The effect of the colour temperature of morning light exposure on wellbeing

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This study investigates whether changing the colour temperature of indoor lighting can help improve the health of healthy adults' emotions in life. Some studies have confirmed the effects of night-time lighting on alertness and sleepiness, but the jury is still out on what parameter range of light is used in the morning to have a lasting effect on mood changes. This study (N=16) investigated the effect of correlated colour temperature (CCT: 2500k, 5000k, 8500k, 18000k, 500lx) on individuals exposed to specific light sources for one hour in the morning. The scores are based on two levels psychological experience and physical performance. PANAS was used to perform mood scores as a psychological level of monitoring. The study found that except for the positive change of emotional PA-P under the condition of 8500k light in the morning, the results of other light parameters showed no noticeable activation effect. It can be seen from the score of PANAS-P that with the increase in colour temperature, PANAS-P has a positive effect. However, it will not improve because of the continuous increase in colour temperature. It will reach a relative peak at around 8500k, but because there is no more detailed classification of lighting parameters, it is impossible to get a precise change interval. Furthermore, a correlation between tympanic temperature and alertness was also found. 2500k light can make people feel sleepy, but there is a slight increase in tympanic temperature. This contradicts the claim that body temperature decreases during sleep. The guess might be that the body is not completely dormant, so the visually warm low colour temperature may affect the body. The data results for both PA-P and PA-N were less positive for participants at 2500k. In addition, at the level of physical changes, although the 8500k lighting parameters have a relatively positive impact on mood, the changes in tympanic temperature are not as stable as those under the other three sets of lighting parameters. A strong correlation was also found between tympanic temperature and KSS score under the four different light parameters, confirming that core body temperature and sleepiness level interacted with each other. Therefore, it is questionable whether universal lighting solutions are suitable for the use of lower CCT in daily life.

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Introduction

Illumination has effects that go beyond the simple requirement to see [1]. Light has many effects on the human body through non-image-forming (NIF) vision [2] and may affect, for example, hormone secretion, body temperature and, of course, sleep [3].

Studies have found that people's mood and tympanic temperature may be affected by lighting and important factors are the spectral composition, the colour temperature, and the intensity of the illumination. In particular, the combination of high colour temperature (psychologically cool) and high intensity is regarded as a visually pleasing light source that may lead to improvements in behaviour and mood. However, such claims for bright cool lighting have mainly been confirmed in patients with Alzheimer's or seasonal-affective depression [4]. Lighting can have potential and long-term effects on people's mood and cognitive behaviour [5]. It is also related to the occurrence of mental illness or prevention and treatment. More than 25 years of research data have proven that light has a significant therapeutic effect on mood and circadian rhythm sleep, specifically for seasonal and non-seasonal depression and various psychiatric diseases [6]. Given the development and application of phototherapy methods, exploring the biological effects of light on the human body has also become an area of great interest. Potential applications exist with healthy adults. Activation of cells in the retina can result in signals being send to the hypothalamus [7]. The hypothalamus is a higher-level centre that plays a regulatory role in visceral activity, body temperature, feeding behaviour, water balance, endocrine functions [8], experience response, biological rhythms, and other critical physiological processes. At the same time, subjective well-being largely depends on current mood. Different wavelengths and intensities have varying degrees of influence on subjective wellbeing and alertness, and circadian rhythm [9]. In one study, exposure to light of different CCT for a short time resulted in a steady decrease in central nervous system activity. Brambilla studied the relationship between thermal perception and correlated colour temperature, and accidentally discovered that CCT affects subjective well-being while studying the hue-heat hypothesis. Whereas there is currently great interest in the role of light in the morning of people, for example, with Seasonal Affective Disorder and evening light exposure on sleep, this work focusses on the role of light, particularly in the early morning on the wellbeing of healthy adults.

Experimental

This study explores the immediate effects of different colour temperatures of morning light on well-being and tympanic temperature. Specifically, we investigate the effect of four colour temperatures (2500k, 5000k, 8500k, 18500k) of morning light. A total of 16 participants (aged 21-27 years and with an even number of males/females) were recruited for the within-subject study. The lighting was provided using a ThousLite luminaire system that allows spectral control of the room illumination (Figures 1 and 2).

Participants were asked to complete the Participants Information Sheet before the experiment started which collected some basic personal information and physical condition information (psychological, visual condition history, travel across time zones, daily caffeine intake, and daily alcohol consumption). At the start of each session (which took place at approximately 9am each day) each participant was placed in a room with a 3500k, 500lux baseline light source for 15 minutes for adaptation. The first data collection (under the baseline light source) took place at the end of the 15-minute period and explored three aspects: mood (using PANAS), and alertness (using KSS). Afterwards, participants were exposed to a test illumination (with a CCT of either 2500k, 5000k, 8500k, or 18500k at 500lx) for a further 40 minutes. A binaural tympanic membrane temperature measurement was performed every ten minutes (to avoid data errors during the measurement, a single binaural tympanic membrane temperature was collected twice, and the average was taken). At the end of the 40-minute period the second data collection was made which was identical to the first.

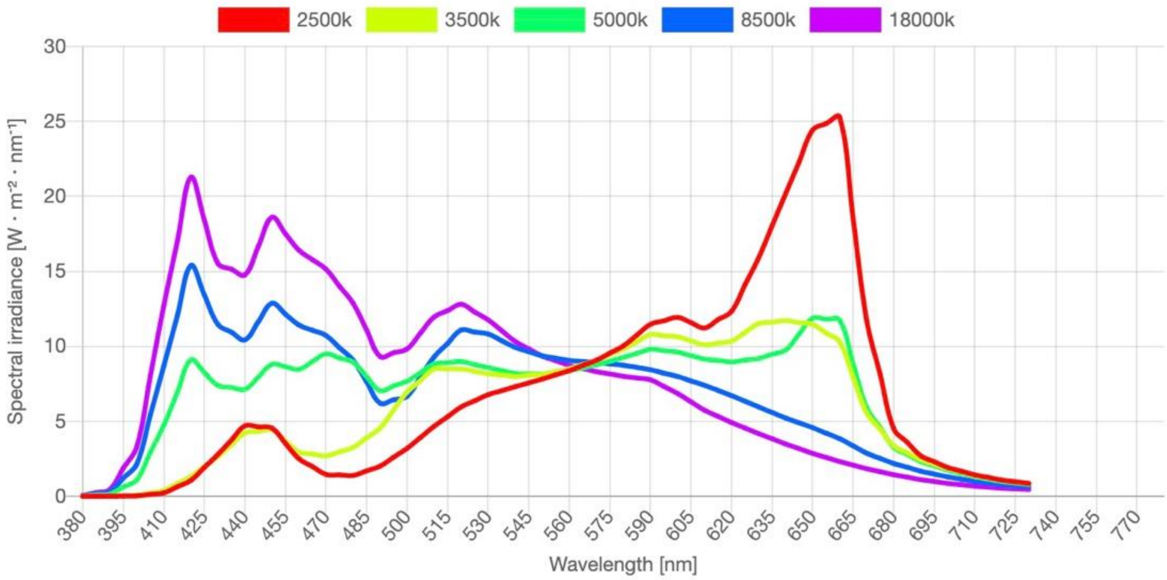


Figure 1: Spectral composition of the test illumination and the baseline condition.

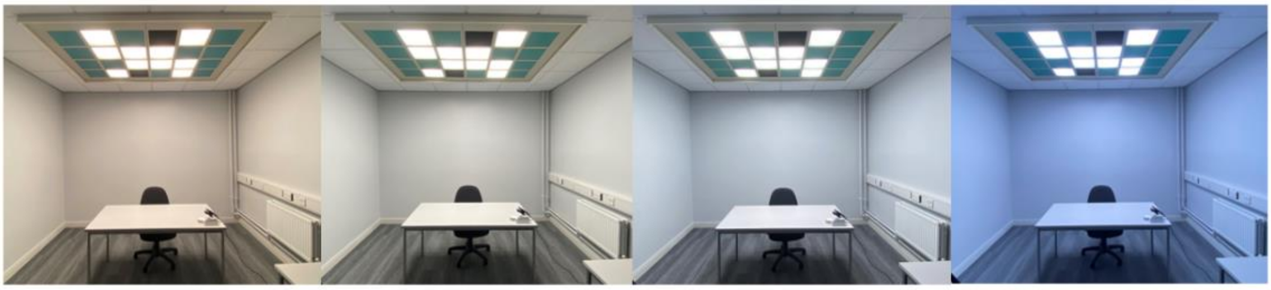


Figure 2: The experimental room with (from left to right) 2500k, 5000k, 8500k, 18500k illumination.

The experiment took place in the Lighting Laboratory in Clothworkers South Building at the University of Leeds in England. There is only one room in the laboratory and the room has no windows (which means there was no problems with sunlight). The lighting experiment area was separated by neutral shades. The environmental dimensions of this laboratory lighting experiment area were 3.3m × 2.2m. The main lighting equipment installed on the ceiling is a set of 10 Thouslite LED Cubes and these luminaires were used to generate the various illumination conditions used during the experiment. The default voltage and frequency are 230-240v and 50-60Hz. The entire laboratory is covered with neutral-coloured carpets, and the ceiling and walls are painted white and have no distracting posters. Figure X shows images taken of the various lighting conditions.

The light was measured using the X-Rite I1 pro2 spectroradiometer. This device can measure the spectral power distribution and various colorimetric indices. Tympanic temperature is measured using the Braun lrt6520 meter. To ensure the reliability of tympanic membrane temperature measurement, a thermometer was used to ensure that the indoor temperature was about 230°C during the experiment. The PANAS, VAS and KSS were provided to the participant on physical paper and were completed using a pen. During the one-hour period in which the participants were in the experimental area, they were given a document to read. Figure 3 shows a schematic summary of the experimental conditions.

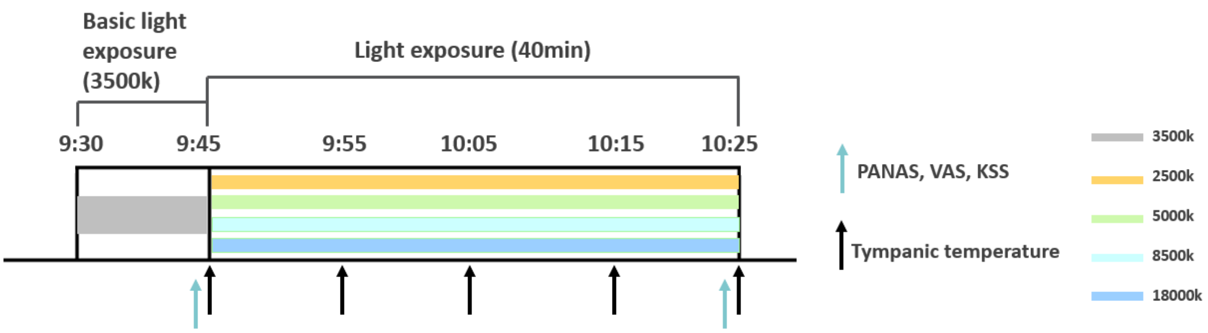
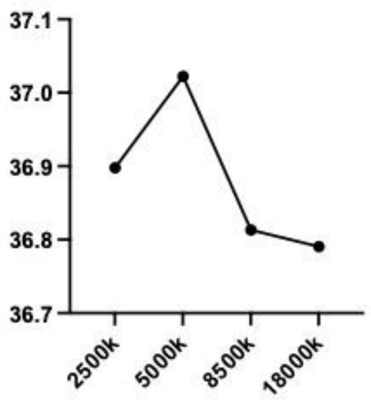


Figure 3: The experimental design of the study.

Discussion

Tympanic temperature

The results showed that different light conditions did not show a continuous significant effect with increasing experimental days. In the ear temperature data on the first day, 2500k, 5000k, 8500k, and 18500k, there were significant differences between ear temperature parameters under light conditions (F43,36; p<0.05). Trends in tympanic temperature in three experiments for all participants under four different lighting parameters are shown in Figure 5. The tympanic temperature values are the change in the average of 5 times temperatures obtained at 10-minute intervals. The overall change trend of tympanic temperature under four different lighting parameters. With the increase of illumination time, except for 2500k, the tympanic temperature under the other three illumination parameters showed a decreasing trend to different degrees. Figure 4 shows the average tympanic temperature under the four lighting parameters. Although the average tympanic temperature at high colour temperature is lower, the tympanic temperature at 5000k is generally high, making people wonder if other factors affect the tympanic temperature change, such as the temperature on the day of the experiment. There were significant differences in the changes in tympanic temperature under the four lighting parameters (F=43.36, p<0.0001). Although there is no significant difference between 8500k and 18000k (p=0.7223). There were significant differences between 2500k (low colour temperature) and 5000k or 8500k (high colour temperature), 18000k (extremely high colour temperature) (p=0.0002; p=0.0117; p=0.0014). Moreover, this upward trend can also be seen in Figure 4.



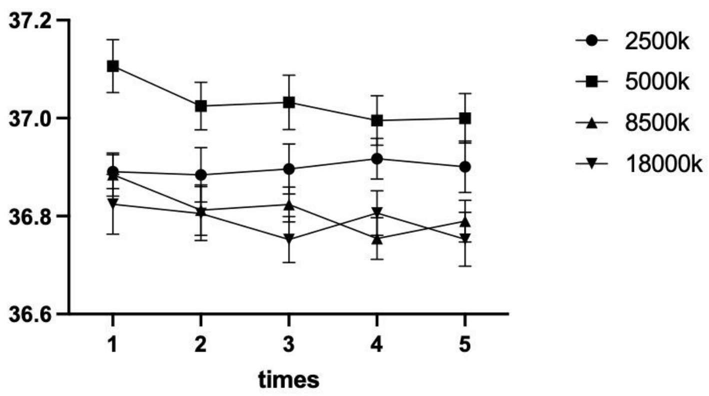


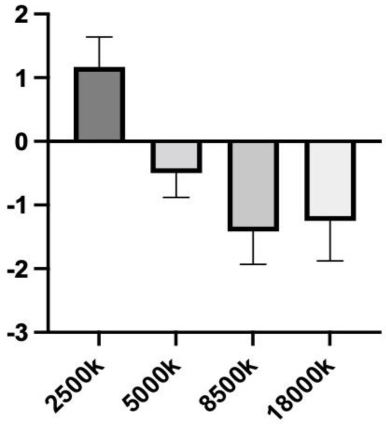
Figure 4 (left): The average value of tympanic temperature under different lighting parameters.
Figure 5 (right): Changes in tympanic temperature during light exposure. These values are temperature averages obtained over consecutive 10-minute intervals during exposure.

It can be seen from the existing data that the tympanic temperature of participants exposed to low colour temperature (2500K) showed a significant upward trend during the experimental period.

Nevertheless, Calo said, during drowsiness or sleep, the core temperature of the human body will show a downward trend. It can be seen in Figure X that the tympanic temperature of participants under 5000K also decreased. In the three groups of tympanic temperature measurement data, only the participants with a colour temperature of 8500K tended to be stable. Since a lowering or tympanic temperature is associated with an increase in sleepiness, these data suggest that a high colour temperature (8500K) did not increase sleepiness. Still, lower colour temperature (e.g., 2500K) did. This finding is confirmed later using KSS.

KSS (Karolinska Sleepiness Scale)

There was a correlation between KSS and tympanic temperature changes. However, it does not show a strong linear relationship. Figure 6 shows the difference in KSS scores under the four lighting parameters.



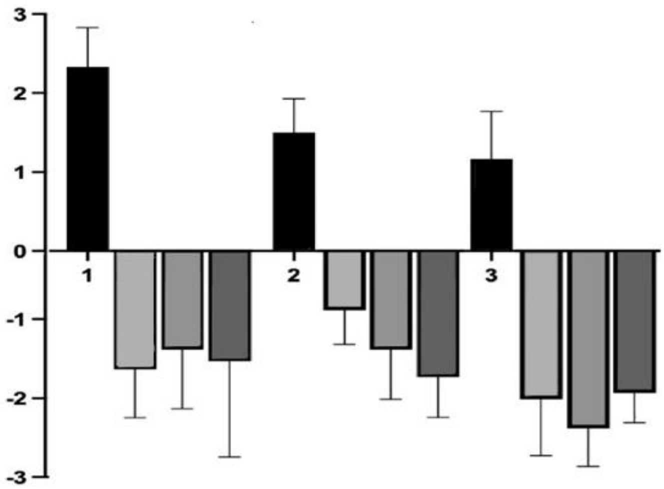


Figure 6 (left): Trend of Karolinska Sleepiness Scale.
Figure 7 (right): The changes in KSS relative to baseline for different light conditions during three days of the experimental p<.01.

Positive values indicate that the light makes the participants feel sleepy, and the higher the value, the more pronounced the degree of sleepiness. Conversely, a negative value indicates that this type of light makes the participants feel a more pronounced increase in alertness, with a higher value indicating a more pronounced before-and-after change. The histogram shows that only a low colour temperature of 2500k made the participants feel sleepy. However, it did not make the participants more alert because of the continued increase in colour temperature. The 8500k illumination showed a relative peak in alertness improvement. It shows that the colour temperature and KSS score are not continuously positively correlated, and the 8500k light can improve the alertness the most. However, there is no more precise parameter interval at present. Moreover, Carl once said that the tympanic temperature gradually decreases during sleep. However, the KSS score shows that 2500k does bring a feeling of sleepiness to the participants, but the tympanic temperature shows a weak upward trend. Therefore, there is a guess that the human body function is not in a dormant state in the sleepy state, so the warm light with low colour temperature can still be visually felt so that the human body is in a warm "illusion". This confirms that in some factories with special ambient temperature requirements, low-colour warm light or high-colour temperature cool light is used to harmonise the subjective feelings of employees. Figure 7 shows the changes in the KSS score under different lighting parameters in the three-day experiment, and there is some evidence that the sleepiness level at 2500k decreases every day over time. ANOVA revealed a significant difference between the 2500k and 8500k conditions, with scores in the 8500k condition significantly lower than those in the 2500k condition (lower KSS scores mean higher alertness). The KSS scores for both the 8500k and 18000k conditions were lower than those for the 2500k and 5000k conditions, although these differences did not reach statistical significance (p>0.05).

PANAS

Regarding the mood scale, we observed that 'light conditions' and 'time' had significant effects when looking at the entire course of the experiment. After the first period of standard light exposure, the first collection of mood scales was conducted. Subsequently, after completing the second period of separate light exposure, the second collection of mood scales was conducted. The change in positive emotions can be seen intuitively from the statistical difference between the two collected data. Figure 8 compares the differences between PA-P and PA-N under four lighting parameters. A positive PA indicates that light positively affects positive emotions, and the larger the value, the more pronounced the effect. In contrast, a negative PA indicates that light has no positive effect on positive emotions. Positive NA indicates that light has an enhanced effect on negative emotions. In contrast, negative NA indicates that light has a weakening effect on negative emotions, and the smaller the value, the more pronounced the effect. Light with high colour temperature can improve PA, especially at 8500k. However, 8500k also has an obvious weakening effect on NA at the same time. A colour temperature of 8500k seems to have a strong positive effect on human mood. Figure 9 shows the changes in PA and NA, respectively, in the three-day experiment. However, no effect of continuity was found over time. Significant correlations were found between PANAS-P and PANAS-N and all measurements. Different negative correlations were found between PANAS-P and PANAS-N under the four lighting parameters. The PANAS changes under the 5000k, and 8500k lighting parameters showed a significant positive increase.

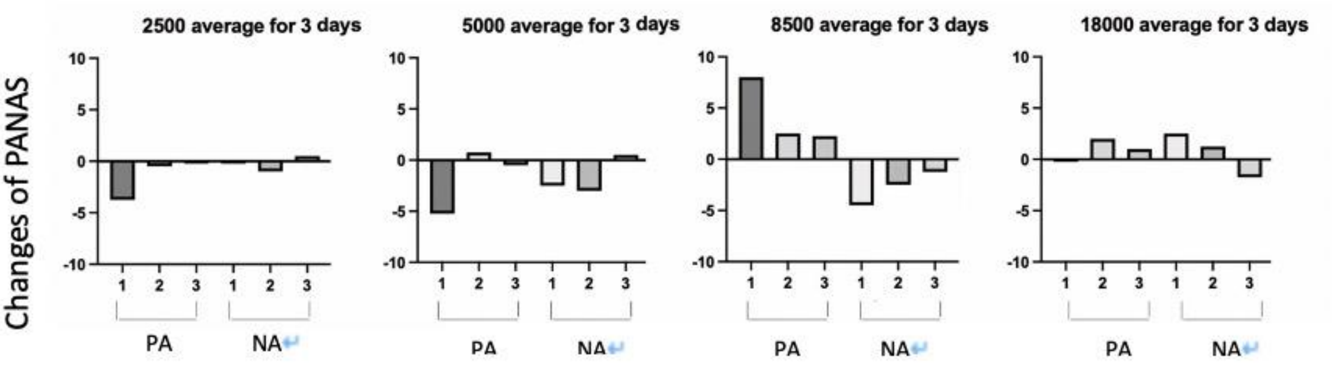


Figure 8: Overall changes of PA-P and PA-N under different lighting parameters.

Wellbeing

Wellbeing is a very subjective feeling. Usually, we make a comprehensive evaluation of emotion, tension, and physical comfort, resulting in well-being. It is also related to sleepiness or alertness. The more factors record, the more comprehensive and accurate the data of wellbeing will be. Body core temperature, that is, tympanic temperature, is one of the most powerful and stable indicators of circadian rhythm synchronisation. Alertness, sleepiness, well - being and tympanic temperature all have some correlation. Subjective sleepiness was measured twice per experiment using the Karolinska

Sleepiness Scale. Physical comfort was measured using a 10-level visual analog scale (VAS). Subjective well-being was assessed using a composite score calculated as follows: Subjective well-being = [PA scores + (100 – NA scores) + KSS score + VAS perceived comfort]/4. Subjective sentiment was surveyed twice per experiment with the Positive and Negative Affect Scale (PANAS), which included two 10-item sentiment scales and provided a 5-point scale for Positive Affect (PA) and Negative Affect (NA).

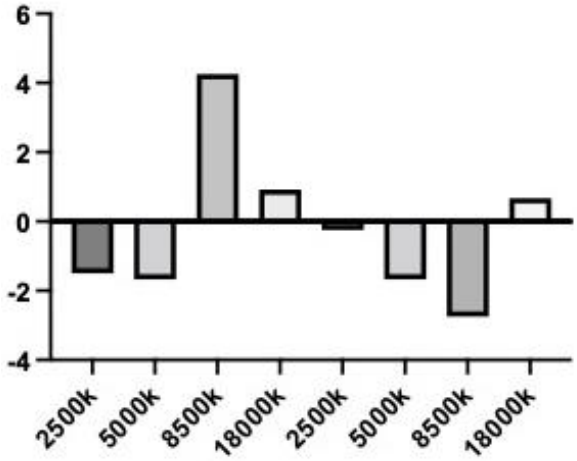


Figure 9: Overall changes of PA-P and PA-N under different lighting parameters.

Conclusions

This study investigated the non-visual biological effects of the low colour temperature of 2500K, neutral colour temperature of 5000K, high colour temperature of 8500K and ultra-high colour temperature of 18000k on the human body in the indoor environment (mainly for impact on well-being). The 18,000k light parameters did not substantially affect circadian rhythm, but this was not because an inappropriate method for assessing circadian rhythm was chosen. While other methods, such as melatonin collection from saliva and actigraphy, were not used in this study because these methods would be too stressful for the participants. The timing and duration of the light may affect the results. The schedule of the whole experiment is also set at the same time in the morning. Although the amount of research in this field has shown an apparent upward trend in recent years, we found that most studies are aimed at groups with certain mental diseases or the elderly as the direction of light therapy. There are significant individual differences in the circadian rhythms in the human body. Because of age and gender, it is impossible to advocate using the same lighting in young people and the elderly [6]. However, these studies still provide great help and guidance on this subject. This study provides evidence that morning light does improve human mood to some extent and is also associated with alertness and physical comfort. However, the correlation with tympanic temperature did not appear very rapidly, although there is evidence that alertness, sleepiness, and melatonin secretion correlate with tympanic temperature. The objective results show that the 8500k lighting parameter surprisingly positively affects mood and alertness. However, the physical comfort under this lighting parameter is not as high as the 5000k lighting condition and the 18000k lighting condition, as can be seen from the values for mood and alertness; these factors were not continuously optimised as the lighting parameters continued to increase. In the current data, 8500k has the most positive impact on the human body's comprehensive factors, but the threshold range has not been determined.

References

1. Papamichael C and Konstantinos B (2017), Adaptive lighting for energy-efficient comfort and wellbeing, *SID Symposium Digest of Technical Papers*, 32-38, California (USA).
2. Westland S, Pan Q and Lee S (2017), A review of the effects of colour and light on non-image function in humans, *Coloration Technology*, **133** (5), 349-361.
3. Wahl S, Engelhardt M, Schaupp P, Lappe C and and Ivanov IV (2019), The inner clock—Blue light sets the human rhythm, *Journal of Biophotonics*,**12** (12), e201900102.
4. Pail G, Huf W, Pjrek E, Winkler D, Willeit M, Praschak-Rieder N and Kasper S (2011), Bright-light therapy in the treatment of mood disorders, *Neuropsychobiology*, **64** (3), 152-162.
5. McCloughan CLB, Aspinall PA and Webb RS (1999), The impact of lighting on mood, *Lighting Research and Technology*, **31** (3), 81-88.
6. Fournier C and Wirz-Justice A (2010), Light, health and wellbeing: Implications from chronobiology for architectural design, *World Health Design: Architecture, Culture, Technology*, **3** (1)**,** 44-49.
7. Pickard GE, Ralph MR and Menaker M (1987), The intergeniculate leaflet partially mediates effects of light on circadian rhythms, Journal of Biological Rhythms, **2** (1), 35-56.
8. Owais C, Small C and Bloom S (2006), Gastrointestinal hormones regulating appetite, *Philosophical Transactions of the Royal Society B: Biological Sciences*, **361** (1471), 1187-1209.
9. Grote V, Kelz C, Goswami N, Stossier H, Tafeit E and Moser M (2013), Cardio-autonomic control and wellbeing due to oscillating color light exposure, *Physiology & Behavior*, **114-115**, 55-64.