# Creating positive atmosphere and emotion in an office-like environment: A methodology for the lit environment

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**Abstract**

This study investigated whether positive human emotion can be set as a goal through the lighting design process. The study first used a model of emotion – the circumplex model of affect – to characterise four different emotion states (liveliness, relaxation, tense and gloom). Second, five professional lighting designers were recruited and were asked to devise the concepts of each lively and relaxing workspace lit environment. A total of fifteen lighting scenarios with the intention to explore the four emotion states were configured and their emotional effect was investigated through a controlled experiment via a self-reported questionnaire with 42 participants (within-subject design). The results indicate that positive emotions of liveliness can be cued under two lighting settings and that of relaxation under three lighting settings of varying colour temperatures and light distribution. There was also a promising link between perceived atmosphere and human emotion, indicating that atmosphere could be a predictor for human emotion.

**Keywords**

Lighting design, atmosphere, emotion distribution, kernel density estimation, affect circumplex

## 1. Introduction

Light has historically been used as an architectural tool to create different space ambiences (or appearances) and emotions by architects and studies showed that different appearances and emotions induced by the lit environment could influence occupants' psychological and physiological health and well-being [1,2] Therefore, lighting (design) as an emotional stimulus has been regarded as an important research item concerning human psychological health and well-being [3].

One of the first attempts to investigate the effects of lighting on human subjective impression was conducted by Flynn *et al*. [4,5]. According to their studies it was suggested that peripheral and non-uniform lighting generated a pleasant and relaxing impression when compared to overhead and uniform lighting on an 'evaluative' factor. Studies by Loe *et al.* [6,7] suggested that average luminance and luminance distribution in the field of view could be design indicators for our perception of visual lightness and interest respectively. Shepherd *et al*. [8,9] found that 'gloom' was a commonly held experience (impression) that was related to the adaptation luminance and the distribution of light in an interior space. Durak *et al.* also investigated the impacts of different lighting arrangements on impressions of a room and reported that the use of cove lighting and/or wall washing lighting was associated with a pleasant impression of a room [10]. Vogels found that correlated colour temperature and luminance were related to atmosphere perceptions in liveliness and cosiness in retail environments [11].

In recent years, light sources have been developed that can be controlled in terms of brightness and colour to produce dynamic lighting of great complexity in indoor lit environments. Several studies [12-15] included such dynamic light settings and the use of saturated colours in their experiments to investigate subjective impressions to different light conditions. It was reported that the combination of warm white lighting with warm coloured accent lighting (orange) could create a cosy ambience, while a high colour temperature with cyan coloured accent lighting would result in a lively atmosphere for older people [16]. The use of more saturated LED lights would lead to less tense, cosier and more lively perceptions [13]. Kompier *et al.* reported a transition to cool, bright light was alerting and activating, yet uncomfortable while the reverse transition to warm, dim light yielded a calm feeling [17]. Denk *et al*. reported an impact of cool-white light on positive affect of human emotion while no significant impact on atmosphere perception was found [18]. Although many of the previous studies demonstrated emotional and psychological impacts of lighting on human being, it is yet unclear whether such emotional impacts of lighting are something that we could set as a goal through the design process. Our aim, therefore, in this *present* study is to test a possibility of an emotion-based lighting design process and to explore workspace lit environments that evokes positive emotions. More specifically, this study used a model of emotion – *the circumplex model of affect* – to characterise emotion into four states. Such a model is characterised by two dimensions [19,20]. One dimension is *activation*-whether a person's emotional state is activated or deactivated: the other is *pleasantness*-whether such emotion is pleasant or unpleasant (see Figure 1).

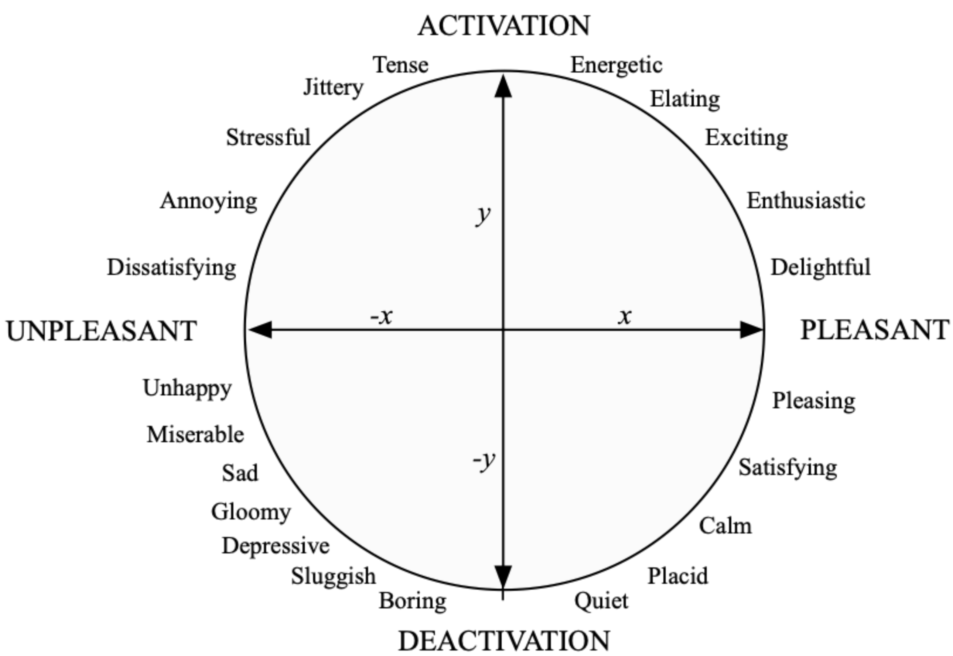



**Figure 1.** A graphical representation of the Circumplex Model of Affect (adapted from Russell [19])

**Note.** The spread of the adjectives does not indicate the precise location of each emotion but an indication of them in each quadrant.

These dimensions divide the psychological domain space into four quadrants. These are: (1) PLEASANT – ACTIVATION ($x+y$), with these components: energetic, elating, exciting, enthusiastic, delightful, (2) PLEASANT – DEACTIVATION ($x$-$y$), with the following components: pleasing, satisfying, calm, placid, quiet, (3) UNPLEASANT – DEACTIVATION (-$x$-$y$): miserable, unhappy, sad, gloomy, depressive, sluggish, boring, (4) UNPLEASANT – ACTIVATION (-$x+y$): tense, jittery, stressful. Besides characterizing the four emotional states, the circumplex model of affect, in this study, also played a role in providing a sound set of emotion adjectives that was used for an assessment of human emotional impacts in lighting.

While there are several other prominent psychological models to characterise our emotions such as the Positive Activation – Negative Activation (PANA) model [21] and the vector model [22], we chose the circumplex model as it has been developed for use when people describe the *affective state*-the emotion that they feel under certain conditions [23] and describe their *affective quality of a space*-the atmosphere that tends to have a similar impression to that of room appearance [24]. The aim of the study was to explore four different human emotions, defined by a psychological model, that can be cued by a lighting setting. Fifteen lighting settings were configured informed by concepts from professional lighting designers and the emotional effects of these settings were investigated in a real-world experiment. The details of the settings and the experimental procedure is explained in the following section.

## 2. Study design and procedure

### 2.1. Lighting designer and kit-of-parts

In order to explore workplace lit environments that creates positive emotions, this study recruited professional lighting designers who were asked to devise two sets of detailed design proposals which could turn an empty room into one *lively* (pleasant – activation in Figure 1) and one *relaxing* (pleasant – deactivation in Figure 1) workspace using prepared lighting equipment from this study (kit-of-parts).

Ten London-based professional lighting designers were initially contacted in April 2015 and seven accepted the invitation, and five designers, ultimately, took part in this study between June 2015 to August 2015. The empty room (5.7m×4m×2.9m (length×width×height)) located on the first floor of the Bartlett School of Environment, Energy and Resources, was chosen as the target space of their design proposals. The room was equipped with eight recessed ceiling luminaires, ChromaWhite™, programmable and colour-tuneable LEDs (from 2,700K to 6,500K) which is developed by Photonstar Ltd (see Appendix A for more information). The kit-of-parts used in this study were (1) a wall partition, (2) pendant lights, (3) table lamps, and (4) a wall-shelf lighting. The light equipment was selected with an intention to represent commonly used light elements in a modern office lit environment. The images and specifications of each light component is shown in Appendix B. Lastly, daylight contribution in the room was excluded using blinds.

**2.2 Concepts of emotionally-rich workspace**

A total of ten design concepts (five 'lively' schemes and five 'relaxing' schemes) were obtained. A variety of design responses from the lighting designers were reported and some of the key features are as follows. First, four out of five lively concepts included continuously colour-changing features in either their task lighting or accent lighting. One designer mentioned that it was for creating visual attraction and two designers explained their intentions were to create a sense of time passing and an artificial connection with the outside in a windowless room. Blue-enriched lighting was predominantly used in two out of the five lively concepts to give an impression of skylight, which, according to their explanations, was to stimulate occupants' alertness. Concerning the relaxing concepts, two out of the five concepts involved the use of dynamic lighting in their accent lighting. Two relaxing concepts included only indirect lighting and one explained that it was to evoke ideas of 'work by candlelight'. The use of warm-white lighting (2,700K to 3,000K) was found in all the relaxing concepts and two concepts highlighted the use of a diffuser (e.g. globe-shaped lampshade). A part of the relaxing design concept from a participating lighting designer is shown in Figure 2 and the full details including the images of the design concepts can be accessed from Kim [25].

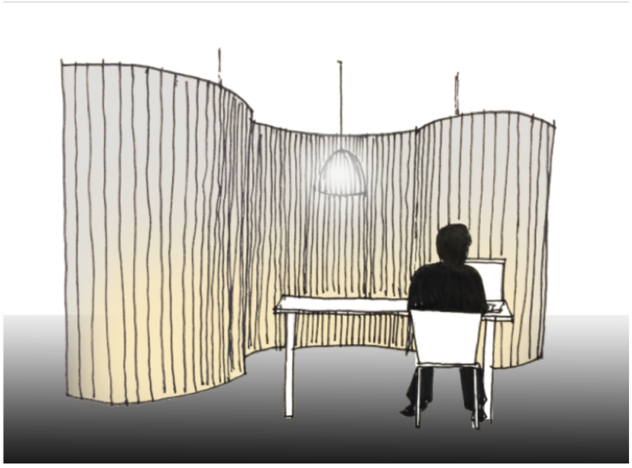


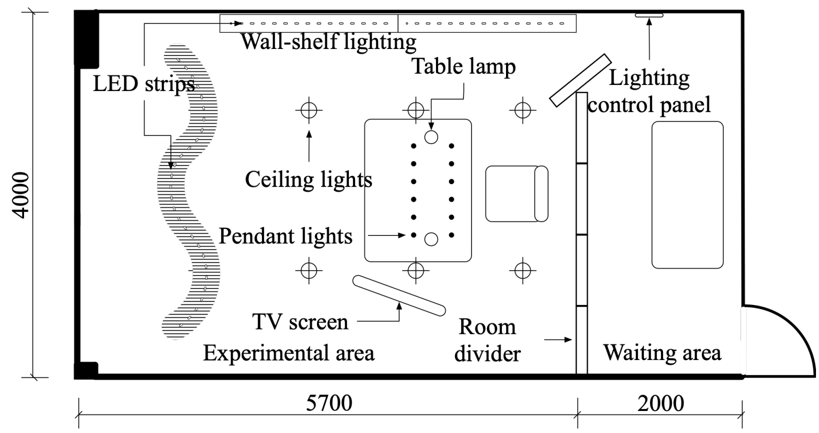
**Figure 2.** A part of the relaxing design concept from a participating lighting designer (adapted from Kim [25])

### 2.3 Experimental settings

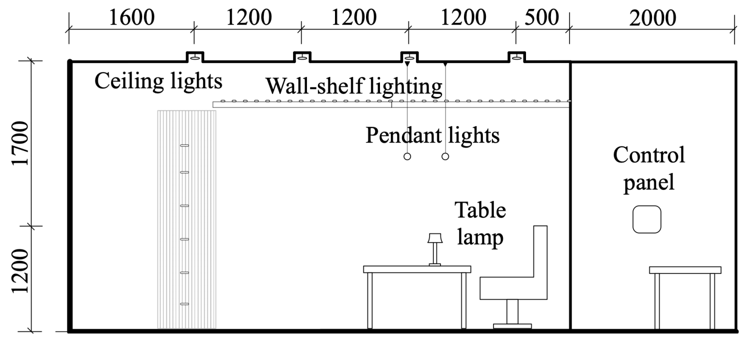
After the ten concepts (hand-drawn sketches or drawings) were all obtained from the designers, these sketches were interpreted by the principal researcher, the authors, who then replicated the key features of the concepts in converting them into ten experimental light conditions with some adjustment. Figure 3 shows the final layout of the furniture and mounting positions of the light sources used during the experiment. Eight luminaires were mounted in the ceiling of the room and twelve pendant lights were hung from a suspended ceiling. Two table lamps were placed on a table and wall shelf lighting was installed. Lastly, a room partition was integrated with six LED lightstrips so it could change from a white textile room partition into a self-luminous partition.

Settings 1 to 5 were based on the lively concepts (referred to lively settings in this study) and settings 6 to 10 were based on the relaxing concepts (referred to relaxing settings). Five additional light settings (setting 11 to setting 15) were configured with the intention to explore workspace lit environments that may be associated with two negative feelings. In this matter, settings 11 and 12 were configured with the intention to create a feeling of *tense* (unpleasant – activation in Figure 1) by providing an excessively high level of uniform illumination (higher than 1,500 lx) with either a high CCT (setting 11 – 6,500K) or a low CCT (setting 12 – 2,000K) only. Settings 13 and 14 were configured to evoke an emotion of *gloom* (unpleasant – deactivation in Figure 1) by providing a low level of nonuniform illumination (approximately 250 lx) with either a high CCT (setting 13 – 6,500K) or a low CCT (setting 14 – 2,000K) only. Lastly, under setting 15 we presented an excessively high level of contrast in colours with the expectation that this would lead to a feeling of annoyance or stress.

Table 1 summarises the use of the lighting fixtures for the fifteen light settings. General views of the fifteen light settings taken with a fisheye lens are presented in Figure 4 with annotations of their photometric and colorimetric characteristics. When a lighting setting contained dynamic features, LUMINAIR 3 (a lighting control platform, developed by Synthe FX, that allows scene-setting with control over both CCT and RGB levels) was used to pre-program the dynamic features of the settings. Figure 5 shows the expected emotion under the fifteen light settings with the circumplex model of affect.




(a) Lighting details in a floor plan




(b) Lighting details in a section plan

**Figure 3.** Location of furniture and light fixtures in the experimental room.

**Note.** The TV screen was not turned on during the experiment (no light emitted from the screen).

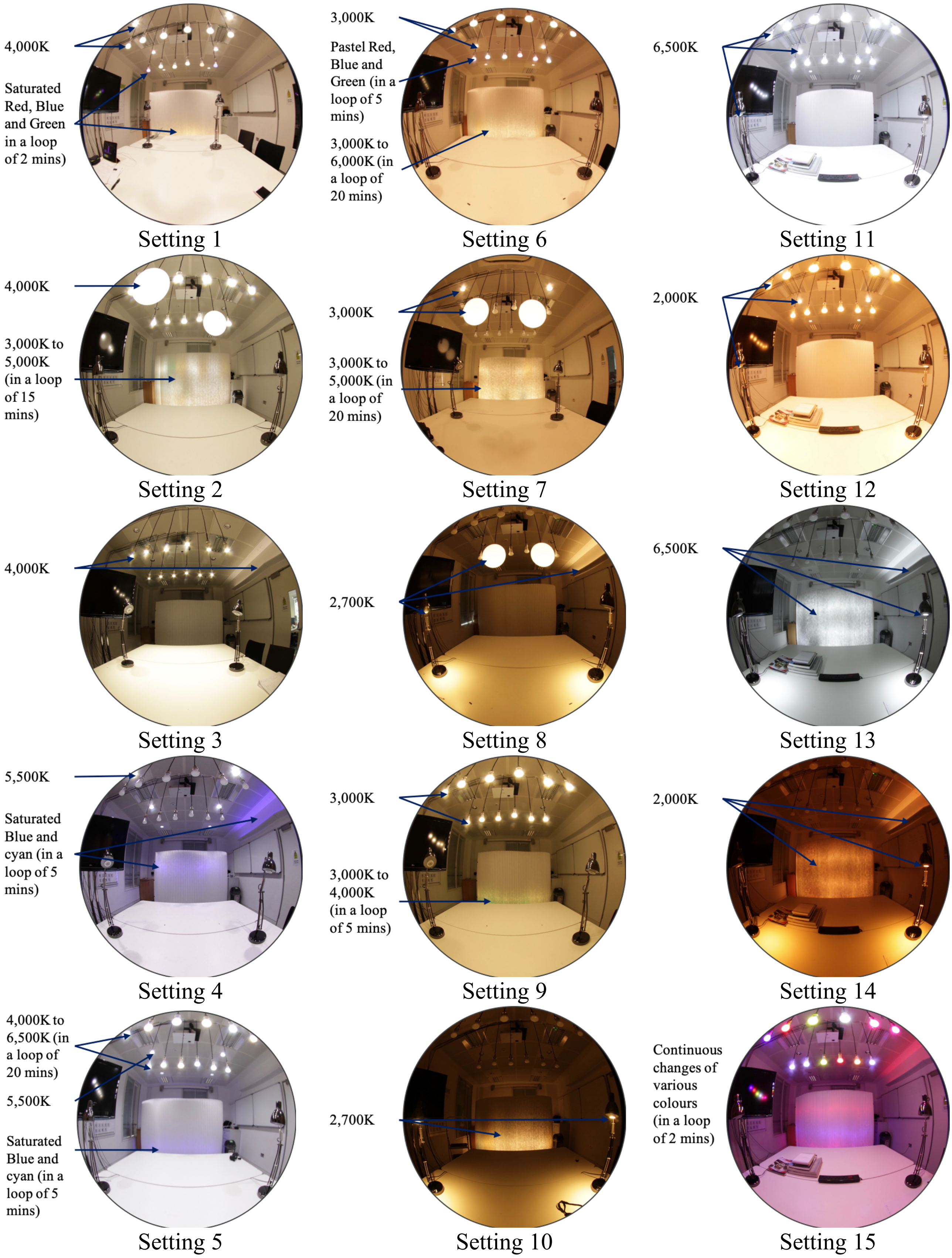


**Figure 4.** General views of fifteen light settings with a fisheye lens with annotations describing the lighting characteristics. **Note.** Detailed information of the light equipment used in the experiment is attached in Appendix B.

**Table 1.** The usage of lighting fixtures for fifteen settings in the experiment

| | Setting No. | Task lighting | | | Accent lighting | | Dynamic lighting |
|---|---|---|---|---|---|---|---|
| | | Ceiling lights | Pendant lights | Table lamps | Wall partition | Shelf lighting | |
| Lively settings | S1 | X | X | | X | | X |
| | S2 | X | X | | X | | X |
| | S3 | | X | | | X | |
| | S4 | X | | | X | X | X |
| | S5 | X | | | | X | X |
| Relaxing settings | S6 | X | X | | X | | X |
| | S7 | X | X | | X | | X |
| | S8 | | X | X | | X | |
| | S9 | | X | | X | | X |
| | S10 | | | X | X | | |
| Additional settings | S11 | X | X | X | | | |
| | S12 | X | X | X | | | |
| | S13 | | | X | X | X | |
| | S14 | | | X | X | X | |
| | S15 | | X | | X | X | X |

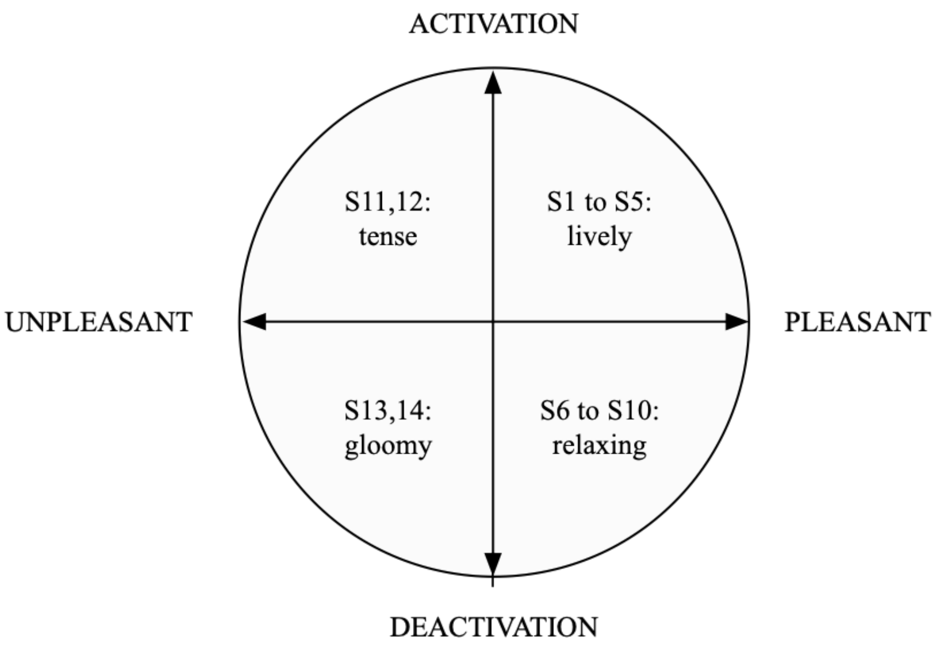



**Figure 5.** Expected emotion under the fifteen light settings with the circumplex model of affect.

### 2.4. Questionnaire development

#### 2.4.1. Perceived atmosphere of a space

In order to access perceived atmosphere (subjective impressions) of a room under fifteen lighting settings, we gave subjects a list of twenty-four emotion descriptors (see Figure 6) and asked them to mark the ones ('Check-All-That-Apply (CATA)' format) that most closely described their impression of the lit environment. CATA questions have been widely used particularly in the field of sensory and consumer science in recent years [26-29]. The application of CATA questions has been regarded as a quick alternative to gather information about perception of the emotion characteristics of products [26]. The use of a method that is based on frequencies of responses, was shown to be effective in reliably describing different environmental experiences [8,9]. The twenty-four words were selected from previous studies of the Circumplex Model of Affect [19,20,24] (see Figure 1). The role of the affect model in this study was to provide a sound sets of emotion adjectives. Figure 6 shows the descriptor lists used during the experiment.

| | | | | | |
|---|---|---|---|---|---|
| Tense | ☐ | Energetic | ☐ | Sleepy | ☐ |
| Gloomy | ☐ | Annoying | ☐ | Delightful | ☐ |
| Quiet | ☐ | Pleasing | ☐ | Unsatisfying | ☐ |
| Activating | ☐ | Stressful | ☐ | Unhappy | ☐ |
| Jittery | ☐ | Miserable | ☐ | Enthusiastic | ☐ |
| Calm | ☐ | Placid | ☐ | Depressive | ☐ |
| Exciting | ☐ | Elating | ☐ | Sad | ☐ |
| Sluggish | ☐ | Boring | ☐ | Satisfying | ☐ |

**Figure 6.** The word lists (24 descriptors in CATA format) used for assessment of perceived atmosphere during the experiment. **Note**. The order of the adjectives in the list was randomly shuffled for each light condition.

### 2.4.2. Emotion

Emotion of the participants under fifteen lighting scenarios were self-reported using the 'Affect Grid' [23], which is a single-item scale in a 9×9 matrix (unpleasantness-pleasantness via 9 points and activation-sleepiness via 9 points), as shown in Figure 7. Participants were instructed to place a mark within the cell of this matrix that best reflects their current *affective status*. This tool has been known to potentially suitable for any study that requires judgements about emotion of either descriptive or subjective kind [23] and this tool is suitable to be administered repeatedly over a relatively short interval without taxing the patience of respondents [30-32].

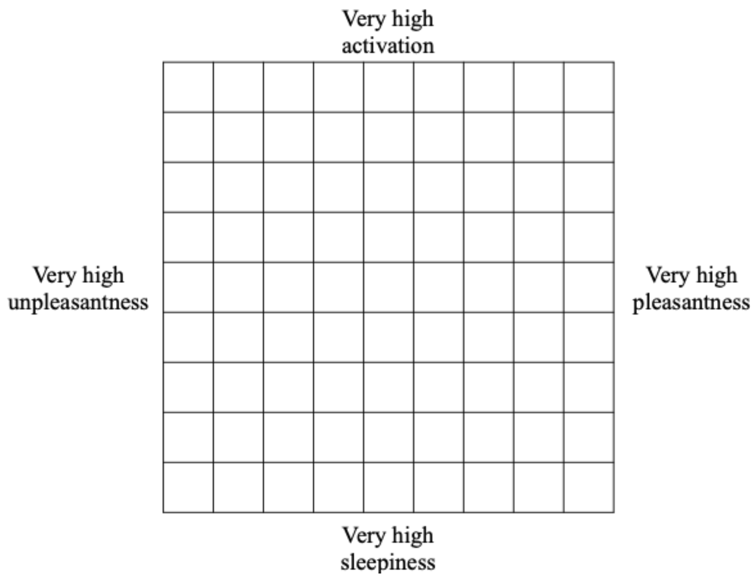



**Figure 7.** The affect grid (adapted from Russel *et al.* [23])

## 2.5. Participants and experiment procedure

The experiment was carried out between 18th June 2016 to 28th August 2016. 42 participants (22 males and 20 females) were recruited, of which 22 were mostly in their 20's and 18 in their 30's. Their educational backgrounds varied from a design-related subject (27), to an engineering subject (10) or a subject in social science (5). Almost half of them (20 out of 42) were recruited from the MSc Light and Lighting course in 2015/2016 at UCL. An Ishihara colour vision test was conducted before the experiment and no one was found to have impaired colour vision although 20 out of 42 wore either glasses or contact lenses.

The activities undertaken during the experiment are displayed in Table 2 in chronological order. A brief introduction to the experiment was provided just after the arrival of a subject. This included collecting demographic information from the participant as well as checking their visual impairments. The maintained room temperature throughout the experiment was 24°C. The participant was then asked to move into a waiting area (where the light level was very low: less than 5 lx) for adaptation (5 mins) until he or she was called again. After the adaptation period participants were asked to move into an experimental space and then were asked to thoroughly observe the lit environment for approximately 2-3 minutes. After an observation, participants were asked to fill in their impression of a space using the CATA question. Once the CATA question was completed, participants were asked to perform a short visual task (reading). Nearly everyone (38 out of 42) worked on reading their literature for their Masters degree dissertation using their own laptops. The other four worked on reading literature from their own printed materials. After ten minutes of the visual task, participants completed a questionnaire on lighting quality (not part of this paper) and they were asked to perform a short communication task. During the communication task, participants were asked to summarise and explain what they had read to the principal researcher who just entered the experimental area and sat in front of them. After the communication task, questionnaires concerning emotion, lighting quality and eyestrain were completed. Then, they were asked to move back to the waiting area while a new setting was prepared (3 mins interval). Exactly the same procedure was repeated for each of the light scenarios except that a relatively long break (10 mins) was given after conducting 10 sessions. During the experiment, the order of the light conditions randomly changed (using MS Excel functions of RANDBETWEEN and VLOOPUP) to minimise potential sequence effects. Further, the order of presenting words (in the CATA question) was changed every session using the same MS Excel functions to minimise response bias. Findings from the communication task and lighting appearance and quality ratings are to be reported elsewhere (in preparation).

**Table 2.** List of activities undertaken during the experiment in chronological order

| **Duration (min)** | **Light condition** | **Activities** | **Area** |
|---|---|---|---|
| 0:00 | Dim | Arrival of a participant | Waiting area |
| 0:00-0:05 | Default | Introduction | Experimental area |
| 0:05-0:10 | Dim | Adaptation | Waiting area |
| | | **Start of 1st session** | |
| 0:10-0:12 | Light scenario 1 | Observation of a room | Experimental area |
| 0:12-0:15 | | Questionnaire (appearance, atmosphere) | |
| 0:15-0:25 | | Visual task (reading) | |
| 0:25-0:27 | | Questionnaire (lighting quality1) | |
| 0:27-0:32 | | Communication task | |
| 0:32-0:34 | | Questionnaire (lighting quality 2) | |
| 0:34-0:36 | | Questionnaire (emotion) | |
| 0:36-0:37 | | Questionnaire (eyestrain) | |
| | | **End of 1st session** | |
| 0:37-0:40 | Dim | Break (adaptation) | Waiting area |
| 0:40-1:10 | | Light scenario 2+ break | |
| 1:10-1:40 | | Light scenario 3 + break | |
| ⋮ | | ⋮ | |
| 4:10-4:40 | | Light scenario 9 + break | |
| 4:40-5:10 | | Light scenario 10 + break | |
| 5:10-5:20 | Dim | Break (adaptation) | Waiting area |
| 5:20-5:50 | | Light scenario 11 + break | |
| ⋮ | | ⋮ | |
| 7:20-7:50 | | Light scenario 15 | |
| | | **End of 15th session** | |

## 2.6. Statistical analysis

The following procedures for data analysis were applied in this paper. We followed guidance by Meyners *et al.* [33] to analyse the data from the CATA question. Concerning the analysis of perceived atmosphere, frequency of use of each descriptor was first determined by counting the number of participants that used that word to describe subjective impression of each light condition. Then, the Cochran's $Q$ test, using the exact probability and distribution of the $Q$ statistic [34], was carried out separately on data from each light setting to identify significant differences among the settings for each of the atmosphere descriptors. Correspondence analysis (CA), considering $\chi^2$ distances, was performed on the frequency tables that were derived from each experiment treatment. CA is a widely used tool for visualising a contingency table, which might be considered as a generalization of principal component analysis (PCA) for ordinary data [33]. The method projects the data into orthogonal components such as to maximize the sequential representation of the variation in the data.

Regarding the analysis of perceived emotion, the following procedure was carried out. First, normality of the self-rated emotion distributions was tested using the Shapiro Wilk test with a significance level of 5% ($p<0.05$). Then, the Friedman's test with Dunn-Bonferroni post hoc correction was performed to compare the difference in self-rated emotion across the light settings. The Friedman's test is a non-parametric statistical test, to use for a repeated measures type of experiment [35]. Lastly, a bivariate kernel density estimate (KDE), a technique that is a powerful exploratory tool especially for a nonparametric dataset [36], was plotted on each emotion plane. In this way, emotion distributions under fifteen light scenarios were visually presented. Such method has been used by Yan and Chen [37] and Zhang and Essl [38] who also focused on emotion distributions.

The above statistical analyses were performed using XLSTAT statistical software (Addinsoft, New York, NY, United States), SPSS 24.0 (IBM SPSS Inc., Chicago, IL, United States) and Origin pro 2019b (OriginLab Corporation, Northampton, MA, United States) [39].

## 3. Results

### 3.1. Atmosphere of a space

### 3.1.1. Frequency of use of the descriptors

The frequency of use of each of the descriptors of the CATA question to describe atmosphere of the spaces under the fifteen lighting scenarios is shown in Table 3. According to Cochran's Q test, statistically significant differences ($p \leq 0.05$) in the frequency with which 22 of the 24 descriptors from the atmosphere question were used to describe the affective quality of the spaces, suggesting the differences in perceived atmosphere caused by different light scenarios. Only the descriptors of 'boring' and 'jittery' were not found to be statistically different in the use of describing perceived atmosphere. Participants selected an average of 2.9 descriptors (SD: 1.3) to describe their atmosphere perception for each light setting and there was no statistical difference in the numbers of the descriptors being used across the fifteen settings (F=2.38, adj. $p$=0.454). Further, the male and female participants used an average of 3 and 2.9 descriptors per each setting respectively and the difference was not significant (t=0.71, $p$=0.479).

### 3.1.2. Perceived atmosphere under each light setting

Figure 8 shows the representation of the light settings and atmosphere descriptors in the first two coordinates of the corresponding analysis (CA) performed on the frequency table using $\chi^2$ distances. The two dimensions explained 67.4% of the variance of the experimental data ($\chi^2$=1461.7, $p$<0.001), suggesting that human perception of atmosphere can reasonably be plotted onto a two-dimensional space. More specifically, dimension 1 ($x$-axis) was the main discrimination factor in perceived atmosphere of the light settings which accounted for 49% of the total variance. The words 'activation' and 'sleepy' scored lowest ($x$=-0.89) and highest ($x$=0.86) in dimension 1, respectively. The second discriminating factor was dimension 2 (*y*-axis) which accounted for 18% of the total variance. The descriptors of ‘unsatisfying’ and ‘pleasing’ scored lowest (*y*=-1.16) and highest (*y*=0.42) in this dimension.

The distance between the circles corresponding to the light settings is a measure of their similarity. For example, perceived atmospheres under setting 4 (*x*=-0.75, *y*=0.31) and 5 (*x*=-0.80, *y*=0.31) were plotted at a very similar point onto the two-dimensional atmosphere plane. The descriptors that were within a short distance to those perceptions were ‘activating’ (*x*=-0.89, *y*=0.25), ‘energetic’ (*x*=-0.85, *y*=0.14) and ‘enthusiastic’ (*x*=-0.74, *y*=0.17). According to the circumplex model of affect (as shown in Figure 1), those words are plotted onto the quadrant of pleasant-activation (liveliness). Coordinates of setting 8 (*x*=0.89, *y*=0.20) and 10 (*x*=0.94, *y*=0.27) indicates that their perceptions were similar to each other. The most neighbouring descriptors were ‘calm’ (*x*=0.66, *y*=0.22), and ‘quiet’ (*x*=0.79, *y*=0.14), indicating that the atmosphere under setting 8 and 10 was pleasant-deactivation (relaxation) according to the affect model. Setting 7 was plotted at a point (*x*=0.39, *y*=0.39) where it was somewhat between ‘pleasing’ (*x*=0.18, *y*=0.42) and ‘calm’ (*x*=0.66, *y*=0.22), suggesting a feeling of relaxation, too. A coordinate of setting 14 (*x*=0.56, *y*=-0.87) was within a short distance of the words of ‘sad’ (*x*=0.58, *y*=-0.73) and ‘gloomy’ (*x*=0.51, *y*=-0.64), suggesting a unpleasant-deactivation (gloom) perception occurring. Setting 11 (*x*=-0.86, *y*=-0.14), setting 15 (*x*=-0.72, *y*=-0.63) and settings 4 (*x*=-0.75, *y*=0.31) and 5 (*x*=-0.80, *y*=0.31) resulted in different atmosphere perceptions and those differences were mainly explained by dimension 2. The atmosphere of setting 11 was plotted close to the descriptor ‘tense’ (*x*=-0.80, *y*=-0.02) and setting 15 was plotted at a point which was between ‘stressful’ (*x*=-0.75, *y*=-0.38) and ‘annoying’ (*x*=-0.51, *y*=-0.73), indicating that both settings were perceived as a feeling of unpleasant-activation (tense). Full coordinates of the descriptors and the fifteen light settings are shown in Tables 4 and 5.

**Table 3.** Number of participants who used each of the descriptors of the CATA question to describe atmosphere of the space under the fifteen light settings

| **Atmosphere descriptors** | **'Lively' settings** | | | | | **'Relaxing' settings** | | | | | **Additional five settings** | | | | | **Sum** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **S1** | **S2** | **S3** | **S4** | **S5** | **S6** | **S7** | **S8** | **S9** | **S10** | **S11** | **S12** | **S13** | **S14** | **S15** | |
| Activating$^{***}$ | 12 | 16 | 10 | 28 | 26 | 6 | 2 | 0 | 2 | 0 | 21 | 4 | 4 | 0 | 12 | 143 |
| Energetic$^{***}$ | 3 | 6 | 6 | 21 | 18 | 6 | 0 | 0 | 4 | 0 | 16 | 8 | 2 | 2 | 11 | 103 |
| Elating$^{**}$ | 0 | 1 | 2 | 2 | 0 | 4 | 0 | 0 | 1 | 0 | 1 | 2 | 0 | 0 | 6 | 19 |
| Exciting$^{***}$ | 6 | 5 | 2 | 8 | 6 | 3 | 2 | 0 | 2 | 0 | 8 | 2 | 0 | 0 | 18 | 62 |
| Enthusiastic$^{***}$ | 8 | 6 | 4 | 15 | 11 | 6 | 6 | 0 | 2 | 0 | 12 | 7 | 0 | 0 | 10 | 87 |
| Delightful$^{***}$ | 16 | 4 | 0 | 4 | 8 | 14 | 19 | 6 | 12 | 6 | 3 | 2 | 2 | 4 | 14 | 114 |
| Pleasing$^{***}$ | 19 | 13 | 6 | 12 | 6 | 10 | 22 | 12 | 19 | 18 | 4 | 8 | 5 | 2 | 2 | 158 |
| Satisfying$^{***}$ | 2 | 14 | 3 | 11 | 10 | 12 | 12 | 10 | 8 | 2 | 4 | 12 | 7 | 4 | 0 | 111 |
| Calm$^{***}$ | 10 | 8 | 10 | 6 | 1 | 16 | 27 | 30 | 14 | 32 | 1 | 10 | 26 | 13 | 0 | 204 |
| Placid$^{***}$ | 0 | 0 | 2 | 0 | 2 | 8 | 8 | 6 | 6 | 4 | 0 | 1 | 4 | 1 | 2 | 44 |
| Quiet$^{***}$ | 3 | 4 | 6 | 4 | 3 | 6 | 14 | 29 | 10 | 35 | 1 | 8 | 27 | 14 | 0 | 164 |
| Sleepy$^{***}$ | 4 | 0 | 2 | 0 | 2 | 4 | 4 | 21 | 14 | 20 | 0 | 10 | 6 | 26 | 2 | 115 |
| Boring$^{n.s}$ | 2 | 6 | 2 | 0 | 2 | 0 | 6 | 6 | 4 | 2 | 4 | 5 | 4 | 4 | 0 | 47 |
| Sluggish$^{**}$ | 2 | 2 | 2 | 2 | 0 | 4 | 6 | 0 | 0 | 4 | 0 | 5 | 0 | 6 | 2 | 35 |
| Depressive$^{***}$ | 4 | 0 | 5 | 0 | 0 | 0 | 3 | 2 | 6 | 0 | 4 | 0 | 8 | 10 | 0 | 42 |
| Gloomy$^{***}$ | 1 | 0 | 1 | 4 | 0 | 0 | 0 | 4 | 4 | 4 | 0 | 2 | 13 | 10 | 6 | 49 |
| Sad$^{***}$ | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 1 | 1 | 0 | 0 | 1 | 6 | 5 | 2 | 19 |
| Miserable$^{*}$ | 1 | 0 | 2 | 4 | 1 | 4 | 2 | 0 | 2 | 0 | 4 | 0 | 2 | 6 | 6 | 34 |
| Unhappy$^{***}$ | 1 | 2 | 2 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 6 | 6 | 27 |
| Unsatisfying$^{***}$ | 1 | 1 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 3 | 0 | 10 | 4 | 24 |
| Annoying$^{***}$ | 1 | 0 | 1 | 0 | 2 | 2 | 2 | 0 | 6 | 0 | 9 | 4 | 0 | 5 | 15 | 47 |
| Stressful$^{***}$ | 0 | 2 | 6 | 0 | 4 | 2 | 0 | 0 | 4 | 0 | 8 | 4 | 0 | 2 | 8 | 40 |
| Jittery$^{n.s}$ | 0 | 2 | 2 | 2 | 4 | 0 | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 3 | 2 | 18 |
| Tense$^{***}$ | 2 | 4 | 12 | 14 | 9 | 0 | 0 | 0 | 2 | 0 | 10 | 4 | 2 | 2 | 6 | 67 |
| Sum | 99 | 96 | 90 | 137 | 115 | 114 | 136 | 127 | 123 | 127 | 116 | 104 | 120 | 135 | 134 | |

$^{***}$Indicates significant differences among the light settings according to Cochran's Q test at $p \leq 0.001$

$^{**}$Indicates significant differences at $p \leq 0.01$

$^{*}$Indicates significant differences at $p \leq 0.05$

$^{n.s}$Indicates no significant differences $p > 0.05$

**Table 4.** Coordinates of the descriptors on a two-dimensional atmosphere plane from the CA

| | Dimension 1, -*x* | Dimension 1, *x* |
|---|---|---|
| Dimension 2, *y* | Activating (-0.89, 0.25) | Pleasing (0.18, 0.42) |
| | Energetic (-0.85, 0.14) | Calm (0.66, 0.22) |
| | Enthusiastic (-0.74, 0.17) | Placid (0.56, 0.19) |
| | Delightful (-0.01, 0.14) | Quiet (0.79, 0.14) |
| | Satisfying (-0.05, 0.33) | Boring (0.25, 0.1) |
| Dimension 2, -*y* | Unhappy (-0.17, -0.95) | Unsatisfying (0.02, -1.16) |
| | Annoying (-0.51, -0.73) | Sad (0.58, -0.73) |
| | Miserable (-0.31, -0.51) | Gloomy (0.51, -0.64) |
| | Stressful (-0.75, -0.38) | Depressive (0.39, -0.49) |
| | Exciting (-0.78, -0.26) | Sleepy (0.86, -0.32) |
| | Jittery (-0.52, -0.27) | Sluggish (0.21, -0.14) |
| | Tense (-0.80, -0.02) | |

**Table 5.** Coordinates of the fifteen light settings on two-dimensional atmosphere plane from the CA

| Lighting conditions | | Atmosphere coordinates | |
|---|---|---|---|
| | | *x* | *y* |
| 'Lively' settings | Setting 1 | -0.12 | 0.20 |
| | Setting 2 | -0.45 | 0.31 |
| | Setting 3 | -0.39 | -0.09 |
| | Setting 4 | -0.75 | 0.31 |
| | Setting 5 | -0.8 | 0.31 |
| 'Relaxing' settings | Setting 6 | 0.02 | 0.07 |
| | Setting 7 | 0.39 | 0.39 |
| | Setting 8 | 0.89 | 0.2 |
| | Setting 9 | 0.31 | -0.01 |
| | Setting 10 | 0.94 | 0.27 |
| Additional settings | Setting 11 | -0.86 | -0.14 |
| | Setting 12 | 0.01 | -0.09 |
| | Setting 13 | 0.75 | -0.1 |
| | Setting 14 | 0.56 | -0.87 |
| | Setting 15 | -0.72 | -0.63 |

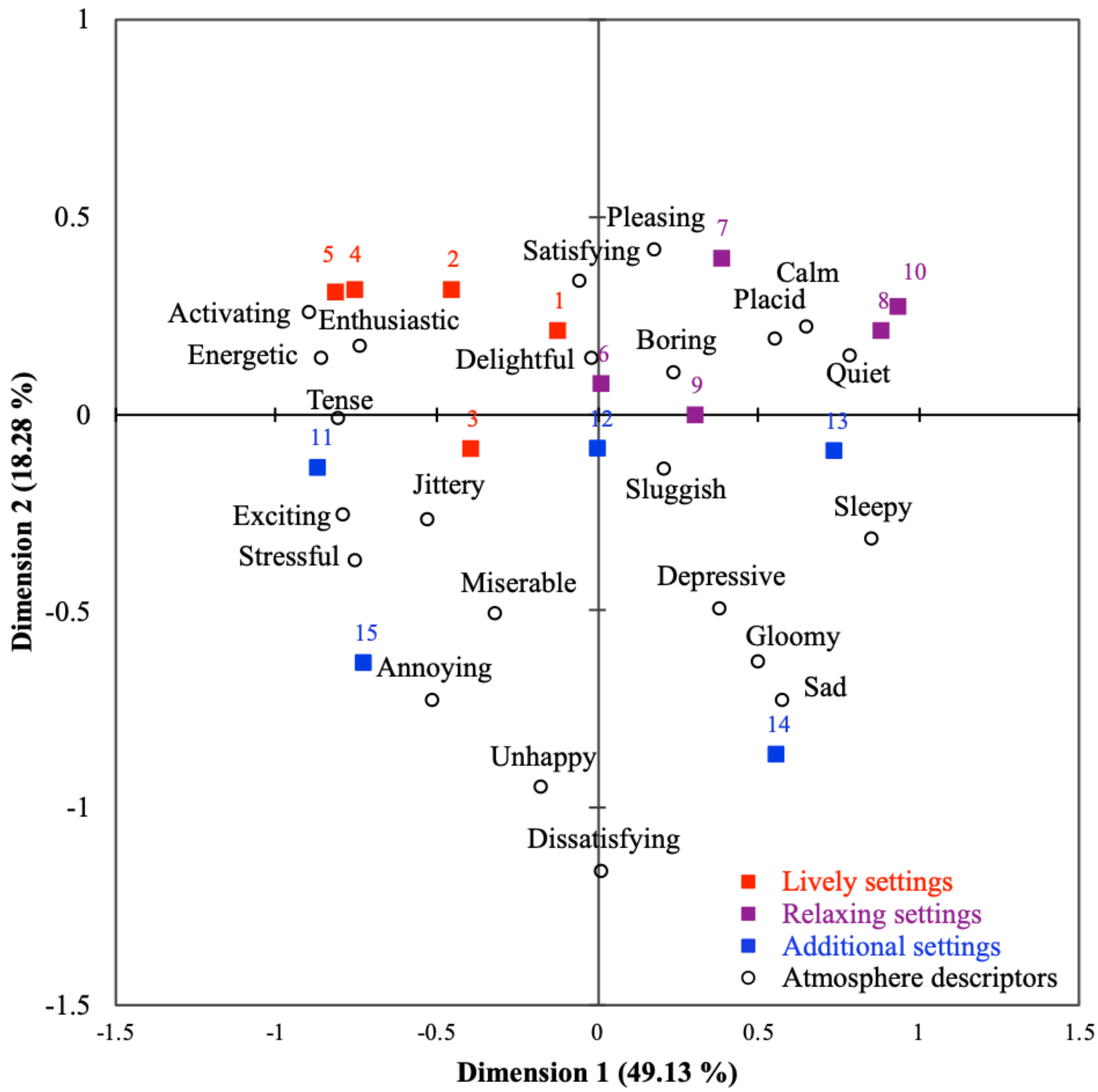



**Figure 8.** The atmosphere descriptors and the fifteen light settings plotted onto two-dimensional atmosphere plane from the CA based on $\chi^2$ distances. **Note.** Green, navy, blue and red circles indicate lively settings, relaxing settings, additional settings and the descriptors, respectively.

### 3.2. Emotion of the subjects

#### 3.2.1. Emotion distributions under five lively settings

An exploratory data analysis was carried out to investigate whether subjects felt liveliness (pleasant – activation) under setting 1 to setting 5. Table 6 summarises the descriptive statistics of perceived emotion. First, of all the emotion distribution (except for perceived sleepiness under setting 1, $p$=0.069) under the five lively settings departed significantly from a normal distribution (Shapiro Wilk test: $p<0.05$). As emotion is expressed as a single point consisting of pleasantness and sleepiness, in order to visualize the patterns of emotion distribution, 2-dimensional plots, combining both dimensions using a bivariate kernel density estimation, were created as shown in Figure 9. The following analysis was carried out by visual inspection of the emotion distributions.

Under setting 4 and setting 5, participants' emotion densities were highly concentrated in the upper right area of the affect space, which indicates that their affective status was very close to 'pleasantness with arousal'. Under setting 1, although participants' emotion was concentrated, the central point of concentration was very close to a neutral feeling, which would mean that subjects felt mostly neutral emotion under the light scenario. Under setting 2 and setting 3, relatively similar shapes of emotion distribution were found. Densities of perceived emotion under both settings showed a low level of concentration in the upper right area of the affect space. A larger spacing between the contour lines indicated that there was high level of individual differences in perceived emotion under these settings. Based on the result, it could be said that our desired emotion (pleasantness with high arousal) was reported under setting 4 and setting 5, which also successfully yielded a 'lively' atmosphere.

#### 3.2.2. Emotion under five relaxing settings

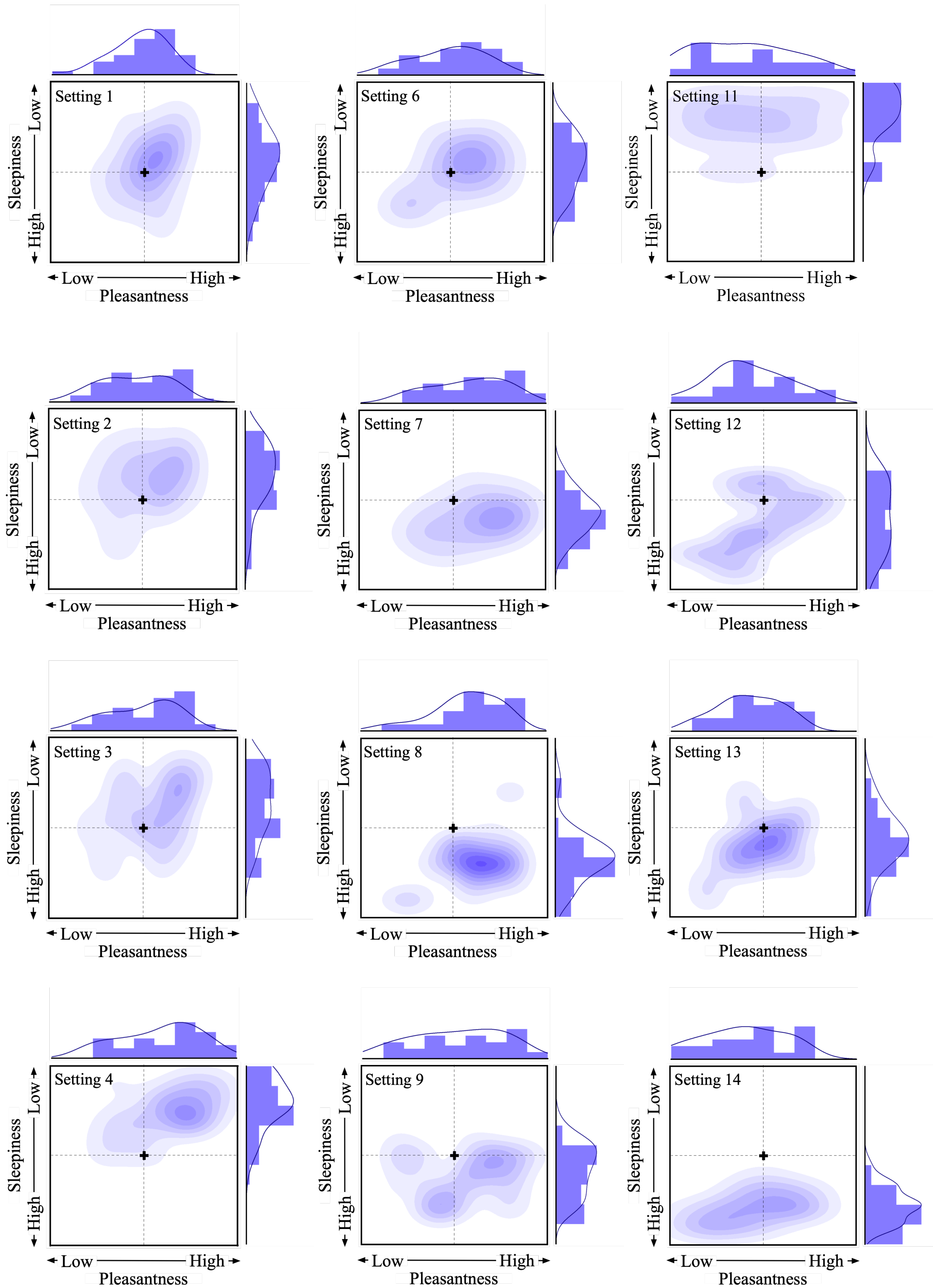
Participants' self-rated emotion under five relaxing settings departed significantly from a normal distribution (Shapiro Wilk test: $p<0.05$ as shown in Table 6). Due to its nonparametric characteristic, emotion distribution was analysed by a visual inspection from Figure 9. The results from the 2-d kernel density plots indicate that participants' feelings under setting 8 and setting 10 were particularly concentrated on 'pleasantness with sleepiness' (lower right part of the circumplex affect diagram). Emotions under setting 7 also showed a similar pattern but with a relatively lower level of concentration. Under setting 6, perceived emotion appeared to have a bimodal tendency; a relatively high concentration in a near neutral feeling and a relatively low concentration on 'unpleasant with sleepiness' (lower left of the circumplex affect diagram). Emotion distribution under setting 9 seemed to have three peaks: one in pleasantness, one in sleepiness and the other one in unpleasantness. Overall, it can be concluded based on the result in this section that our desired emotion was found under lighting scenario 7, 8 and 10. The other relaxing settings did not cue the shared feelings of the emotion.

### 3.2.3. Emotion under five additional settings

Perceived emotion under the five additional light settings were also investigated through a visual inspection as all of the emotion distributions departed significantly from a normal distribution of emotion (Shapiro Wilk test: $p<0.05$). Under setting 11, subjects' emotion was highly concentrated in activation but widely spread along the dimension of pleasantness-unpleasantness. Under setting 12, the result indicates that there appeared to be no shared feeling perceived by the participants. Emotion distribution under setting 13 showed a high concentration on sleepiness. It can be concluded the majority of subjects felt a weak degree of sleepiness under setting 13. Under light setting 14, participants felt a strong degree of sleepiness and a weak degree of unpleasantness. Lastly, under setting 15 emotion distribution showed a tendency to unpleasantness with arousal.

**Table 6.** Summary of descriptive statistics for perceived pleasantness and sleepiness under each light setting

| | Setting No. | Pleasantness (1: very high unpleasantness to 9: very high pleasantness) | | | Sleepiness (1: very high activation to 9: very high sleepiness) | | |
|---|---|---|---|---|---|---|---|
| | | Mean (SD) | Median (IQR) | Shapiro-Wilk test (*p*) | Mean (SD) | Median (IQR) | Shapiro-Wilk test (*p*) |
| Lively settings | 1 | 5.2 (1.3) | 5 (2) | 0.002 | 4.7 (1.6) | 5 (2) | 0.069 |
| | 2 | 5.1 (1.6) | 5 (3) | 0.009 | 4.1 (1.6) | 4 (2) | 0.003 |
| | 3 | 5.4 (1.7) | 6 (3) | 0.003 | 4.2 (1.6) | 4 (2) | 0.003 |
| | 4 | 6.2 (1.9) | 7 (3) | 0.003 | 2.7 (1.3) | 3 (1) | 0.003 |
| | 5 | 6.1 (1.4) | 6 (2) | 0.028 | 3.1 (1) | 3 (2) | <0.001 |
| Relaxing settings | 6 | 5.4 (1.7) | 6 (3) | 0.021 | 5 (1.3) | 5 (2) | 0.002 |
| | 7 | 6.1 (1.9) | 6 (4) | 0.003 | 6.1 (1.2) | 6 (1) | 0.002 |
| | 8 | 6.1 (1.7) | 6 (2) | 0.001 | 6.9 (1.2) | 7 (1) | <0.001 |
| | 9 | 5.5 (2.2) | 6 (3) | 0.006 | 6.2 (1.3) | 6 (2) | 0.001 |
| | 10 | 6.1 (1.7) | 5 (2) | <0.001 | 7 (1.1) | 7 (2) | <0.001 |
| Additional settings | 11 | 4.7 (2.5) | 4 (5) | 0.007 | 2.3 (1.2) | 2 (2) | <0.001 |
| | 12 | 4.8 (1.9) | 4 (2) | 0.025 | 6.2 (1.6) | 6 (2) | 0.003 |
| | 13 | 4.8 (1.5) | 5 (2) | 0.008 | 5.9 (1.6) | 6 (2) | 0.01 |
| | 14 | 4.4 (2) | 5 (3) | 0.003 | 8 (0.9) | 8 (2) | <0.001 |
| | 15 | 3 (1.6) | 3 (2) | 0.002 | 4 (2.1) | 3 (4) | <0.001 |


Setting 1
Setting 6
Setting 11
Setting 2
Setting 7
Setting 12
Setting 3
Setting 8
Setting 13
Setting 4
Setting 9
Setting 14
Sleepiness
Low
High
Pleasantness
Low
High

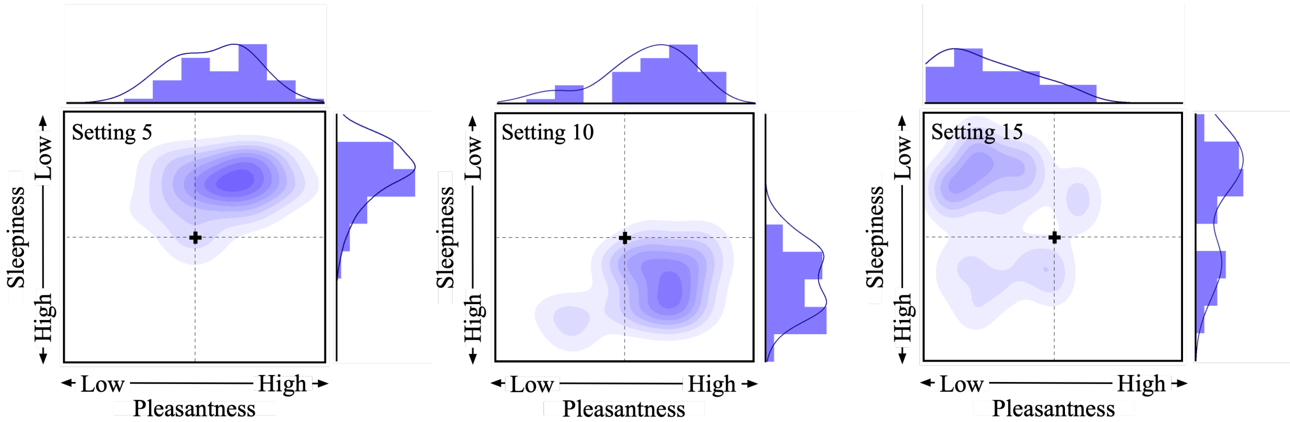



**Figure 9.** Combined unpleasantness-pleasantness and activation-sleepiness plotted as bivariate kernel density estimates (under 15 light conditions). The horizontal axis of the grid indicates perceived pleasantness-unpleasantness and the vertical axis indicates perceived activation-sleepiness. The cross in the middle of 2-d plots indicates a neutral point of both pleasantness and sleepiness.

### 3.2.4 Comparison of the emotion distributions

A non-parametric Friedman's test of differences among repeated measures of self-rated emotions under the fifteen light settings was conducted and the result revealed that there was a significant difference in both pleasantness and sleepiness scores across the settings ($\chi^2(14)=315.202$, $p<0.001$). Post-hoc tests using a Dunn-Bonferroni correction showed that pleasantness scores did not significantly differ among setting 1 to setting 10 (all 'lively' and 'relaxing' settings). However, self-rated pleasantness scores under setting 4 and 5 were significantly different from the scores reported under settings 11, 12, 14 and 15 at Bonferroni adjusted $p<0.05$. The result from the post-hoc analysis also shows that pleasantness scores under three relaxing settings (setting 7, 8 and 10) were significantly different from the self-rated pleasantness under settings 11, 12, 14 and 15 (adj. $p<0.05$). Participants felt a significantly lower level of pleasantness under setting 15 as compared to their pleasantness feelings under setting 1 to setting 10 (adj. $p<0.05$).

With regard to self-rated sleepiness score, there was found to be no statistical difference among the five lively settings. Among the five relaxing settings, participants reported significantly higher levels of sleepiness under setting 8 and setting 10 than setting 6 (adj. $p<0.05$). The highest level of activation was reported under setting 11, which showed a statistically significant difference with most of the settings, except for setting 4 and setting 5 (adj. $p<0.05$). On the other hand, self-rated sleepiness under setting 14 was significantly different from the sleepiness scores obtained from all the other settings except for setting 8 and 10 (adj. $p<0.05$). Figure 10 shows a graph [comparison] of the emotional responses under fifteen light settings

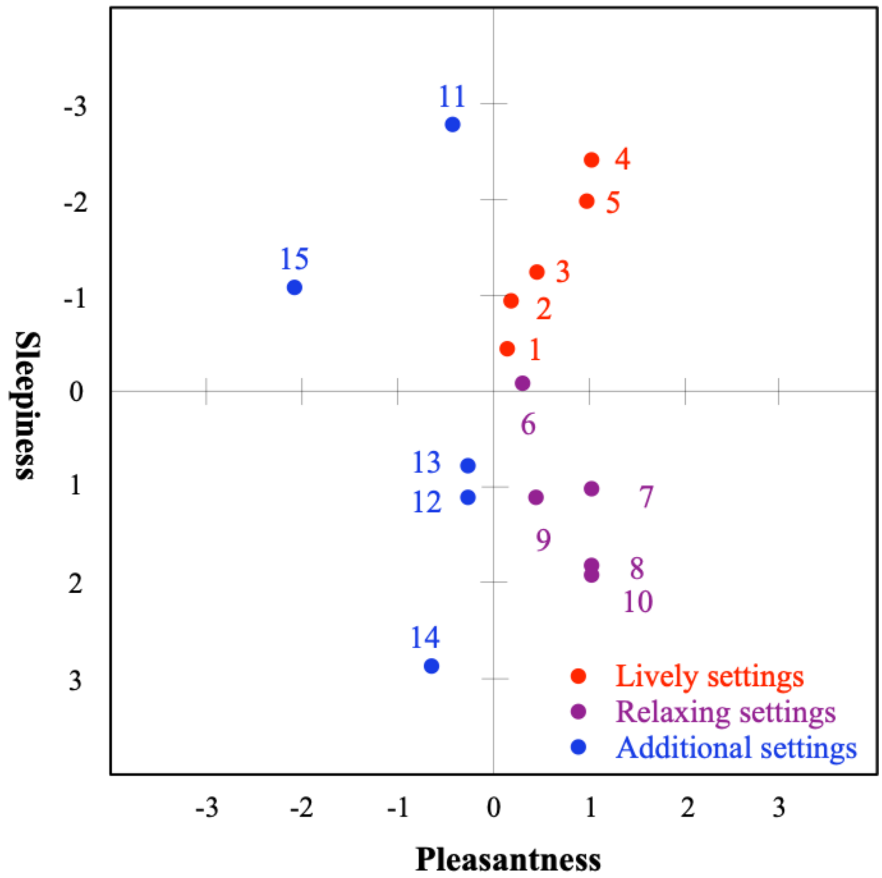



**Figure 10.** Emotional responses under fifteen light settings. Mean emotion scores under the fifteen settings are plotted onto the two-dimensional emotion plane. Green, navy and blue circles indicate lively settings, relaxing settings, and additional settings, respectively.

 https://doi.org/10.1016/j.buildenv.2021.107686

## 4. Discussion

### 4.1. Towards emotion-based workspace lighting design

In this study, the lighting designers devised their own lighting concepts with a goal to create positive emotions (pleasant – activation (liveliness) and pleasant – deactivation (relaxation)) with the kit-of-parts and the results showed that five concepts (two lively and three relaxing) succeed in yielding both positive atmosphere and intended emotions. Based on this finding, it could be suggested that there is the potential of emotion-based lighting design even with the limited resources in lighting equipment.

The results of this study also allow the introduction of four workspace lit environments that may well generate four different human emotions (liveliness, relaxation, gloom and tense). First, the human emotion of liveliness was reported under two light settings, which shared the following design characteristics: (1) task lighting with a CCT range of 5,000K to 5,500K, (2) accent lighting generating directional pattern and (3) the use of saturated blue and cyan colour in the accent lighting. Secondly, the human emotion of relaxation was evoked under three light settings with following design characteristics: (1) task lighting with a CCT range of 2,700K to 3,000K, (2) the use of lamp diffuser and/or (3) a cove effect or an uplight effect created by the accent lighting. Thirdly, the emotion of gloom was reported in the workspace lit environment: (1) low task illumination (~250 lx) by the use of indirect lighting with a CCT of 2,000K, and (2) accent lighting generating a wall-washing effect and a cove effect. Lastly, a tense emotion occurred with high task illumination (~1500 lx) by the use of direct lighting with a CCT of 6,500K. However, it should be noted that such lit environments that generated the negative emotions are very unlikely to be encountered in a real-world office environment, and therefore we assume that in most real office environments lighting scenarios based on *current* lighting recommendations would not yield any of the negative emotions.

Another finding from this study is that atmosphere perception and emotion can be cued by relatively short light exposure. For example, 3-minutes of exposure to different light conditions were shown to evoke different atmosphere perceptions. 20-minutes of exposure to different light conditions were also shown to evoke different human emotions. Additionally, the findings suggest that perceived atmosphere of a space could be a good predictor of self-rated emotion of occupants. In this study, atmosphere perception was assessed after 3-minutes of an observation and human emotion was self-rated after approximately 20-minutes of an exposure to each light condition and four different atmospheres all resulted in four representative emotions. This suggests that there may be a promising link between perceived atmosphere of a space and human (short-term) emotion. Lastly, this study shows the usefulness of an emotion model-*the circumplex model of affect*-as a tool to characterise and describe the emotional effect of (dynamic) lighting.

### 4.2. Limitations and recommendations

We claim that this study is one of the first attempts to characterise and describe emotional effect of lighting at a workspace through a real environment experiment with the involvement from professional lighting designers. However, further studies are recommended as the current study has a few following limitations. First, the findings of human emotion and perceived atmosphere in this study were solely obtained through analysis of self-rated questionnaires. It would be interesting to include additional objective measures of emotion such as facial expressions [40], brain activity [41] or pupil dilation. Second, this study investigated the short-term emotional effect of lighting and therefore, it would be interesting to determine whether the effects occur over the long-term. Third, there may be potential factors (cultural, educational) that could have influenced the results of this study. For example, under setting 2, participants with non-design background reported relatively higher ratings of pleasantness (mean: 6.3) than the subjects with design-related background (mean: 4.8). Therefore, a further study controlling such factors would be needed to support the findings from this study. Lastly, a further investigation on how the emotional effect of lighting can be characterised by commonly used illuminance metrics, luminance ratios and colorimetric variables would assist better understanding of the impacts.

Lastly, the following procedure can be suggested to lighting designers or architects who would like to implement the findings from this study for a practical application. First, lighting designers and/or architects should identify which positive emotions (liveliness or relaxation) are to be set as a goal in their design project. This may involve collecting information of preferred emotion/atmosphere of a workspace from current or potential occupants. The CATA question with the descriptors, presented in this study, (from the circumplex model of affect) could be used for this purpose. For example, the occupants' preferred atmosphere was mainly described with descriptors such as 'calm', 'quiet' and 'pleasing'. The designer could then set the human emotion of 'relaxation' as a goal in their design process and start to deliver their own solution. Lynes [42] argued that lighting is not an art, not a science but rather a language. In this sense, we are now being given an opportunity to invent a new 'language of light', a non-verbal communication of not only expressing our preferred appearance but also expressing our preferred emotions. For a long period, our vocabulary extensively focused on describing the appearance of the space, which is without doubt, one of the most crucial parts of the language. Hopefully, this study would lead an ignition of interest in the development of our vocabulary of human emotion in lighting.

Inevitably, one most important aims of lighting design, in principle, is to provide *adequately* and *pleasantly lit environments* while maintaining visual clarity and promoting non-visual positive health impacts. However, in the real world, it is not surprising that such vague, non-calculable aspects of lighting design have been paid less attention to engineers and facility managers. As a consequence, it is also not surprising that many lighting installations, as a visual experience, in contemporary office environments are described in less than *enthusiastic* terms. This study shows the potential for emotion-based lighting design in an office-like environment and proposes a methodology that may be used to characterise the emotional effect of lighting arrangements. Only then is there the enticing prospect of moving beyond lighting schemes that are merely ‘indifferent’ to those, in the words of Boyce [43], that actually ‘lift the spirits’.

**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**

We would like to thank the lighting designers and the participants who undertook the field study. No specific funding has been used to support this study.

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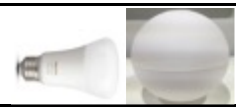
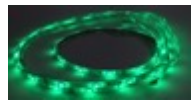
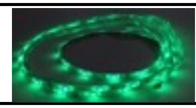
**Appendix A.** Photographs of the unfurnished experimental area

**Figure A.1** Photographs of the unfurnished experimental area
(up: illuminated by ChromaWhite at 6,500K and down: illuminated by ChromaWhite at 2,000K).

**Appendix B.** Lighting in the experiment

**Table B.1** Lighting in the experiment

| Types of light sources | Location | Light sources | | | | Lighting control | | | Photographs |
|---|---|---|---|---|---|---|---|---|---|
| | | Manufacturer | Model name | Beam angle | Installed quantities | Pre-programmed | Colour changing | CCT tuneable |  |
| Ceiling lights | Recessed mounted on a ceiling | Photonstar LED | Chromawhite™ Circadian | 36º | 8 | Yes | Yes | 2700K ~ 6500K |  |
| Pendant lights | Hung from a suspended ceiling | Philips | Hue White and colour ambience (A19 lamp) | 160º | 12 | Yes | Over 16m colours | 2000K ~ 6500K |  |
| Pendant lights with a lampshade | Hung from a suspended ceiling | Philips | Hue White and colour ambience (A19 lamp) | 160º | 2 | Yes | Over 16m colours | 2000K ~ 6500K |  |
| Pendant lights | Hung from a suspended ceiling | Philips | Hue White and colour ambience (GU10 lamp) | 38º | 12 | Yes | Over 16m colours | 2000K ~ 6500K |  |
| Table lamps | Task table | Philips | Hue White and colour ambience (A19 lamp) | 160º | 2 | Yes | Over 16m colours | 2000K ~ 6500K |  |
| Self-luminous room partition | Mounted inside the curved room partition | Philips | Hue White and colour ambience LightStrip+ | 120º | 6 | Yes | Over 16m colours | 2000K ~ 6500K |  |
| Wall shelf lighting | Mounted on a wall shelf | Philips | Hue White and colour ambience LightStrip+ | 120º | 1 | Yes | Over 16m colours | 2000K ~ 6500K |  |

 https://doi.org/10.1016/j.buildenv.2021.107686