# DESIGN RECOMMENDATIONS FOR PERIMETER OFFICE SPACES BASED ON VISUAL PERFORMANCE CRITERIA

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**ABSTRACT**

Optimal positioning of workstations in perimeter offices is a key factor affecting visual comfort and satisfaction, depending on façade design and control. Visual comfort is related to different factors, such as daylight glare and light adequacy. In addition, connection to the outdoors, delivered through window views, is related to the amount of view as well as view clarity. This study presents a new approach to evaluate office workplaces in terms of overall visual environment. Visual comfort, daylight provision and outside view are used as the three basic criteria. A new index, the Effective Outside View (*EOV*), is introduced to characterize the connection to the outdoors considering the amount and clarity of outside view. In addition, the Visual Comfort Autonomy (*VCA*) is defined as the portion of time when visual comfort criteria, based on vertical illuminance on the eye, are satisfied. The spatial variation of these indices and continuous daylight autonomy are used to evaluate perimeter offices with glass facades and window shades. Detailed simulations, based on a validated daylighting-glare model, are used to evaluate visual conditions for different occupant positions and main view directions. A case study is presented for an open plan office with different façade orientations. Selected glazing and shading properties are used as an example to present results on appropriate seating configurations in order to reduce the risk of glare and maximize daylight use, while maintaining effective outside view. This study, along with future occupant surveys, will help define clear regulations and guidelines for comfortable daylit indoor environments.

*Keywords: daylight, glare, window views, visual performance*

**INTRODUCTION**

Open plan offices are a developing trend in commercial buildings. Not only they result to unified operations, encouraging team work and better cooperation, but they also lead to more efficient space utilization, a critical element in urban commercial districts. However, they are also associated with design challenges: since personalized comfort in larger spaces is quite challenging, visual and thermal comfort issues arise and generalized comfort regulations are helpful. In terms of visual comfort, the situation becomes more complex, as it is position-dependent, and in several cases, securing comfortable conditions for one group of occupants leads to unacceptable ones for another. There is a fair amount of literature covering the topic of open plan offices with respect to visual comfort and glare. Jakubiec and Reinhart [1] performed a survey in student facilities of Harvard to conclude that discomfort can be assessed in three different forms: glare, reflections and poor contrast. Hirning et al. [2] investigated open plan offices to obtain correlations with existing glare indices, while Konis [3] investigated the occupants' preferences in side-lit open plan offices. The viewing direction of occupants plays a significant role: rotated views can reduce or eliminate discomfort glare [4], while wall-facing directions lead to less uncomfortable conditions over the year [5]. Another visual aspect however, the connection to the outdoors, in terms of amount and clarity of view is not adequately studied, especially for open plan offices. Konis [3] found that occupants in perimeter zones left a portion of the window unshaded for most of the time to maintain adequate outdoor view, despite the occurrence of visual discomfort. Other studies [6-7] pointed the qualitative relationship between sensation of glare and outside view, while Hellinga and Hester [8] presented a computational method to assess view and view quality.

This study proposes a methodology for comparing different spaces configurations with respect to visual comfort, lighting energy use and connection to the outdoors, all of which constitute a total Visual Performance Index. Towards that objective, two new terms, the annual visual comfort autonomy (*VCA*) and the effective outside view (*EOV*) are introduced.

## METHOD

### A set of metrics for assessing visual comfort, lighting energy savings potential and connection to the outdoors

As design decisions require annual performance data, an annual index is introduced, the Visual Comfort autonomy (*VCA*), defined as the portion of working hours when a person in a specific position is under comfortable conditions. While currently visual comfort is well predicted using the Daylight Glare Probability or DGP [9], Konstantzos et al. [10] stated that DGP may overestimate discomfort for occurrences with the sun directly visible through a shading fabric, especially for fabrics of low openness. That is due to the dramatic increase of the contrast term due to the extreme magnitude of the solar corona's luminance. While this high value is accurate by definition, DGP was not developed under such conditions and moreover, the way the human eye receives light through dense fabrics is not adequately studied. These facts, combined with common experience that fabrics of small (< 2%) openness do not result in significant discomfort, suggest that other criteria could be used to assess discomfort for these cases. Within that scope, Chan et al. [11] suggested a double discomfort criterion including (i) the 0.35 limit for DGPs [12] to account for total vertical illuminance on the eye and (ii) a 1000 lux limit for direct light on the eye, as a modification of IES Standard LM-83-12 [13]. As this study is focused on closed shades, these discomfort criteria are preferred. Therefore, the Visual Comfort Autonomy (*VCA*) is defined as the percentage of annual working hours when the restrictions of the above double criteria are met.

Foe daylight provision and lighting energy use reduction, the annual index of continuous Daylight Autonomy [14] is used. This metric is more suitable for obtaining light energy use for offices with light dimming control systems. A threshold of 300 lux on the work plane is used, complying with IES recommendations [13].

For the connection to the outdoors, a combined quantification of the amount and the clarity of view is proposed. As the quality of view is a highly subjective variable, dependent on the exterior scenery, the clarity of outside view is used instead, as a more objective and measurable concept. For that purpose, the View Clarity Index (*VCI*) is utilized, a metric recently developed [15] to characterize view clarity through windows with shading fabrics (Eq. 1), which depends on the basic optical properties of fabrics.

$$VCI = 1.43 \cdot (OF)^{0.48} + 0.64 \cdot \left(\frac{OF}{T_v}\right)^{1.1} - 0.22 \tag{1}$$

where $OF$ is the openness factor and $T_v$ is the normal total visible transmittance of the fabric as provided by manufacturers.

The amount of view is evaluated with the projected solid angle of the visible part of the window (for each position and view direction), normalized with the overall solid angle of the human visual field, $\Omega_{FOV}$ (circular cone with a half-angle of 78°), in order to provide a sense of measure against an "ideal" visual field, entirely connected to the exterior. In this process, the window is discretized into rectangular fragments to approximate the total solid angle of the window as the sum of the respective solid angles of the fragments. This makes calculations straightforward and faster, compared to applying transformations and integrations otherwise required due to the spherical definition of solid angle [16]. The model checks whether each fragment is within the field of view for each viewing direction, and excludes the rest of the window from the view calculations. *VCI* is then merged with the projected solid angle of the visible part of the window in a new metric, the Effective Outside View (*EOV*), considering both the amount and the clarity of outdoor view for any seating position, view direction and shading fabric (Eq. 2).

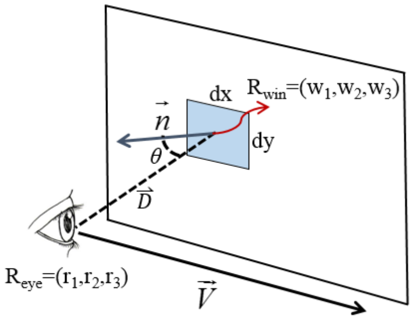


*Figure 1: Geometry for calculation of differential solid angles and projected solid angle of each window segment in the direction of the observer.*

$$EOV = \frac{\sum \Omega^{proj}_{i\in(FOV)} \cdot VCI}{\Omega_{FOV}} = \sum_{i\in(FOV)} \frac{\frac{A_i \cdot cos\vartheta_i \cdot VCI}{\left|\vec{D_i}\right|^2}}{2\pi \cdot (1 - cos78^0)} \qquad (2)$$

where $A_i$ is the area of each visible window fragment *i*, $\theta_i$ is the angle between the normal to the window and the line connecting the eye and the fragment, and $D_i$ is the distance between the eye and the fragment as shown in Fig. 1. The spatial variation of the three metrics (*VCA*, *cDA* and *EOV*) is used to calculate respective annual Visual Performance Indices as described next.

**Simulation Methodology and overall Visual Performance Indices**

A validated hybrid ray tracing and radiosity model [17] was used for the daylighting simulation. The model uses: TMY3 or measured weather data and anisotropic sky models to calculate the incident illuminances on the façade; data from WINDOW software [18] to calculate the angular properties of the glazing system; and implements the semi-empirical model by Kotey et al. [19] for calculating the angular optical properties of roller shades. Then, a ray-tracing module computes direct illuminance on interior surfaces, while a radiosity module handles diffuse inter-reflections. The model outputs include a detailed luminance and illuminance mapping for all interior surfaces and for a specified grid of occupant seating locations (*n* total), as well as DGP values when desired. The direct and total vertical illuminance are calculated over the year for each of the *n* occupant positions. The continuous Daylight Autonomy (*cDA*) in this study considers a set point of 300 lux on the work plane (0.8 m from the floor) and is calculated from virtual sensors on the same grid.

The spatial variation of the three metrics (*VCA*, *cDA* and *EOV*) is finally used to calculate respective annual Visual Performance Indices for comfort, energy use and outdoor view (*VPIc*, *VPIe* and *VPIv*) as follows. Visual comfort is the main priority, therefore *VPIc* (Eq. 4) is first defined as the portion of comfort-autonomous area (number of seating locations satisfying the VCA criteria for 95% of the working hours). For that area only, *VPIe* and *VPIv* are calculated from *cDA* and *EOV* respectively, averaged over the remaining seating location grid, to obtain average VPI “scores” for each directional seating layout (Eqs. 5-6).

$$VPI_c = \frac{\sum_{i=1}^{n} i}{n}\bigg| i \in (VCA > 95\%) \quad (4)$$

$$VPI_e = \frac{\sum_{i=1}^{n} cDA_i}{n}\bigg| i \cap [n \in (VCA > 95\%)] \quad (5)$$

$$VPI_v = \frac{\sum_{i=1}^{n} EOV_i}{n}\bigg| i \cap [n \in (VCA > 95\%)] \quad (6)$$

For each directional layout, the output is a triplet of *VPI* factors, which can be compared with results for alternate layouts on a relative basis, for an overall visual environment evaluation of any space with a given geometry, orientation, glazing and shading properties. The process is described in Fig. 2.

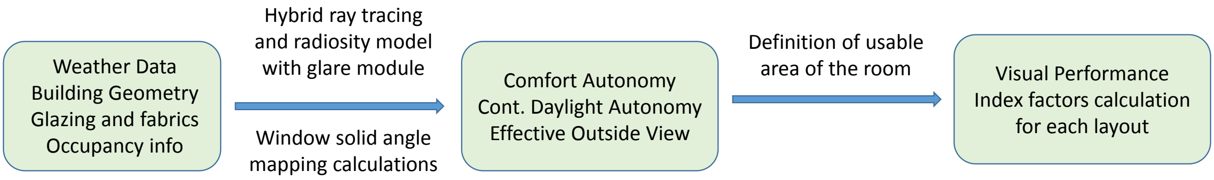


*Figure 2: Flowchart of simulation methodology and VPI factors*

## RESULTS

For this case study, a 10 m x10 m x 4 m high open-plan office space is considered, with a 70% of the façade covered by double clear windows. A dark-colored shade is used with high *OF*=11.2% and $T_v$=12%, which has a high *VCI* (87%) and provides good connection to the outside even with closed shades. The simulation was performed for West Lafayette, Indiana, for different façade orientations and for two directional workstation layouts (facing the left side wall and facing the windows).

The results are presented in Figures 3-4. Orientation plays a significant role: for south-facing façades (Fig. 3), due to more sunlight exposure and low winter sun, a significant portion of the space (37%) does not satisfy the visual comfort autonomy criteria (VCA>95%) for window-facing positions. For the rest of the (acceptable) space, VPIe = 39% and VPIv = 8.2%, as all positions near the window (which contribute to higher effective view) are outside the “comfort-autonomous” zone. However, for left side wall-facing positions, the entire space is within acceptable comfort limits (VPIc=100%), therefore VPIe increases to 54% and VPIv slightly decreases to 7.3% due to not facing the window. For north-facing facades (Fig. 4), where the sun is not visible and the brightness conditions are lower, the entire space is “comfort-autonomous” for both viewing directions and therefore cDA is the same. However, the average EOV is by 12.7% higher for window-facing layouts, which makes this configuration better. The results for all other orientations can be seen in Table 1.

## CONCLUSION

This paper presents a new methodology for evaluating the overall visual performance in offices based on visual comfort, lighting energy use and outdoor view criteria. The method can be used either during the design phase, to compare different envelope configurations, or for existing buildings, to make decisions about the directional layout of workstations. In this case study, wall facing layouts are the best option for south, east or west-facing facades, as they lead to higher space usability, lower lighting energy use and higher connection to the outdoors. This study part of ongoing research, aiming to provide more conclusive regulations for perimeter offices in terms of comfort, energy and connection to the outdoors. The presence of furniture and interior partitions was ignored; in reality, these surfaces will block a portion of daylight and will alter illuminance distributions and window views. Also, the issue of sunlight (through closed shades) incident on computer screens was not considered; but the exact direction of the screen is up to the occupants. In any case, fabrics with limited openness and visible transmittance should be used to better protect from glare. Finally, there is a dependence of view clarity on viewing distance [15] that should be addressed in future studies.

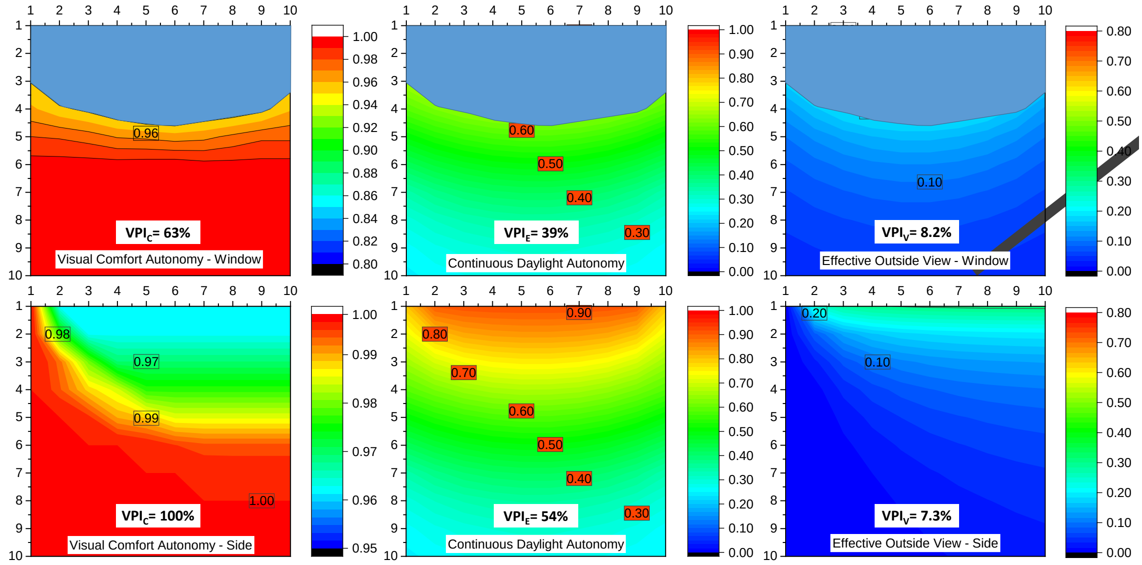


*Figure 3: VPI factors for south facades –facing the window (top) and the left wall (bottom).*

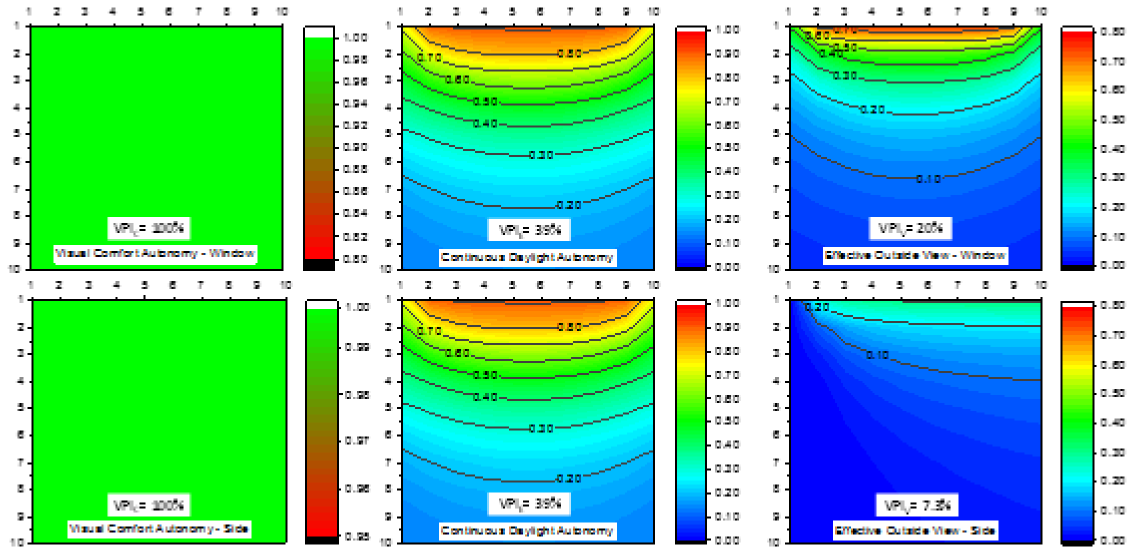

*Figure 4: VPI factors for north facades –facing the window (top) and the left wall (bottom).*

| | VPIc (%) | | VPIe (%) | | VPIv (%) | |
|---|---|---|---|---|---|---|
| View direction | Window | Wall | Window | Wall | Window | Wall |
| **South** | 63 | 100 | 39 | 54 | 8.2 | 7.3 |
| **North** | 100 | 100 | 39 | 39 | 20 | 7.3 |
| **West** | 41 | 100 | 33 | 52 | 6.2 | 7.3 |
| **East** | 68 | 100 | 35 | 48 | 9.4 | 7.3 |

*Table 1: VPI factors for different orientations and view directions*

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