buildings

Article

Subjective and Physiological Responses towards Interior Natural Lightscape: Influences of Aperture Design, Window Size and Sky Condition

Zhe Kong [1,*], Keming Hou [2], Zhongyu Wang [3], Feifei Chen [3], Yunhao Li [2], Xinyue Liu [2] and Chengyu Liu [3]

[1] School of Architecture, Southeast University, Nanjing 210096, China
[2] College of Architecture and Urban Planning, Qingdao University of Technology, Qingdao 266033, China
[3] School of Instrument Science and Engineering, Southeast University, Nanjing 210096, China
* Correspondence: kongzhe@seu.edu.cn

Abstract: Indoor daylighting quality has impacts on occupants' physical and psychological aspects. Although daylighting design metrics have strictly restricted the amount of sunlight penetration, studies have shown occupants' preference towards an appropriate amount of sunlight and distributions. Currently, insufficient studies have focused on the composition of interior daylighting distributions. Therefore, this paper presents a laboratory experiment exploring the psychological influences of sunlight patterns under immersive virtual reality scenes. The sunlight patterns are created by a combination of nine aperture designs, two window sizes and two sky types. The experiment collects 41 valid architecture students' assessments and their physiological responses. Degrees of eight adjectives, including pleasantness, calmness, interest, excitement, complexity, spaciousness, satisfaction with exterior view amount and brightness, are rated by the participants. Physiological data of heart rates and electroencephalogram are collected. According to the analysis, both the aperture designs and sky types have influences upon subjective responses. The large window enhances beta oscillations and beta power on the right prefrontal lobe area, and the clear sky attenuates the theta rhythm on the pre frontal lobe areas. These findings indicate the important influence of natural lightscape compositions created by aperture designs and sky types upon occupants' psychological processes.

Keywords: sunlight patterns; aperture design; immersive virtual reality; EEG; ECG; sky type

check for updates

Citation: Kong, Z.; Hou, K.; Wang, Z.; Chen, F.; Li, Y.; Liu, X.; Liu, C. Subjective and Physiological Responses towards Interior Natural Lightscape: Influences of Aperture Design, Window Size and Sky Condition. *Buildings* **2022**, *12*, 1612. https://doi.org/10.3390/buildings12101612

Academic Editors: Eusébio Z.E. Conceiçã and Mark Bomber

Received: 10 August 2022
Accepted: 29 September 2022
Published: 5 October 2022

1. Introduction

Lighting quality, especially daylighting quality, plays an important role within offices [1]. Daylighting quality influences occupants from both biopsychological and psychological processes [2,3]. To create sufficient and comfortable daylighting environments, many studies have explored the performance of daylighting design metrics from the biopsychological processes [4–8]. However, there are still insufficient studies concerning the psychological processes of daylight. With the development of building forms, as well as façade and aperture designs, many buildings provide diverse sunlight patterns and daylighting compositions to individuals [9], which demonstrates the necessity of exploring daylighting psychological influences.

Different interior sunlight patterns and daylighting compositions are influenced by many factors. According to previous studies, spatial properties, window properties and sky types are three primary influencing factors. Spatial properties include spatial dimension and spatial context [10]. Window properties include window dimension [10], window number [11], window shape [12] and aperture design (or façade design) [13]. Sky types include overcast skies and clear skies [10,14–18], varying in sunlight existence and luminance distributions. Interior sunlight patterns and daylighting compositions are composed by a combination of multiple design parameters, defined as natural a lightscape by Wu [19].

Different interior sunlight patterns and daylighting compositions trigger various subjective lighting impressions and mood states [10,14–17,20], which requires further exploration.

Due to the difficulty of controlling sky conditions in the real world, simulation-based methods have commonly been employed. Researchers have utilized simulation software to generate various daylighting distributions under different sky conditions and presented these daylighting scenes by using monitors or projection screens [21,22]. This method solves the problem of controlling sky conditions with the lack of providing 3D spatial perceptions. Another improved method of using virtual reality (VR) scenes to both control sky conditions and provide subjective 3D perception has been rapidly developed and used in the last five years. Although VR headsets have limited ranges of luminance values, valid studies have demonstrated no statistically significant differences of subjective visual assessments of the lighting scenes between VR headsets and in the real world [23,24]. In other words, immersive VR is an effective tool for representing interior lighting scenes with spatial perceptions.

Additionally, given that some previous studies concluded insignificant effects of lighting environments on subjective assessments [25–27], physiological data are recommended to be employed for reflecting participants' physiological reactions at a high level of sensitivity. Therefore, this study utilizes immersive VR to create various natural lightscapes composed of a combination of aperture designs, window sizes and sky types. Subjective assessments and physiological data of both electroencephalogram (EEG) and electrocardiogram (ECG) are collected. The primary research question is to find out whether different daylighting compositions affect subjective responses.

2. Materials and Methods

2.1. Experimental Conditions and Materials

This study aims to explore subjective evaluations and psychological data according to various patterns of sunlight and shadows resulting from a combination of aperture design, window size and sky type. Nine aperture designs derived from architecture projects were selected due to their results of various sunlight patterns. Figure 1 presents the aperture design drawn from the associated architecture projects. As Figure 1 shows, representative aperture designs of five types (Design 1 to Design 8), along with a regular design of façade—curtain walls (Design 6)—were selected for comparison in this study.

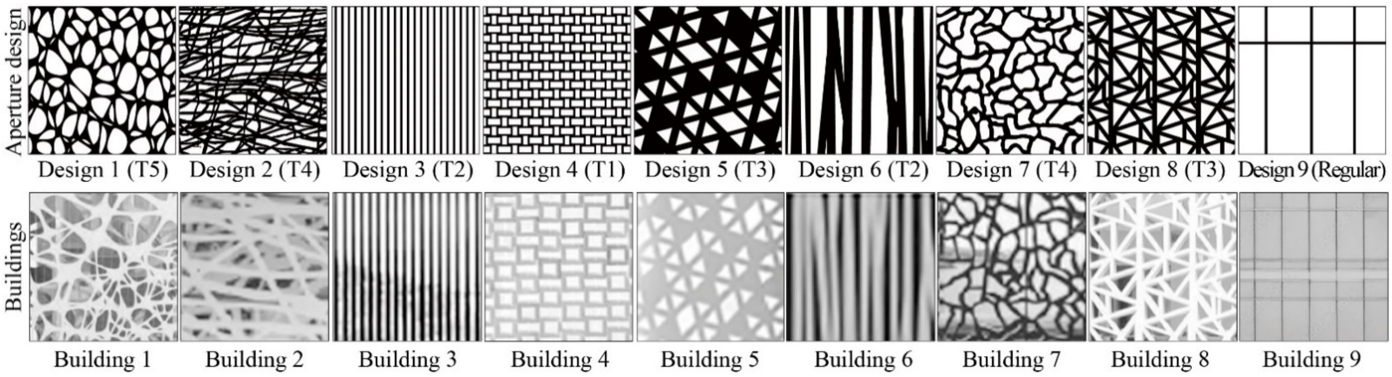


Figure 1. Nine aperture designs (the upper row) and the original buildings (the lower row). Building 1: Tokyo Airspace, Japan; Building 2: Art Wall, Qatar; Building 3: Freshwater House, Australia; Building 4: MAC headquarters, Thailand; Building 5: Panama Diamond Exchange, Panama; Building 6: Selcuk Ecza Headquarters, Turkey; Building 7: MuCEM, France; Building 8: Nakara Residential Hotel, France; Building 9: BMW Experience Center, Chengdu, China.

All nine aperture designs were employed in the same open-plan office. Figure 2 illustrates the office layout and section, the spatial dimensions and aperture dimensions for the large window. A mezzanine floor containing 12 workstations was designed to increase spatial richness. A hallway with the exact window design as the office was added to prolong the participants' walk. The red dot at the left end of the hallway on the layout demonstrates the starting point where a participant stood in each scene. The 3D models were generated in SketchUp [28] and rendered in Enscape, which integrates building information modelling (BIM) and visualization and converts 3D models to Virtual Reality (VR) environments [29]. Interior materials were determined based on the material properties of regular classrooms on the Sipai Lou campus at Southeast University, which architecture undergraduate and graduate students are familiar with. The open-plan office was embedded into an urban environment to enhance the spatial realism.

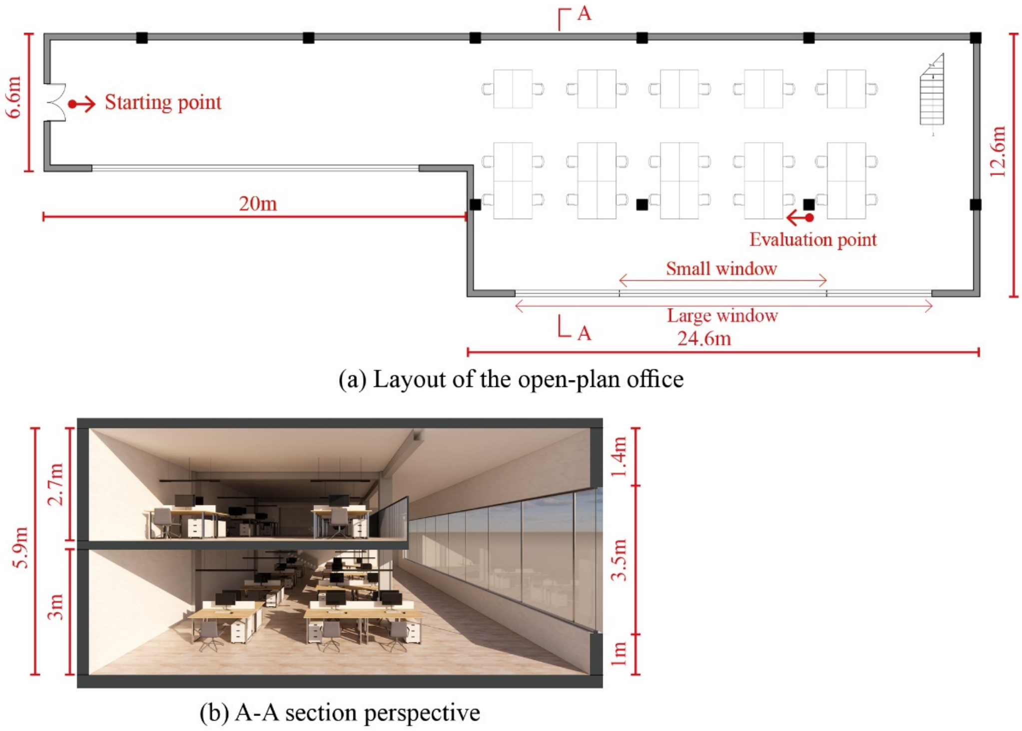


Figure 2. (**a**) Layout and (**b**) Section perspective of the open-plan office.

2.2. Experimental Design

This study followed a mixed 9 × 2 × 2 full factorial design. The design consisted of the within-subjects and between-subjects factor of aperture design (seven aperture design variations for each participant), as well as the between-subjects factors of window size (a small window of 10 m in width and 3.5 m in height and a large window of 20 m in width and 3.5 m in height) and sky type (overcast sky and clear sky with low sun angle). The size and location of both small and large windows are illustrated by the red lines on the layout of the open-plan office, Figure 2. A combination of aperture designs, window sizes and sky types produced 36 unique scenes. All four scenes of aperture design one (D1) are shown in Figure 3. All nine aperture designs with the large window under the clear sky are shown in Figure 4. An HTC Vive Pro headset was used to present the stimuli. Due to current technical limitations, the maximum luminance of the device measured at the level of the lens is 92 cd/m^2. The headset used an AMOLED display with a resolution of 1440 × 1600 pixels per eye, a refresh rate of 90 Hz and a 110° diagonal field of view [30].

Figure 3. Four scenes for Design One with the combination of window size and sky type.

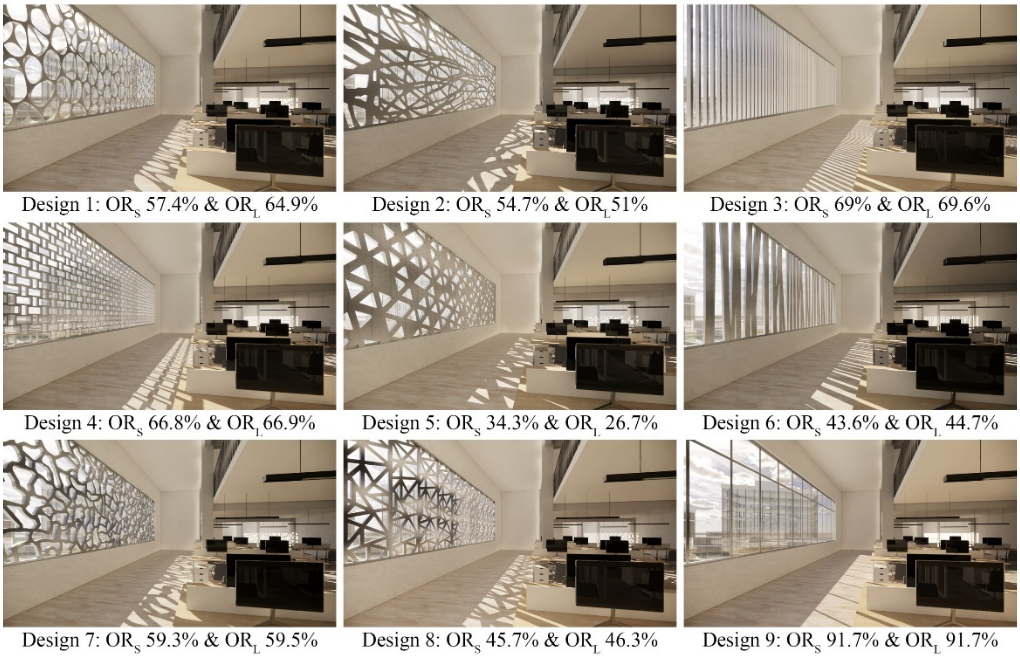


Figure 4. Nine aperture designs with the large window under the clear sky (OR_S represents the openness ratio for the small window, and OR_L represents the openness ratio for the large window).

2.3. Measures

In this study, self-reported assessments were collected by digital surveys. Psychological data, including electroencephalogram (EEG) and electrocardiogram (ECG), were collected.

2.3.1. Subjective Questionnaires

Each participant needed to complete three questionnaires: a start-up questionnaire, an evaluation questionnaire and an ending questionnaire. Table 1 lists all the questions for the three questionnaires. The start-up questionnaire contained the demographic information of gender, age, eyesight, grade and major, as well as the subjective current state of fatigue and alertness (Questions 4 and 5 in the Ending questionnaire of Table 1). The evaluation questionnaire contained eight questions followed Moscoso and Chamilothori's studies, which explored subjective assessments of daylighting patterns through VR scenes [10,14–17]. The ending questionnaire asked participants to report their current state of eye soreness, vision clearness, mind freshness, fatigue and alertness after the experiment. All the questions were designed on an 11-scale from 0 (Not at all) to 10 (Very) except for Karolinska Sleepiness Scale (KSS), which used a 9-point scale [31]. Given that each participant evaluated seven scenes and answered the evaluation questionnaire seven times, the eight questions were asked in a random order.

Table 1. The evaluation questionnaire and ending questionnaire.

	Evaluation questionnaire	
No.	Theme	Question
1	Pleasantness	How pleasant is this space?
2	Calmness	How calming is this space?
3	Interest	How interesting is this space?
4	Excitement	How exciting is this space?
5	Complexity	How complex is this space?
6	Spaciousness	How spacious is this space?
7	Satisfaction with views	How satisfied are you with the amount of outside view?
8	Brightness	How bright is this space?
	Ending questionnaire	
No.	Theme	Question
1	Eye soreness	How sore do your eyes feel?
2	Vision clearness	How clear is your vision?
3	Mind freshness	How fresh does your head feel?
4 *	Fatigue *	How fatigued do you feel?
5 *	KSS *	The Karolinska Sleepiness Scale
6	Open-ended question	Do you have any other symptoms or suggestions?

* Questions included in both start-up and ending questionnaires.

2.3.2. Physiological Measures

A heart rate sensor developed and validated by Liu et al. [32] was set at 500 Hz for collecting heart rate variability (HRV). Before the experiment, the sensor was stuck on the chest. The raw data stream was preprocessed with the BioSPPy Python software [33], and the parameters of time–domain mean and median of beat interval, denoted as Mean_{NN} and Median_{NN}, were extracted for each participant evaluating each scene. Moreover, an EEG device, developed and validated by Liu et al. [34], was set at 256 Hz and positioned FP1 and FP2 channels on pre frontal lobe areas for collecting EEG data. Following the data processing steps in [35], EEG data were processed using the EEGLAB plugin [36] for MATLAB 2022 [37]. To exclude the influences of participant movements, thinking and speaking, only the EEG data of 40 s while participants standing still within each scene were extracted for further analysis. Apparent spikes or oscillations outside of the normal range were discarded. Since the AC working frequency caused the EEG spectrum to sag at 50 Hz, signals between 1 Hz and 48 Hz were removed. EEG signal noises such as eye movement artifacts, ECG artifacts and skin artifacts were also moved. The time domain signal was converted to the frequency domain by Fast Fourier Transform (FFT), which were separated into four bands: δ (0.5 Hz~4 Hz), θ (4 Hz~8 Hz), α (8 Hz~12 Hz) and β (12 Hz~30 Hz). Representative values of the time domain means (Mean_{δ}, Mean_{θ}, Mean_{α} and Mean_{β}), time domain standard deviations (SD_{δ}, SD_{θ}, SD_{α} and SD_{β}) and the average power of the EEG signal ($\text{PowerMean}_{\delta}$, $\text{PowerMean}_{\theta}$, $\text{PowerMean}_{\alpha}$ and PowerMean_{β}) of each participant's left and right FP channels of each scene were extracted.

2.4. Experimental Protocol

The experiment was conducted between the end of April and the end of May, lasting around a month in 2022. The experiment was conducted in the lighting lab, which is located on the second floor, at the northeast corner of Zhongda Yuan. Indoor air temperature and relative humidity were monitored throughout the entire data collection. Throughout the entire experiment, the indoor air temperature varied between 22.3 °C and 26.6 °C, with a mean of 23.7 °C and a standard deviation (SD) of 1.3 °C. The relative humidity varied between 41.7% and 61.8%, with a mean of 50.5% and a SD of 7%. The variations of indoor air temperature and relative humidity satisfied occupants' basic requirement [38].

Figure 5 illustrates the experimental protocol for each participant. After entering the lab, the participant was introduced to the whole experimental procedure. Once the participant agreed to contributing to this study, a consent form was signed. The participant first filled out the start-up questionnaire and then wore the psychological instruments with an investigator's assistance. Once the investigator ensured the stability of the EEG and ECG, the participant was assisted to wear the HTC Vive pro headset. After wearing the headset, the participant stayed still for 30 s to ensure that the psychological data was stable.

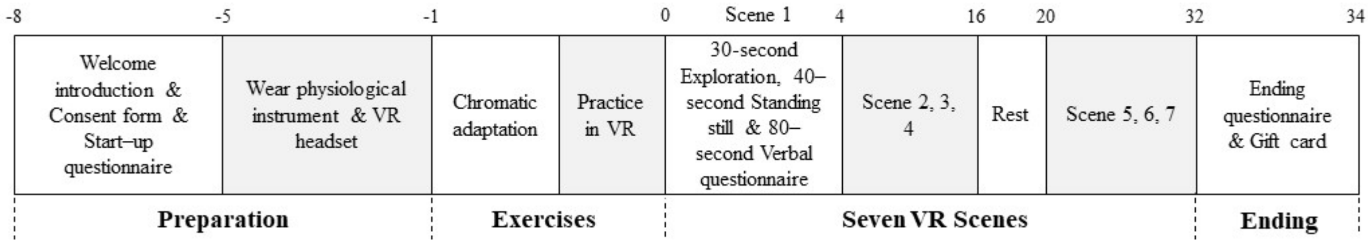


Figure 5. VR experiment protocol.

Before presenting the first scene, a single color was displayed in VR for 15 s to ensure chromatic adaptation. When presenting the first scene, each participant was told to imagine that they were working in this open-plan office. Participants entered at the starting point (the starting point on the layout of Figure 2). They were asked to freely explore each scene for 30 s, including walking within the office or going upstairs to the mezzanine floor. Participants used controllers to move forward in each scene and slowly turned around if necessary. After a 30 s walk, participants were instructed to stand on the predetermined evaluation spot (the evaluation point on the layout of Figure 2) and stand still to look towards the entrance to ensure that their field of view was composed of half window view and half interior office. Figures 3 and 4 present the associated field of view when a participant stood at the evaluation point. After standing still for 40 s, they verbally responded to the eight questions of the evaluation questionnaire while remaining immersed in the VR environment. Once the evaluation questionnaire was completed, the participant would wait for the second scene. The participant repeated the same procedure in the second scene as in the first scene. Each scene took around 2.5 min. Figure 6 shows the experimental scenes with six of the participants.

Figure 6. VR experimental scenes with six random participants.

In order to control the experimental duration to minimize subject fatigue, each participant only evaluated seven scenes consisting of a combination of seven aperture designs, two window sizes and two sky types in random order. After completing four scenes, participants were asked to either take a 2 min break or carry on to complete the remaining three scenes. The entire experiment for each participant lasted between 43 and 55 min. The investigator observed the psychological data throughout each participant's entire experiment.

2.5. Participants

Since participants with or without design background evaluated aperture designs differently [39], this study merely concentrated on participants with at least four years of architecture design experience. In other words, first year to third year undergraduates majoring in architecture, as well as undergraduates and graduates majoring in urban planning and landscape, were not recruited.

From an initial sample size of 44 participants, two were excluded as they demonstrated Virtual Reality (VR) sickness during the experiment, and one was excluded due to the controllers being out of power. The resulting sample size thus corresponded to 41 participants, with 21 males and 20 females. Participant age ranged from 21 to 33 years with a mean of 25.2 years and a SD of 3.2 years. All 41 participants majoring in architecture were right-handed. Table 2 lists the average eyesight of each participants' left and right eyes, as well as their grades.

Table 2. Eyesight and grade information of 41 participants.

Eyesight		Grade	
Diopters	**Count**	**Grade**	**Count**
Normal vision	3	Fourth- or fifth-year undergraduates	10
Mild myopia < −3.00 diopters	17	Master students	25
Moderate myopia −3.00 to −6.00 diopters	17	Ph.D. students	6
High myopia −6.00 to −9.00	4		

Given that the aperture design nine (D9) represented a regular –wall design, it was assessed by all participants. Therefore, each participant evaluated six aperture designs plus D9. In the end, D1 to D4, along with D6 and D7 were evaluated by 31 participants; D5 and D8 were evaluated by 30 participants; D9 was evaluated by 41 participants. Large windows and small windows were assessed 143 and 144 times, respectively. The overcast sky and the clear sky were assessed 145 and 142 times, respectively. In order words, all levels of each independent variable were evaluated by a relatively equal number of participants unless it was designed in particular (D9).

2.6. Statistical Analysis

Since this experiment mixed within–between design with repeated measures for the factor of aperture design, a Linear Mixed Model (LMM) was used, which has been employed by previous studies [14,40]. The identification number of each participant was specified as a random factor, and the aperture design, window size and sky type were specified as fixed effects. The interactive effects between two factors were also explored: aperture design × window size, aperture design × sky type and window size × aperture design. Potential confounding factors, including individual differences (gender, age and eyesight) and experimental procedure (scene order and the first aperture design) were added as covariates. All the factors were analyzed as ordinal variables. A factor was removed from the model whenever it was not significant. In this paper, aperture design, window size and sky type were the three fixed factors. The lightscape scene presentation order, gender and age were the three covariates. Additionally, the three studied interactions were aperture design × window size, aperture design × sky type and window size × sky type. Therefore, a Bonferroni-corrected significance level $\alpha' = 0.05/((3 + 3 + 3) \times 8) = 0.0007$ was used to account for the multiple analyses, since there were eight questions. In other words, any p-value greater than 0.0007 failed to reject the null hypothesis.

3. Results

3.1. Effects of Aperture Design, Window Size and Sky Type on Subjective Responses

The interaction of design × window size failed to meet the adjusted significance threshold (all p-values > 0.0045). The interaction of design × sky was only significant for impressions of brightness ($F(8, 247.26) = 3.64$, $p = 0.00051$). Additionally, gender was insignificant for all eight attributes, and age was only significant for impressions of calmness ($F(8, 39.582) = 10.733$, $p = 0.002194$). Therefore, all interaction terms and gender were excluded from the final models.

Table 3 presents an overview of the LMM analyses for the main factor of interest in the final models. Grey cells indicate that p-values are greater than 0.0045, and the correlations between the associated predictors and attributes are insignificant. Significant effects of aperture design are found for six attributes except for pleasantness. Significant effects of sky type are also found for seven attributes except for satisfaction with views. Detailed LMM results concerning each factor will be discussed below.

Table 3. Results of the LMM analysis for the main factors of aperture design, window size and sky type on all subjective responses.

Predictor	Attribute	df	F	*p*-Value
Aperture design	Pleasantness	229.43	2.21	0.028
	Calmness	232.15	4.82	0.0000165 **
	Interest	229.41	6.90	<0.00001 ***
	Excitement	228.81	4.98	<0.00001 ***
	Complexity	229.19	16.52	<0.00001 ***
	Spaciousness	223.56	4.89	<0.000014 **
	Satisfaction with view amount	223.11	15.35	<0.00001 ***
	Brightness	228.97	2.99	0.0033
Window size	Pleasantness	224.55	0.20	0.66
	Calmness	224.94	0.01	0.92
	Interest	223.80	1.00	0.318
	Excitement	224.16	5.03	0.026
	Complexity	224.20	3.80	0.053
	Spaciousness	221.54	6.25	0.013
	Satisfaction with view amount	219.87	1.16	0.283
	Brightness	224.43	4.24	0.041
Sky type	Pleasantness	227.26	104.57	<0.00001 ***
	Calmness	229.11	55.43	<0.00001 ***
	Interest	226.96	184.00	<0.00001 ***
	Excitement	226.72	190.72	<0.00001 ***
	Complexity	226.98	171.55	<0.00001 **
	Spaciousness	222.36	5.66	0.018
	Satisfaction with view amount	221.47	17.89	0.0000342 **
	Brightness	226.92	165.86	<0.00001 ***

Note: * $p < 0.0007$, ** $p < 0.00014$, *** $p < 0.00001$.

Table 4 lists the marginal and conditional R^2 for the LMM of each dependent variable. Compared to R^2 marginal, the proportion of explained variance in the model is greatly increased for R^2 conditional. According to Ferguson's suggestions [41], one R^2 marginal and four R^2 marginal in bold were moderate effects ($R^2 > 0.5$), and the remaining R^2 were minimum practical effects ($R^2 > 0.2$) with the exception of impressions of spaciousness (R^2 marginal = 0.149).

Table 4. Results of the LMM analysis for the main factors of aperture design, window size and sky type on all dependent variables.

Attribute	R^2 Marginal	R^2 Conditional
Pleasantness	0.322	0.427
Calmness	0.304	0.352
Interest	0.456	0.525
Excitement	0.454	0.546
Complexity	0.506	0.581
Spaciousness	0.149	0.488
Satisfaction with view amount	0.294	0.495
Brightness	0.417	0.518

3.2. *Perceptual Differences between Aperture Design*

To further investigate the effect of aperture design on subjective responses, post-hoc pairwise analyses were conducted for all combinations of aperture design for each dependent variable. As the pairwise comparisons are too numerous to be depicted in a table, Table 5 lists the estimated marginal means (EMM), SE and 95% confidence intervals (CI) for all attributes. Grey cells indicate that there is no statistically significant difference between two designs. White cells indicate that there is at least one other aperture design statistically different from this aperture design in terms of associated attributes. The maximum and minimum EMMs of nine aperture designs associated with each attribute are in bold. The following paragraphs describe differences between aperture designs in details.

A Spearman test was conducted between the eight subjective questions, the result shows that subjective impressions of interest, excitement and complexity are mutually strongly correlated with the *p*-values lower than 0.001 and the correlation coefficient varies between 0.725 and 0.82. Therefore, these three attributes will be discussed in one section. Subjective impressions of calmness will be individually discussed due to its negative correlations with interest ($R^2 = -0.284$), excitement ($R^2 = -0.37$), complexity ($R^2 = -0.$ 425) and brightness ($R^2 = -0.144$). Subjective impressions of spaciousness and satisfaction with exterior view amount will be discussed in one section, due to their moderate correlation ($R^2 = 0.439$). Finally, subjective impressions of pleasantness and brightness will be discussed in one section due to their insignificant difference.

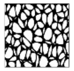
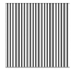
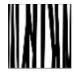
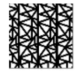
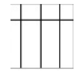
3.2.1. Impressions of Interest, Excitement and Complexity

For impressions of interest, D3 is different from D1 (B = 1.566, $p = 0.0076$), D2 (B = 1.630, $p = 0.0046$) and D7 (B = −1.7264, $p = 0.0019$), respectively. Compared to these three aperture designs (D1, D2 and D7), D3 induced decreases in interest ratings varying between 14.2% and 15.6%. D9 is different from six aperture designs, including D1 (B = 1.991, $p < 0.0001$), D2 (B = 2.0544, $p < 0.0001$), D4 (B = 1.421, $p = 0.0113$), D5 (B = 1.5264, $p = 0.0049$), D7 (B = 2.1511, $p < 0.0001$) and D8 (B = 0.5879, $p = 0.0044$). Given that D9 was rated the least interesting aperture design with an EMM of 5.05, those six aperture designs increased subjective ratings of interest varying between 12.9% and 19.5%. Neither D3 nor D6 is different from D9 in terms of subjective ratings of interest.

For impressions of excitement, D6 is different from D1 (B = 1.4507, $p = 0.0189$) and D7 (B = −1.5896, $p = 0.0067$) with a decrease in subjective ratings of excitement of 13.2% and 14.5%, respectively. As shown in Table 5, D9 is different from five aperture designs (D1, D2, D5, D7 and D8) but similar to three aperture designs (D3, D4 and D6). Nonetheless, D9 was rated the least exciting aperture design with an EMM of 4.86.

For impressions of complexity, D3 differs from D1 (B = 1.6495, $p = 0.0044$), D5 (B = −1.7222, $p = 0.0022$) and D7 (B = −2.2452, $p < 0.0001$) with a decrease in subjective ratings of complexity varying between 15% and 20.4%. Besides D3, D7 is also different from D4 (B = −1.5892, $p = 0.0076$) and D6 (B = −1.7540, $p = 0.0022$) with an increase in subjective ratings of complexity of 14.5% and 15.9%, respectively. Due to the lowest EMM of 3.43, D9 is different from all remaining eight aperture designs.

Table 5. Estimated marginal means (EMM), standard errors (SE) and 95% confidence intervals (CI) per attribute and aperture design (without interaction).

		D1	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**
										
Pleasantness	EMM	7.58	7.42	6.67	7.52	6.38	6.44	6.67	6.94	6.96
	SE	0.334	0.337	0.33	0.33	0.334	0.336	0.336	0.352	0.297
	95% CI	[6.65, 8.52]	[6.48, 8.36]	[5.75, 7.6]	[6.6, 8.45]	[5.45, 7.32]	[5.5, 7.38]	[5.73, 7.61]	[5.96, 7.92]	[6.13, 7.79]
Calmness	EMM	6.98	7.4	7.85	7.63	6.64	7.64	5.43	6.94	7.56
	SE	0.362	0.365	0.357	0.357	0.362	0.363	0.363	0.381	0.319
	95% CI	[5.97, 5.97]	[6.38, 6.38]	[6.85, 6.85]	[6.64, 6.64]	[5.63, 5.63]	[6.62, 6.62]	[4.42, 4.42]	[5.88, 5.88]	[6.67, 6.67]
Interest	EMM	7.04	7.1	5.48	6.47	6.58	5.91	7.2	6.64	5.05
	SE	0.314	0.316	0.31	0.31	0.314	0.315	0.315	0.331	0.278
	95% CI	[6.16, 7.92]	[6.22, 7.99]	[4.61, 6.34]	[5.61, 7.34]	[5.7, 7.45]	[5.03, 6.79]	[6.32, 8.08]	[5.71, 7.56]	[4.27, 5.83]
Excitement	EMM	6.63	6.2	5.51	5.87	6.3	5.18	6.77	6.2	4.86
	SE	0.314	0.317	0.31	0.31	0.314	0.316	0.316	0.331	0.279
	95% CI	[5.75, 7.51]	[5.31, 7.08]	[4.64, 6.37]	[5, 6.74]	[5.42, 7.18]	[4.3, 6.06]	[5.88, 7.65]	[5.28, 7.13]	[4.08, 5.64]
Complexity	EMM	6.67	6.1	5.02	5.67	6.74	5.51	7.26	6.31	3.43
	SE	0.32	0.323	0.317	0.316	0.32	0.322	0.322	0.338	0.284
	95% CI	[5.77, 7.56]	[5.2, 7.01]	[4.13, 5.9]	[4.79, 6.56]	[5.84, 7.63]	[4.61, 6.41]	[6.36, 8.16]	[5.36, 7.25]	[2.64, 4.23]
Spaciousness	EMM	7.69	7.95	6.92	7.85	6.38	6.69	6.94	7.42	7.85
	SE	0.325	0.328	0.323	0.323	0.325	0.327	0.327	0.339	0.298
	95% CI	[6.77, 8.6]	[7.02, 8.87]	[6.01, 7.82]	[6.94, 8.75]	[5.46, 7.29]	[5.77, 7.61]	[6.02, 7.86]	[6.47, 8.37]	[7.02, 8.69]
Satisfaction with view amount	EMM	6.88	6.09	5.87	6.57	4.66	6.01	5.77	6.01	8.58
	SE	0.343	0.346	0.34	0.34	0.343	0.345	0.345	0.359	0.31
	95% CI	[5.92, 7.85]	[5.12, 7.06]	[4.92, 6.82]	[5.62, 7.52]	[3.7, 5.62]	[5.05, 6.98]	[4.81, 6.74]	[5, 7.02]	[7.71, 9.45]
Brightness	EMM	7.3	6.81	7.16	7.6	6.26	6.33	7.13	6.52	7.6
	SE	0.337	0.34	0.333	0.333	0.337	0.339	0.339	0.354	0.299
	95% CI	[6.36, 8.24]	[5.86, 7.76]	[6.23, 8.09]	[6.67, 8.53]	[5.32, 7.2]	[5.39, 7.28]	[6.19, 8.08]	[5.53, 7.51]	[6.77, 8.44]

3.2.2. Impressions of Calmness

For impressions of calmness, D7 statistically differs from D2 (B = 1.9708, $p < 0.0033$), D3 (B = 2.41889, $p = 0.0001$), D4 (B = 2.20156, $p = 0.0004$), D6 (B = 2.20605, $p = 0.0005$) and D9 (B = −2.13048, $p = 0.0003$). Since D7 was rated as the least calm scene with an EMM of 5.43, it decreased the calmness of the participants between 17.9% and 22%. Besides D7, there are no statistically significant differences between other aperture designs.

3.2.3. Impressions of Spaciousness and Satisfaction with View Amount

For impressions of spaciousness, with the lowest EMM of 6.38, D5 statistically significant differs from D1 (B = 1.30958, $p = 0.0158$), D2 (B = 1.56863, $p = 0.0013$), D4 (B = 1.46963, $p = 0.0035$) and D9 (B = −1.47755, $p = 0.0012$), with a decrease in spaciousness impressions varying between 11.9% and 14.3%. Additionally, with a slightly greater EMM of 6.669, D6 is statistically significantly different from D2 (B = 1.25904, $p = 0.0292$) and D9 (B = −1.16796, $p = 0.0286$) with a decrease in spaciousness impressions of 11.5% and 10.5%, respectively.

For satisfaction with exterior view amount, D5 was also rated as the least satisfying aperture design with the lowest EMM of 4.66. D5 is statistically significantly different from D1 (B = 2.22535, $p < 0.0001$), D2 (B = 1.42785, $p = 0.0246$), D4 (B = 1.91267, $p = 0.0003$), D6 (B = −1.35500, $p = 0.0431$) and D9 (B = −3.92385, $p < 0.0001$) with the satisfaction rating decreasing between 13% and 35.6%. However, D5 presents no difference from D3, D7 or D8 in terms of satisfaction with exterior view amount. Given the greatest satisfaction level of EMM of 8.58, D9 is also different from the other seven aperture designs, in addition to D5, with a decrease in satisfaction rating percentage varying between 15.5% and 25.5%.

The openness ratios (OR) for D1 to D9, as marked in Figure 4, demonstrate that D9 (91.7%) and D5 (34.3% and 26.7%) are the top and bottom designs in terms of OR, respectively. In other words, subjective responses to impressions of spaciousness and satisfaction with exterior view amount could be ascribed to OR, especially to D9 and D1.

3.2.4. Impressions of Pleasantness and Brightness

Finally, none of the nine aperture designs presents statistically significant differences in terms of subjective assessments of pleasantness or brightness. For pleasantness impressions, the greatest rated aperture design is D1 with an EMM of 7.58, while the lowest rated aperture design is D5 with an EMM of 6.38. All nine aperture designs presented EMMs of pleasantness greater than 6, meaning that none of the aperture designs was rated as unpleasant. For brightness impressions, the greatest rated aperture designs are D4 and D9 with the same EMM of 7.6, while the lowest rated aperture design is D5 with an EMM of 6.26. Similarly, all nine aperture designs present EMMs of brightness above 6.

3.3. Perceptual Differences between Sky Type

Table 6 lists the EMM and SE for all eight dependent variables, along with the estimated B and SE for the pairwise comparisons between the overcast sky and the clear sky. Only the spaciousness impressions had no statistically significant differences between the overcast and clear skies, although the EMM of 7.11 under the overcast sky was slightly lower than that of 7.49 under the clear sky. Participants rated the six attributes of pleasantness, interest, excitement, complexity, satisfaction with exterior view amount and brightness as greater under the clear sky than under the overcast sky. Compared to the overcast sky, the clear sky increases subjective impressions of pleasantness by 18.5%, interest by 23.9%, excitement by 24.2%, complexity by 22.9%, satisfaction with exterior view amount by 7.1% and brightness by 23.1%. On the contrary, However, compared to the overcast sky, the spatial calmness is decreased by 15.8% under the clear sky.

3.4. Effects of Aperture Design, Window Size and Sky Type on EEG

Table 7 presents the LMM analyses for the main factors of aperture design, window size and sky type on EEG representative predictors. Given the 12 EEG predictors, only the ones with p-values within 0.05 are shown in Table 7. However, since only three main factors were tested herein, the adjusted p-value of the initial 0.05 was adjusted to 0.0021 (0.005/(3 × 8)). Although both the mean of beta power and S.D. of beta rhythm of the right prefrontal lobe area are influenced by aperture designs, the p-values are greater than 0.0021. Neither the S.D. of alpha rhythm are influenced by the window size. However, mean power of beta (F(1, 203.41) = 5.8359, p = 0.00166) and the S.D. of beta rhythm (F(1, 203.41) = 5.9674, p = 0.00154) on the right prefrontal lobe area are influenced by window size. Table 8 lists the estimated marginal means (EMM), SE and 95% confidence intervals (CI) of sky types for $\log_{10}$ of $\mathrm{PowerMean}_{\beta}$ (B = 0.0337, p = 0.0166) and $\log_{10}$ of SD_{β} (B = 0.0337, p = 0.0166). The large window resulted in higher oscillations and stronger power of the beta rhythm on the right prefrontal lobe area than the small window did.

Table 6. Estimated marginal means (EMM), standard errors (SE), 95% confidence intervals (CI) for all eight dependent variables, along with the estimates B and standard errors (SE) for pairwise comparisons.

	Overcast Sky			**Clear Sky**		
	EMM	**SE**	**95% CI**	**EMM**	**SE**	**95% CI**
Pleasantness	5.94	0.184	[5.52, 6.36]	7.97	0.185	[7.55, 8.39]
Calmness	7.99	0.184	[7.57, 8.40]	6.25	0.186	[5.83, 6.68]
Interest	5.07	0.167	[4.69, 5.45]	7.70	0.168	[7.31, 8.08]
Excitement	4.62	0.172	[4.22, 5.01]	7.28	0.174	[6.88, 7.67]
Complexity	4.60	0.174	[4.20, 4.99]	7.12	0.175	[6.71, 7.52]
Spaciousness	7.11	0.225	[6.59, 7.62]	7.49	0.226	[6.97, 8.01]
Satisfaction with view amount	5.88	0.217	[5.38, 6.38]	6.66	0.219	[6.16, 7.17]
Brightness	5.70	0.189	[5.27, 6.13]	8.24	0.190	[7.80, 8.67]

Table 7. Results of the LMM analysis for the main factors of aperture design, window size and sky type on EEG predictors.

EEG Predictors	**Independent Variables**	**df**	**F**	***p*-Value**
$\log_{10}(\mathrm{SD}_{\alpha\text{-right}})$	Window size	203.26	4.58	0.03354
$\log_{10}(\mathrm{PowerMean}_{\beta\text{-right}})$	Design	203.77	2.4094	0.01664
	Window size	203.41	5.8359	0.00166 *
$\log_{10}(\mathrm{SD}_{\beta\text{-right}})$	Design	203.77	2.3918	0.01743
	Window size	203.41	5.9674	0.00154 *
$\mathrm{Mean}_{\theta\text{-left}}$	Sky type	88.074	8.2583	0.00208 *
$\mathrm{Mean}_{\theta\text{-right}}$	Sky type	4.7805	11.0845	0.00123 *

Note: * $p < 0.0021$, ** $p < 0.0004$, *** $p < 0.0001$.

Table 8. Estimated marginal means (EMM), standard errors (SE) and 95% confidence intervals (CI) per EEG attribute and window size (without interaction).

	Large Window			**Small Window**		
	EMM	**SE**	**95% CI**	**EMM**	**SE**	**95% CI**
$\log_{10}(\mathrm{PowerMean}_{\beta\text{-right}})$	−3.70	0.0459	[−3.80, −3.61]	−3.74	0.0459	[−3.83, −3.65]
$\log_{10}(\mathrm{SD}_{\beta\text{-right}})$	−3.70	0.0459	[−3.80, −3.61]	−3.74	0.0459	[−3.83, −3.65]

Regarding the sky type, $\log_{10}$ of Mean_{θ} on both the left (F(1, 88.074) = 8.2583, p = 0.00208) and right (F(1, 4.7805) = 11.0845, p = 0.00123) prefrontal lobe areas are influenced by the sky types. Table 9 lists the estimated marginal means (EMM), SE and 95% confidence intervals (CI) of the sky types for $\log_{10}$ of $\mathrm{Mean}_{\theta\text{-left}}$ (B = -3.56×10^{-6}, p = 0.0045) and $\log_{10}$ of $\mathrm{Mean}_{\theta\text{-right}}$ (B = -4.27×10^{-6}, p = 0.0010). The mean theta values on both the left and right prefrontal lobe areas under the overcast sky were three times greater than the mean theta values under the clear sky. In other words, the clear sky attenuates the theta rhythm on the prefrontal lobe areas.

Table 9. Estimated marginal means (EMM), standard errors (SE) and 95% confidence intervals (CI) per EEG attribute and sky type (without interaction).

	Overcast Sky			Clear Sky		
	EMM	**SE**	**95% CI**	**EMM**	**SE**	**95% CI**
$Mean_{\theta\text{-left}}$	7.74×10^{-6}	1.94×10^{-6}	$[3.84 \times 10^{-6}, 1.16 \times 10^{-5}]$	4.18×10^{-6}	1.93×10^{-6}	$[2.98 \times 10^{-7}, 8.07 \times 10^{-6}]$
$Mean_{\theta\text{-right}}$	7.96×10^{-6}	1.73×10^{-6}	$[4.49 \times 10^{-6}, 1.14 \times 10^{-5}]$	3.69×10^{-6}	1.72×10^{-6}	$[2.37 \times 10^{-7}, 7.14 \times 10^{-6}]$

3.5. Effects of Aperture Design, Window Size and Sky Type on ECG

No significant effects are found for aperture design, window size or sky type on ECG data (all p values > 0.0021). In other words, neither $Mean_{NN}$ nor $Median_{NN}$ was influenced by aperture design, window size or sky type herein.

4. Discussion

4.1. Influences of Aperture Design

Subjective assessments of spatial interest, excitement and complexity were mutually positively correlated. The aperture designs that were rated more interesting were also rated more exciting and complex. D7, D1 and D5 were reported more interesting, exciting and complex than the remaining designs, which agrees with Chamilothori's conclusion that participants responded more positively towards irregular than regular aperture designs [13]. Additionally, D9, representing regular curtain walls, D3, representing vertical shades, and D6, representing vertical shades with a low degree of variations, were reported less interesting, exciting and complex. D9 was rated the highest levels in calmness, satisfaction with exterior view amounts and brightness. Subjective greatest satisfaction with exterior view amounts was in alignment with Abboushi and colleagues' conclusion in [42]. It is understandable that no aperture design was significantly different in terms of brightness, given that the VR headset provides a limited range of luminance. All nine aperture designs were rated as EMM greater than 6, meaning that participants were pleased with all aperture designs on average. Nonetheless, subjective VR experience might have contributed to their positive responses.

Finally, physiological data of neither EEG nor ECG was influenced by aperture design. The insignificant results of ECG is in line with Chamilothori's conclusion in [17] but different from Chamilothori's conclusion that participants showed a larger decrease in heart rate while exposed to the irregular condition in [13]. In other words, influences of aperture designs upon physiological measures are still inconsistent and cannot be drawn a general conclusion.

4.2. Influences of Window Size

Concerning window size, no statistically significant difference was found among subjective assessments. However, beta variations and powers on the prefrontal right lobe areas were enhanced more by the large window than the small window. According to the theory of left and right brain segmentation proposed by Roger Sperry [43], the left hemisphere is mainly responsible for functions such as logical understanding, memory, time, judgment, classification, analysis and writing, whereas the right hemisphere is mainly responsible for memory, intuition, emotion, vision, imagination, inspiration and thinking. Greater power means and variance of beta band under the large window indicate a strong intensity of EEG signal oscillations and higher levels of neuronal activity. Although no significant subjective assessments concerning the window size was observed, EEG data might be more sensitive to reflect the different influences of window size.

4.3. Influences of Sky Type

The sky types influence both subjective assessments and psychological data. Compared to the overcast sky, the clear sky results in higher levels in subjective impressions of pleasantness, interest, excitement, complexity, brightness and satisfaction with exterior view amount, but lower levels in subjective impressions of calmness. Moreover, the overcast sky results in greater levels of mean theta rhythm on both left and right prefrontal lobe areas. Unlike Moscoso et al. and Chamilothori et al.'s conclusion that sky types have no significant influence on subjective assessments [10,40], the contradictory conclusion reported in this study might be caused by the different simulation method. In both Moscoso et al. and Chamilothori et al.'s studies, they projected simulated luminance maps to create 3D VR scenes with a fixed evaluation spot for the participants. However, this study uses Enscape to create interior simulation scenes, where the participants could freely explore each scene. However, the rendered scenes exaggerated the color temperature difference between the overcast and clear skies. As shown in Figure 3, in addition to the existence of sunlight patterns, the warm color appearance under the clear sky and the cool color appearance under the overcast sky might affect subjective assessments and their theta rhythm in high likelihood. Further studies are required to calibrate and validate the method of using Enscape for creating VR scenes in terms of daylighting appearance.

4.4. Research Limitations

In addition to the exaggerated color temperature differences between the overcast and clear skies, this study contains the following limitations. First, the participants in the studies are experts in architecture designs. Assessments of non-experts were not included in this study. Second, this study only measured the EEG on the left and right prefrontal lobe areas, other channels require further exploration. Third, this study only included 41 participants' valid responses. More participants with diverse distributions of age ranges could provide more concrete conclusions.

5. Conclusions

This paper presents a laboratory experiment using VR scenes. Nine aperture designs, two window sizes and two sky types were explored. Forty-one participants with four years or longer architecture background evaluated eight aspects of interior natural lightscape. Physiological data of both ECG and EEG of the prefrontal lobe areas were collected during the experiment. According to the data analysis, the aperture designs have impacts on subjective assessments of calmness, interest, excitement, complexity, spaciousness and satisfaction with exterior views. The sky types influence subjective assessments of pleasantness, calmness, interest, excitement, complexity, spaciousness, brightness and satisfaction with exterior views. Compared to the small window, the large window enhances beta oscillations and beta power on the right prefrontal lobe area. Compared to the overcast sky, the clear sky attenuates the theta rhythm on the prefrontal lobe areas.

Based on the subjective responses, the design recommendations are proposed as below:

1 Regular windows (Design 9) rated as the least interesting, exciting and complex design are appropriate in spaces where a calm and stable atmosphere is required. In other words, classrooms and offices, where occupants need to focus on their work rather than to be distracted by sunlight patterns, are suitable environments in which to employ regular window design.

2 Regular-shape aperture designs (Designs 3, 4, and 6) were also rated with low levels of interest, excitement and complexity, as well as high level of calmness. Similar to regular windows, these designs (Designs 3, 4, and 6) are also suitable for spaces with the requirement of a relatively calm and stable atmosphere.

3 Irregular shape aperture designs (Designs 1, 2, 7 and 8) were rated with high levels of interest, excitement and complexity, as well as low level of calmness. These aperture designs, as well as the sunlight patterns, are more likely to trigger participants' positive feelings and responses. Spaces that require a lively and dynamic atmosphere, such as hotel lobbies, shopping malls and art museums, could employ these irregular aperture designs.

4 Finally, openness ratios of aperture designs, which had great a impact on subjective impressions of spatial spaciousness and satisfaction with exterior view amounts, need be considered during the aperture and façade design.

Author Contributions: Conceptualization, Z.K., K.H. and C.L.; methodology, Z.K., K.H. and C.L.; software, Z.W. and F.C.; validation, Z.K., K.H. and C.L.; formal analysis, Z.W., F.C., Y.L. and X.L.; investigation, Z.W. and F.C.; resources, Z.K., K.H. and C.L.; data curation, Z.K.; writing—original draft preparation, Z.K. and K.H.; writing—review and editing, Z.K., K.H. and C.L.; visualization, Z.K., Y.L. and X.L.; supervision, C.L.; project administration, Z.K.; funding acquisition, K.H. All authors have read and agreed to the published version of the manuscript.

Funding: This work was funded by National Natural Science Foundation of China (Grant No. 52208012), Natural Science Foundation of China Youth Science Foundation (Grant No. 51908301), National Natural Science Foundation of China Youth Science Foundation (Grant No. 51908111), General project of Shandong social science planning and research project (Grant No. 21CSHJ06), Shandong Natural Science Foundation Training Fund (Grant No. ZR2019PEE034) and Qingdao social science planning and research project (Grant No. QDSKL2101178).

Acknowledgments: The authors would like to thank these six students for their help with data collection: Ruyan Zhang, Xingqi Kong, Pengxuan Ning, Jinghao Ni, Jiayue Wang and Qilin Liu. The authors also would like to thank the 44 participants, who contributed their time, enthusiasm and valuable feedback to this experiment.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Veitch, J.A.; Charles, K.E.; Farley, K.M.J.; Newsham, G.R. A model of satisfaction with open-plan office conditions: COPE field findings. *J. Environ. Psychol.* **2007**, *27*, 177–189.
2. Veitch, J. Psychological Processes Influencing Lighting Quality. *J. Illum. Eng. Soc.* **2001**, *30*, 124–140.
3. Veitch, J.A. Lighting Quality Contributions from Biopsychological Processes. *J. Illum. Eng. Soc.* **2001**, *30*, 3–16.
4. Kong, Z.; Zhang, R.; Ni, J.; Ning, P.; Kong, X.; Wang, J. Towards an integration of visual comfort and lighting impression: A field study within higher educational buildings. *Build. Environ.* **2022**, *216*, 108989.
5. Kong, Z.; Jakubiec, J. Instantaneous lighting quality within higher educational classrooms in Singapore. *Front. Arch. Res.* **2021**, *10*, 787–802.
6. Kong, Z.; Jakubiec, J.A. Evaluations of long-term lighting qualities for computer labs in Singapore. *Build. Environ.* **2021**, *194*, 107689.
7. Hirning, M.B.; Isoardi, G.L.; Garcia-Hansen, V.R. Prediction of discomfort glare from windows under tropical skies. *Build. Environ.* **2017**, *113*, 107–120.
8. Van Den Wymelenberg, K.G. Visual Comfort, Discomfort Glare, and Occupant Fenestration Control: Developing a Research Agenda. *Leukos* **2014**, *10*, 207–221.
9. Chamilothori, K. Perceptual effects of daylight patterns in architecture in School of Architecture. *Civ. Environ. Eng.* **2019**.
10. Moscoso, C.; Chamilothori, K.; Wienold, J.; Andersen, M.; Matusiak, B. Window Size Effects on Subjective Impressions of Daylit Spaces: Indoor Studies at High Latitudes Using Virtual Reality. *Leukos* **2020**, *17*, 242–264.
11. Lam Lo, W.; Steemers, K. The art of brightness and darkness a critical investigation on daylighting quality. In Proceedings of the 26th Conference on Passive and Low Energy Architecture, Quebec, QC, Canada, 22–24 June 2009.
12. Dogrusoy, I.T.; Tureyen, M. A field study on determination of preferences for windows in office environments. *Build. Environ.* **2007**, *42*, 3660–3668.
13. Chamilothori, K.; Chinazzo, G.; Rodrigues, J.; Dan-Glauser, E.S.; Wienold, J.; Andersen, M. Subjective and physiological responses to façade and sunlight pattern geometry in virtual reality. *Build. Environ.* **2019**, *150*, 144–155.
14. Moscoso, C.; Chamilothori, K.; Wienold, J.; Andersen, M.; Matusiak, B. Regional differences in the perception of daylit scenes across Europe using virtual reality. Part I: Effects of window size. *Leukos* **2021**, *18*, 294–315.
15. Rockcastle, S.; Amundadottir, M.; Andersen, M. Contrast measures for predicting perceptual effects of daylight in architectural renderings. *Light. Res. Technol.* **2016**, *49*, 882–903.
16. Rockcastle, S.F.; Chamilothori, K.; Andersen, M. An Experiment in Virtual Reality to Measure Daylight-Driven Interest in Rendered Architectural Scenes. In *Building Simulation 2017*; Pubilsher: San Francisco, CA, USA, 2017.
17. Chamilothori, K.; Wienold, J.; Moscoso, C.; Matusiak, B.; Andersen, M. Subjective and physiological responses towards daylit spaces with contemporary façade patterns in virtual reality: Influence of sky type, space function, and latitude. *J. Environ. Psychol.* **2022**, *82*, 101839.
18. Kong, Z.; Utzinger, D.M.; Freihoefer, K.; Steege, T. The impact of interior design on visual discomfort reduction: A field study integrating lighting environments with POE survey. *Build. Environ.* **2018**, *138*, 135–148.

19. Wu, S. Main Points of Lightscape. *South Archit.* **2017**, *3*, 4–6.
20. Kong, Z.; Liu, Q.; Li, X.; Hou, K.; Xing, Q. Indoor lighting effects on subjective impressions and mood states: A critical review. *Build. Environ.* **2022**, *224*, 109591.
21. Abboushi, B.; Elzeyadi, I.; Taylor, R.; Sereno, M. Fractals in architecture: The visual interest, preference, and mood response to projected fractal light patterns in interior spaces. *J. Environ. Psychol.* **2018**, *61*, 57–70.
22. Moscoso, C.; Matusiak, B.; Svensson, U.P. Impact of window size and room reflectance on the perceived quality of a room. *J. Archit. Plan. Res.* **2015**, *3*, 294–306.
23. Chamilothori, K.; Wienold, J.; Andersen, M. Adequacy of Immersive Virtual Reality for the Perception of Daylit Spaces: Comparison of Real and Virtual Environments. *Leukos* **2018**, *15*, 203–226.
24. Abd-Alhamid, F.; Kent, M.; Bennett, C.; Calautit, J.; Wu, Y. Developing an Innovative Method for Visual Perception Evaluation in a Physical-Based Virtual Environment. *Build. Environ.* **2019**, *162*, 106278.
25. Veitch, J. Revisiting the Performance and Mood Effects of Information about Lighting and Fluorescent Lamp Type. *J. Environ. Psychol.* **1997**, *17*, 253–262.
26. Küller, R.; Wetterberg, L. Melatonin, cortisol, EEG, ECG and subjective comfort in healthy humans: Impact of two fluorescent lamp types at two light intensities. *Light. Res. Technol.* **1993**, *25*, 71–81.
27. Boray, P.F.; Gifford, R.; Rosenblood, L. Effects of warm white, cool white and full-spectrum fluorescent lighting on simple cognitive performance, mood and ratings of others. *J. Environ. Psychol.* **1989**, *9*, 297–307.
28. Trimble Inc. *SketchUp*; Trimble Inc.: Munich, Germany, 2022.
29. Enscape GmbH. *ENSCAPE*; Enscape GmbH: Karlsruhe, Germany, 2022.
30. Pro, V. VIVE United States, (n.d.). 2022. Available online: https://www.vive.com/us/product/vive-pro/ (accessed on 30 July 2022).
31. Åkerstedt, T.; Gillberg, M. Subjective and objective sleepiness in the active individual. *Int. J. Neurosci.* **1990**, *52*, 29–37.
32. Liu, Y.; Li, L.; Li, Y.; Li, J. A wearable device to collect and display pulse and ECG data. In *Southeast University*; Yu, J., Ed.; Nanjing Zhonglian Patent Agency Co.: Nanjing, China, 2022.
33. Carreiras, C.; Alves, A.P.; Lourenço, A.; Canento, F.; Silva, H.; Fred, A. *BioSPPy: Biosignal Processing in Python*, Python package version 0.6.1. 2015.
34. Xing, Y.; Xiao, Z.; Wang, Z.; Li, R.; Li, J.; Liu, C. *A Device for Testing the Performance of ECG Electrodes*; Xu, X., Ed.; Nanjing Zhonglian Patent Agency, Co.: Nanjing, China, 2022.
35. Chen, M.F.; Zhao, L.; Li, B.; Yang, L. Depression evaluation based on prefrontal EEG signals in resting state using fuzzy measure entropy. *Physiol. Meas.* **2020**, *41*, 095007.
36. GitHub. *EEGLAB*; GitHub: San Francisco, CA, USA, 2022.
37. The MathWorks. *MATLAB*; The MathWorks, Inc.: Natick, MA, USA, 2022.
38. ASHRAE. *Thermal Environmental Conditions for Human Occupancy*; ASHRAE: Atlanta, GA, USA, 2020.
39. Sawyer, A.O.; Niermann, M.; Groat, L.N. The use of environmental aesthetics in subjective evaluation of daylight quality in office buildings. In Proceedings of the IES Annual Conference, Indianapolis, IN, USA, 8 November 2015.
40. Chamilothori, K.; Wienold, J.; Moscoso, C.; Matusiak, B.; Andersen, M. Regional Differences in the Perception of Daylit Scenes across Europe Using Virtual Reality. Part II: Effects of Façade and Daylight Pattern Geometry. *Leukos* **2022**, *18*, 316–340.
41. Ferguson, C.J. An effect size primer: A guide for clinicians and researchers. *Prof. Psychol. Res. Pract.* **2009**, *40*, 532–538.
42. Abboushi, B.; Elzeyadi, I.; Van Den Wymelenberg, K.; Taylor, R.; Sereno, M.; Jacobsen, G. Assessing the Visual Comfort, Visual Interest of Sunlight Patterns, and View Quality under Different Window Conditions in an Open-Plan Office. *Leukos* **2020**, *17*, 321–337.
43. Pearce, J. The "split brain" and Roger Wolcott Sperry (1913–1994). *Rev. Neurol.* **2019**, *175*, 217–220.