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A Parametric Study of Window-to-Wall Ratio and Daylight Performance under Different Obstruction Conditions in High-Rise Urban Environments

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Abstract: Daylight conditions are different across a façade in dense high-rise urban locations due to the neighbouring buildings, which limit the exposure to the sky. The study investigates the effect of window-to-wall ratio (WWR) on daylight provision and visual comfort with varied degrees of external blockage, modelled by sky view factor (SVF). Central Plaza in Hong Kong provided the case study for identifying representative obstruction conditions. SVF was calculated across the south, northwest and northeast façades, and three values 0.10, 0.30 and 0.50, were selected for investigation using a controlled reference office model. For each condition, six WWR configurations ranging from 0.10 to 0.87 were tested through climate-based daylight simulations in Rhino and Grasshopper using Ladybug and Honeybee. Performance was evaluated using spatial daylight autonomy, daylight glare probability, and spatial glare autonomy. The results show that increasing WWR generally improves daylight provision but simultaneously increases glare risk. More significantly, the metric-based daylight response is non-linear, with the biggest benefits in daylight provision often occurring at low-to-moderate WWRs, after which improvements taper down as sDA approaches saturation. Visual comfort shows a different response, with greater deterioration occurring at the lower and higher ends of the tested WWR range, while changes are relatively moderate within the intermediate range. The influence of WWR also varies with obstruction conditions: higher-SVF environments are generally more responsive to changes in WWR, resulting in increasingly pronounced differences in daylight performance as WWR increases. A similar interaction is observed for façade orientation. The south façade shows greater sensitivity to WWR in terms of visual comfort than the other orientations, whereas orientation has a comparatively limited influence on the relationship between WWR and daylight provision. The findings demonstrate the value of SVF as a quantitative descriptor of high-rise daylight obstruction and support an SVF-responsive façade strategy. Rather than prescribing a uniform WWR, façade design should respond to local obstruction conditions while balancing daylight provision and visual comfort.

Keywords: Window-to-Wall Ratio, Sky View Factor, daylight performance, daylight provision, visual comfort, high-rise buildings, parametric modelling and simulation.

1. Introduction

"A room is not a room without natural light." -- Louis Kahn

1.1. Background

Many studies show that incorporating appropriate daylight into built environment design positively affects occupant comfort, health, well-being, and productivity [1, 2]. However, the increasing urban densification and the proliferation of high-rise developments have significantly affected access to natural daylight in many cities, particularly in high-rise districts where surrounding buildings create substantial and complex obstructions to facades [3, 4]. Under such conditions, the Window-to-Wall Ratio (WWR) is widely recognised as one of the most influential design parameters affecting daylight performance [5, 6]. Nevertheless, in high-rise urban environments, lower, middle, and upper floors experience fundamentally different daylight conditions due to varying degrees of obstruction from surrounding buildings. WWR designs effective in one area may not perform well in another. This highlights the need for floor-specific, or more precisely, obstruction-specific WWR design strategies to optimise daylight performance in buildings in the dense high-rise urban environment.

1.2. Research Aim and Questions

Using Central Plaza, Hong Kong, as a case study, this study aims to employ a parametric approach to investigate how different daylight obstruction conditions based on Sky View Factor (SVF) influence the relationship between WWR and daylight performance. It is expected to provide obstruction-specific façade design guidance for daylighting design in a high-rise urban environment.

To achieve the research aim, this study will respond to three research questions:

RQ1: How can daylight obstruction conditions across different floor levels be systematically defined and quantified for subsequent analysis?

RQ:2 How does WWR affect daylight performance (daylight provision and visual comfort) under different obstruction conditions?

RQ3: Under different obstruction conditions, within which ranges does adjusting the WWR provide the greatest improvement in daylight performance?

2. Literature Review

2.1. Daylight Design for Offices in Dense Urban Environments

2.1.1. Challenges and Approaches

Daylight plays an important part in the quality of built environments. It affects visibility, how spacious rooms feel, occupants' preferences and health-related responses. Office occupants often spend long periods on visual tasks. Providing

suitable daylight in these spaces is particularly important [1, 2, 7].

The link between lighting conditions and health at work is not a simple one. A systematic review of office-lighting research suggested that the benefits of daylight should not be assumed to apply equally in every setting [8]. Good daylight design must provide enough light. Excessive brightness and sun exposure need to be controlled to prevent visual discomfort. Finding the right balance is harder in high-rise districts. The daylight available indoors depends on the building envelope and the layout of surrounding buildings [3]. Building height, the gaps between buildings and street-canyon proportions affect the amount of sky visible from different parts of a building and the solar radiation reaching them. Simulations with different levels of obstruction showed large differences in daylight performance across the building. Lower floors were more likely to receive insufficient daylight. Upper floors faced greater glare exposure [9, 10, 11].

Façade design is one of the most practical ways to control the daylight entering a building. It is particularly useful in dense urban areas with limited sky access. The façade forms the boundary between outdoor light and indoor space. Its design can be adjusted using parameters such as Window-to-Wall Ratio (WWR), glazing transmittance, shading devices and façade depth [12, 13]. WWR is considered an important measure of a building's performance. Designers can easily adjust it during the early stages of the design. It has a strong direct effect on the amount of daylight reaching the interior [14]. Yet WWR is not a monotonic more-is-better variable. A larger glazed area can increase daylight autonomy in obstructed settings, but it can also amplify luminance contrast and discomfort glare, particularly where façades are more exposed to the sky or direct sun [15]. As described above, it is significant to find the appropriate WWR that balances daylight availability and visual comfort. For this reason, the WWR of the rooms in high-rise districts should not be treated as a fixed universal recommendation. Instead, in high-rise urban environments, an appropriate WWR is more plausibly obstruction-specific.

To describe obstruction conditions, researchers have used geometric metrics to translate surrounding morphology into quantities relevant to daylight access. A tropical study applied Sky View Factor (SVF) to describe the obstruction conditions [16]. A later optimisation study considered WWR alongside building-height difference and obstruction angle [11]. Collectively, these studies have made an important contribution to describing and defining obstruction conditions in building performance studies.

2.1.2. Conditions in Hong Kong

For daylight design in dense urban environments, Hong Kong is an especially appropriate context because it is internationally recognised as a high-rise and high-density urban environment. A recent benchmark dataset developed from Hong Kong described the city as a representative high-rise, high-density environment and noted that conventional urban datasets often fail to capture this level of vertical intensity [17]. This urban form makes the daylight design problem more obvious than in typical cities: lower floors may have reduced access to daylight due to tight building spacing, while upper floors may be more exposed and thus more vulnerable to excessive sunlight and glare. This vertical contrast is also consistent with Hong Kong-based window-view research showing substantial variation in sky and construction visibility across high-rise settings [18]

The Central Plaza was among Hong Kong skyscrapers that had been used as a full-scale research object in prior studies on super-tall buildings [19, 20]. The building is located at 18 Harbour Road, Wan Chai North, Hong Kong, in a commercial area with a concentration of high-rise office complexes. Central Plaza is a 75-story office tower with an official claimed height of 374 m including its antenna. Moreover, the tower is generally triangular in shape with three main aspects of the façade: south, northwest and northeast [21]. While studies on Central Plaza mostly concentrated on the structural and wind performance rather than daylight, the studies show that it is a well-documented research object in the high-rise urban context of Hong Kong. Hence, its considerable height and surrounding high-rise development also make it a suitable case for daylight study in high-rise districts.

2.2. Parametric Modelling and Daylight Simulations

2.2.1. Parametric Design

Parametric design describes an approach in which geometry is defined through explicit variables, rules, and relationships. When an input changes, related parts of the model can update systematically rather than being redrawn independently [22]. Compared with conventional modelling, this enables the production of a consistent family of design alternatives while retaining the same underlying geometric relationships.

In building-performance studies, parametric modelling allows geometric inputs to be linked directly to simulation outputs. A greater design space can be examined under consistent assumptions, instead of comparing a small set of manually generated options. This method could be applied in Rhino and Grasshopper. Earlier work has merged parametric geometry with environmental performance evaluation and optimisation algorithms to explore links between shape and performance [23]. Parametric design can thus be seen not just as a tool for the generation of complicated forms, but as a technique of structuring relationships between variables, constraints and performance requirements [24].

2.2.2. Daylight Simulation

Daylight simulation has moved from simple static calculations to dynamic and climate-based methods. Earlier daylight assessments often used the Daylight Factor method. This method is useful for simple comparisons. It does not consider local climate, the sun's position or changes in sky conditions from hour to hour. Climate-based simulation uses local weather data and annual sky conditions to predict daylight availability over the course of a full year [25, 26]. The influence of the local climate makes this approach more suitable for assessing daylight performance in real urban settings.

Ladybug and Honeybee provide a link between climate data, parametric geometry and environmental simulation within the Rhino and Grasshopper workflow. Ladybug imports weather information and presents it in a visual form. It supports environmental analysis during the process of designing a building. Honeybee converts geometric models into file formats that the simulation engines can read and use [27]. Climate-based simulation needs a weather file as a key input, usually in EnergyPlus Weather (EPW) format. EPW files provide hourly weather data for a typical year. These include solar radiation and sky-condition data for setting up annual daylight simulations. The weather file is important in daylight studies. A façade's daylight performance is closely

tied to local daylight conditions. The same WWR can give different results with changes in solar radiation levels, cloud conditions and sun paths.

2.2.3. Reference Room

Using a standardised reference room helps keep geometric and environmental variables under control in daylight studies involving parametric modelling and climate-based simulation. The MIT Reference Office was introduced as a basic reference model for comparing façade and lighting technologies under the same set of assumptions. Its early use included façade studies based on annual simulations [28]. It describes a typical shoebox office space with simple geometric features that are clearly defined. Different design options can be tested in this space without unnecessary changes to the room's form.

A reference room enables investigators to isolate individual design variables for systematic examination. In a genuine workplace, room depth, ceiling height, façade geometry, internal layout and material qualities may all alter simultaneously. These factors are kept fixed in a controlled reference model. The changes are in the selected variables only. The findings of the simulation are more easily comparable. It is easy to detect the precise effect of each design parameter. Simulation studies are easy to reproduce for a conventional room geometry. It encourages broader usage of the findings. The model is not connected to the internal arrangement of any actual office. Performance trends can be seen as larger links between design variables. Their meaning is not confined to the response of a particular space. This is especially helpful in studies looking to identify overall trends in daylight performance without having to recreate the precise lighting circumstances of an existing area.

2.3. Daylight Performance Assessment

2.3.1. Daylight Provision

Daylight provision is a key part of assessing daylight performance. It describes the availability of enough natural light across an occupied space for a meaningful share of the time. Earlier assessments mainly used static measures such as the Daylight Factor. These measures are useful under a standardised overcast sky. They cannot show the effects of orientation, direct sunlight or changes in daylight from hour to hour and season to season. Climate-based metrics were developed to assess daylight across a full year [26]. These metrics are relevant to this study. A single static sky condition cannot fully capture the effect of WWR at different levels of external obstruction.

Spatial Daylight Autonomy (sDA) is one of the most widely used climate-based measures of daylight provision. It gives the proportion of the assessed area receiving at least a set daylight illuminance level for a specified percentage of annual occupied hours [29]. It accounts for changes across space and time. This gives a fuller picture of overall daylight provision than the illuminance at a single calculation point. The commonly used expressions are $sDA_{100,50\%}$, $sDA_{300,50\%}$, $sDA_{500,50\%}$, and $sDA_{750,50\%}$, which respectively represent the percentage of floor area receiving at least 100, 300, 500, and 750 lx, from daylight for at least 50% of the specified occupied period. The standard *BS EN 17037* [29] provides a useful recommendation for daylight provision based on these (see Table 1).

Table 1. Daylight provision recommendations based on $sDA_{100,50\%}$, $sDA_{300,50\%}$, $sDA_{500,50\%}$, and $sDA_{750,50\%}$

Level of recommendation	Minimum target illuminance (95% of floor area)	Target illuminance (50% of floor area)
Minimum	$sDA_{100,50\%} \geq 95\%$	$sDA_{300,50\%} \geq 50\%$
Medium	$sDA_{300,50\%} \geq 95\%$	$sDA_{500,50\%} \geq 50\%$
High	$sDA_{500,50\%} \geq 95\%$	$sDA_{750,50\%} \geq 50\%$

Note. Adapted from BS EN 17037 [29]

However, a high sDA value should not automatically be interpreted as superior overall daylight performance. The metric primarily evaluates the sufficiency of daylight and does not directly punish excess daylight, extreme brightness contrast or unpleasant glare. Therefore, daylight provision should be examined in conjunction with a complementary visual comfort metric, not as a single indicator [26].

2.3.2. Visual Comfort

The assessment of glare is particularly important in façade design because increasing glazing area may simultaneously improve daylight provision and increase exposure to bright sky or direct sunlight. This creates an inherent trade-off between daylight quantity and visual comfort that cannot be captured by illuminance-based metrics alone. Therefore, several indices have historically been proposed to quantify glare, such as the Daylight Glare Index. However, it has limitations when applied to contemporary daylight assessment. Its predictive performance has been found to be limited under complex daylight conditions [15].

Daylight Glare Probability (DGP) was developed specifically to assess discomfort glare in daylit environments and demonstrated a stronger relationship with subjective responses [15]. The metric combines vertical illuminance at the observer's eye with information describing glare-source luminance, solid angle, and position within the field of view. More recent CIE guidance continues to recognise DGP as one of the established models for assessing daylight discomfort glare [30]. *BS EN 17037* [29] additionally evaluates DGP through annual frequency, namely the $DGP_{e<5\%}$, which means DGP should not exceed a maximum value for more than 5% of the space's usage time (see Table 2).

Table 2. Visual comfort recommendation based on $DGP_{e<5\%}$

Level of recommendation	$DGP_{e<5\%}$
Minimum	0.45
Medium	0.40
High	0.35

Note. Adapted from BS EN 17037 [29]

Additionally, $DGP_{e<5\%}$ values normally describe glare from a particular viewpoint and viewing direction. This creates a limitation when evaluating an entire office. To better describe the visual comfort, Spatial Glare Autonomy (sGA) was introduced, which describes the proportion of evaluated positions or views that remain within an acceptable glare condition for a specified proportion of occupied time. Recent daylight studies have therefore adopted sGA as a dynamic indicator for comparing the spatial distribution of glare performance across different façade and shading configurations [31, 32]. However, there is no specific standard for it. Instead, it can be understood as a spatial extension of DGP-based annual glare assessment.

Combining $DGP_{e<5\%}$ and sGA enables visual comfort to be

assessed both in terms of glare severity and its spatial-temporal prevalence. Alongside sDA, these metrics provide complementary dimensions of daylight performance. This combined assessment is therefore well suited to identifying WWR ranges that improve daylight provision without disproportionate increases in glare.

2.4. Research Gap

Previous research has established a broad understanding of daylight performance in dense urban buildings. In high-rise urban environments, daylight is strongly affected by surrounding building geometry and the resulting reduction in sky exposure to varying degrees [3, 9, 10, 11]. WWR is widely recognised as an important design variable because changes in glazing area directly influence the amount and distribution of daylight entering an interior space [14, 13]. Meanwhile, the development of parametric modelling and climate-based simulation has made it possible to systematically test façade alternatives under annual climate conditions rather than relying solely on static daylight calculations [25, 26, 23]. Daylight performance can now also be simulated and assessed from complementary perspectives, using metrics such as sDA, $DGP_{e<5\%}$, and sGA [29, 30, 31, 32, 15]. Together, these studies provide the methodological and theoretical basis for this study.

Despite these developments, gaps remain that are directly relevant to the research questions of this study. The first gap concerns how obstruction conditions are defined and quantified across the façades. Previous studies have used measures such as building-height difference, obstruction angle, and SVF to describe external urban geometry [16, 11]. However, building height and obstruction angle provide only a simple and effective description of external obstruction. Although SVF has been widely used to quantify urban sky openness and has also been applied to building façades, it has primarily been used to generally describe urban geometry, rather than systematically translating vertical variations into representative obstruction conditions for controlled daylight analysis. This gap corresponds to RQ1 and motivates the use of a consistent SVF to quantify and classify obstruction conditions for further exploring the effect of WWR on daylight performance.

The second gap concerns the isolated effect of WWR under different quantified obstruction conditions. Existing studies have already shown that WWR affects daylight performance [14, 11, 15]. However, these studies have not systematically assessed how WWR affects daylight performance under different SVFs. RQ2 therefore addresses the need for a simple yet systematic simulation and analysis of WWR, SVF, and daylight performance.

Additionally, previous studies mostly vary WWR together with other parameters for final optimization [11]. While this is useful for identifying high-performing design combinations, it makes it difficult to determine how much of the resulting change is caused by WWR itself, and less attention has been given to identifying where increasing WWR produces the greatest marginal improvement, where daylight benefits begin to diminish, and where additional glazing mainly increases glare risk. These transition points may also shift with obstruction level. RQ3 therefore moves beyond the search for a single optimal WWR and instead examines the WWR performance response under each obstruction condition.

Accordingly, this study addresses the three gaps through a linked process of quantifying obstruction with SVF, isolating the effect of WWR, and identifying high-impact WWR ranges. Using Central Plaza to derive representative high-rise obstruction conditions and a controlled reference office for simulation, the study aims to develop SVF-specific WWR guidance.

3. Methodology

3.1. Research Framework

This study uses parametric daylight simulations to examine how Window-to-Wall Ratio (WWR) affects daylight performance under different Sky View Factor (SVF) conditions in a high-rise district. The approach combines the urban geometry of the case study with a controlled reference room.

The target building, surrounding buildings and reference room were first modelled in Rhino and Grasshopper. SVF was then calculated across the target building's façades to map differences in external obstruction. Representative conditions were selected from this distribution, and the reference room was placed at the corresponding façade locations. Climate-based daylight simulations were carried out using Ladybug and Honeybee, with WWR varied systematically while the remaining parameters were held constant.

The results were assessed using metrics for daylight provision and visual comfort. Plotting these metrics against WWR allowed comparisons between obstruction conditions and helped identify the ranges in which changes to window size produced the greatest improvements.

3.2. Hong Kong Central Plaza and Urban Context

Central Plaza in Hong Kong was selected to identify representative obstruction conditions in a dense high-rise setting. Its height and the varied arrangement of nearby buildings provide a range of sky-exposure conditions across its façades. The building was used to map these differences and select locations for the reference room simulations. However, the analysis did not model daylight in Central Plaza's actual interior spaces.

The building and its surroundings were modelled using 3DS-format files from the Hong Kong Lands Department's *3D Spatial Data (3D-BIT00)* dataset [33]. The urban model was limited to a 200 m radius around Central Plaza to include nearby obstructions. It was large enough while keeping the simulations computationally manageable.

After import into Rhino, the geometry was simplified into closed building masses. Building locations, footprints, principal roof heights and relative positions were retained. However, architectural details judged unlikely to affect daylight materially were removed to lighten the calculation workload. The final model is shown in Figure 1.



Figure 1. The model of the target building Central Plaza (gray) and its urban context (yellow)

3.3. Reference Office Room

The parametric daylight simulations were conducted using a controlled reference office model based on the MIT Reference Office [28] described in Section 2.2.3. The reference model of MIT has a relatively large room depth of 8.2 m and can be used for a wide variety of research applications [28]. Since the current paper focuses only on the influence of the WWR on daylight factor, the reference room depth was changed to 5 m, which denotes the daylit zone in previous studies [28]. This aims to highlight more the impact of the WWR on daylight performance and to simplify a comparison between obstruction situations. The final reference room size is $3.6 \times 5.0 \times 2.8$ m (W × L × H). Similarly, furniture and other intricate geometry were not included in the main model to simplify the calculation load. As for the window, it has a similar configuration to the MIT reference room. The number of WWR iterations has been reduced from nine to six to reduce the computational load while retaining sufficient iterations [28], namely 0.10, 0.26, 0.39, 0.52, 0.70, and 0.87 to reduce the computational load while having enough iterations (see Figure 2). These windows were additionally parametrically constructed and controlled in Grasshopper (see Figure 3).

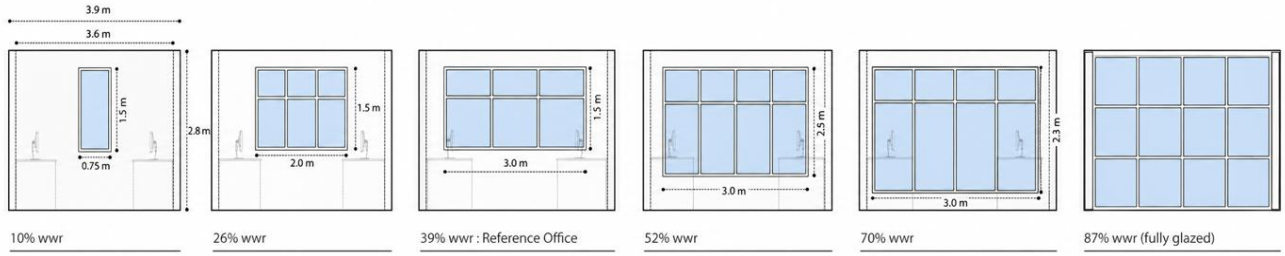


Figure 2. WWR layouts for the reference room [28]

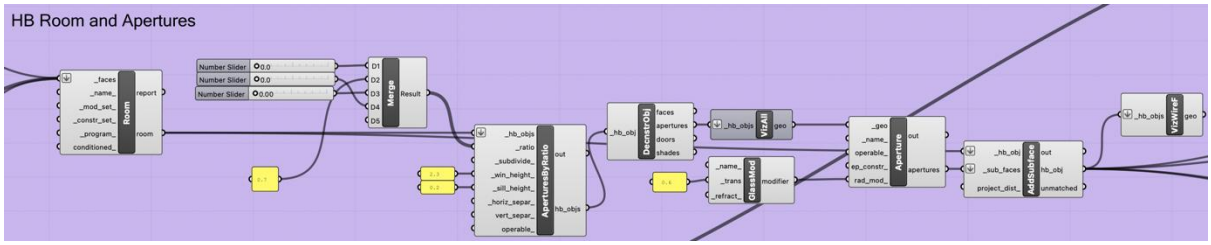


Figure 3. Grasshopper workflow for WWR adjustment

The use of this standardised reference office in place of an actual Central Plaza tenant space enables the internal geometry, material qualities and occupancy assumptions to be kept controlled. Therefore, the variations between simulated scenarios can be more directly associated with WWR and external blockage, the main variables studied here.

3.4. Obstruction Quantification and Classification based on Sky View Factor

To systematically quantify external obstruction around Central Plaza, SVF was adopted as the primary geometric indicator, as it represents the proportion of the sky vault visible from a given point or surface and provides a quantitative measure of how much surrounding urban geometry obstructs sky exposure. It provides a more consistent descriptor for systematically defining obstruction. SVF theoretically ranges from 0 for complete obstruction to 1 for an unobstructed point with full-sky exposure. However, for this study, SVF was calculated across the three principal façades of Central Plaza: south, northwest, and northeast, so the maximum value is approximately 0.5, since the façade can receive sky only from the outward-facing half of the vault.

To capture the spatial variation in SVF, each façade was subdivided into a 2.8 m grid, corresponding to the height of the reference office. SVF was then calculated for each grid cell. Finally, the calculated values were mapped onto the façades to visualise variations in sky exposure both vertically and across different orientations. These calculations and visualisations were achieved in Grasshopper.

Based on the calculated façade SVF distribution, three representative conditions were selected for the subsequent parametric analysis: SVF = 0.1, 0.3, and 0.5. These values represent, respectively, highly obstructed, partially obstructed, and minimally obstructed or near-unobstructed conditions. Rather than assigning fixed lower, middle, and upper floors in advance, representative locations were identified according to their SVF values.

3.5. Climate-based Daylight Simulation

Climate-based daylight simulations were carried out in Rhino and Grasshopper using Ladybug and Honeybee. The reference room, Central Plaza façade and surrounding buildings were modelled in Rhino. Grasshopper was used to vary WWR systematically and manage the simulation cases. Ladybug imported and processed the local climate data, while Honeybee linked the parametric model to the daylight simulation engine. This integrated workflow enabled geometric and environmental parameters to be controlled

consistently across all simulation scenarios, ensuring comparability between different WWR and obstruction conditions. The specific parameters for daylight simulation are demonstrated in Table 3 and Table 4 below:

Table 3. Fixed parameters for daylight simulation

Reference Room	Wall	Lambertian diffuser with a 50% reflectance
	Ceiling	Lambertian diffuser with an 80% reflectance
	Floor	Lambertian diffuser with a 20% reflectance
	Glazing	Double glazing with a 65% visible transmittance
	Horizontal Position	At the centre of each façade on selected height.
	Occupied Hours	8:00 am to 6:00 pm
	Viewpoint for Glare	On the central axis of the room, at 2 m from the window
Urban Context	Ground	Lambertian diffuser with a 20% reflectance
	Buildings	Lambertian diffuser with a 40% reflectance
	Obstruction Range	Within a 200 m radius
Simulation Parameters	Weather file	Hong Kong SAR EPW
	Radiance	-ab 5 -ad 2048 -as 2048 -aa 0.2 -ar 64 (medium resolution)
	Grid size	0.5 m for daylight provision, 1.0 m for visual comfort
	Working plane	0.85 m for daylight provision and 1.2 m for visual comfort

Table 4. Variables for daylight simulation

Obstruction Conditions	Decided by the Sky View Factor (0.10, 0.30, 0.50)
Window-to-Wall Ratio	0.10, 0.26, 0.39, 0.52, 0.70, and 0.87
Orientations	South, northwest, northeast

3.6. Daylight Performance Metrics

Daylight performance was evaluated from two complementary perspectives: daylight provision and visual comfort.

Daylight provision in this study was assessed using Spatial Daylight Autonomy (sDA), specifically, $sDA_{100,50\%}$, $sDA_{300,50\%}$, $sDA_{500,50\%}$, and $sDA_{750,50\%}$. The interpretation of these metrics followed the daylight provision recommendation adopted from *BS EN 17037* [29], which is shown in Table 1 in Section 2.3.1. These metrics allow the daylight response to changes in WWR to be examined across different illuminance levels rather than relying on a single criterion. All sDA results are expressed as proportions ranging from 0 to 1. A larger value indicates that a greater proportion of the reference office achieves the specified daylight illuminance for at least half of the evaluated period, referring to better daylight provision.

Visual comfort was evaluated using Daylight Glare Probability (DGP) that does not exceed a maximum value for more than 5% of the space's usage time, namely $DGP_{e<5\%}$. This metric followed the daylight provision recommendation adopted from *BS EN 17037* [29], as shown in Table 2 in Section 2.3.2. To extend the point-based DGP analysis spatially across the reference office, Spatial Glare Autonomy (sGA) was calculated as a supplementary metric. All $DGP_{e<5\%}$ and sGA results range from 0 to 1, but their interpretations are opposite: a higher sGA indicates better visual comfort, whereas a higher $DGP_{e<5\%}$ indicates less visual comfort.

3.7. Data Processing

Following the simulations, all daylight performance results were compiled and processed in Microsoft Excel. The data were organised and demonstrated according to façade orientation, SVF condition, and WWR, with $DGP_{e<5\%}$, sGA, $sDA_{100,50\%}$, $sDA_{300,50\%}$, $sDA_{500,50\%}$, and $sDA_{750,50\%}$, recorded for each simulation case.

The results were visualised using line charts, with WWR as the independent variable and the daylight performance metrics as dependent variables. For metrics with recommendations specified in *BS EN 17037,* multiple corresponding performance thresholds were indicated using dashed reference lines [26]. The resulting response curves were compared across different SVFs and façade orientations to identify overall trends in the relationship between WWR and daylight performance. Particular attention was given to non-linear responses, saturation effects, and changes between adjacent WWR iterations. These comparisons were used to identify the WWR ranges in which increasing glazing produced the greatest improvement in daylight provision, as well as the ranges in which further increases resulted in diminishing daylight benefits or increased glare risk.

4. Results and Findings

This section presents the results and findings of the parametric daylight simulations, examining the effects of Window-to-Wall Ratio (WWR), Sky View Factor (SVF), and façade orientation on daylight provision and visual comfort. Six WWR configurations, ranging from 0.10 to 0.87, were evaluated under representative SVF conditions of 0.10, 0.30, and 0.50. As no representative northeast façade location corresponding to SVF 0.10 was available, this combination was excluded from the analysis. The final dataset therefore comprises eight valid orientation-SVF combinations and 48 simulation cases. This section focuses on the principal response patterns and uses selected figures to illustrate the most representative relationships between WWR and daylight performance.

4.1. Sky View Factor across the Three Target Façades

Figure 4 maps the calculated SVF across the south, northwest, and northeast façades of Central Plaza. A clear vertical gradient is visible on all three façades. The lower parts of the tower generally have lower SVF values, while SVF increases with height and approaches approximately 0.50 in the more exposed upper parts of the façades. This confirms that external obstruction is not uniform over the height of the tower and that different façade areas experience substantially different access to the sky.

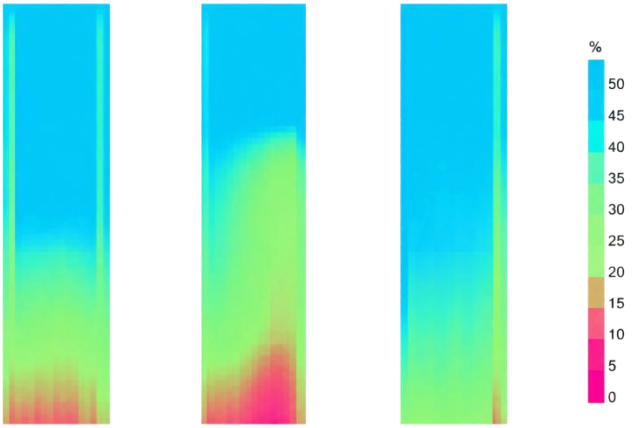


Figure 4. The SVF pattern of façade: south (left), northwest (middle), and northeast (right)

According to Figure 4, the three façades nevertheless show different spatial distributions. On the south façade, the lowest SVF values are concentrated near the base, followed by a relatively rapid transition through intermediate SVF values before the upper façade becomes predominantly high. The northwest façade contains the most extensive low-to-intermediate SVF region. Its transition from highly obstructed to highly exposed conditions results in an expanded vertical zone of intermediate SVF. The northeast façade is comparatively more open. Its lower region is dominated by intermediate rather than very low SVF values, and a large proportion of the upper façade is close to the maximum façade SVF. However, no sufficiently representative area around SVF 0.10 was identified on the northeast façade, which accounts for the missing result in the northeast-SVF 0.10 simulation set.

4.2. Effects of Window-to-Wall Ratio on Daylight Provision

4.2.1. General Trend

Across all orientations and SVF conditions, the four sDA metrics either remain constant or increase as WWR rises. Across the valid cases, raising WWR from 0.10 to 0.87 increases mean $sDA_{100,50\%}$ from 50.7% to 96.4%, $sDA_{300,50\%}$ from 14.0% to 82.4%, $sDA_{500,50\%}$ from 5.6% to 69.3%, and $sDA_{750,50\%}$ from 2.2% to 55.7%. This indicates that enlarging the window area increases the spatial coverage or duration of daylight within the room, thereby improving overall daylight provision.

However, the relationship between WWR and sDA is not linear. In general, increasing WWR at lower values produces a substantial improvement in all four sDA metrics. As WWR continues to grow, the rate of improvement eventually slows, and some indicators begin to saturate. The connection thus follows an asymptotic saturation pattern, with a quick initial increase followed by increasingly diminishing marginal gains at higher WWR values. This impact is especially visible for lower illuminance thresholds like $sDA_{100,50\%}$.

4.2.2. Effect of different Sky View Factor Conditions

Under the same orientation and WWR conditions, a higher SVF generally produces higher values across all four sDA metrics, indicating that greater sky exposure improves indoor daylight provision. However, the influence of SVF is not constant. Before the sDA metrics approach saturation, the differences between SVF conditions generally become larger as WWR increases. Once the sDA of the room with higher SVF reaches 100%, these differences stop increasing and begin to narrow.

The $sDA_{300,50\%}$ results for the south façade provide a clear example (see Figure 5). At WWR 0.10, $sDA_{300,50\%}$ is 4.28%, 12.85%, and 25.71% under SVF 0.10, 0.30, and 0.50, respectively, producing a maximum difference of 21.43%. At WWR 0.39, the corresponding values rise to 31.43%, 57.14%, and 100%, increasing the maximum difference to 68.5%. At WWR 0.87, however, the difference decreases to 54.29% because the SVF 0.50 case has already reached saturation. A similar overall response is observed for the other sDA thresholds. Lower illuminance thresholds, particularly $sDA_{100,50\%}$, tend to reach saturation earlier, whereas higher thresholds such as $sDA_{500,50\%}$ and $sDA_{750,50\%}$ remain responsive over a larger WWR range.

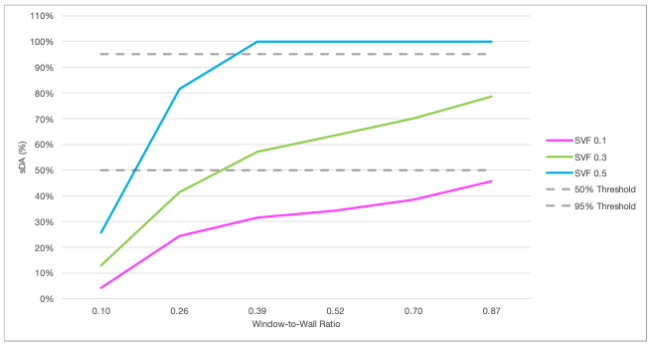


Figure 5. Effect of WWR on $sDA_{300,50\%}$ under different SVFs on the south façade

This pattern results from the interaction between window size and external obstruction. At low WWRs, the small window area limits daylight admission for all obstruction conditions, so the benefit of greater sky exposure cannot be fully utilised. As WWR increases, larger windows allow high SVF conditions to admit substantially more skylight, widening the performance gap. Once sDA approaches its upper limit, although more lights come in, further increases in daylight cannot be fully represented by these metrics.

4.2.3. Effect of Different Orientation Conditions

Under the same SVF and WWR conditions, façade orientation affects daylight provision, but its influence is very small. In most cases, the sDA curves of the south, northwest, and northeast façades remain relatively close.

For example, under SVF 0.1, for $sDA_{300,50\%}$, under WWR 0.87, the results are 46.79% for northwest and 45.71% for south, while similarly small differences are observed across the other WWR conditions. Their daylight-provision result curves are almost identical (see Figure 6). This indicates that orientation has only a limited effect when surrounding obstructions substantially restrict access to the sky. Similar patterns appear under SVF 0.5. Although under SVF 0.3 there are slight differences between orientations, they are significantly smaller than the differences between SVFs, which might be due to inaccuracies in the simulation.

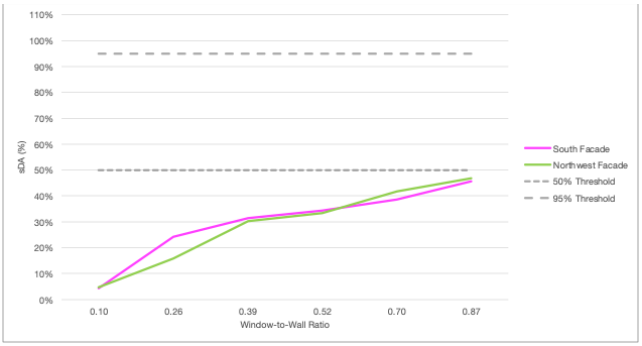


Figure 6. Effect of WWR on $sDA_{300,50\%}$ on different orientations under SVF 0.1

This pattern may be explained by the substantial contribution of diffuse skylight to annual daylight provision. Diffuse light is distributed more evenly across orientations than direct sunlight (which is more strongly affected by façade orientation), reducing the overall orientation effect on sDA. In addition, surrounding buildings may block directional sunlight, thereby further reducing orientation-related differences in daylight performance.

4.3. Effects of Window-to-Wall Ratio on Visual Comfort

4.3.1. General Trend

Across all valid simulation cases, increasing WWR was consistently associated with a deterioration in visual comfort. As WWR increased from 0.10 to 0.87, the mean $DGP_{e<5\%}$ increased from 0.245 to 0.468, while the mean sGA decreased from 95.7% to 69.5%. This indicates that the improvement in daylight access associated with larger windows was accompanied by a progressively greater glare risk.

In general, the largest sGA reduction occurs between the beginning and end of the WWR increase, namely WWR 0.10-0.26 and 0.52-0.87. Between WWR 0.26 and 0.52, the decline is relatively gentle. The variation in $DGP_{e<5\%}$ is essentially the inverse of sGA, characterised by an initial rapid increase at lower WWR, followed by a more gradual increase, and then a further increase at higher WWR values.

4.3.2. Effect of different Sky View Factor Conditions

Under the same orientation and WWR condition, a higher SVF generally results in a higher $DGP_{e<5\%}$ value and a lower sGA value. More importantly, the influence of SVF is not constant but becomes progressively stronger as WWR increases. As the WWR increases, the differences in $DGP_{e<5\%}$ and sGA between SVF conditions become progressively larger.

The northwest façade clearly illustrates this interaction (see Figure 7). At WWR 0.10, $DGP_{e<5\%}$ values under SVF 0.10, 0.30, and 0.50 yield a maximum difference of only 9.47%. The corresponding sGA values result in a maximum difference of only 8.33%. However, at WWR 0.87, visual comfort in the room with higher SVF tends to worsen with higher percentage points. The $DGP_{e<5\%}$ values produce a maximum difference of 28.18%. Similarly, the corresponding sGA values result in a maximum difference of 30.21%. Similar amplification effects can be observed on the south and northeast façades.

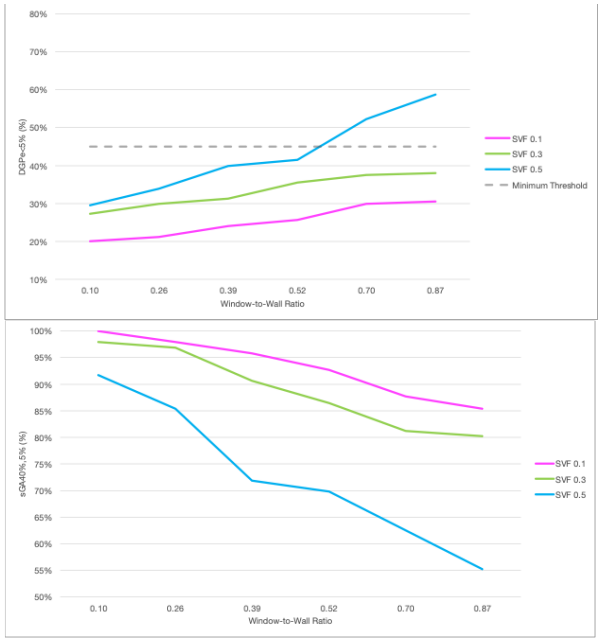


Figure 7. Effect of WWR on $DGP_{e<5\%}$ (left) and sGA (right) under different SVFs on northwest façade

This indicates that at low WWRs, the relatively small window area limits the amount of light entering the room, so visual-comfort differences across SVF conditions remain modest. As WWR increases, the larger glazed area admits more light from the visible sky, substantially enlarging the performance difference between highly obstructed and highly exposed conditions.

4.3.3. Effect of different Orientation Conditions

Unlike the sDA results, which have similar values under different orientations, under the same SVF and WWR conditions, the south façade generally produces a higher $DGP_{e<5\%}$ value and a lower sGA value, indicating poorer visual comfort than the northwest and northeast façades. Nevertheless, although the differences between orientations become more apparent as both SVF and WWR increase, the overall influence of orientation on the visual-comfort metrics is smaller than the influence of SVF, especially under severe obstruction conditions.

Under SVF 0.10, at WWR 0.10, their performance is similar, and the south façade even records a lower $DGP_{e<5\%}$ than the northwest, at 16.71% and 20.13%, respectively. As WWR increases, however, the south façade experiences a greater deterioration in visual comfort. At WWR 0.87, the northwest façade records a $DGP_{e<5\%}$ of 30.53% and an sGA of 85.42%, whereas the south façade reaches a higher $DGP_{e<5\%}$ of 35.56% and a lower sGA of 80.00% (see Figure 8). This suggests that orientation has a stronger influence on visual comfort. The effect of orientation becomes more pronounced under SVF 0.30 and 0.50.



Figure 8. Effect of WWR on $DGP_{e<5\%}$ (left) and sGA (right) on different orientations under SVF 0.10

This pattern can be explained by the interaction between façade orientation, sky exposure, and glazing area. Unlike sDA, the metrics of visual comfort are influenced more by direct sunlight, which is significantly affected by the orientations. When SVF or WWR is low, surrounding obstructions and the limited window area restrict daylight entry, reducing the importance of orientation. As SVF and WWR increase, a larger proportion of the direct sunlight becomes visible through the window. The south façade consequently receives stronger and more variable daylight exposure, resulting in higher DGP values and a faster reduction in sGA.

5. Discussion

The findings show how Sky View Factor (SVF) can be used to describe external obstruction and examine the relationship between Window-to-Wall Ratio (WWR) and daylight performance in a dense high-rise setting. This section addresses the three research questions before considering the implications for window sizing under different obstruction conditions.

5.1. Sky View Factor as Quantification of High-Rise Daylight Obstruction

The first research question asks how daylight obstruction can be defined and quantified across different floor levels. Previous studies have shown that the three-dimensional arrangement of surrounding buildings strongly influences daylight performance in dense urban environments [3, 4]. In this study, SVF provided a consistent measure for comparing obstruction across façade locations. This use of SVF also follows the approach to characterising external obstruction described in [16].

SVF expresses sky exposure as a single numerical value, making it easier to compare locations with different surroundings. Floor level alone cannot fully describe these conditions: locations at the same height may have different amounts of visible sky because of the position and height of neighbouring buildings. Classifying façade locations by SVF therefore provides a more direct description of sky exposure. The three values selected here, 0.10, 0.30 and 0.50, represent high, intermediate and low obstruction within the range investigated.

Organising the WWR analysis around these SVF values provides a basis for comparisons with other buildings, without assuming that equivalent floor levels have equivalent sky exposure. However, this does not establish that the same daylight responses will occur elsewhere. SVF describes the amount of visible sky, while differences in the distribution of obstructions, façade orientation and climate may still affect daylight performance.

5.2. Daylight Performance Response to Window-to-Wall Ratio

The second and third research questions concern how daylight performance responds to WWR across different obstruction conditions. A key finding of this study is that the relationship between WWR and daylight performance should be understood as a non-linear response. It is important to distinguish between light admission and metric-based daylight performance. The non-linear response identified here does not imply that WWR has a non-linear relationship with the amount of light admitted through the window. Rather, it describes how daylight performance, as evaluated using sDA- and DGP-based metrics, responds to changes in WWR.

For daylight provision, across different SVFs, the greatest gains generally occur between WWR 0.10 and 0.39, after which the rate of improvement gradually becomes smaller. This suggests that the low-to-moderate WWR range is the most sensitive part of the response, while further enlargement produces increasingly smaller marginal benefits. Additionally, this non-linear pattern shows differences under different SVFs. Under the highly obstructed condition (SVF 0.10), daylight provision improves relatively slowly across the entire WWR range. However, the daylight metrics remain responsive even at large WWRs because the room is still constrained by limited external sky exposure. Increasing window area therefore continues to provide some benefit, but the improvement is insufficient to fully compensate for the severe obstruction. The daylight provision under partially obstructed conditions (SVF 0.30) shows a more pronounced response to WWR, but the saturation comes earlier. The response effect is strongest under SVF 0.50, in which increasing WWR from 0.10 to 0.26 produces the greatest improvement in daylight provision. This explains the widening sDA gap before achieving saturation observed in the Results and Findings section. As WWR increases, higher SVF conditions become progressively more sensitive to additional glazing, while lower-SVF conditions remain comparatively buffered by surrounding obstruction.

Visual comfort exhibits a similar but different non-linear response. Across the tested SVF conditions, the deterioration generally follows a rapid-moderate-rapid pattern as WWR increases. At very low WWR, even a modest window enlargement produces an initial rapid deterioration in visual comfort. However, at low WWR, the deterioration is usually acceptable. As WWR moves into the intermediate range, the additional change in glare becomes comparatively less pronounced. At high WWR, the window occupies a much larger proportion of the façade and exposes the interior to more bright sky and, depending on orientation, to direct solar components. The glare response therefore intensifies again. The magnitude of this rapid-moderate-rapid pattern also varies with SVF, similar to daylight provision. This also

explains the widening $DGP_{e<5\%}$ and sGA gap observed in the Results and Findings chapter as WWR increases, similar to sDA.

Together, these results suggest three broad stages in the response to increasing WWR. At low WWR, enlarging the window produces the greatest gains in daylight provision, particularly at moderate and high SVF. Visual comfort declines rapidly over this range, although the overall change remains relatively small, especially under low-SVF conditions. At intermediate WWR, daylight provision continues to improve at a slower rate, while visual comfort deteriorates more gradually. At high WWR, further increases in window area offer diminishing daylight gains and a greater glare penalty. These patterns help identify the WWR ranges in which changes to window size are most effective under different obstruction conditions. They also inform the SVF-responsive design recommendations in the following section.

5.3. Suggestion for High-Rise Façade Design

The main design implication is that a uniform WWR across an entire high-rise façade may not respond effectively to the large variation in daylight obstruction occurring with height and orientation. Instead, the findings support an SVF-responsive façade strategy, in which WWR is adjusted according to local sky exposure.

Under highly obstructed conditions, represented by approximately SVF 0.10, the façade can be considered the most daylight-constrained. Although increasing WWR continues to decrease visual comfort rapidly, the values remain within the acceptable range throughout. The more important part is to improve the daylight provision. Therefore, a larger WWR is suggested. Nevertheless, simply maximising WWR is sometimes unlikely to fully compensate for severe external obstruction.

At SVF 0.10, none of the tested WWR configurations on the south and northwest façades met the minimum daylight provision recommendation. Increasing window area alone was therefore insufficient under these conditions. Other daylight solutions, such as light shelves, atria or light wells, could also be investigated, although their applicability depends on the building geometry and its plasticity and the amount of existing obstructions. Adequate lighting can also be achieved with the help of electric lights.

In SVF 0.30, using WWR adjustments to increase daylight has a bigger benefit than to enhance visual comfort, when a suitable increase is applied in the middle of the tested range. The discovery that larger WWR has a bigger benefit for daylight than for visual comfort indicates that WWR is a useful variable for design under a partially obstructed sky.

At SVF 0.50, glare places a greater restriction on window size. Daylight gains diminish as WWR increases, while visual comfort can deteriorate substantially. Smaller WWRs may therefore be appropriate, provided that they still deliver sufficient daylight. On the south and northeast façades, WWR 0.26 was the only tested configuration that met the recommendation at this SVF. Where larger windows are required, shading should be considered alongside window size to manage glare. Its effectiveness would need to be assessed through further simulations.

These suggestions focus on WWR because it was the main façade variable examined in this study. The identified values provide starting points for design under different levels of sky exposure, rather than fixed prescriptions. Their suitability in practice will also depend on other environmental requirements, architectural constraints and the way the building is used.

6. Conclusion

6.1. Summary

This study examines the combined effects of window size, external obstruction, and façade orientation on daylight performance in high-rise buildings. SVF measures the amount of visible sky at each location. It helps explain these relationships. In the cases tested, sDA rises with WWR. The gains become smaller with larger windows. The glare results, measured using $DGP_{e<5\%}$ and sGA, show a faster decline in visual comfort at both ends of the WWR range. The change is more gradual in the middle of the range.

The findings add to earlier research on the effect of urban geometry on daylight. The study offers three contributions: a method linking SVF patterns across a real building's façades to WWR assessment; simulated WWR–daylight response curves covering different orientations and levels of external obstruction; a practical design approach based on local SVF for choosing WWR. The sections below explain these contributions, discuss the study's main limitations, and give specific recommendations for building design, policy, and future research.

6.2. Contributions

First, the methodological contribution is that the study uses façade SVF mapping to translate a complex 3D urban context into representative obstruction conditions. Rather than assume fixed lower, middle, and upper floor categories, the actual visible sky for the south, northwest, and northeast façades of the case building. This approach extends earlier applications of SVF in urban daylight analysis and provides a transferable obstruction metric.

Second, the empirical contribution is the systematic response curves generated for daylight provision ($sDA_{100,50\%}$, $sDA_{300,50\%}$, $sDA_{500,50\%}$, and $sDA_{750,50\%}$) and visual comfort ($DGP_{e<5\%}$ and sGA) as functions of WWR under each SVF and orientation. These curves quantify how WWR influences daylight performance under different SVFs. This empirical mapping of the WWR and daylight performance relationship has not been reported in the literature for a real high-rise façade and thus fills a knowledge gap.

Lastly, the study presents a practical way to choose WWR based on local sky exposure in dense high-rise districts. This approach is explored in the Discussion section. The findings support using different WWR values across a building to reflect external obstruction. In the most obstructed case tested (SVF 0.10), improving daylight provision is the priority. Larger windows alone may not provide enough daylight. Additional daylight strategies may be needed. At SVF 0.30, moderate WWR increases can greatly improve daylight provision. At SVF 0.50, larger WWR values bring smaller daylight gains. Glare becomes a greater concern. Mapping SVF early in the design process could help designers choose window sizes suited to the daylight conditions at different locations across the building's façades.

6.3. Limitation

Nevertheless, these results should be considered with some important limitations. The study used only one case study, namely Central Plaza in Hong Kong, and it used only one urban context in one climate. The selected façades

represented different levels of obstruction. SVF patterns could be different in districts with different building densities, street sizes and surrounding building heights. Daylight responses could be different in such alternative urban contexts. The humid subtropical climate of Hong Kong restricts generalisation of these results to other climates. The relative dominance of diffuse skylight in some climates could be different in temperate, arid, high-latitude climates.

The simulations used a standard reference office. No occupied rooms were modelled within Central Plaza. Room geometry, glazing type, visible transmittance, internal surface reflectance, occupant schedule and simulation options were all kept fixed. This allowed a controlled comparison of the effects of WWR and external obstruction on a controlled internal space. However, it does not represent the wide range of office layouts, occupancies and schedules experienced by the actual office occupants of the building. Neither were furniture, internal partitions, occupant behaviour or blinds modelled.

The number of specific values of SVF and WWR tested was limited. Three representative SVF values were tested – 0.10, 0.30, 0.50 – as a convenient coarse representation of the range of SVF values in the case study. No suitable location on the façade of Central Plaza for SVF 0.10 was found on the northeast façade, for example. For WWR, six different values were tested – 0.10, 0.19, 0.24, 0.32, 0.67, 0.87 – as a convenient coarse representation of the range of WWR values considered in the case study. The transition ranges found in these cases are approximate. More closely spaced samples would be needed to identify their positions more precisely.

The research investigated daylight provision and visual comfort. It did not evaluate thermal comfort, solar heat gain, heating demand, cooling demand or view quality. These variables affect window design. Including them in an assessment may modify the WWR option. The results are particularly valuable for understanding the patterns of response of WWR–SVF under the conditions investigated. They do not provide numerical design rules applicable to all high-rise offices.

6.4. Recommendations

The findings are relevant to office occupants, designers, and policymakers. Occupants choosing a workspace need to consider daylight availability and glare. Larger windows do not necessarily offer better visual conditions. Designers could assess SVF early in the design process. A similar measure of external obstruction could serve the same purpose. This assessment could guide local WWR choices across the façade. Locations with low SVF may need larger windows. Additional daylight strategies may be needed to improve daylight provision. Locations with high SVF may benefit from moderate glazing areas combined with glare control to balance daylight provision with visual comfort. Policymakers could use the findings to make daylight guidance for dense high-rise districts more responsive to surrounding obstructions and the amount of visible sky. Allowing different WWR values to reflect local sky exposure would give designers more freedom to address variations in daylight conditions across different parts of a building.

6.5. Future Research

Future research could test the relationships found in this study across other buildings in different climates. The approach could be applied to a wider range of urban geometries across temperate, arid, and continental climates. Combining daylight simulations with models of thermal performance and energy use would allow WWR optimisation to include heating demand, cooling demand, daylight provision, and glare. The current analysis could cover shading options such as automated blinds and adaptive shading. Separate scenarios for occupant operation could examine the effects of shading controls and user behaviour on glare. More closely spaced samples for SVF and WWR would help describe the response curves in greater detail. Field measurements in existing high-rise offices could help assess how closely the simulated performance matches the measured results. Post-occupancy surveys could examine occupants' satisfaction with daylight and their experience of glare. Additional parametric studies could test different values for glazing visible transmittance and the reflectance of internal surfaces. These studies could show how these factors affect the WWR–daylight relationships found in the current research

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