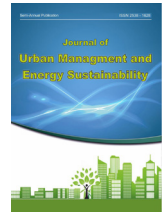


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ORIGINAL RESEARCH PAPER

Explaining the Relationship between Opening Structure and Daylight and Glare Indices in Tall Office Buildings of Tehran: A Case Study of Pars Tower

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ABSTRACT

Tall buildings define modern cities, and in office towers, managing daylight penetration and glare is a key design concern. Openings must admit enough daylight for energy efficiency and occupant comfort while preventing the uncontrolled light that causes disabling glare. Moreover, computer simulations cannot fully reproduce real building conditions. This study examines the relationship between opening structure and daylight and glare indices in tall office buildings in Tehran, using Pars Tower as a case study. It also identifies the index that best captures this relationship. This quantitative, applied, experimental study used in-situ measurement. In a selected office unit, five indices were evaluated from calibrated high-dynamic-range (HDR) images: DGP, UGR, DGI, CGI and VCP. The images were captured with a Canon 7D and a fisheye lens and merged in Bracket. They were calibrated in HDRscope against a grey card and a TES-137 luminance meter, then processed with Evalglare. A total of 680 evaluations were conducted over 30 clear-sky days at half-hourly intervals and analyzed using ANOVA. Opening structure was significantly related to all indices in the imperceptible category and to some indices in the perceptible category. It was not significantly related to them in the disturbing or intolerable categories, and glare never reached those levels in the building. DGP showed the lowest dispersion across all categories, making it the most reliable index. Opening structure significantly affects daylight and glare in tall office buildings. DGP is recommended as the most accurate index for explaining this relationship, as recent comparative studies of office spaces also confirm.

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INTRODUCTION

Tall buildings have become one of the salient features of modern urban landscapes. Since their emergence in the mid-twentieth century they have transformed not only city skylines but also the way urban space is used (Albatayneh *et al.*, 2021; Chatzikonstantinou & Sariyildiz, 2016). The growth of high-rise architecture is linked to rapid urbanization: as cities expand and populations grow, the demand for efficient use of space drives the vertical extension of urban areas. This is especially evident in Tehran, where high-rise buildings such as Pars Tower have become prominent features of the cityscape. Tall buildings are not merely tall structures but complex entities that influence and are influenced by architectural design, engineering requirements, urban planning, social dynamics, and environmental factors (Ali & Moon, 2007; Gifford, 2007). One important aspect of tall-building design is the management of natural-light penetration and the control of glare (Birat & Uprety, 2020). Adequate daylight in office buildings enhances energy efficiency and occupant comfort; however, uncontrolled daylight can cause glare, which adversely affects the productivity and well-being of building occupants (Albatayneh *et al.*, 2021; Fasi & Budaiwi, 2015). The challenge lies in designing building openings—windows and skylights that optimize these two conflicting requirements. The window-to-wall ratio (WWR) and the design of shading devices play a fundamental role in determining daylight quality and glare levels in office spaces (Lu *et al.*, 2019): too much glazing can cause excessive glare and increased cooling loads, while too little results in insufficient natural light and over-reliance on artificial lighting (Chaloeytoy *et al.*, 2020). Recent optimization studies confirm that the appropriate WWR is strongly climate- and orientation-dependent (Tawfeeq & Qaradaghi, 2024; Sayadi *et al.*, 2021), and that well-designed shading can improve visual comfort without sacrificing daylight (Xue *et al.*, 2022; Lim *et al.*, 2020). Despite the importance of this issue, many aspects of the relationship between

opening structure, daylight, and glare remain unclear. For example, the effect of shading devices on daylight and glare is not fully understood, and their optimization remains a significant research gap (Mangkuto *et al.*, 2022). A further aspect is the gap between the predictive capability of current simulation tools and the real performance of buildings; designers often rely on these tools at later design stages, yet there is a need to apply them from the earliest stages for more accurate performance prediction (Ankova, 2020). Current methods, such as computer simulations, have limitations in reflecting real building conditions, which leads to a gap between simulated predictions and actual performance; before addressing this, it is necessary to establish which index most accurately evaluates daylight and glare in relation to opening structure. Accordingly, the central problem of this study is to explain the relationship between opening structure and the daylight and glare indices in tall office buildings, and the research question is: which of the five indices provides the most reliable basis for characterizing this relationship? This study focuses on Pars Tower, a prominent high-rise in Tehran, to provide a real-world setting for studying these relationships; the tower's specific architectural and design characteristics, such as its window-to-wall proportions and façade systems, are crucial for understanding how such variables affect daylight and glare in high-rise office environments.

MATERIALS AND METHODS

In the contemporary architectural landscape, the design and performance of high-rise office buildings particularly regarding daylight and glare control are of great importance. The significance of daylight in office buildings is well established, as it affects not only energy efficiency but also occupant comfort and productivity (Ahmad & Refat, 2018). Studies by Sayadi *et al.* (2021) have emphasized the importance of façade systems and window-opening types in enhancing daylight while minimizing energy consumption. However, the integration of daylight with artificial

lighting remains a complex challenge that calls for innovative solutions for energy-efficient and comfortable interiors. The interplay between the window-to-wall ratio and daylight performance in tall office buildings has been the subject of considerable research. Lu et al. (2019) highlight the effect of this ratio on daylight performance and point to the critical balance required for optimal design. In parallel, studies by Grynning et al. (2013) and Mangkuto et al. (2022) examine the energy implications of window designs and emphasize the dual role of windows as energy gainers and losers. The evaluation of glare, a critical aspect of visual comfort in office spaces, has been addressed in studies such as Chaloeitoy et al. (2020), who propose simplified criteria for glare assessment. Similarly, Hou (2020) provides an overview of glare in high-rise office buildings, reflecting growing concern for occupants' visual comfort. Furthermore, the research of Chatzikonstantinou and Sariyildiz (2016) addresses machine-learning approaches for approximating visual-comfort indicators, suggesting a potential avenue for using advanced technologies in building design and analysis. The exploration of sustainable design practices in tall buildings, discussed by Raji et al. (2017), adds a further layer, emphasizing the need for energy-efficient and sustainable design strategies from the earliest stages. A recurring theme across this literature is the proliferation of competing glare indices and the difficulty of choosing among them. Comprehensive reviews of visual-comfort metrics (Carlucci et al., 2015) catalogue more than a dozen indices and stress that no single metric is universally accepted, while the daylight glare probability was introduced specifically to overcome the weak correlation of earlier indices with subjective response (Wienold & Christoffersen, 2006). Recent field and simulation work confirms this concern: Faraji et al. (2023) compared DGI, CGI, VCP, and DGP in office spaces with light shelves and found DGP the most reliable across glare levels, and Overen et al. (2023), assessing an institutional office building, reported an average

DGP of about 21% corresponding to imperceptible glare. These findings directly motivate the present study's comparison of five indices in a real high-rise office setting.

Case Study: Pars Tower, Tehran

Pars Tower also known as the Bime Markazi (Central Insurance) Tower is a landmark high-rise office building in Tehran, Iran. Completed in 2013, it rises to a height of 105 m over 20 storeys and is among the notable tall structures of the Tehran skyline (building data from public tall-building databases). Its predominantly glazed curtain-wall façade makes it a representative example of the contemporary tall office building in which the balance between daylight admission and glare control is governed largely by the structure of the openings. These characteristics make the tower a suitable real-world setting for examining how opening structure relates to daylight and glare indices in a working office environment. Within the tower, a representative office unit on a mid-rise floor was selected for measurement. The measurement geometry reproduced normal working conditions: the fisheye HDR camera was positioned at the seated occupant's eye level (about 120 cm), and images were captured in two view directions parallel and perpendicular to the window plane so that the luminous field actually experienced by an occupant facing and sitting beside the glazing could be characterized. Figure 1 summarizes the case-study context and the measurement configuration, and Table 1 lists the building and studied-unit specifications. (Fig. 1 and Tab. 1)\

Methodology

This study is quantitative, applied, and experimental, combining physical measurement with an experimental design. Its principal aim is to explain the relationship between the structure of openings in tall office buildings and the daylight and glare indices by means of in-situ measurement rather than simulation. After reviewing prior studies on the relationship between open-

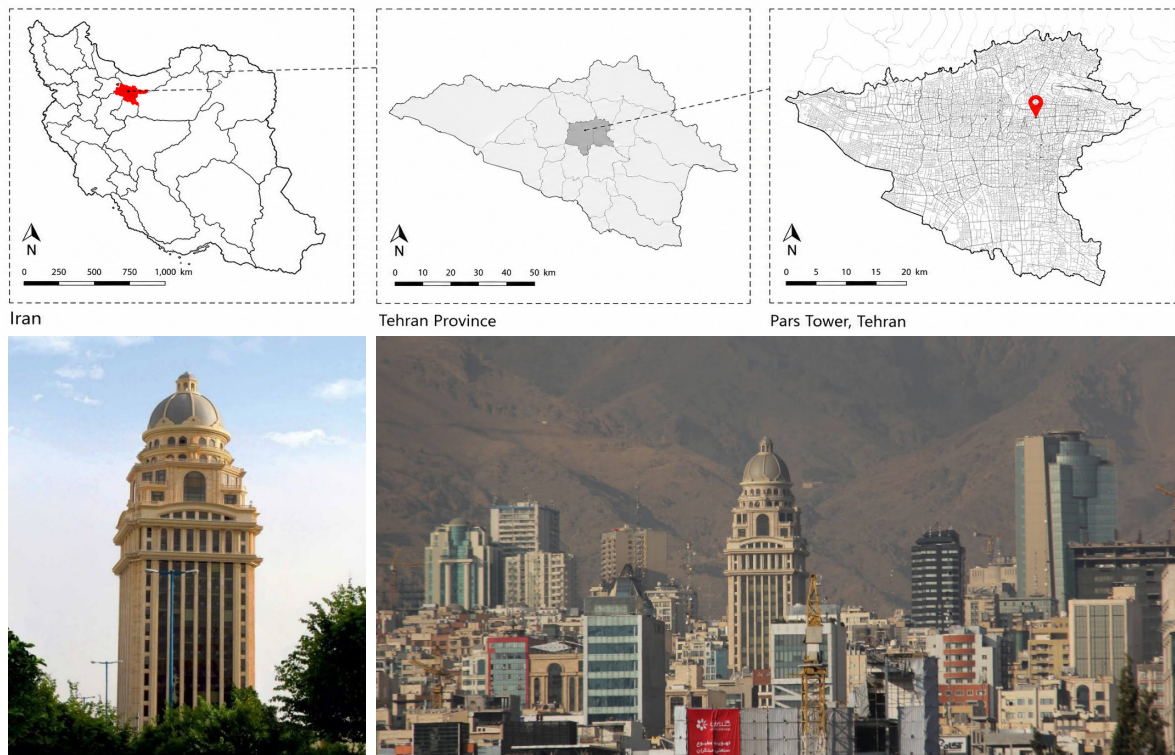


Figure 1: Pars Tower location in Tehran city, Iran and photos

Table 1: Building and studied-unit specification of the Pars Tower case study.

Attribute	Value
Building name	Pars Tower (Bime Markazi / Central Insurance Tower)
Location	Tehran, Iran
Height	105 m
Number of floors	20
Year completed	2013
Primary use	High-rise office building
Façade / opening type	Glazed curtain wall (studied opening structure)
Studied space	Office unit on a mid-rise floor
Camera / occupant eye level	120 cm (seated)
View directions measured	Parallel and perpendicular to the window
Window-to-wall ratio (WWR)	Not reported in the source [authors to confirm]

ing structure and daylight and glare indices, an experimental design was established and the indices were measured in the physical environment. The following procedures were used to answer the research questions: (i) to determine

the relationship between opening structure and daylight, measurements were taken at different times of day and at different positions so that the change in the angle and intensity of the sun could be captured; (ii) to determine the relationship

between opening structure and glare potential, glare sensors and a light meter were used, and the collected data were used to compute the proportion of blinds or shading required to reduce glare to an acceptable level; and (iii) to determine the best index for capturing the effect of opening structure on the daylight-glare balance, the measurement results were analysed and compared.

Selection of the appropriate index

In this study the most appropriate index for evaluating daylight and glare was selected from among five indices: Daylight Glare Probability (DGP), CIE Glare Index (CGI), Daylight Glare Index (DGI), Visual Comfort Probability (VCP), and Unified Glare Rating (UGR). The evaluation was carried out through calibrated images, and the most suitable index was then determined. The subjective daylight- and glare-sensation thresholds used to interpret each index are given in (Tab. 3).

Instrumentation

HDR images and their properties were generated with Bracket, and glare was evaluated with HDRgen and the Evalglare add-on. The imaging equipment comprised a Canon 7D digital camera with an equidistant fisheye lens. The measurement equipment comprised a TES-137 colour luminance meter, an HS-101 lux meter, a desk and chair, and a neutral grey card. Figure 2 summarizes the instrumentation and the four-step HDR imaging workflow. (Fig. 2)

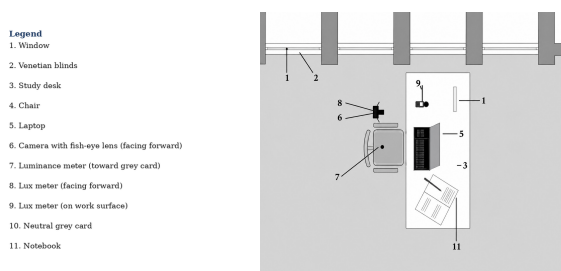


Figure 2: Plan of the studied office unit showing the arrangement of the measurement equipment (recreated in English from the original figure).

Surface-reflectance measurement

The reflectance of all room surfaces is reported in Table 2. To determine these reflectances, the lux meter was used in two stages. In the first stage the surface was free of obstruction or relative shadow, the photocell was placed on the surface, and the illuminance was measured. In the second stage the photocell was set facing the surface at a distance of 15 cm, so that no penumbra or shadow of the device or of the researcher's hand fell on the surface, and the reflected illuminance was measured. The reflectance of the surface was then computed as the ratio of the second reading to the first. (Tab. 2)

Imaging protocol and calibration

Measurements were carried out over a 30-day period (20 Mehr to 20 Aban) on clear, cloudless days. Evaluations were performed at half-hourly intervals from 08:00 to 16:00, giving a total of 680 evaluations; electronic devices were kept switched on throughout so that working conditions were normal. The HDR images used to measure luminance in the visual field and to compute DGP were obtained in four steps: selecting the JPEG images; merging the LDR images into HDR images with Bracket; correcting the effect of light and shade in the fisheye view with the pcomb command in Radiance; and calibrating the images against a grey target using the TES-137 luminance meter. The camera was placed adjacent to and at the eye level of a seated occupant (about 120 cm). ISO was fixed at 100 and the aperture set to F11, using a range of shutter speeds (1/4000, 1/2000, 1/1250, 1/1000, 1/500, 1/400, 1/250, 1/100, and 1/25 s); this is the common procedure for capturing HDR images. Research shows that no exact rule specifies which shutter speed is preferable, and the only general guideline is to use a wide range of exposure values (Hirning et al., 2016). Because HDR images cover a wider luminance range, the accuracy and quality of their pixel information are greater. With nine shutter-speed values, nine LDR images were combined to produce

one HDR image; the interval between successive LDR images was about 1–2 s, so roughly 20 s were needed to capture one set of HDR images representing a given scene. Figure 3 shows an

example of an HDR image and its false-colour luminance map in the two view directions parallel and perpendicular to the window based on the opening structure.

Table 2: Reflectance of the room surfaces of the studied office unit.

Surface	Reflectance
Ceiling	81.9%
Floor	14.2%
Wall	81.9%
Desks	43.4%
Curtains (when closed)	76.3%

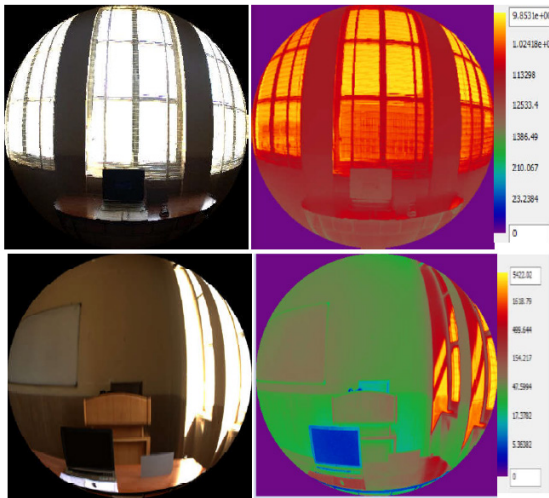


Figure 3: HDR images (left) and their false-colour luminance maps (right, cd/m^2) for the two view directions parallel to the window (top row) and perpendicular to the window (bottom row).

To calibrate the HDR images, HDRscope and Evalglare were used. Calibration was performed with a neutral grey card placed on one of the desks in the selected room: the luminance of

the card was measured with the luminance meter, and in HDRscope the luminance of the grey card in the recorded image was matched to it so that every point in the recorded images acquired a luminance consistent with reality. The luminance-meter sensors recorded the luminance of the grey card, while the illuminance-meter sensors recorded the vertical illuminance reaching the eye. After processing the images with HDRscope, the values of the VCP, CGI, UGR, DGI, and DGP indices for the opening structure were obtained, as reported in the results.

FINDINGS AND DISCUSSION

The five indices for evaluating daylight and glare show considerable inconsistency in the measured degree of glare sensation. To test the relationship between opening structure and the indices, analysis of variance (ANOVA) was applied at a significance level of 5% (0.05). Table 3 presents the subjective sensation thresholds, and Table 4 reports the index means, standard deviations, and significance values by sensation category together with the overall test statistics. (Tab. 3 and 4)

Table 3: Subjective daylight- and glare-sensation thresholds for the five indices.

Sensation	DGP	UGR	D GI	CGI	VCP
Intolerable	> 0.45	> 28	> 31	> 28	< 40
Disturbing	0.40–0.45	22–28	24–31	22–28	40–60
Perceptible	0.35–0.40	13–22	18–24	13–22	60–80
Imperceptible	< 0.35	< 13	< 18	< 13	> 80

Table 4: Index values (mean, standard deviation, significance) and ANOVA results by sensation category.

Category	Statistic	DGP	UGR	DGI	CGI	VCP
Imperceptible	Mean	0.23	13.39	14.96	8.62	79.82
	S.D.	0.109	0.511	1.078	0.098	0.154
	Sig.	0.023	0.042	0.003	0.021	0.000
Perceptible	Mean	0.21	14.52	19.52	20.61	39.14
	S.D.	0.214	0.099	0.327	1.216	0.366
	Sig.	0.039	0.154	0.216	0.059	0.011
Disturbing	Mean	0.27	21.0	21.36	24.98	31.27
	S.D.	1.028	0.432	1.125	0.264	0.339
	Sig.	0.136	0.087	0.055	0.164	0.127
Intolerable	Mean	0.36	28.0	28.12	26.39	24.56
	S.D.	0.154	1.228	0.137	0.225	0.367
	Sig.	0.118	0.083	0.062	0.149	0.216
Overall	p-value	0.001	0.042	0.000	0.028	0.003
	t-statistic	10.29	7.54	4.33	9.87	2.27

The results indicate that, for the imperceptible category, a significant relationship exists between opening structure and daylight and glare across all five indices, and that some indices (DGP and VCP) also remain significant in the perceptible category; in the disturbing and intolerable categories the relationship is not significant. Overall, therefore, a significant relationship exists between opening structure and daylight and glare in the studied building, and in this building daylight and glare never reached the disturbing or intolerable level. The overall p-values for all indices are below 0.05, and the overall t-statistics exceed the absolute value of 1.96, providing further evidence of significance. Figure 4 maps the significance pattern across indices and categories. (Fig. 4)

The results further show that, in the imperceptible category, after DGP (dispersion 0.23) the lowest dispersion belonged to CGI, while the highest belonged to VCP (79.82); in the perceptible category DGP again had the lowest value (0.21) and VCP the highest (39.14). As Figure 4 makes clear, DGP is the only index that remains significant in both lower-glare categories (imperceptible and perceptible), the range

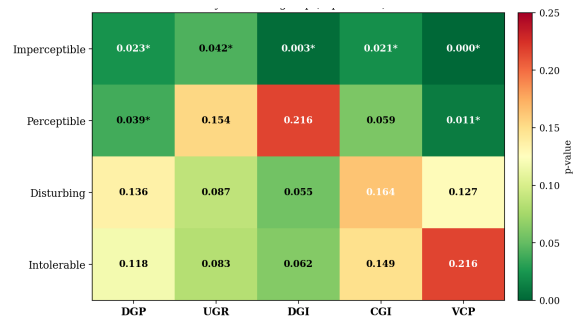


Figure 4: Significance (p) of the opening-structure, index relationship by sensation category (* $p < 0.05$).

over which the studied building actually operates. Across all four categories DGP showed the lowest variance and is therefore the most reliable index for processing and evaluation. Consequently, the DGP index is preferable for explaining the relationship between opening structure and daylight and glare in tall office buildings. This conclusion is consistent with the metric-comparison study of Faraji et al. (2023), who likewise found DGP to yield the most reliable results across glare levels, and with Overen et al. (2023), whose office-building assessment reported an imperceptible average DGP of about 21%; it also reflects the

design rationale of DGP as a vertical-illuminance-based measure with a stronger correspondence to subjective response than the older indices (Wienold & Christoffersen, 2006; Carlucci et al., 2015).

RESULTS AND CONCLUSION

This study explained the relationship between opening structure and daylight and glare indices in tall office buildings of Tehran, taking Pars Tower as the case study. As the investigation showed, one of the important aspects of tall-building design is the management of natural-light penetration and the control of glare: adequate daylight enhances energy efficiency and occupant comfort, but uncontrolled daylight can cause glare that adversely affects productivity and well-being. The challenge lies in designing openings windows and skylights that optimize these two conflicting requirements. As Ankova (2020) notes, current methods such as computer simulation have limitations in reflecting real building conditions, which leads to a gap between simulated predictions and actual performance; hence the need first to establish which index most accurately evaluates daylight and glare in relation to opening structure. On this basis, the five indices VCP, CGI, UGR, DGI, and DGP were evaluated in the studied office unit of Pars Tower. The results showed a significant relationship between opening structure and daylight and glare for the imperceptible category, and for some indices in the perceptible category, whereas the relationship was not significant in the disturbing and intolerable categories; in the studied building daylight and glare never reached disturbing or intolerable levels. In the imperceptible category, after DGP the lowest dispersion belonged to CGI and the highest to VCP (79.82); in the perceptible category DGP again had the lowest value (0.21) and VCP the highest (39.14). Across all four categories DGP showed the lowest variance and proved the most reliable index; it is therefore recommended for explaining the relationship between opening structure

and daylight and glare in tall office buildings, so that more accurate results are obtained. For the Pars Tower case, the practical implication is that its glazed curtain-wall openings maintained visual comfort within the imperceptible-to-perceptible range, and that DGP-based assessment supported by in-situ HDR measurement rather than simulation alone offers the most dependable route to verifying and fine-tuning opening design in comparable tall office buildings. Future work should extend the measurement to several orientations and floors of the tower and report the window-to-wall ratio explicitly, so that the influence of opening geometry can be quantified across the full height of the building.

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