Exploring the use of immersive virtual reality to assess occupants' productivity and comfort in workplaces: An experimental study on the role of walls colour

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Exploring the use of immersive virtual reality to assess occupants' productivity and comfort in workplaces: an experimental study on the role of walls colour

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Abstract
Virtual Reality application in holistic investigations for energy and cost-saving building design, aimed at humans' well-being and performance, is still emerging and needs validation.

In this study, tests in real and virtual scenarios of an office room were performed, investigating the impact of three walls colours (red, white, blue) and two indoor air temperatures (17-22°C) on 23 participants' work productivity (through a proofreading task) and thermal and visual sensations (through surveys). The first goal was the comparison of the results obtained in the real and virtual settings; the second one the assessment of the effect of walls' colour and temperature levels on the mentioned variables in each environment. Statistical analyses were then performed "between groups" (Wilcoxon and t-tests, among datasets of the two environments) and "within groups" (ANOVA and Scheirer test, within each environment).

The study revealed no statistically significant variations in productivity and sensation votes, thus supporting the suitability of VR as a proper research technology in this domain. The study also demonstrated no statistically significant effects of colour and temperature on productivity and comfort results within the tested settings. Future investigations should involve a wider range of temperatures and colours and address a wider subjects' sample.

Highlights

- Validation of virtual reality for comfort and productivity assessments
- Experimental tests in a real and an immersive virtual office room
- 23 subjects tested under 3 walls colour and 2 temperature levels
- No statistically significant results variation among real and virtual environments
- No statistically significant colour's effect on comfort perception and productivity

Keywords

- Indoor environmental quality
- Immersive virtual environment
- Virtual reality

- Wall colour
- Workers' Productivity
- Indoor comfort
- Human-centric design

Graphical Abstract
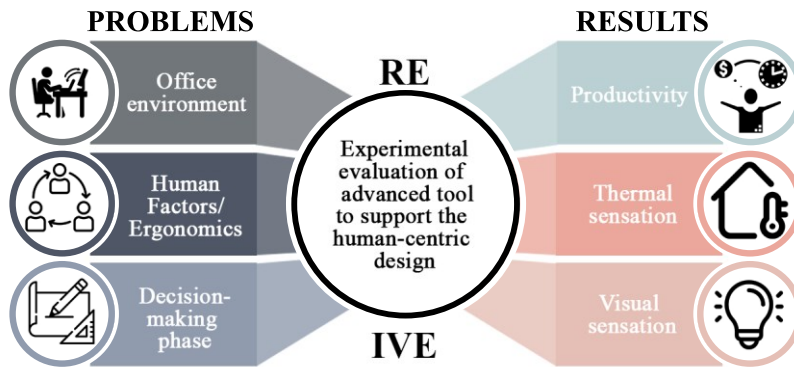
Nomenclature

IEQ	Indoor Environmental Quality
CCT	Correlated Colour Temperature
IVE	Immersive Virtual Environment
VR	Virtual Reality
RE	Real Environment
VRSQ	Virtual Reality Sickness Questionnaire
met	Metabolic rate
clo	Clothing insulation
TSV	Thermal Sensation Vote
VSV	Visual Sensation Vote
R	Red
W	White
B	Blue
C	Colour
T	Temperature
CxT	Colour-Temperature interaction

1. Introduction

According to Organization for Economic Co-Operation and Development in developed countries a full-time employee works on average between 1734 hours per year, which means 36.8 hours per week [1] A large portion of working days are spent indoors, hence it is important to create efficient and comfortable workplaces, to increase workers' productivity and wellbeing, to keep satisfying environmental conditions and to reduce energy consumption.

The effects of Indoor Environmental Quality (IEQ) on workers' productivity and well-being are widely documented [2]. According to Al Horr et al. eight environmental factors especially affect occupants' comfort and productivity: indoor air quality and ventilation, thermal comfort, lighting and daylighting, noise and acoustics, office layout, biophilia and views, look and feel, location and amenities [3]. As confirmed by Andargie and Azar, these are highly connected and together with personal factors as demographical features (gender, age), clothing insulation and metabolic rate-contribute to employees' satisfaction and stress during workhours, also affecting how they perceive indoor environments [4]. Recently, a cross-sectional survey data from six countries stressed the impact of interconnected factors among building physical, attitudinal, social and demographic components, on occupants' IEQ-productivity belief, thus the need of prioritizing occupants' wellbeing in workplaces since the early design stage [5].

Recent researches on the inclusion of human factors in the design of working spaces shown a great potential to reduce the energy consumption while optimizing productivity, health, well-being and comfort [6]. It is well established that if humans and their environment are not related, this results in less productivity and comfort, which will turn on higher business time and energy costs [7]. Understanding the occupants' behaviour and preferences in working places has then a great potential in reducing buildings operating costs, which include energy and maintenance costs, but also costs related to employee productivity, which may generally represent a much higher percentage of overall organizational expenses than energy costs [8].

The look and feel of an office environment have an effect on occupants' comfort satisfaction after accounting for other IEQ and personal control factors. A good office design would incorporate aesthetical features that compliment company's organisational values and provides a pleasant perception for employees [3]. Colour is one of the strongest "*stimuli that we received from the external world connected with our internal world: our psyche*", and human psychological responses vary due to different colours used in the design of indoor spaces [9]. Hence the presence of specific colours or colour schemes in an indoor environment may affect human performance, well-being and productivity [10,11].

In order to assess the relation among offices colours and occupants' productivity, several researches have been conducted in the last decades, where participants performed tasks in test rooms under different walls colour layout conditions [10,12–15]. Some authors compared detailed-oriented tasks against creative ones [12,14] to find out the most suitable colour to improve the cognitive task performances. During the experimental procedures, surveys are usually provided in order to understand subjects' preference and personal attitude toward the indoor design [10,12,15,16].

For almost a century, thanks to the "hue-heat hypothesis" [17], it became also clear that objects colour has an effect on their perceived temperature. Indeed, according to this theory, colours toward the red end of the visual spectrum are perceived as warm, while those toward the blue end as cold. More recently this subject regained the attention of researchers, interested in assessing if, and how much, the application of warm and cool colours in indoor spaces (through walls, furniture or colour temperature of lighting) could enhance users' thermal perception against their actual thermal condition, eventually leading to energy saving. However, the research is still in its infancy and with inconsistent and contradictory results [18]. Starting from a first study of Fanger et al [19]. which found a slight effect of colour on human comfort, some works fully confirmed the hue-heat hypothesis with important outcomes in terms of comfort optimization. For instance, Wang et al., performing tests in a climatic chamber with different coloured walls and several indoor temperature setpoints, found a certain effect of effects of warm and cool colours on thermal sensation and thermal comfort [20].

D'Ambrosio Alfano et al. performed studies that confirmed the hue-heat hypothesis in a test room with different Correlated Colour Temperature (CCT) of luminaires [21,22]. Chinazzo et al. confirmed the assumption in a test office with three coloured glazing types [23]. Brambilla et al. recently found results consistent with the hue-heat hypothesis only for neutral and cool white light for warm environments [18]. Conversely, other studies partly provided support or even did not provide support for the hue-heat hypothesis [24–27].

Traditionally, human behaviour and preferences are quantitatively assessed and modelled based on data collected from experiments and post-occupancy evaluations using test beds or actual buildings. Some Universities developed dedicated facilities to simulate different other design factors and assess occupants' comfort theories [28], however these are limited experiences in terms of possible configurations of physical environments. Specific correlations should be created for each individual design case to guide choices, whose alternatives and changes could be assessed in real time, also considering the many variables affecting users' comfort, satisfaction, and performance. However, of course, research based on full-scale reproductions of alternative design solutions to investigate comfort theories involves a considerable waste of time and resources. [29]

In this context, Virtual Reality (VR) is a valid mean to simulate alternative design configurations, without the limitation of physical models [30]. The main advantages, and the differences with respect to the technologies and systems used so far to evaluate the comfort-oriented design, are: low cost, repeatability, speed of execution. The potential of Immersive Virtual Environment (IVE) (i.e. based on head-mounted displays providing a realistic experience) has increasingly widespread in the past two decades to facilitate engineering, construction and management for the built environment [30]. Several studies have already pointed out that IVE could provide also a promising approach to explore behavioural design, studying occupants' interactions, perceptions and habits in built, unbuilt or during maintenance environments [31,32].

However, its application to investigate the behaviour and perception of occupants in buildings in relation to their design, therefore for a design aimed at comfort, well-being and performance, is still emerging. Vittori et al. demonstrated the potential of VR applications for the assessment of human perception of the built environment since the early design phase [30]. They modelled an office environment in VR and recorded subjects' comfort perception under several scenarios determined by the combination of design variables (glass filter, window aspect ratio, and artificial lighting colour temperature).

Some recent studies addressed the validation of the hue-heat hypothesis in virtual environments. For instance, Chinazzo et al. investigated temperature–colour interaction effects on subjective perception and physiological responses (heart rate, skin conductance, and skin temperature) [33]. 57 people participated in an IVE experiment with three coloured glazing (blue, orange, neutral) under two temperature conditions (24°C, 29°C). Huang et al. tested the effect of coloured ambient light on the perceived thermal comfort, context of use and ambient atmosphere, for two national groups of 15 people each, in four virtual rooms with different walls colours [34]. Both these studies revealed that colour stimuli significantly affected thermal perception in VR, also confirming the hue-heat hypothesis.

However, the actual research in the field still needs to further validate VR by comparing in-situ evaluation outcomes [35]. The current imperative is to demonstrate that VR is a suitable tool to simulate the Real Environment (RE), also generating a multi-sensory experience (i.e. visual, thermal, auditory, etc. or their combination) [36,37]. An important step forward in this sense was made by Ozcelik and Becerik-Gerber which compared the human response in real and virtual environments

under different thermal and visual settings, in order to analyse the number and type of participants interactions with the building systems (fans, thermostat, radiant heater or hot/cold beverages), the perceived thermal comfort and satisfaction before and after each interaction and the perceived air temperature [38]. Findings proved that there was no significant difference between RE and IVE sessions. Heydarian et al. performed an experiment that investigated the performance on a set of everyday office-related activities of 112 people in both real and virtual environments [39]. The obtained results indicated that IVE was a satisfactory representation of the physical environment and can be effectively used to study user behaviour and measure user performance.

Despite research related to performance, thermal and visual comfort in IVE was reported, thermal behavioural and performance studies employing VR are at the initial state [40]. This work thus aims to provide a further contribution in validating VR for occupants' perception and behavioural studies, by evaluating the potentialities of using IVE, instead of experimental RE, to analyse the impact of the colour of offices' walls on the workers' productivity, thermal and visual perception. Real and immersive virtual scenarios of an office room were set up, considering different walls colour layouts (white, red, blue) under two temperature levels. 23 volunteer participants were involved in the experimental tests, performing a productivity task and answering thermal and visual comfort surveys, in both the RE and the IVE under all scenarios.

In order to provide a robust procedure, the present study includes a VR "validation" phase (i.e. the assessment of its effectiveness for thermal behavioural and performance assessments compared to a real environment) and a VR "application" process (i.e. its use to perform comfort and productivity assessments).

Thus, the first goal of the study is to verify any possible deviation and difference between the obtained results in the real and virtual environments. The second aim is the assessment of the effect of walls colour layouts and temperature levels on subjects' productivity and sensation in each environment. Indeed, a correlation between indoor colour layouts and users' comfort and productivity would further support an energy and cost saving-oriented building design.

The rest of the paper is structured as follow. Section 2 presents the methodology of the research, including the detailed description of the operative phases, the instruments, the real test room, the VR modelling, the productivity test and comfort questionnaires, the experimental procedure. Section 3 reports the study findings, while their discussion is drawn in Section 4 together with concluding remarks, limits and future perspectives of the study.

2. Materials and methods

The experimental campaign was carried out in an office room located in a laboratory of the Department of Information Engineering (DII) at Università Politecnica delle Marche (Ancona, Italy) (section 2.1). In the test room, 23 volunteer participants were asked to perform a productivity test (section 2.3) and to answer to a visual and thermal sensation questionnaire (section 2.4).

The 23 volunteer participants were selected among students, PhD students, researchers, professors end employees, based on the eligibility criteria of full colour vision and a generally healthy condition. A 3 x 2 factorial design was carried out testing two types of stimuli in both IVE and RE: three levels of factor "walls colour" (white, red, blue) in combination with two levels of factor "temperature" set point (17°C and 22°C, during the heating season). In this repeated-measures design the group of subjects took part to all the experimental conditions. The tests were conducted in the RE and in an

IVE modelled for the purpose, representing the test room with the different colour layouts (section 2.2).

2.1 Test room

The test room was part of an office room, created by delimiting a portion of the larger office environment with curtains (Figure 1). A black curtain was hung towards the windows to screen daylight, thus guaranteeing the same (artificial) light conditions to all test participants during the day. The other three sides of the test rooms consisted on coloured curtains which were replaced during the different tests. The colours of the curtains assessed during the tests were: white (W), blue (B), red (R). The room had a surface of 8.65 m^2, with a ceiling height of 2.80m and was equipped with desk and seats to host up to 3 people during the test. The room floor was insulated with 5cm of expanded polystyrene to reduce the vertical temperature gradient.
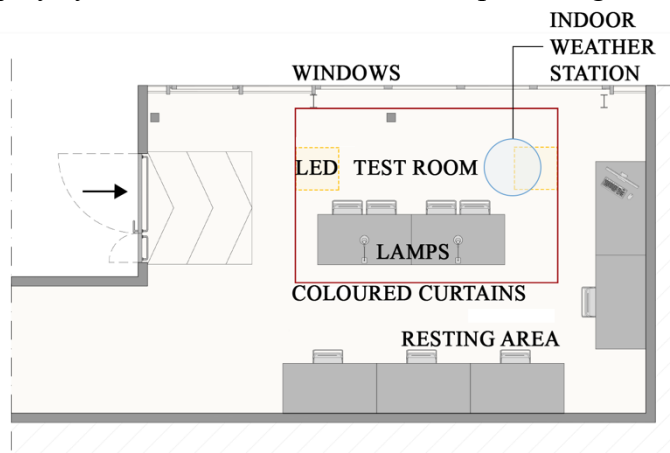

Figure 1 Layout of the test room

An indoor climate station (*Dantec Dynamics ComfortSense,* Figure 2a) was placed in the test room to monitor the following indoor conditions with a time step of one second: air temperature (range: -20°C to +80°C, accuracy above 0.5m/s: ± 0.5°C), air velocity (accuracy = 0.2-20m/s: ± 2% or ± 0.02 m/s; 20-30m/s: ± 5%), humidity (accuracy +2%RH/0-10 °C; +1.5%RH/10-30 °C; +2%RH/30-45 °C) and operative temperature (accuracy ± 0.5K/0-10 °C; ± 0.2K/10-40 °C; ± 0.5K/40-45 °C).

The indoor climate station data and the operation of a heating equipment (*Mitsubishi Electric Corporation PUMY-P112YKM4, Indoor Unity: PLFY- PVFM-E1*) were controlled with *LabView* software. The operative temperature set-points were set at 17°C and 22°C during the tests.
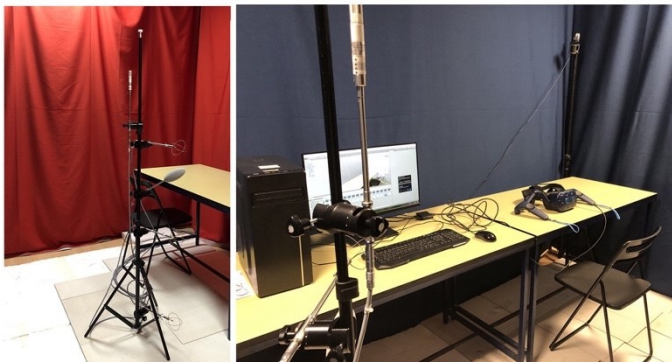

Figure 2 The test room with different wall colour layouts. Detail of the indoor climate station (a) and the setting up for the VR tests (b)

The room artificial lighting was provided by two *Novalux* LED lamps installed on the room ceiling and by two work lamps (*TERTIAL from IKEA*) placed on the desks. To ensure subjects visual comfort, light intensity and colour has been assessed. The measurement of illuminance (E_m) on the task area consisting on four workstations was carried out by using two broad band radiometers from *LSI LASTEM* (accuracy ±3% VL/reading ±10lx) (Figure 3). According to standard EN 12464-1 [41], the minimum requirement is 500 lx for "*Writing, typing, reading, data processing*" activity. This regulatory minimum was fulfilled by using the double lighting, as E_m reached 554lx ÷ 584lx. Both *Novalux* LED lights and LED bulbs of the work lamps were used at a correlated colour temperature of 4000K (neutral white), considered functional for working activities [42–44].

Figure 3 Em (lx) measurement of the workstations 1-3 (above) and 2-4 (below)

2.2 Virtual model

To generate the IVE, a 3D geometric model of the test room was created using a CAD software, then the realistic virtual immersive 3D representation was generated by using *Unity* software [45], which especially allowed to manage the application of materials, lights and cameras.

Colour appearance and perception in digital modelling must be properly addressed, in order to ensure a high level of immersivity to all users [46,47]. Thus, in order to realistically and properly represent the colours of the curtain walls, measures of the luminance parameters (L*) and chromatic components (a*b*) of the CIELab model of the coloured curtains were performed, through a spectrophotometer (*CM-2500d Konica Minolta*). For each coloured curtain, 5 measures were performed with a measurement area with a diameter of 8 mm. Then CIELab model coordinates were converted into RGB model coordinates for each curtain colour for the Unity 3D model.

Lighting (point light and spot light) effects were added to the model to represent the realistic lighting conditions, using the RGB value corresponding to 4000K to properly depict the light colour.

The productivity test, consisting in a text written on a sheet of paper (described later in section 2.3), was applied on cubic elements over the working desk. Finally, the Capsule Camera has been added to the model to get the first-person player control.

Three IVE scenarios were created in Unity, considering the setting of the experimental activity with the three wall colours (Figure 4). For each scenario a different productivity text was provided. A "scene 0", containing the correct text for the pre-experimental phase (as described in section 2.5), was also modelled.

The IVE model was experiences through the *HTC Corporation VIVE PRO Eye* (1440 x 1600 resolution image per eye) (Figure 5) using *SteamVR* plugin [48]. Before wearing the headset, subjects' interpupillary distance was estimated with a ruler, to adjust the distance between the lenses, making the headset more comfortable and improving the sharpness of images.

Figure 4 IVE scenarios with the three colour layouts

Figure 5 VIVE Pro Eye headset

2.3 Productivity test

Users' office/learning performance can be tested with several methods: detail-oriented tasks (i.e. writing story [12], finding differences among visualized items [13]), problem solving [14,43,49,50], cognitive tests [50,51], creative tasks [14] and proofreading [10,12,49,52,53].

In this study, a proofreading task was selected as performance test, given its easy reproducibility in virtual environments and recognised general effectiveness.

During the pre-experimental phase, participants were invited to read a 48 lines text, in its original version without errors (i.e. grammatical errors, typos, words replacements, etc…). Then, during the operative phase, they were asked to count all the errors contained in a modified version of the text (totalling 12 errors). In each experimental session, the errors in the text were changed, but their number (12) and typology remained unchanged, thus creating a similar level of difficulty. The text

was written by using *Microsoft Word*, in *Times New Roman* font, size 11, line spacing 1.0. This serif typeface (with orthogonal extensions at the ends) eases the reading, as guides it horizontally, increasing the contrast of letters with the background. An exemplary text used during a session is provided in Appendix A.

2.4 Questionnaire

At the end of productivity test, participants were asked to fill a questionnaire to evaluate their wellbeing during each experimental test session. Subjects were not informed about the aim of the tests in order to get answers based on their authentic feelings. The questionnaire was written in Italian and consisted of four sections with closed and open-ended questions on: volunteers' personal information, overall colour-productivity perception, thermal sensation and visual sensation. A fifth section about the cybersickness due to VR was included in the questionnaire version during the IVE test sessions. The whole questionnaire submitted to the volunteers is reported in Appendix B (translated from Italian to English).

The first section was provided to collect general personal information on the volunteers: gender, age, height, employment, health status. Moreover, an activity checklist was provided to evaluate their metabolic rate (met) value according to standard ISO 8996 [54], based on the physical movement they were doing half an hour earlier the test. Finally, a clothing insulation value (clo) checklist was added, based on standard ISO 9920 [55], to estimate the thermal insulation of participants clothing ensemble.

The second section of the survey intended to evaluate the perception and opinion of participants on the relationship among walls colour and their working productivity and well-being.

The third one focused on thermal sensation. Participants' thermal sensation was evaluated based on the recommendations of standard ISO 10551 [56], considering the Thermal Sensation Vote (TSV), as in previous studies in VR [30,57].

The visual sensation has been assessed in the fourth section of the survey, in order to understand participants' perception of artificial lighting in both tested environments (RE and IVE). Subjects were asked about the lighting cold-warm association using the Visual Sensation Vote (VSV) on a 5-point scale [58]. They were also asked about the glare, causing visual discomfort [59]. The wordings and scales of the thermal and visual sensation surveys are shown in Table 1.

Scale	TSV	VSV
4	-	cool
3	hot	slightly cool
2	warm	neither warmer nor cooler
1	slightly warm	slightly warm
0	neutral	warm
-1	slightly cool	-
-2	cool	-
-3	cold	-

Table 1 Thermal and visual comfort questionnaire subjective scales

Cybersickness related to using IVE technologies is usually due to motion sickness and eye strain [31,60]. It is an important factor to be considered when using IVEs for data collection, especially for limiting the duration of an experiment to less than 20–30 min or to divide longer experiments into shorter sessions with a break between two sessions [32]

In this work, the Virtual Reality Sickness Questionnaire (VRSQ), developed in the study of Kim et al. [61], was used to detect the level of individuals' sickness, in order to control IVE data quality. The VRSQ includes nine symptoms: general discomfort, fatigue, eyestrain, difficulty focusing, headache, fullness of head, blurred vision, dizzy (eyes closed) and vertigo. Participants were asked to evaluate them using a 4-degree scale (from «0 = not at all» to «+4 = a lot»).

2.5 Experimental procedure

Each test session took place as shown in Figure 6. It consisted in performing the productivity tests and answering the survey for each wall colour and two temperature set points. The test was firstly conducted in the RE and, a couple of weeks later, in the IVE.

The same subjects were exposed to all test conditions in order to compare each subject performance and ratings across all scenarios. Hence, the total test sessions for each participant were 4 (2 in the RE and 2 in the IVE, for each temperature level). Each session lasted about 75 min.
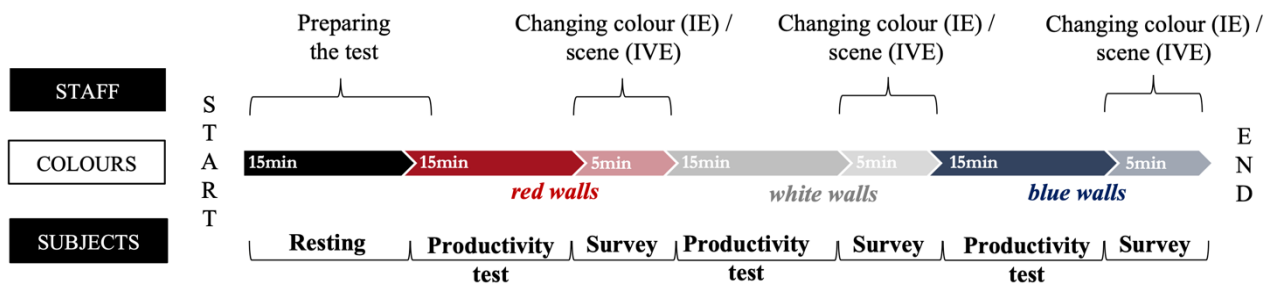

Figure 6 Experimental schedule

After the arrival of volunteers, a pre-experimental phase was carried out, to allow them to get used to the environmental conditions, according to Goto et al. [62]. The subjects were sitting in the resting area for 15 minutes, received instruction on the experimental procedure and read the productivity text in the original version (without errors and typos).

Then they entered the test room for the real experimental phase. At first, subjects were asked to focus on the colour walls for 3 min. According to Küller et al. [12], this time period is necessary to allow the participants to be unconsciously affected by colour stimulus. With a shorter time-frame (e.g. 1 minute) only the initial colour response would be measured and not its real influence on work productivity.

After that, the participants performed the proofreading tasks. For each wall colour, the exposure and test time was a maximum of 15 minutes, to avoid motion sickness during the IVE sessions [49].

At the end of the experimental phase in the test room for each wall colour, participants went out in the resting area to fill in the questionnaire, while the test staff was replacing the curtains (RE) or changing the scenes on *Unity3D* (IVE). Especially during the IVE tests, this pause was necessary for the subjects, to avoid any motion sickness consequence due to a prolonged exposure [49]. Before each test in the virtual environment, participants were asked if they positively considered their sense of presence and if they felt comfortable using the headset.

The procedure (proof-reading task and survey) was repeated three times, one for each colour (Figure 7). Participants were not told about the colours sequence and operative temperatures, to get rid of expectation distortion concerning the experimental conditions.
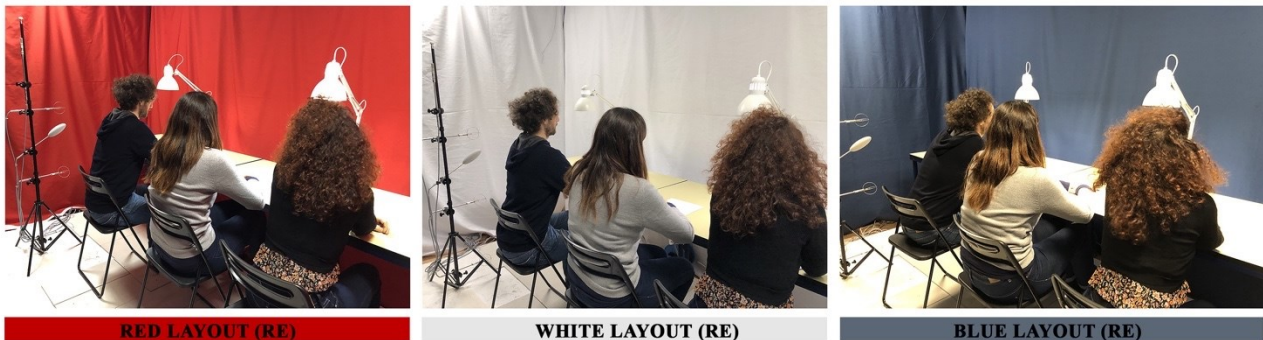

Figure 7 Volunteers during RE tests in the office room with the three colour layouts

Table 2 shows the mean operative temperature and the standard deviation of each experimental session.

	RE		IVE	
Walls colour	17°C	22°C	17°C	22°C
Red	17,85 (0,86)	22,16 (0,17)	17,24 (0,21)	21,60 (0,57)
White	17,64 (0,72)	22,04 (0,10)	17,18 (0,21)	21,64 (0,48)
Blue	17,56 (0,76)	22,17 (0,18)	17,14 (0,24)	21,60 (0,50)

Table 2 Mean operative temperature (and standard deviation) of each experimental session

3. Results and discussion

In the following sections, the analysis of the two collected datasets (in RE and IVE) is conducted for each parameter (productivity, thermal and visual sensation). Moreover, results from cybersickness analysis and from the general questions on colour-productivity perception are presented.

The first goal of the analysis is to assess any difference on the outcomes given by the two environments. The second one is to verify the effect of the walls colour on the subjects' productivity and sensation, eventually also verifying the hue-heat hypothesis.

The validation of VR is based on the analysis of differences (Δ) on errors detected by the participants (productivity assessment) and of differences on the thermal and visual sensation votes (comfort assessment) in RE and IVE (between groups) under each experimental condition (different temperatures and walls colour). This concept is highlighted by the vertical arrow in Figure 8, which schematically represents the analysed datasets.

In addition, according to the second aim, the influence of walls colour (C), temperature (T) and the interaction between them (C x T) are assessed (within groups, horizontal arrow in Figure 8).
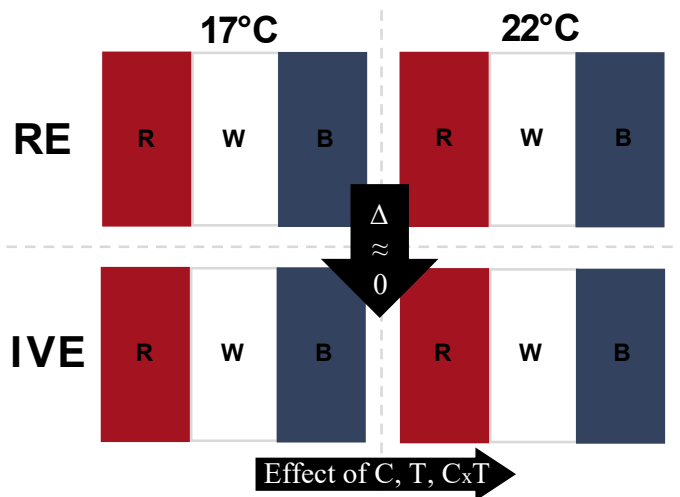
Figure 8 Schematic representation of experimental scenarios and the analysed datasets

All datasets were firstly tested for normality with the Shapiro–Wilk test [63] and then analysed with parametric or nonparametric tests according to the results on the normality of the distributions. The significance level was set as equal to 0.05 (5%) for all tests and *R Studio* [64] used for the statistical analysis. Together with the statistical significance values, the effect sizes has been calculated as a further measure of the absolute magnitude of the differences across the experimental conditions for both parametric and nonparametric tests [51,65].

3.1 Personal variables and Virtual Reality Sickness Evaluation

An overall view of the subjects' demographic and personal information is shown in Figure 9. The sample of 23 volunteers had a well-balanced male-female ratio (52% vs 48%). The age group distribution was composed of young people between 23 and 32 years old (μ=26 years old, SD=3) as follow: 39% under 25 (μ=23.44, SD=0.52), 43% between 25 and 30 (μ=27.2, SD=1.68) and only the 17% over 30 years old (μ=31.5, SD=0.57).

The 86% of participants was selected among students, PhD students, researchers, professors thus they attend every weekday the university spaces (classrooms, offices, departments) and the remaining 14% were employees or freelancer elsewhere. None of them expressed any experience with IVEs. The 48% of the sample with eyesight problems (myopia, astigmatism, hyperopia) wore corrective lens during the tests. None of the subjects suffer from colour blindness.

Concerning the metabolic rate, before each experimental session, at least the 65% of subjects were mostly involved in sedentary activities (<1,2met). Otherwise, more intense activities (1,8 – 2,5 met and >2,5met) were performed in few cases but the pre-experimental phase of 15 minutes allowed the subjects to go back to a typical resting level.

The experimental sessions took place in four different days among December and January, thus the 0,9clo value was considered as typical of the winter garments. The participants did not wear the same clothes during each test day, as a consequence there is a slight variability among their clothing insulation.
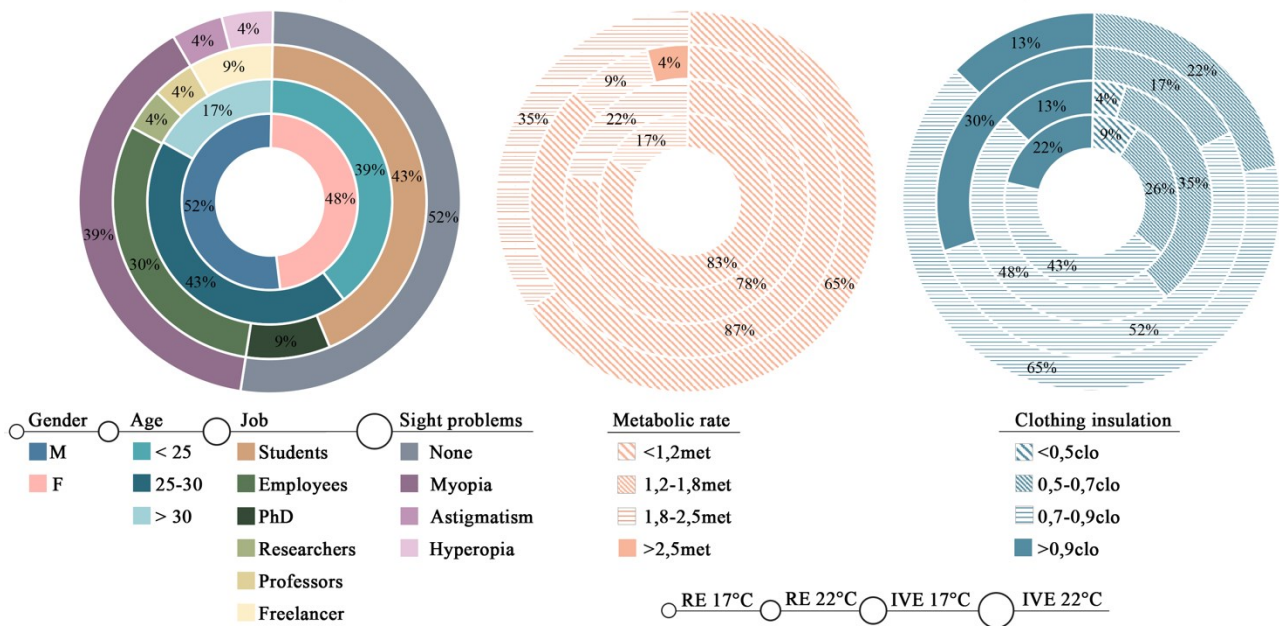
Figure 9 Demographic and personal information of the 23 volunteers

Concerning VRSQ results, Figure 10 shows the mean percentage of votes. About the 96% of the subjects did not experience dizzy (eyes closed) and vertigo since the test was carried out in static conditions. Other disorders (general discomfort, fatigue, headache, fullness of head, blurred vision) can be evaluated as not significant due to an average rate (between 41% and 58%) assigned by participants to score «0 = not at all» and «+1 = a little bit». On the other side, at least 37% of subjects pointed out a quiet (score«+3» and «+4») difficulty in focusing, due to slightly blurred images and eyestrain.
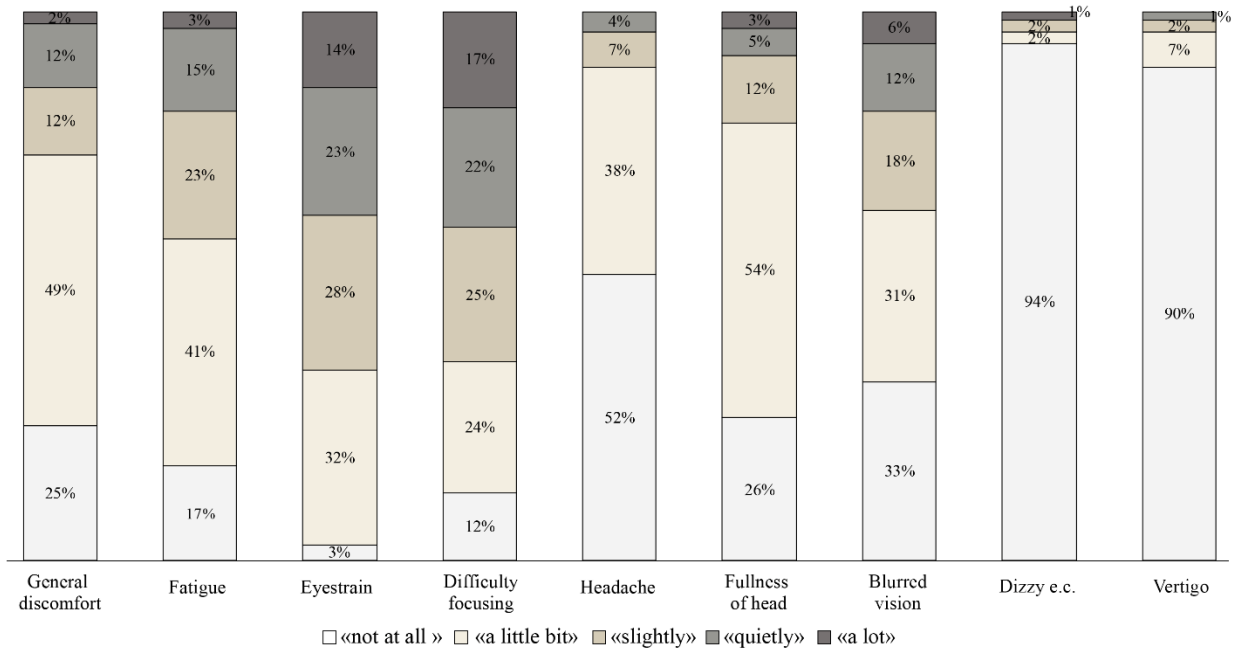

Figure 10 Results of the cybersickness disorders expressed by the 23 volunteers

To further investigate this point, Figure 11 shows the trend of percentage responses given to the eyestrain symptom during the progress of the tests focusing on the highest available ratings («quietly»

and «a lot»). Within each temperature level (on the left-hand side for the 17°C, on the right-hand side for the 22°C) level), the red shadow indicates an increasing trend for the rating «a lot» (+4) among each test session in the virtual environment. Despite that, all participants were able to fully complete the tests.
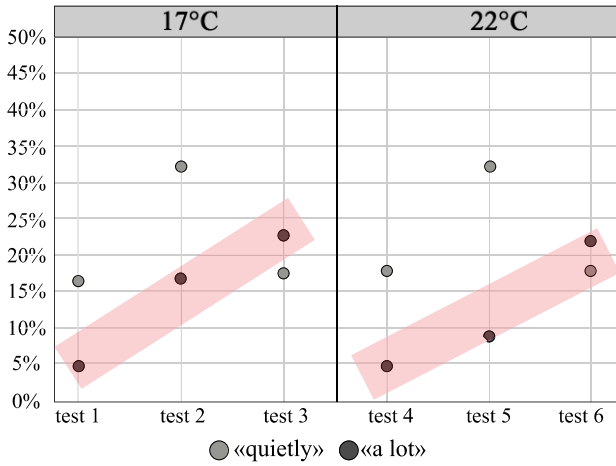

Figure 11 Eyestrain» ratings among the test conditions during the IVE session

3.2 Productivity

Participants answered the general questions in Section II of the questionnaire (paragraph 2.4) about the relationship between workplaces walls colour and productivity. Collected responses from a 7-degree scale (from «-3 = not at all» to «+3 = a lot») are summarized in Figure 12. According to the pie-charts, about 47% and 38% of interviewees expressed that walls colour can have an influence (score «+2 = quietly» and «+3 = a lot») on people in general (first sentence) and on own personal productivity (second sentence), respectively.
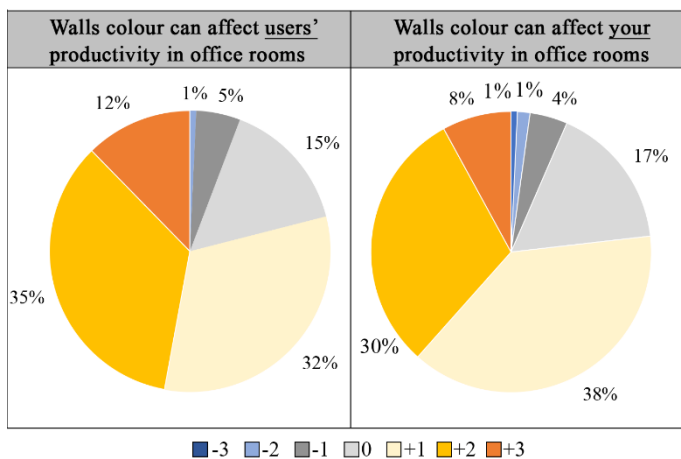
Figure 12 Percentage of ratings to the general questions about the office interior design

The authors also focused on subjective preferences to better study the walls colour-productivity interaction. The stacked histograms in Figure 13 highlight that, according to the participants, the white walls is the most suitable and tolerable (score **Errore. L'origine riferimento non è stata trovata.**«0») among the tested experimental conditions, i.e. 67% and 87% of participants respectively. Thus, the 65% of subjects evaluated the white layout to be the one which can better

improve their productivity (score **Errore. L'origine riferimento non è stata trovata.**«+1 slightly» to «+3 = a lot»).

Otherwise, the 59% of subjects evaluated the red walls colour to be the least suitable for an office room, difficult to tolerate in the 46% of cases (from score «+2= fairly difficult to tolerate» to «+4 = intolerable») and also not useful to improve personal productivity (45%, from score «-1 = a little bit» to «-3 = barely»).

Nevertheless, the awareness of an effect and the preference of colour manifested by the participants appeared not to be consistent with the productivity task results as follows.
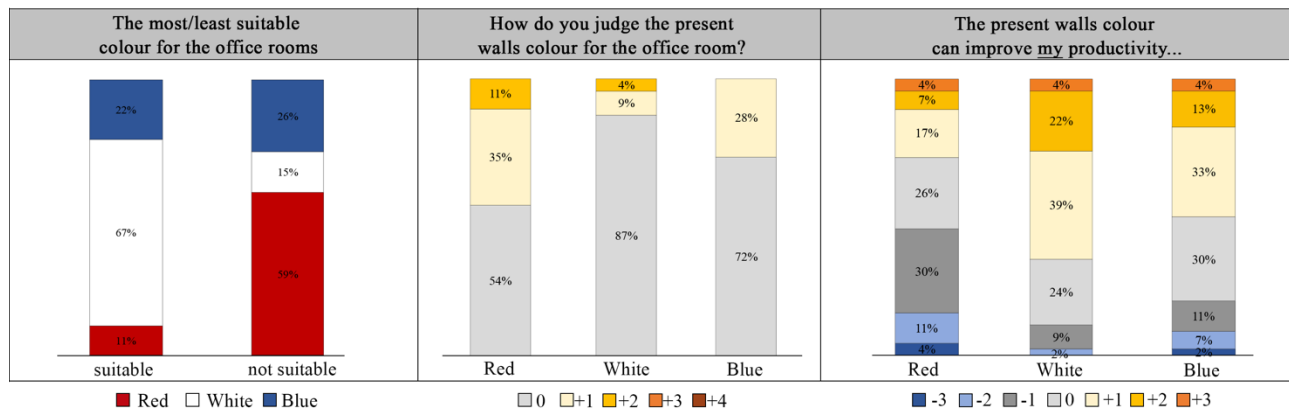

Figure 13 Percentage of ratings to the question about the colour-productivity interaction among the experimental conditions

To investigate any differences between the real and the virtual environments in terms of productivity, the distributions of errors detected in the proofreading task by volunteers were then compared. Table 3 shows the means and standard deviations of the participants' errors detected in the text for each test condition, together with the results of the Shapiro-Wilk test which stated the normality of the results' samples (p-value > 0.05).

		17°C		22°C	
Environment	Walls colour	p-value	μ (sd)	p-value	μ (sd)
	Red	0.639	8.26 (2.37)	0.141	8.78 (2.37)
RE	White	0.394	9.78 (2.29)	0.284	8.08 (2.55)
	Blue	0.052	10.1 (2.04)	0.285	9.04 (2.60)
	Red	0.451	8.30 (2.54)	0.648	8.09 (1.91)
IVE	White	0.312	8.74 (2.13)	0.055	7.35 (2.25)
	Blue	0.386	8.78 (2.52)	0.073	8.70 (2.37)

Table 3 The results of the Shapiro-Wilk normality test and the means and standard deviation (in brackets) of participants' productivity among each experimental condition between RE and IVE

On average, of the total 12 errors contained in the text, participants found 9.03 errors in the RE (sd=2.32) and 8.33 in the IVE (sd=2.28). Table 4 reports the difference between the means ($\Delta\mu$) of the errors detected in the RE and IVE for all the tested conditions.

The difference of errors (Δ) in the proofreading tasks was evaluated through a paired-samples t-test. The null hypothesis stated that the mean difference between the errors number in RE and IVE was zero for all the tests conditions, i.e. for any temperature and colour ($\mu_\Delta = 0$). The obtained t statistics for each sample (Table 4) falls outside the critical region (± 2.074). Thus, the authors fail to reject the null hypothesis and according to these results conclude that the productivity test environment (virtual

or real) did not appear to influence subjects' productivity. Moreover, the Cohen's d effect size for ratio scales has been also calculated to measure the size of the errors difference between the two environments, obtaining "small" magnitude ($0,20 \leq d \geq 0,50$) in five cases and a "negligible" one ($d < 0,20$) in one case.

	Walls colour	p-value	t-value	$\Delta\mu$ RE-IVE	Effect size (d)
$\Delta \approx 0$ 17°C	Red	0.93	0.09	-0,04	0,04
	White	0.12	1.60	1,04	0,32
	Blue	0.06	2.02	1,30	0,26
$\Delta \approx 0$ 22°C	Red	0.12	1.61	0,70	0,29
	White	0.06	1.96	0,74	0,48
	Blue	1.00	0.00	0,35	0,32

Table 4 The results of the paired-sample t-test on the difference of errors (productivity). Evaluation of the effect size: d < 0,20 = negligible; 0,20 ≤ d < 0,50 = small; 0,50 ≤ d > 0,80 = medium; d ≥ 0,80 = large.

A two-way repeated-measures analysis of variance (ANOVA) was then carried out to assess any effect of experimental factors on participants' productivity in both environments. The null hypothesis stated that there were no mean differences on errors numbers among the experimental conditions. Because the obtained F-ratios for both RE and IVE are outside the critical region (F-ratio < 4.35), the authors fail to reject the null hypothesis and conclude that the main effect of C and temperature T and the interaction C x T appeared to be not significant on influencing subjects' productivity in both tests environments (Table 5).

Environment	Factor	df	F-ratio	p-value
	C	2	2.16	0.12
RE	T	1	3.76	0.05
	C x T	2	2.75	0.07
	C	2	2.04	0.13
IVE	T	1	2.04	0.15
	C x T	2	1.84	0.16

Table 5 The results of two-way ANOVA (productivity)

Nevertheless, the awareness of an effect and the preference of colour manifested by the participants appeared not to be consistent with the productivity task results.

3.3 Thermal sensation

Figure 14 shows the subjective thermal sensation votes (TSV) on the left-hand side for the 17°C temperature level while on the right-hand side for the 22°C level. Within each temperature level, the plots represent participants' mean thermal evaluation for each tested environment and walls colour and the related 95% confidence interval values. As a general trend, no significant variation between groups might be highlighted by considering the physical and the virtual environments. Indeed, paired comparison for the thermal sensation did not show relevant differences between RE and IVE, as also highlighted by the mean difference ($\Delta\mu$) of the rating scores in each experimental condition in Table 6.

As expected, temperature have a significant influence on TSV which increased with the highest set-point. Indeed, the figure demonstrates that the mean values for the 22°C level correspond to the thermal neutrality (score «0»), otherwise for the 17°C level the mean is located around the slightly cool rating («-1»). Moreover, participants' thermal sensation appears not to be affected by the coloured layouts in both the cooler and the warmer physical and virtual environment.
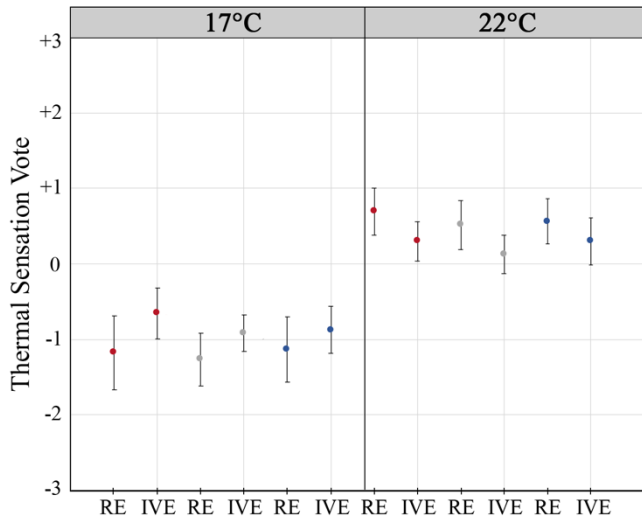

Figure 14 Subjects' average thermal sensation votes (TSV) among the experimental conditions

A statistical analysis was conducted to support the previous assumptions. The results of the comfort questionnaires are ordinal data; thus, Wilcoxon signed-ranks test was used as alternative to the repeated-measures t-test to evaluate the significance of the votes differences in the two environments (p=0.05). The null hypothesis stated that there was no difference in terms of TSV ($\mu_\Delta = 0$). Because the sample data produced T values higher than the critical value (T = 73), the authors failed to reject the null hypothesis and concluded that there was a non-significant difference between RE and IVE in terms of TSV for all walls colours and temperature levels (Table 6). Moreover, r effect size for Wilcoxon signed-ranks test [66] reported a "negligible" effect (r < 0,20) of the tested environment on participants' votes in four cases and a "small" effect ($0,10 \leq r \geq 0,30$) in two out of the six cases.

	Walls colour	T-value	p-value	$\Delta\mu$ RE-IVE	Effect size (r)
	Red	78	0.77	-0,52	-0,07
17°C	White	90	0.31	-0,35	0,14
	Blue	104.5	0.09	-0,26	-0,18
	Red	79	0.95	0,39	0,04
22°C	White	55	0.55	0,30	0,14
	Blue	101	0.08	0,26	0,05

Table 6 The results of Wilcoxon signed-ranks test (thermal sensation). Evaluation of the effect size: r < 0,10 = negligible; 0,10 ≤ r < 0,30 = small; 0,30 ≤ r > 0,50 = medium; r ≥ 0,50 = large.

Then, the nonparametric Scheirer-Ray-Hare test was implemented to evaluate if the experimental conditions, i.e. colour, temperature, and their interaction, have the same influence on TSV in both tested environments. The null hypothesis stated that there were no mean differences on TSV votes among the experimental conditions and was assessed by computing the Kruskal-Wallis H-statistics and comparing the calculated H-ratio with the critical chi-square value.

Considering the obtained H-ratio outside the critical region (<5.99 for two-degrees of freedom, df), the main effect of colour (C) and the interaction colour *temperature (C x T) appeared not to be significant on influencing subjects' TSV in both tested environments (Table 7). Otherwise, for temperature, the obtained H-ratio above the critical one (3.84, for one-degree of freedom) allowed the authors to reject the null hypothesis on the effect of temperature, thus revealing a strong effect on participants' thermal sensation ($\eta^2_{RE}=0.53$ and $\eta^2_{IVE}=0.41$).

Environment	Factor	df	H-ratio	p-value	Effect size (η^2)
	C	2	0.37	0.83	
RE	T	1	72.2	0.00	0.53
	C x T	2	0.13	0.94	
	C	2	1.72	0.42	
IVE	T	1	55.6	0.00	0.41
	C x T	2	0.27	0.87	

Table 7 The results of Scheirer-Ray-Hare test (thermal sensation)

3.4 Visual sensation

A final step of the work involved verifying whether the visual perception in the virtual model was deeply congruent with that on the real environment, by analysing the subjects' visual votes collected in Section IV of the questionnaire (paragraph 2.4).
Figure 15 shows the subjects' average visual sensation votes under each temperature level, tested environment and walls colour. The figure shows a general trend for the mean values to be located around the score «neither warmer nor cooler (+2)» which correspond to a neutral white LED light.
On average, a paired comparison among the real and virtual environment did not highlight significant variations. Moreover, participants' visual sensation appeared not to be affected neither by the temperature level neither by the walls colour in both the cooler and the warmer environments.
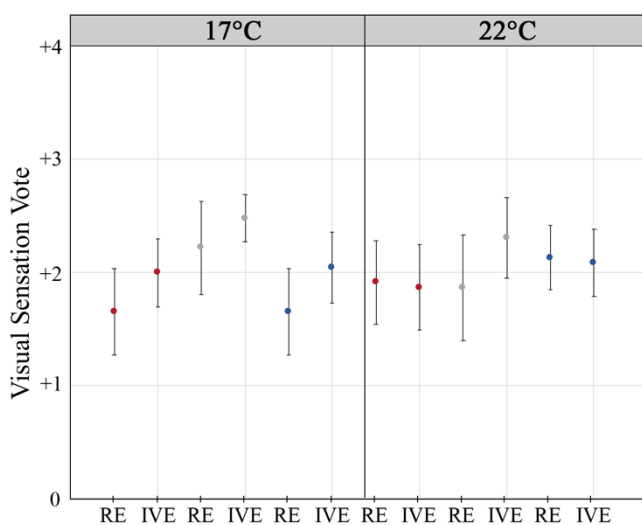

Figure 15 Subjects' average visual sensation votes (VSV) among the experimental conditions

These assumptions are confirmed by the statistical analysis carried out as in previous section 3.3. Results obtained through the Wilcoxon signed-rank test on the significance of the votes differences

in the two tested environments confirmed a non-significant difference between RE and IVE in terms of VSV for all colours layout and temperature levels (Table 8, T-values higher than T critical=73, p=0.05). Table 8 provides the mean difference ($\Delta\mu$) between the RE and IVE and the effect size for the nonnormal data of the Visual Sensation Votes, with a "negligible" magnitude (r < 0,20) in five cases and a "small" one (0,10 $\leq$ r $\geq$ 0,30) in one out of the six cases.

	Walls colour	T-value	p-value	$\Delta\mu$ RE-IVE	Effect size (r)
	Red	89.5	0.07	-0,35	-0,14
17°C	White	112	0.51	-0,26	-0,22
	Blue	82	0.11	-0,39	0,13
	Red	131,5	0.14	0,04	-0,07
22°C	White	90	0.21	-0,43	0,02
	Blue	132	0.06	0,04	-0,06

Table 8 The results of Wilcoxon signed-ranks test (visual sensation). Evaluation of the effect size: r < 0,10 = negligible; 0,10 $\leq$ r < 0,30 = small; 0,30 $\leq$ r > 0,50 = medium; r $\geq$ 0,50 = large.

According to results of the nonparametric Scheirer-Ray-Hare test (Table 9), the main effect of colour, temperature and the interaction appeared not to be significant on influencing subjects' VSV in both tested environments. Indeed, the overall H-ratios are located outside the critical region (<5.99 for two-degrees of freedom and <3.84, for one-degree of freedom, df).

Environment	Factor	df	H-ratio	p-value
	C	2	3.79	0.15
RE	T	1	0.95	0.33
	C x T	2	4.07	0.13
	C	2	3.61	0.13
IVE	T	1	0.44	0.51
	C x T	2	0.66	0.72

Table 9 The results of Scheirer-Ray-Hare test (visual sensation)

Figure 15 summarizes the expressed percentage of glare throughout the whole test conditions. According to the stacked histograms, the same distributions could be highlighted between the real and the virtual environment for all the walls colours and temperature set point. As a general trend, the percentage of participants expressing to suffer from glare is the following: between 16% and 19% for the red layout, between 28% and 35% for the white layout and between 13% and 15% for the blue one.
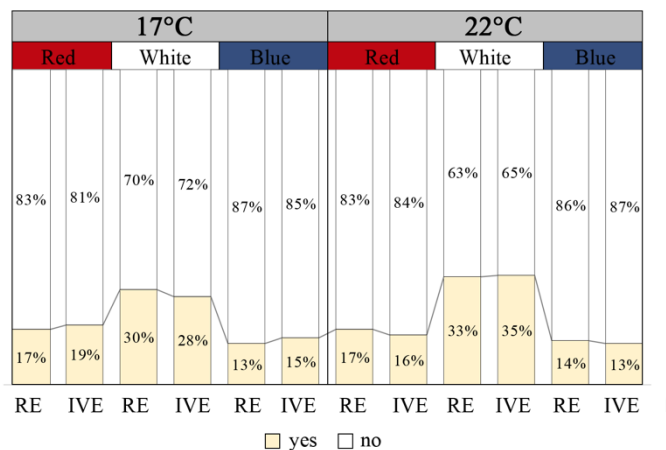
Figure 16 Percentage of response to the question «Do you perceive glare?» for each colour and temperature combination

4. Discussion

The first goal of this study concerned the comparison of results obtained in IVE and RE, in order to provide a contribution in "validating" the use of VR for thermal behavioural and performance assessments studies. We then focused on the analysis of difference (Δ) on the errors detected by the participants' (productivity assessment) and on the thermal and visual sensation votes (comfort assessment) in both tested environments (between groups analysis) under each experimental condition (different temperatures and walls colour).

The results obtained from productivity tests in both RE and IVE, represented by the number of detected errors, were very similar. The slight difference (on average 9.03 errors detected in the RE against 8.33 errors in the IVE, of the total 12 errors) was considered not statistically significant, according to the t-test and the effect size measure.

Also concerning thermal and visual perception, no significant variation has been detected between the sensation votes expressed by participants in the physical and the virtual conditions. With regard to visual comfort, there was a strong match between RE and IVE, thanks to a highly detailed virtual modelling, especially referring to artificial lighting that the subjects perceived as equal in both environments. This is an extremely important fact, as only with an adequate level of realism it will be possible to fully exploit the potential of IVE in the building design. Moreover, a quite low percentage of subjects declared to suffer from glare with a very close trend according to colour layouts in both environments. These results are quite interesting, considering that the tests in the IVE were performed a couple of weeks later than those in the RE. The correspondence between RE and IVE in terms of visual comfort suggests that an accurate modelling and high sense of presence could increase the subjects' reliability toward virtual technologies [30].

The preliminary analysis of the cybersickness revealed that the majority of participants did not experience high disorders levels, except for about 65% of subjects which felt from "slightly" to "a lot" of eyestrain and difficulty in focusing. Before each IVE test, subjects set their interpupillary distance to gain the greater sharpness of the images. Despite that, the difficulty in focusing could be attributed to the headset performance for detailed-oriented tasks. It is interesting to notice that the subjects' difficulty in focusing increased on average with the progress of the tests. Despite that, and the rather long duration of each session (about 75 minutes), all subjects have been able to perform the tasks with results close to those in the RE.

The results obtained in relation to the secondary objective of the study (the investigation of the impact of walls colour on subjects' productivity and comfort, even regardless of the test environment) were somewhat surprising. They revealed in general a not significant effect of C, T and their interaction C x T on subjects' productivity, thermal and visual sensation in both test environments, except, as expected, for the effect of temperature level on thermal comfort.

Interestingly, the majority of subjects believed that the walls colour may have an influence both on people in general and on their own productivity. Moreover, participants quite strongly considered the white colour as the most suitable and comfortable for office tasks, and the red one the least, among the experimental conditions. These considerations are not reflected by the statistical results. However, subjects also stated that the walls colour employed in the tests did not improve (46%) or might only slightly improve their productivity (33%).

For what concerned the comfort assessments, both tests in RE and IVE did not support a possible impact of walls colour on thermal and visual sensation, hence especially the hue-heat hypothesis. However, it should be considered, as reported in the introduction, that the results of the research on this topic, documented in the literature, are still conflicting. Several works did not support the hypothesis at all [24,67,68] or just in certain conditions of temperature [18,25,42].

With regard to this second part of the work, in which no significant effects of colour and temperature on productivity and comfort were detected, various factors might have contributed to this result, and consequently have to be further investigated in the future. Firstly, the temperature levels were closed to the winter comfort range, while several studies better supported the hue-heat hypothesis in more extreme temperature ranges [18,20,69,70]. A wider range of thermal conditions, eventually tested in both heating and cooling seasons, could provide more significant trends. Secondly, although the sample size already gave statistically significant results, larger sample sizes are required to increase the accuracy of the results. Moreover, the sample was composed by quite young people (even if they had no experience with VR before), while it is possible that older adults might obtain a different performance in VR compared to RE. Finally, only three walls colours have been tested under artificial lighting to improve the reliability of the virtual model. Future investigations should involve the impact of colours layouts under different lighting conditions also testing a wider range of colours and material patterns supporting the architectural design.

Finally, further studies could implement alternative work efficiency verification methods, according to the existing literature, leading to a better compromise for the test duration: a prolonged exposure is necessary to study the effect of colour on thermal sensation but may be impractical in IVE affecting the cybersickness disorders.

5. Conclusion

The investigation of potentials of IVEs for occupants' perception and behavioural studies is relevant, in order to overcome the actual limitations of physical models, thanks to the many advantages offered in terms of low cost, repeatability and speed of execution. However, the literature in this field is still in its infancy.

Thus, this work provided a further contribution, especially focusing on the use of VR for the assessment of buildings occupants' productivity and comfort. The study investigated a specific design aspect, i.e. the colour of indoor walls, considering the importance of colour *stimuli* on human psychological responses.

An assessment of comfort and productivity in workplaces was performed in a real office and in an immersive virtual environment representing the same room, under the same test conditions: two temperature levels (17°C and 22°C) and three wall colours (red, white, blue). The productivity of 23 participants was examined through a proofreading task and their thermal and visual comfort evaluated through questionnaires provided at the end of each colour exposure. Each test session, consisting on the exposure to all three colours at a certain temperature set-point, was repeated, for each subject, 4 times (given by the combination of 2 temperature levels and 2 environments).

The obtained outcomes, even if related to this specific case and given the highlighted limitations, support the use of VR as an effective tool for evaluating users' productivity and comfort under different test conditions and let the present work to be coherent with the few previous researches about productivity [39] and perceived comfort [38] in IVEs.

These results then suggest to further deepen and investigate the possible integration of VR in holistic approaches to building design and operation, in order to better include human perception of the built environment since the early design phase, creating spaces around the users' preferences and needs, improving their satisfaction, work productivity energy-related behaviour.

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Appendix A

Negli anni succ<mark>essivi</mark> alla Grande Guerra, a Firenze si forma un gruppo giovanile sionista, capeggiato dall'avvocato Alfonso Pacifici. Nato a Firenze nel 1889, dotato di <mark>un oratoria</mark> trascinante e di un notevole fascino personale, sionista della prima ora, animatore del sionismo fiorentino, co-fondatore e co-direttore, con Dante Lattes, del settimanale Israel, dal 1916 al 1934, anno della sua emigrazione in Israele (allora Palestina, sotto il mandato inglese). A Firenze è in stretto contatto con il rabbino Margulies e durante la Prima Guerra Mondiale ricopre il ruolo di rabbino militare; dopo il trasferimento a Gerusalemme diviene rabbino ortodosso, continuando a prom<mark>ou</mark>vere l'ebraismo integrale accentuandone l'aspetto religioso e l'osservanza ortodossa dei precetti; si allontana poi progressivamente dal sionismo politico e nel 1948 propugna l'internazionalizzazione di Gerusalemme. Muore a Gerusalemme, dove gli viene intitolata una strada, nel 1983, dopo aver dato alle stampe vari testi di studi ebraici e un libro di memorie autobiografiche. Al gruppo dei giovani sionisti partecipano i Genazzani, i Bonaventura, gli Ottolenghi, i Cassuto, i Cividalli, i <mark>F</mark>ratelli Servadio ed altre giovani leve delle famiglie ebraiche fiorentine. Alla fine degli anni '20 del Novecento la comunità ebraica fiorentina è composta da circa tremila persone, pari allo 0,87 per cento della popolazione; nel corso della guerra 280 di loro sono stati combattenti al fronte, di cui 17 volontari; tra di loro ci sono ben 28 caduti, 5 mutilati, 55 feriti e invalidi e 100 decorati al valore. Si tratta di famiglie perfettamente integrate nel tessuto sociale fiorentino che sono attive soprattutto nel campo delle professioni liberali (medici, ingegneri, avvocati, architetti), ma ben rappresentate anche tra i professori universitari e i docenti delle scuole superiori. Enrica Calabresi, che si uccider a 53 anni per non salire su un convoglio diretto ad Auschwitz, è stata la prima donna <mark>h</mark>a ottenere la libera docenza in zo<mark>o</mark>ologia prima di essere allontanata dall'insegnamento "a causa della razza" e diventare una delle animatrici della scuola di via Farini, che preparò agli esami da privatisti i ragazzi ebrei, espulsi dalle scuole del Regno per lo stesso motivo per il quale lei stessa aveva perso il posto. Due sono le case editrici: Bemporad ed Olschki, che seppur attive in fasce diverse di mercato, costituiscono un punto di riferimento della vita culturale cittadina. I titolari di industrie hanno alle loro dipendenze numerosi lavoratori non ebrei. A <mark>p</mark>rato la Siva (Società italiana valigeria e affini), di proprietà della famiglia Bemporad, dà lavoro a 180 dipendenti; il calzificio Passigli, a Rifredi, ne occupa invece 594; significativa anche la presenza nel settore crediti<mark>z</mark>zio con tre banche: la Del Vecchio, la Ravà e la Meyer. Tra gli anni '20 e '30, Firenze è ancora la capitale culturale del sionismo italiano per la presenza della casa editrice Israel e del Collegio Rabbinico italiano, improntato ai principi di Samuel Hirsch Margulies, il rabbino della Comunit fiorentina arrivato dalla Galizia nel 1890 e mort<mark>a</mark> alla vigilia della festa di Purim del 1922, ma anche e soprattutto per <mark>l impegno</mark> di persone come Elia Samuele Artom, Alfonso Pacifici e Carlo Alberto Viterbo. Nella Comunità fiorentina si trovano a coesistere, non senza momenti di attrito, il gruppo dei sionisti e gli ebrei integrati, che vivono le vicende nazionali come un naturale percorso storico comune a tutti i cittadini. Così naturale da far aderire molti, in taluni casi con entusiasmo, al Partito Nazionale Fascista. Nel 1929 viene fondato a Firenze, con sede in piazzale Donatello 7, il Convegno di Studi Ebraici che si propone di "coltivare lo studio della lingua e della cultura ebraica e promuovere l'osservanza della Torah mediante cicli di lezioni, conferenze, concerti, esposizioni d'arte e l'istituzione di una biblioteca, nonché promuovere l'<mark>affinamento</mark> tra i frequentatori delle manifestazioni di studio con qualche familiare trattenimento specialmente in occasione di ricorrenze festive dell'anno ebraico". Vista la presenza nella nuova associazione di molti sionisti, la Direzione generale di pubblica sicurezza viene subito informata dalla Prefettura fiorentina delle attività del convegno; non a caso sarà la prima emanazione della Comunità di via Farini ad essere soppressa il 29 marzo 1938, pochi mesi dell'entrata in vigore delle "leggi razziali". Nell'informativa che il Prefetto invia a Roma è scritto che il Convegno conta ufficialmente 47 iscritti: di essi ben 33 seguono la corrente sionista che le autorit<mark>à</mark> dell'epoca sospettano fortemente di essere contraria all'idea fascista. Nella bella Sinagoga di via Farini, costruita in stile moresco e inaugurata nel 1882, i sionisti si siedono tutti insieme in uno degli ultimi banchi, chiamato dalla larga maggioranza della Comunità "il banco dei matti" perché gli ebrei borghesi della generazione precedente così vedono il sionismo. Fra gli aderenti il dottor Aldo Servadio figura al secondo posto, preceduto dall'avvocato Augusto Levi e seguito dai fratelli Gino e Mario, da Nathan Cassuto, che diventerà rabbino di Firenze, e sarà poi deportato e ucciso dai nazisti, dall'ingegner Gualtiero Cividalli, pronto a diventare di lì a poco un altro fiorentino di Palestina come Umberto Genazzani, pure lui sionista militante.

Figure A.1 Proofreading task of a given text in Italian to test subjects' productivity (in red some errors highlighted)

Appendix B

Date: ___ / ___ / _____   Cod. _____

SECTION I

GENERAL INFORMATIONS *(fill it once)*

Gender: ☐ M ☐ F

Age: ___

Height: ___   Weight: ___

Employment: ☐ Student   ☐ Graduated   ☐ Employee   ☐ Self-employed

How often do you attend university spaces as office rooms, study rooms, ..?

☐ Never   ☐ Seldom   ☐ Often   ☐ Every weekday

Healt status: *Do you suffer from body temperature altering illness?*

☐ No   ☐ Fever   or ☐ _____

Do you suffer from visual defects?

☐ No   ☐ Myopia   ☐ Presbyopia   ☐ Astigmatism   or ☐ _____

If yes, do you have corrective lenses?

☐ Yes   ☐ No

Activity: **Half an hour earlier, you have meanly:**

☐ Playing sport   ☐ Walking   ☐ Attending (seated) ☐ Attending (standing)

Clothing: *Please tick all the clothes you are wearing at this moment*

☐ Undershirt   ☐ T-shirt   ☐ Shirt   ☐ Sweater   ☐ Jumper/Hoodie

☐ Coat   ☐ Tights   ☐ Socks   ☐ Short skirt   ☐ Long skirt/trousers

SECTION II

DESIGN EVALUATION OF THE OFFICE ROOM *(fill it once)*

1. Please, evaluate the statements below, referring to the following legend:

-3	-2	-1	0	+1	+2	+3
barely	a little	a little bit	indifferent	slightly	quietly	a lot

	-3	-2	-1	0	+1	+2	+3
▪ Walls colour can affect users' productivity in office rooms	☐	☐	☐	☐	☐	☐	☐
▪ Walls colour can affect <u>my</u> productivity in office rooms	☐	☐	☐	☐	☐	☐	☐
▪ <u>The present</u> walls colours in office rooms, can improve <u>my</u> productivity	☐	☐	☐	☐	☐	☐	☐

2. How do you judge the present walls colour for the office room?

0	1	2	3	4
tolerable	slightly difficult to tolerate	fairly difficult to tolerate	very difficult to tolerate	intolerable

3. Which walls colour do you think is <u>the most suitable</u> in the office room? (fill it at the end of the last colour session)

_____

4. Which walls colour do you think is <u>the least suitable</u> in the office room? (fill it at the end of the last colour session)

_____

Figure B.1 The questionnaire structure distributed after each test session (page 1)

SECTION III
THERMAL SENSATION EVALUATION OF THE OFFICE ROOM

At this moment, how do you feel in this environment?

-3	-2	-1	0	+1	+2	+3
cold	cool	slightly cool	neutral	slightly warm	warm	hot

SECTION IV
VISUAL SENSATION EVALUATION OF THE OFFICE ROOM

1. How do you judge the artificial light colour?

0	1	2	3	4
warm	slightly warm	neither warmer nor cooler	slightly cool	cool

2. Do you perceive glare?

☐ Yes   ☐ No

SECTION V
MOTION SICKNESS EVALUATION *(fill it in IVE phase)*

Please, evaluate motion sickness symptoms, referring to the following legend:

0	1	2	3	4
barely	a little bit	slightly	quietly	a lot

	0	1	2	3	4
General discomfort	☐	☐	☐	☐	☐
Fatigue	☐	☐	☐	☐	☐
Eyestrain	☐	☐	☐	☐	☐
Difficulty focusing	☐	☐	☐	☐	☐
Headache	☐	☐	☐	☐	☐
Fullness of head	☐	☐	☐	☐	☐
Blurred vision	☐	☐	☐	☐	☐
Dizzy (eyes closed)	☐	☐	☐	☐	☐
Vertigo	☐	☐	☐	☐	☐

Figure B. 2 The questionnaire structure distributed after each test session (page 2)