Building and Environment 180 (2020) 106932

Contents lists available at ScienceDirect

Building and Environment

journal homepage: http://www.elsevier.com/locate/buildenv

Evaluating the impact of viewing location on view perception using a virtual environment

Fedaa Abd-Alhamid [a,b,*], Michael Kent [c], John Calautit [a], Yupeng Wu [a,*]

[a] Department of Architecture and Built Environment, Faculty of Engineering, University of Nottingham, University Park, Nottingham, NG7 2RD, United Kingdom
[b] Department of Architecture, Faculty of Architecture and Design, Al-Zaytoonah University of Jordan, Amman, Jordan
[c] Berkeley Education Alliance for Research in Singapore, Singapore

ARTICLE INFO

Keywords:
Visual comfort
Virtual reality (VR)
View perception
View quality
Physiological assessment
Parallax

ABSTRACT

Window views are an important design feature in buildings. Views can impact the cognitive attention, psychological and physiological well-being of building occupants due to their ability to provide recovery in stressful working environments. The impact of viewing position on view perception as a result of the visual parallax effect resulted from occupants seeing a window from different relative positions in any given room has not been comprehensively investigated. In this study, view perception was evaluated using a physically-based 360° virtual environment at three different viewing locations: close, middle, and far. The three conditions were presented to thirty-two participants. The study employed a comprehensive method by collecting subjective and physiological evaluations. A stress-recovery methodology to assess restorativeness effects was used by presenting a window view observing period after a stressful task was performed. Subjective assessments included questions on view restorative ability, view content and size preferences, view valance/arousal, and positive and negative affects. Physiological measures included skin conductance, heart rate, and heart rate variability. Results showed significant differences in subjective parameters and measures of skin conductance. Decreased view quality was reported as participants observed the view from the further viewing locations compared to the close position. The study highlights the importance of the informative content seen in the window view such as the sky and ground, which may impose limitations on recommended room depth and windows design. The results of this study show that the design of window views has important implications on the health and well-being of building occupants.

1. Introduction

The need for natural light, fresh air, and connection to the outdoor environment (i.e., time of day and weather conditions) are just some of the reasons why windows are an important feature in the design of any building [1,2]. View and daylight are often seen as separate functions of the window. The view as to what is seen outside and the daylight as to the illumination transmitted inside the building. However, views could be considered as the perceived visual messages perceived by the human perceptual system that are transmitted into the building using daylight [3,4] (i.e., daylight reflected from outside surfaces carries visual information and enters into the building through windows, which is perceived by building occupants as the view). Through this process, daylight could be referred as a carrier of outdoor view.

View preference can have a profound influence on cognitive attention and performance [5–7] and on the psychological and physiological well-being [3,6–9] of building occupants. Despite their known importance on occupant satisfaction in buildings, the visual connection provided by windows with the outdoor environment is not well understood [10]. Studies have mainly focus their efforts on understanding the roles that view content (e.g. natural and urban elements) and horizontal stratification (e.g., the layering of view content) have on window view perception [1,9,11–15]. Other studies have evaluated the preferred size of the window that provides the view [11,16–21]); nevertheless, studies have often shown inconsistent conclusions; for example, people reported different preferred window sizes in different studies (e.g., 35% [16], 25–30% [18], 50 and 80% [17], 40% [20], 100% [21]).

Experiments would often use different methods of collecting

* Corresponding authors. Department of Architecture and Built Environment, Faculty of Engineering, University of Nottingham, University Park, Nottingham, NG7 2RD, United Kingdom.

E-mail addresses: laxfa10@nottingham.ac.uk, fedaa.abdalhameed@yahoo.com (F. Abd-Alhamid), Yupeng.Wu@nottingham.ac.uk, Jackwuyp@googlemail.com (Y. Wu).

https://doi.org/10.1016/j.buildenv.2020.106932
Received 18 February 2020; Received in revised form 15 April 2020; Accepted 30 April 2020
Available online 19 May 2020

subjective ratings of views from windows, and this may be one reason why studies found inconsistent results. Another might be the fact that these studies are only relying on subjective ratings, which are often prone to methodological biases [22]. The experimental setting in different window view studies has also varied; some studies used 2-dimensional representation methods [14,15,23,24], while in other cases, reduced-scale models using fixed viewing positions [16–19] were utilised. Both approaches have not considered dynamic changes when observing windows. The dynamic criterion relates to the observer's viewing position relative to the window, which changes the amount of view that is visible or blocked by adjacent walls [11]. This dynamic criterion of visual perception for the relative position of objects is known as movement parallax [25–27].

As a result of this parallax, window-view relationship changes and objects at different vertical layers (i.e., depths) or at certain location within the view change their relative position when an observer changes their position. The change in distance from the window will also result in relative changes in view, whereby at closer viewing positions the window area appears larger and more content is visible. The view content will also look larger since more distant objects occupy smaller angles across the retina than closer objects, and thus, relatively appear smaller when further away [26,28]. This reduction in relative size is not linear: i.e., as the distance from the observer increase, change in relative size will occur with smaller magnitudes for the same displacement [28]. When an observer is positioned further away from the window, the aperture appears smaller and parts of the view in relation to the aperture edges cannot be seen, which are usually the most informative parts of the view providing information about the outdoor (i.e., the sky and the ground) [11]. This lost in visual information could offset the benefits of the view, implying that a good, informative, and satisfying view could impose limitations on room depth for a given window to wall ratio.

Previous studies indicate that windowless environments or having poor access to a window view (e.g., due to office furniture arrangement and seating positions) can increase levels of stress in buildings [7,23]. Close proximity to the window is generally preferred by occupants [11,29,30], and studies have indicated that the distance an occupant is located from the window affects the self-reported levels of satisfaction [11,31]. When occupants cannot be close to a view, they generally prefer to have a larger window [16]. Although it is not entirely clear why occupants desire window views, they offer psychological benefits by providing cognitive restoration and recovery [32]. The mechanism underlying the restoration and recovery has been explained by the attention restoration [33] and affective response [34] theories.

According to the attention restoration theory, when an individual is presented with fascinating stimuli (e.g., visual or auditory), this may involuntarily capture their mental attention and consequently promotes cognitive psychological recovery [33]. By replacing the cognitive mechanisms responsible for direct attention, this creates a mental restoration that is experienced by an individual. Supportively, literature has shown that views of nature elements (e.g., greenery) modestly captures attention and promotes cognitive restoration; while in an urban environment (e.g., built), attention is intensely captured and there is less cognitive restoration [5]. The affective response theory [34] states that stimuli of high interest elicit positive emotional responses, thereby promote sustained psychological attention and also reduce levels of stress. This theory has been used to explain the preference of natural environments over those with urban (built) content. Both theories indicate that when the perceived impression of a stimulus is positive, the following cognitive and physiological reactions induced will be also positive. Accordingly, this increases the ability to sustain attention, reduces levels of negative affect, and reduces physiological stress [35].

When linking these two theories back to how occupants perceive windows, it could be inferred that restorative benefits can be experienced when the view diverts their attention away from the stressful stimuli. This may decrease levels of stress [31,34,36], increase sustained attention and cognition [37–39], and could create health working environments that promote levels of work productivity. Also, the view content plays an important role on how occupants perceive the window, which can be explained in the Circumplex model of affect [40]. While environments that provide high arousal and low pleasure can lead to high levels of stress, high pleasure and lower arousal environments promote relaxation [38,41,42]. Lower arousal and pleasure levels result in a perception of dullness (i.e., less stimulating environments) [43].

The mechanisms underlying view perception as stress influencing factor are summarised in Fig. 1.

Because the view has a profound influence on both psychological (i.e., subjective ratings that appraise the visual content) and physiological (i.e., levels of stress) when a window is observed by an occupant, a multi-criteria approach that includes both types of measures is needed to quantify the differences in view perception. When considering the dynamic interaction between the window view and the relative viewing position of the occupant, there are strong reasons to believe that both measures will be needed to provide a comprehensive understanding (i.e., how occupants react to the view at different distances away from the window).

Stress levels can be measured using many physiological indicators including skin conductance (SC), heart rate (HR), and heart rate variability (HRV) [44,45]. All three measures have been used to evaluate differences between different visual stimuli. HR decreased (i.e., showing signs of decreased stress levels) when engaging visual stimuli require cognitive attention were presented [46–48] and when the visual stimuli were considered to be fascinating or gave the feeling of being away (i.e., shift away from the present situation to a different environment) [49]. HR reflects the stress state of humans and can be further evaluated using HRV [44,50] (i.e., changes in the time intervals between adjacent heartbeats [51–53]).

HRV can be separated into four frequency bands: high frequency (HF-HRV) (0.15–0.4 Hz), which reflects relaxation; low frequency (LF-HRV) (0.04–0.15 Hz); the very low frequency (VLF) (0.04–0.003 Hz); and ultra-low frequency (ULF) (<0.003 Hz) [53], whereby the

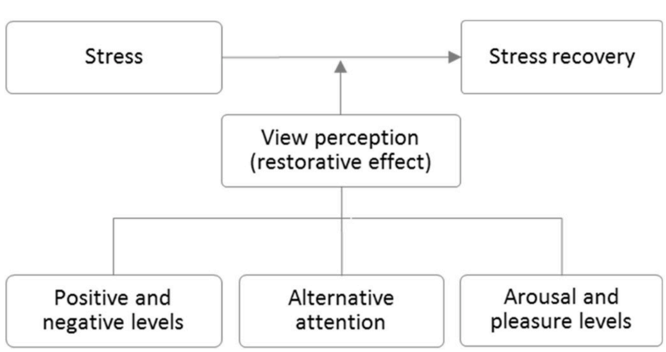

Fig. 1. Summary of the mechanisms that promote the view as stress influencing factor.

variability in any of the lower frequencies represents a mixture of stress and relaxation [44]. The ratio of LF to HF power (LF/HF) has been used as an indicator for stress level [53], whereby a higher ratio indicates elevated stress level and a low value indicates more relaxation [51,54,55].

SC measures sweat glands activity and consists of two components: phasic Skin Conductance Response (SCR) and tonic Skin Conductance Level (SCL). SCRs are associated with short-term events and occur in the presence of discrete environmental stimuli (e.g., visual or auditory) which usually show up as sudden increase (peaks) in the SC data; while SCL is used to measure continuous responses and represents the base level of SC [56]. SCR can increase when visual stimuli elicit amusement [57], pleasure and pleasantness [48], or attention and arousal [44]; while increased SCL indicates higher stress levels [44].

This study aims to develop a comprehensive method (including both subjective and physiological assessments) to evaluate the view perception from different viewing observing locations. To be more specific, this evaluation has been undertaken in a typical office room with a view that includes both natural and urban elements observed at three different locations in the room. A validated 3-dimensional virtual reality (VR) representation method [58] was adopted to determine whether the viewing position mattered in an experiment. This method displayed an office-like environment in an immersive VR setting, which was comparable to the original environment. This approach utilises stereoscopy vision to create depth perception in the VR setting [59] and, within a certain degree, can produce realistic visual contrast and colour properties [58]. VR is also capable of providing a much higher degree of experimental control over parameters that would vary in buildings (e.g. temperature, noise, daylight, etc.), which is one of the main challenges in experimental studies using windows [20,60]. Across different experimental conditions the illumination levels can also be maintained in VR settings, which can affect the investigated visual stimuli perception if left uncontrolled [20].

Accordingly, three research objectives were derived: (1) Developing a replica in virtual reality based on the physical and luminous conditions at three viewing locations: close, middle, and far from the window within an office room; (2) Collecting subjective responses on view quality parameters, including view restorative ability, view content and size preferences, view valance/arousal, self-reported stress, and positive and negative affects; and (3) measuring physiological markers, namely: SC, HR, and HRV. Objectives (2) and (3) were used to assess the differences in view perception at different viewing locations as seen within an office room replicated in the VR environment.

2. Methodology

The methodology was designed to provide controlled luminous conditions to evaluate the subjective and physiological responses to the change in window view based on different observing locations within a virtual office room. The real experimental environment luminous conditions and the stress inducing task contrast properties were assessed to be replicated in the virtual environment. In this section, subjective evaluations and physiological apparatus and markers are explained, followed by the designed experimental procedure. The statistical tests used to analyse the data collected in this study are also described in this section.

2.1. Experimental Environment

Controlled luminous conditions were used to evaluate the subjective and physiological responses in a virtual office room.

The virtual office was created by replicating an office room (test-room) that was lit by both natural and artificial lighting. Using a validated approach [58], the physical and photometric conditions of the test-room were presented within a VR environment. A virtual environment was considered appropriate for this study as opposed to relying on daylight from real windows, since photometric parameters would continuously change over time [61–63]. Other extraneous variables (e.g. temperature, humidity and noise) could also be controlled in the test room.

The test room was located in the Energy Technology Building (University of Nottingham, UK) (Fig. 2). The room had internal dimensions of 4.35 m × 2.85 m and a floor to ceiling height of 3.2 m (Fig. 2). The internal surfaces of the room had reflectance (ρ) properties: $\rho_{wall} \approx 0.7$ for walls, $\rho_{floor} \approx 0.1$ for the floor, and $\rho_{ceiling} \approx 0.8$ for ceiling, which were estimated using the Munsell values [64]. The office was located on the first floor and the view from the window is considered a neutral with a mixed of urban and natural elements which would be considered by the green building practice guide BREEAM to be an adequate view [65]. The room had a double glazing window with 20% window to wall ratio as recommended for rooms with depth ≤8 m [65], and the window had a 1:1 aspect ratio.

The room contained furniture to resemble an office environment. A visual task was mounted onto a wall at 1.50 m from the viewer position at three different distances from the window: Close (C), Middle (M), and Far (F) (Fig. 2(a)). The middle location was placed at the median value of the length from the window to the rear wall of the room, and the C and F locations were selected based on the minimum standards for office furniture [66], which allowed a 0.80 m space at both ends of the room. The same locations were replicated in the virtual environments.

2.2. Stress Inducing Task (Stroop test)

The proposed methodology to quantify the view used stress recovery as an indicator of view quality, which was measured by subjective and physiological responses. The Stroop test is a colour-word conflict test [67] and was selected for its ability to increase stress levels when the task is being performed [68–70]. The Stroop test can also be used as a neuropsychological tool in the assessment of cognitive work [69,71] as it comprises of a selective attention feature (i.e., the process by which individuals focus on task-relevant information and ignore irrelevant distracting information [72], which usually occurs in office environments [73,74].

The Stroop-test (Fig. 3) composed of a total of 15 rows with five words on each row for each task, and the text size was 20 mm creating a 0.76° angular size produced by character height, which is within the range needed for fluent reading (between 0.2 and 2°) [75]. Four colours: Red, Green, Blue (RGB), representing the three main components of the RGB colour model usually used in lighting studies [63,76], and black were used in the Stroop test. The selected colours had the values of chromaticity as described in previous study [58]. The words and colours were randomly allocated in three versions of the tests (for C, M, and F) to counterbalance any learning effect.

Subjects were instructed to name the colours of the words as fast as they can, attempting to name even the ones they were uncertain of. The Stroop test lasted 45 s [68]. Luminance values of the task were measured using Hagner S3 photometer and compared to those created in the counterpart virtual environments. This was used to elevate the stress levels to assess the view quality based on restorative effects (i.e., recovery from stress).

2.3. Physically-based Virtual Environment

To replicate the luminous conditions of the test room in the virtual environment, the following equipment were used: 1) Canon EOS 5D camera equipped with a fish-eye lens (Sigma 4.5 mm f/3.5 EX DG) mounted on a tripod; 2) Hagner S3 photometer with illuminance sensor; 3) Minolta Chroma-meter CL-200; 4) HTC-Vive headset. The camera was mounted on a tripod 1.5 m from the wall containing the visual task. To keep the window view at the centre of the participant's field of view in the VR setting, the camera was mounted 1.60 m from the floor. Lighting measurements were repeated three times at different distances from the

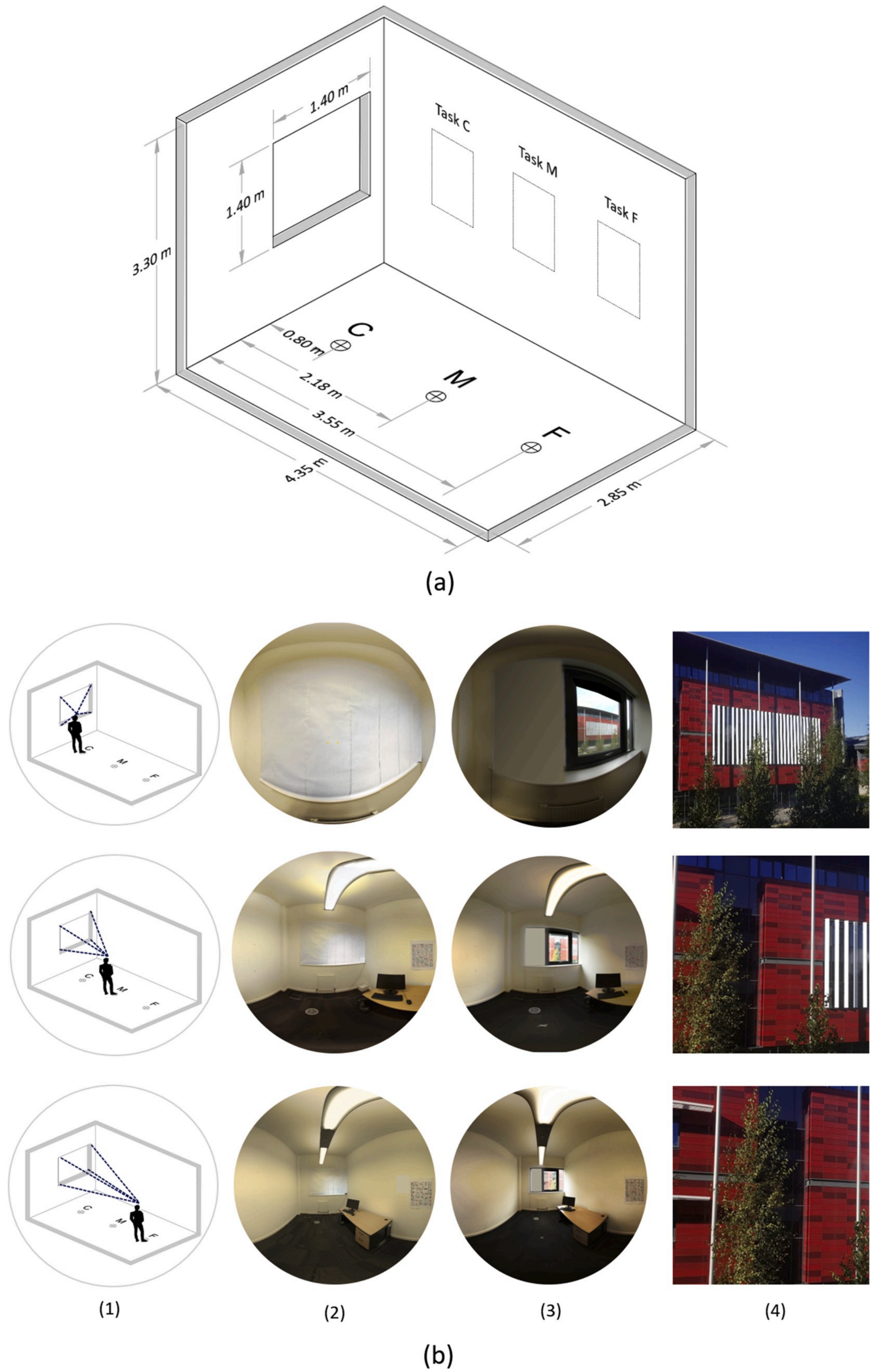

Fig. 2. Image (a): The test room dimensions. Image (b): (1) Three observing locations; (2) the three windowless baseline environments; (3) the three environments with view indicating the view size in the visual field; (4) the corresponding view content for each location.

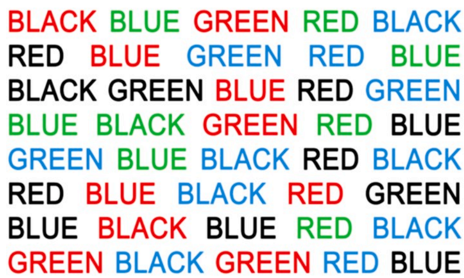

Fig. 3. Example of the Stroop-test used to elevate stress levels.

window, corresponding to C, M, and F, respectively.

High dynamic range images (HDRI) were created by combing seven low dynamic range images (LDRI) with different exposure values [58]. Six virtual environments were created in this study. Three for the windowless neutral baseline conditions and three for window view conditions taken from the three different viewing locations [46]. The lowest sensitivity (ISO) 100 was used to reduce the noise in the HDRI with fixed white balance (i.e., correct colour temperature (CCT)) to maintain consistent colour space transitions [77]. A white balance of 4300 K was used, which was approximate to the average CCT in the room measured using the Chroma-meter CL-200 (accuracy ± 0.02%). Across the three locations at the camera position, the CCT measured were: C = 4881, M = 4032, and F = 3851 K. The HDRI images were calibrated with point luminance measurements and were tone-mapped with 2.2 gamma and key value of 0.01 [78], which created similar contrast values to the real environment.

The images were taken in June between 11:00 a.m. and 12:30 p.m. on a day under a mostly clear (but stable) sky condition. The room had a north facing window with no access to direct sunlight and was lit by artificial lighting in this period. The measured horizontal illuminance values taken from a height of 0.8 m from the floor [79] at the three viewing positions were: C = 1347, M = 709, and F = 491 lux.

The images were taken with a fish-eye lens covering 180° in each direction from the same viewing position, aligning the entrance pupil axis to the rotation axis to minimise the differences between the various pictures composing the 360° view [80]. The resultant six tone-mapped images were combined into 360° panorama. To create the depth perception from 2-dimensional images, the previous process was conducted twice from two viewpoints 65 mm horizontally apart to reproduce the distance between the centres of the observer's eyes [81]. The same process was utilised to create interactive virtual stereoscopic images giving the observer the impression of being immersed within a 3-dimensional environment. HTC Vive head-mounted display [82] with a computer with two 2.40 GHz 4 core processors and NVIDIA GeForce GTX 1060 graphics card were used along with Whirligig software, which supports the display of stereoscopic images, to display the immersive 360° images. The VR HTC Vive has a dual AMOLED 3.6'' diagonal screen with a resolution of 1080 x 1200 pixels per eye (2160 x 1200 pixels when combined) and provides 110° nominal field of view.

2.4. *Visual Task Properties in the Virtual Environments*

Luminance values of the actual task were measured using Hagner S3 Photometer and the contrast ratios for the Stroop task were obtained using Weber's formula (1) [83], which was calculated using the background luminance of the task (L_b) and target luminance of the visual characters (L_t).

$$C = (L_t - L_b)/L_b \quad (1)$$

Since current virtual head-mounted displays cannot display HDR quality images, the tone-mapping process to the images projected in the virtual environment was applied to correct the luminance and contrast values [58]. Table 1 displays the real and virtual contrast values of the Stroop tasks and the percentage change in contrast between the real and virtual environments across the three conditions.

The contrast ratios for the same colour are similar across the three locations in the virtual environments: Red ($M = -0.47$, $SD = 0.06$); Green ($M = -0.51$, $SD = 0.08$); Blue ($M = -0.54$, $SD = 0.14$); and Black ($M = -0.76$, $SD = 0.07$) with slightly lower contrast in the close location. This is important for the Stroop test to sustain the stress level induced by the task across the three different locations as different contrast ratios might affect the task difficulty; hence, influence the stress-induced level.

2.5. *Physiological Apparatus and Objective Assessments*

To evaluate the participants' responses to the views and to evaluate stress levels during the experiment, SC, HR, and HRV were measured to assess the responses at the three locations.

When immersed in the VR setting, participants sat at the centre of the room on a rotatable chair with an armrest that was used to minimise hand-movement when the physiological measurements were taken. SC and HR were recorded using sensors connected to the Mind Media Nexus-10 MKII acquisition device and Biotrace software (Fig. 4). The Nexus10 MKII device was attached to the back of the rotatable chair, which allowed flexible movement when the participant needed to change their view direction within the virtual environment. The device was wirelessly connected to a laptop for data collection. Both SC and HR data were sampled at 32 samples per second (SPS) rate. These signals can continuously monitor nervous system activity in terms of stress and recovery [34,35,84–86].

The SC and HR changes during the exposure to the window view and during recovery from stress were subtracted from baseline measurements in order for the physiological data to be standardised for each participant to allow the comparison between different experimental manipulations [44]. The baseline and following physiological recordings were taken while the participants are immersed in the VR. A detailed explanation of baseline measurements can be found in section 2.5.1.

During the experiments, the SC sensors measured the sweat gland activity of participants, which is regulated by the sympathetic nervous system reflecting states of heightened stress [44]. Ag-AgCL electrodes were attached to the distal phalanx of the index and ring fingers of the participants' left hand to measure skin conductivity – expressed in

Table 1
Luminance and contrast values of the different colours used in the Stroop tasks.

Colour	Real environment luminance (cd/m^2)			Tone-mapped images relative luminance			Real environment contrast			Virtual environment contrast		
	C	M	F	C	M	F	C	M	F	C	M	F
Red	68	36	38	0.19	0.27	0.30	−0.75	−0.71	−0.60	−0.40	−0.50	−0.52
Green	68	38	37	0.23	0.23	0.28	−0.75	−0.69	−0.61	−0.41	−0.57	−0.55
Blue	43	32	29	0.19	0.18	0.28	−0.84	−0.74	−0.70	−0.40	−0.67	−0.55
Black	25	18	14	0.10	0.10	0.14	−0.91	−0.85	−0.85	−0.70	−0.81	−0.77
White (background)	269	123	96	0.30	0.54	0.62						
Average Percentage Error (%)										45	15	14

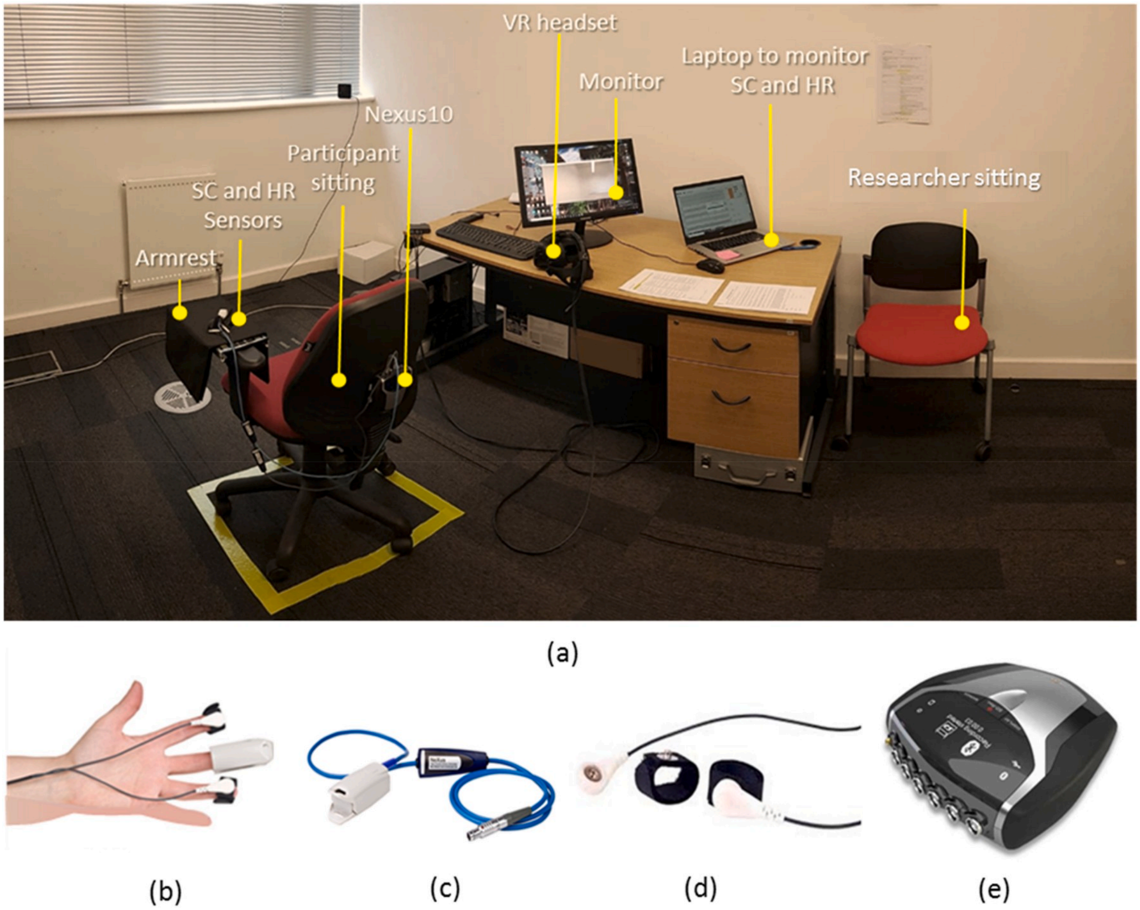

Fig. 4. (a) The experimental setup; (b) sensors placement on participant's fingers; (c) HR sensor; (d) SC sensors; (e) Nexus10 MKII device. Note: The yellow square marks the viewing position during the experiment, which ensured that participants did not move outside this demarcated area. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

microsiemens (μS – a unit of electric conductance) [56]. The HR sensor uses light-based technology to sense the rate of blood flow. Different measures of HRV, including LF-HRV and HF-HRV, can be acquired, which are expressed in milliseconds squared (ms^2) for different frequency bands. This sensor was connected to the middle finger of the participants' left hand.

Physiological responses were continuously collected during each session, and data at specific points of interest baseline, stress, and recovery was extracted [56,87,88] to identify the initial responses for discrete stimulus [44,48,86] (e.g., when participants observed the window view).

2.5.1. *Physiological Data Screening*

The SC values were visually inspected to discard any data that was not considered to be reliably based on criteria recommended in the literature (e.g., sudden SC signal breaks) [56]. Four cases showed that the SC data may not be reliable to evaluate and were discarded from any further analyses. The SC data was imported from Biotrace and analysed using Ledalab V3.4.9 toolbox: a MATLAB-based analysis tool for extracting SCL and SCR values from the SC data, using a continuous decomposition analysis method [89,90].

HRV data was directly acquired from the Biotrace software and the default criteria of automatic removal and correction of detected artefacts was used, in which if the difference between the adjacent inter-beat intervals was greater than 25%, it will be removed and replaced with interpolated data (i.e., an average value that is computed from the neighbouring normal inter-beat intervals). To accept the HRV value for further analysis, a minimum of 80% normal inter-beat intervals is required [88]. Accordingly, no value was identified from the HRV dataset. However, the excluded cases from SC data were also removed to have balanced sampled data sizes between the physiological measurements. The final sample size for the physiological data analysis was 28 participants; 22 males and 6 females with mean age of 29 years (SD = 6.24).

SCR data for the initial response of view observing was extracted using a response time of one to 4 s after presenting the window view with a minimum amplitude of 0.01 μS (i.e., minimum required shift in the signal to be counted as SCRs) [44,56,91]. Deflections (sudden shifts) in the signal that do not satisfy the threshold criteria are not counted as SCRs [87]. HR and HRV data for the initial response to the view was assessed using the mean data for the first 30 s of stimuli exposure. Measurements between 10 and 30 s were used to evaluate the observers' HR response to visual stimuli [15,46,49]. A respective baseline measurement was subtracted using similar response time of SCR and HRV to allow the comparison between experimental conditions [44].

The analysis of stress and recovery was performed using SCL and HRV measures. The change in SCL and HRV were assessed using the first minute of recovery to measure the stress recovery from the first minute of exposure to the view (i.e., to measure the restorative effects caused by the exposure to view, which usually occur in short breaks taken by office workers). Respective baseline measurements (i.e. in the last minute of the baseline) were subtracted from recovery data to attain the change from the baseline. Physiological data of baseline and recovery is usually analysed over a time range between one and 3 min [34,45,69,70]. Additionally, the SCL and HRV during the stress induction (45 s) were compared after being subtracted from the corresponding baseline values

Table 2
List of the view perception questionnaire items used during the experiment.

Parameter		Adopted to view Questions	Bipolar descriptors	Ref.
View restorative ability adopted from perceived restorativeness scale	Fascination	This view is fascinating	"Not at all" – "Very much"	[95–99]
		My attention is drawn to many interesting things in this view		
	Being away	Looking at this view would give me a break from the work routine		
		Looking at this view helps me to relax my focus on getting things done		
View content		I like the view provided by the window		[95–98]
View size		How satisfied are you with the amount of view in this space?		[19,20,23,60]
View valance/arousal		How pleasant is the view?		[23,46,60]
		How exciting is the view?		
View interest and complexity		How interesting is this view?		
		How complex is this view?		

to explore stress level during the task performance at the three different locations in the office [45].

2.6. Subjective Evaluations

View perception was assessed based on four aspects: view restorative ability, view content, size preferences, and view valance/arousal (see Table 2). Two questions related to daylight visual interest and complexity were also used. All questions were measured on a continuous scale ranging from, "Not at all" (= 0) to "Very much" (= 10). The continuous scale was explained to the participants during the experimental demonstration and they were reminded upon making their evaluation. Stress recovery was evaluated using the positive and negative affect schedule (PANAS) [92] and self-reported stress question, which were performed before and after completing the tasks.

Questionnaires were answered verbally and the answers were recorded using Dictaphone, which is more convenient when VR is used [46,60]. The questions were randomised across the three conditions to eliminate any bias in subjective responses [93]. Reported simulator sickness symptoms produced from immersion in the virtual environment were assessed using the Simulator Sickness Questionnaire (SSQ) [94], which was completed at the beginning and the end of the experiment.

2.7. Experimental Procedure

The study used a repeated-measure design with the same participant taking part in three conditions to reduce individual variability in the collected data [93]. The change in visual environment due to the distance from the view was the independent variable with three conditional variables: C, M, and F. The subjects were randomly assigned to test order to counterbalance the effect of presentation order of the stimuli between participants [93].

The experimental procedure and questionnaires used in the study were assessed and approved by the University of Nottingham Ethics Committee. Subjects were either taught/research students or academic staff members and were recruited via posters and online advertisements. A total of 32 subjects from different ethnic backgrounds voluntarily participated in the experiment. Twenty-three were male and 9 female and the mean average age of the group was 28 years (SD = 6.08). None of the participants reported any colour vision problems, and 15 participants wore corrective glasses during the experiment. The study was conducted during summer months (July–September) and indoor air temperature and humidity were measured in each session at the position of the participants.

The average temperature and humidity values measured inside the test-room during the experiment were 22.3 °C and 49.1%. These remain relatively constant throughout the duration of the experiment, whereby indoor temperature varied between 19.0 °C (minimum) and 25.7 °C (maximum) and humidity between 42.4% (minimum) and 51% (maximum), respectively. Across the three test sessions, temperature and humidity also remained relatively constant, whereby the maximum differences (i.e. maximum minus minimum) recorded when considering all test sessions that participants had taken part in were 1.5 °C and 2.4%, respectively.

The experimental procedure and duration are shown in Fig. 5 and detailed in the Appendix. At the beginning of each session, subjects read the experimental instructions and signed a consent form. Afterwards, subjects completed a questionnaire surveying demographic and vision acuity information (e.g., corrective lenses and reported colour blindness) and completed the SSQ. Since the repeated-measure design minimises the influence of individual differences caused by variations in demographics, this helped to reduce the influence of age on physiological responses collected from subjects [44,46,100]. Participants were required to abstain from intaking caffeine 8 h and alcohol 24 h prior to the test [101]. Those who suffer from epilepsy, migraines, motion sickness, dizziness, sleep disorders, or blurred vision were excluded from the study to avoid unwanted symptoms experienced from the VR setting [102]. Participants were not informed about the actual purpose of this study until the experiment had finished.

Upon arrival to the test room, participants were seated on the chair. The SC and HR sensors were connected, and their arm was rested on the chair armrest. This minimised hand movement and ensured that the signals were correctly recorded. Participants were asked to wear the VR to familiarise themselves with a baseline scene. When the participants were ready, they were asked to answer the Stress and PANAS questionnaire to be used as a subjective baseline. The physiological baseline measurements were then recorded for 5 min, which was more than the recommended 2 min [35,48,53,87]. The virtual content was then changed to the view corresponding to the baseline environment (Fig. 2) and participants observed the first view condition for 1 min before answering the questions on view perception.

Participants performed the Stroop test for 45 s [68] followed by another 5 min of physiological measurements while observing the virtual window view. Participants then answered the stress and PANAS questionnaire again as a subjective measure of recovery. The participants were instructed to limit their hand movement and to remain silent during the baseline, recovery, and window view observation periods to limit the noise in the recorded signals [103], with the exception when they were answering the questionnaires. The same procedure was repeated until the three conditions were evaluated and participants were given a 7-min break between each condition [86,103] (Fig. 5).

2.8. Statistical analysis

Statistical analysis was conducted to analyse subjective and physiological responses. The statistical test that was used to analyse the data depended on the data distributions and/or variances. The subjective data analysis was conducted for the full sample (n = 32), while the

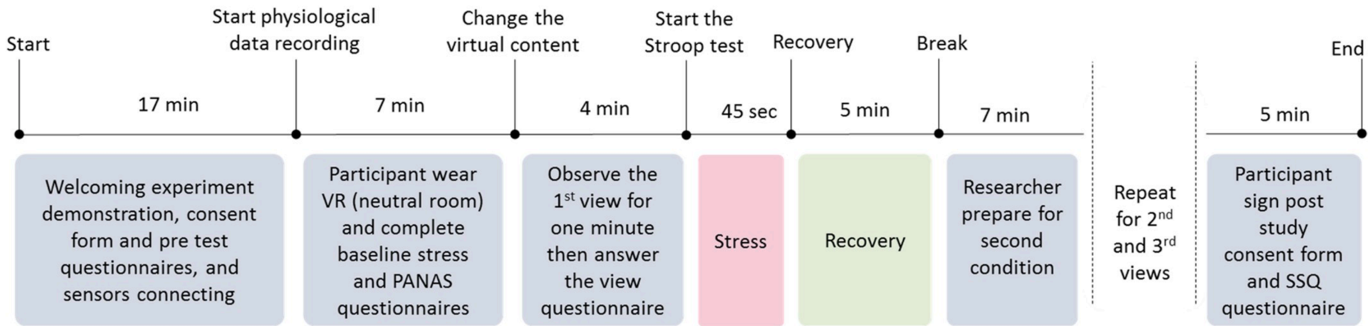

Fig. 5. Overview of the experiment procedure from start to the end of a single test session.

physiological data was analysed using pre-screened data from 28 participants. Physiological data was evaluated based on *z*-scores which is a recommended method to analyse physiological data [44,104]. The original data was transformed to *z*-scores scores by subtracting the individual values from their sample mean and dividing this by the standard deviation.

To test the reliability of the questionnaires, that is, the survey items measured the same construct (i.e. view perception quality), the Cronbach's alpha (α) test [105] was used. The questionnaire had a high-reliability Cronbach's $\alpha = 0.94$, attaining the accepted range (0.70–0.80) [105]. Hence, the collected questionnaire items measured the same construct.

Data collected from responses of view perception, reported stress, and PANAS was analysed using the repeated measures analysis of variance (ANOVA) test. For this test, the assumptions of normality and sphericity were assessed [93]. Sphericity refers to the equality of variances across repeated conditions (i.e., the variance between one pair could not be significantly different from another pair of conditions). Normality of the data about the mean was evaluated using the Kolmogorov-Smirnov [106] and Shapiro-Wilks [107] tests. When the assumption of normality was violated, the non-parametric Friedman's ANOVA test was used [93]. When the assumption of sphericity was not met for normally distributed data, Huynh-Feldt corrections were applied [103]. In order to determine which observing location was perceived differently from the other, pairwise comparisons were performed. To control the experimental-wise error rate, Bonferroni corrections were applied [93].

The effect sizes will be reported along with statistical significance values. The effect size is an inferential statistical parameter that can be derived from different statistical tests, providing a standardised measure of the magnitude of the difference and allowing comparisons among similar studies [105]. The effect sizes partial eta squared (η_p^2) and Pearson's ***r*** were estimated from the inferential tests. Interpretation of the effect sizes was inferred using "small", "moderate", and "large" thresholds recommended by Ferguson [108].

3. Results

3.1. Subjective Data

Fig. 6 presents the results of subjective view perception. The y-axis shows the rating of view from 0 (Not at all) to 10 (Very much) by participants for different perception parameters displayed on x-axis when presented at different observing locations: C, M, and F.

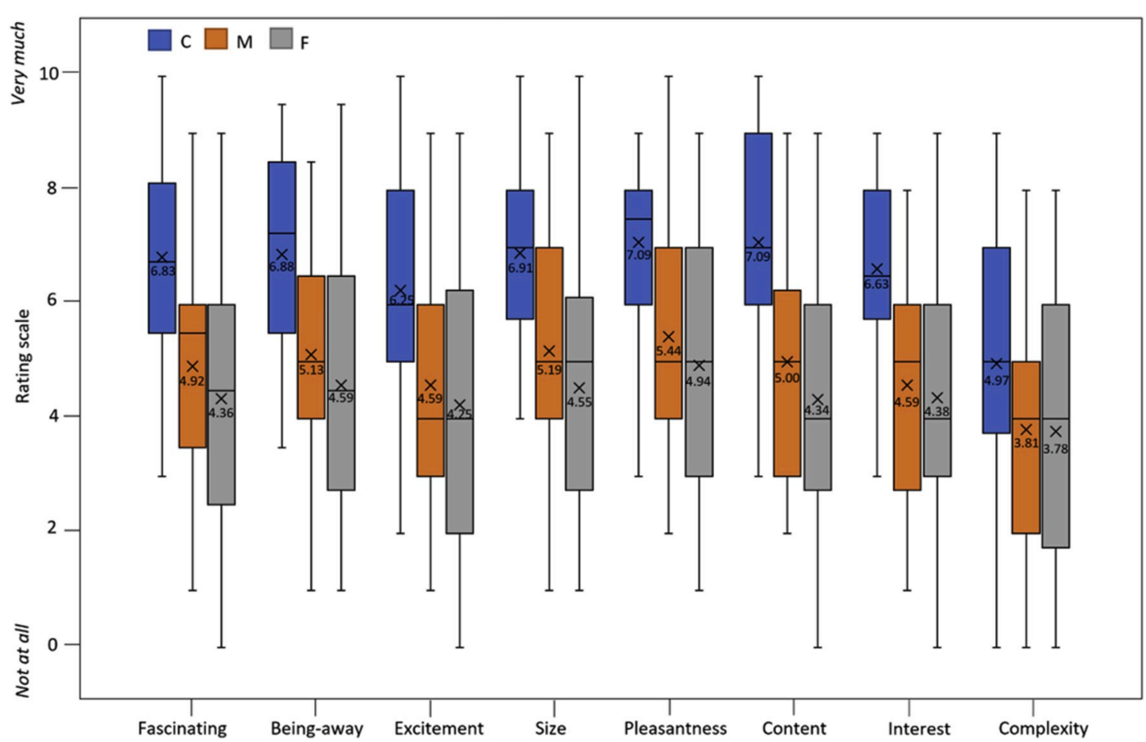

Fig. 6. Boxplots of view perception parameters at each test session (variation of observing location). Note: the crosses indicate the mean of the group condition.

Table 3
ANOVA and effect sizes for each questionnaire item on view perception.

Parameter	F ($df = 2$)	p-value	Effect size (η_p^2)
Fascinating	25.06	0.00***	0.45
Being away	22.09	0.00***	0.42
Excitement	19.53	0.00***	0.39
Size	16.18	0.00***	0.38
Pleasantness	19.98	0.00***	0.39
Content	24.76	0.00***	0.44
Interest	22.66	0.00***	0.42
Complexity	5.82	0.02**	0.16

* weakly significant; ** significant; *** highly significant; n.s. not significant.
η_p^2<0.04 = negligible; η_p^2≥0.04 = small; η_p^2≥0.25 = moderate; η_p^2≥0.64 = large.

As indicated in Fig. 6, the statistical parameters (mean, minimum, 25th percentile, median, 75th percentile, and maximum) tend to correspond to higher ratings of view perception when considering the eight parameters and when participants are closer to the window. The repeated-measures ANOVA test was used to compare the mean average evaluations given to the right parameters of view perception across the three observing locations. Table 3 reports the F test statistic and the degrees of freedom (df), the statistical significance (p-value), and the effect size (η_p^2). The results from the ANOVA indicate significant differences for all eight parameters across the three viewing locations.

Substantial effects were detected ($0.25<\eta_p^2\leq0.64$), except for complexity which had a significant difference at ($p < 0.05$) with small detected effect. The analysis of the data suggests that for these parameters, the distance from the window has a substantial influence on view perception. When the participant viewed the window view from a closer location, they gave higher ratings to the eight parameters. To isolate the relevant differences in the analyses found in Table 3, pairwise comparisons were performed using the dependent t-test with Bonferroni adjustment for p-value (p is significant at 0.05 divided by number of paired comparisons) to control type I error of rejecting the null hypothesis when it is true [93]. Hence, adjusted significant threshold of p-value ($0.05/3 = 0.016$) will be used to identify the significant criterion.

Table 4 presents the results of the pairwise comparisons for each questionnaire parameter, providing the mean and the standard deviation (SD) for the rating scores calculated at all test sessions, the difference between the means (ΔMean), the p-values, and the effect size (r). The pairwise comparisons provide evidence that the differences between subjective rating scores, reported at different observing locations within the room, were highly significant in 15 cases, not significant in nine cases, out of a total of 24 comparisons. The differences have "moderate" effect sizes in 15 cases, "small" in six cases, and "negligible" in three cases.

For nearly all parameters, highly significant differences and the largest effect sizes were detected when comparisons were made with both the middle and far viewing locations against the close condition, except for complexity between C and F. This generally shows that there were significant decreases in the evaluations given for all parameters measured when participants were positioned further away from the window in the VR setting. Interestingly, comparisons made between the viewing positions M and F showed no statistically significant differences. The size of the differences ranged from "small" and "negligible", which suggests that participants have similarly perceived the views in these two conditions.

Fig. 7 indicates the change in mean ratings on the valance/arousal Circumplex model of affects. The locations of mean rating demonstrate the change in perceived affects corresponding to each viewing location. When participants were closer to the window in the virtual environment, they reported more pleasantness and arousal compared to middle and far locations – with "moderate" differences as shown in Table 4. The location of the close position suggests that there was a stimulating affect. However, the mean ratings of view perception given to the middle and far locations in terms of arousal/valance shifted towards the dull criterion, which is associated with lower arousal and pleasantness resulting in a less stimulating working environment.

3.2. Self-reported Stress and PANAS

The results of the Friedman's ANOVA showed that there was a significant difference in the change in positive affects (ΔPA) when compared to the baseline PA across the three viewing locations: $\chi^2(2) = 8.93$, $p \leq 0.01$**. The differences in self-reported stress (ΔStress) and negative affects revealed no significant differences and no follow-up

Table 4
Pairwise comparisons between test sessions and effect sizes for each parameter.

Parameter	Sessions	$Mean_1$ (SD)	$Mean_2$ (SD)	ΔMean	p-value	Effect size (r)
Fascinating	C vs. M	6.83 (1.87)	4.92 (1.89)	1.91	0.00***	0.69
	C vs. F	6.83 (1.87)	4.36 (2.31)	2.47	0.00***	0.79
	M vs. F	4.92 (1.89)	4.36 (2.31)	0.56	0.16 n.s.	0.25
Being away	C vs. M	6.88 (1.84)	5.13 (1.82)	1.75	0.00***	0.69
	C vs. F	6.88 (1.84)	4.59 (2.30)	2.28	0.00***	0.73
	M vs. F	5.13 (1.82)	4.59 (2.30)	0.531	0.16 n.s.	0.25
Excitement	C vs. M	6.25 (2.10)	4.59 (2.06)	1.66	0.00***	0.66
	C vs. F	6.25 (2.10)	4.25 (2.55)	2.00	0.00***	0.73
	M vs. F	4.59 (2.06)	4.25 (2.55)	0.34	0.34 n.s.	0.17
Size	C vs. M	6.90 (1.65)	5.19 (2.12)	1.72	0.00***	0.62
	C vs. F	6.90 (1.65)	4.55 (2.46)	2.36	0.00***	0.66
	M vs. F	5.19 (2.12)	4.55 (2.46)	0.64	0.13 n.s.	0.27
Pleasantness	C vs. M	7.09 (1.53)	5.44 (1.98)	1.66	0.00***	0.67
	C vs. F	7.09 (1.53)	4.94 (2.26)	2.16	0.00***	0.73
	M vs. F	5.44 (1.98)	4.94 (2.26)	0.50	0.20 n.s.	0.23
Content	C vs. M	7.09 (1.79)	5.00 (2.16)	2.09	0.00***	0.69
	C vs. F	7.09 (1.79)	4.34 (2.38)	2.75	0.00***	0.76
	M vs. F	5.00 (2.16)	4.34 (2.38)	0.66	0.11 n.s.	0.28
Interest	C vs. M	6.63 (1.74)	4.59 (2.10)	2.03	0.00***	0.71
	C vs. F	6.63 (1.74)	4.38 (2.34)	2.25	0.00***	0.68
	M vs. F	4.59 (2.10)	4.38 (2.34)	0.22	0.48 n.s	0.13
Complexity	C vs. M	4.97 (2.43)	3.81 (2.09)	1.16	0.01**	0.52
	C vs. F	4.97 (2.43)	3.78 (2.42)	1.19	0.05 n.s.	0.41
	M vs. F	3.81 (2.09)	3.78 (2.42)	0.03	0.93 n.s	0.02

Bonferroni corrected: * weakly significant; ** significant; *** highly significant; n.s. not significant.
$r < 0.20$ = negligible; $0.20 \leq r < 0.50$ = small; $0.50 \leq r < 0.80$ = moderate; $r \geq 0.80$ = large.

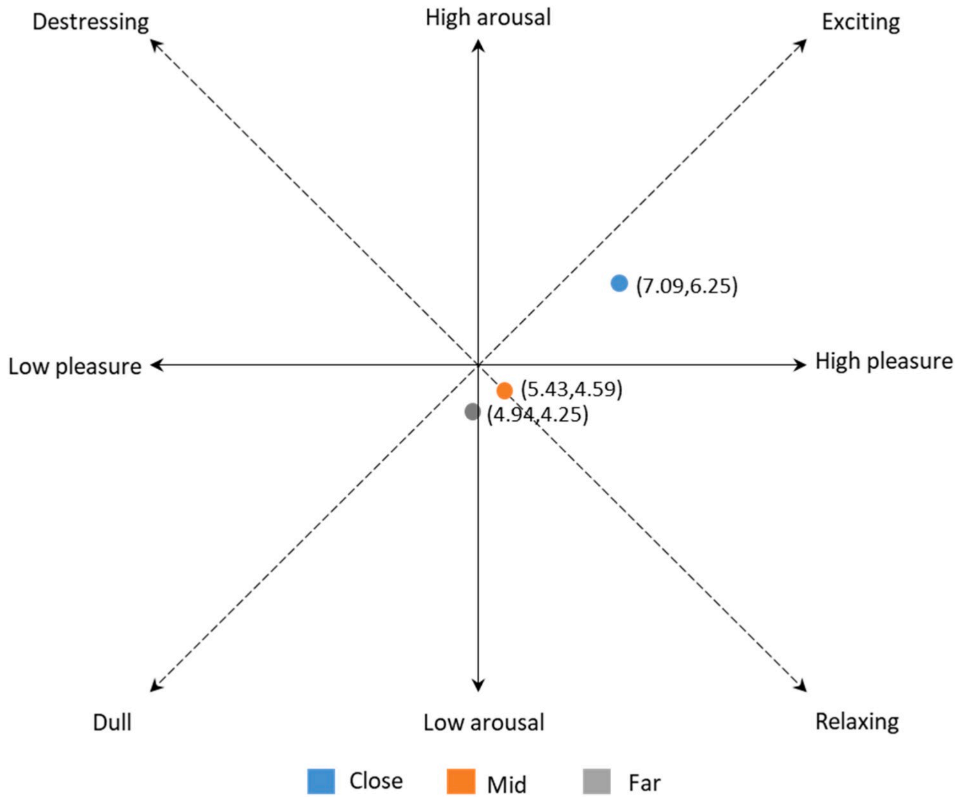

Fig. 7. Locations of mean ratings of view perceived valance/arousal on the Circumplex model of affects adopted from [42].

Table 5
Wilcoxon signed-rank tests and effect sizes for subjective recovery parameters.

Parameter	Conditions	M_{1dn} (IQR)	M_{2dn} (IQR)	*p*-value	Negative	Positive	Ties	Effect size *r*
ΔPA	C vs. M	−0.38 (5.25)	−1.00 (4.38)	0.02*	7	18	7	−0.28
	C vs. F	−0.38 (5.25)	−1.50 (3.75)	0.06 n.s.	5	18	9	−0.23
	M vs. F	−1.00 (4.38)	−1.50 (3.75)	0.76 n.s.	11	11	10	−0.04

Bonferroni corrected: * weakly significant; ** significant; *** highly significant; n.s. not significant.
$r < 0.20$ = negligible; $0.20 \le r < 0.50$ = small; $0.50 \le r < 0.80$ = moderate; $r \ge 0.80$ = large.

analyses were performed. These results suggested that subjective recovery was almost equal at all three locations from the window, except for ΔPA. Pairwise comparisons using Wilcoxon signed-rank test were conducted to explore the magnitude of differences in ΔPA across the three different locations.

The Wilcoxon signed-rank tests (Table 5) indicate that the differences between subjective recovery parameters reported at different observing distances from the window were significant when comparing the viewing location C to M. The results showed lower ΔPA at the close location, indicating better stress recovery for this parameter. The decrease in reported PA was smaller at the C location compared to M and F, with negligible difference between latter as indicated by the median values and large numbers of positive ranks. ΔPA was reported lower at the three conditions compared to the baseline as indicated by the median values; hence, was not able to retain the original state of positive affects before stress induction.

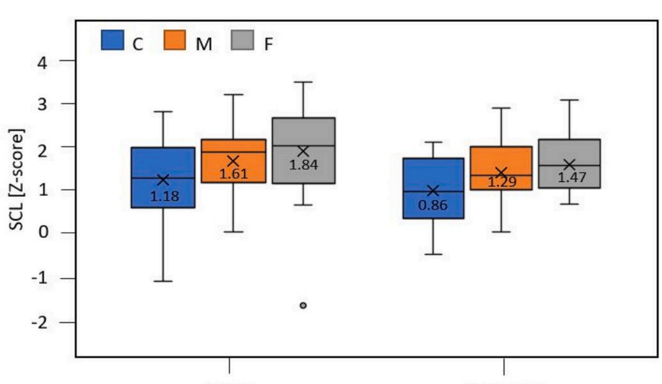

Fig. 8. Boxplots of SCL during stress and recovery at different viewing positions.

3.3. Physiological Data

Enhanced non-significant recovery trend in HRV (LF-HRV, HF-HRV, and HR/LF) as participants become closer to the window was detected. However, the initial inferential results when comparing the differences in the initial response and stress-recovery data when participants first observed the view using SCR, HR, LF-HRV, HF-HRV, and HF/LF were not statistically significant and have not been evaluated in further analyses.

Fig. 8 presents the results of SCL during stress induction and recovery. The y-axis shows SCL, and the stress and recovery periods are displayed on x-axis for when the physiological measurements were collected at different observing locations: C, M, and F. The boxplots in

Table 6
Pairwise comparisons between test sessions and effect sizes for each parameter.

Parameter	Sessions	M_1 (SD)	M_2 (SD)	ΔMean	*p*-value	Effect size *r*
Task SCL	C vs. M	1.18 (1.01)	1.61 (0.84)	−0.44	0.04 n.s.	0.39
	C vs. F	1.18 (1.01)	1.84 (1.11)	−0.66	0.02 n.s.	0.44
	M vs. F	1.61 (0.84)	1.84 (1.11)	−0.22	0.36 n.s.	0.18
Recovery SCL	C vs. M	0.86 (0.77)	1.29 (0.70)	−0.43	0.01*	0.48
	C vs. F	0.86 (0.77)	1.47 (0.62)	−0.61	0.00***	0.62
	M vs. F	1.29 (0.70)	1.47 (0.62)	−0.18	0.27 n.s.	0.20

Bonferonni corrected: * weakly significant; ** significant; *** highly significant; n.s. not significant.
$r < 0.20$ = negligible; $0.20 \le r < 0.50$ = small; $0.50 \le r < 0.80$ = moderate; $r \ge 0.80$ = large.

Fig. 8 suggest a tendency for statistical parameters (mean, minimum, 25th percentile, median, 75th percentile, and maximum) to correspond to lower SCL values when participants are closer to the window during task performance and recovery.

ANOVA tests were used to compare the SCL score for the three observing locations. The results from the ANOVA indicate a significant difference in SCL during task performance and recovery. SCL data showed weakly significant values $F(2,54) = 4.01$, $p < 0.05$ among the three conditions with small effect detected ($0.04<\eta_p^2\le0.25$) during the task performance; whereas for recovery, SCL showed highly significant difference $F(2,54 = 8.26$, $p < 0.001$ among the three conditions with small effect detected ($0.04< \eta_p^2\le0.25$).

Pairwise comparisons were used to identify which observing location has affected the SCL. Table 6 shows the results of the pairwise comparisons for SCL during stress induction (i.e., task performance) and recovery, providing the mean (M) and the standard deviation (SD) for the rating scores calculated at all test sessions, the difference between the means (ΔMean), the statistical significance (*p*-value), and the effect size *r*.

The pairwise comparisons provide evidence that the differences between SCL data were not significant in all three comparisons. The differences have "small" magnitudes ($0.20 \le r < 0.50$) in two cases and "negligible" ($r < 0.20$) in one out of three cases. The differences examined for the SCL data were highly significant in one case, significant in one case, and not significant in one out of three cases. The effect size has a substantive magnitude and was "moderate" in one case ($0.50 \le r < 0.80$) and "small" ($0.20 \le r < 0.50$) in two out of three comparisons.

The analysis of the data suggests that, the view perceived at different viewing locations from the window may have a direct influence on the stress levels during task viewing and recovery. The differences were largest when the difference in viewing location varied the most (C vs. F). But the differences in task viewing and recovery were still practically significant for comparisons made between viewing locations C vs. M. Interestingly, comparisons between M vs. F were not significant and had "negligible" effect sizes. This result is consistent with the findings derived from the subjective evaluations reported in Table 4, whereby no convincing evidence of the viewing location across these same two conditions was found. This suggests that after a certain distance from the window, the view quality will be similarly perceived.

3.4. Reported Simulator Sickness Symptoms

SSQ before and after using the experiment were collected using ordinal scale and analysed using the Wilcoxon signed-rank test. The following symptoms were significantly different before and after using the VR: 'Fatigue', 'Eye Strain', 'Difficulty concentrating', 'Fullness of the Head', and 'Blurred Vision' all with small effect sizes, except for eye strain which showed a moderate effect size. The other symptoms: 'General Discomfort', 'Headache', 'Difficulty Focusing', 'Salvation Increasing', 'Sweating', 'Nausea', 'Dizziness', 'Eyes Open', 'Dizziness Eyes Closed', 'Vertigo', 'Stomach Awareness', and 'Burping' were not significantly different ($p > 0.05$) with small or negligible effect sizes. The significant results are indicated in Table 7.

Table 7 indicates that significantly reported symptoms were denoted by small effect sizes and a high number of ties (tied ranks >19) for all symptoms (i.e., when the evaluations across both conditions were the same), except for reported levels of eye strain. However, as found in the first experiment, all participants before leaving the experiment setting have reported that any discomfort that was experienced during the VR trial has subdued.

4. Discussion

The results of this study show substantially difference in the subjective and physiological measures given to perceived view quality at different locations in virtual environment replicating a daylit office room.

The findings in this study showed that when participants observed the view at the close position in the VR setting, higher positive affects were reported (Table 4), and lower stress levels were observed from physiological measurements of skin conductance (Table 6). These same restorative benefits were not found when participants observed the window view in the VR setting from the further distances. These findings may be linked to the attention restoration [33] and the affective response [34] theories, whereby stimuli that are perceived positively (e.g., visual information from a window view) induce positive cognitive and physiological reactions (e.g., reduced levels of negative emotions and reductions in physiological stress). At the close position from the window view, the visual information perceived by the participants diverted their attention away from stressor (i.e. the Stroop-test) and decreased the levels of psychological and physiological stress. At further distances in the VR setting, this process may have been less apparent and

Table 7
Results of the Wilcoxon signed-rank tests for responses to questions on simulator sickness questionnaire.

Parameter	After (M_{dn})	Before (M_{dn})	*p*-value	Negative	Positive	Ties	Effect size *r*
Fatigue	1	1	0.01*	10	1	21	−0.34
Eyestrain	2	1	0.00***	19	0	13	−0.55
Difficulty Concentrating	1	1	0.03*	7	1	24	−0.27
Fullness of the Head	1	1	0.04*	9	2	21	−0.26
Blurred Vision	1	1	0.02*	8	1	23	−0.29

*weakly significant; ** significant; *** highly significant; n.s. not significant.
$r < 0.20$ = negligible; $0.20 \le r < 0.50$ = small; $0.50 \le r < 0.80$ = moderate; $r \ge 0.80$ = large.

accordingly, the beneficial responses measured also decreased.

All subjective parameters used to evaluate view perception (i.e. view restorative ability, view content and size, view valance/arousal, interest and complexity) were significantly higher for the close condition compared to middle and far conditions. View perception parameters were not significantly different between middle and far conditions. These differences suggest that participants did not perceive any difference between the two viewing positions, which was also detected in the physiological data (Table 6). The main change between view content across the viewing locations was the sky component of the view, whereby this was only visible from the closest position. Literature has emphasized the importance of being able to see the sky within the window view [95], which may provide occupants valuable information regarding the time of day and weather that they might not have limited access to when inside the building.

At a certain viewing distance away from the window, observer location does not matter, and the window view is similarly perceived. This might be due to the sky is being no longer visible as seen in Fig. 2 from the middle position. Therefore, the design of windows in offices should take into consideration the role of the sky component to promote a higher quality view.

In general, the subjective assessment of the view perception indicated that increasing the distance from the window results in a lower preference of view perception to wide range of parameters. Observers' satisfaction with view size was rated moderately higher for the close condition compared to middle and far conditions. This supports that satisfaction with view size should be assessed in terms of view size in the visual field instead of the WWR. On the Circumplex model of affects (Fig. 7), the change in valance/arousal across the three viewing positions in the VR setting also resulted in notable changes in the mean values of affect along with the excitement–dull axis. This also supported the idea that, less stimulating working environments are created when occupants are further away from the window view [101].

Subjective recovery from the stress (ΔPA) showed improved values when participants were located closer to the window in the virtual environment (Table 5). Similar values of PA to those recorded prior to being exposed to the stressor (Stroop test) were found when participants viewed the view from the close position (i.e., indicating lower levels of stress when they were positioned closer to the window). On the other hand, objective stress recovery using SCLs was substantially lower when measured at the close position, and slightly lower between the middle when compared to the far viewing condition (Table 6). This finding indicates that more restorativeness of the view occurred at the close location and supports other derived results. The subjective and objective findings could help explain why occupants generally have a preference to sit closer to the window (i.e., attaining its restorative benefits) [11,29,30].

In BREEAM recommendations, a 20% WWR for rooms with depth ≤8 m is recommended for view, and all occupants are to be within 8 m from the window which consist of landscape or buildings not only sky, or to be an internal view as long as it is 10 m away from the window to allow visual relief for the eye by refocussing on distant content. In this study, a window view with a façade WWR of 20% that was viewed from approximate 2 m away from the window (i.e., the middle position) considerably reduced the physiological restorativeness effects experienced by the observer. Therefore, what would be considered an adequate view can maintain its quality only up to a small distance from the window. This might impose limitations on room depth concerning WWR to attain the view benefits in a deep plan or large open-plan offices, and also highlight the restorative value of the informative elements of the view in an urban context (sky and ground). This study also suggests that views of buildings (i.e., neighbouring building or internal views) might not guarantee an adequate view as shown by mean ratings that shifted from the positive to the negative part of the rating scale as the participants are placed further from the window and the view becomes limited to buildings.

Because window proximity not only influenced subjective evaluations, further work may be needed to evaluate different numbers and shapes of windows, which control the amount of visual information that can be seen by the building occupant. This would, in turn, vary the amount of restorativeness in deep parts of the offices that is needed to satisfy more occupants. The results of these studies can be used to understand how physiological parameters measured from the participants translate onto the health and well-being of building occupants.

Although VR can produce realistic visual environments [58] and offer a high degree of control that is difficult to achieve in daylit environments [23], they produce a relatively limit range of luminances due to the current constraints of the technology. While measures were put into place to minimise high luminances from being present in the real environment (e.g. using a north-orientated window and a room without direct sunlight), it may not be possible to accurately evaluate the influence of glare or high brightness contrasts in VR settings.

This study only considered one window view to evaluate the effect of viewing location, which was selected based on experimentational considerations (i.e. its orientation, three layers, etc.). However, the view utilised in this study may not be representative of typical scenaries due to the unique architecture of the neighbouring building seen in the landscape. Therefore, further work may be needed to understand how other views with a wider range of visual characteristics may have influence the outcome.

Another limitation of this study is the unwanted simulator symptoms that were reported by the participants following the use of VR technology. Although these symptoms have been associated with the application of VR environments [60], they are generally minor and short-lived [109], which is consistent with our findings.

5. Conclusion

In this study, a novel comprehensive method to assess view perception was developed. A 360° virtual environments were used to represent three different viewing positions showing their corresponding window views as seen in a daylit office. Several subjective and physiological measures were used to quantify the differences in view perception based on parameters of restorativeness from stress. These differences were evaluated across the different viewing positions. The designed methodology identified statistically significant differences in view perception in the measures that were evaluated. The main findings of this study are:

- The viewing location of the participant from the window has a significant influence on view quality measured through the use of subjective and physiological parameters, whereby decreased view quality was reported the further away the participant was located from the window within the virtual environment.
- Increased view quality was found when participants were closer to the window in the VR setting. When comparing the differences in subjective evaluations given between the far and close viewing positions: the self-reported levels of "facination" and "being away" increased by 36% and 33%; "excitement" and "pleasentness" increased by 32% and 30%; and satisfaction with "view content", "size", and percieved "interest" and "complexity" increased by 39%, 34%, 34% and 24%, respectively.
- Decreases in physiological stress levels were found when participants were closer to the window in the VR setting. Stress levels during recovery showed a 71% reduction in skin conductance when comparing the measurements collected at the far and close positions.
- At a distance of 2.18 m from the window, no significant changes in view quality were reported between different viewing locations in the VR setting – for both the subjective and physiological parameters. It is postulated that this may be due to the fact that at a certain distance from the window, the sky is no longer visible and participants perceive the view in the same way.

- The recommended use of a 20% WWR given by standards might not guarantee the view benefits (restorativeness) across the room. Alternatively, the windows' solid angle, position, and other physical dimensions in relation to the view content should be considered.

Cognitive performance was not tested in this study due to the limited resolution of the current VR headset. Future studies could account for this by using non-visual stress induction tasks to assess viewing position impact on cognitive performance. Moreover, different levels of content such as naturalness and moving elements should be studied. Other window design factors impact on view quality perception such as window shape, location, window size, and smart windows applications could be assessed using a similar methodology. Additionally, their corresponding lighting and energy performance could be evaluated using multi-disciplinary research to provide a deeper and complete understanding of widows' performance.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors would like to extend their thanks to Al-Zaytoonah University of Jordan for their contribution through a PhD studentship to Fedaa Abd-Alhamid, and to all participants who took part in the experiment. This work was also supported by the Engineering and Physical Sciences Research Council, UK [grant number EP/S030786/1].

Appendix

Table A.1
Experiment detailed procedure and duration

Time progress in minutes	Activity	Duration in minutes
0–10	Welcome and introduction, sign the consent form and complete the Pre-test participant questionnaires (demographic and SSQ).	10
10–15	Demonstration of the experiment in the test room to make sure subjects understand the procedures and familiarise with VR.	5
15–17	Connect SC and HR sensors to non-dominant hand and start physiological recordings	2
17–19	Participants wear VR/start baseline physiological measurement	2
19–24	Participants complete the questionnaire (stress and PANAS)	5
24–34	View the first condition for 1 min, and answer view perception questionnaire, complete Stroop test, and then look at window view to recover.	10
34–36	Participants complete the questionnaire (stress and PANAS)	2
36–43	Participants rest outside the experiment room and experimenter prepare for second condition	7
43–47	Take baseline measurements	4
47–57	View the second condition for 1 min, and answer view perception questionnaire, complete Stroop test, and then look at window view to recover	10
57–59	Participants complete the questionnaire (stress and PANAS)	2
59–66	Participants rest outside the experiment room and experimenter prepare for next condition	7
66–70	Take baseline measurements	4
70–80	View the third condition for 1 min, and answer view perception questionnaire, complete Stroop test, and then look at window view to recover.	10
80–82	Participants complete the questionnaire (stress and PANAS)	2
82–87	The participants sign post-study consent form and SSQ questionnaire	5
87–90	End of experiment. The participant will be thanked for their time, led to the door and told they are free to leave	3

References

[1] J.H. Heerwagen, G.H. Orians, Adaptations to windowlessness: a study of the use of visual decor in windowed and windowless offices, Environ. Behav. 18 (5) (1986) 623–639.
[2] J. Christoffersen, K. Johnsen, Daylighting and window design, Postoccupancy Stud. Environ. 19 (2000) 31–33. Light and Lighting.
[3] N. Baker, A. Fanchiotti, K. Steemers, Dayliging in architecture–a European reference book. Commission of the European communities, directorate–general XII for science research and development, in: Research and Development, James & James Ltd, London, 1993.
[4] P. Tregenza, M. Wilson, Daylighting: Architecture and Lighting Design, Routledge, 2013.
[5] C.M. Tennessen, B. Cimprich, Views to nature: effects on attention, J. Environ. Psychol. 15 (1) (1995) 77–85.
[6] L. Heschong, Windows and classrooms: a study of student performance and the indoor environment. California Energy Commission, 2003.
[7] L. Heschong, Windows and offices: a study of office worker performance and the indoor environment. California Energy Commission, 2003, pp. 1–5.
[8] K.M. Farley, J.A. Veitch, A room with a view: a review of the effects of windows on work and well-being, 2001.
[9] M.B.C. Aries, J.A. Veitch, G.R. Newsham, Windows, view, and office characteristics predict physical and psychological discomfort, J. Environ. Psychol. 30 (4) (2010) 533–541.
[10] I. Konstantzos, A. Tzempelikos, A holistic approach for improving visual environment in private offices, Proc. Environ. Sci. 38 (2017) 372–380.
[11] T.A. Markus, The function of windows— a reappraisal, Build. Sci. 2 (2) (1967) 97–121.
[12] H. Hellinga, T. Hordijk, The D&V analysis method: a method for the analysis of daylight access and view quality, Build. Environ. 79 (2014) 101–114.
[13] N. Tuaycharoen, The Reduction of Discomfort Glare from Windows by Interesting Views, University of Sheffield, 2006.
[14] N. Tuaycharoen, P. Tregenza, View and discomfort glare from windows, Light. Res. Technol. 39 (2) (2007) 185–200.
[15] C.-Y. Chang, P.-K. Chen, Human response to window views and indoor plants in the workplace, Hortscience 40 (5) (2005) 1354–1359.
[16] E. Ne'Eman, R.G. Hopkinson, Critical minimum acceptable window size: a study of window design and provision of a view, Light. Res. Technol. 2 (1) (1970) 17–27.
[17] A. Ludlow, The functions of windows in buildings, Light. Res. Technol. 8 (2) (1976) 57–68.
[18] E.C. Keighley, Visual requirements and reduced fenestration in office buildings — a study of window shape, Build. Sci. 8 (4) (1973) 311–320.
[19] E.C. Keighley, Visual requirements and reduced fenestration in offices — a study of multiple apertures and window area, Build. Sci. 8 (4) (1973) 321–331.
[20] E. Guidolin, Impact of window amount and size on user perception, daylighting and energy demand in an office space, University of Padua, 2014, pp. 15–29. Thesis.
[21] I.T. Dogrusoy, M. Tureyen, A field study on determination of preferences for windows in office environments, Build. Environ. 42 (10) (2007) 3660–3668.
[22] E. Poulton, Quantitative subjective assessments are almost always biased, sometimes completely misleading, Br. J. Psychol. 68 (4) (1977) 409–425.
[23] D. Cetegen, J. Veitch, G. Newsham, View size and office illuminance effects on employee satisfaction, Proc. Balkan light (2008) 242–252.
[24] G.Y. Yun, J.Y. Shin, J.T. Kim, Influence of window views on the subjective evaluation of discomfort glare, Indoor Built Environ. 20 (1) (2011) 65–74.
[25] A.S. Radikovic, et al., Artificial window view of nature, in: CHI'05 Extended Abstracts on Human Factors in Computing Systems, Association for Computing Machinery, 2005.
[26] W.A. IJsselsteijn, et al., A room with a cue: the efficacy of movement parallax, occlusion, and blur in creating a virtual window, Presence Teleoperators Virtual Environ. 17 (3) (2008) 269–282.

[27] H.R. Kim, D.E. Angelaki, G.C. DeAngelis, The neural basis of depth perception from motion parallax. Philosophical transactions of the Royal Society of London. Series B, Biol. Sci. 371 (1697) (2016) 20150256.
[28] McCready Jr., D.W., Size-distance perception and accommodation-convergence micropsia—a critique, Vis. Res. 5 (4–5) (1965) 189–206.
[29] N. Wang, M. Boubekri, Investigation of declared seating preference and measured cognitive performance in a sunlit room. Journal of Environmental Psychology 30 (2) (2010) 226–238.
[30] N. Wang, M. Boubekri, Design recommendations based on cognitive, mood and preference assessments in a sunlit workspace, Light. Res. Technol. 43 (1) (2011) 55–72.
[31] P. Leather, et al., Windows in the workplace: sunlight, view, and occupational stress, Environ. Behav. 30 (6) (1998) 739–762.
[32] J. Heerwagen, G. Orians, The psychological aspects of windows and window design, EDRA (1990) 269–280.
[33] S. Kaplan, The restorative benefits of nature: toward an integrative framework. Journal of Environmental Psychology 15 (3) (1995) 169–182.
[34] R.S. Ulrich, et al., Stress recovery during exposure to natural and urban environments, J. Environ. Psychol. 11 (3) (1991) 201–230.
[35] D. Valtchanov, K.R. Barton, C. Ellard, Restorative effects of virtual nature settings, Cyberpsychol., Behav. Soc. Netw. 13 (5) (2010) 503–512.
[36] M. West, Landscape virsus and stress response in the prison environment, MLA thesis, in: Department of Landscape Architecture, University of Washington Washington, DC, 1985.
[37] C. Carver, Pleasure as a sign you can attend to something else: placing positive feelings within a general model of affect, Cognit. Emot. 17 (2) (2003) 241–261.
[38] A.M. Isen, K.A. Daubman, G.P. Nowicki, Positive affect facilitates creative problem solving. Journal of personality and social psychology 52 (6) (1987) 1122.
[39] B.L. Fredrickson, The role of positive emotions in positive psychology: the broaden-and-build theory of positive emotions, Am. Psychol. 56 (3) (2001) 218.
[40] J.A. Russell, A circumplex model of affect. Journal of personality and social psychology 39 (6) (1980) 1161.
[41] J.A. Russell, J. Snodgrass, Emotion and the environment, Handb. Environ. Psycol. 1 (1) (1987) 245–281.
[42] M. Boubekri, R.B. Hull, L.L. Boyer, Impact of window size and sunlight penetration on office workers' mood and satisfaction: a novel way of assessing sunlight, Environ. Behav. 23 (4) (1991) 474–493.
[43] P.A. Bell, et al., Environmental Psychology (1996). Harcourt Brace College Publishers, fourth edition.
[44] J.T. Cacioppo, L.G. Tassinary, G. Berntson, Handbook of Psychophysiology, Cambridge University Press, 2007.
[45] J. Kim, et al., The effects of indoor plants and artificial windows in an underground environment, Build. Environ. 138 (2018) 53–62.
[46] K. Chamilothori, et al., Subjective and physiological responses to façade and sunlight pattern geometry in virtual reality, Build. Environ. 150 (2019) 144–155.
[47] R.J. Giuliano, et al., Parasympathetic and sympathetic activity are associated with individual differences in neural indices of selective attention in adults, Psychophysiology 55 (8) (2018) e13079.
[48] J.L. Higuera-Trujillo, J.L.-T. Maldonado, C.L. Millán, Psychological and physiological human responses to simulated and real environments: a comparison between Photographs, 360 Panoramas, and Virtual Reality, Appl. Ergon. 65 (2017) 398–409.
[49] C.-Y. Chang, et al., Psychophysiological responses and restorative values of natural environments in Taiwan, Landsc. Urban Plann. 85 (2) (2008) 79–84.
[50] G.G. Berntson, et al., Heart rate variability: origins, methods, and interpretive caveats, Psychophysiology 34 (6) (1997) 623–648.
[51] A. Riener, A. Ferscha, M. Aly, Heart on the road: HRV analysis for monitoring a driver's affective state, in: Proceedings of the 1st International Conference on Automotive User Interfaces and Interactive Vehicular Applications, Association for Computing Machinery, 2009, pp. 99–106.
[52] A. Lanatà, et al., How the autonomic nervous system and driving style change with incremental stressing conditions during simulated driving, IEEE Trans. Intell. Transport. Syst. 16 (3) (2014) 1505–1517.
[53] F. Shaffer, J.P. Ginsberg, An overview of heart rate variability metrics and norms, Front. Publ. Health 5 (2017), 258–258.
[54] F. Beute, Y. De Kort, Natural resistance: exposure to nature and self-regulation, mood, and physiology after ego-depletion. Journal of Environmental Psychology 40 (2014) 167–178.
[55] C. Endukuru, S. Tripathi, Evaluation of cardiac responses to stress in healthy individuals-a non invasive evaluation by heart rate variability and stroop test, Int. J. Sci. Res. 5 (2016) 286–289.
[56] Society for Psychophysiological Research Ad Hoc Committee on Electrodermal, M., Publication recommendations for electrodermal measurements, Psychophysiology 49 (8) (2012) 1017–1034.
[57] J.C. Britton, et al., Differential subjective and psychophysiological responses to socially and nonsocially generated emotional stimuli, Emotion 6 (1) (2006) 150.
[58] F. Abd-Alhamid, et al., Developing an innovative method for visual perception evaluation in a physical-based virtual environment, Build. Environ. 162 (2019) 106278.
[59] M. Lambooij, et al., Evaluation of stereoscopic images: beyond 2D quality, IEEE Trans. Broadcast. 57 (2) (2011) 432–444.
[60] K. Chamilothori, J. Wienold, M. Andersen, Adequacy of immersive virtual reality for the perception of daylit spaces: comparison of real and virtual environments, Leukos (2018) 1–24.
[61] N. Tuaycharoen, P. Tregenza, Discomfort glare from interesting images, Light. Res. Technol. 37 (4) (2005) 329–338.
[62] M. Kent, et al., Temporal variables and personal factors in glare sensation, Light. Res. Technol. 48 (6) (2016) 689–710.
[63] R. Liang, et al., Development of experimental methods for quantifying the human response to chromatic glazing, Build. Environ. 147 (2019) 199–210.
[64] P. Tregenza, D. Loe, The design of lighting, published by E&FN SPON, 1998. London.
[65] BREEAM, BREEAM New Construction 2018. 2018.
[66] E. Neufert, P. Neufert, J. Kister, Architects' data, 2nd, John Wiley & Sons, 2012.
[67] H.G. Belanger, C.R. Cimino, The lateralized Stroop: a meta-analysis and its implications for models of semantic processing, Brain Lang. 83 (3) (2002) 384–402.
[68] M. Svetlak, et al., Electrodermal complexity during the Stroop colour word test, Auton. Neurosci. 152 (1–2) (2010) 101–107.
[69] B. Pehlivanoğlu, N. Durmazlar, D. Balkancı, Computer adapted Stroop colour-word conflict test as a laboratory stress model, Erciyes Med. J. 27 (2) (2005) 58–63.
[70] P. Renaud, J.-P. Blondin, The stress of Stroop performance: physiological and emotional responses to color–word interference, task pacing, and pacing speed. International Journal of Psychophysiology 27 (2) (1997) 87–97.
[71] L.A. Gottschalk, et al., Computerized measurement of cognitive impairment and associated neuropsychiatric dimensions, Compr. Psychiatr. 41 (5) (2000) 326–333.
[72] Y. Tong, R.D. Melara, Behavioral and electrophysiological effects of distractor variation on auditory selective attention, Brain Res. 1166 (2007) 110–123.
[73] A. Hashizume, M. Kurosu, T. Kaneko, Multi-window system and the working memory, in: International Conference on Engineering Psychology and Cognitive Ergonomics, Springer, 2007.
[74] J.Y. Garretón, R. Rodriguez, A. Pattini, Effects of perceived indoor temperature on daylight glare perception, Build. Res. Inf. 44 (8) (2016) 907–919.
[75] G.E. Legge, C.A. Bigelow, Does print size matter for reading? A review of findings from vision science and typography, J. Vis. 11 (5) (2011), 8–8.
[76] S. Fotios, C. Cheal, Lighting for subsidiary streets: investigation of lamps of different SPD. Part 1—Visual Performance, Light. Res. Technol. 39 (3) (2007) 215–232.
[77] M. Inanici, Evaluation of high dynamic range photography as a luminance data acquisition system, Light. Res. Technol. 38 (2) (2006) 123–134.
[78] E. Reinhard, et al., Photographic tone reproduction for digital images, ACM Trans. Graph. 21 (3) (2002) 267–276.
[79] J. Wienold, J. Christoffersen, Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras, Energy Build. 38 (7) (2006) 743–757.
[80] C. Cauwerts, Influence of presentation modes on visual perceptions of daylit spaces. Université catholique de Louvain (UCL), Louvain-La-Neuve, Belgium (2013) 119–121.
[81] T. Dashwood, A beginner's guide to shooting stereoscopic 3D. Dashwood Cinema Solutions, 2011.
[82] Vive.com, VIVE™ | VIVE virtual reality system, 2016, https://www.vive.com/us/product/vive-virtual-reality-system/. (Accessed 29 October 2018).
[83] B. Ortiz-Jaramillo, et al., Content-aware contrast ratio measure for images, Signal Process. Image Commun. 62 (2018) 51–63.
[84] J.J. Alvarsson, S. Wiens, M.E. Nilsson, Stress recovery during exposure to nature sound and environmental noise, Int. J. Environ. Res. Publ. Health 7 (3) (2010) 1036–1046.
[85] Karthikeyan, P., M. Murugappan, and S. Yaacob. A review on stress inducement stimuli for assessing human stress using physiological signals. in Signal Processing and its Applications (Cspa), 2011 Ieee 7th International Colloquium on. 2011. (IEEE).
[86] D. Cho, et al., Detection of stress levels from biosignals measured in virtual reality environments using a Kernel-based extreme learning machine, Sensors 17 (10) (2017) 2435.
[87] J.J. Braithwaite, et al., A guide for analysing electrodermal activity (EDA) & skin conductance responses (SCRs) for psychological experiments, Psychophysiology 49 (1) (2013) 1017–1034.
[88] M.A. Peltola, Role of editing of R-R intervals in the analysis of heart rate variability, Front. Physiol. 3 (2012), 148–148.
[89] M. Benedek, C. Kaernbach, A continuous measure of phasic electrodermal activity, J. Neurosci. Methods 190 (1) (2010) 80–91.
[90] M. Benedek, C. Kaernbach, Decomposition of skin conductance data by means of nonnegative deconvolution, Psychophysiology 47 (4) (2010) 647–658.
[91] M.E. Dawson, A.M. Schell, D.L. Filion, The electrodermal system. Handbook of psychophysiology 2 (2007) 200–223.
[92] E.R. Thompson, Development and validation of an internationally reliable short-form of the positive and negative affect schedule (PANAS), J. Cross Cult. Psychol. 38 (2) (2007) 227–242.
[93] A. Field, G. Hole, How to design and report experiments, SAGE Publications Ltd, 2002. ISBN: 9780761973836.
[94] R.S. Kennedy, et al., Simulator sickness questionnaire: an enhanced method for quantifying simulator sickness, Int. J. Aviat. Psychol. 3 (3) (1993) 203–220.
[95] S. Masoudinejad, T. Hartig, Window view to the sky as a restorative resource for residents in densely populated cities, Environ. Behav. 52 (4) (2018) 401–436, https://doi.org/10.1177/0013916518807274.
[96] H. Nordh, et al., Components of small urban parks that predict the possibility for restoration, Urban For. Urban Green. 8 (4) (2009) 225–235.

[97] P.J. Lindal, T. Hartig, Architectural variation, building height, and the restorative quality of urban residential streetscapes, J. Environ. Psychol. 33 (2013) 26–36.

[98] P.J. Lindal, T. Hartig, Effects of urban street vegetation on judgments of restoration likelihood, Urban For. Urban Green. 14 (2) (2015) 200–209.

[99] P. Tabrizian, et al., Exploring perceived restoration potential of urban green enclosure through immersive virtual environments, J. Environ. Psychol. 55 (2018) 99–109.

[100] G. Labouvie-Vief, et al., Age and gender differences in cardiac reactivity and subjective emotion responses to emotional autobiographical memories, Emotion 3 (2) (2003) 115.

[101] S. Ferré, M.C. O'Brien, Alcohol and caffeine: the perfect storm, J. Caffeine Res. 1 (3) (2011) 153–162.

[102] S. Bouchard, et al., Using virtual reality in the treatment of gambling disorder: the development of a new tool for cognitive behavior therapy, Front. Psychiatr. 8 (27) (2017).

[103] J. Tomaka, J. Blascovich, L. Swart, Effects of vocalization on cardiovascular and electrodermal responses during mental arithmetic. International Journal of Psychophysiology 18 (1) (1994) 23–33.

[104] L.K. Bush, U. Hess, G. Wolford, Transformations for within-subject designs: a Monte Carlo investigation, Psychol. Bull. 113 (3) (1993) 566.

[105] A. Field, Discovering statistics using IBM SPSS statistics, London:Sage 5th ed. (2018).

[106] A. Kolmogorov, Sulla determinazione empirica di una lgge di distribuzione, Inst. Ital. Attuari, Giorn. 4 (1933) 83–91.

[107] S.S. Shapiro, M.B. Wilk, An analysis of variance test for normality (complete samples), Biometrika 52 (3/4) (1965) 591–611.

[108] C.J. Ferguson, An effect size primer: a guide for clinicians and researchers, Prof. Psychol. Res. Pract. 40 (5) (2009) 532.

[109] A.G. Solimini, et al., A survey of visually induced symptoms and associated factors in spectators of three dimensional stereoscopic movies, BMC Publ. Health 12 (1) (2012) 779.