BNUT

Iranica Journal of Energy & Environment
Journal Homepage: www.ijee.net
IJEE an official peer review journal of Babol Noshirvani University of Technology, ISSN:2079-2115

Enhancing Daylight Performance and Visual Comfort in Office Buildings with Electrochromic Glazing: A Case Study of Mashhad

H. Kamelnia[1]*, A. Ghalehnovi[2]

[1] *Faculty of Architecture and Urban Planning, Ferdowsi University of Mashhad, Mashhad, Iran*
[2] *Department of Architecture Group, Khorasan Institute of Higher Education, Mashhad, Iran*

P A P E R I N F O

Paper history:
Received 13 October 2023
Accepted in revised form 09 February 2024

Keywords:
Discomfort glare probability
Electrochromic glazing
Modern office building
Useful daylight illuminance
Visual comfort

A B S T R A C T

Electrochromic Glazing (EC) has seen a significant surge in adoption today, primarily attributed to its pivotal role in enhancing visual comfort, mitigating excessive heat, regulating cooling and heating requirements, and curbing lighting consumption, especially within office buildings. Moreover, electrochromic glazing effectively contributes to glare control. This research aims to explore the impact of electrochromic glazing, as compared to conventional clear windows, on both the south and north facades, with the overarching goal of enhancing thermal and visual comfort within an office complex located in Mashhad. The research process unfolds in two key steps. Firstly, a comprehensive building simulation was conducted to assess daylight performance and gauge thermal and visual comfort using the GrassHopper plugin. Ubsequently, the Honeybee and Ladybug plugins were harnessed to evaluate the Discomfort Glare Probability (DGP) index and the Useful Daylight Illuminance (UDI) index. The findings of this study underscore the compelling advantages of electrochromic glazing over conventional clear windows as a prime choice to maintain balanced daylight levels throughout the day. In practice, using electrochromic glazing on both north and south facades of a building reduces the annual heating and cooling energy demand by 6.5 and 4.5%, respectively. Additionally, it has a significant impact on reducing intrusive light radiation and intolerable glare levels compared to reference transparent windows, with reductions of 40 and 34.52%, respectively.

doi: *10.5829/ijee.2025.16.01.16*

NOMENCLATURE

BAS	Building Automation Systems	*UC*	Liquid Crystal
CGI	CIE Glare Index	*SP*	Suspended Particles
DGI	Daylight Glare Index	*UDI*	Useful Daylight Illuminance
DGP	Discomfort Glare Probability	*UGR*	Unified Glare Rating
EC	Electrochromic Glazing	*VCP*	Visual Comfort Probability
EUI	Energy Use Intensity	*WWR*	Window-to-Wall Ratio

INTRODUCTION

In the present era, energy conservation stands as one of the most pressing challenges humanity faces. Access to energy resources has become a pivotal factor in achieving sustainable development worldwide (1). The surging demand for energy has spurred extensive research into passive design strategies. Sustainable design, when implemented effectively, can result in an impressive reduction of energy consumption, ranging from 80 to 90%, contingent upon the local climate conditions (2).

Designing buildings that harness natural daylight presents architects with a multifaceted challenge. This involves intricately balancing factors such as the size and placement of daylight sources with the surface geometry. The goal is to create spaces that not only maximize the

*Corresponding Author Email: kamelnia@um.ac.ir (H. Kamelnia)

Please cite this article as: Kamelnia H, Ghalehnovi A. Enhancing Daylight Performance and Visual Comfort in Office Buildings with Electrochromic Glazing: A Case Study of Mashhad, Iranica Journal of Energy and Environment, 16(1):154-63. Doi: 10.5829/ijee.2025.16.01.16

use of natural daylight but also achieve a harmonious and evenly distributed illumination (3).

Concurrently, the well-being of occupants within buildings has gained paramount importance, considering that the majority of individuals now spend a substantial 80 to 90% of their time indoors (4, 5).

A formidable challenge in building design lies in the harmonious balance between reducing energy consumption and enhancing thermal and visual comfort (6, 7). Striving for a satisfactory indoor environment is a key objective of passive building design, which has garnered substantial attention for its efficacy and proven impact on elevating building energy efficiency (8).

Renewable sources of energy, such as natural light, are a crucial factor to reduce the artificial lighting needs in designing energy-efficient buildings (3).

Design parameters encompassing building orientation, form, materials, and window design have always been subject to the influence of weather and solar conditions (9). However, by scrutinizing building envelope designs, which serve as the boundary between the interior and exterior, we can significantly reduce energy consumption while enhancing occupant comfort.

Whilst reducing total energy consumption of buildings (electricity, gas and other fuels) is important in the context of climate change, better understanding of the key drivers of electricity use is crucial (10).

Among these building elements, window design emerges as particularly crucial in bridging the gap between architecture and energy efficiency, directly impacting Energy Use Intensity (EUI) and resident comfort (11).

As mentioned, the envelope of the building and openings can regulate the increase of solar heat and the transmittance of incoming light into the building. It is necessary to use the appropriate envelope in high-rise buildings as much as possible due to high energy consumption (12).

While factors like Window-to-Wall Ratio (WWR) and Light shelves hold great significance in bolstering building energy efficiency and occupant visual comfort, the judicious selection of window glass can effectively mitigate excessive summer heat and glare (13, 14). Employing appropriate glazing can facilitate the blocking of undesirable solar radiation during summer while permitting it during winter, ultimately resulting in reduced energy consumption and heightened occupant comfort (15).

In the contemporary context, the adoption of switchable electrochromic (EC) glazing has gained prominence, primarily owing to its pivotal role in managing visual comfort, mitigating excessive heat, and addressing the heating, cooling, and lighting needs of buildings, especially in office environments. Reconfigurable electrochromic glazing not only aids in energy conservation but also enhances the visual well-being of occupants (16).

The Electrochromic glazing (EC) system comprises multi-layer coatings on glass, inducing the migration of ions from the EC layer through low-voltage applications, thereby modulating its optical properties, resulting in a change in the glaze's color. This modulation is reversible, allowing dynamic control over solar heat and daylight penetration into the building (17). In essence, this system encompasses Liquid Crystal (LC), Suspended Particles (SP), and Electrochromic (EC) control systems, all of which can be adjusted as needed in response to input signals from Building Automation Systems (BAS), network sensors, or occupant feedback. This technology made its debut in the construction industry as early as 2006 (18).

Switchable Electrochromic Glazing (EC) allows visible light to penetrate the space while effectively shielding against excessive heat when required. EC glazing can significantly reduce heating and cooling loads, ensuring user comfort by mitigating glare.

In a study conducted in Switzerland on EC smart windows, it was found that these windows reduce lighting energy consumption and cooling demand by about 11% (19).

Based on the studies, the optimal performance of EC windows is largely dependent on the application and site’s location (20).

A study by Lee et al. (21) modeling a full-scale test cell with EC glazing at a 40% window-to-wall ratio, demonstrated that EC glazing surpasses conventional windows in energy efficiency. The research reported a remarkable 91% reduction in lighting energy consumption, with annual energy savings and electricity peak demand decreasing by 48 and 35%, respectively (21, 22).

Ganji Kheybari et al. (22) also conducted simulations for small and medium-sized office. The results indicated a range of savings: 15 to 25% in lighting, 3% to 17% in cooling, and 7% to 15% in heating consumption (22).

In a resident survey conducted in a building equipped with Switchable Electrochromic Glazing by Zinzi (23), it was observed that EC glazing provides a consistent level of daylight in rooms under conditions of no direct sunlight and moderate sky illuminance. Investigating the impact of EC glazing on visual comfort in 2007, Lee et al. (24) reported a 10% decrease in the annual average Daylight Glare Index (DGI) and energy consumption.

In a study by Lawrence Berkeley National Laboratory, it was noted that ordinary windows led to glare discomfort for 95% of users, a problem largely alleviated by the use of electrochromic (EC) windows (25).

While the literature review reveals numerous studies on the application of electrochromic glazing in buildings to enhance thermal and visual comfort, fewer have explored its impact on glare and related indicators. While the primary function of electrochromic glazing is to prevent dazzling glare (26).

To address this gap, the present research investigates the use of EC glazing versus standard clear windows on both the south and north facades, with the aim of improving thermal and visual comfort conditions in an office building in Mashhad. This research unfolds in three phases, as illustrated in Figure 1. We hope that the findings of this study will prove valuable to architects and urban planners seeking to design more sustainable buildings.

MATERIAL AND METHODS

To assess the impact of electrochromic glazing on the energy consumption of the building, the Total Energy (TE) index has been employed. The TE index represents the total required energy in the building. In the present study, the modeling procedure takes into account the required energies for two rooms, encompassing electrical, heating, and cooling energies.

$$TE = EE + HE + CE \quad [1]$$

In which, the parameters of TE, EE, HE and CE are total, electrical, heating and cooling energies, respectively.

While the advantages of daylight and visibility in promoting a healthy working environment are well-established, it is imperative to ensure that these factors do not lead to visual discomfort and glare for users. Glare is characterized by a sudden and intrusive bright light within the visual field, resulting in disturbance and discomfort. The assessment of glare is a multifaceted task, with varying methodologies employed to quantify its discomfort-inducing potential.

The evaluation of glare typically relies on five key indices, including the Visual Comfort Probability (VCP), the CIE Glare Index (CGI), the Discomfort Glare Index (DGI), the Unified Glare Rating (UGR), and the Discomfort Glare Probability (DGP). Among these indices, the DGP holds particular significance due to its robust correlation with users' subjective experiences of glare perception, setting it apart from existing glare evaluation metrics (27).

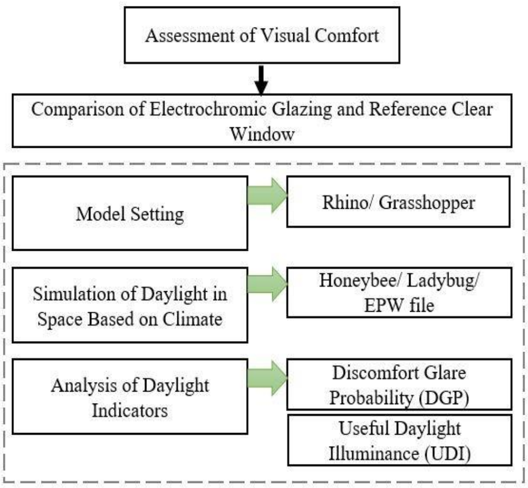

Figure 1. Diagram of the research process

The DGP index, developed by Wienold in 2006, represents the probability of user dissatisfaction with their visual environment. This measure was crafted based on subjective responses from 349 tests conducted in an office setting, encompassing three window sizes and three shading systems. Notably, the DGP has emerged as the preeminent luminance-based metric for assessing discomfort arising from daylight-induced glare (17, 28). Extensive research has substantiated the reliability of the DGP in predicting light exposure in typical workplace scenarios (22, 29, 30). As described in the general Equation 2.

$$DGP = 5.87 \cdot 10^{-5} \cdot E_v + 9.18 \cdot 10^{-2} \cdot \log\left(1 + \sum_{i=1}^{n} \frac{L_{s,i}^2\, \omega_{s,i}}{E_v^{1.87} + P_{s,i}^2}\right) + 0.16 \quad [2]$$

In this formula, Eν represents the vertical Eye illuminance (lux), Ls: luminance of the source (cd/m²), ωs: Solid angle of source, and Ps: position index (31, 32). In Table 1, the four scales of feeling glare by index DGP are stated.

In this research, for a more comprehensive analysis, we have expanded our evaluation beyond the Discomfort Glare Probability (DGP) index to include the assessment of the Useful Daylight Illuminance (UDI) index. The UDI is an annual metric that gauges the extent of adequate daylight coverage within a space during standard working hours (33). The recommended UDI range falls between 100 lux and 2000 lux, signifying that areas with illuminance levels below 100 lux are considered very dim, whereas those exceeding 2000 lux are categorized as excessively bright (34–36). According to LEED v4 certification, UDI300-3000lux must achieve 75% of the occupied floor area in new construction.

Leveraging energy performance simulation in the design phase proves to be a potent strategy for enhancing both energy efficiency and resident comfort (37).

Given the intricate designs of modern buildings and the advancements in building energy simulation software, their utilization has become widely accepted. In the aforementioned study, we employed Rhinoceros and Grasshopper 6 software, along with the Ladybug 0.0.69

Table 1. Relationship between DGP and subjective glare rating (29)

Subjective Rating	DGP Range
Imperceptible Glare	<0.35
Perceptible Glare	0.35-0.40
Disturbing Glare	0.40-0.45
Intolerable Glare	>0.45

and Honeybee 0.0.66 plugins, to assess the aforementioned metrics. It's worth noting that to achieve a more realistic modeling approach, we incorporated dynamic weather conditions, encompassing all months and hours of the year, utilizing both EPW File and STAT File formats. Detailed thermophysical properties of the materials used are presented in Table 2 for reference.

In this research, the radiance parameters in the simulation are set as Table 3, and optical properties of the Electrochromic Glazing shown in Table 4.

THE CASE STUDY

In this study, we have selected the administrative building of the Chamber of Commerce, Industries, Mines, and Agriculture, located in Mashhad, as our primary case study. Mashhad city is situated at coordinates 36 degrees 15 minutes north and 59 degrees 38 minutes east, with an elevation of 999 meters (3278 feet) above sea level. According to the Köppen-Geiger classification, the city boasts a cool steppe climate with a medium/semi-arid latitude. The annual average temperature in Mashhad stands at 13.6 °C (56.5 °F) (38). For detailed climatic data on a monthly basis, please refer to Table 5.

Table 2. Properties of the surface for simulation (34)

Element	Thickness (m)	U-Value ($W/m^2.K$)	Reflectivity (%)
Roof	0.42	0.345	25
Interior Ceiling	0.31	1.449	90
Internal Wall	0.13	2.581	80
External Wall	0.41	0.459	80

Table 3. Radiance parameter (Author)

Param	Description	Value
-ab	Ambient bounces	2
-aa	Ambient accuracy	0.15
-ar	Ambient resolution	128
-ad	Ambient divisions	512
-as	Ambient super-samples	256

Table 4. Thermal and optical parameters (10)

Design parameter	Value
Electrochoromic pane type	Generic ECREF-1 COLORED
Electrochoromic thickness	6 mm
Electrochoromic conductivity (W/m.K)	0.90
Electrochoromic solar transmittance	9.90%
Electrochoromic visible transmittance	15.50%
Electrical power needed to change electrochromic windows between clear and tinted state (W/m^2)	2
The time needed to switch between clear and tinted state (Minute)	20
Total electricity needed to switch between the dimmed and clear state for the entire building (Wh/year)	52240.76

This building is situated on a plot of land covering an area of 672 square meters. It features a substantial vertical footprint, consisting of 3 underground floors and 8 above-ground floors. Notably, the building exhibits a distinct architectural characteristic with a notable 58-degree

Table 5. Monthly table of climatic data of Mashhad city (35)

Month	Average Temperature °C	Average Precipitation mm	Average Daylight Hours/ Day	Sun altitude at solar noon on the 21st day (°)
Jan	0	33	9h 59'	33.8
Feb	2	36	10h 48'	43.1
Mar	8	52	11h 54'	54
Apr	14	49	13h 05'	65.6
May	20	26	14h 04'	73.9
Jun	25	3	14h 35'	77.2
Jul	27	1	14h 21'	74.1
Aug	25	1	13h 30'	65.8
Sep	20	2	12h 22'	54.4
Oct	13	11	11h 11'	42.9
Nov	8	16	10h 12'	33.7
Dec	3	27	9h 43'	30.3

rotation towards the west. To visualize its location and architectural layout, please refer to Figures 2 and 3, which provide an overview of the project's site and an external view, respectively.

In order to understand the performance difference of electrochromic glazing on the south and north facades of buildings, spaces have been selected in a way that, in addition to similarities in the dimensions and size, they are positioned in the southern and northern facades.

In our current investigation, we focused on two working rooms, each measuring 5.50 meters in depth, 3.05 meters in width, and 3.50 meters in height. These rooms were intentionally designed to facilitate direct interaction with the external environment, as depicted in Figure 4. Both of these rooms are equipped with windows on their north-facing side (A) and south-facing side (B), boasting an expansive window-to-wall ratio of 90%. To conduct our simulations, we assessed each of these rooms under two distinct conditions: firstly, with conventional clear windows, and secondly, with the integration of electrochromic glazing (EC) set to its white mode. Furthermore, we established a minimum lighting threshold within the rooms, ensuring a baseline illumination level of 300 lux, and during daylighting simulations, the Eye height ranges sight is considered to be 1.20 m above the floor level.

The test rooms are furnished with two office desks, and the users' seating arrangement is such that they directly face the windows. For a visual representation of the test room layout, including the positioning of all equipment, please refer to Figure 5.

Figure 2. The geographical location of the city of Mashhad in Iran

Figure 3. Location of the project

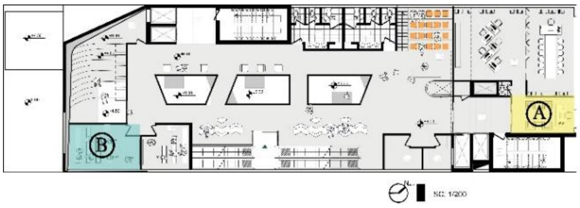

Figure 4. Showing the location of room A and B in the plan (Author)

RESULTS AND DISCUSSION

In assessing the performance of light shelves, a fundamental approach is to compare the annual simulation results of key indices, such as glare, daylight availability, thermal comfort, and energy efficiency, against established criteria. As previously outlined, our research was undertaken with the specific aim of evaluating the impact of electrochromic glazing (EC) on thermal and visual comfort, focusing on aspects related to daylight and glare control.

To achieve this objective, the annual energy requirement was calculated for both reference clear windows and electrochromic glazing.

The analysis result for Mashhad, are presented in Table 6. These results indicate that, with 500 w/m^2 solar

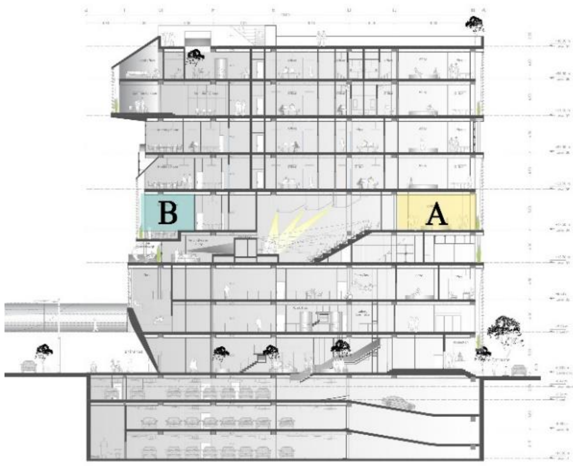

Figure 5. Showing the location of rooms A and B in the section of the office building (Author)

radiation, the annual energy was lower than the reference clear windows under all the control conditions for EC glazing.

In the next step, we utilized the Useful Daylight Illuminance (UDI) and Discomfort Glare Probability (DGP) parameters. Simulations for these parameters were conducted across three pivotal dates: March 21st, June 21st, and December 21st, each representing critical solar and sky conditions, at four distinct time intervals (9 AM, 12 PM, 3 PM, and 5 PM) when the sky was clear and sunny.

Figure 6 presents a comparative analysis of glare levels (DGP) in two scenarios: one with reference clear windows and the other with electrochromic glazing (EC) for the north-facing workroom. As outlined in Section 2, DGP values below 0.35 indicate negligible glare within a space.

The simulations reveal that when employing electrochromic glazing (EC) on the north facade, 33% of the simulated time periods exhibit imperceptible glare (DGP < 0.35), while 41.6% fall within the realm of perceptible glare. Only 25.4% of the time results in disturbing or intolerable glare. In contrast, the baseline model with reference clear windows reports 25% of time with imperceptible glare, 33% with perceptible glare, and 42% with disturbing or intolerable glare.

Table 6. Total annual heating, cooling and lighting energies

Energy (KWh)	Reference clear windows	EC glazing
Heating	25216.14	23568.57
Cooling	6670.57	6365.59
Lighting	3943.86	3781.95
Total	35830.57	33716.11

Figure 7 illustrates a similar simulation process for the south facade, with findings indicating that the use of electrochromic glazing (EC) reduces disturbing and intolerable glare by 50.4% compared to the absence of this glazing. Specifically, 33% of the time features imperceptible glare, and 33% is characterized by perceptible glare.

In summary, the utilization of electrochromic glazing (EC) on both north and south facades results in a 40% reduction in disturbing glare and a 34.52% decrease in intolerable glare compared to reference clear windows.

These results are similar to the research conducted by Amirazar and his colleagues (39) investigated the performance of different shading strategies including electrochromic glazing. They found that residents of the peripheral area benefit from electrochromic glazing as it can reduce glare in the area by more than 40% annually.

Daylight performance (UDI Index)

Another vital metric we evaluated in this study is the Useful Daylight Illuminance (UDI) index. UDI not only offers insights into the intensity of useful daylight but, due to its correlation with glare indices, also provides an indication of residents' comfort levels. This index succinctly encapsulates the overall daylight functionality within a space. Figure 9 displays the average UDI values between 100 and 2000 lux for both reference clear windows and electrochromic glazing (EC) on the north and south facades. Notably, lighting maps reveal a more uniform distribution of sufficient daylight when electrochromic glazing (EC) is employed, particularly in proximity to the windows. Furthermore, observations indicate that electrochromic glazing (EC) effectively controls and reduces high-intensity daylight (above 2000 lux) near windows without significantly affecting light levels in areas further from windows. This, in turn, results

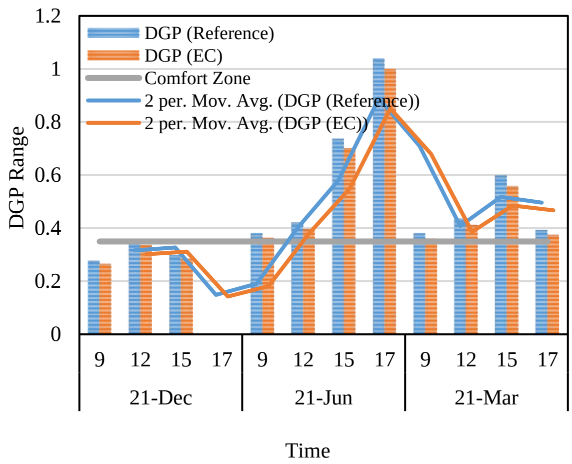

Figure 6. Comparison of DGP parameter of two types of reference clear windows and electrochromic glazing for a north-facade office

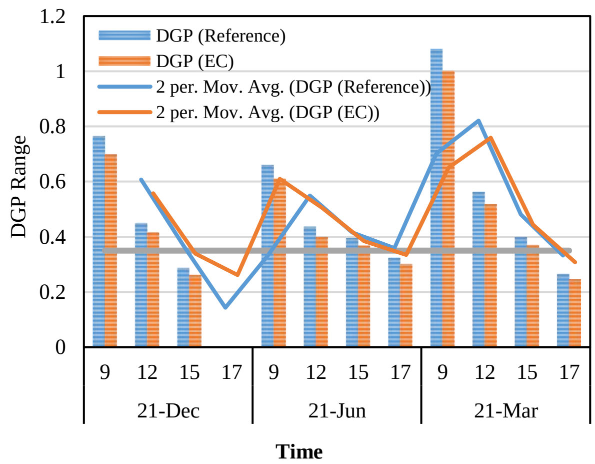

Figure 7. Comparison of DGP parameter of two types of reference clear windows and electrochromic glazing for a south-facade office

in reduced glare from excessive radiation. Comparing both models, it is evident that electrochromic glazing (EC) is particularly effective in managing light intensity on the south facade.

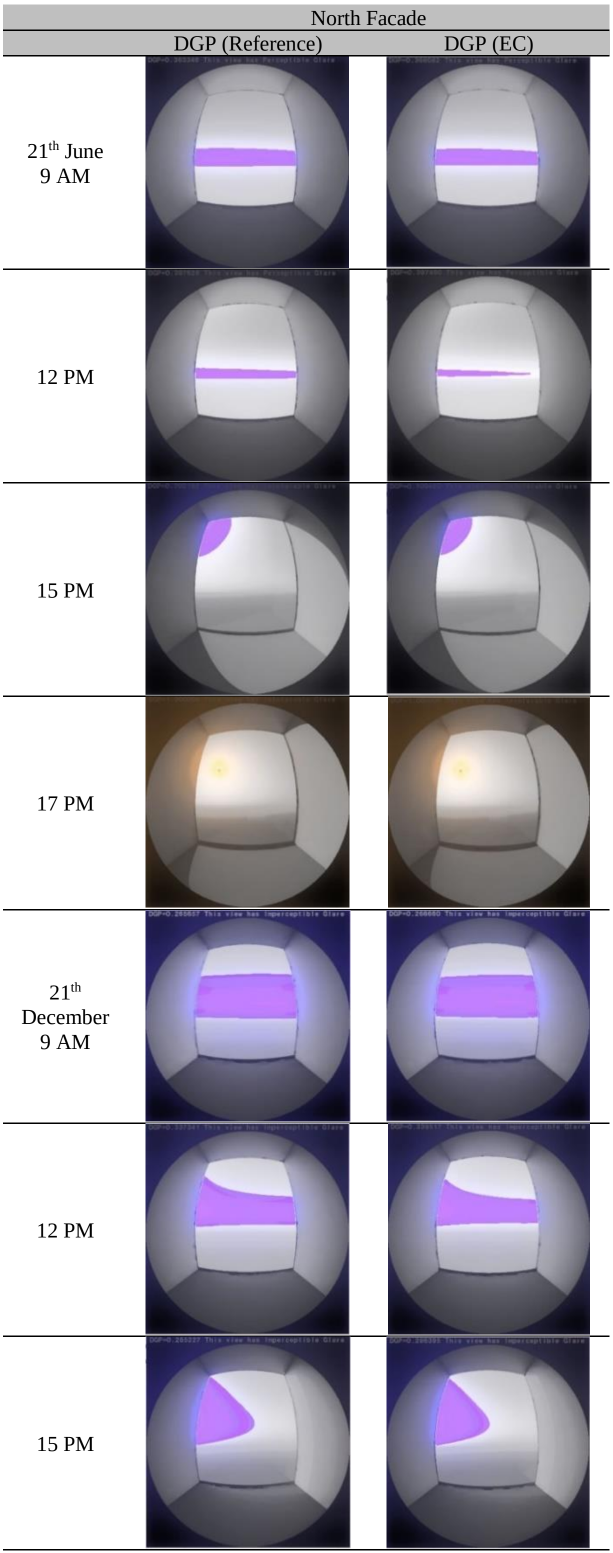

Figure 8. DGP images resulting from the simulation for north facade

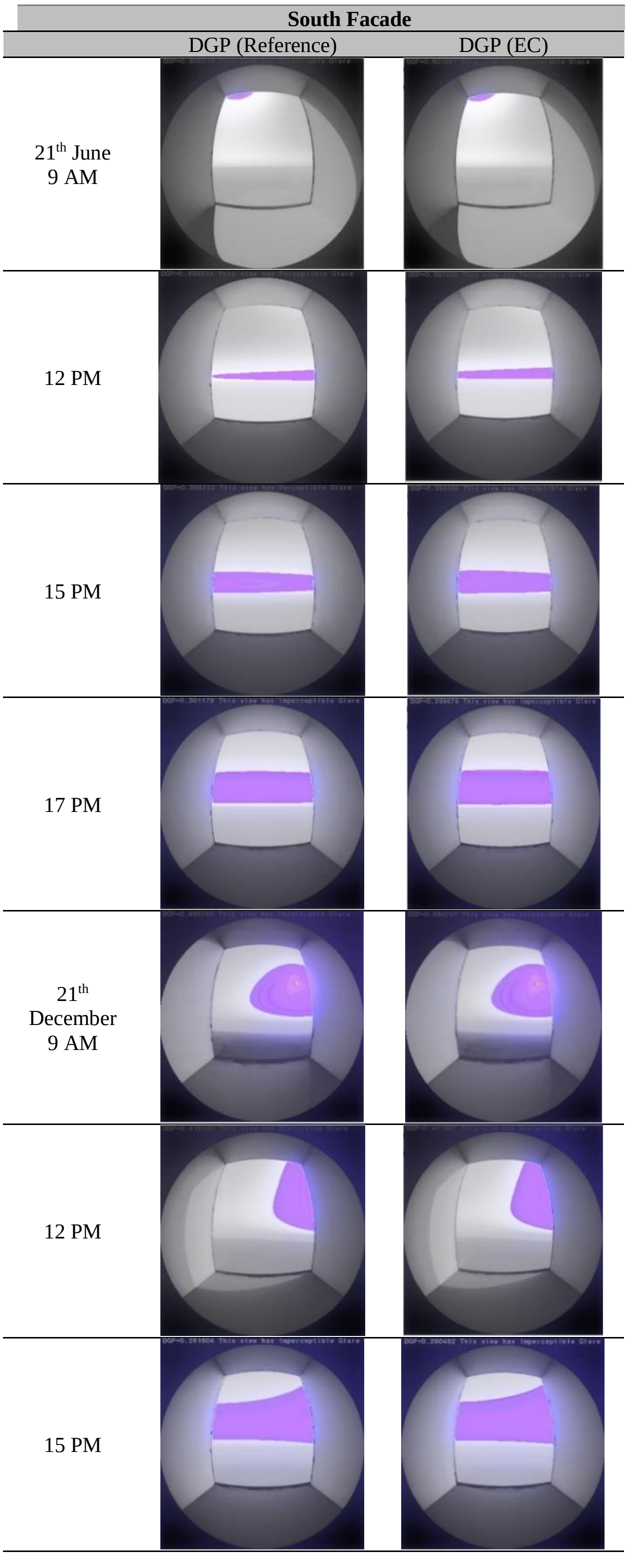

Figure 9. DGP images resulting from the simulation for South facade

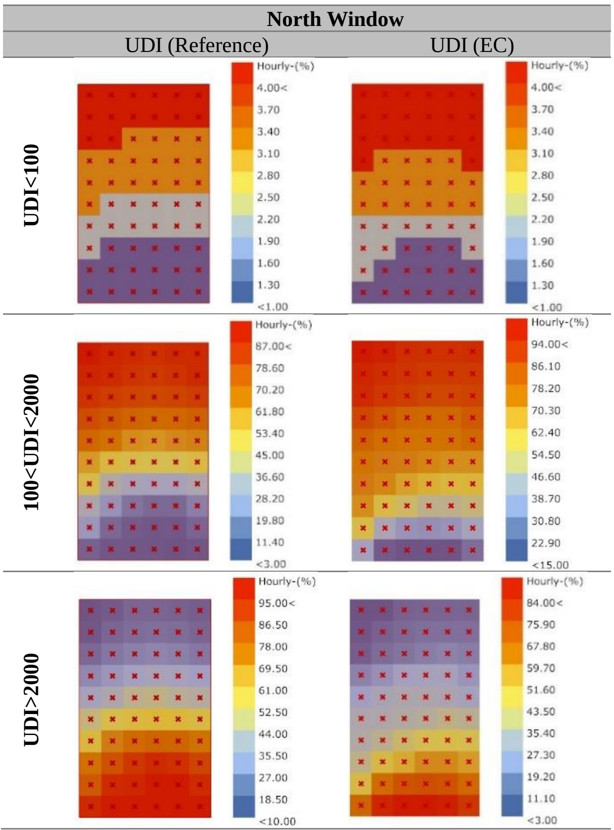

Figure 10. Display the UDI index of the north window

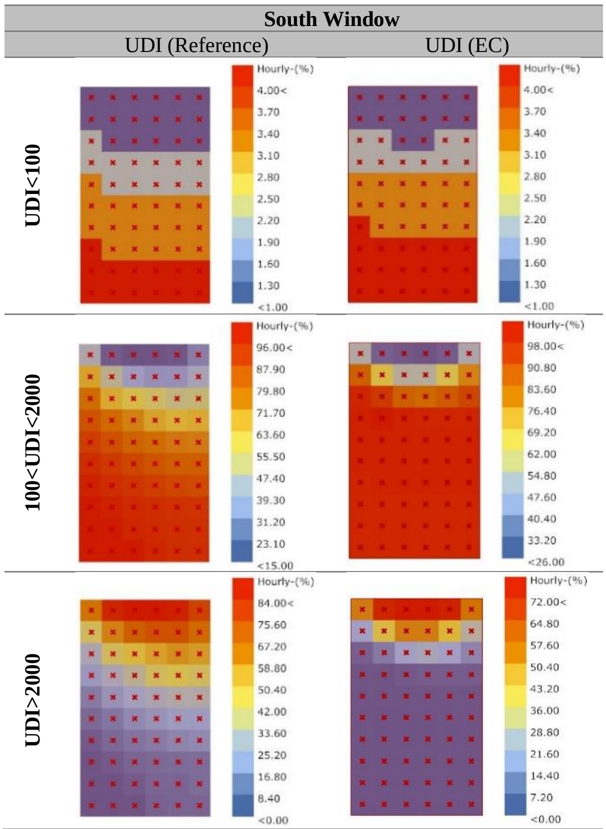

Figure 11. Display the UDI index of the south window

CONCLUSION

In the pursuit of fostering occupant comfort and optimizing visual well-being, a profound understanding of architectural elements, particularly the role of windows, emerges as paramount. Windows serve as a critical link between architectural aesthetics and energy efficiency, wielding a direct influence over Energy Use Intensity (EUI) and the overall comfort of building occupants.

This study was conducted with the main objective of evaluating and comprehensively comparing the effectiveness of active windows compared to conventional windows, with a focus on reducing the energy consumption of the building and controlling light radiation and the intensity of useful daylight. To achieve this goal, we carried out a detailed analysis of the established indicators, namely total energy (TE) and DGP (probability of nuisance lighting) and UDI (useful daylighting), in two scenarios: the base model with standard glass and the model Equipped with active glass. Our assessment included both the north and south facades of an office building located in Mashhad.

Using sophisticated computational tools such as Grasshopper software and the Honey Bee plugin, energy simulations were calculated using the climate file (EPW) for the entire year and run to simulate illumination on 21, at four specific times of the day (9 AM, 12 PM, 3 PM, and 5 PM), all in clear sky conditions.

In practice, using electrochromic glazing on both north and south facades of a building reduces the annual heating and cooling energy demand by 6.5 and 4.5%, respectively. Additionally, our findings resoundingly confirm that opting for active windows over conventional ones represents an optimal strategy for achieving well-balanced lighting levels throughout the day. Active glass installations on the north and south facades of the building exhibited remarkable efficacy in reducing both glare and excessive radiation, with reductions of 40 and 34.52%, respectively. Furthermore, active windows excelled in moderating and controlling high-intensity daylight (above 2000 lux) compared to the baseline model. This reduction in light intensity near the windows, without causing significant deviations in light levels in more distant areas, contributed substantially to mitigating glare resulting from excessive radiation.

In conclusion, our research emphasizes the potential benefits of using active windows in building design, especially in enhancing visual comfort and controlling glare in office buildings in semi-arid and cold climates.

To ensure broader applicability, we recommend extending these simulations across an entire year, encompassing diverse sky conditions and different usage contexts, such as educational spaces. Furthermore, the real-world validation of these findings remains a promising avenue for future research, bridging the gap between simulation and practical application in built environments.

CONFLICT OF INTEREST

Authors have no relevant financial or nonfinancial interests to disclose.

REFERENCES

1. Ebrahimi-Moghadam A, Ildarabadi P, Aliakbari K, Arabkoohsar A, Fadaee F. Performance analysis of light shelves in providing visual and thermal comfort and energy savings in residential buildings. Journal of the Brazilian Society of Mechanical Sciences and Engineering. 2020;42(9):484. Doi: 10.1007/s40430-020-02565-2.
2. Gupta SK, Chanda PR, Biswas A. A 2E, energy and environment performance of an optimized vernacular house for passive cooling - Case of North-East India. Building and Environment. 2023;229:109909. Doi: 10.1016/j.buildenv.2022.109909.
3. Kamyab A, Mahmoudi Zarandi M, Nikpour M. Effect of Window Area and Proportions of Iwan on Daylight in Adjacent Room: An Investigation in Yazd City. Iranica Journal of Energy and Environment. 2024;15(1):67–79. Doi: 10.5829/ijee.2024.15.01.07.
4. Zhao A, Zhou M, Yu J, Zhang J, Yang X. Control and Optimization of Indoor Environmental Quality Based on Model Prediction in Building. In: Advances in Intelligent Systems and Computing. Springer Verlag; 2019. p. 45–57. Doi: 10.1007/978-981-13-6733-5_5.
5. Wortmann T, Costa A, Nannicini G, Schroepfer T. Advantages of surrogate models for architectural design optimization. Artificial Intelligence for Engineering Design, Analysis and Manufacturing. 2015;29(4):471–81. Doi: 10.1017/s0890060415000451.
6. Godithi SB, Sachdeva E, Garg V, Brown R, Kohler C, Rawal R. A review of advances for thermal and visual comfort controls in personal environmental control (PEC) systems. Intelligent Buildings International. 2019;11(2):75–104. Doi: 10.1080/17508975.2018.1543179.
7. Dos Santos LFBS. Efficient modeling strategies for performance-based building design supported by daylight and building energy simulations. University of California, Berkeley; 2020.
8. Chen X, Huang J, Yang H, Peng J. Approaching low-energy high-rise building by integrating passive architectural design with photovoltaic application. Journal of Cleaner Production. 2019;220:313–30. Doi: 10.1016/j.jclepro.2019.02.137.
9. Kolokotsa D, Santamouris M. Review of the indoor environmental quality and energy consumption studies for low income households in Europe. Science of The Total Environment. 2015;536:316–30. Doi: 10.1016/j.scitotenv.2015.07.073.
10. Tayari M, Burman E. Electrical Energy Auditing by Analyzing End-Use Energy Consumption: A Case Study of an Office Building in Tehran. Iranica Journal of Energy and Environment. 2018;9(3):153–62. Doi: 10.5829/ijee.2018.09.03.01.
11. Yong SG, Kim JH, Gim Y, Kim J, Cho J, Hong H, Baik YJ, Koo J. Impacts of building envelope design factors upon energy loads and their optimization in US standard climate zones using experimental design. Energy and Buildings. 2017;141:1–15. Doi: 10.1016/j.enbuild.2017.02.032.
12. Fathi S, Kavoosi A. Optimal Window to Wall Ratio Ranges of Photovoltachromic Windows in High-Rise Office Buildings of Iran. Journal of Daylighting. 2021;8(1):134–48. Doi: 10.15627/jd.2021.10.
13. Singh R, Lazarus IJ, Kishore VVN. Uncertainty and sensitivity analyses of energy and visual performances of office building with external venetian blind shading in hot-dry climate. Applied Energy. 2016;184:155–70. Doi: 10.1016/j.apenergy.2016.10.007.
14. Chi F, Wang R, Li G, Xu L, Wang Y, Peng C. Integration of sun-tracking shading panels into window system towards maximum energy saving and non-glare daylighting. Applied Energy. 2020;260:114304. Doi: 10.1016/j.apenergy.2019.114304.
15. Ishac M, Nadim W. Standardization of optimization methodology of daylighting and shading strategy: a case study of an architectural design studio – the German University in Cairo, Egypt. Journal of Building Performance Simulation. 2021;14(1):52–77. Doi: 10.1080/19401493.2020.1846618.
16. Ajaji Y, André P. Thermal Comfort and Visual Comfort in an Office Building Equipped with Smart Electrochromic Glazing: An Experimental Study. Energy Procedia. 2015;78:2464–9. Doi: 10.1016/j.egypro.2015.11.230.
17. Jain S, Karmann C, Wienold J. Behind electrochromic glazing: Assessing user's perception of glare from the sun in a controlled environment. Energy and Buildings. 2022;256:111738. Doi: 10.1016/j.enbuild.2021.111738.
18. Konis K, Selkowitz S. The Challenge of Effective Daylighting. In 2017. p. 1–31. Doi: 10.1007/978-3-319-39463-3_1.
19. Chambers J, Hollmuller P, Bouvard O, Schueler A, Scartezzini JL, Azar E, Patel MK. Evaluating the electricity saving potential of electrochromic glazing for cooling and lighting at the scale of the Swiss non-residential national building stock using a Monte Carlo model. Energy. 2019;185:136–47. Doi: 10.1016/j.energy.2019.07.037.
20. Karlsson J, Roos A. Angle-resolved optical characterisation of an electrochromic device. Solar Energy. 2000;68(6):493–7. Doi: 10.1016/s0038-092x(00)00021-9.
21. Lee E. Application issues for large-area electrochromic windows in commercial buildings. Solar Energy Materials and Solar Cells. 2002;71(4):465–91. Doi: 10.1016/s0927-0248(01)00101-5.
22. Ganji Kheybari A, Steiner T, Liu S, Hoffmann S. Controlling Switchable Electrochromic Glazing for Energy Savings, Visual Comfort and Thermal Comfort: A Model Predictive Control. CivilEng. 2021;2(4):1019–53. Doi: 10.3390/civileng2040055.
23. Zinzi M. Office worker preferences of electrochromic windows: a pilot study. Building and Environment. 2006;41(9):1262–73. Doi: 10.1016/j.buildenv.2005.05.010.
24. Lee ES, Tavil A. Energy and visual comfort performance of electrochromic windows with overhangs. Building and Environment. 2007;42(6):2439–49. Doi: 10.1016/j.buildenv.2006.04.016.
25. Clear RD, Inkarojrit V, Lee ES. Subject responses to electrochromic windows. Energy and Buildings. 2006;38(7):758–79. Doi: 10.1016/j.enbuild.2006.03.011.
26. Oh M, Jang M, Moon J, Roh S. Evaluation of Building Energy and Daylight Performance of Electrochromic Glazing for Optimal Control in Three Different Climate Zones. Sustainability. 2019;11(1):287. Doi: 10.3390/su11010287.
27. Pourahmadi M, Khanmohamadi M, Mozafar F %J J of ES, Technology. Investigation the Performance of Glare Indices in Iran's Hot and Dry Climate. Journal of Environmental Science and Technology. 2021;23(1):41–52.
28. Wienold J, Christoffersen J. Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras. Energy and Buildings. 2006;38(7):743–57. Doi: 10.1016/j.enbuild.2006.03.017.

29. Wienold J. Dynamic daylight glare evaluation. IBPSA 2009 - International Building Performance Simulation Association 2009. 2009. 944–951 p.

30. McNeil A, Burrell G. Applicability of DGP and DGI for evaluating glare in a brightly daylit space. In: ASHRAE and IBPSA-USA Building Simulation Conference. ASHRAE/IBPSA-USA; 2016. p. 57–64.

31. Wienold J, Jain S, Andersen M. Transmittance thresholds of electrochromic glazing to achieve annual low-glare work environments. Hviid CA, Khanie MS, Petersen S, editors. E3S Web of Conferences. 2022;362:08001. Doi: 10.1051/e3sconf/202236208001.

32. Jain S, Karmann C, Wienold J. Subjective assessment of visual comfort in a daylit workplace with an electrochromic glazed façade. In: Journal of Physics: Conference Series. IOP Publishing; 2021. p. 12179. Doi: 0.1088/1742-6596/2042/1/012179.

33. Najafi Q, Mahlabani YG, Goharian A, Mahdavinejad M. A Novel Design-based Optimization Method for Building by Sensitivity Analysis. Journal of Solar Energy Research. 2023;8(2):1446–58. Doi: 10.22059/jser.2023.352184.1269.

34. Sun Y, Shanks K, Baig H, Zhang W, Hao X, Li Y, He B, Wilson R, Liu H, Sundaram S, Zhang J, Xie L, Mallick T, Wu Y. Integrated semi-transparent cadmium telluride photovoltaic glazing into windows: Energy and daylight performance for different architecture designs. Applied Energy. 2018;231:972–84. Doi: 10.1016/j.apenergy.2018.09.133.

35. Sun Y, Liu D, Flor JF, Shank K, Baig H, Wilson R, Liu H, Sundaram S, Mallick TK, Wu Y. Analysis of the daylight performance of window integrated photovoltaics systems. Renewable Energy. 2020;145:153–63. Doi: 10.1016/j.renene.2019.05.061.

36. Liu X, Wu Y. Numerical evaluation of an optically switchable photovoltaic glazing system for passive daylighting control and energy-efficient building design. Building and Environment. 2022;219:109170. Doi: 10.1016/j.buildenv.2022.109170.

37. Ahmadi J, Maddahi SM, Mirzaei R. Optimization of Residential Spatial Configuration based on Energy Performance, Daylight Brightness, and Thermal Comfort through Pareto Evolutionary Algorithm, Case Study: Mashhad City Climate. Iranica Journal of Energy and Environment. 2023;14(3):228–39. Doi: 10.5829/ijee.2023.14.03.05.

38. www.mashhad.climatemps.com [Internet]. 2023.

39. Amirazar A, Azarbayjani M, Futrell B, Zarrabi AH, Ashrafi R. Visual Comfort Assessment of Different Shading Strategies in a Commercial Office Building in the Southeastern US. In: Healthy, Intelligent and Resilient Buildings and Urban Environments. Syracuse, New York: International Association of Building Physics (IABP); 2018. p. 727–32. Doi: 10.14305/ibpc.2018.hf-4.06.

Persian Abstract

چکیده

امروزه استفاده از پنجره‌های فعال (قابل تعویض) بخاطر نقش‌شان در مدیریت آسایش بصری، گرمای بیش از حد و همچنین نیازهای سرمایشی و گرمایشی و مصرف روشنایی به خصوص در ساختمان‌های اداری گسترش یافته است. پنجره‌های قابل تعویض علاوه بر کاهش مصرف انرژی، در کنترل خیرگی نیز نقش موثری دارند. تحقیق فوق با هدف بررسی تاثیر بکارگیری پنجره‌های تغییر لعاب (EC) در مقایسه با پنجره‌های معمولی، در دو جبهه جنوبی و شمالی، به منطور بهبود شرایط آسایش حرارتی و بصری در یک ساختمان اداری در شهر مشهد، انجام شده است. در گام اول شبیه‌سازی ساختمان به منظور ارزیابی عملکرد نور روز و آسایش حرارتی و بصری با استفاده از پلاگین گرس هاپر در نرم‌افزار راینو انجام شده است و سپس از پلاگین‌های Honeybee و Ladybug برای ارزیابی شاخص خیرگی و شاخص نور مفید روز استفاده شده است. نتایج نشان داد، ایده بکارگیری پنجره‌های فعال بجای پنجره‌های معمولی یکی از بهینه‌ترین گزینه‌ها برای دستیابی به سطوح روشنایی متعادل در روز است. در واقع شیشه‌های فعال در نمای شمالی و جنوبی ساختمان، در مقایسه با شیشه‌های معمولی، تقاضای انرژی گرمایشی و سرمایشی سالانه را به ترتیب ۶/۵ ٪ و ۴/۵ ٪ کاهش می‌دهد. علاوه براین، می‌توانند میزان تابش خیره‌کننده و غیرقابل تحمل را به ترتیب به میزان ۴۰ درصد و ۳۴/۵۲ درصد کاهش دهند.