Dynamic Envelope and Control Shading Pattern for Office Buildings Visual Comfort in Tehran

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Abstract

This work reviews the effect of parametric programming on visual performance, daylighting and shading in office buildings in Tehran-Iran and studies their influences that help not only to reduce the glare but also to promote useful daylight illuminance through promoting visual comfort. It starts by establishing a review of the effective parameters on visual comfort indices, glare indices, and daylight metrics. The aim of the study was to characterize the impact of innovative, dynamic envelope design strategy to control shading pattern.The method used in this research is computer configuration and simulation.To parametric modeling and analysis used Rhinoceros, Grasshopper and its plug-in ladybug, honeybee, honeybee plus and daylight performance on visual comfort, as well as the impact on the best dynamic envelope option for a three-occupant office.The results show that the dynamic responsive to sun envelope often very efficiently effect on the occupants' visual comfort indices than the static envelope. They further show that this efficient envelope minimizes the percentage of upper useful daylight illuminance (UDI) and minimize the discomfort glare probability (DGP) for keeping an indoor glare-free environment.

Keywords: Control shading pattern, Dynamic envelope, Visual Comfort, Office building, Tehran.

1. Introduction

Nowadays, the adaptation of building to the surrounding environment to provide occupants comfort on the one hand and energy-saving, on the other hand, has particular importance and suitable use of the sunlight is a Building strategy to achieve this. Office spaces are key sources in the world of economics and industry. They are the most important and suitable areas for improving the productivity of organizations to the quantity and quality of outputs in these spaces changed and achieved the desired results by changing the factors affecting occupant's comfort. According to studies, glazing of the facades controls more than 50% of conventional energy demand in office buildings of the OECD (Organization for Economic Cooperation and Development) countries (Pérez-Lombard L, 2008, p. 394). Design of an efficient envelope is the solution that leads the design towards energy efficiency along with improving occupants' visual and thermal comfort. A general study shows that building residents tend to adjust the amount of light and shading inside the space, because setting these conditions not only effects on realization of comfort but also effects on independent behavioral motivations to their environment(Correia Da Silva P et al, 2012, pp. 35-48). In this regard, this research investigates issues related to the quality of light in office space and the effect of control shading pattern by envelope on the parameters resulting in occupant's visual comfort. This research aims to study the effect of dynamics parametric facade on optimal control of glare and access to maximum optimal illuminance in an office room.

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1. Literature Review

Studies on the history of research in this area showed that each of them has done with an emphasis on one or more components of the effective parameters on visual comfort; generally, they categorized in three important parts: the amount of illuminance, the distribution of light and glare. There is a general agreement in the researches that one of the most basic needs of visual comfort is the amount of illuminance in the field of view. The amount of illuminance is a quality inherent in visual comfort, the most referenced in the literature of light. People prefer to do their work in daylight. However, in the periods of the day, lighting is insufficient, in parts of the year, is too bright, and warm, which can also be a nuisance.

On the other hand, different tasks require different quantities and types of light (Newsham G, 2003, p. 30). The first factor affecting the determination of the level of selective lighting is the type of activity of the users. Some studies have shown that for employees working with computers, the optimal level of illuminance is between 100- 300 lux. While for those who work on paper-based tasks, such as writing and reading administrative materials, the desired levels of illuminance is higher, 200-600 lux and in Computer-based task and the maximum amount of light in the workspace is 1280- 1800 lux, and above these amounts, glare happens(Correia Da Silva P et al, 2012, pp. 35-48).

According to studies of IRC (Institute for Research in Construction-National Research), the average illuminance level on the desktop is 400-500 lux(Newsham, G.R.and others, 2004, p. 4). In this study (Dubois D, Dubois EF, 1989, pp. 303-311), and some similar studies found that

people sometimes reduce the amount of artificial light to the utilization of natural light or saving energy, and or because of High levels of illuminance. (Newsham, G.R.and others, 2004, p. 4).
So many employees, when there is daylight, choose a lower level of artificial light to get more natural light. Sometimes, in contrast to expectations, some of them increase the level of artificial light along with increasing natural light levels, it can be due to heterogeneous distribution of daylight in near and far regions of window that result in difference in intensity of light (contrast) (Newsham & Veitch, 1998, p. 3).

Table 1
Nomenclature (Source: Researchers)

Nomenclature					
VC	visual comfort	-	**UDI** average	Useful Daylight Illuminance Ratio	-
DA	Daylight autonomy (%)	300-3000	**VT**	Visual Transmittance	77%
VCI	Visual comfort indices	-	**DGP**	Daylight Glare Probability	DGP<0.4
WWR	Window to wall ratio (%)	40%	**RGB**	RGB colure reflectance	35%
UDI	Useful daylight illuminance (lx)	300-1800	**SHGC**	Solar Heat Gain Coefficient	25%
ELA	Equipment Load Per Area W/M2	2	**VPP**	Ventilation Per Personcfm	5

Da Silva and others recommended the minimum to the maximum light ratio on the task are more than 0.7, and the optimal ambient light ratio to task area is between 0.2-0.8, meaning that the illuminance of the task area should be more than the subject ambient(Correia Da Silva P et al, 2012, pp. 35-48).
In the classification of the intensity of the illuminance required by each space, in addition to the mentioned studies, the IESNA (Illuminating Engineering Society of North America) World Standard, Canada, and the United States consider office space as a zone that needs illuminance on task area. They have classified office spaces as part of the C and D group, and the intensity of illuminance required for this group is 100 to 500 lux(Williams, 1999)(Krarti, Moncef, 2011)(Kreider J.F, 2000).
About more precise works in the workroom or studio, these spaces are categorized as part of the E Group, required a range of the intensity of illuminance is 500 to 1000 lux.
Another effect of the inappropriate distribution of illuminance is glare, and high illuminance in the field of view is a nuisance factor (Correia Da Silva P et al, 2012, pp. 28-35).

The individual's reactions to this are highly dependent on surrounding conditions that they adapted(Heidari.sh, 2012). Also, it seemed that the type of light source affected judgments about visual desirability and the quality of the lighting environment.
Most employees prefer a combined lighting system for each light source alone (Newsham & Veitch, 1998, p. 3). On the other hand, tolerance of glare of natural light is easier than other light sources. In general, employees do not complain about the glaring result of windows. It indicates that people are very tolerant against the glare outcome of light natural (Kim, G. & et al., 2012, pp. 105-111),(Kim & Kim, 2010, pp. 175 – 183). Researchers have presented various methods to measure and assess glare. For example, Kim created a formula based on an average illuminance of the visual field and one that results in glare(Kim & Kim, 2010, pp. 175 – 183). Iwata et al. (1994) (Iwata, 1994, pp. 91–97) examined the applicability of daylight glare index (DGI) and unified glare rating UGR (Unified Glare Rating) about real windows through glare mental assessments in actual rooms. In addition, Nazzal(A.A.Nazzal, 2000, pp. 19-27) presented a change in computing (DGI) and proposed a new daylight glare index (DGIn) for non-uniform light sources, taking into account the component of direct sunlight along with diffused natural light. This new index was created as a modification of the previous methods of glare evaluation based on experiments on homogenous light sources or assumption of lack of direct sunlight in space, In order to test the applicability of the new method, Nazzal compares the actual measurement quantities with the quantities obtained from the Radiance software. Nazzal method, unlike previous methods, depended on the presence of the sun near the horizon line and entering the sunlight into the room, mainly depends on the illuminance of the natural light source, the window. However, this method does not provide how to assess residents.
One of the passive and efficient ways to overcome internal heat and reach thermal comfort is to provide shading in buildings. Sometimes we have to limit the dimensions of the window due to the amount of light and glare or the outcome heat of it, and in this circumstance, the interior view is reduced. Shaders help to solve such a problem(Heidari.sh, 2012, p. 67).
In a well-designed building, there will be measures to control daylight. Skylights and air vents can be part of the building wall. Also, windows or special glasses are part of the building envelope. Several studies have shown the effect of control shading pattern instruments on the optimum daylight conditions and have considered the various components as effective. Olgyay & Olgyay have documented various types of static and dynamic shaders that effectively act and provide visual comfort at the same time by examining case examples (Olgyay & Olgyay, 1957)(Konis, 2013, p. 662).
The International Energy Agency, in its solar heating and cooling program, has provided a comprehensive reference of application and monitoring systems of daylight in buildings, considering their capabilities in energy saving, visual features, and monitoring on solar radiation. In this

area, researchers generally have studied ways, which staff use shading and monitoring instruments to achieve predictable patterns or at least determine that these patterns change under which variables.

In some of the studies, factors such as window orientation, time of day, sky conditions, seasons, altitudes, and task area position investigated to determine how much and how they affect these patterns(Galasiu & Veitch, 2006, pp. 728-742). The results of these studies show preferences and patterns of shading instrument changes by employees. Other types of studies investigate the function of various types of shaders by simulation programs, validate, and generalize them with laboratory works (Newsham & Arsenault, 2009, pp. 143-163), (Kapsis, Tzempelikos, Athienitis, & Zmeureanu, 2010, pp. 2120–2131), (Foster M, Oreszczyn T, 2001, pp. 149-155).

Also, these results indicate that the closure of Venetian blinds on the southern face (about 80%) is higher than the north one (about 50%). In general, despite the wide variation in patterns, Venetian blinds on the southern face are frequently moved more than each other facades .The average daily operation is confirmed by 40-35% on the Venetian blinds on the southern facades in Japan and the United Kingdom (Galasiu & Veitch, 2006, pp. 728-742)which implies that employees use Venetian blinds more than anything in order to prevent sunlight and overheating in a room. The main reason which most employees keep open the curtain is concern about overheating inside the room (Foster M, Oreszczyn T, 2001, pp. 149-155).

Estimates in similar studies showed that when the illuminance on the window is more than 8,000 lux, Venetian blinds rolled up to meet visual performance criteria(Galasiu & Veitch, 2006, pp. 728-742). Some studies address these challenges by presenting a novel simulation framework for the performance evaluation of responsive building envelope technologies and, particularly, of switchable glazing. The results show that the control strategy has a significant impact on the performance of the photovoltachromic switchable glazing, and of switchable glazing technologies in general (Favoino F, 2016, pp. 943–961).

The optimization of a shading system through parameters of visual comfort show, change shaders shape, generating overlapped pleats and angle variation and using different materials provide alterations of the direct light transmission inside the building while maintaining a certain degree of diffuse light component(Pesentia M , Maseraa G, Fioritob F, 2015, pp. 346 – 351).

Some research studies on a shading device consisting of a perforated screen. This screen has been supposed to be used in an office space in Australia with windows on the north and the west façades. The optimization process increases the possibilities of achieving maximum efficiency in the proposed solutions. The optimized perforated screen in this research has proven to achieve much better results in terms of useful daylight distribution compared with a base case with no shading (Lavina C, Fioritob F, 2017, pp. 571-581).

2. The Visual Comfort Indices

Most of the collected indices are devoted to assessing or predicting glare (17/34; 50%) firstly, secondly the amount of light (9/34; 26%); then, the light quality (7/34; 21%) and lastly the light uniformity (1/34; 3%) (Carlucci S, 2015, pp. 1016-1033).

3.1 Glare indices

Glare considered an indicator of visual discomfort and divided into two types. The first one is Glare with point shine, which is the amount of light that reaches from the point on the opaque surface. As the shining of a star in the sky or dropping a spotlight on a dark surface and the second one is Adaptive glare which is occurred when the eyes are adapted to the average illuminance of the environment, but the amount and intensity of illuminance suddenly change so high that at one moment loses its compatibility. The British standard considers that lack of the glare is depended on the circumstance that there isn't any sign of the discomfort in vision, lack of light or excessive light then disorder in the detection of objects, as a result, doesn't to exist much light or the color confusion of the environment. Sometimes glare leads to an inability to see and visual discomfort.

A mathematical and qualitative study of the glare phenomenon is difficult. However, it can be somewhat closed to the reality of this concept by field research. One point that should do not be forgotten is that people dependent on the environment in which they are adapted display different psychological reflections. People living in the severe sunny areas are likely to exposure glare later than those who live in the low sunlight areas, and their tolerance against the light intensity is more. Because of this, regional differences affection illuminance needs and this point considered in lighting design and visual comfort phenomenon. Residents of the regions with cloudy sky tend to use less light at night. While residents of hot areas tend to have more light in space at night(Heidari.sh, 2012, p. 25). There is a cross-relationship between controlling daylight to solve the thermal problems and to overcome the glare. Dealing with sunlight to escape the overheating of the summer's heat will reduce the interior glare, but reducing light to prevent the glare cannot overcome the thermal problems resulted from daylight. The higher intensity of light leads to more glare.

The amount of it, in addition to the intensity of light, also depends on features of the surface that are exposed to the light. In a space where control of glare is not possible by windows, glass, and other factors, using suitable materials for surfaces can be effective. Proper evaluation of the photometric properties of materials is one of the main issues in light modeling. In simulation tools, the precise details of the materials of the inner surfaces (such as reflection, roughness, etc.) are very necessary (Ghiabaklou, 2013, pp. 34-35). The most appropriate metrics to analyze absolute glare is Discomfort glare probability (DGP), a short-term tailed index-assessing glare (Wienold J, 2006, pp. 743–757).

Table 2
Glare comfort criteria (Source: (Wienold J, 2006))

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

3.1 Daylight Metrics

The illuminance is one of the Indices for assessing the quantity of light. Illuminance at a point P of a given surface is a physical quantity, measured in lux and defined as the ratio between the luminous flux incident on an infinitesimal surface in the neighborhood of p and the area of that surface (Carlucci S, 2015, p. 1021).
Therefore, the illuminance is a measure showing the amount of light reached on a surface and is widely used by designers to determine the levels of illuminance. Indices for assessing the quantity of light are divided into two static and dynamic categories. In this study, the dynamic factor is used for evaluation. According to the changing daylight in various seasons and at different times, these criteria take annual data. These indices are calculated to predict the quality and quantity of natural light based on annual occupancy time. Useful daylight illuminance is one of the best factors for assessing interior illuminance. This criterion, developed by Mardaljevic and Nabil in 2005 (Erlendsson, 2014, p. 27), is defined as the fraction of the time in a year when indoor horizontal daylight illuminance at a given range. A lower and upper illuminance limit values proposed to split the analyzed period into three bins: the upper limit is meant to represent the percentage of the time when an oversupply of daylight might lead to visual discomfort (can create glare and unwanted solar gains). The lower limit represents the percentage of the time when there is too little daylight(insufficient daylight), and the intermediate bin represents the percentage of the time with appropriate illuminance level (suitable for visual activities).
The useful daylight illuminance range according to the survey of past research is considered between maximum 1800 and minimum 300 lux(Correia Da Silva P et al, 2012, pp. 35-48).

$$UDI_{useful} \text{ With } w_{I}= \begin{cases} 1 \text{ if } E_{Lower\ limit\ (300)} \leq E_{DL} \leq E_{Upper\ limit\ (1800)} \\ 0 \text{ if } E_{Daylight} < 300 \text{ or } E_{Daylight} > 1800 \end{cases}$$

4. Research Methodology

The method used in this research is computer configuration and simulation. The simulation of research is the study of dynamic interactions in the environment of those situations and events. Rhino is a powerful 3D software with great modeling capabilities and compared to the same software it is easier to work. The principles and environment of the Rhino software are very similar to AutoCAD. Since the curves and surfaces produced by Rhino calculated on a special mathematical formula, it operates more precise than network-based software such as Sketch-Up, 3DS Max. With a range of simple but very practical tools in recent years. Also, the Rhino Software has gained its popularity thanks to a powerful plugin, Grasshopper, which attracted a large number of architects who are active in the field of parametric design.
Grasshopper is a free plugin installed on the Rhino and allows designers to create complex forms by a parametric graphical algorithm and observe the changes of the form by changing these parameters at the same time. Changing the complex form by the main parameters allows architects to more easily and quickly achieve ideal forms, and also finding optimal forms in terms of the objective function will be easier. The Grasshopper plugin makes it possible to build three-dimensional models based on functions, complex formulas, and algorithms without the need for any scripting.
In this research, Honeybee and Honeybee plus plugins were used to simulate and evaluate the quantity of daylight in office space. Honeybee, introduced in 2014, is free and is installed on the Grasshopper, a plugin of the Rhino. The honeybee can create powerful space for its users by Radiance, Daysim, Energy Plus, and Open Studio software that can put them together in the same environment. So it used to calculate daylight, along with heat calculations and cost estimation. This plugin can specify the material and type of the sky, determine the type of arbitrary calculations (based on the Radiance engine) or annual (based on the Daysim engine) and take data like photos, charts or numbers.
In 2018, to solve the limitation of the Honeybee operators to get the daylight outputs spatially light quality issues, the Honeybee Plus plugin added to the Grasshopper environment in 2018.

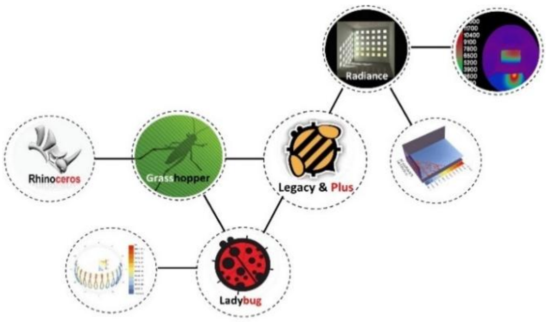

Fig. 1. Algorithmic integrated software workflow
(Source: Researchers)

4.1 Parametric design and Dynamic envelope

As the theoretical point of departure for this study, parametric design is a computational method that can apply both generative and analytical approaches from the perspective of design explorations and indicates a fundamental shift from design alternatives to design logic

(Leach, 2009, pp. 32–37).The envelope of the building separates it from the surrounding environment, and its shape affects the urban scale, hence considered the most salient characteristic in a building. Architecture practice is increasingly considering environmental aspects, but the focus on better energy performance can lead to neglecting other architectural qualities in design, such as aesthetic and functional qualities (Schlueter A, Thesseling F, 2009, pp. 153–163).

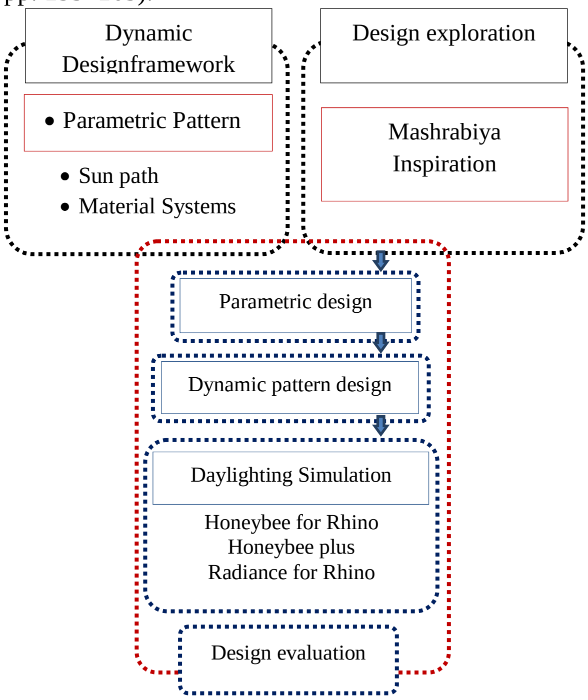

Fig. 2. Geometry design methodology (Source: Researchers)

The envelope shape, the most salient design characteristic in a building and Design dynamic envelope and intelligent daylight gain through increasing user comfort and reduction of building energy consumption is more and more importance. Shading control by dynamic envelope on glazed surfaces have an impact on the energy demand for lighting, heating, and cooling of buildings.

Fig. 3.Plan of office (Source: Researchers)

4.2 Office model

South-Lit office space constructed as the base-case study model for an office building located in Tehran, Iran.

MODEL PARAMETERS

Site Location
Tehran, Iran, Kargar St.

Function & Space Area
Office Room -24m^2

Design Objectives
A. Dynamic Envelope
B. UDI$_{average}$: useful daylight illuminance density ratio
C. Discomfort glare probability(DGP)

Visual Comfort Design Requirements
Acceptable UDI Domain< 1800 lx
Acceptable DGP: < 0.35

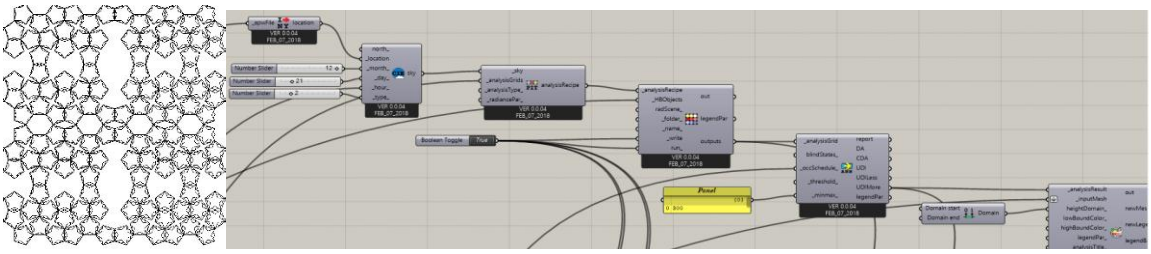

Fig. 4. Annual Daylight Metrics (Simulation Output: Honeybee Plus)

This simulation runs on the climate-based sky and was selected intermediate sky with the sun for different types of tests. The climate of Tehran gave to the simulator software by energy plus weather file. Energy simulation was considered annually and daily in 4 critical days of the year (21-Jun,21-dec,21-Sep,21-mar) and in three hours of each day at 9 am, 12 pm and3 pm.

In this simulation for both, base case and proposed models, the interior surfaces were assigned reflectance of 70% for the ceiling, 50% for walls, and 20% for the floor. Also, Theproposedenvelopes material was made of void plastic with 35% diffuse reflection. The windows were assigned by doubled-glazed material with 77% visual transmittance and 25% solar heat gain coefficient. Also, the depth of the pentagram dynamic envelope is about 2 centimeters.

The considered fixed parameters in the modeling are 40% for WWR, 80centimeters for task area height, and sill height. The simulation was planned to perform daily in 4 critical days of the year (21-Jun, 21-dec, 21-Sep, 21-mar) and at three hours per day (9:00 am, 12:00 pm and 3:00 pm). Those times and dates were chosen, to have a more right evaluation of the performance in the case study model for its two proposed patterns. The first simulation focuses on the analysis of daylighting performance for a window without shaders as the base case model. The second simulation represents a daylighting performance, using static pentagram geometry, and the third one parametric tools for dynamic pentagram geometry.

5. Analysis of the effect of Dynamic Control Shading Pattern

The analysis was carried out in useful illuminance of the daylight and glare, metric parameters of visual comfort, in the office room, from the observer's view and on the task area.

5.1 Analysis Useful daylight illuminance

To analyze the effect of the dynamic envelope on the useful daylight illuminance in a single south-faced office, three positions considered, the window without a shader, with fixed shader and sun responsive parametric shader, were investigated in the range of illuminance upper than1800 lux. This process is done by considering the average percentage of illuminance on the task area in the room when it was occupied. By gain, the range of daylight upper than 1800 lux has been determined. The grid on the task area was considered at a distance of 0.5 meters from the length and width and 0.8 meters from the floor suitable for the task area. This procedure is done in three positions. In the base case, the window without the shader, and in the first case (A) the shader fixed with the porosity of the cavities in 80% and in the parametric position (case B) is minimum and the maximum porosity of the cavities is assumed to be 20 to 80%.

Analysis figures, 5 to 7weredefined as $UDI_{average}$ (useful daylight illuminance density ratio) in upper bins of three situations. These bar charts show the percentage of UDI (upper than the range of sufficient daylight)to the area with a dynamic envelope is deeper than other situations. When UDI is more than the mentioned range (>1800 lux), glare and overheating occur. Consequently, the trend shows decreasing the probability of disturbing glare.

To explain, it is very well clear that the role of sunshade has dramatically affected the incoming light inside. The trend in all four selected days follows the same pattern. With the addition of a fixed shade to the window (Case A), the area with UDI>1800 has dropped by almost 50 percent, while the addition of the kinetic shade has had a much lower impact on the illumination of the inner space. For instance, the area with UDI>1800 on 21 December was 30% for the base case and was decreased to 15.62 % when a fixed shade (Case A) was annexed to the window. Likewise, the replacement of the fixed shade with a kinetic one (Case A and B) dropped the is from 15.62 % to 11.46 %. This showed the efficiency of the kinetic shade

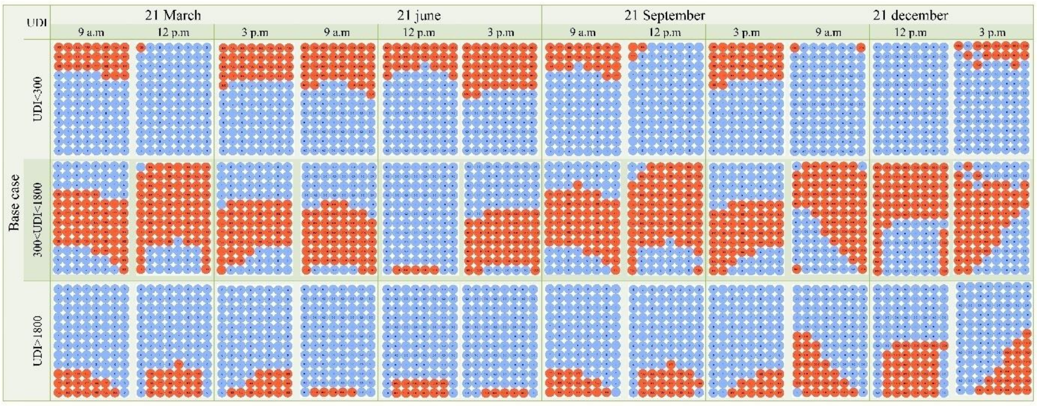

Fig. 5. Results of set Base Case (Simulation Source: Researchers& Simulation Output: Honeybee Plus)

Fig. 6. Results of set Case A (Simulation Source: Researchers&Output: Honeybee Plus)

Fig. 7. Table 1 Results of set case B (SimulationSource: Researchers& Output: Honeybee Plus)

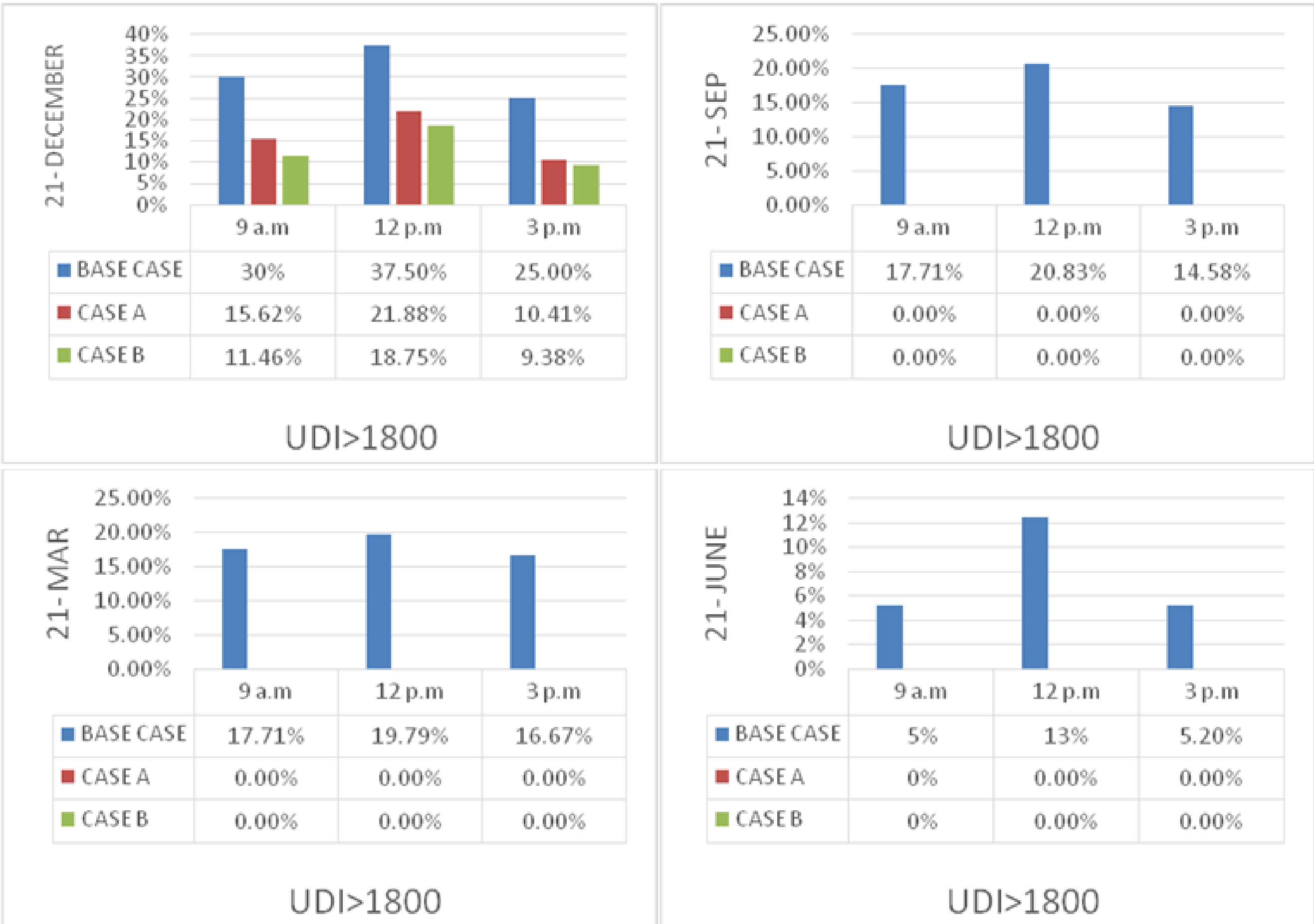

Fig. 8. Bar chart of UDI $_{average}$ (UDI>1800 lux)
(Simulation Source: Researchers&Output: Honeybee Plus)

5.2 Analysis glare

All three positions, without shader, with fixed shader and the dynamic parametric shader, are considered for the analysis of the glare in the office room. The results of the glare control are presented by changing the area of the cavities as follows.

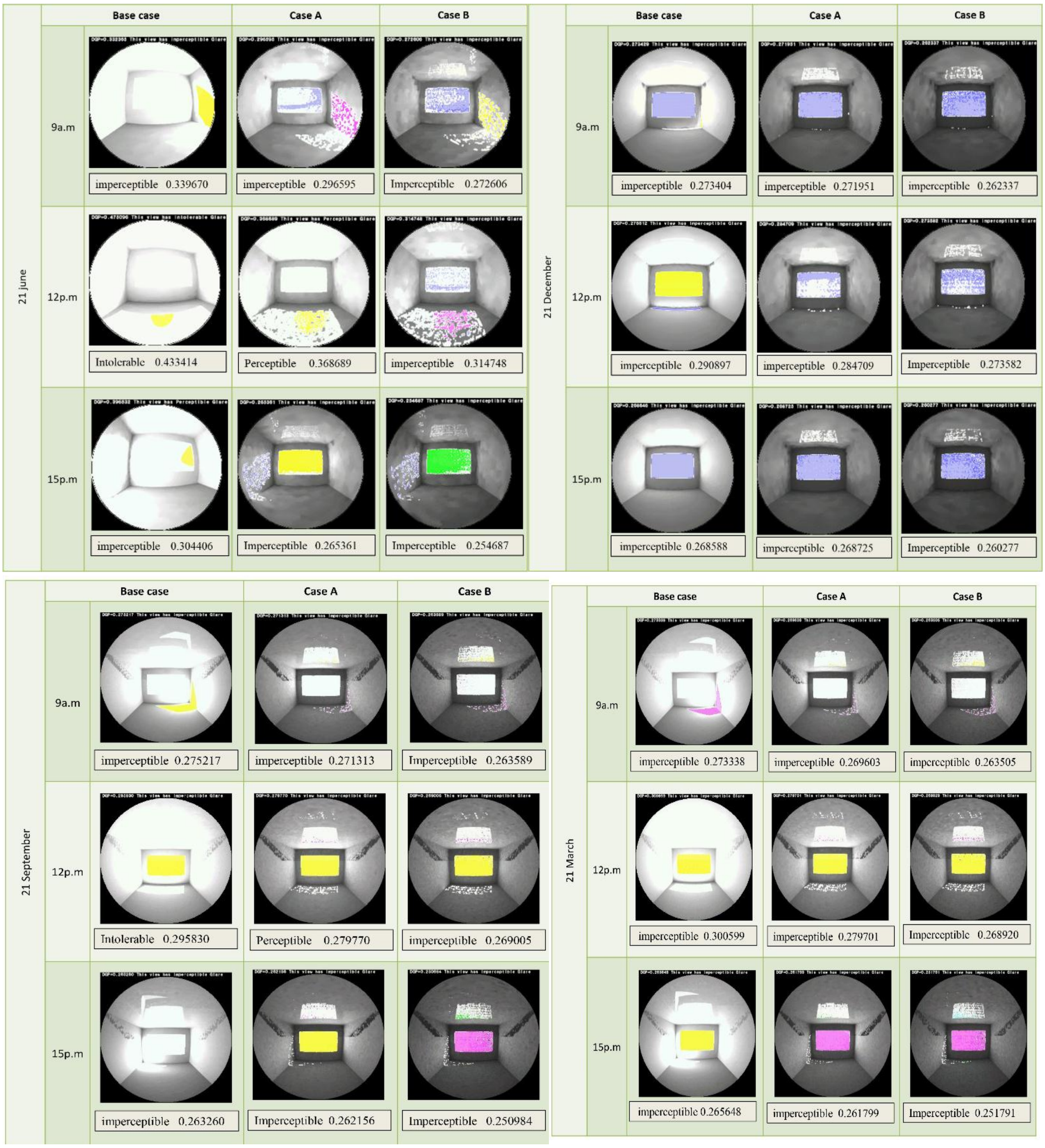

Fig. 9. DGP evaluation in December 21st and June 21st
(Simulation source: Researchers& Output: Honeybee Plus)

In all cases, DGP evaluation has demonstrated an improvement in glare control when equipping the window with a shade (Fig. 9). The base case has experienced perceptible and intolerable degrees of glare after analysis. In 21 of June and 21 of September, it is intolerable, meaning that measures should be taken to alleviate the problem. When adding the fixed shade (Case A), we realized that the shade greatly impacts the glare index. On 21 June at 12 pm, it changed from intolerable to perceptible. Likewise, on 21 September at 12 pm, it turned from intolerable to perceptible. The addition of parametric shade has also been beneficial for glare control. In 21 of June and September at 12 pm, when the glare is recorded as perceptible, changing the shade from a fixed one to a parametric one turned the glare to imperceptible. It is noteworthy to say that during some hours that glare was recorded imperceptible, the intensity of glare was reduced when replacing the fixed shade with a kinetic one.

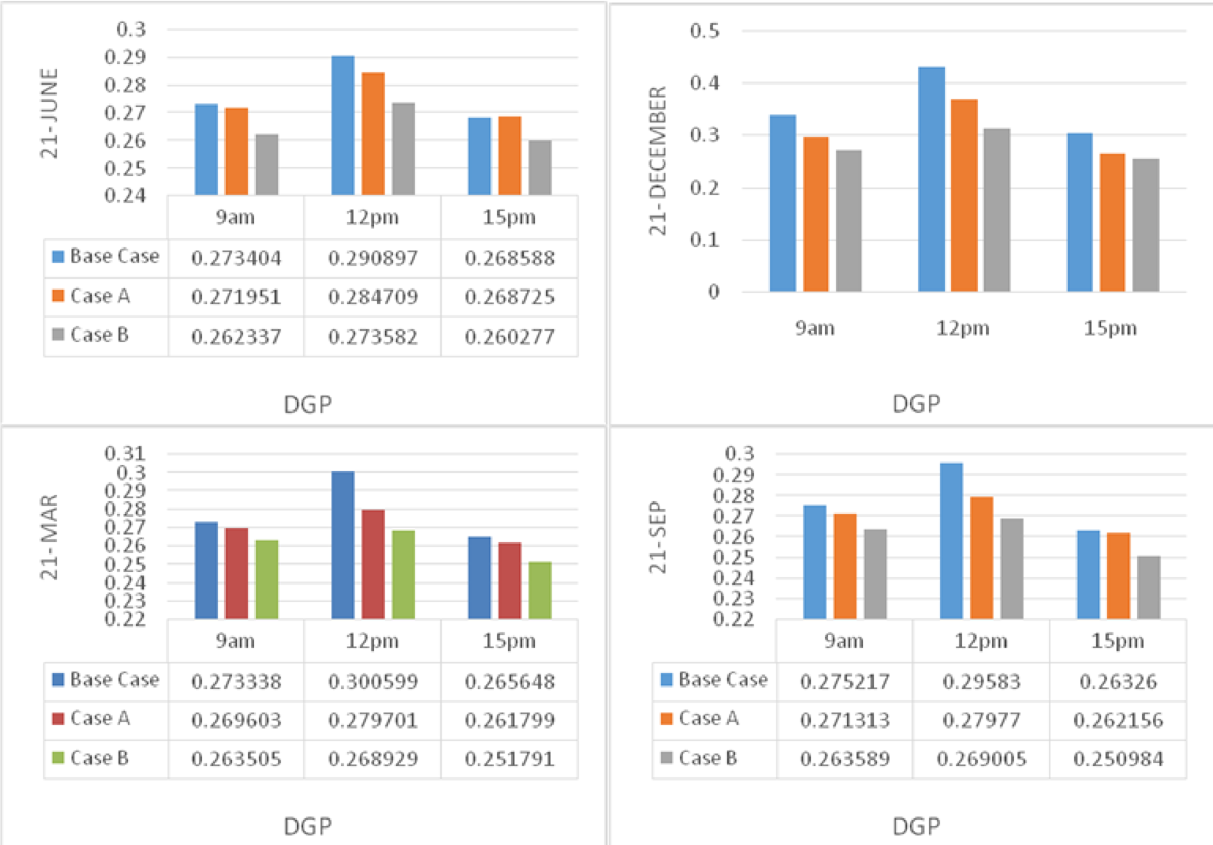

Fig.10. DGP evaluation in December 21st and June 21st
(Simulation source: Researchers & Output: Honeybee Plus)

The trend for discomfort glare probability in figure 10 on 21st June has been shown the steady fall at 9 am, and 3 pm from base case to case B and to drop significantly at 12 pm and this decline was sharply on 21st December at 12 pm. But at 15 pm, the change was not that noticeable when fixed shade was added to the base case. In 21 of December at 9 am, the decrease is uniform, but at 12 pm, it is much more significant. At 15 pm, the addition of parametric shade does not make a greater contribution when comparing with previous cases. In 21 of March at 12 pm, the presence of the fixed shade makes a much greater difference in comparison with other cases. The downtrend experienced at 9 am and 15 pm is almost the same as in other cases. 21 of September follows almost the same pattern as 21 of March. The most noticeable difference is observed when adding sun shades to the window at 12 pm..

6. Conclusion

The survey results showed that the performance of the shading pattern in the dynamic envelope not only control privacy and access to external visual interactions but also influence on visual comfort.

The geometrical properties of the pentagram shader such as measures and its fabric settings were applied in simulations. The research paper presents the evaluation of visual comfort by useful daylight illuminance and glare as the main factors on the dynamic responsive solar envelope for a single south-faced office unit in Iran-Tehran. The result showed enhancement in the performance of dynamic and parametric envelope which porosity is variable between 20% to 80% in comparison with static shader with porosity 80%. The first bar charts indicate that the percentage of UDI upper than the range of sufficient daylight (>1800 lx) was declined by dynamic shader 18.54% at 9 am, 18.75% at 12 pm and 15.62% at 3 pm on 21^{st} December. In addition, these drops have occurred 5% at 9 am, 13% at 12 pm and 5.2% at 3 pm on 21^{st} June. The second bar charts indicate that the percentage of discomfort glare probability (DGP) was declined by dynamic shader 19.74% at 9 am, 27.37% at 12 pm and 16.33% at 3 pm on 21^{st} December. In addition, these drops have occurred4% at 9 am, 6% at 12 pm and 3% at 3 pm on 21^{st} June. As a tried-and-tested procedure, the proposed dynamic parametric envelope was found to be effective to minimize DGP and upper limit UDI for keeping an indoor glare-free environment.

The ongoing research ofthePh.D.hasthe potential to become a basis for the future intelligent and adaptive dynamic envelope that controls the shading pattern, aiming to optimize occupant's visual and thermal comfort. Moreover, it will provide the daylight metric factors as a framework to understand the responsive dynamic envelope in occupants' comfort.

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