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The effect of a horizontal light pipe and a custom-made reflector on the user's perceptual impression of the office room located at a high latitude

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ABSTRACT

This paper describes a qualitative study on user opinion of daylight supplementation via a horizontal light pipe (HLP) applied in a test office in a building located in southern Norway. The study is part of a full-scale long-term study analysing lighting energy consumption and the photometry of supplemented light. This study employs a custom-made reflector for daylight distribution via HLP to preserve the features of natural light, noted as the primary human association with daylight, and is, as such, first of its kind. The main research aim was to find out if noticeable daylighting provision from the HLP leads to a positive user perception of the space when compared to a situation without a HLP. The study collects user responses to a new illumination solution using a user-survey method based on exposure to the visual environment of an experimental office. Statistical correlation and a *t-test* were used to analyse the results. The paper concluded that the user appraisal of the office was more positive when there was a noticeable daylight supplement from the HLP in the space, but the appraisal was negative for the higher light variability in the illuminance level both indoors and outdoors. The conclusion serves as an additional argument for the implementation of the HLP in building design, besides its energy saving potential.

1. Introduction

This paper presents a qualitative study carried out as part of a full-scale study performed in an office equipped with a horizontal light pipe (HLP) in a high-latitude area in southern Norway. The full-scale office was designed with particular decisions regarding artificial lighting system, a sun-shading system, and a daylight-linked light control (DLC) system, to cover requirements for both qualitative and quantitative study. This paper focuses on qualitative features of the daylighting delivered by the HLP, while the results from the quantitative study will be reported in a subsequent dedicated publication.

1.1. Literature review

Good daylighting can generate sustainable architecture that supports human physiological and psychological visual functions, as discussed by Boubekri [8]. Veich, Bisegna et al. [39] and Krusselbrink, Drangol et al. [26] argue about the function of human vision supported by the image-firming effect of light, and the function of the human circadian system (health and wellbeing) supported by the non-image-forming effect. Longer periods with natural light are an indisputably positive amenity to the built space as nowadays people spend as much as 90% of their time indoor, as discussed by Boyce, Hunter et al. [9] and Knoop, Stefani et al. [22]. Even in available daylight, the long hours humans spend indoors are not necessarily spent in areas adjacent to the building façade with available natural light but instead in areas far from windows. As one moves away from the window, the available daylighting decreases exponentially. To daylight a building's deeper areas, a daylight transport system (DTS) needs to be used. Horizontal daylight tubes (or light pipes) are passive DTSs that have proven by many studies to be efficient in delivering daylight to deeper areas of multistorey buildings [35,36,44–48]. Besides increasing the illuminance levels and light uniformity of an entire room, the HLP can reduce the room's front and rear areas' luminous contrast, which is associated with a room's perceived "gloominess", as discussed by Courret, Scartezzini et al. [14], and Scartezzini and Courret [38].

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Nomenclature

E_1	Illuminance value on the test desk in the office, lux
E_2	Vertical illuminance value incident to the tube's entrance, lux
E_3	Global horizontal illuminance value, lux
E_{1Mean}	Mean value of the illuminance values on the test desk for the participant adjust. period, lux
E_{2Mean}	Mean value of the vertical illuminance values incident on the tube's entrance, for the participant adjust. period, lux
E_{3Mean}	Mean value of the global horizontal illuminance values, for the participant adjust. period, lux
v-E_1	Variation of the illuminance values on the test desk in the office for the participant adjust. period, %
v-E_2	Variation of the vertical illuminance values incident on the tube's entrance for the participant adjust. period, %
v-E_3	Variation of the global horizontal illuminance values for the participant adjust. period, %

Humans experience a 20% higher light level (at the same lumen level) with daylight than with electrical lighting due to daylight's distinctive features, as argued by Boubekri [8]. Other authors, such as Fontoynont [16] and Reinhart [37], state that higher level of natural light in the office, especially in the mornings, prolong the period during which people avoid switching on the lights. Humans perceive artificial and natural lighting levels differently due to the "geometry of the natural lighting" as stated by Lam [27]. Daylight's higher horizontal component, which lights vertical surfaces, more effectively meets the human need for the good luminous design of a room or space. The dynamics of natural light in terms of its variability and the rhythm of change in light intensity are argued to be essential factors influencing the general human impression of a space. Daylight dynamics lead to improved visual performance, based on the fact that the nervous system is more attuned to noticing changes in the environment than steady states as argued by Heschong [19]. Therefore, it is considered more stimulating and leads to higher levels of arousal in people, as argued by Kruisselbrink, Dangol et al. [26]. Further, some studies investigating the perceptual effects of both window size [32,49,50] and architectural design [51,52] have shown that varying sunlight intensity in a space, e.g., light patches, can bring about a more positive human experience with the space when the patches are of a certain size and at a certain distance from the observer. Furthermore, the spread of the light was assumed as positive, because it would affect the peripheral area of the desk. Good peripheral light conditions are vital for the visual perception of a space, as argued by several authors [53–55].

Issues of glare and people's interference with a glare control system are a known problem in regard to daylighting for improved energy efficiency. Studies addressing lighting energy-saving potential, have noted an unreliability of the resulting metrics of energy consumption, photometry, and visual comfort in situations with excessive sunlight [28,5,20,21,4]. The predicted (simulated) energy use for lighting, based on a daylighting availability model, has shown to be bellow realistic values, which is the result of unreliability in predicting human reactions to glare and their motivation to control it. The most common model for daylight linked control (DLC)—which is far from optimal and is assumed to be a compromised solution—involves completely closing the blinds when the daylight illuminance on the façade exceeds the predefined threshold, which results in artificial lights being switched on to their full level. This model has undermined many daylight and lighting control strategies, as stated by Bordass, Cohen et al. [7]. Moreover, a study by Velds [41] found that a procedure considering human visual comfort generated reliable energy-savings; the amount of energy saving was relatively low, but more realistic because they took into account actual human reactions. The study is consistent with Christoffersen, Johnsen et al. [11] and Veitch and Newsham [40] who noted that lighting metrics alone cannot describe how humans perceive a room and its daylighting/lighting. The optimal method for such a human-environmental study would be to simultaneously perform photometrical measurements and a user opinion study because of the possibility of correlating users' answers with lighting conditions, as stated by Christoffersen, Johnsen et al. [11] and Christoffersen and Wienold [12].

The reliability of the results from such user survey studies has been debated, and the selection of "lighting quality descriptors" has been discussed several times in the last two decades [40,17]. Recent studies by Moscoso and Matusiak [33] and Moscoso, Chamilothori et al. [32], focusing solely on human appraisal of the visual appearance of daylit spaces, selected the most suitable aesthetic attributes of the space, which are semantically correct, and provided results with high reliability in human-environmental studies. This study applies this selection of light quality descriptors in its evaluation of the test office in addition to questions regarding visual comfort, daylight dynamics, human satisfaction with the daylight conditions, and the integration of daylight with artificial light.

In the last two decades, studies on human reaction to daylit environments equipped with some special daylighting systems have been performed, concluding on issues that can decrease user satisfaction with daylighting systems [41,16,42,1]. Several studies on particularly daylight tubes have considered the issue of the diffuser, which is an understudied element, specifically in this field [24,23,24,23,31,35]. Such studies have reported partial user dissatisfaction caused by light being delivered through a luminaire-like diffuser, which diminishes the essential connection of the delivered daylight with its original source. Even in the first pilot projects using DTSs from 40 years ago, the pointlessness in equipping the light pipe with a luminaire-like diffusor as a light distributor in the room was noted. While a significant amount of effort and resources have been given toward designing a collector and tube with a high light transmission efficiency, the distributor was completed with a standard light fixture.

The application of light pipes in Norway has been minimal, and no horizontal light pipes have been installed. Based on the knowledge presented above, it was decided for this study to introduce its own sun-shading strategy to support and preserve visual comfort, which will be described later on. Additionally, the authors noticed that other daylighting systems, such as the mirror system, which redistributes light into a space, retain the characteristic qualities of sunlight and suggest that this quality has to be preserved in any daylighting system. The greatest novelty of the study is a custom-made mirror reflector as a distributor of the light from the HLP in order to preserve the association of the daylight delivered via HLP with natural light.

This study's main objective was to evaluate the user's subjective appraisal of this office, which was daylit by a HLP in addition to windows. Therefore, it was designed to answer the following research question: Does significant daylighting provision from the HLP lead to a positive user perception of the space when compared to a situation with no daylight provision from a HLP.

Statistical analysis of an independent sample *t*-test as well as correlative analyses were performed to determine the answer.

2. Method and procedure

This qualitative study is part of a full-scale research that investigates how daylight delivered through a HLP affects illuminance in specific areas in an office as well as the energy consumption for each luminaire installed to provide artificial lighting on two working areas during times with daylight shortages. The qualitative part was designed as a user survey consisting of a pre-test (oral reading test and colour vision test) and a questionnaire. The pre-test functioned as a visual adaptation to the test office and allowed participants to experience lighting conditions by reading a paper and attempting to discriminate colours. Independent parameters in the qualitative part of the study are parametric data from the study's quantitative part. Findings and analyses are thus based on nominal parameters obtained from the light metrics and then related to the subjective evaluation. This methodology is known as a mixed-methods approach, Fig. 1.

2.1. Experimental design: Full-scale test office

In a fully operative building at Norconsult Headquarters in Sandvika (59°0.53′N, 10°0.31′E), Norway, a two-person office on the top (6th) floor was used as a test room for one year. The office did not have as perfect of a form, size, or orientation as researchers would aim for in high-quality scientific studies, still, considering the limited time and available resources of the study, the office was considered the best choice (Fig. 2).

2.1.1. Test room

The office had an area of 13 m^2, and a height of 2.8 m after the suspended ceiling was removed. The finishes and colours of the room surfaces as well as the equipment inside were representative of offices in Nordic countries. The office had windows on its southeast and southwest walls; however, for the purpose of the experiment, the southeast window was covered with a wall panel, and the horizontal daylight tube was installed 45° from the wall (Fig. 3). This was to allow for the placement of the tube's exit above the second work area, desk 2, without the use of any tube elbows (i.e., the tube was straight) as well as to position the tube with a southern orientation. The office was equipped with a few pieces of necessary furniture: two desks and two chairs (Fig. 5b).

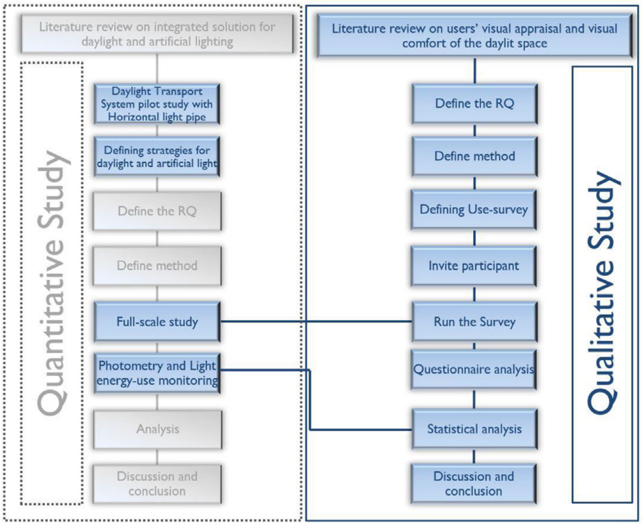


Fig. 1. Methodology of the qualitative part of the full-scale study.

Fig. 2. Situation plan for the building at Norconsult Headquarters in Sandvika (59°0.53′N, 10°0.31′E), Norway, where full-scale test office is situated on the top (6th) floor.

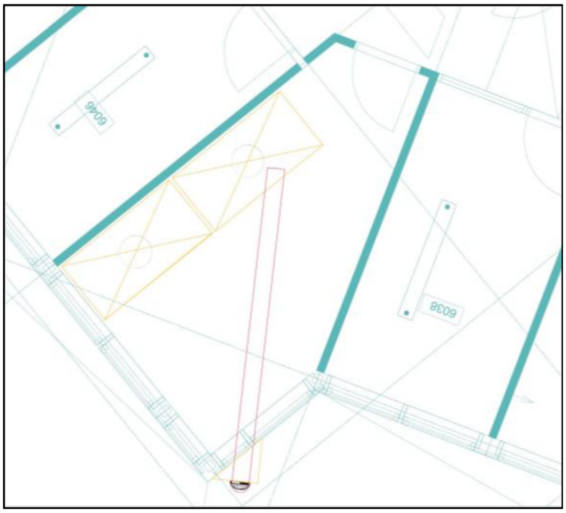


Fig. 3. Office plan, windows on the southwest wall, horizontal light pipe (red lines) was installed 45° from the southeast wall, with entrance nearly oriented against south. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Regarding the parametric part of the study, photometric and energy logging were performed every minute for one year, starting from 21 June 2020, and also during the user survey. Indoor illuminance logging was performed using five photosensors placed to cover the horizontal illuminance on the first and second work areas (0.8 m height) and the vertical illuminance on a wall in front of the work areas (1.2 m height). The last photosensor was placed on a tripod to record the vertical illuminance at the eye level of the user of the second work area. Outdoor illuminance logging was provided via photosensors placed vertically along the same south-oriented vertical plane as the tube's entrance dome as well as via photosensors placed horizontally on the roof. The lighting energy consumption for every minute was measured using separate power meters (10–20 A) for each luminaire. The data was logged into a computer.

2.1.2. Sun-shading strategy in the test office

As discussed in the introduction, a sun-shading strategy in the test office was developed to provide visual comfort at any time of the day and year. The sun-shading strategy was implemented to keep (manually controlled) the outdoor sun-shading slats partly open, with tilt angle for sunlighting cut-off 45°. In this way, the office was made glare-free, while a partial view is provided. Fig. 4 shows the view (visual conditions) from the entrance of the office (4a), from the desk 2 (4b), and from the desk 1 (4c).

The configuration of the slats tilt angle used here was based on the study by Kolås [25], particularly at a low solar altitude. Kolås determined that, in the case of an intermediate sky (sun's altitude 30°, azimuth 45°, at approx. 5PM, ground illuminance values of sunlight approx. 43,000 lx and skylight approx. 13,000 lx), this configuration can provide approximately 1200 lx for the first two metres from the window and half of this value, approximately 500 lx at 4 m distance from the window. The essential point here is that the light reflected from the slats is directed to the ceiling to be further re-directed to areas farther from the window. In the test office, the distances of 2 and 4 m correspond to desk 1 and desk 2, and the reflectance of the slats, together with the ceiling reflectance, corresponded with those of the Kolås' study. Further, Kolås found that, under an overcast sky (ground illuminance value of approx. 11,000 lx), the same configuration can re-direct diffuse daylight to the ceiling; resulting in the illuminance at the middle of desk 1 slightly over 100 lx; and the illuminance at the middle of desk 2 approximately 60–70 lx.

2.1.3. Daylighting conditions in the office

Daylight in the office was provided by two windows facing southwest. The window glazing was a double glass (4-12Ar-4) with a light transmission factor of 0.8. The daylight calculations for the room were performed by applying the mentioned sun-shading strategy (section 2.1.2) using Dialux 4.3 software. The results are presented in Appendix A. The calculations were done without accounting for daylight from the HLP. Results showed that, under an overcast sky, during equinox, 100 lx can be expected on the desk closest to the window and 50 lx on the desk closest to the door (app. A2). Under a clear, sunny sky during equinox at 12:00 h (sun altitude 30°, azimuth 180°) the values will be 350 lx on the desk closest to the window and 120 lx on the desk closest to the door (app. A1). These measurements were taken into consideration when performing the analyses. The results were very similar to those discussed in chapter 2.1.2 and found by Kolås [25]. The daylight factor calculated at the middle of the room, 0.8 m above the floor, was almost 1%, even though the sun-shading configuration described in 2.1.2 was applied (app. A3).

2.1.4. Horizontal light pipe in the test office

The horizontal light pipe used in this study was LW300 manufactured by LightWay. The most suitable light pipe configuration for the study should have been an aspect ratio of 12 (ratio of length to diameter), which was dictated by the necessary length of the pipe, 375 cm, and given a diameter of approximately 30 cm. However, due to the building's constructive issues, only a diameter of 22 cm could fit. These dimensions provided an aspect ratio of the installed light pipe of 17, which corresponded to a recent study done by the authors [36]. The light pipe's dome was manufactured of crystal glass, and had a light transmission factor of about 95% (test performed by the authors) (Fig. 5a), while light distributor was clear glass with a light transmission of 92%. The direction of the light down to the working area and the wall in front of it was provided by a custom-made reflector, designed by non-imaging optics rules [10] (Fig. 5b). Here, the aim was to redirect light to the working area while maintaining the qualitative features of the daylight (i.e., dynamics, variation, colour) that would be delivered through the HLP. The custom-made reflector was layered with a reflective mirror folium, product of 3M, which has a light reflectivity of 0.99. In the case of high daylight supplement through the pipe and in a period of 10 AM to 2 PM, the reflector provided delicate and balanced light patches both on the desk and on the wall (Fig. 5c).

The highest effectivity of daylight delivered via a pipe HLP oriented to the south, is, as argued in Obradovic and Matusiak [36], when the sun's azimuth angle aligns with the pipe's longitudinal axis and up to a 30° incident angle. This coincided with the time period from 10 AM to 2 PM. During this period, in the case of clear, sunny conditions, the daylight delivered through the pipe was up to 330 lx on desk "2". Before and after this period, the daylight delivered via the pipe was of lower intensity, and, especially after 2 PM, when the sunlight incident was aligned with the window, the daylighting via the window (sun-shading strategy, section 2.1.2) was much higher than the daylight via the pipe.

2.1.5. Artificial lighting in the office

The artificial light in the test office consisted of two smaller ceiling-mounted luminaires. The luminaires provided 2700 lm of light flux each, which enabled the required 500 lx of horizontal illuminance on both desks along with a uniformity of over 0.6, as specified in NS-EN 12464-1 (calculations in Appendix B). The unified glare rate was under 19. The luminaires had a colour temperature of 4000 K and a colour rendering of Ra = 80. Each luminaire was connected to its own photosensor and programmed by a daylight-linked control system (DLC). Luminaires should supplement additional light levels when the daylight provided by the

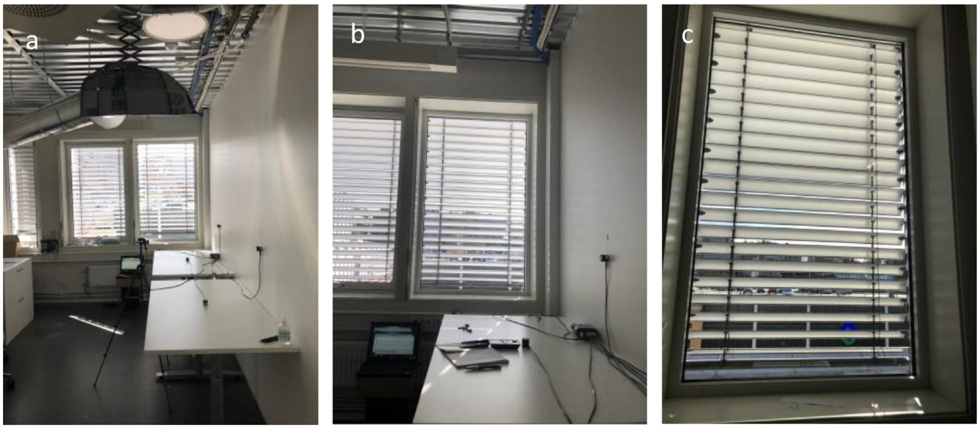


Fig. 4. Visual conditions in the full-scale test office using sun-shading strategy with slats tilt for sunlighting cut-off 45°: the observers view from the entrance of the office (4a), the observers view from the 2nd desk, closest to the door (4b) and the observers view from the 1st desk, closest to the window (4c).

Fig. 5. Light pipe mounted on the facade in the room and an adaptation element for angled mounting (5a); two working areas in the room (5b); light patches on the 2nd desk delivered from the HLP and via the custom-made reflector (5c).

window and light pipe do not reach 500 lx. As discussed in section 2.1.2 and 2.1.3, the daylight coming through the window hit the two desks to different extents, while the daylight supplement from the light pipe was mainly directed toward the second desk.

The DLC system did not perform as expected due to the daylight reflection on the sun-shading slats (in tilt angle 45°) resulting in a partial re-direction of the light to the DLC sensors. This is the weakness of this study, and several similar studies reported the same problem, as mentioned in the introduction. Luminaires often receive incorrect information regarding the illuminance they need to provide; here, the illuminance on the tables from the artificial lighting varied greatly. The illuminance level on desk 2 (the user position in the survey) was as low as 230 lx in some situations. Moreover, 500 lx was only achieved under an overcast sky—given that the sensors were not affected at all. In all other situations, the DLC sensors were affected. Hence, the regulated artificial light was very low—far under the needed 500 lx. In most cases, artificial illuminance was equal to zero, and the illuminance level registered by the illuminance meter on the desk was only obtained from daylight—both daylight via the light pipe and daylight from the window. The illuminance on the test desk (desk “2”), E_{1Mean} , was one of the independent values in the statistical and descriptive analyses and was collected from the photometric loggings for each participant for the period they spent in the office before filling out the questionnaire.

2.2. Experimental design: User survey

The user-survey was conducted in September 2020 (between 10 AM and 3 PM), since the period for this study was purposely planned to be around the equinox (representing an average yearly daylighting condition).

2.2.1. Participants

The study involved 50 participants, most of whom were company employees recruited by an announcement on the company’s website as well as—to a smaller extent—via social media. Participation in the study was voluntary and rewarded with colour-vision test results. The participants were aged 23–65 years (M = 37 and SD = 12.2) and comprised of 26 males and 24 females. To avoid professional bias, participants without architectural or lighting engineering backgrounds were chosen. The user-survey design was approved by a human resources officer as well as the working environment committee of Norconsult after checking that ethical and privacy policies were not impaired.

2.2.2. User survey procedure

The participants had the opportunity to stay and work (on their own laptop) in the test office for half an hour prior to the survey. The participants sat at desk 2 in order to experience a working area far from the window and under the daylighting conditions from the light pipe (Fig. 6c). At the beginning of their participation, the participants received practical information regarding, i.e., the experimental protocol and the approximate duration of the experiment, and were asked to fill out a consent form. The user participation consisted of three parts: 1) a reading test, 2) a colour vision test, and 3) a questionnaire. The reading and colour tests were done during the preparation time in order for the participants to accommodate to the lighting conditions of the room. The additional function of the reading and colour tests was to obscure the main goal of the study, as mentioned in the introduction.

The first part of the pre-test was a Tambartun Oral Reading Test, developed by the Fosse [18], in Norwegian, where the participants were asked to read two paragraphs aloud. The participants were informed that the first chart functioned as preparation and a way to familiarise them with the concept of Tambartun charts, while the second chart was the real test and the researcher was going to measure the time it took them to read the second chapter using a stopwatch. The Tambartun test concept made it suitable for usage in this study, as the functional equivalence of the elements upon which the test was built make it possible to compare reading ability of different participants under different physical conditions, such as under different light levels, as recently used in Matusiak, Fosse et al. [30]. Each chart consisted of 50 unrelated words (two- to six-letter words) chosen from the 300 most frequently used words in the Norwegian language. Thus, the reader could not base his or her reading on syntactic or semantic clues available in the text. Examples of the test can be provided upon request.

The second part of the pre-test was a colour vision test employing the Farnsworth-Munsell Hue 100 physical test (Fig. 6). The test was introduced in 1940s by Dean Farnsworth and is an easy-to-administer test and a highly effective method for evaluating an individual’s ability to distinguish colors, as argued by Farnsworth [15]. It consists of a series of colored chips in which the color changes from one to the next in small steps. It includes four distinct rows of similar color hues, covering orange/magenta hues, yellow/green hues, blue/purple and purple/magenta hues. The test contains a pair of a fixed cap to serve as a reference and 25 removeable chips of distinct variations of each hue. The caps were mixed up and the task for participants was to arrange the chips in an order where the observer sees them fit, so that each chip is next to the color closest to it in appearance. The participants were informed about the typical two-minute duration needed to complete each of the four colour-sample plates, although they were told they could take more time if needed to ensure they were satisfied with the results. The participants spent an average of 8.6 min on this test, and the entire survey was designed to take half an hour. The test was performed “binocularly”, because it was made only for vocational purposes (to give participants a chance to experience lighting conditions via reading the Tambartun test and

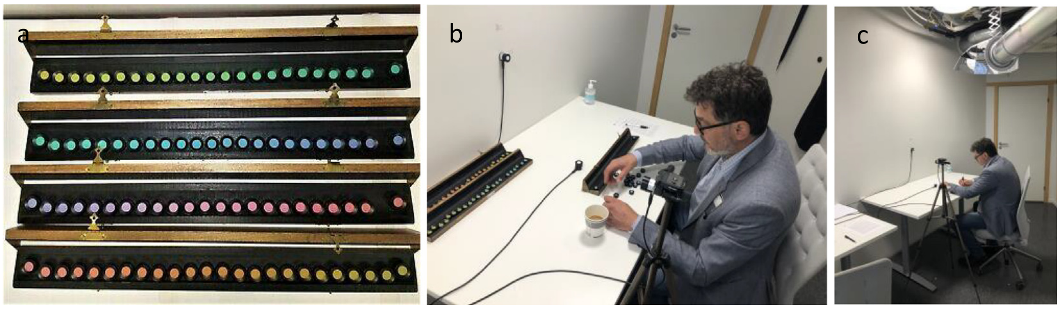


Fig. 6. Farnsworth-Munsell Hue 100 test physical model (6a); participant performing the test (6b); participant sitting at the desk closest to the door under daylight delivered from the HLP and via a custom-made reflector (6c).

discriminating between colours). The results of the colour vision test were sent to the participants after analysis, which was usually one day after their participation.

The survey involved a questionnaire with 46 questions divided into four parts: perception of the test office (the most important and relevant part for this study), personal information, the social and physical climate in the original workplace and at the end, daylighting, sun-shading, and lighting conditions in the original sitting place evaluation. The questions were provided to the participants in the above order to avoid them being biased by their own workplace. The first part of the questionnaire included lighting quality attributes of a daylit space, as discussed in the introduction; statements regarding possible issues of visual comfort; and, after that, statements about the integration of daylight and artificial lighting. The questionnaire is available upon request.

The participants' appraisals in the questionnaire were collected using semantic differential rating scales based on a bipolar adjective of agree/disagree. For this research, a five-point scale was established between the extremes: strongly disagree, disagree, neutral, agree, and strongly agree. The second part of the questionnaire employed multiple -choice and open questions, while the last two parts were based on the same five-point bipolar semantic differential scales.

The majority of participants were Norwegians (80%), and the rest were of other nationalities, with compliance to participate in the study due to the socio-environmental acclimatization period being fulfilled, as discussed in the Lysgaard [29] and Black and Mendenhall [6]. The questionnaire was translated into Norwegian in order to avoid any language barriers. For the three participants who did not speak Norwegian, the questionnaire was provided in English.

3. Results

Statistical and descriptive analysis was performed to determine whether a noticeable daylighting provision from the HLP onto the desk closest to the door led to a more positive perception of that working area as well as the room in general when compared with no daylighting supplement from the HLP. The participants were divided into two groups. These were comprised of 27 participants in the test group and 23 participants in the reference group. The group assignment was made post hoc, by analysing "every minute loggings" (described in section 2.1.1) for the indoor illuminance level on desk 2 (E_1), the outdoor illuminance on the tube's entrance (E_2), and the outdoor global horizontal illuminance (E_3) together with data regarding the energy consumption for the luminaire over desk 2. The participants in the test group had a noticeable amount of daylight delivered through the light pipe when they filled out the questionnaire's first page (addressing the test office conditions). This comprised, on average, 70% (from 50% to 90%) of the light on desk 2 that was delivered via the pipe, for the test participants and just 14% of the light for the reference participants. For comparison purposes, there were just 9.5% of the E_1 light level that came from the artificial light, for the test participants, while, for the reference participants, this range was over 70%.

The selection of the test/reference groups was validated via a theoretical estimation of the light transmission values using the light transmission efficiency of the HLP applied in the study. The noticeable daylight (minimum 50%) on the desk, delivered via the light pipe, would have a threshold value for the incident light at the pipe (E_2) around E_2 = 50,000 lx, based on the estimation described in Technical report 173, Tubular daylight guidance systems by CIE [13]. The test/reference participant selection, based on previously mentioned lighting energy consumption, matched this one.

The participants' reactions, impressions, and scores in response to the questionnaire were dependent on the E_1, E_2, and E_3 levels. The authors expected that a variation in these levels during their participation in the experiment (i.e. 45 min. adjustment period plus first part of the survey) would also affect the participants' reactions and scores. In terms of this, the illuminance values of E_1, E_2, and E_3 for each minute were collected, and the *Means* of these illuminances as well as the *Variation* in the values were calculated. Variation was calculated as a standard deviation of the minutes' values (STDEV), divided by the MEAN of the minutes' values. The means (E_{1Mean}, E_{2Mean}, and E_{3Mean}) and variations (v-E_1, v-E_2, and v-E_3) were further used in both the descriptive and statistical analyses as independent factors.

The dependent values in the analyses were the scores given by participants for each question. The five-point bipolar semantic differential scales were translated into nominal values from 0 to 4, which were defined as follows: strongly disagree (0), disagree (1), neutral (2), agree (3), and strongly agree (4).

3.1. Statistical analyses

The statistical analyses were performed using *IBM SPSS statistics 27* software. A comparison between the test and reference group scores regarding the test office was made using independent sample *t*-tests. Table 1 shows the results in regard to the participant's visual experience and perceptual impression (question 1) in both the test and reference group. Statistically significant higher scoring in the test group was recorded for the attributes *pleasant, interesting and exciting*. Table 2 shows the results for visual comfort, daylight dynamics, and the level of illuminance (daylight and artificial light together) (questions 2–6). Statistically significant higher scoring was recorded for statement 6b, *Satisfying level of artificial and daylight together in the entire room*, in the test group compared with the reference group.

Table 1
Independent sample *t*-test analyses compare the scoring in the test and reference groups in terms of visual experience and perceptual impression of the test office.

1. How do you experience this room?	Test group			Reference group					
Attributes:	M	SD	SE	M	SD	SE	t	df	p
bright	2.59	1.010	0.194	2.74	1.214	0.253	−0.466	48	0.643
spacious	3.15	0.949	0.183	2.78	1.126	0.235	1.246	48	0.219
open	2.89	0.801	0.154	2.43	0.992	0.207	1.791	48	0.080
uniform	2.96	1.065	0.222	2.64	1.217	0.259	0.940	43	0.352
pleasant	1.96	1.038	0.204	1.30	1.063	0.222	2.186	47	**0.034**
interesting	2.37	1.275	0.245	1.43	1.080	0.225	2.771	48	**0.008**
exciting	2.22	1.219	0.235	1.35	1.027	0.214	2.714	48	**0.009**
legible	3.19	1.001	0.193	2.95	1.046	0.223	0.786	47	0.436

Table 2
Independent sample *t*-test analyses compare the scoring in the test and reference group regarding visual comfort and level of illuminance (daylight and artificial light together) in the test office.

	Test group			Reference group					
Questions from the survey	M	SD	SE	M	SD	SE	t	df	p
2. The daylight conditions in the room are satisfying	2.70	0.993	0.191	2.26	1.251	0.261	1.395	48	0.169
2a. Temporal changes of light have been noticed	1.40	1.506	0.476	1.31	1.316	0.365	0.157	21	0.877
3. No difficulties regarding the visibility of the task on the screen	3.15	0.989	0.190	3.27	0.767	0.164	−0.484	47	0.631
4. No reflections on the PC screen caused by the light	3.44	0.712	0.142	3.33	0.913	0.199	0.445	44	0.658
5. Difference between the colour of light were noticed	1.72	1.275	0.255	2.05	1.468	0.328	−0.807	43	0.424
6a. Satisfying level of artificial and daylight together at the workplace	2.96	1.020	0.204	2.41	1.182	0.252	1.716	45	0.093
6b. Satisfying level of artificial and daylight together in the entire room	2.88	0.927	0.185	1.95	0.999	0.213	3.293	45	**0.002**
6c. Satisfying level of artificial and daylight together on the screen	3.28	0.843	0.169	3.05	1.117	0.244	0.804	44	0.426

Correlation analyses were computed for the variables of interest—E_{1Mean}, E_{2Mean}, E_{3Mean}, v-E_1, v-E_2 and v-E_3—and scores for survey questions 1–6 in order to check if there were any statistically significant correlations between the variables. Several statistically significant correlations for visual experience and perceptual impression of the test room were found (Table 3). For the mean value of the indoor illuminance on the test desk, E_{1Mean}, a statistically significant (negative) correlation was found for perceiving the room as *exciting* (Pearson's −0.308 [$p < .05$]). For the mean value of the outdoor vertical illuminance incidence on the tube, E_{2Mean}, a statistically significant correlation was found for perceiving the room as *open* (Pearson's 0.298 [$p < .05$]), *pleasant* (Pearson's 0.332 [$p < .05$]), *interesting* (Pearson's 0.419 [$p < .01$]), and *exciting* (Pearson's 0.436 [$p < .01$]). For the mean value of the outdoor global horizontal illuminance, E_{3Mean}, a statistically significant correlation was found for perceiving the room as *pleasant* (Pearson's 0.305 [$p < .05$]), *interesting* (Pearson's 0.341 [$p < .05$]), and *exciting* (Pearson's 0.372 [$p < .01$]). Graphs for the correlation analyses are enclosed in Appendix C, Fig. C1a-h. For the variation in the outdoor illuminance value incident to the tube, v-E_2, a statistically significant (negative) correlation was found for perceiving the room as *pleasant* (Pearson's −0.326 [$p < .05$]), *interesting* (Pearson's −0.392 [$p < .01$]), and *exciting* (Pearson's −0.338 [$p < .05$]). For the variation in the outdoor global horizontal illuminance, v-E_3, a statistically significant (negative) correlation was found for perceiving the room as *uniform* (Pearson's −0.330 [$p < .05$]), *interesting* (Pearson's −0.318 [$p < .05$]), and *exciting* (Pearson's −0.305 [$p < .05$]). Graphs for the correlation analyses are enclosed in Appendix C, Fig. C2a-h

The authors did not find any statistically significant correlation between the — variables of interest—E_{1Mean}, E_{2Mean}, E_{3Mean}, v-E_1, v-E_2 and v-E_3 — and scores regarding visual comfort, daylight dynamics, and the level of illuminance (daylight and artificial light together) in the test office (Table 4).

Table 3
Correlation analyses between the E_{1Mean}, E_{2Mean}, E_{3Mean}, v-E_1, v-E_2 and v-E_3 and scores given by participants for visual experience and perceptual impression in the test office.

1. How do you experience this room?							
Attributes		E_{1Mean}	E_{2Mean}	E_{3Mean}	v-E_1	v-E_2	v-E_3
bright	Pearson Corr.	0.141	-0.055	-0.063	-0.234	-0.266	-0.180
	P value	0.328	0.706	0.664	0.101	0.062	0.212
spacious	Pearson Corr.	-0.122	0.187	0.060	0.030	-0.161	-0.193
	P value	0.398	0.193	0.679	0.837	0.264	0.180
open	Pearson Corr.	-0.223	**0.298***	0.262	-0.033	-0.229	-0.227
	P value	0.119	0.036	0.066	0.822	0.109	0.113
uniform	Pearson Corr.	-0.081	0.126	0.054	-0.067	-0.196	**-0.330***
	P value	0.598	0.410	0.724	0.663	0.198	0.027
pleasant	Pearson Corr.	-0.281	**0.332***	**0.305***	-0.014	**-0.326***	-0.281
	P value	0.051	0.020	0.033	0.923	0.022	0.050
interesting	Pearson Corr.	-0.147	**0.419****	**0.341***	0.026	**-0.392****	**-0.318***
	P value	0.309	0.002	0.015	0.859	0.005	0.025
exciting	Pearson Corr.	**-0.308***	**0.436****	**0.372****	0.065	**-0.338***	**-0.305***
	P value	0.029	0.002	0.008	0.652	0.016	0.032
legible	Pearson Corr.	-0.090	0.132	0.108	0.009	-0.169	-0.267
	P value	0.540	0.367	0.461	0.950	-0.246	0.064

Significance levels: * $p < .05$; ** $p < .01$. The analyses are based on n: 45–50.

Table 4

Correlation analyses between E_{1Mean}, E_{2Mean}, E_{3Mean}, v-E_1, v-E_2 and v-E_3 and scores given by participants regarding visual comfort and level of illuminance (daylight and artificial light together) in the test office.

Questions from the survey		E_{1Mean}	E_{2Mean}	E_{3Mean}	v-E_1	v-E_2	v-E_3
2. The daylight conditions in the room are satisfying	Pearson Corr.	0.126	0.043	-0.029	0.050	-0.200	-0.091
	P value	0.382	0.769	0.841	0.728	0.163	0.530
2a. Temporal changes in the light have been noticed	Pearson Corr.	-0.167	-0.028	0.032	0.207	0.028	0.056
	P value	0.446	0.900	0.884	0.344	0.901	0.799
3. No difficulties regarding the visibility of the task on the screen	Pearson Corr.	0.106	-0.143	-0.092	-0.021	0.122	0.135
	P value	0.470	0.326	0.528	0.885	0.405	0.356
4. No reflections on the PC screen caused by the light	Pearson Corr.	0.078	0.089	0.036	0.008	0.019	-0.012
	P value	0.607	0.557	0.813	0.960	0.898	0.936
5. Difference between the colour of light were noticed	Pearson Corr.	0.019	-0.212	-0.147	0.115	0.254	0.124
	P value	0.899	0.162	0.335	0.451	0.092	0.417
6a. Satisfying level of artificial and daylight together at the workplace	Pearson Corr.	0.059	0.145	0.051	0.017	-0.197	-0.170
	P value	0.693	0.332	0.734	0.912	0.184	0.254
6b. Satisfying level of artificial and daylight together in the entire room	Pearson Corr.	-0.067	0.268	0.201	0.192	-0.231	-0.101
	P value	0.656	0.069	0.176	0.196	0.118	0.501
6c. Satisfying level of artificial and daylight together on the screen	Pearson Corr.	0.018	0.181	0.181	0.153	-0.092	-0.073
	P value	0.906	0.230	0.230	0.310	0.544	0.631

Significance levels: * $p < .05$; ** $p < .01$. The analyses are based on n: 23–50.

3.2. Descriptive analyses

The average score given by the participants in the test group in terms of the visual experience and perceptual impression of the test room indicated a more positive evaluation of the test room as *spacious*, *open*, *uniform*, and *legible* when compared to the reference group; this was even more evident for evaluations of the test room as *pleasant*, *interesting*, and *exciting* (Fig. 7). The *brightness* of the room was rated higher by the reference group than the test group. This result can be explained by the level of illuminance on the desk (E_1), which, in the case of the higher daylighting supplement, was lower as a result of the light being re-directed from the slats against the DLC sensors and the fault signal given to the luminaires. This situation is briefly explained in section 2.1.5.

The average scores given by the participants in their evaluation of whether the daylighting conditions were satisfying were higher in the test group than in the reference group (Fig. 8). The underlying visual conditions' effect on visual comfort in the room as a glare-free space could also be noted, as both groups evaluated the room above neutral (2). For the evaluation of the light dynamics, which was in terms of whether temporal changes in the light were noticed, the scores were low (under 2). This result indicates that the participants did not notice the dynamics of the daylight.

The average scores for questions regarding visual comfort were analysed. These questions asked whether the participants experience difficulties regarding the visibility of the task on the screen or observe reflections caused by the light; or if they noticed the difference in colour of the light. As previously discussed, the participants answered very positively (Fig. 9). No significant differences between the test and reference group were noted. This underly the issues widely discussed in the daylighting field regarding glare-free spaces.

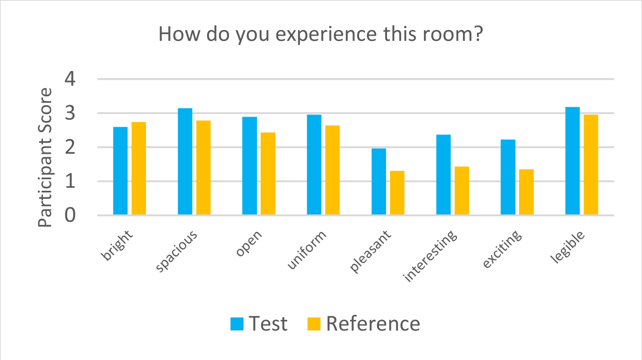


Fig. 7. Average scores given by the participants in the test and reference groups in terms of their visual experience and perceptual impression of the room.

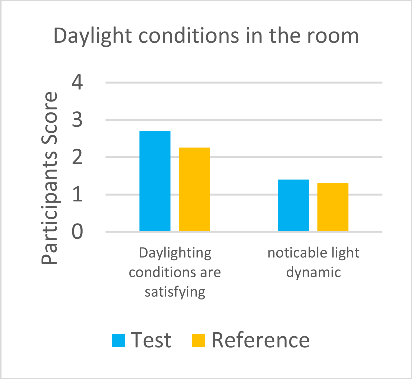


Fig. 8. Average scores given by the participants in the test and reference groups in terms of the daylight conditions and daylight dynamics in the room.

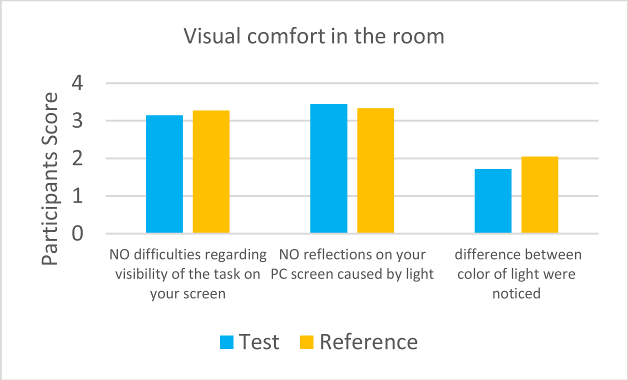


Fig. 9. Average scores given by the test and reference groups in terms of their visual comfort in the test room.

Evaluation of the test and reference group in regard to the daylight and artificial light levels indicated differences in the average scores. There was a more generally positive assessment in the test group in regard to the light level in the workplace as well as in the entire room and on the PC screen (Fig. 10). The largest difference in the assessment between the two groups was in regard to the light level (artificial and daylighting) in the entire room and at the workspace (desk 2).

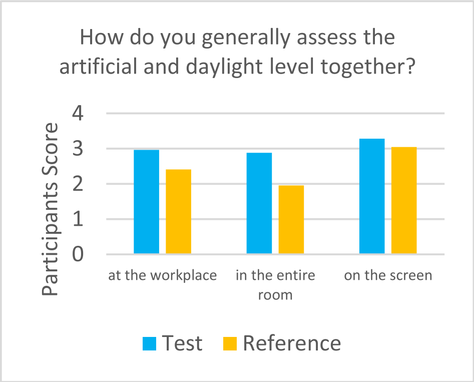


Fig. 10. Average scores given by the test and reference groups in terms of the level of light (artificial and daylight together).

In the evaluation of the participants' visual experience and perceptual impression of the test office, it was found that their scores slightly increased with their age. Furthermore, rated their visual experience and perceptual impression of the test office more positively than the males.

4. Discussion

Statistical and descriptive analyses show compatible results. While statistical analyses emphasize factors with an effect at a certain significant level, descriptive analyses provide easily understandable ideas about how results are distributed, relationships, and correlations between them.

The analyses confirm previously discussed issue that the sole use of photometric measurement (here illuminance) is an unreliable assessment tool for light condition qualification The light conditions in a space are created for human use. Human reactions to lighting have been historically marked as unreliable, but many studies have shown that human responses to light stimuli, sometimes noted as inexplicable, have logic under certain conditions. It is not easy to identify such conditions by comparing parametric measurements, but the human reaction can and, in the case of this study, did help in understanding such conditions. The authors' expectation of more positive participant reactions with an increasing variety in the daylight was disproven. This helped to shed light on this occurrence, and the authors put focus on finding how unbalanced light levels indoor are related to light levels outdoors. The variation in the daylight in the office here was supplemented (unplanned) by a non-attendant (wrongful and not balanced) level of artificial light, which, altogether, produced an uncomfortable situation for the participants, often known as "gloominess.

The participants' evaluation of the room's pleasantness was relatively low in both groups, which could have resulted from the room having been released of any possible decorative elements (pictures, flowers) that are common in many workplaces, in addition, the suspended ceiling was removed. The participants' sitting position was too close to the door, without visual control over the office entrance. Humans prefer to have visual control over a space, such as having a direct view of the entrance at any time. This issue was discussed by several authors [2,3,34].

Daylight reflected on the slats and directed against the ceiling affected the DLC sensors, which resulted in incorrect information being given to the DLC system in its adjustment of the artificial light level. When under an overcast sky, the fade time for the DLC was not as unsuitable as when under a clear, sunny sky, under which the magnitude of the sun/sky luminance variation was much higher.

None of the participants complained about glare or excessive light in the test office. In situations where the level of light recorded by the illuminance meters on the desk was as low as 300 lx, higher daylighting spread in the room made the room appear pleasant, and participants commented that they noticed the light level was low but that it was comfortable to work. The fine-tuning of the sloping of the slats in the sun-shading system to 45°proved to protect participants against glare.

Comments from the participants for the open ended question in the survey, when the light level on the desk was about 350 lx and the amount of the daylight via the pipe was noticeable: "It feels pleasant, and my eyes can relax"; "very unusual lighting: it feels simple/flat, but it is satisfying to work on the screen"; and "my first impression was that the room was not bright compared to the lighting in the corridor and neighbouring rooms, but the room is bright enough to be able to perform work."

Participants' comments when the level was 450 to 500 lx under an overcast sky and when the luminaires supplied the entire light included: "The corner towards the door is dark"; "the room and furniture/tables are white and uninspiring. Can probably seem a little cold in our climate"; "the room is somewhat monotonous and dull"; and "no colour dynamics. It keeps me awake, but I can get tired faster with exertion."

The crucial point here is that the aspect ratio of the used HLP, 17, could be used to supply daylight to the third workspace, as discussed in Obradovic and Matusiak [36]. This suggests that similar effects can be expected even much further from the window.

5. Conclusion

The research question raised at the beginning of this study, whether noticeable daylighting provision from the HLP leads to a more positive impression of the space compared to a situation without daylight provision via the HLP, can be answered using the findings from the statistical and descriptive analyses. The general conclusion is that the user appraisal of the office was more positive when there was a noticeable daylight supplement from the HLP in the space, but the appraisal was negative for the higher variability in the illuminance level both indoors and outdoors. The importance of this study lays in the user'-survey results and conclusions that will serve as an additional argument for implementation of the HLP in the building design, besides its energy saving potential.

The independent sample *t*-test showed that there was an overall more positive evaluation of the room as *pleasant*, *interesting*, and *exciting* in the test group which had significant light from the outside delivered through the HLP. The test group also evaluated the *daylight and artificial light conditions in the entire room* more positively than the reference group.

The increase in E_2 had a statistically significant relationship with the increase in perceiving the room as *open, pleasant*, *interesting*, and *exciting.* There was also an increased positive evaluation for the room attributes of *spacious*, *uniform* and *legible* with an increasing E3.

Unexpectedly, there was a statistically significant negative relationship between v-E_2 and v-E_3 and the participants' evaluation of the test room as *uniform*, *pleasant*, *exciting* and *interesting*. This can be explained by the inconsistent variation in the artificial light level, which was supposed to supplement the missing light level to achieve a recommended level in the office; however, this did not happen due to the daylight reflection on the slats and the false information given to DLC system.

Furthermore, there was a significant negative relationship between the level of indoor illuminance and the participants' perception of the room as *exciting*. The level of indoor illuminance was higher in cases when the DLC was not affected by the higher levels outdoor daylight reflected on the slats, which means that the higher level of indoor illuminance was strictly provided from the artificial light, which resulted in participants' negative impressions of the room in regard to it being "exciting".

The authors of this study had the opportunity to introduce a completely novel approach to distribute light from the light pipe, via a *custom-designed mirror reflector*. During this long-term study, it was observed that such a mirror reflector managed to provide visually clear and obvious sun patches, light sparkling, and sharp light variations on the desk under the pipe, which was directly associated with the variation in the natural light outside. The standard solution for a distributor provided by the manufacturer, opal, satin, or micro-prismatic diffuser, would never be able to produce those effects. Participants did not make any comments regarding the light sparkles on the desk.

Finally, this study has certain limitations: For instance, it is unknown whether the results can be generalized to spaces and offices of different sizes than the one used in this study. We assume that, in open-plan offices, in which the user has a deeper view of the space, the aspects of daylighting and lighting quality that are discussed in this paper will have an even higher significance in terms of user opinion. This assumption outlines a suggestion for further research.

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.

Acknowledgement

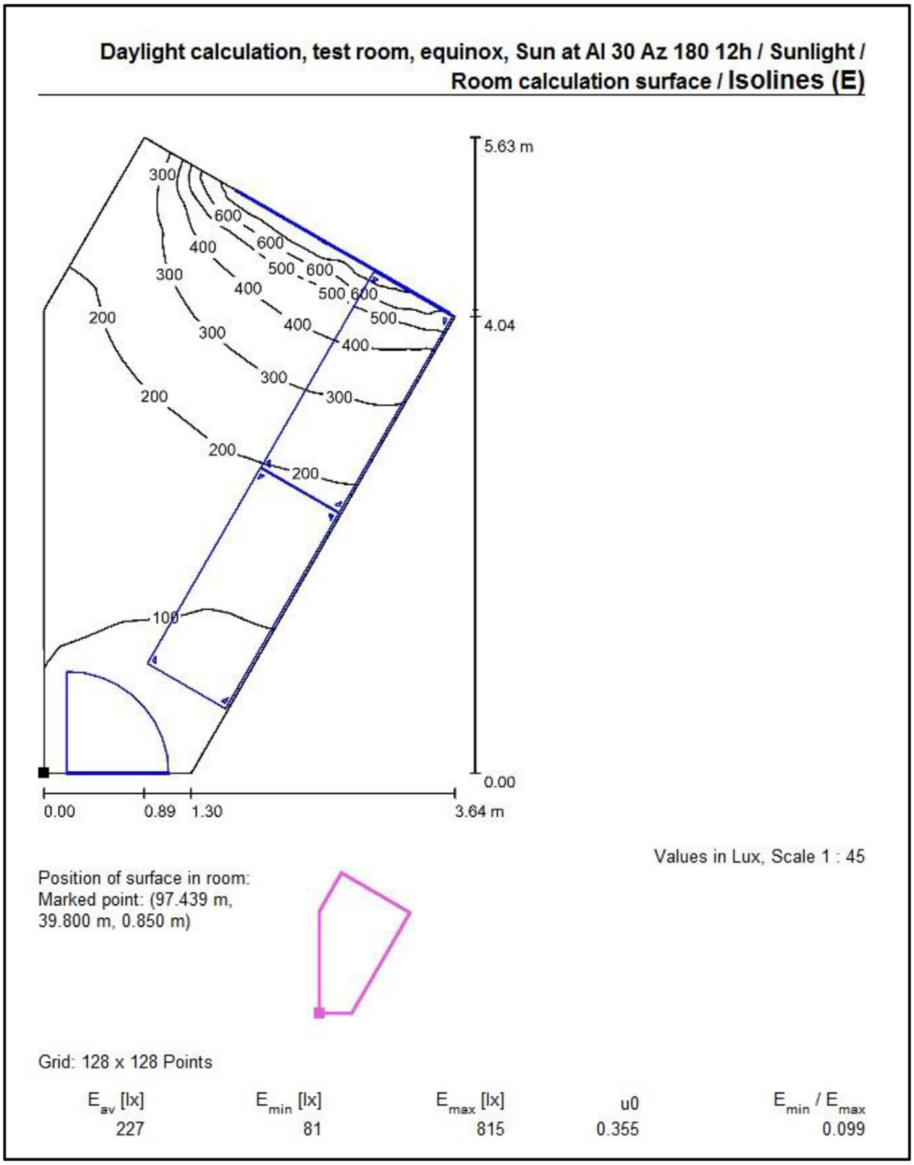
This study was conducted as a part of a PhD-study at the Norwegian University of Science and Technology with Norconsult AS and the Norwegian Research Council's support. The concept of the full-scale test office was motivated by limited knowledge regarding daylighting by HLP in the form of image-forming lighting effects and non-imaging forming light effects on humans; potential in lighting energy reduction; and reference projects on HLP application in Norway. The authors hope the full-scale study results will fill the knowledge gap for architects, lighting designers, and investors by providing insight into the application possibilities of the HLP in buildings in Norway. Moreover, the authors are grateful to Per Fosse for supplying them with the Tambartun Oral Reading Test. We appreciate the sponsorship of the full-scale test office from Glamox along with the luminaires and photosensors as well as Carlo Gavazzi for the outdoor illuminance meters and controlling units. Last, the authors are grateful to Norconsult AS for the access to the test office for a whole year and the caretakers of the building for additional technical support.

Contributions

B.O. conceived and wrote the study; B.M. helped define the methodology, gave feedback on the paper's content, and contributed by performing quality assurance and proofreading. C.K. helped perform the statistical analysis and interpretation. S.A. helped prepare the user-survey, gave feedback on the content of the paper, and contributed by performing quality assurance and proofreading.

Appendix A

Fig. A1-A3



Daylight calculation, test room, equinox, Sun at Al 30 Az 180 12h / Sunlight / Room calculation surface / Isolines (E)

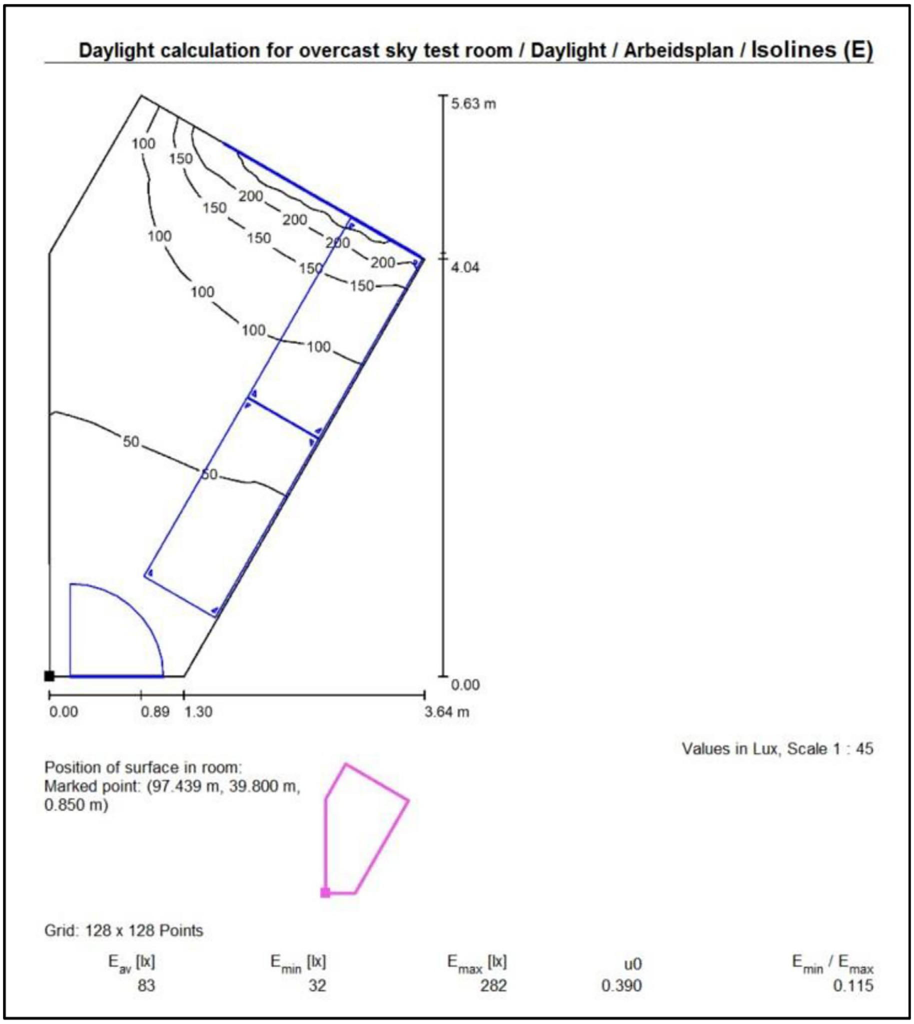
Values in Lux, Scale 1 : 45

Position of surface in room:
Marked point: (97.439 m,
39.800 m, 0.850 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
227	81	815	0.355	0.099

Fig. A1. Daylight calculation for equinox at 12:00 h under a clear sunny sky sun at Al 30° and Az 180°.



Daylight calculation for overcast sky test room / Daylight / Arbeidsplan / Isolines (E)

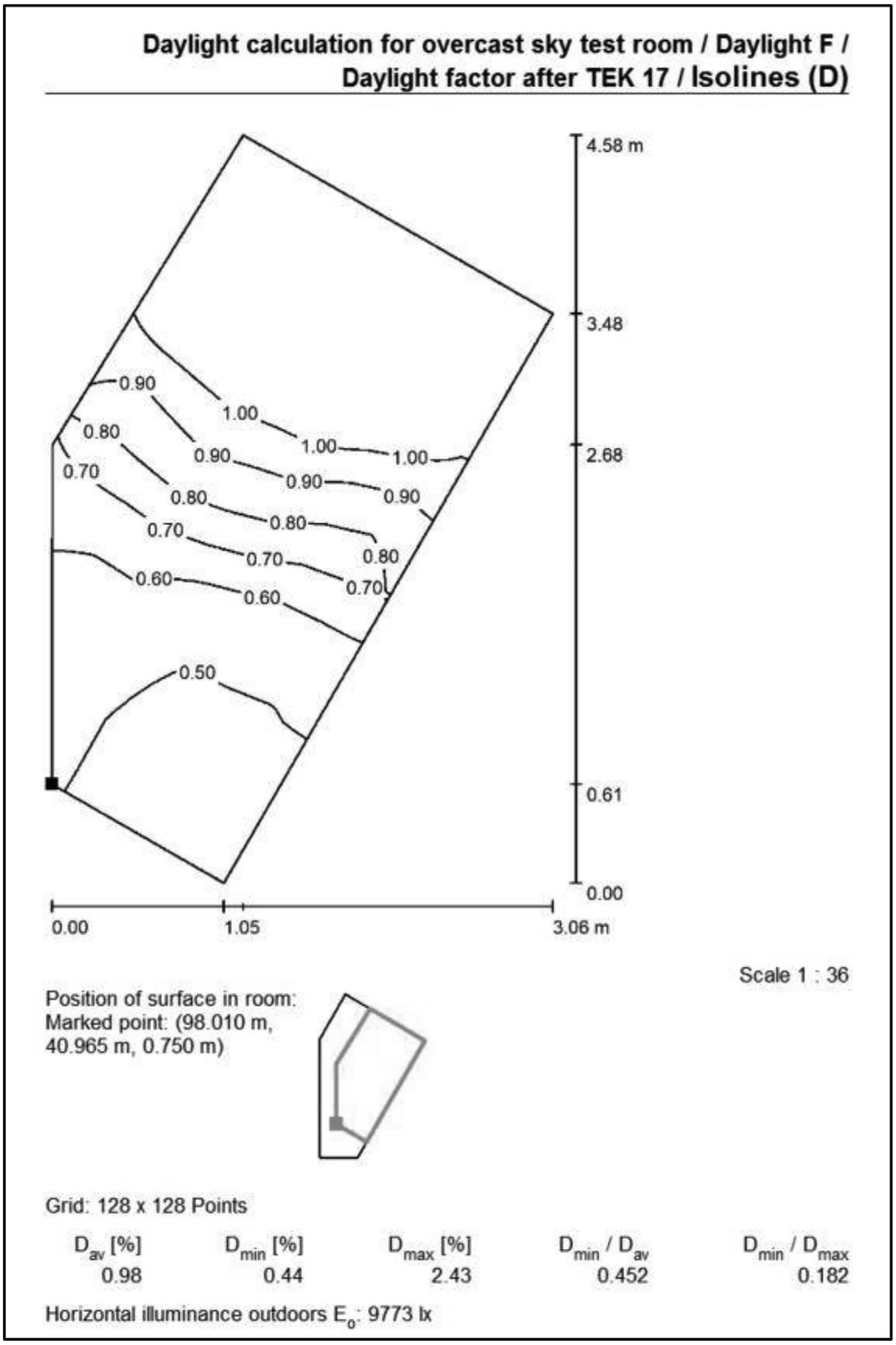
Values in Lux, Scale 1 : 45

Position of surface in room:
Marked point: (97.439 m, 39.800 m, 0.850 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
83	32	282	0.390	0.115

Fig. A2. Daylight calculation for equinox under an overcast sky.



Daylight calculation for overcast sky test room / Daylight F / Daylight factor after TEK 17 / Isolines (D)

Scale 1 : 36

Position of surface in room:
Marked point: (98.010 m,
40.965 m, 0.750 m)

Grid: 128 x 128 Points

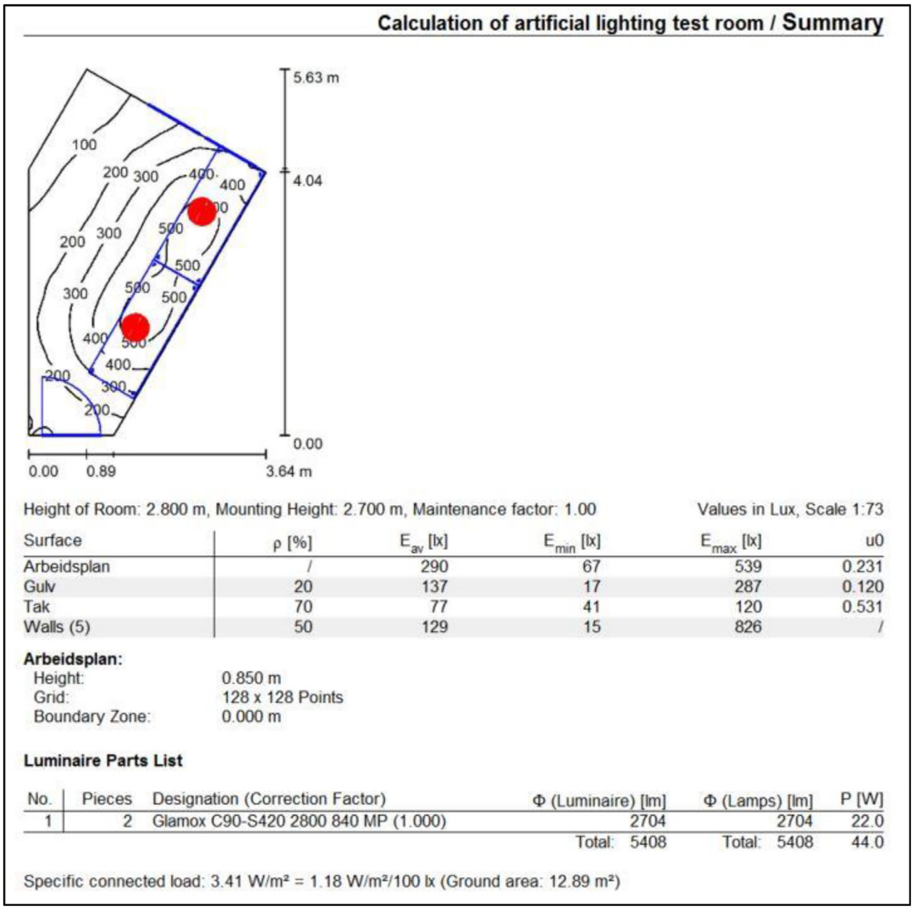
D_{av} [%]	D_{min} [%]	D_{max} [%]	D_{min} / D_{av}	D_{min} / D_{max}
0.98	0.44	2.43	0.452	0.182

Horizontal illuminance outdoors E_0: 9773 lx

Fig. A3. Daylight calculation of the test room, daylight factor (Df) after TEK17 (Norwegian Technical standard).

Appendix B

Fig. B1 and B2



Calculation of artificial lighting test room / Summary

Height of Room: 2.800 m, Mounting Height: 2.700 m, Maintenance factor: 1.00 Values in Lux, Scale 1:73

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Arbeidsplan	/	290	67	539	0.231
Gulv	20	137	17	287	0.120
Tak	70	77	41	120	0.531
Walls (5)	50	129	15	826	/

Arbeidsplan:

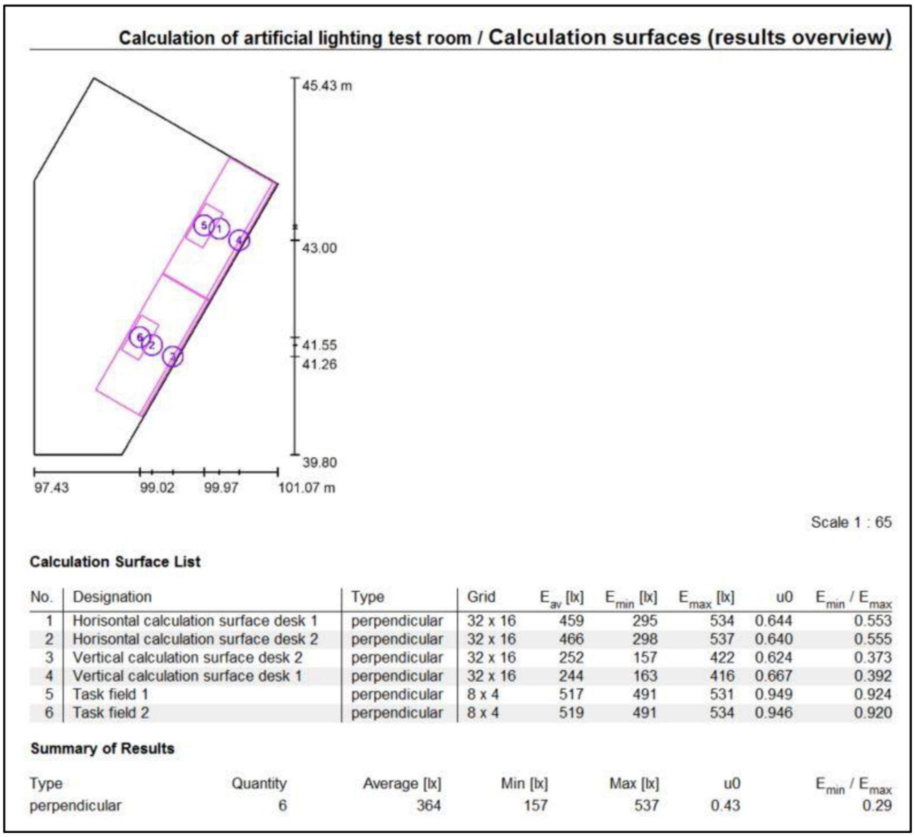
Height:	0.850 m
Grid:	128 x 128 Points
Boundary Zone:	0.000 m

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	2	Glamox C90-S420 2800 840 MP (1.000)	2704	2704	22.0
			Total: 5408	Total: 5408	44.0

Specific connected load: 3.41 W/m² = 1.18 W/m²/100 lx (Ground area: 12.89 m²)

Fig. B1. Lighting calculation for the test room, artificial lighting.



Calculation of artificial lighting test room / Calculation surfaces (results overview)

Scale 1 : 65

Calculation Surface List

No.	Designation	Type	Grid	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
1	Horisontal calculation surface desk 1	perpendicular	32 x 16	459	295	534	0.644	0.553
2	Horisontal calculation surface desk 2	perpendicular	32 x 16	466	298	537	0.640	0.555
3	Vertical calculation surface desk 2	perpendicular	32 x 16	252	157	422	0.624	0.373
4	Vertical calculation surface desk 1	perpendicular	32 x 16	244	163	416	0.667	0.392
5	Task field 1	perpendicular	8 x 4	517	491	531	0.949	0.924
6	Task field 2	perpendicular	8 x 4	519	491	534	0.946	0.920

Summary of Results

Type	Quantity	Average [lx]	Min [lx]	Max [lx]	u0	E_{min} / E_{max}
perpendicular	6	364	157	537	0.43	0.29

Fig. B2. Lighting calculation for the test room, artificial lighting on a relevant calculation surfaces.

Appendix C

The analyses of participants' scores for the first question regarding the visual appearance and perceptual impression of all 50 participants according to the E_{1Mean}, E_{2Mean}, and E_{3Mean} values are illustrated in Fig. C1a–h. The evaluation was in agreement with that previously discussed in section 2.1.5. A reason for the increase in E_1 and how it is connected to the level of daylight delivered via the light pipe is explained in section 2.1.5.

The analysis of participants' scores of the various attributes in terms of visual experience and perceptual impression of the test office was assessed in terms of the level of variation in the illuminance values (E_1, E_2 and E_3) v-E_1, v-E_2 and v-E_3.the graphs are presented in Fig. C2a-h.

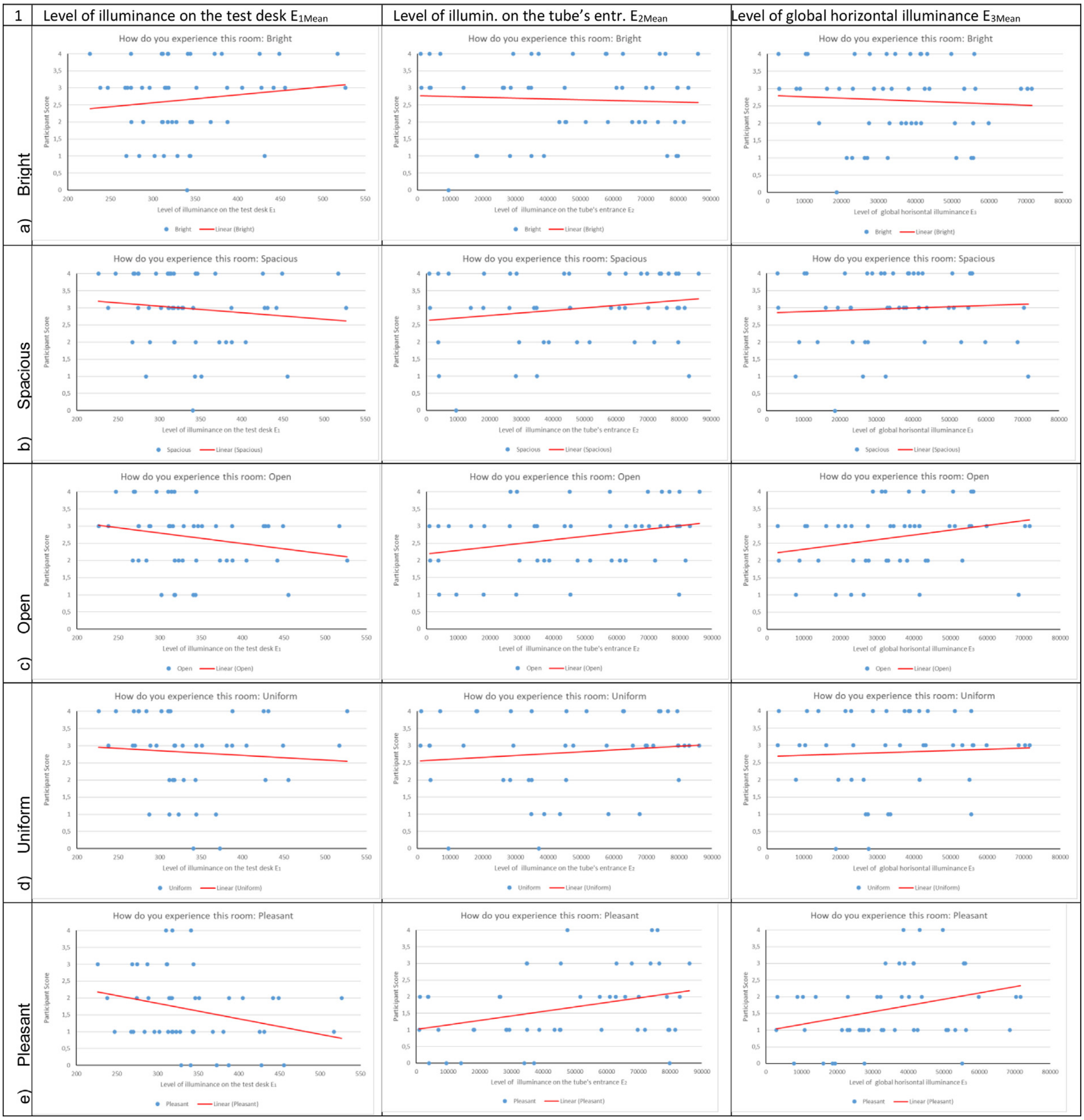


Fig. C1. a-h. Participants' scores for different attributes related to visual appearance and perceptual impression of the test room based on E_{1Mean}, E_{2Mean}, and $E_{3Mean.}$ In the evaluation of brightness, the participants' scores increased with the illuminance on the test desk (E1Mean), Fig. 11a, and slightly decreased as both the outdoor illuminance at the tube's entrance (E2Mean) and the global horizontal illuminance (E3Mean) increased. Figs. 11b–h show that, as E1Mean increased, the participants' scores decreased, and, as E2Mean and E3Mean increased, the scores increased for all other attributes related to visual appearance and perceptual impression (except brightness). This is clear in the evaluation of the room as a pleasant, interesting and exciting.

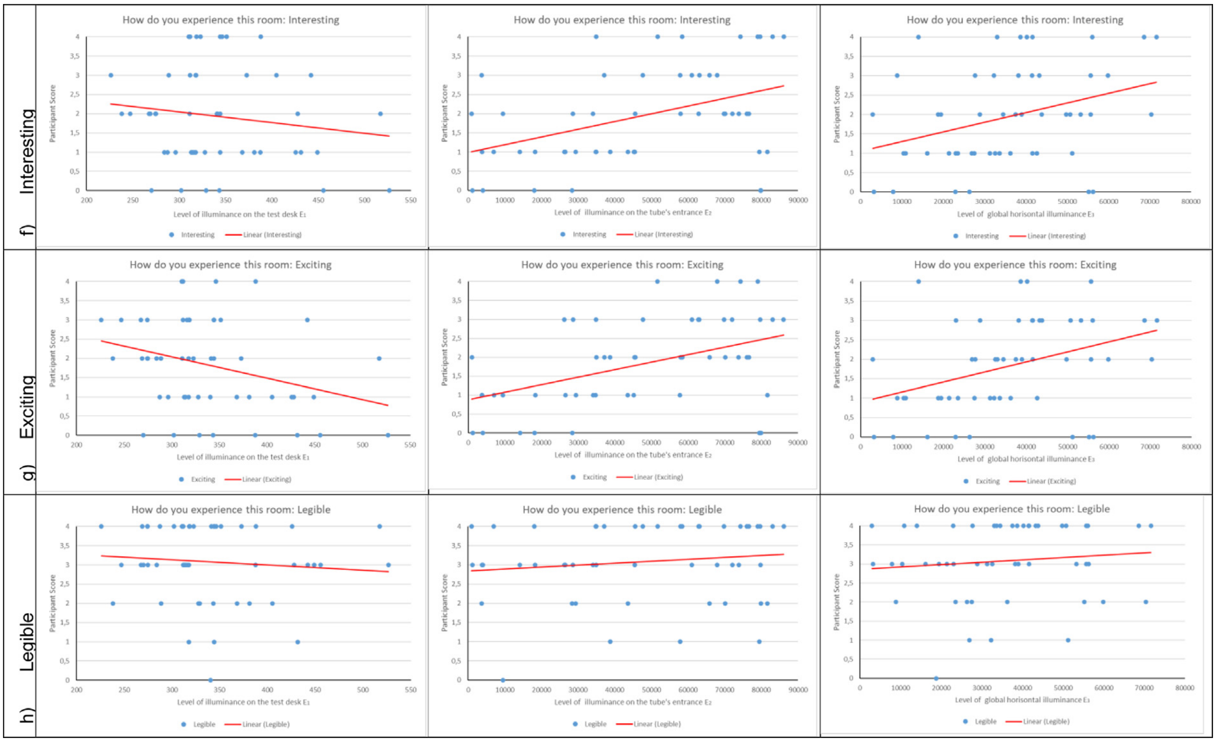


Fig. C1 (*continued*)

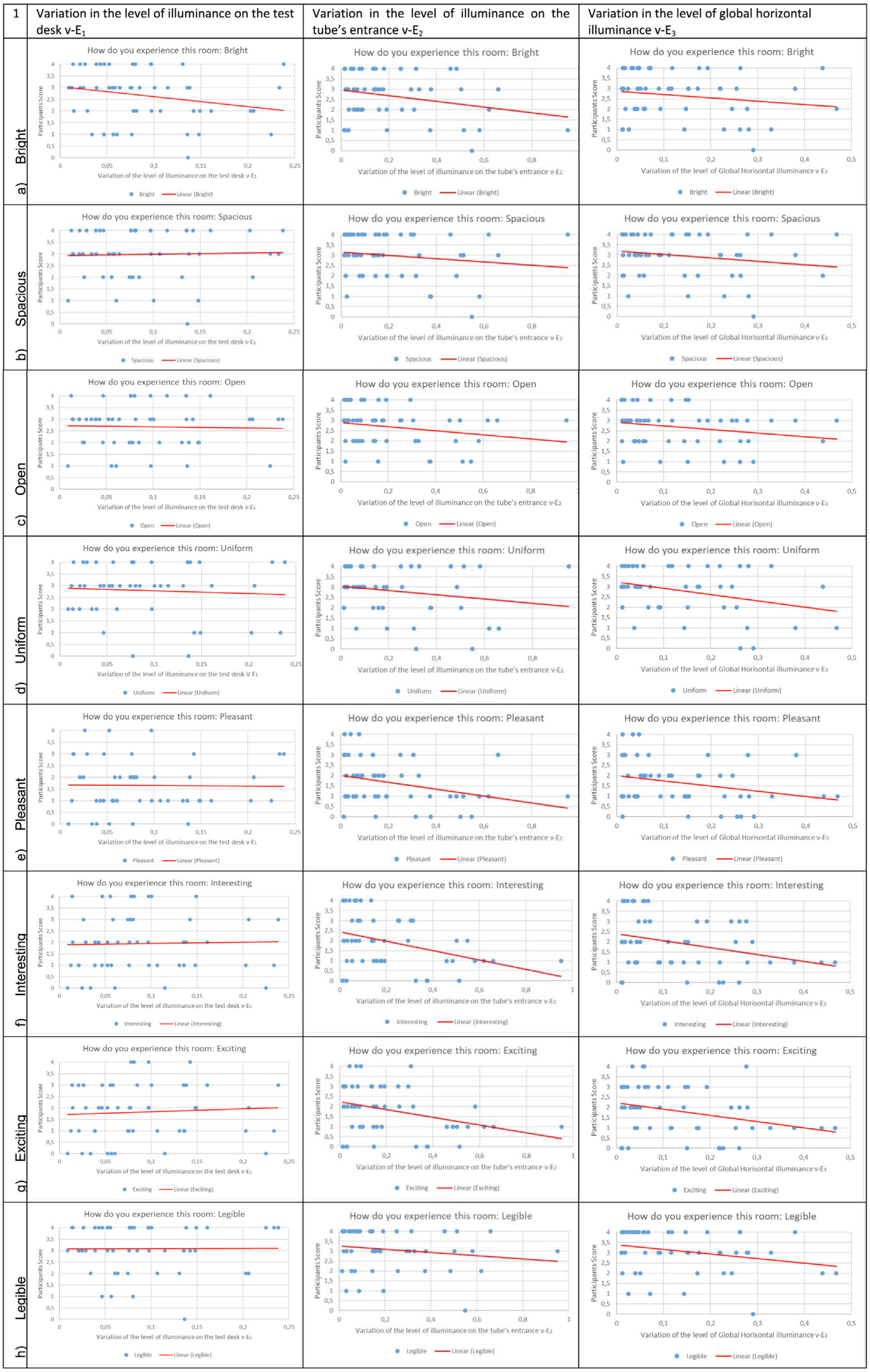


Fig. C2. a–h. Participant scores for the attributes related to visual experience and perceptual impression of the test office based on v- E_1, v-E_2 and v-E_3. Left column with figures show that the variation in the illuminance values on the desk (v-E1) did not have any visible correlation to the participants' scores—except in the case of the room's brightness. The higher v-E1 brought about lower scoring for the room as bright, as a higher variation is also correlated to higher outdoor illuminance conditions, E2 and E3. Higher daylight supplement, (unplanned) brought about higher variation in illuminance levels on desk 2 (v-E1), which participants evaluated negatively. The increasing variation in E2 and E3 was associated with lower participants scores (Fig D3a–h; middle and right) for all other evaluation attributes. This trend is especially noticeable for perceiving the room as pleasant, exciting, and interesting.

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