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Comparative Study of Different Design Configurations Based on the Daylight and Visual Comfort Performance of Electrochromic Glass in a side-lit Office building

Amir Hosseinzadeh Zarrabi[,*], Mona Azarbayjani[,1], Armin Amirazar[1] , Roshanak Asharafi[1]

KEYWORDS

Daylighting; Shading strategies; Workstation; Electrochromic Glass; office building; glare; Furniture layout; Daylight simulation

ABSTRACT

The objective of this research is to demonstrate the application of an optimization framework to assess and improve the impacts of workstation properties in relation to the performance of electrochromic glass regarding daylight and visual comfort. This framework is executed through a simulation-based parametric modeling workflow of an open-plan office to optimize partition layout, height, direction to windows, and materiality in response to annual glare probability (DGP) and climate-based daylighting metrics. In this paper, different office layouts equipped with Electrochromic glass, located in a mixed-humid climate has been simulated with DIVA plug-in for Rhinoceros/grasshopper software to maximize the daylight and reduce the visual discomfort.

The results of the optimization study show that the visual comfort and daylighting can be increased from 17 % to 36 UDI (100–2000 lx) while maintaining the percentage of occupied hours glare between 3.1 and 4.1. Considering these two aspects, the workstation with opaque 42" partition height in perimeter and 60" in Interior ("Pre 42_Int 60") layout in 10° oriented towards the south perform the best with the Electrochromic user-based schedule.

INTRODUCTION

According to a broad range of studies, the quality of office environment is influenced by office layout, furnishing, and lighting quality (Kim & de Dear, 2013; Lee & Guerin, 2009). Although the previous studies believe that partitions in an open plan office spaces provide privacy for employees as the first objective in the design process, the robust role of partition layouts in the better distribution of daylight into the space and occupant visual comfort can not be undermined (Paper, Carolina, Modaresnezhad, & Nezamdoost, 2017). Lighting has a significant direct impact on office workspace, as the studies show daylit offices increase employees' comfort, productivity, satisfaction, health, and well-being (Kelly, Painter, Mardaljevic, & Irvine, 2013). However, overlit spaces can cause glare and visual discomfort, especially with sunlight penetration when the amount of daylight is not sufficiently controlled. There are internal and external design strategies to control the daylight. The electrochromic glass as a dynamic shading device is used to both prevent and control undesirable daylight and solar radiation(Sbar, Podbelski, Yang, & Pease, 2012).

Recently, by allowing the occupants to control the stage of tinting in glazing through a timed override, the window can be darkened only when the occupants are exposed to excessive daylight and the presents of glare, otherwise, it permits daylight penetration in the space (Arnold, 2010). In this case, the attributions of occupant locations (office layout properties, partition's height, materiality and direction to windows) become crucial to provide visual comfort (Modaresnzhad, M Nezamdoost, 2017). Nevertheless, daylight buildings are rarely studied in terms of the impact of interior design strategies on the user-based performance of electrochromic glass. This study outlines the daylight performance of workstation strategies based on the user- based control of electrochromic glass to 1. Maximize daylight illuminance while minimizing visual discomfort and 2. Find the optimum solution for the future office layout refurbishment.

METHOD
In order to study the daylight performance and visual comfort of multiple workstation designs scenarios, a simulation-based design workflow was developed in grasshopper. The workflow consists of modeling the existing workstation and the façade in an office building and analysing different scenarios of workstation attributions based on the annual climate-based daylight. In the optimization process, the occupant comfort feedback (levels of comfort) is used to find the optimum attributions of the workstation model that will provide the optimum daylight and visual comfort. An overview of each step is as follows:

1. Geometry Creation
Building the base case
For the purposes of this study, one section of an office building in warm and humid climate was modeled as illustrated in Figure 1. The office layout is divided into a core, interior (6 to 14m) and perimeter (1 am to 5 am) zones to represent the typical floor plan of high rise office building that is rotated 45° clockwise from the north axis. In order to examine daylighting and visual comfort of the occupants, the south-east orientation in the 20th floor (without exterior obstruction) is chosen as a critical orientation that receives a significant amount of morning exposure.

Figure 1. Office plan with workstation layout
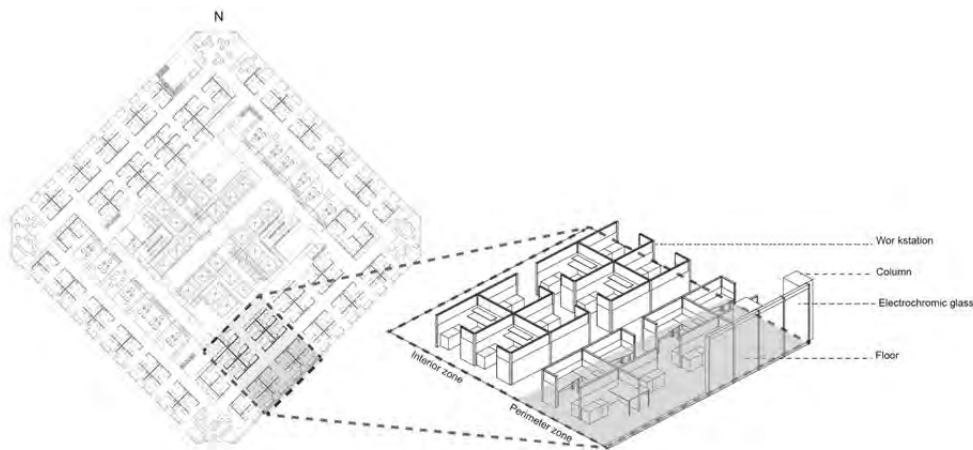
2. Modelling the Shading Device
The exterior envelopes are modeled with switchable Electrochromic windows with the same window position and size illustrated in Figure 1, the Electrochromic window is switched based on user preference level into three tinted states as stated in table 1, based on their visual comfort (manual glare control). In this case, occupants can activate shading systems as their visual discomfort increases (DGP>0.4).

Table 1. Workstation design scenarios

Electrochromic Glass	65 EC Clear state	60%
	EC Tinted state 1	30%
	EC Tinted State 2	2%

3. Defining the Workstations properties

The 56 alternative workstation partition designs are modeled based on the four variables including partitions' height, material, and direction to the window and layouts as indicated in Table 2. The layouts consist of three configurations: 1. "Pre 42_Int 60": 42" partition in perimeter zone and 60" partition height in the interior zone. 2. "Pre 40, 48_In 60": the partition height gradually increased from perimeter zone to the interior zone (40" to 60"). 3. "Pre 60_Ver: 60" partition in the vertical (y-axis) of the workstation in the perimeter zone.

Table 2. Workstation design scenarios

Layout	Pre 42_Int 60	Pre 40,48_In 60	Pre 60_Ver
Height	W_42"	W_48"	W_60"
Material	Translucent Ref .4 Trn 20	Transparent 88 Trn	Opaque 88 Ref
Orientation	Perpendicular to window	10° to the south	10° to the North

4. Simulation

Annual glare simulation is conducted to calculate the Daylight Glare Probability (DGP) for multiple camera views based on the occupants' view directions. As the occupants of perimeter zones are exposed to daylighting, the shading device (EC) assumed to be tinted by occupants when glare becomes uncomfortable. This value is calculated for the location of occupants at the eye level (1.2m) that points directly at the screen of the monitor.

An annual climate-based daylighting simulation is executed utilizing the plug-in DIVA-for-Rhino 5.0 to quantify the annual daylighting performance of each scenario, the "Useful Daylight Illuminance" or UDI (Nabil & Mardaljevic, 2006) is used to measure the annual percentage of time that a sensor point receives an amount of daylight that is sufficient for office work while avoiding glare.

5. Optimization

In the last phase of the workflow, the outcomes are examined relative to one or more performance goals. The best trades between designed daylighting objectives; visual comfort and interior design strategies are explored to reach a series of possible optimum solutions.

As the quality of daylight and avoidance of glare are equally important, subtracting percentage of occupied hours DGP (g) from the percentage of the space with a UDI<100-2000lux larger than 50% (u) yields a single maximization objective (both UDI and DGP are in the range [0, 100]). It turned this result into a minimization objective by subtracting it from 100.

$$min\ f(x) = 100 - \bar{u}(x) + \bar{g}(x)$$

RESULTS

The following section, first, compares the results of 56 scenarios of workstation designs based on the following variables and second, the best optimized solutions are analysed and compare with the base case scenario.

Height

The highest UDI values were recorded for 42" height partition, in perpendicular orientation to windows (28 %) that in comparison to base case scenario 11% was improved. As it was expected, by increasing the partition height, the amount of daylight that enters into the space reduces, which consequently decreases the percentage of the UDI<100-2000lux during occupied hours. The lowest percentage of occupied hours glare is recorded for the 60" height partition according to base case layout (3.7%). The percentage of occupied hours that occupants are exposed to glare are (3.7 %, 4.1%) for the 42" and 48" respectively and

unexpectedly the value for the 48" slightly is more than 42" due to the reflection of partition surfaces.

Material

The UDI value in figure 2a, implementing transparent material, brings more daylight into the study space. As it was expected, UDI values were reported higher in transparent partitions (with 88% visual transmittance) in comparison to the 20% visual transmittance in translucent partitions (base case), while the percentage of glare for both materials have quite similar values (2.9% and 3.1%). In opaque partitions (85% Reflection), the UDI value is less than the transparent material (20 to 25), however, it is slightly more than the translucent material (20% to 17%) and even the high glare value and more hours shading did not make significant differences.

Orientation

The orientation investigation of daylighting's impacts on translucent materials with 30% and 50% VLT was conducted and illustrated in figure 2 c) respectively. It shows that the UDI values for workstations with perpendicular partitions to the window (base case) are relatively low (17 %.). Regardless of rotation direction, the UDI values of rotated partition are higher than in the partitions with orientations perpendicular to the windows. In the workstation with 10° rotated towards the south and north directions, UDI values are more than the base case (22% and 19%). Although the workstation with 10° rotation towards the south has higher UDI value in comparison with others, the percentage hours of visual discomfort is considerably high (6.4%). The workstation with 10° rotation towards north are not exposed to daylight and the percentage of glare hours and shading hours in all states are significantly lower than the base case and other. This led to higher UDI value for the workstation with direction towards north even in comparison with perpendicular partitions to the window (19%)

Layout

As the plots illustrated in figure 2 d) the UDI and Glare values reveal that in the translucent partitions all alternatives have the better performance in comparison with the base case scenario. The highest useful daylight illuminance (UDI) belongs to the workstation with 60" vertical partitions oriented perpendicular to the windows (Pre 60_Ver) and the workstation layout with 42" partitions in perimeter zone and 60" partitions in interior zone (Pre 42_Int 60) that both are almost identical (28%). The lowest values were recorded 2.9% in a layout with 60" partition in the vertical axis of the workstation in perimeter zone (Pre 60_Ver) that prevent excessive daylight into the space and where the occupants are located. The UDI value of "42, 48 PR_ 60 In" workstation layout is more than base case scenario (24%) but the glare value is quite similar to "Pre 42_Int 60" workstation layout (3.7%).

Overall

Based on the simulated plots illustrated (Figure 3), the base case scenario has good performance regarding the visual comfort and low occupied hours of glare (3.1%). However, the daylight in the base case scenario is the lowest ranked value (17%) that is recorded in which the 60" partitions block the daylight and reduce the UDI significantly. The best scenarios belong to a workstation with opaque partition layout in 10° oriented towards the south ("Pre 42_Int 60") illustrated in Figure 4. The hours which the EC is fully shaded, is low and the reflected diffuse light of surfaces in perimeter zones are also low due to the absence of high reflective partitions. Therefore the 4.1% hour of glare provide the more unshaded hours that led to more daylight entering the space and recorded the highest value of useful daylight illuminance (36%). According to the ranking, the workstation with 60" vertical opaque partition in the perimeter zones for the case rotated 10° towards the south (Pre 60_Ver) could provide a balance between daylight and glare (32 UDI and 4.1 DGP). This scenario would be considered as a good alternative for the first ranked scenario if the level of privacy considered.

Figure 2. a) Height, b) Material, c) Direction to windows, d) Layout
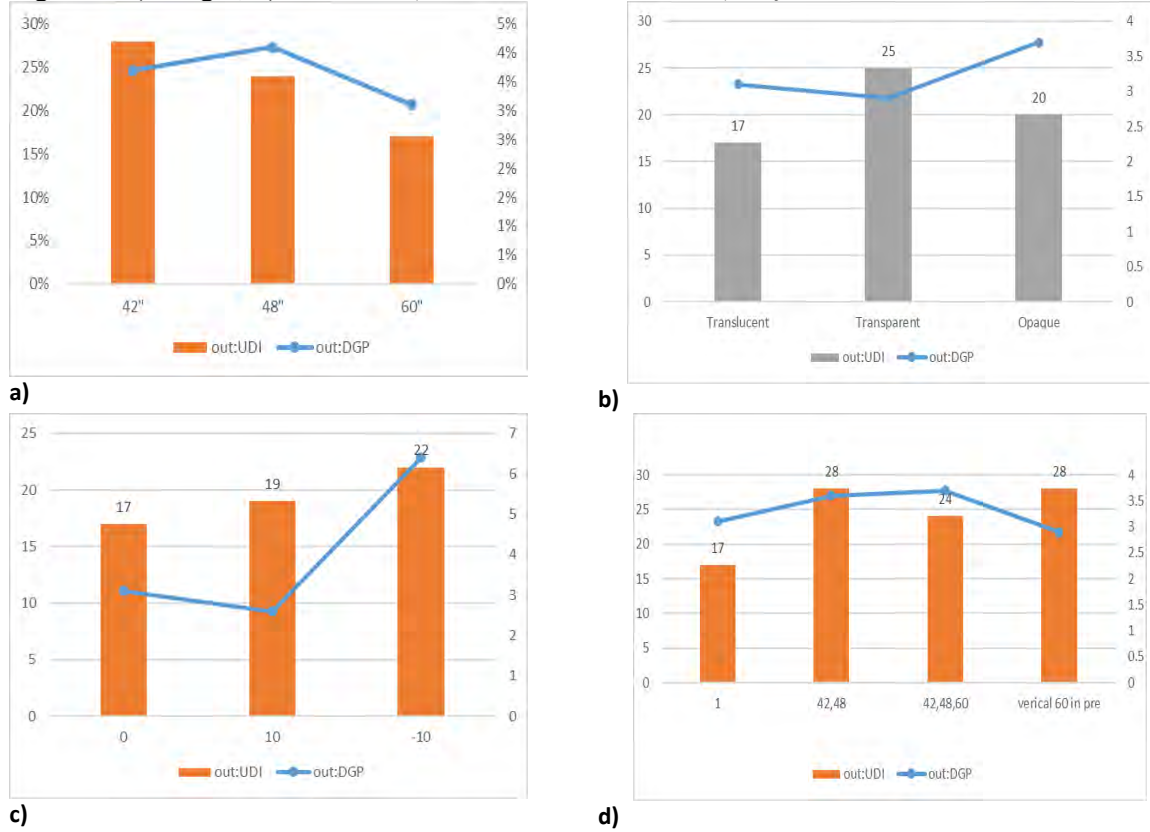

a)

b)

c)

d)

Figure 3. Parallel coordination of all variables Red: Worst case scenario, Blue: Best case scenario

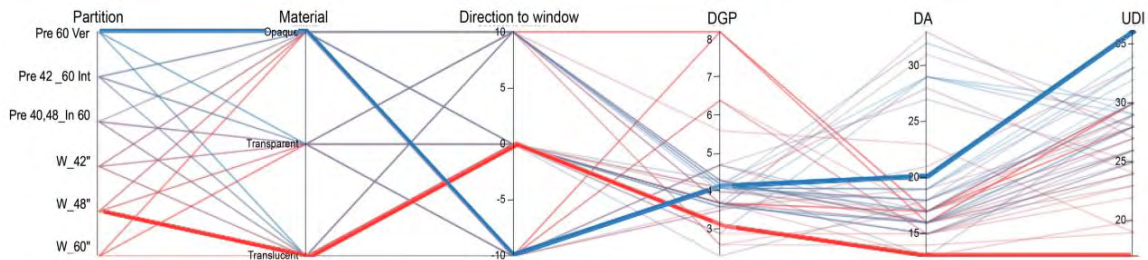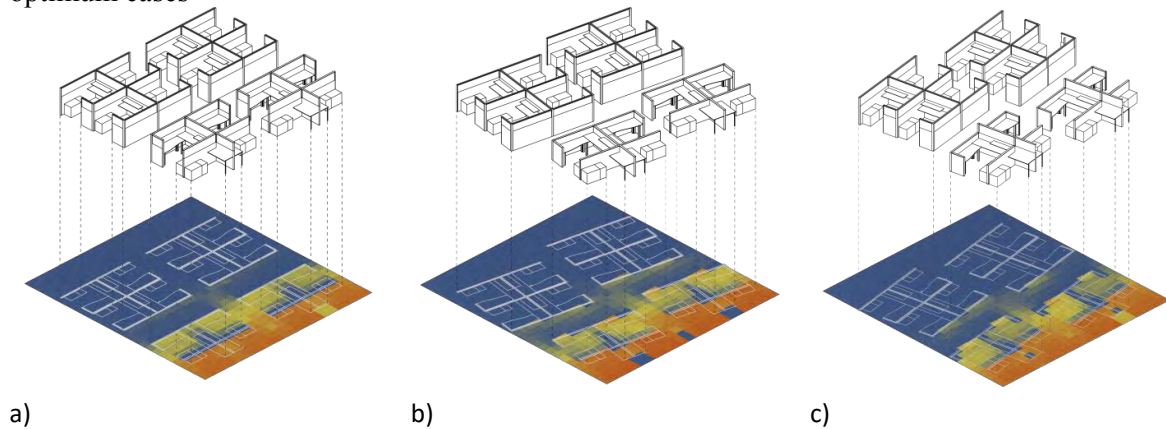Figure 4. The layout and The Daylight Autonomy. a) Worst case (Base case), b and c. optimum cases

a)   b)   c)

815

Discussion

Generally, the ranges of workstation properties are limited to certain degrees and materials and they could be expanded to different choices. For instance, because of the high reflectivity of selected opaque surfaces, the reflection of defuse light can cause more glare and lead to more shading time while the other opaque material with lower range of reflectivity could produce less glare that reduce the shading time.

Electrochromic glass works with different schedules beside the visual comfort. The energy and thermal schedules in some cases are in contrast with daylighting and visual comfort and their impact on the occupants' visual comfort at workstation needs to be studied and explored for the possible trade-off among all other parameters.

Conclusion

This paper presented an optimization method, used multi objective workflow with visual comfort and daylight simulation, and applied them to selected optimal values of design parameters associated with workstations (partition height, layout, direction to windows and materials) in an office building equipped with EC (user-based schedule) to deliver optimum daylight values while minimizing Glare Probability in the course of the year.

Considering the workstation design layouts into the simulation of dynamic shading (EC glass) makes the relation of UDI and Glare interdependent so that the daylight depends on the glare value. For instance, although the lower percentage of glare in high partition (60") reduces the shading hours and allows more daylighting that enter into the space, however, the high partition height prevent the penetrations of daylight.

The result of optimized scenarios show improvements of UDI ranging from (65% to 100%) across a diverse range of layouts and partition properties while simultaneously reducing visual discomfort varying degrees (between 4% and 17%) depending on variables. For instance the workstation with opaque ("Pre 42_Int 60") partition layout in 10° oriented towards the south is one of the optimum scenario that increase the performance of EC regarding daylight and comfort. This study tries to raise the awareness and attention of manufacturers and designers to the performance of workstation in relation to the user-based scheduled EC.

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