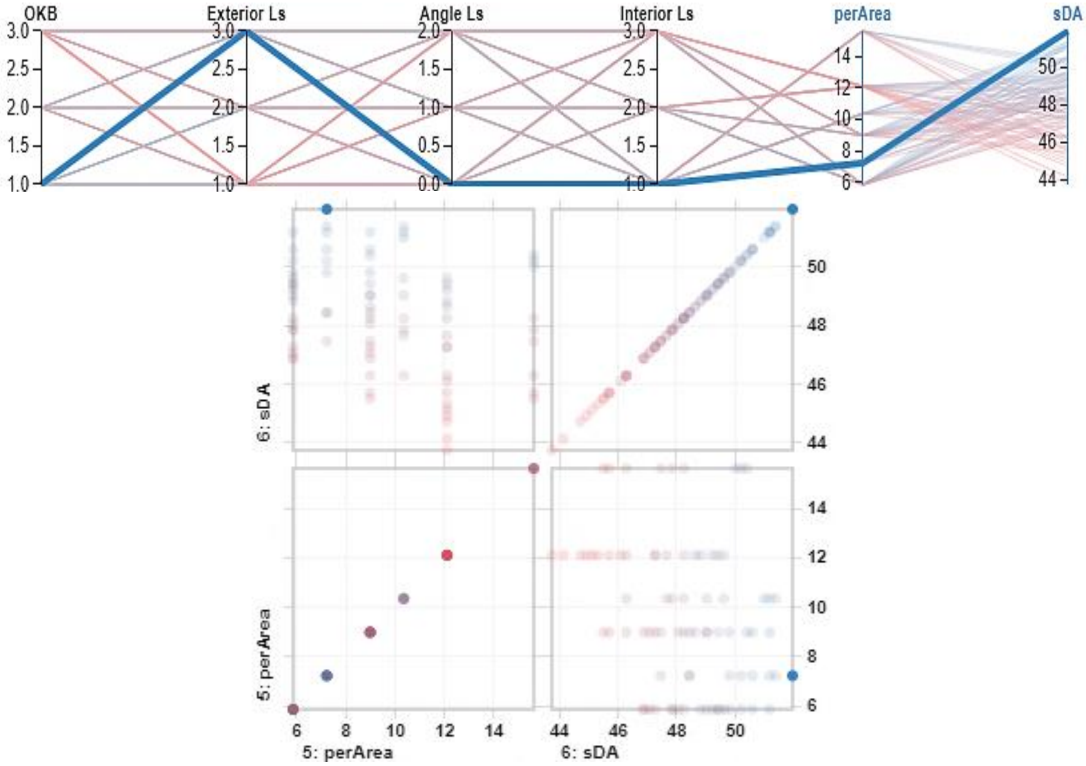


Diagram 7. Diagrams of the optimum state analysis.

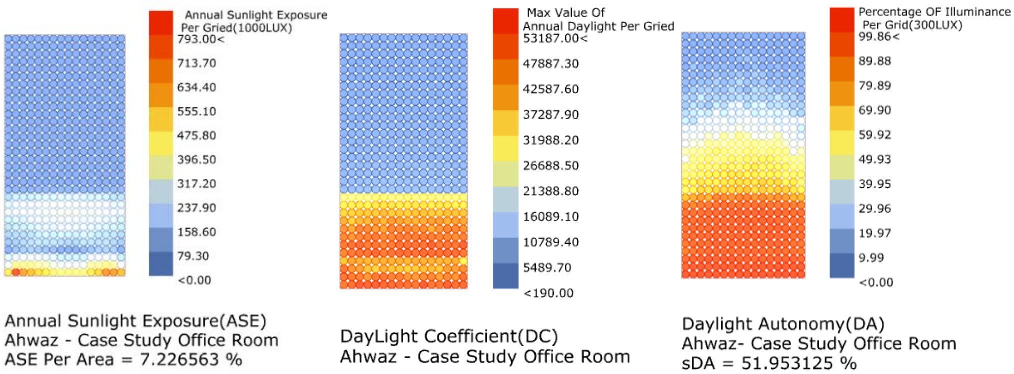


Diagram 8. Diagrams of the optimum state analysis.

Table 6. Honeybee-plus radiance motor parameters for lightness simulation.

dt	ar	aa	ad	ab	dt
0.15	128	0.1	4096	6	0.15

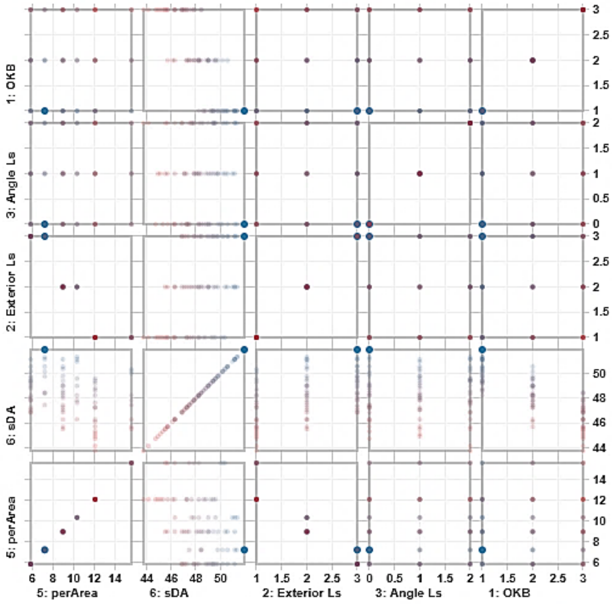


Diagram 9. Diagrams of the optimum state analysis

Table 7. Annual matrices, objective functions and values of parameters in the optimum state.

OKB	Ex Ls	Angle Ls	In Ls	ASE (%)	sDA (%)	UDI_{av}	DA_{av}
0.3	0.9	0	0.3	7	52	323.45	221.26

Table 8. Comparison between lightness analysis results of the reference and the studied rooms.

ASE	sDA	Title
52%	7%	Study office room
11%(-41%)	28% (+21%)	Reference office room

Althugh the global LEEDV4 standard is very accurate in the field of lightness and providing visual ease for residents of various spaces, it does not investigate the subject of glare completely. The ASE index cannot represent the visual ease alone, since it is based on measuring a percentage of working surface which receives 1000 Lux daylight illumination for more than 250 hours. On the other hand, daylight glare probability (DGP) index is related to numerous patameters including the user's angle of view to the light source, user's location, radiation angle, shading and etc. Standard values for the glare index are given in Table 9.

Table 9. Defined Glare comfort criteria [17]

Daylight glare probability	Glare comfort
DGP < 0.35	Imperceptible glare
0.35 < DGP < 0.4	Perceptible glare
0.4 < DGP < 0.45	Disturbing glare
0.45 < DGP	Intolerable glare

For the optimum state, the level of glare was investigated in the 21th day of each month at 9 and 12 A.M. as well as 4 P.M. According to the results obtained from glare analysis in the model with optimum dimensions, glare is enhanced in months with oblique sunlight radiation angle. Several cases with glare levels higher than the visual ease range are demonstrated in Figures 6 to 10.

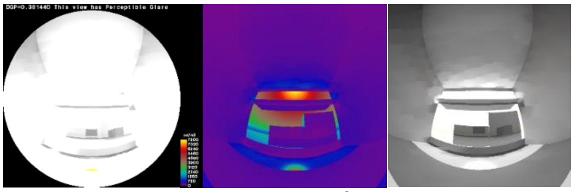


Figure 6. December 21th, 12 o'clock.
(0.35< DGP <0.4)

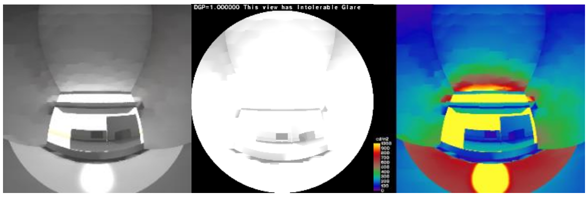


Figure 7. January 21th, 12 o'clock.
(DGP >0.45)

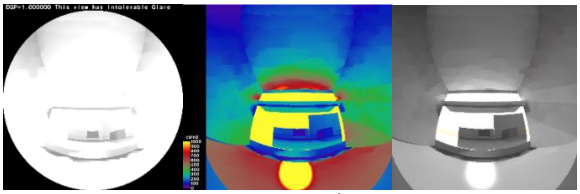


Figure 8. February21th, 12 o'clock.
(DGP >0.45)

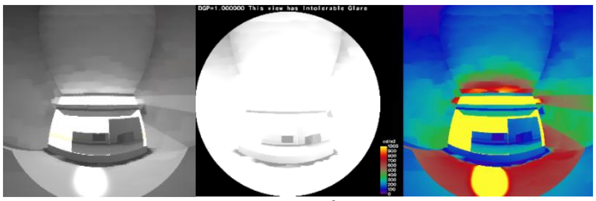


Figure 9. March21th, 12 o'clock.
(DGP >0.45)

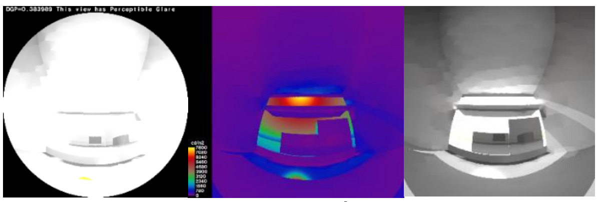


Figure 10. April 21th, 9 o'clock.
(0.35< DGP <0.4)

The maximum created glare in spring and summer seasons was obtained at 12 o'clock. In these seasons, the glare phenomenon is usually in the tolerable range during the initial hours of day (0.35<DGP<0.4). Movable canopy equipped with sun location-sensitive sensor was used to control glare in all seasons and hours. This canopy not only avoids annoying sunlight, but also allows the entrance of proper light into the room and does not restrict sight. The canopy is made of collapsible star-shaped fabric panels which are opened and closed via sun location- sensitive sensors, so that the panels are opened and closed with daily movements of sun and variations in its location (Figure 11).

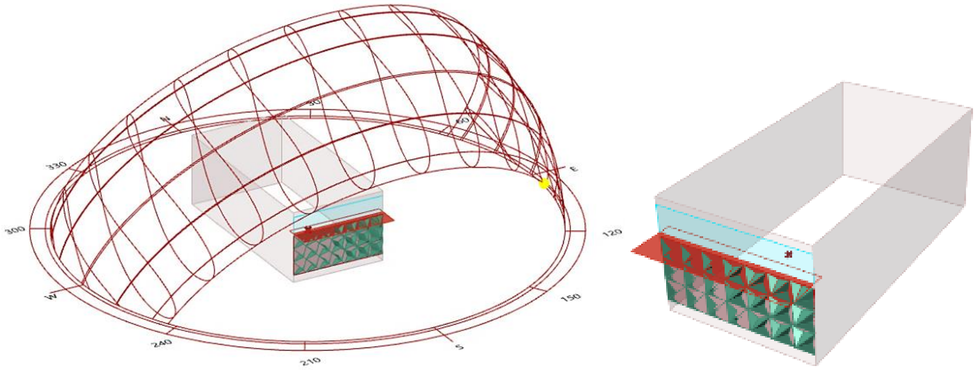


Figure 11. movable window canopy with sun location-sensitive sensor

In order to investigate the performance of the proposed canopy, the glare level was calculated by extracting the critical months and hours in the optimum state from the point earning stage of the LEEDV4 standard, and compared with canopy-free states. The results of glare analysis are represented in Figures 12 and 13.

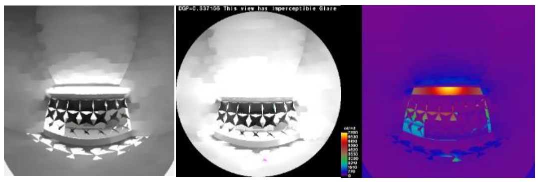


Figure 12. December 21th, 12 o'clock.
DGP<0.35, ASE = 6%, sDA = 64%.

In all critical states at 12 o'clock, the glare was controlled in the visual ease range by the movable vanopy.

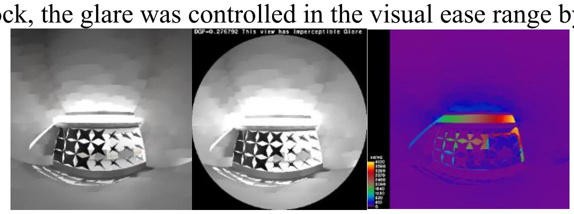


Figure 13. April 21th, 9 o'clock.
DGP<0.35, ASE = 8%, sDA = 74%.

In all cases, the glare was controlled in the visual ease range by the movable vanopy at 9 A.M. Moreover, at 4 P.M., needless of movable canopy, the glare was controlled at visual ease range in all seasons by using a fixed canopy which is an external light shelf with 90cm length and 0° angle.

Conclusion

According to the lightness simulation and analysis in the studied office room as well as variables and objective functions, a protrusion between 0.3 to 0.6m is suitable for internal shelf, while it must be in the range of 0.6 to 0.9m for external light shelf. To achieve optimum conditions, the external light shelf can be located at 0, 15 and 30° angles. In addition, a value of 0.3 to 0.6m is suitable for the height of window bottom. These values were obtained by extraction of optimum states form the software for the defined variables of this research. However, the most optimum case for an office window with light shelf in the city of Ahvaz is the one with 0.3m distance between window bottom and floor, 0.9m protrusion length of external light shelf, 0.3m protrusion of internal light shelf and 0° angle for the external light shelf. Using these dimensions in the window can improve the daylight deepening performance of the light shelf in all seasons. Since the daylight penetration length is enhanced by employing light shelf with optimum direction and considering the importance of glare control, the performance of fixed canopy (external shelf with 0° angle) was found to be proper in summer and autumn, reducing the glare level. Using movable canopies with collapsible panels and sun location-sensitive sensors in the optimum state resulted in glare control and visual ease of space during all investigated critical hours. The effect of movable canopy in controlling glare especially at 12 A.M. was more significant in the investigated days.

References

1. LM, I., *Approved method: IES spatial Daylight autonomy (sDA) and annual sunlight exposure* (ASE). 2013.
2. Littlefair, P.J., *Light shelves: computer assessment of daylighting performance.* International Journal of Lighting Research and Technology, 1995. **27**(2): p. 79-91.
3. Benton, C., *Field measurements of light shelf performance in a major office installation.* 1986.
4. Soler, A. and P. Oteiza, *Light shelf performance in Madrid, Spain.* Building and Environment, 1997. **32**(2): p. 87-93.
5. Eckerlin, H., et al. *A new daylighting strategy for a middle school in North Carolina*. in *PROCEEDINGS OF THE SOLAR CONFERENCE*. 2007. AMERICAN SOLAR ENERGY SOCIETY; AMERICAN INSTITUTE OF ARCHITECTS.
6. Brotas, L. and D. Rusovan. *Parametric daylight envelope*. in *PLEA*. 2013.
7. Hu, J., J. Du, and W. Place. *The assessment of advanced daylighting systems in multi-story office buildings using a dynamic method*. in *World Renewable Energy Congress-Sweden; 8-13 May; 2011; Linköping; Sweden*. 2011. Linköping University Electronic Press.
8. Antoniou, K. and A. Meresi. *The use of the artificial sky as a means for studying the daylight performance of classrooms*. in *Proceedings of the PLEA*. 2006.
9. Claros, S.-T. and A. Soler, *Indoor daylight climate–influence of light shelf and model reflectance on light shelf performance in Madrid for hours with unit sunshine fraction.* Building and Environment, 2002. **37**(6): p. 587-598.
10. Daum, D., *On the Adaptation of Building Controls to the Envelope and the Occupants*. 2011, EPFL.
11. Raphael, B., *Active control of daylighting features in buildings.* Computer‐ Aided Civil and Infrastructure Engineering, 2011. **26**(5): p. 393-405.
12. PÉREZ, M., P. OTEIZA, and J. NEILA. *Fragmented Light Shelf: Sun protection system and daylighting optimization*. in *28th International PLEA Conference. Lima, Perú*. 2012.
13. Abboushi, B.K., *The Effects of Adaptive Shading and the Selective Reflector Light Shelf on Office Building Energy Efficiency and Daylight Performance in Hot Arid Regions.* 2013.
14. Konstantoglou, M. and A. Tsangrassoulis, *Dynamic operation of daylighting and shading systems: A literature review.* Renewable and Sustainable Energy Reviews, 2016. **60**: p. 268-283.
15. Kontadakis, A., et al., *An active sunlight redirection system for daylight enhancement beyond the perimeter zone.* Building and Environment, 2017. **113**: p. 267-279.
16. Kontadakis, A., et al., *A review of light shelf designs for daylit environments.* Sustainability, 2018. **10**(1): p. 71.
17. Tabadkani, A., S. Banihashemi, and M.R. Hosseini. *Daylighting and visual comfort of oriental sun responsive skins: A parametric analysis*. in *Building simulation*. 2018. Springer.
18. Beltran, L., et al., *The design and evaluation of three advanced daylighting systems: light shelves, light pipes and skylights.* 1994.
19. Oteiza, P. and A. Soler, *A comparison of the daylighting performance of different shading devices giving the same solar protection.* Architectural Science Review, 1995. **38**(4): p. 171-176.
20. Beltran, L., E. Lee, and S. Selkowitz, *Advanced optical daylighting systems: light shelves and light pipes.* Journal of the

illuminating engineering society, 1997. **26**(2): p. 91-106.
21. Floyd, D.B. and D.S. Parker, *Daylighting: measuring the performance of light shelves and occupant-controlled blinds on a dimmed lighting systems.* 1998.
22. Ochoa, C.E. and I.G. Capeluto, *Evaluating visual comfort and performance of three natural lighting systems for deep office buildings in highly luminous climates.* Building and Environment, 2006. **41**(8): p. 1128-1135.
23. Kim, G., et al., *Comparative advantage of an exterior shading device in thermal performance for residential buildings.* Energy and buildings, 2012. **46**: p. 105-111.
24. Hirning, M., V. Garcia Hansen, and J. Bell, *Theoretical comparison of innovative window daylighting devices for a sub-tropical climate using radiance.* Proceedings of IEECB'10, 2010.
25. Subramaniam, S., *Daylighting Simulations with Radiance using Matrix-based Methods.* Lawrence Berke-ley National Laboratory, 2017.