Proceedings Paper:
Chen, T.-T., Wang, T.-H. and Lu Chiang, T. (2025) Investigating the impact of balcony design on indoor visual comfort: a case study of subtropical office environments in Taiwan. In: Reinhardt, D., Rogeau, N., Herr, C.M., Globa, A., Chen, J. and Narahara, T., (eds.) ARCHITECTURAL INFORMATICS - Proceedings of the 30th CAADRIA Conference. CAADRIA 2025: Architectural Informatics, 22-29 Mar 2025, Tokyo, Japan. CAADRIA, pp. 233-242. ISSN: 2710-4265. EISSN: 2710-4265.

https://doi.org/10.52842/conf.caadria.2025.3.233

Investigating The Impact of Balcony Design on Indoor Visual Comfort

A case study of subtropical office environments in Taiwan

Tzu-Ting Chen[1], Ting Lu Chiang[2], and Tsung-Hsien Wang[3]
[13]School of Architecture, University of Sheffield.
[2]National Taiwan University of science and technology department of architecture.
[1]c.tzuting122@gmail.com
[2]d11013010@mail.ntust.edu.tw
[3]tsung-hsien.wang@sheffield.ac.uk

Abstract. Indoor visual comfort influences office workers' satisfaction, productivity, and overall physical and mental wellbeing. In this study, we investigate glare issues to maintain good indoor visual comfort in daylit contemporary office environments. Specifically, this study examines the effective balcony designs that enhance indoor visual comfort. Thirty-three balcony designs were considered through lighting simulation and glare evaluation to cross-examine daylight performance with visual comfort. The findings reveal that office space with only a balcony and no soffit is undesirable due to extreme glare problems during the winter months. Extending the soffit depth to 2 meters can help alleviate these glare issues. While incorporating vegetation on the balcony does reduce glare, it is less effective than extending the soffit. Increasing balcony and soffit depth, along with vegetation, may not consistently improve daylight performance in the back of the room despite minimising glare in areas next to windows. The ideal balcony design combines vegetation with a 2-meter-deep soffit, which ensures a fine balance between glare reduction and daylight performance.

Keywords. Indoor visual comfort, office building, glare mitigation, balcony design, balcony vegetation

1. Introduction

Even though working from home has become a popular way of working during and after a pandemic, according to the data from the Taiwan Employment Gold Card (2024), most workers in Taiwan adhere to a working culture that involves spending at least 8 hours per day in the office. It is, therefore, crucial to ensure good indoor environmental quality for individuals who spend most of their time within. Numerous studies have illustrated that natural daylight is one of the significant indoor environment factors influencing occupants' wellbeing, productivity, perception, physical health, reduced depression, and increased satisfaction (Loche et al., 2021; Park

ARCHITECTURAL INFORMATICS, Proceedings of the 30th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2025, Volume 3, 233-242. © 2025 and published by the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA), Hong Kong.

et al., 2021; Woo et al., 2021). High-quality office settings enhance occupants' productivity and contribute to energy conservation and the real estate market (Loche et al., 2021).

In the office building design, windows and other building elements, such as balconies, can significantly influence the amount of natural daylight entering the indoor spaces. In subtropical countries such as Taiwan, balconies are a prevalent feature for facilitating the flow of fresh air and natural light in residential buildings in Taiwanese architectural history (Sari and Chiou, 2019). They also possess visual appeal, increase visual comfort, directly offer shade to occupants in indoor spaces (Ribeiro et al., 2020), mitigate undesirable solar radiation, and increase the diffusion of daylight into the office in subtropical climates (Loche et al., 2021).

Balconies are typically designed as semi-open areas surrounding a building and can be accessed by an upper-floor window or door. A soffit is the base of another balcony above the level, as shown in Figure 1. Open balconies are commonly seen in subtropical and tropical climates, providing a shading system to improve thermal comfort (Ribeiro et al., 2020).

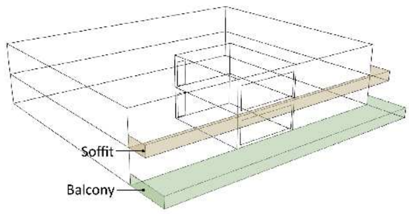

Figure 1. Definition of balcony and soffit

In recent years, Taiwan has enacted its net-zero strategy to address climate change, targeting a reduction in carbon dioxide emissions by 2050 through energy-efficient architectural design. An efficient balcony can optimise daylight for passive energy savings (Chiu, 2024) and enhance inhabitants' satisfaction (Ministry of the Interior, 2024). However, the impact of balconies on office buildings' daylight performance and occupants' visual comfort satisfaction is still not well understood, particularly in subtropical climates like Taiwan. As such, this study investigates how an effective balcony design maximises daylight in office spaces while enhancing indoor visual comfort.

2. Glare assessments for the indoor visual comfort

2.1. WHAT IS GLARE? WHAT FACTORS CAUSE GLARE?

Glare happens because of a great deal of light, resulting in annoyance, discomfort, or a decline in visual perception for individuals. Moreover, the presence of glare in office buildings is a concern that specialists aim to mitigate (Suk et al., 2017).

Osterhaus (2005) highlights that occupants' visual discomfort comes from the window size, the distance between the occupants and the windows, the computer's orientation with the window, the shading system, and the office layout. The contrast effect refers to the relationship between the level of adaptation, a glare source's illuminance, the perception of glare, and the ratio of window to background (Pierson et al., 2018).

2.2. DAYLIGHT GLARE PROBABILITY (DGP)

Multiple metrics are available for assessing the glare intensity based on illuminance, viewing position, the glare source position, glare perceived size, and the background illumination's level. Previous studies (Suk et al., 2017; Wienold et al., 2019) suggest that the DGP index is the most effective tool for predicting discomfort glare within the daylight-dominate workplace.

This study employs parametric daylight simulation to automate DGP calculation, discussed in previous studies (Huang and Wang, 2016; Wang et al., 2022). Specially, DGP classifies glare degrees at four levels: imperceptible, perceptible, disturbing, and intolerable (Suk et al., 2017; Wienold and Christoffersen, 2006), as shown in Table 1.

Table 1: The degree of perceived glare

Degree of perceived glare	Threshold
Imperceptible	<0.35
Perceptible	0.35~0.40
Disturbing	0.40~0.45
Intolerable	>0.45

2.3. USEFUL DAYLIGHT ILLUMINANCE (UDI)

UDI serves as an additional metric for assessing the distribution of daylight within a workplace. UDI examines the meteorological data on an hourly basis for one year. It can evaluate undesirable solar radiation or excessive illumination. The recommended UDI threshold for an office setting ranges from 300 lux to 3000 lux (Mardaljevic et al., 2012; Loche et al., 2021).

2.4. BALCONY DESIGN IN SUBTROPICAL AREAS ADDRESS GLARE

Previous studies have examined shading systems in countries at higher latitudes but without balconies. Architects in tropical or subtropical regions commonly incorporate balconies into their building designs, serving self-shading. In Brazil, narrow and shallow balconies on the southern side of the building decrease the need for a cooling system. While the north-facing façade features deeper and wider balconies, they were strategically positioned to reduce solar gains and enhance thermal performance (Loche et al., 2024). The balcony serves as a cooling or shading system to minimise solar radiation, reduce the possibility of glare, and improve energy performance. Loche et al. (2021) also highlight that the width of the window in the room must exceed 3 meters, the visual transmittance of the glazing should be 0.88, and the depth of the balcony should not be greater than 1 meter in the south-facing façade to maintain indoor visual comfort with an acceptable daylight factor without glare in Brazil.

3. Methodology

This research investigates three office buildings with balconies in Taichung to identify essential parameters of the effective balcony design for glare reduction. Taichung has a subtropical climate in the west-central part of Taiwan, at coordinates 24.16° N and 120.67° E. In this climate, the southern building façade receives more sunlight throughout the year, which likely results in a higher probability of glare during the winter months due to the sun's position in the southern part of the sky (Fasi & Budaiwi, 2015).

The proposed methodology evaluates glare probabilities using DGP indexes and UDI daylight performance. As a result, this study cross-examines the assessment findings and suggests applicable design principles for future development. The proposed methodological workflow starts with key building parameter identification, followed by daylight simulations and glare evaluations, to evaluate effective balcony design for buildings in subtropical regions, as illustrated in Figure 2.

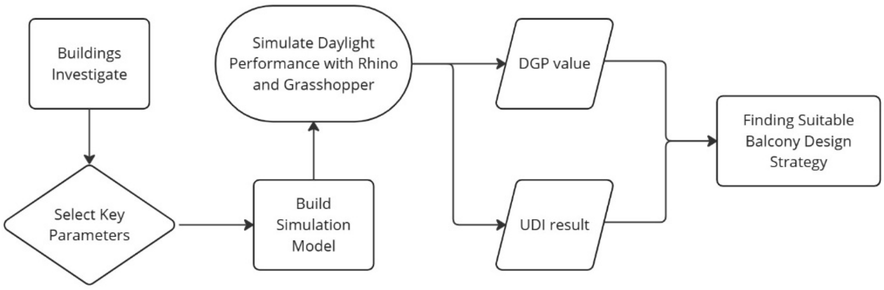

Figure 2: Flow chart of methodology

3.1. CASE STUDIES OF THREE OFFICE BUILDINGS

Keywow Architecture, CBD Time Square, and Kuma Tower are investigated. CBD Time Square and Kuma Tower feature identical balconies on each floor with matching sizes and shapes. Keywow Architecture's balcony design is unique in that the soffit covers only half of the balconies' width and depth, providing only half of the shading. Figure 3 illustrates three buildings chosen for this study.

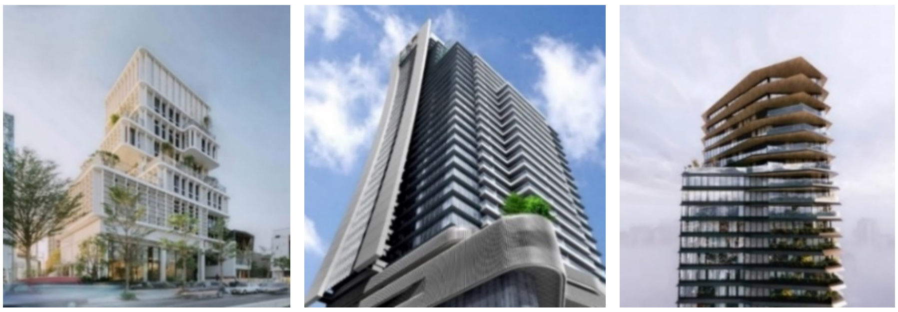

Figure 3. The appearance of Keywow, CBD Time Square and Kuma Tower

3.2. CONTROL VARIABLES: OFFICE BUILDING SIZE, TARGETED ROOM SIZE, LAYOUT, WINDOW-TO-WALL RATIO (WWR=65%) AND VIEWPOINTS

The depth of the office and where the occupants sit affect how they perceive glare. Maintaining a room depth that is no more than two and a half times the window's height will enhance the dispersion of sunlight and reduce excessive luminance (Osterhaus, 2005; Konstantzos and Tzempelikos, 2017). This study utilised the Keywow Architecture building layout as the baseline model, with dimensions of 6 meters by 8 meters by 2.8 meters in width, depth, and height. In Figure 4 (left), the window measures 5.46 meters in width and 2 meters in height, resulting in a 65% window-to-wall ratio and a glass transmittance of 0.88 (Loche et al., 2021).

As shown in Figure 4 on the right, this study considered three viewing directions per location in the room. In total, 18 views across six locations are tested during the simulation. The sitting eyesight height is 1.1 meters.

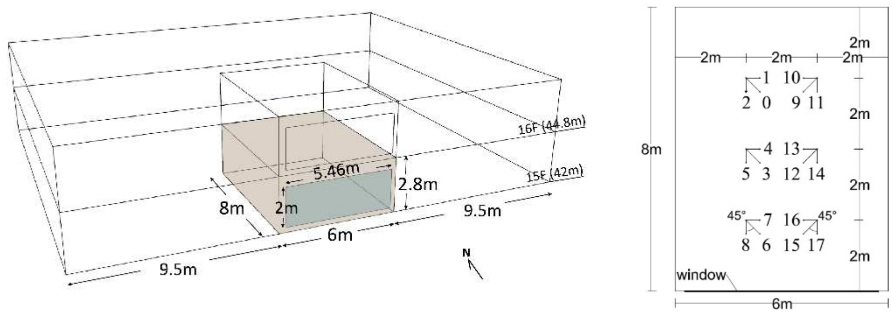

Figure 4. Simulated prototype setting

3.3. PARAMETER 1: THE DEPTH OF BALCONY (BD)

In this study, the experiment set-up explores four distinct balcony designs (1.5 m, 4 m, 6.5 m, and 9 m) with the chosen case studies. The depth variations cover the numerical ranges from the chosen case studies in Taichung, Taiwan.

3.4. PARAMETER 2: BALCONY-TO-SOFFIT DEPTH RATIO

A change in the soffit's depth would impact the shading area, leading to varying illumination levels below the surface. This study proposes four balcony-to-soffit depth ratios, 1:0, 2:1, 4:3, and 1:1, for gauging the DGP index.

3.5. PARAMETER 3: VEGETATION

Plants, or any other form of vegetation, are also popular and commonly placed on balconies in Taiwan. Previous studies showed that vegetation could benefit both humans and the climate (Mangone and van der Linden, 2014). In this study, we consider two variations. One is that the vegetation is placed 0.3 meters from the building boundary in all balcony types with varying depths, 2 meters spacing, and 2 meters high. The other is for all balcony types without vegetation.

3.6. SIMULATION SCENARIOS BY ROOM AND BALCONY PARAMETERS

The experiment considers a testing room with 6 meters in depth and 8 meters in width with a window-to-wall ratio (WWR) of 65% for the simulation. The simulation scenarios cover balcony variations using four distinct balcony depths, four balcony-to-soffit depth ratios, and the existence or absence of plants on the balcony. The simulation days include March 21st, June 21st, and December 21st to cover transitional, summer, and winter seasons. Simulation tests take place at 10 a.m., 2 p.m., and 4 p.m., representing the usual working hours for office occupants. Six locations with three viewing orientations in the targeted office room are examined for each balcony type. In total, 33 different balcony types were evaluated, as shown in Figure 5.

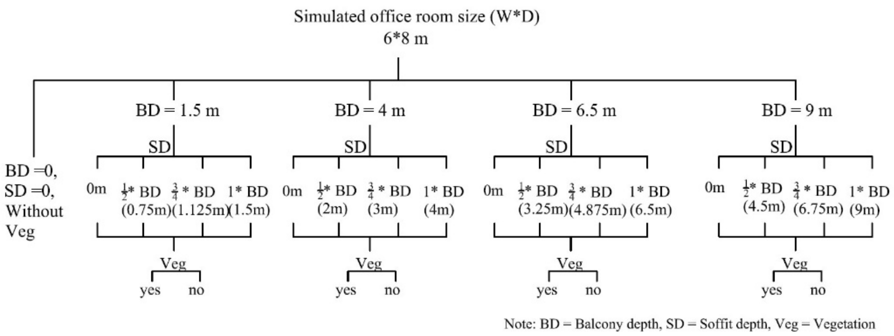

Figure 5. 33 combinations of balcony types

4. Results and Discussion

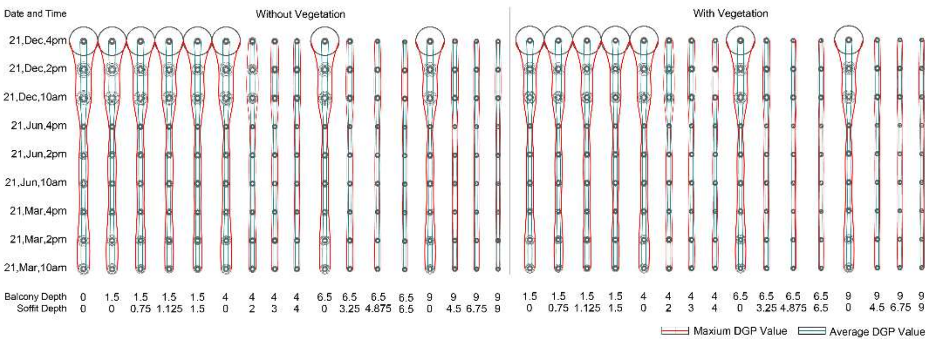

Figure 6. General results

Figure 6 presents 33 balcony designs with 17 DGP values from varying viewpoints (at two, four, and six meters from the window). Viewing directions include perpendicular, parallel, and diagonal viewing to the window per viewpoint, as shown in Figure 4. In Figure 6, the circle dimensions per balcony design were based on DGP values, representing the probability of visual discomfort. The red line indicates the maximum DGP values, and the green line represents the average values.

In December, the sun's lower position, slanting angle, and closer distance to the Earth increase the likelihood of observing higher DGP values in the afternoon. The glare probability is at its lowest point in June at 4 p.m. These findings align with other research indicating that individuals in the northern hemisphere may experience glare issues throughout the winter (Fasi and Budaiwi, 2015).

An office setting without a balcony, soffit, or plant usually receives excessive daylight, resulting in the highest DGP value among balcony design variations. Some viewpoints in the room even reach the threshold of intolerable glare due to being closer to the window and direct sunlight. Nevertheless, in any balcony depth, maintaining a 1:1 ratio between the balcony's depth and the soffit's depth while incorporating vegetation into the design generally exhibits the lowest DGP value.

4.1. THE IMPACT OF BALCONY DEPTH

Increasing the depth of the balcony without a soffit and planting vegetation will reduce the glare probability. Namely, a balcony is likely to block unwanted lighting and prevent excessive sunlight from entering the office space. Moreover, the differences in DGP values among balcony depths of 4 meters, 6.5 meters, and 9 meters do not exhibit statistical significance throughout the year. The findings also suggest that although having a balcony attached to an office building will reduce DGP values, a balcony with a depth greater than 4 meters will not significantly reduce glare further.

4.2. THE IMPACT OF BALCONY-TO-SOFFIT DEPTH RATIO AND THRESHOLD OF LIGHTING REQUIREMENT

Increasing the ratio of the balcony-to-soffit depth can reduce glare issues through self-shading. However, the findings do not imply that a balcony with a 1:1 balcony-to-soffit depth ratio is always the ideal solution. This is because there is a threshold for the artificial light requirement. In Figure 7, the diagrams present the balcony-to-soffit depth ratios ranging from 1:0 to 1:1. According to the UDI analysis, when a balcony depth exceeds 4 meters and the balcony-to-soffit depth ratio is greater than 2:1, regardless of whether there is vegetation on the balcony, the office room receives insufficient illumination, leading to a higher demand for artificial lighting. Such an increase in the energy demand would not be desirable.

One of the key findings from Figure 6 shows that serious glare issues persist even with vegetation on the balcony, particularly when the soffit depth is shallower than 2 meters. As the sun moves lower in winter, sun rays could penetrate through windows towards occupants' eyes to cause unbearable glare, as shown in Figure 8 (left). However, the soffit depth, when equal to or exceeding 2 meters, could effectively mitigate glare issues, as shown in Figure 8 (right). As a result, an effective way to tackle glare issues in subtropical regions such as Taiwan can be a soffit with 2 meters in depth.

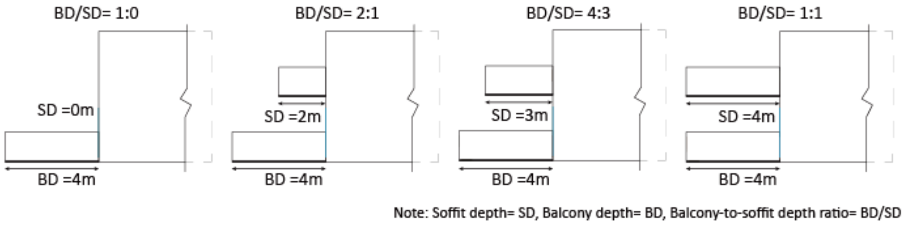

Figure 7. Four of balcony-to-soffit depth ratios

Figure 8. The requirement of mitigating glare issues

4.3. THE IMPACT OF ADDING VEGETATION ON THE BALCONY AND THRESHOLD OF LIGHTING REQUIREMENT

Adding greenery to the balcony will mitigate the issue of excessive brightness (refer to Figure 6). However, its efficacy is not superior to raising the ratio between the balcony's and soffit's depth. Moreover, placing plants in some settings will reach the threshold for extra artificial lighting, which is not recommended. In this study, cross-examining DGP with UDI results shows that planting vegetation on a balcony with a depth of above 4 meters and a balcony-to-soffit depth ratio above 2:1 will worsen daylight performance, even though it mitigates glare problems.

4.4. OPTIMAL SCENARIO AMONG 33 COMBINATIONS

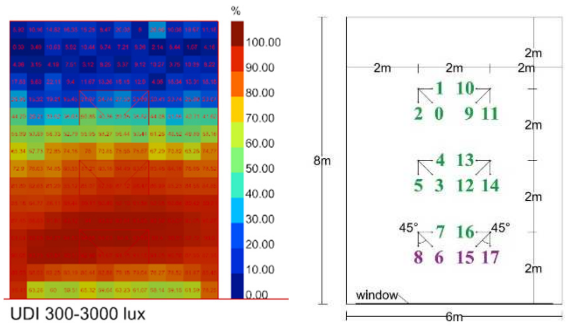

Figure 9: optimal scenario

When UDI reaches 80% of the time throughout the year, the well-daylit spaces do not require additional artificial lighting. Figure 9 (left) shows the best scenario among the

33 combinations—a 4-meter-deep balcony with a balcony-to-soffit depth of 2:1 and vegetation on the balcony. In this scenario, sitting two meters away from the window with a parallel view can achieve the highest indoor visual comfort, as illustrated in Figure 9 (right).

5. Conclusion and Recommendations

In conclusion, extending the depth of the balcony, increasing balcony-to-soffit depth ratios, and adding vegetation on the balcony will reduce the glare issues for the occupants, especially those located within 2 meters of a window. However, some thresholds exist for controlling these parameters to reach better indoor lighting performance. Regardless of the presence of vegetation, if the balcony depth exceeds 4 meters and the balcony-to-soffit depth ratio exceeds 2:1, the introduction of vegetation on a balcony will worsen the daylight performance, leading to a higher demand for artificial lighting while mitigating glare problems.

This study recommends that the soffit depth in office buildings with balconies should equal or exceed 2 meters to provide a glare-free office environment and maintain good daylight performance for future subtropical countries. Incorporating balconies will improve indoor visual comfort, create a better working environment, and benefit the microclimate. This will also decrease the amount of energy needed for better thermal performance.

Some parameters, such as the size of the plants on the balconies, the window-to-wall ratio, window dimensions, window shading, windows with a film coating, and any other design elements, limit the balcony's optimisation and diversity. The proportions of streets to the heights of buildings, which might still influence daylight performance indoors (Kim and Kim, 2015), have yet to be included in fully assessing glare mitigation. Incorporating user experience testing and considering economic feasibility may comprehensively improve the overall design, which makes the design more implementable. As the study results show, considering the soffit depth is critical in reaching a glare-free working environment rather than the balcony depth. In future studies, a balcony with a soffit depth equal to 2 meters is worth first testing with a combination of other parameters to gauge impacts in a practical way.

References

Architecture and Building Research Institute, ministry of the Interior, ROC (Taiwan) (2024) *The Study on Green Building Evaluation of Existing Building.* Retrieved 20 June 2024, from https://www.abri.gov.tw/en/News_Content.aspx?n=908&s=40678.

Chiu, C. (2024). Negotiating Urban Greening Through Housing Development: Stakeholders and Sociospatial Strategies in a Municipality-Led Eco-Building Programme. *Housing, Theory, and Society*, 41(2), 169–191. https://doi.org/10.1080/14036096.2023.2272826

Fasi, M. A., & Budaiwi, I. M. (2015). Energy performance of windows in office buildings considering daylight integration and visual comfort in hot climates. *Energy and Buildings*, 108, 307–316. https://doi.org/10.1016/j.enbuild.2015.09.024

Huang, Y. & Wang, T.-H. (2016). Automatic Calculation of a New China Glare Index. In: *Proceedings of the 3rd IBPSA-England Conference*, Newcastle, UK, 12 September 2016, (p. 1010).

J. Mardaljevic, M. Andersen, N. Roy, J. Christoffersen, Daylighting metrics: is there a relation between useful daylight illuminance and daylight glare probability? In: *First Building Simulation and Optimization Conference*, *2012*, pp. 189–196.

Kim, H.-J., & Kim, K.-H. (2015). A Design Methodology for Street-Oriented Block Housing with Optimization of Natural Daylight. *Journal of the Architectural Institute of Korea Planning & Design*, 31(5), 45–56. https://doi.org/10.5659/JAIK_PD.2015.31.5.45

Konstantzos, I., & Tzempelikos, A. (2017). A Holistic Approach for Improving Visual Environment in Private Offices. *Procedia Environmental Sciences*, 38, 372–380. https://doi.org/10.1016/j.proenv.2017.03.104

Loche, I., Bleil de Souza, C., Spaeth, A. B., & Neves, L. O. (2021). Decision-making pathways to daylight efficiency for office buildings with balconies in the tropics. *Journal of Building Engineering*, 43, 102596. https://doi.org/10.1016/j.jobe.2021.102596

Loche, I., Bre, F., Gimenez, J. M., Loonen, R., & Neves, L. O. (2024). Balcony design to improve natural ventilation and energy performance in high-rise mixed-mode office buildings. *Building and Environment*, 258, 111636. https://doi.org/10.1016/j.buildenv.2024.111636

Mangone, G., & van der Linden, K. (2014). Forest microclimates: Investigating the performance potential of vegetation at the building space scale. *Building and Environment*, 73, 12–23. https://doi.org/10.1016/j.buildenv.2013.11.012

Osterhaus, W. K. E. (2005). Discomfort glare assessment and prevention for daylight applications in office environments. *Solar Energy*, 79(2), 140–158. https://doi.org/10.1016/j.solener.2004.11.011

Park, J., Loftness, V., Aziz, A., & Wang, T.-H. (2020). Strategies to achieve optimum visual quality for maximum occupant satisfaction: Field study findings in office buildings. *Building and Environment*, 107458. https://doi.org/10.1016/j.buildenv.2020.107458

Pierson, C., Wienold, J., & Bodart, M. (2018). Review of Factors Influencing Discomfort Glare Perception from Daylight. *Leukos*, 14(3), 111–148. https://doi.org/10.1080/15502724.2018.1428617

Ribeiro, C., Ramos, N. M. M. and Flores-Colen, I. (2020) ‘A review of balcony impacts on the indoor environmental quality of dwellings’, *Sustainability* (Basel, Switzerland), 12(16), p. 6453. doi: 10.3390/su12166453.

Suk, J. Y., Schiler, M., & Kensek, K. (2017). Investigation of existing discomfort glare indices using human subject study data. *Building and Environment*, 113, 121–130. https://doi.org/10.1016/j.buildenv.2016.09.018.

Taiwan Employment Gold Card. (2024) *Taiwanese Work Culture: Four Key Cultural Differences to Look Out For*. Retrieved 4 January 2024, from https://goldcard.nat.gov.tw/en/whytaiwan/taiwanese-work-culture-four-key-cultural-differences-to-look-out-for/.

Wang, T.-H., Huang, Y., & Park, J. (2022). Development of Daylight Glare Analysis Method Using an Integrated Parametric Modelling Approach: A Comparative Study of Glare Evaluation Standards. *Buildings*, 12(11), 1810. https://doi.org/10.3390/buildings12111810

Wienold, J., & Christoffersen, J. (2006). Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras. *Energy and Buildings, 38*(7), 743–757. https://doi.org/10.1016/j.enbuild.2006.03.017

Wienold, J., Iwata, T., Sarey Khanie, M., Erell, E., Kaftan, E., Rodriguez, R., … Andersen, M. (2019). Cross-validation and robustness of daylight glare metrics. *Lighting Research & Technology (London, England : 2001)*, 51(7), 983–1013. https://doi.org/10.1177/1477153519826003

Woo, M., MacNaughton, P., Lee, J., Tinianov, B., Satish, U., & Boubekri, M. (2021). Access to Daylight and Views Improves Physical and Emotional Wellbeing of Office Workers: A Crossover Study. *Frontiers in Sustainable Cities*, 3(0). https://doi.org/10.3389/frsc.2021.690055