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View Access Index: The effects of geometric variables of window views on occupants' satisfaction

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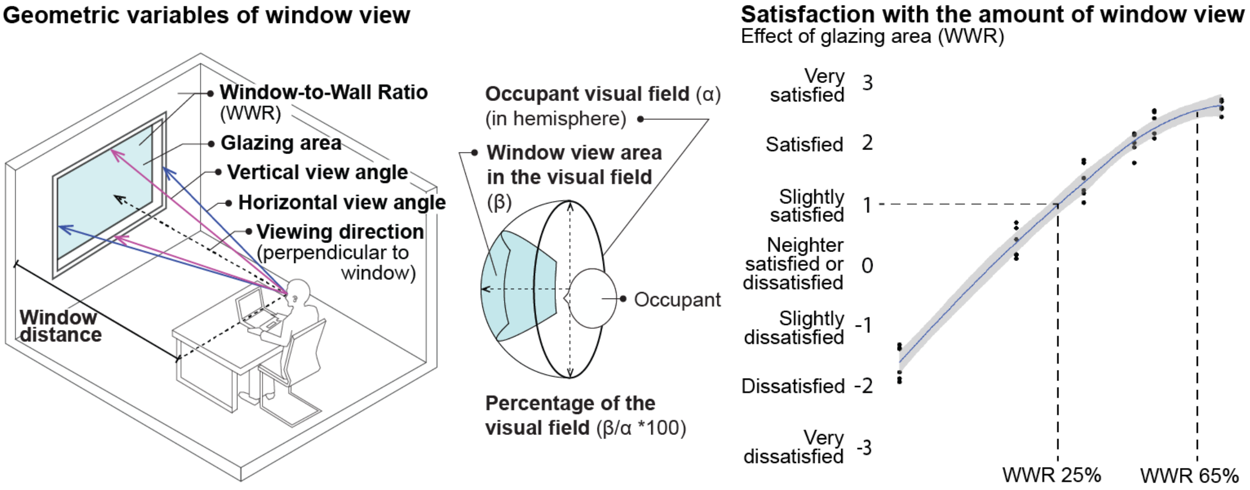
Highlights

- We assessed the effect of geometric variables on view access satisfaction
- 40 participants rated simulated images in virtual reality headsets
- Glazing area, window distance and viewing direction are the primary predictors
- We developed an index that predicts view access satisfaction.
- At minimum, we recommend 25% WWR and 35° horizontal view angle for view access

Abstract

One of the important aims of window design is to provide quality views that affect occupant health, well-being, and work performance. We assessed the effect of geometric variables (i.e., view angles, glazing area (Window-to-Wall Ratio, WWR), window distance, viewing direction and percentage of window view area in the visual field (PWV)) had on occupants' satisfaction to view access. We conducted a human subject experiment with 40 participants using simulated images displayed in virtual reality headsets. Each participant rated 40 images with the geometric window view variables being presented in various combinations. The results showed that glazing area (WWR), window distance, and viewing direction were the three primary predictors for view access satisfaction. Based on the empirical results, we developed a view access index. This index found that satisfactory view access cannot be achieved with WWRs < ~25%, and the level of satisfaction with view access did not increase substantially when WWRs > ~65%. The proposed index is the first model that predicts occupant satisfaction to view access by considering the complex interplay of multiple geometric window view variables derived from an immersive environment. Given the impact of glazing area, window distance and viewing direction have on occupant satisfaction in the workplace, it is important to integrate them during the early stages of building design. For minimum view access requirements, we recommend WWRs and horizontal view angles that are greater than 25% and to 35°.

Graphical Abstract



Keywords

Window view quality, view access, window size, virtual reality, occupant satisfaction

1. Introduction

Windows are an important architectural element in building design as they are the primary means of creating a connection between the indoors and outdoors. Window design directly influences different aspects of indoor environmental quality (IEQ), such as (day)lighting, thermal, acoustic, and air quality [1,2]. They also enable outdoor views (i.e., window views), and the quality of such views affects occupant health [3,4], well-being [5–8], and work performance [6,9–11].

Designing for a quality view is a complex problem. Multiple factors affect view quality, including, but not limited to, the conditions surrounding the building, aperture size, and the optical properties of the window [12–14]. Nonetheless, the lack of guidance through the design process prevents designers from being able to systematically evaluate window view quality (defined as “the quality of the visual connection to the outdoors that satisfies building occupants” [15]). To help streamline this process, our previous research identified three primary variables that converged on the concept of window view quality: namely, content, access, and clarity [16], whereby this study focused on features responsible for access.

View access is defined as "the amount of the view an occupant can see from the viewing position” [16]. View access primarily depends on the geometric relationships between the window(s) and the occupant, which are determined by window size and shape, viewing distance and direction. View access has been evaluated using view angles, window-to-wall ratio (WWR), viewing distances, and spatial metrics (i.e., the percentage of occupied space that has direct line of sight to outdoors). However, none of these collectively consider the interplay of all factors that affect visual access [16,17], which cannot be easily assessed without the empirical findings using a controlled environment. For example, it remains unclear whether the view angle has the same effect on the perceived view access, depending on the viewing distance from the window. Although a controlled study had reported a general decrease in view quality when moving further away from the window [17], another field study [18] showed no effect of viewing distance. The latter may have been a consequence of glare, overheating, or privacy, which are more prevalent nearby windows, confounding the outcome. Moreover, occupants sat closer to windows do not invariably look directly at the view. Viewing direction (i.e., seated parallel or perpendicular to the window) can change the location of the window view relative within the occupants’ visual field (e.g., primary vs periphery). This situation significantly varies the access granted when occupants are seated perpendicular to the window, yet is not considered in design guidelines.

Solid angles can be used to assess view access [19]. Based on the size of a window, viewing distance and direction, we can calculate either solid angles or a percentage of how much of the observer’s visual field is filled with window. Solid angle is also one of the parameters embedded in daylight glare metrics (e.g., Daylight Glare Probability, [20]). The visual field percentage method is similar to the solid angle. Some studies have used similar concepts, including:180° equidistant projection of the windows to plot [21]; External View Factor that represents the number of view vectors that are not blocked by any interior obstructions [22]; or Minimum View Potential that calculates the proportion of total rays cast from one origin point that intersect outdoor view elements [23]. However, these simulation methods and tools also were not developed based on the empirical results and require further validation for their efficacy. It is important to identify what the primary factors for view access and the critical thresholds for each, in order to further improve the current metrics and visualization methods.

The major guidelines that provide recommendations for view access are:

- EN 17037 and SLL-LG 10 [24,25]: both only use the horizontal view angle from the position of the observer to the opening to inform window width. Position may be defined by utilizing the furthest zonal distance from the glazing to the window.
- WELL v2-pilot [26] uses the vertical view angle that translates to the window height relative to the observer position, while LEED v4 [27] uses the smaller of either the horizontal or vertical angle to determine the size of the view for View Factor assessments.
- DIN 5034 (DIN, 2011) require workspaces to be located within a 10 m perimeter from a window [28].
- BREEAM defines the minimum size (by the WWR) depending on viewing distance from window(s) [30].

Other green certification systems mostly rely on a spatial assessment approach, defined by the percentage of floor space that provides visual contact to the window(s) [31–37].

To the best of our knowledge, most of the above guidelines were not developed based on human-subject studies. In order to evaluate view access, building designers and engineers need an assessment metric that is developed based on empirical findings, yet has inherent practical utility (i.e., not overly complex) [15]. Therefore, we aim to: (1) Experimentally assess the effect of the geometric window variables (i.e., view angles, window distance, viewing direction, glazing area, percentage of window area in the visual field) on occupant satisfaction with view access; (2) Develop an index that predicts view access satisfaction based on such geometric variables; and (3) Identify the minimum and saturation thresholds for occupant satisfaction with view access.

To achieve these aims, we conducted a human-subjects study, with the visual environment being displayed in a virtual reality (VR) environment.

2. Method

Varying the geometry of any window and assessing its impacts on occupant satisfaction, under controlled conditions, is inherently difficult in a real-world setting. Architectural parameters (e.g., window configuration and furniture layout) will naturally change the content seen in the view. The temporal characteristics of daylight also prevents two or more conditions from being assessed under comparable illumination, meaning that glare or overheating, among many other confounding factors, may negatively influence occupant satisfaction, and impede robust and replicable conditions. In response to these constraints, we used a VR headset and adapted experimental methods [38] to investigate the changes to the geometric variables of a window view on visual perception (i.e., view access). These protocols have been developed and validated against real environments [39–44] and window sizes [45], often revealing either no, or somewhat minor changes, in visual perception across the conditions experienced.

2.1 Experimental design

We conducted a randomized within-subject experiment. The experiment entailed the variation of the geometric window variables (e.g., view angles, window distances and viewing directions), changing the window size and the percentage of window area seen in the visual field (Figure 1).

Each subject rated 40 virtual environment scenes, with different combinations of the geometric factors (see Table 3). To avoid an order effect, we presented the virtual environment scenes in a randomized order using the List Randomizer [46], that creates a sequence for the 40 different scenes that would appear in a random order for each participant. The experiments took place between December 2020 and April 2021.

2.2 Participants

A total of 40 subjects (23 males and 17 females) participated in the experiment. The total sample size was determined using the software G*Power [47], which indicated that a sample size of 40 participants would have been sufficient to provide a power of 0.80. We used the paired samples t-test and aimed to achieve effect sizes (i.e., differences in satisfaction with view access across our experimental conditions (e.g., horizontal view angle, distance to window, and WWR)) that met a minimum predefined threshold ($d > 0.41$) denoting practical significance [48]. Effect sizes less than this threshold would have been too small to have any practical implications to occupant satisfaction. Although we had multiple outcome variables, our analysis was primarily applied to the horizontal viewing angle, as this is currently one of the main design parameters for view access advocated by the EN 17037. Due to COVID-19 safety restrictions, our experiment was conducted remotely to avoid in-person contact. We recruited people that owned an Oculus Rift S headset and were able to configure their device to meet our experimental requirements via online VR user groups in the United States. While recruiting, we considered the following inclusion criteria: at least 18 years old, no known visual impairments (e.g., color blindness, eye disorders), no history of photosensitive seizures, and were not pregnant. The Committee for the Protection of Human Subjects (CPHS) at the University of California, Berkeley reviewed and approved the study protocol (2020-03-13132). All participants provided informed consent, and each received 20 USD to compensate for their participation.

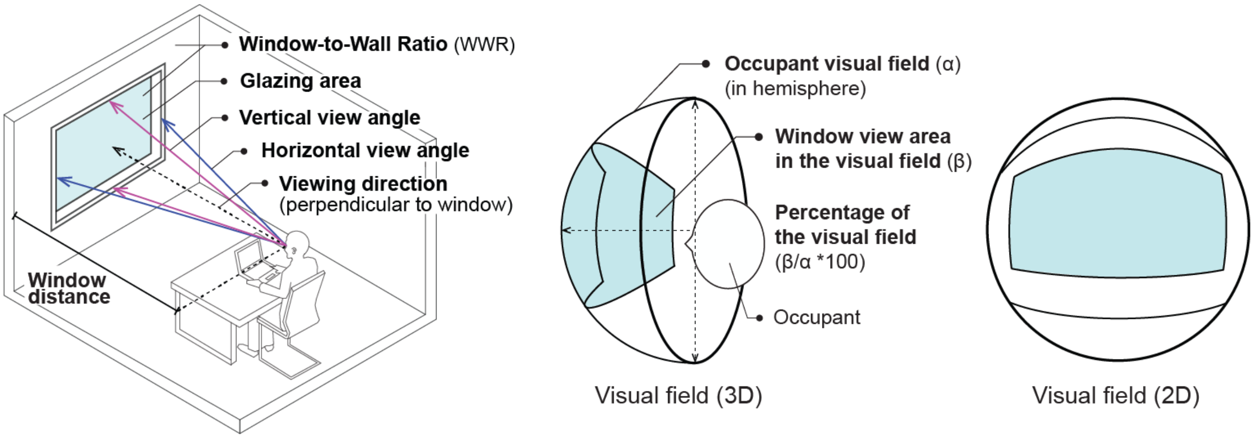


Figure 1 Variables of view access: WWR, viewing directions (perpendicular and parallel), viewing distance, view angles (horizontal and vertical), and the percentage of the visual field.

2.3 Virtual environment scenes and equipment

In our experiment, simulated images represented the visual environment. Participant satisfaction with view access was measured when viewing each visual environment displayed by the VR headset. We described below how we developed the images.

Base office space

To assess how window geometry affected occupant satisfaction to view access, we modeled a typical office space based on the Medium Office Model sourced from the United States Department of Energy Commercial Reference Buildings [49]. Our model was 50 m (width) x 16.5 m (depth) x 2.74 m (ceiling height), which represented half of a single floor from the reference building. Our model had a north-orientated window to control the direct sunlight admittance, permitting only diffused daylight transmittance into the office at midday.

Glazing area

Glazing area is often analyzed using Window-to-Wall Ratio (WWR) in building standards and guidelines. WWR is calculated as the ratio of the glazing area to the wall area. The commercial reference building has 48% WWR [49]. To assess the effect of the geometric window variables, we redefined the window configuration to follow the guidelines in the EN 170370 [24], which recommends a horizontal angle of 14° for "minimum" view quality, 28° for "medium," and 54° for "high." The new configuration kept a typical jamb height of 2.1 m (~7 ft) and a sill elevation of 0.9 m (~3 ft). This configuration consisted of a series of windows, which repeated the same window opening pattern for every 60° horizontal view angle interval, which coincided with the immediate field of vision [50]. This approach to model windows ensured that the windows reflected EN 17370 guidelines, while keeping a constant WWR for the facade of each model.

We found that the repeated window placement that followed the horizontal view angle guidelines resulted in a 10%, 20%, and 40% WWR, respectively. To assess the relationship between window size and occupant satisfaction in more granularity, we also added a 30% and 45% WWRs. This created a condition that resided between medium and high-quality horizontal view angles (i.e., 41°) and larger than high-quality horizontal view angle, beyond the maximum horizontal angle of 54° (i.e., 60°). Table 1 summarizes the modeled window configurations and their resulting conditions (e.g., WWR), including the breakdown according to the main parameters. We also tested two more window configurations with different horizontal view angles or aspect ratios and the same WWR (i.e., additional parameters studies found in Table 1).

Window distance

Within the maximum depth (16.5 m), three occupant viewing positions were defined as follows: 2 m (closest distance to the window), 5.5 m, and 9 m (farthest distance to the window), representing open-plan office layout considering the allocation of core and circulation spaces. The viewing distances coincided with the achievement of different design criteria supported by WELL V2: L05, where credits are assigned for desks that are within 7.5 m (1-credit) or 5 m (2-credits) from the glazing [29]. Table 1 and Figure 3 shows the resulting view conditions based on the different combinations of glazing area and distance.

Viewing direction

In a typical open-plan office space, seated occupants have mainly two viewing directions in relation to the window: perpendicular or parallel. To avoid daylit glare from windows, desks might be angled perpendicular to the windows, resulting in a viewing direction that is parallel to the window. In general, window view design standards and guidelines (e.g., EN 17370, SLL, LEED v4, WELL v2) do not explicitly define viewing directions, perhaps due to the complex conditions designer may encounter in practice. However, we thought viewing direction could be an important factor because it changes the size (e.g., percentage area) and location (e.g., peripheral) of the window view within the occupants' visual field. Therefore, we modeled two desk layout designs with different viewing directions for the occupants' window views.

Percentage of window view area in the visual field (PWV)

The percentage of window view area in the visual field (PWV) was calculated from the hemispherical visual field available from an occupant's viewing direction (i.e., visual angles extending 90° up and down, with a 180° horizontal view angle). We also tested the percentage based on the primary view angle (50° view angle up, 70° view angle down, 120° horizontal view angle) or the sphere (90° view angle up, 90° view angle down, 360° horizontal view angle), but we found that the percentage based on the hemisphere of an occupant's viewing direction correlated better with the satisfaction score than the percentage with the primary view angle. Hence, the PWV that was calculated based on the hemisphere of the occupants' viewing direction was selected.

We developed a PWV calculation component, refer to as "View Out Percentage Calculator" [51] in Rhinoceros-Grasshopper, which is commonly used in the domains of architecture and building science for parametric modeling and geometric calculations. This component creates a user defined visual cone of the observer, and then calculates the percentage of vectors received at visible window surfaces at a given location of the floor plan. Based on this component, designers can quantify the relative window view area within the occupants' visual field. Figure 2 showed how the component visualizes the view vectors from an occupant's viewing position using intersecting points on the building surfaces (i.e., ceiling, wall and floor). The percentage of vectors that do not intersect with building surfaces would represent how much of the occupants' visual field has exposure to the outdoor environment (i.e., window view access) if the considered visual cone of the observer is a hemisphere (Figure 2-A).

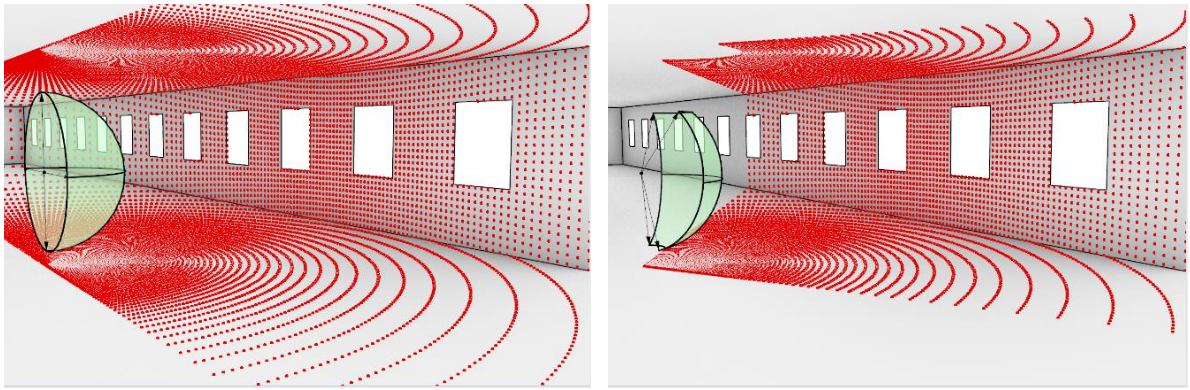


Figure 2 PWV calculation: View Out Percentage Calculator; A hemisphere (i.e., 180° vertical and horizontal view angles) visual field (left); and the primary human view angle (i.e., 50° angle above the normal sight line, 70° below the normal sight line, and 120° horizontal view angle) visual field (right).

Table 1 Virtual environment scenes: the geometric and other information. Figure 1 describes each variable.

Study	**Horizontal view angle (°)***	**WWR (%)**	**Distance (m)**	**Vertical view angle (°)**	**Direction**	**Percentage of window view area in visual field (PWV) (%)**
Main parameters	14	10	2/5.5/9	37/13/8	Perpendicular to the window (direct-viewing)	2.7/1/0.5
	28	20				5.2/1.9/1.1
	41	30				7.8/2.9/1.7
	54	40				10.4/3.8/2.3
	60	45				11.8/4.3/2.5
	14	10	2/5.5/9	37/13/8	Parallel to the window (side-viewing)**	2.1/0.8/0.4
	28	20				4.2/1.6/0.9
	41	30				6.6/2.4/1.5
	54	40				8.8/3.3/2.0
	60	45				10.1/3.7/2.2
Additional parameters	34	10	2	14	Perpendicular to the window (direct-viewing)	2.6
	34	20	2	28		5.3
	60	67***	2/5.5/9	45/18/11		16/6.4/3.8
	34	10	2	14	Parallel to the window (side-viewing)**	2.2
	34	20	2	28		4.4
	60	67***	2/5.5/9	45/18/11		13.6/5.5/3.3

* Horizontal view angle is obtained from the primary window (i.e., ≤ 30° laterally left and right from the central fixation point). We also tested the aggregated horizontal view angles considering all windows, but we found that the horizontal view angle from the primary window correlated better with the satisfaction score than the aggregated horizontal view angle. Hence, we use horizontal view angle from the primary window in this paper.

** When calculating the PWV for the direction parallel to the window (side-viewing), we calculated the centerline of the viewing angle as 45° rotated from the actual centerline (looking at the wall). This is congruent with a person's viewing angle when they are seated parallel to the window (they rotate their head toward windows to look at the outdoor view). We tested this with 30°, 45°, and 60° and found that 45° showed the highest correlation with the satisfaction score.

*** 67% WWR, the maximum WWR considering the jamb and ceiling height, was tested against 45% WWR while keeping the same horizontal view angle, 60°.

Window view

The outdoor view in the model is based on a location in Albany, California that satisfies high-quality view content criteria, as defined by the EN 17370 [24] and experimentally validated by [52]. This included three layers, namely: sky, landscape, and ground; and a distant building and relatively near nature (e.g., lawn and trees). Previous studies [53,54] had observed an interaction between content and access (e.g., window size) but there is no quantified information on how they interact. Therefore, isolating the effect of the window view access by controlling the view content should be a salient feature to the experimental design. We kept view content quality constant throughout the different window configurations, distances, and viewing direction when setting up the outdoor view. Notably, the distance to the window usually shifts the view content, being one of the critical uncontrolled factors in other view studies [17,55]. The sky or ground layers are obscured by the interior walls, when seated further away from the windows. To avoid the issue, we adjusted the location of the outdoor visual elements for the different window distances to ensure all windows had comparable view content with all three layers.

Image generation

VR allowed us to control important experimental variables, such as window configuration and outdoor view content quality. There are three main image generation methods for VR: 1) modeling the environment using a 3D modeling software program to create 360° stereoscopic rendered images, 2) scanning the real environment using a 3D scanner and rendering the 3D point-cloud data in Unity, and 3) taking 360° HDR stereoscopic photographs in a physical environment. We initially tested all three options to examine their practical viability. Method 1 was eventually selected as it allowed us the greatest amount of flexibility and control over the key experimental variables (e.g., the geometric window variables and view content). However, methods 2 and 3 could create more realistic environments in VR headsets. We tried to overcome this by using Revit® [56] and Enscape™ [57], which used model properties and the texture of the interior surfaces, furniture, and lighting fixtures for actual products commonly used in architectural practice. By combining all factors (i.e., horizontal view angle, window distance, and viewing direction), we generated 30 primary testing images for the main parameters studied and 10 additional images that vary other factors (e.g., view aspect ratio). These were rendered in 360° stereo-equirectangular images with a resolution of 12960 x 12960 px. The renderings were based on the viewing position of each workstation and the typical eye-level of the seated position (1.12 m).

Displaying images

The VR headset used to display the simulated images was the Oculus Rift S. It uses a PenTile organic light-emitting diode (OLED) display with a 2160 x 1200 px low persistence OLED (1080 x 1200 px resolution per eye), with a refresh rate of 90 Hz, and a maximum self-luminance of 98 cd/m^2. There are two approaches generally used to display images in VR headsets: three Degrees of Freedom (3-DoF) and six Degrees of Freedom (6-DoF). 3-DoF allows rotational tri-directional head movement (i.e., pitch, yaw, and roll) within a 360° generate virtual environment, while 6-DoF provides both rotational and translational (e.g., bodily) movement. Since participants only needed to gaze from a seated position at the window views (i.e., no walking was required), the 3-DoF image display function was selected for our study. The VR media player used to project the simulated images into the VR headsets was Whirligig Media Displayer [39,58]. Each pair of equirectangular images creates stereoscopic content for each experimental stimulus, resulting in fully immersive 360° stereoscopic scenes.

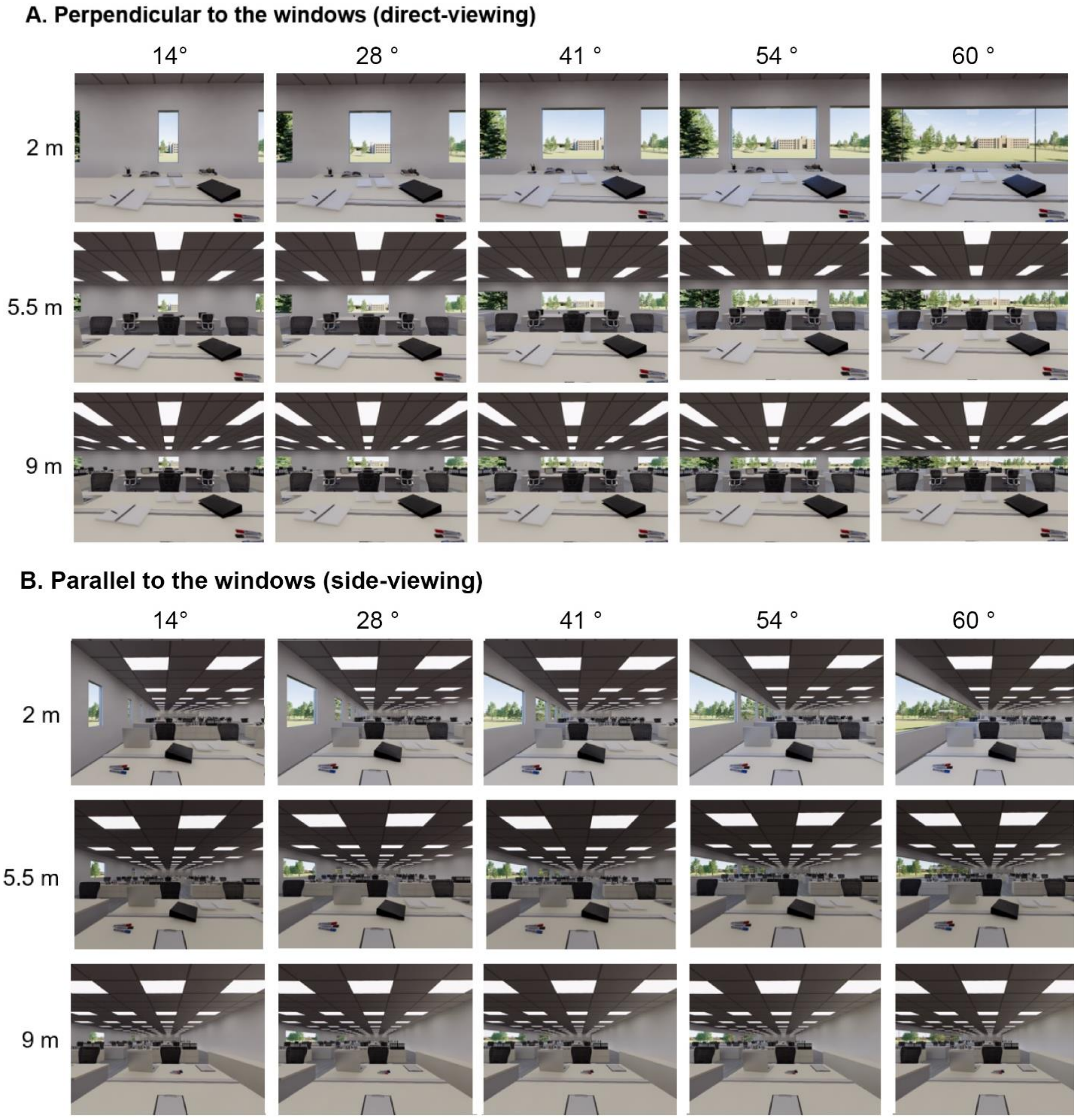


Figure 3 Resulting window view conditions based on the different combinations of horizontal view angle, distance, and direction for the main parameters study. Cropped from the original (360° HDR stereoscopic images for the purpose of show-casing).

2.4 Procedure

The preparation for the study session

Before the study began, each participant was required to download a set of randomly assigned images, install the Whirligig Media Displayer, and display and switch the images in their displayer.

These activities helped participants familiarize themselves with the displayer interface, before the main study session. Each participant was invited to participate in a 1-hour study session. During the study session, the participant should be at their workstation at home or in their office, and carried out the study remotely via a Zoom session, while communicating with researchers through a speaker phone (Figure 4-A).

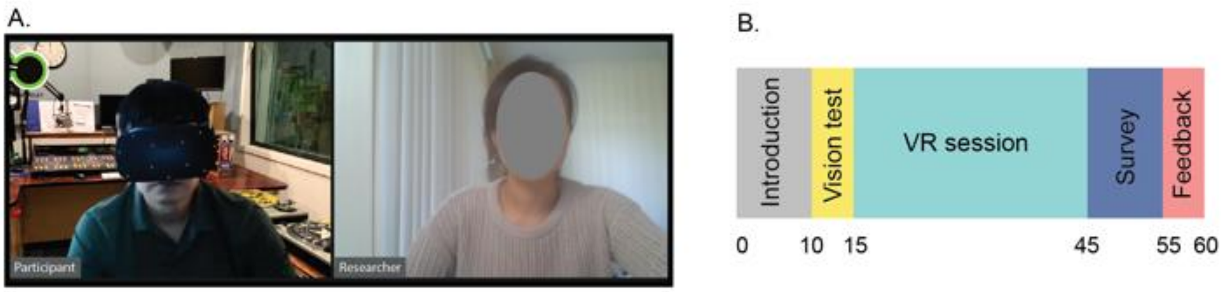


Figure 4 A. Virtual experimental session B. Experimental procedure.

The study session procedure

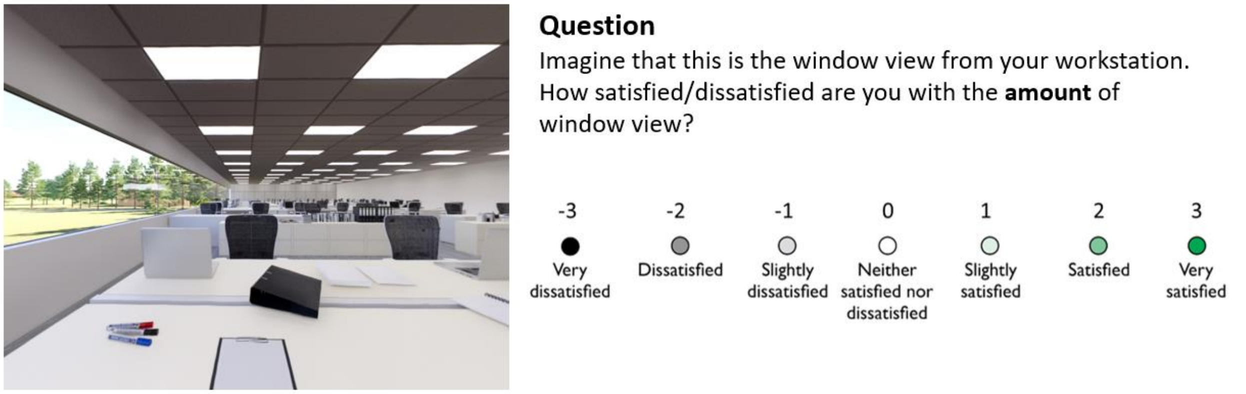
Figure 4-B shows the procedures of the experiment. Participants first read and signed the informed consent form via an online survey system. After signing the form, they heard an introductory presentation about the experiment procedure. Participants learned how to rate each virtual environment using a 7-point scale (Section 2.5). Participants were then asked to put on their VR headset and display the vision test images for visual calibration. When looking at the images, participants could adjust the headset's pupillary distance to meet their optimal point of visual acuity (i.e., when the image appeared clearest). Participants then partook in practice rounds, viewing ranges of window conditions (six images) that would be presented in the main study and rated each virtual condition. The practice round helped minimize the anchoring effect [59], which is a common issue in visual perception research [60,61]. Whenever participants saw a new image, they were asked to read its file name aloud. This promoted active engagement to the experiment procedure and reduced the likelihood of memorization to previous images by shifting their focus and attention onto a new image. Each image is named with a combination of random alphanumerical characters using the Bulk Rename Utility [62]. We also asked participants to first observe the notepad on the desk in front of them and then at toward the surrounding environment when they were presented with a new image. After they were familiarized with each window condition, participants verbally rated the view and the researcher recorded the ratings. This procedure was particularly important to have a realistic depth perception under VR conditions by overcoming the limited visual field [63] and perceiving objects located in multiple distances [64].

After the practice rounds, each participant examined 40 images (one image at a time), and spent up to 30-seconds per image to get familiar with the environment and rate their satisfaction with the amount of the window view. Participants wore the VR headset less than 30-minutes in total and allowed a short break period, thereby minimizing simulation sickness symptoms that are sometimes associated with VR headsets [40,65,66]. After completing the rating of all images, participants answered the “sense of presence” question, before taking off the VR headset and then proceeding to complete a post-experiment survey (Appendix A).

2.5 Measures

Satisfaction with the amount of the window view

Participants were asked to consider that the virtual environments they experienced were actual window views seen from their workstations. We measured the satisfaction level for the amount of the window view with a survey question. The participants verbally answered questions about their satisfaction using a 7-point Likert scale, ranging from: "Very dissatisfied" (-3) to "Very satisfied" (+3), and were balanced across an indifference (0) point (Figure 5). This satisfaction scale is commonly used in IEQ research [67,68] and window view research [54,69], where occupants rated their satisfaction levels to the conditions.



Question

Imagine that this is the window view from your workstation. How satisfied/dissatisfied are you with the **amount** of window view?

Figure 5 An exemplar image with the survey question asking occupant satisfaction with the amount of window view.

Potential moderator variables

Sense of presence in the VR environment [70] and individual differences (e.g., environmental preference, personality traits, life satisfaction, etc.) may affect participants' satisfaction with indoor environmental conditions [71]. The effects of these factors in IEQ research have been studied across a relatively limited number of studies (e.g., [71–73]; yet have not been commonly controlled or measured in studies previous to these). Therefore, this study measured and analyzed these factors that may have influenced the results (see Appendix A).

2.6 Statistical analysis

To understand how viewing distance and direction affected satisfaction to view access, we compared mean values at the same view angles (Section 3.1). While median values are more commonly applied to nominal or ordinal measurements, the mean provides more granular information (i.e., non-integer values) that describe the differences between groups of data [74].

The permutation test determined the statistical significance of the geometric variables on satisfaction within subjects (i.e., pairwise-comparison). Permutation tests are non-parametric tests that do not assume the distribution of the sample is normal about its mean [75]. For the permutation tests, we used the General Symmetry Test using R package “coin” [76] that paired results from the same individual with different window conditions (i.e., repeated measure) and then analyzed the difference between the conditions for each individual. For the p-values, we applied Bonferroni corrections to increase the confidence of the discovered effects, by dividing the alpha-levels by the number of variables that we tested (Figure 1, Table 3, and

Table 4). Although it is a conservative approach, we used it to increase the confidence of the results.

The Linear Mixed Model (LMM) analysis [77] was selected to determined how well view angles, WWR, viewing distance, viewing direction, and the PWV, could accurately predict satisfaction with the amount of the window view (Section 3.3). LLM also allowed the specification of variance-covariance patterns to account for an imbalanced condition [77]. As discussed in Section 2.5, we used a 7-point Likert scale ranging from -3 to +3. We visually inspected the normal probability plot for both the testing variables and residual errors to verify the normality assumption for the LMM [78]. To individually determine the relative importance of each variable with the satisfaction score, we tested each variable as a sole fixed effect. We specified the participant ID as a random effect to control for personal variance (Appendix A). We used R (Version 1.43.6, [79] and the R package "lmerTest" [80] to perform linear mixed-effects analyses, "MuMIn" to calculate the marginal R^2 (the variance explained by the fixed effects), conditional R^2 (the total explanatory power of the model; [81]), and "stats" to calculate Akaike Information Criterion (AIC), an estimator of prediction error and thereby indicating relative quality of statistical models.

3 Results

3.1 Main study: Effect of the horizontal view angle, distance and direction

Figure 6 shows the effect of the horizontal view angle, distance and direction on the participants' satisfaction. The horizontal view angle has, in general, a remarkable effect on satisfaction. A higher horizontal view angle resulted in higher satisfaction. This is evident for each of the three perpendicular viewing positions, except when participants were seated 5.5 m from the window (Figure 6-B). Comparisons across 41^o and 54^o horizontal angles were not statistically significant, albeit satisfaction ratings did rise when the opening angle was larger, indicating that further increases to the horizontal angle beyond 41^o may not yield any substantial improvements. This was also corroborated by the effect size, which also revealed that the difference was smaller than the recommended minimum effect size representing a practically significant influence [48]) to satisfaction with view access. This is similarly supported by comparisons for the two largest horizontal view angles (i.e., 54° and 60°), which also were not statistically different for any of the three distances for the perpendicular position (direct-viewing). There were, however, statistically significant differences when participants were seated at a view direction parallel to the window (Figure 6-A and 6-C), with the sole exception for one comparison (i.e., between 54° and 60°, at 5.5 m from the window). This indicates that increases in satisfaction to the amount of view may have saturated for a smaller horizontal opening size (i.e., 41^o or 54^o) when seated perpendicular to the window, whereas this saturation point seems to be much larger for the parallel viewing direction. Distance had a moderate effect on satisfaction when we compare the results between the 5.5 m and 9 m cases. Participants were more satisfied with the amount of view when they were 5.5 m from the window compared to their location at 9 m. However, increasing the viewing distance from 2 m to 5.5 m did not show a statistically significant difference.

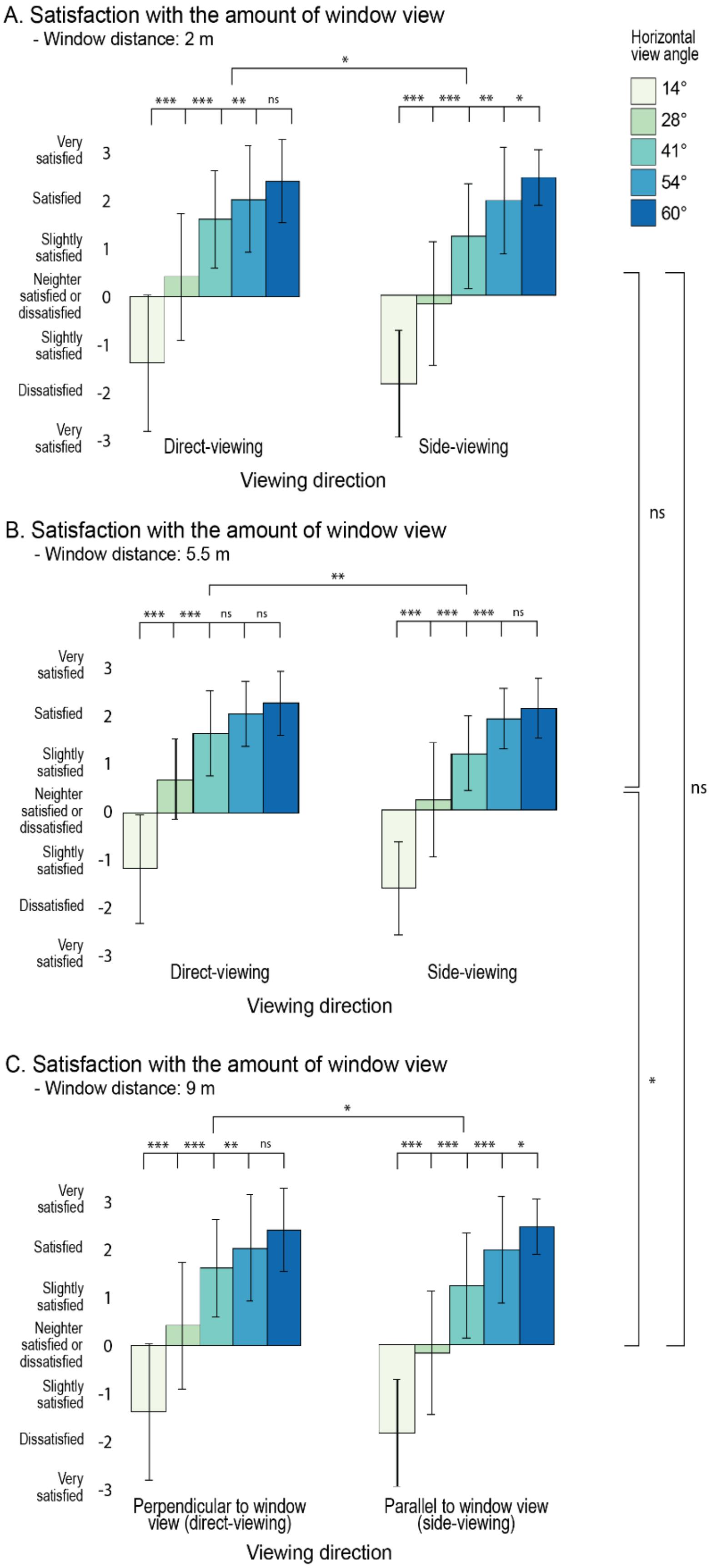

A. Satisfaction with the amount of window view
- Window distance: 2 m
B. Satisfaction with the amount of window view
- Window distance: 5.5 m
C. Satisfaction with the amount of window view
- Window distance: 9 m
Horizontal view angle
14°
28°
41°
54°
60°
Very satisfied
Satisfied
Slightly satisfied
Neighter satisfied or dissatisfied
Slightly satisfied
Dissatisfied
Very satisfied
3
2
1
0
-1
-2
-3
***
**
*
ns
Direct-viewing
Side-viewing
Perpendicular to window view (direct-viewing)
Parallel to window view (side-viewing)
Viewing direction

*Figure 6 Effect of horizontal viewing angle, direction and distance on occupants' satisfaction with view access; Mean of satisfaction with the amount of window view and the standard error bars A. Window distance: 2 m; B. Window distance: 5.5 m; Window distance: 9 m. Bonferroni-corrected significance levels: *p < 0.002 (0.05/24), **p < 0.0004 (0.01/24), *** p < 0.00004 (0.001/24), ns "not significant" p ≥ 0.002 (0.05/24) for view angle comparisons; *p < 0.017 (0.05/3), **p < 0.003 (0.01/3), ns "not significant" p ≥ 0.017 (0.05/3) for viewing direction and window distance comparisons.*

3.2 Additional study: Horizontal view angle vs. WWR

We created our test conditions based on a series of horizontal angles while keeping the increase in WWRs constant. Although this mean that the effects of the horizontal view angle and WWR on view access satisfaction were strongly correlated, it was difficult to infer whether both effects were identical. Thus, we analyzed eight additional window view conditions to assess the difference between these two variables (Table 2).

*Table 2 Effect of WWR on the satisfaction score; Z-statistics, statistical significance (p-value; permutation test, Bonferroni corrected significance level: 0.05/8= 0.00625, *), and effect size (r).*

Horizontal view angle (°)	**WWR (%)**	**Distance (m)**	**Direction to window**	***Z***	***p*-value**	**Effect size (*r*)**
34	10 vs. 20	2	Perpendicular	-4.95	p<.001*	0.79 (moderate)
			Parallel	-5.27	p<.001*	0.83 (large)
60	45 vs. 67		Perpendicular	-0.82	.41	0.13 (negligible)
			Parallel	-1.89	.06	0.30 (small)
14 vs. 34	10		Perpendicular	-1.29	.20	0.20 (small)
			Parallel	-1.02	.31	0.16 (negligible)
28 vs. 34	20		Perpendicular	-2.14	.03	0.34 (small)
			Parallel	-2.48	.01	0.39 (small)

Table 2 shows the comparisons between different WWRs on view access satisfaction scores when the horizontal view angle was held constant and vice versa. When comparing the 10% vs 20% WWRs, participants' satisfaction showed a statistically significant difference when the horizontal angle was 34°. However, the comparison between the 45% vs 67 % WWRs, both with a 60° horizontal angle did not show a statistically significant difference. Despite the small number of cases and anecdotal nature for these comparisons, they indicate that people can perceive the effect of WWR when the window view did not saturate their visual field. In other words, occupants could be insensitive to further increases in WWR when they are already satisfied with the amount of window view. It would be valuable to conduct an additional study focusing on the comparison between the effect of horizontal view angle and WWR (e.g., long strip windows that have a large horizontal view angle, but relatively smaller WWRs). When comparing the horizontal angles 14° vs 34° at a 10% WWR and the horizontal angles 28° vs 34° at a 20% WWR, no statistically significant differences were found to satisfaction with view access (Table 2). This may indicate that the effect of horizontal angle is less prominent compared to the effect of WWR.

3.3 Prediction model: The development of a view access index

Based on the data collected from this study, we develop a linear mixed model to predict satisfaction ratings with the amount of window view. At first, linearity between each predictor variable (i.e., glazing area (WWR), horizontal and vertical view angles, PWV, window distance and viewing direction), and the outcome (i.e., satisfaction) was checked using the locally weighted scatter plot smoothing (LOESS) lines. When applying a log function to the WWR (Figure 7-A)

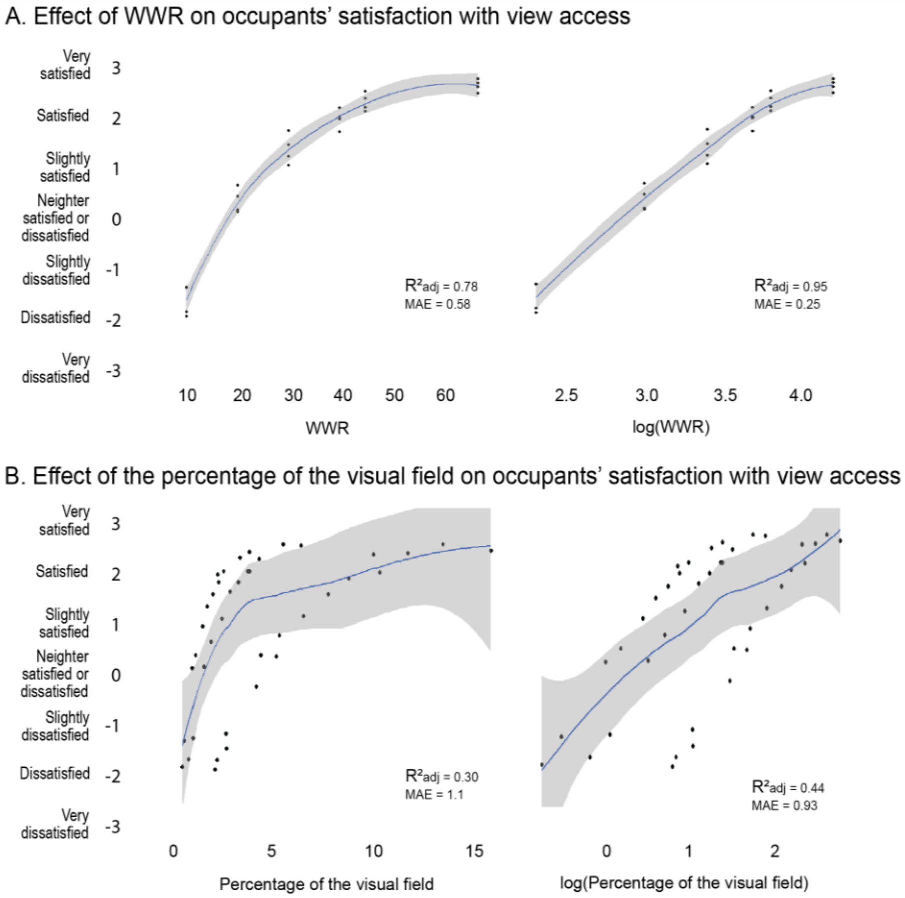


Figure 7 Locally Weighted Scatterplot Smoothing (LOESS) lines.

and PWV (Figure 7-B), an improved model fit was observed. This was congruent with Fechner's law, stating that the subjective sensation is proportional to the logarithm of the stimulus intensity [82].

All examined variables were statistically significant, except for distance to the window (9 m), which showed a slightly higher *p*-value than the Bonferroni corrected threshold cutoff that denoted statistical significance, indicating insignificant (Table 3).

Table 3 shows the variables sorted by the best AIC and R^2 values. Ranked from the highest to lowest, levels of satisfaction score prediction were: (1) log (WWR), (2) horizontal view angle, (3) log (PWV), (4) vertical view angle, (5) viewing direction, and (6) window distance. According to the coefficient (β), most variables were positively related (i.e., both predictor variable and satisfaction score simultaneously increased). The coefficient for viewing direction showed that participants who were sat perpendicular to the window were more satisfied with the amount of view than when they were seated parallel. Distance to the window was analyzed as a three-level categorical variable, based on the three discrete steps tested during the experiment. As a categorical variable, the model yielded a better prediction performance than if it was treated as a continuous variable. The coefficient *(β)* for distance showed that people seated 2 m from the window view were less satisfied with the amount of window view compared to 5.5 m window distance.

Table 3 Comparison of performance for each geometric variable according to: estimated coefficient (β), standard error (SE), and statistical significance (p), Marginal R2 (R_M^2), Conditional R2 (R_C^2), and Akaike Information Criterion (AIC). For the p-values, we applied Bonferroni corrections to increase the confidence of the discovered effects, by dividing the alpha-levels (0.05, 0.01 and 0.001) by the number of variables that we tested (0.05/6 = 0.008, 0.01/6 = 0.0017**, 0.001/6 = 0.0000017***).*

Model	**Variable**	***β***	**SE**	***p-value***	R_M^2	R_C^2	**AIC**
1	Log (WWR)	2.26	0.04	p<.001 ***	0.66	0.72	4514
2	Horizontal view angle	2.82	0.05	p<.001 ***	0.60	0.66	4819
3	Log (PWV)	1.19	0.04	p<.001 ***	0.31	0.36	5779
4	Vertical view angle	0.30	0.00	p<.001 ***	0.01	0.05	6396
5	Window distance (5.5 m)	0.46	0.11	p<.001 ***	0.01	0.05	6400
	(9 m)	0.28		.009 ns			
6	Viewing direction (parallel)	-0.30	0.09	p<.001 **	0.01	0.05	6403

After understanding the relationships between each variable, we built a model that included all variables that are statistically significant and respective interaction terms. For the variables that had significant effects, we conducted *post-hoc* pairwise comparisons by applying the multiplicity adjustment of Tukey's Honestly Significant Difference (HSD) test to control the false discovery rate [83]. Variance inflation factors (VIFs) (Craney and Surles, 2002) were also checked to determine whether any of the variables caused a multi-collinearity violation, leading to inaccurate estimations for the prediction model standard errors [84]. Factors below a conservative threshold (i.e. VIF < 4) were retained [85]. Two pairs of variables, horizontal view angle-WWR and vertical view angle-distance, showed high VIFs, indicating that these were highly correlated. Therefore, we kept one variable of each set and removed the others to avoid a multi-collinearity violation for our final model. The assumption of multi-collinearity (i.e., VIFs = 4) for PWV was unable to meet when the other variables (i.e., WWR, distance, direction) were included, so it was discarded. As a consequence, the remaining factors of the final model resulted in VIFs =1. In addition, we merged distance 2 m and 5.5 m as 'near' distance and tested against 'far' distance (9 m) as 2 m or 5.5 m by itself did not show a significant difference when it was added to the final model with the WWR and direction.

The final model selected gave the highest AIC, marginal R^2, and conditional R^2 values, translating to a model that produced the highest prediction accuracy. Other models, that are less performative or require more complex input, were tested and their performance are included in the Appendix C. For the final model, we used glazing area (m^2) instead of WWR. The effect of WWR and glazing area on the satisfaction are identical in this study as the windows are regularly distributed. In the case of buildings where windows are not regularly placed, the use of glazing area is more appropriate. Hence, we used glazing area in the final model for a more generalized application.

Table 4 displays the estimated coefficient (*β*), standard error (SE), and statistical significance (*p*-value) for each factor. The variance explained by the fixed effect factors (marginal R^2) was 0.67. The variance explained by both the fixed and random effect factors (conditional, R^2) was 0.73, indicating that the effect of the variables was a lot larger than the individual variations. The final model could be described by the following equation (1):

$$Y_i = a_i + \beta_1 \cdot X_1 + \beta_2 \cdot X_2 + \beta_3 \cdot X_3 + A_i + \varepsilon_i \tag{1}$$

The variables are defined as:

- Y_i: occupant satisfaction with the amount of window view
- X_1: log (glazing area)*
- X_2: distance (near)
- X_3: direction (parallel)
- A_i: random intercept due to subjects' variation
- a_i: intercept
- ε_i: error term

Table 4 The statistical information of the final model; estimated coefficient (β), standard error (SE), and statistical significance (p).

Factor	***β***	**SE**	***p*-value**

Intercept	-7.1	0.16	p<.001 ***
log (Glazing area)	2.3	0.04	p<.001 ***
Distance (near)	0.16	0.05	.001 **
Direction (parallel)	-0.3	0.05	p<.001 ***
Conditional R^2 (R_C^2)	0.73		
Marginal R^2 (R_M^2)	0.67		
AIC	4476		

3.4 Critical minimum and saturation view access

Considering the practical usage of the model as well as the fact that the effect of glazing area (expressed either as WWR or as an absolute value) was the strongest predictor compared to the other two variables (i.e., window distance and viewing direction), we calculated the critical minimum and saturation view access based on glazing area.

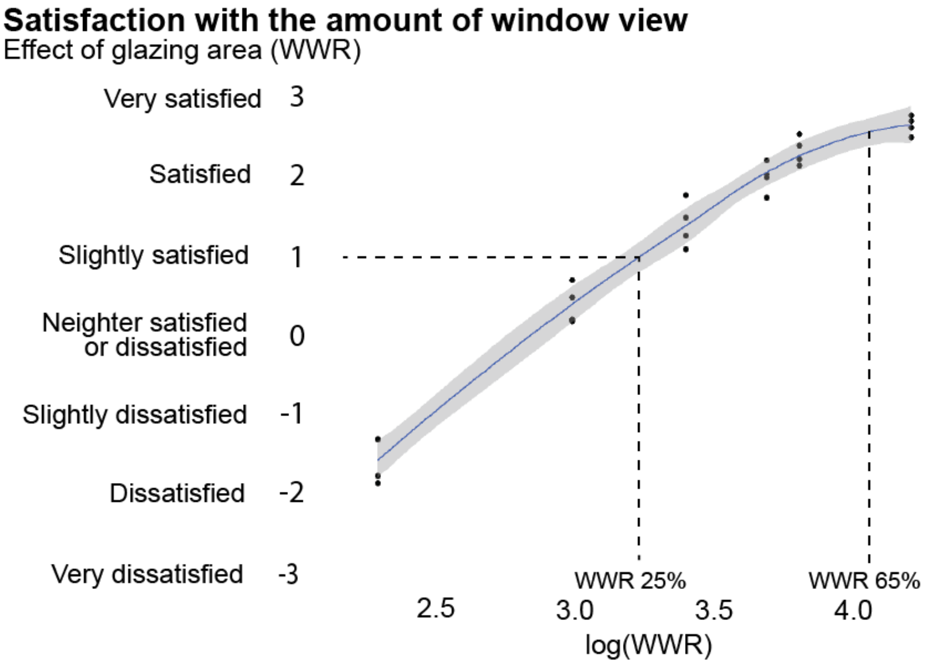


Figure 8 Effect of WWR on the mean of satisfaction with the amount of window view

Figure 8 describes the relationship between WWR and the mean of satisfaction score with the amount of window view. Using a modified Equation (1) which excludes the effect of window distance and viewing direction, we determine the critical minimum amount of window view (Figure 8) that meets and exceeds the minimum threshold of satisfaction on our scale (satisfaction $\geq +1$). This intersects at the point where average ratings of satisfaction for view access intercept the ordinate at the criterion of satisfaction (i.e., +1), and then identifying the corresponding value for WWR along the x-axis (i.e., abscissa). Based on the experimental setting considered in this study, the critical minimum view access threshold coincided with a WWR of 26%, which equivalent to a mean satisfaction score of +1. On the other hand, a WWR of 64% coincides with the point of saturation, indicating any further increases in WWR beyond this size, may not lead to any considerable increase in satisfaction with view access. In the design and standardization context, these two values can be rounded to 25% and 65%.

4 Discussion

4.1 View access index

The analytical model showed that the glazing area, window distance, and viewing direction were the three primary predictors for satisfaction to view access, with the glazing area being the strongest predictor. This finding generally aligns with design recommends found in BREEAM [30], supporting the use of the WWR to ensure building designs provide occupants with enough visual access to the outdoor environment. However, the guideline allows a smaller WWR (20%) for the cases with a closer window distance (< 8 m). Also, the use of WWR would be only applicable to the window conditions where they are regularly placed.

The horizontal and vertical view angles are also used in view quality guidelines [24–27]. However, we found that there was a high correlation and collinearity between the horizontal view angle and WWR. Similar problems also occurred when certain combinations of variables were analyzed in conjunction with each other (i.e., vertical view angle and window distance, and PWV and glazed area, window distance and viewing direction). We selected the primary predictor and other significant variables in the final model only, discarding weaker predictors that were correlated to the former.

Effect of window distance and viewing direction

We made our recommendation for the critical minimum view access based on the glazing area

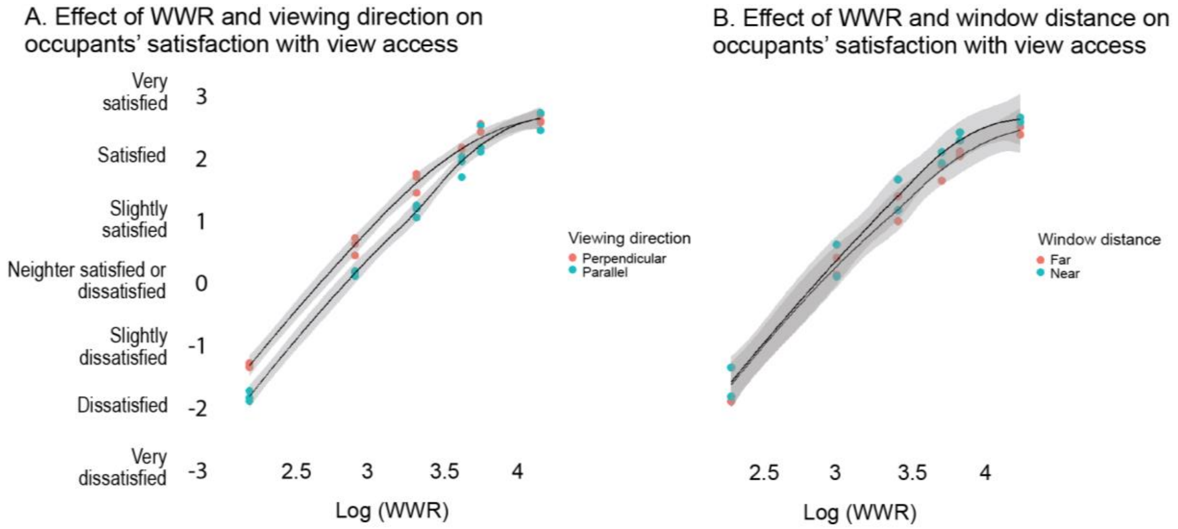


Figure 9 Effect of window distance and viewing direction on the mean of satisfaction with the amount of window view

(WWR). Since the effects of window distance and viewing direction were small, for practical purposes, recommendations were independent from window distance and viewing direction. However, it does not mean that their effects were insignificant.

Figure 9 shows the moderating effects of window distance (Figure 9A) and viewing direction (Figure 9B) across different glazing areas (log (WWR)) had on satisfaction to view access. The effect of window distance played a larger role when the glazing area is larger (WWR > minimum view access). Contrary, the effect of viewing direction is larger when the glazing area is smaller (WWR < minimum view access). It may be worthwhile to investigate: (1) more window distances by extending viewing proximity further, depicting cases where occupants are located far away from the view within an open-plan office that contains a deep floorplan, and (2) window conditions with multiple viewing directions, especially when the glazing area is smaller.

In a future study inclusive of more window conditions, these factors could be incorporated to inform window size and floor layout design criteria.

4.2 Critical minimum view access

Our findings indicated that the minimum WWR necessary to meet the minimum threshold of satisfaction occurred at 25 %, which is equivalent to the horizontal angle of 35° for the setting we studied. This finding challenges the minimum WWR specified by BREEAM, recommending the following values that vary depending on window distances: 20 % (< 8 m), 25 % (8 - 11 m), 30 % (11 - 14 m), and 35 % (> 14 m). Among the viewing distances, only the range of 8–11 m is congruent with our findings. In addition, our findings also challenge the minimum horizontal view angle (i.e., 11° and 14°) set by the EN 17037, SLL-LG 10, and LEED v4 [24,25,27]. Our study consistently showed that a horizontal angle of 14° (equivalent to a ‘minimum’ view defined by EN17037) corresponded to a ‘dissatisfactory' amount of window view, regardless of the distance from the window and viewing direction. Therefore, we recommend increasing the minimum horizontal angle from 14° to 35°.

4.3 Effect of percentage of window view area in the visual field (PWV)

In Section 3.3, we found that the effect of PWV on satisfaction was not as strong ($R_M^2 = 0.31$) as the glazing area or horizontal view angle ($R_M^2 = 0.66$ or 0.60); also producing collinearity when it was included, and resultantly being removed from the final model. However, we found an interesting relationship between the PWV and window distance. Even if the PWV values are similar (i.e., log (PWV) = 1), depending on the distance, view access satisfaction may vary (Figure 10). This could indicate that participants had lower expectations for view access when they are seated further away from the window(s). It is similar to the forgiving effect that other researchers found in their building environment studies [14,86,87]). In other words, the PWV has an effect on satisfaction but it should be carefully considered with the window distance. The view calculation methods that are based on the solid angle or view vectors [22,23] would benefit the inclusion of window distance when evaluating view access.

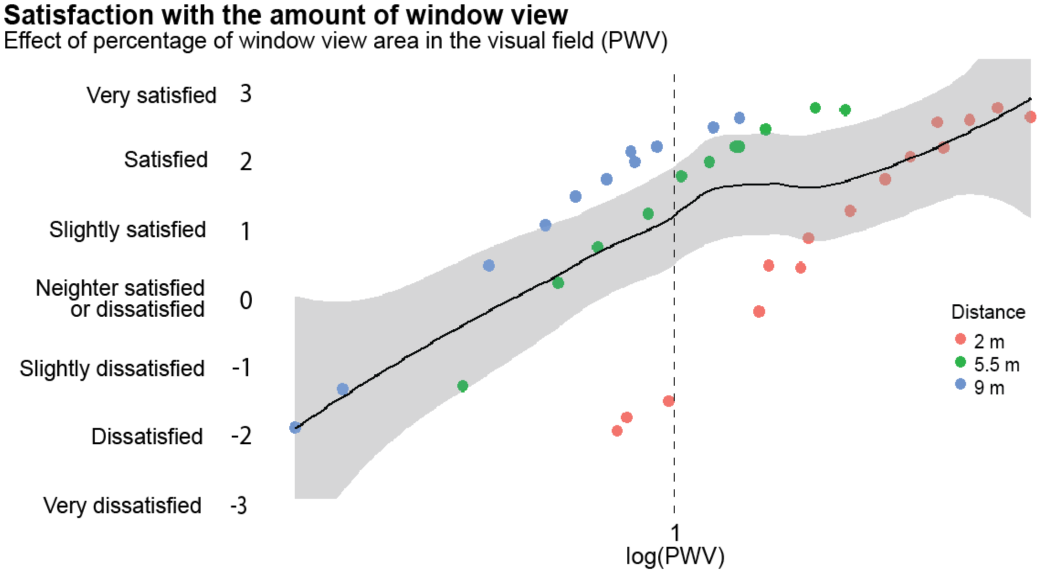


Figure 10 Effect of log (PWV) and window distance on satisfaction with the amount of window view.

4.4 Study limitations

Our study aims to develop a view access index that can predict occupant satisfaction with the amount of window view. Though view content (i.e., visual elements can be seen through a window) is not a primary focus of the current study, view content could moderate the effect of view access in other studies [17,50]. For that reason, LEED v4's View Factor calculation method also includes considerations for view content when determining view angle thresholds [16,27,53]. View content can vary depending on the site context (e.g., urban or nature), content distance, and even floor elevation. These changes not only convey differences to the quality of content seen in the view, but also could have reverberating influences on how view access is perceived. These relationships should be studied in the future. As a proof-concept study, we examined the effect of content on satisfaction to view access by comparing a high-quality 3-layered view to a low-quality building view. There was a ‘moderate’ effect [48,88], which is congruent with the aspects demonstrated in the previous studies. This finding presented the need for a systemic study, elucidating the interaction and trade-offs between view content and view access.

Another limitation of our current study was the restricted number of window view conditions and the exposure time. Given that the prolonged use of the VR can cause discomfort, we limited the time participants wore their headsets no more than 30 minutes. Previous VR studies also kept their studies within relatively short timeframes to prevent simulation sickness [40,45,65,66]. This limited the time each participant saw each individual scene to up to 30 seconds, before they then rated their satisfaction to view access. This was to accommodate the presentation of 40 total scenes, with the tradeoff being that we could allocate five view angles, three viewing distances, two viewing directions, and other additional testing stimuli, into the test procedure. While this was sufficient to unearth the statistical relationship between these measured variables, these may not represent every complex relationship underlying how occupants perceive view access in a real office environment. For example, [89] showed that space size also affects the perceived amount of view access from the window. Therefore, further investigation of a wider range of scenarios (e.g., ceiling and window heights, floor plan areas, viewing distance from window, etc.) for each variable, including more granular intervals between each extreme, would help generalize the purview of our work to more buildings and architectural designs.

The calculation method of each variable can be refined further based on future empirical findings. Our study mainly used regularly placed window openings that adopted a repeated pattern, enabling participants to be seated at the center of a window opening. This helped clearly define which opening was the primary window. However, the primary window may not have always been obvious for some conditions (e.g., multiple or irregular window placements). Further work may be needed to verify some of the underlying assumptions made for view access. When multiple windows are within close proximity of each other, the EN 17037 [24] allows the designer to treat separate windows as one single entity. However, it is not entirely clear if occupants will still perceive this as one being a primary window or two separate openings. Research has shown that a horizontal view angles that coincide with the immediate field of view (60°) can be assumed to be the addictive angle [14], but this may still require further validation. In addition, the hemisphere-based PWV was selected as it produced a better model fit for our data than the primary view angle (Section 2.3). Whether the former visualization approach would invariably outperform its counterpart method remains unclear, examining both under a wider range of window conditions would help verify which method would be the most appropriate for evaluating view access.

Window distance generally had very small effects in our final model. The effect of distance was statistically significance only after two of the two distances (i.e., 2 m and 5.5 m) were merged together. Although a larger sample size could have been used to reveal the more granular effects for the two closest distances, utilizing a larger maximum for window distance may have offset the need of merging some of the categories. A greater range of distances could also have inflated its overall effect on satisfaction to view access, enabling us to detect larger effects.

The use of simulated views displayed in the virtual environment is another limitation. While controlling intrinsic factors (e.g., outdoor view and window configuration) supplemented the utility for VR in the context of view access assessment, there were several limitations that inevitably arise from its use. First, the limited visual field may have prevented participants from experiencing realistic spatial dimensions. This could be a major limitation to the use of VR as it may produce limited depth perception. To overcome this, the present study used simulation images that include detailed spatial elements (e.g., furniture, desk stationary) to provide enough spatial and visual cues that helped participants form a better sense of depth. Also, the experimental protocol required participants to carefully look around every time they displayed the new images, which could improve the limited visual field. Second, the use of static images may have created a less realistic view. Real-world daylit windows provide content inherent with dynamic visual stimuli (e.g., people, tree leaves, birds, and temporal effects of daylight). Third, the limited self-luminance to the VR headsets could not produce the range and contrast expected for spatial features being displayed, which also may create a less-realistic experience. However, controlling contrast could also minimize other confounding factors, such as the effect extreme luminance that are conducive for glare or visual comfort, which may influence satisfaction to view access.

Due to the relatively small sample size (n= 40) and uniform recruitment of some sampled demographics (e.g., participants all lived in the United States), we may not be able to generalize our work to every population across different cultures or countries. Some perceived consequences resulting from greater view access (e.g., visual privacy) may have some underlying cultural influence [90,91], causing diverging levels of satisfaction for the same geometric window sizes; hence, we would need to examine possible regional effects to determine their influences on our prediction model. Finally, the study was conducted online due to COVID-19, which presented additional restrictions to this human subject-based research, but of unknown impact.

5 Conclusion

This study assessed the effect of geometric variables (i.e., glazing area (WWR), horizontal and vertical view angles, percentage of window view area in the visual field (PWV), window distance and view direction) on satisfaction to view access. To the best of our knowledge, this was the first view access index developed based on the assessment of 40 different window configurations under controlled conditions (e.g., with comparable view content) in a virtual environment. Since the use of VR headsets spatially immerse the participants in the testing environment [38], VR experiments are allegedly superior to those generated by using scaled models or adjusting window sizes by moving artificial partitions [14,50]. The former cannot provide a full-scale experience of the space and the latter is unable to convey the real configuration of windows. Through this study, we concluded that glazing area (WWR), window distance, and viewing direction are the three primary predictors for occupant satisfaction to view access. The proposed model (prediction accuracy of 0.67, as determined by the marginal R^2) enabled the identification of the minimum and saturation points for the WWR.

We found that a 25% WWR and 65% WWR coincided with the minimum and saturation thresholds of satisfaction that met participants' expectations for view access. Below, we propose changes to the current view access standards:

- BREEAM: increase WWR from 20 % to 25% when sat less than 8 m from the window.
- EN 17037: increase horizontal view angle from 14° to 35°. This recommendation applies to an angle from a single window or aggregate angles measured from multiple smaller adjoining windows separated by small gaps. Designers would have the flexibility of meeting target values by increasing the width of one or more windows, or equally widen every adjoining window to promote view access.

These suggestions, while keeping all parameter the same, will lead to larger windows. Further studies with other window and space conditions that further examine the fundamental relationships we identified in our work may be needed. The nexus between view content (i.e., what occupants see) and view access (i.e., how much occupants can see) creates many complex and nuanced relationships that are not yet well understood. For example, distance from the window could be less influential to occupant satisfaction with view access if the window has low quality view content (e.g., ground floor window showing nearby buildings). More research along this stream is necessary and a global collaborative effort would be valuable to collect a shared database that could be used to build more reliable and comprehensive prediction models. Nonetheless, the findings presented in this paper contribute to initiating discussion and advancing and developing of new aspects for window design standards and architectural practice, specifically supporting view access, and further, view quality.

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Appendix A

We collected potential moderator variables. These include the sense of presence in the VR environment and preference for window view and workstation types.

Sense of presence

We measured the sense of presence in the virtual environment using questions from the Igroup Presence Questionnaire (IPQ) [92,93]. Researchers from various fields used or adapted the IPQ to verify if a virtual environment was successful in creating an immersive setting in which the observer feels they are actually present in the environment [45,70,94,95]. The sense of presence questionnaire consists of 14 items and is measured using a 7-point Likert scale from "Strongly disagree" to "Strongly agree" with the center value indicating "Neither agree nor disagree." The results show that mean IPQ scores are higher than the mid-point on the 7-point Likert scale (i.e., *neither agree nor disagree*), indicating that participants had a sense of presence in the virtual environment. In comparison to previous studies [45], the mean of each score (general presence, 4.8; spatial presence, 4.62; involvement, 3.26; experience realism, 3.07) is generally similar or higher, indicating that the virtual environment provided participants with experimental conditions that support a sufficient and relatively higher sense of presence.

Window view preference

Individual window view preferences in terms of content, such as visual elements seen in the window and characteristics of scale, distance, etc., could be different, affecting our results. Therefore, we included questions asking participants to rank the window views (Figure A1) containing various visual features such as a building view, an elevated view, a close-up look of nature, and a distant view based on their preferences. Participants ranked highest the window view containing three visual layers (i.e., sky, landscape, and ground) with distant greenery (M = 3.69, SD = 0.49). The close-up view of nature scored second highest (M = 2.74, SD = 1.01), and the elevated building view with sky followed (M = 2.34, SD = 0.64). As expected, the building view ranked lowest (M = 1.23, SD = 0.49). These are congruent with previous findings [69], indicating that participants generally prefer to see multiple layers of visual features and nature in their windows while at their workstations. Interestingly, 25% of participants ranked the close-up view of nature as their top preference rather than the view with three layers and distant nature (63% of participants). This indicates that a subset of participants prefers a more private, secure view of nature to the three-layer view.

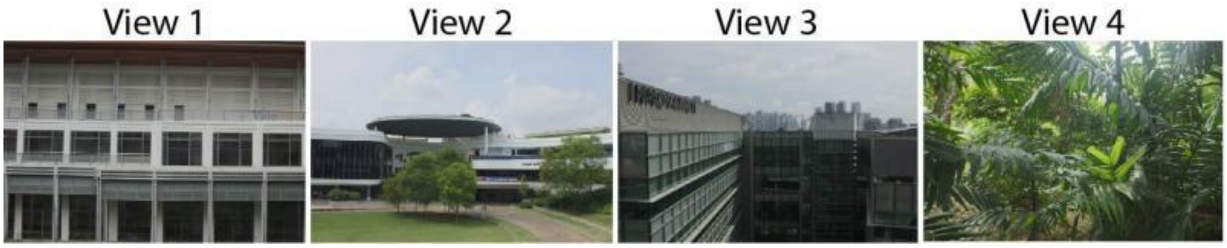

Figure A1 Different window views

Workstation preference

While working in an open-plan office, the preferred type of partition or cubicle could be an indicator of how much visual privacy each participant would like to have. The difference between the preferred partition type could also affect their satisfaction with the amount of the window view and the office conditions. To address this, we included a question asking about their workstation type preference, as seen in Figure A1. The results of each participant's preferred type of partition or cubicle while working in an open-plan office showed that low partitions were most preferred (M = 2.28, SD = 0.72), followed by no partitions (M = 1.98, SD = 0.8). Participants ranked high partitions lowest (M = 1.77, SD = 0.87). While 50% of participants ranked high partitions as their least preferred workstation type, 33% ranked no partition lowest. This indicates that people generally prefer some level of connection with their surroundings, but at the same time, they appreciate some sense of boundary and ownership of their desk. It also shows that a subset of participants finds working in an open-plan office with no partitions acceptable.

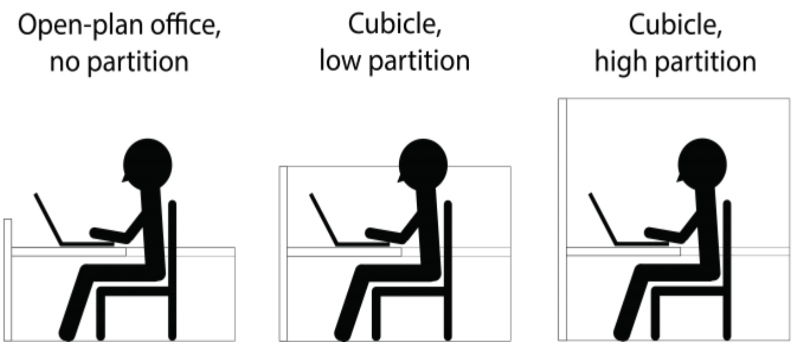

Figure A2 Workstation type in an open-plan office

Effect of potential moderator variables

To understand the contribution of the aforementioned differences to participants' satisfaction with the extent of window view, we treated them as a covariate in the linear mixed model with Bonferroni-corrected significance levels for each category. Although nearly all variables (minimum non-significant p = 0.08) were insignificant, we found a small effect of workstation preference (i.e., partition height) on satisfaction with the amount of window view ($p < 0.001$, $R^2 = 0.016$). This result suggests that individual preferences for the level of privacy, known to affect preference judgments on view [8], played a minor role in this experiment. Nonetheless, results concerning the level of privacy should be treated with caution, but not completely disregarded, as it contributes in theory and in the literature. Indeed, the results align with those of Yildirim et al. (2007), who reported that people were happy to have low partitions (1.4 m). Presumably, the low partition gives them a higher level of visual and acoustical privacy, and also minimizing distractions and interruptions.

Appendix B

Results from the main study and the additional study (40 window conditions).

Horizontal view angle (°)	**WWR (%)**	**Distance (m)**	**Direction to window**	**Mean**	**SD**	**Median**
14	10	2	Perpendicular	-1.48	1.52	-2
			Parallel	-1.90	1.15	-2
		5.5	Perpendicular	-1.25	1.21	-1
			Parallel	-1.69	1.00	-2
		9	Perpendicular	-1.30	1.09	-2
			Parallel	-1.85	1.14	-2
28	20	2	Perpendicular	0.45	1.41	1

			Parallel	-0.18	1.34	0
		5.5	Perpendicular	0.75	0.90	1
			Parallel	0.23	1.23	1
		9	Perpendicular	0.48	0.99	1
			Parallel	0.21	1.20	1
33.9	10	2	Perpendicular	-1.15	1.39	-1
			Parallel	-1.70	1.26	-2
	20		Perpendicular	0.88	1.20	1
			Parallel	0.48	1.24	1
41	30	2	Perpendicular	1.73	1.09	2
			Parallel	1.28	1.13	1
		5.5	Perpendicular	1.80	0.95	2
			Parallel	1.23	0.80	1
		9	Perpendicular	1.48	0.64	2
			Parallel	1.08	1.12	1
54	40	2	Perpendicular	2.18	1.20	2.5
			Parallel	2.05	1.15	2
		5.5	Perpendicular	2.20	0.72	2
			Parallel	1.98	0.66	2
		9	Perpendicular	1.98	0.83	2
			Parallel	1.73	0.96	2
60	45	2	Perpendicular	2.58	0.93	3
			Parallel	2.55	0.60	3
		5.5	Perpendicular	2.45	0.71	3
			Parallel	2.20	0.65	2
		9	Perpendicular	2.20	0.79	2
			Parallel	2.13	0.88	2

	67	2	Perpendicular	2.63	0.93	3
			Parallel	2.75	0.54	3
		5.5	Perpendicular	2.73	0.60	3
			Parallel	2.75	0.49	3
		9	Perpendicular	2.60	0.74	3
			Parallel	2.48	0.68	3

Appendix C

Table comparing the predictive performance of the final model to the other models. The performance of the A1 model is very similar to the final model, but this was discarded in favor of the latter due to reduced complexity distance (second factor) had in comparison to the PWV.

Model	**Factors**	**VIF**	R_M^2	R_C^2	**AIC**
Final	Log (WWR), Distance, Direction	1	0.67	0.73	4476
A1	Log (WWR), Log (PWV), Direction	1.7	0.67	0.72	4479
A2	Horizontal and vertical view angles, Distance, Direction	1.6	0.61	0.67	4785
A3	Log (PWV), Distance, Direction	1.4	0.45	0.50	5302