Impacts of Lighting on Psychology, Physiology, and Productivity

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Contributor: Ruijun Chen, Meng-Chun Tsai, Yaw-Shyan Tsay

People spend almost 90% of their time in indoor environments. Indoor environment quality has begun to play a more important role in people's daily lives. The impact on occupants of various environmental factors of buildings has been actively studied. Among them, lighting conditions have been shown to have a significant influence on all aspects of human life and health.

Keywords: lighting environment ; productivity ; satisfaction ; lighting control

1. Background

These days, people spend almost 90% of their time in indoor environments. Indoor environment quality (IEQ) has begun to play a more important role in people's daily lives [1][2]. The impact on occupants of various environmental factors of buildings has been actively studied [3][4]. Among them, lighting conditions have been shown to have a significant influence on all aspects of human life and health [5]. They can affect both the physiological and psychological health of people, and dynamic lighting changes have a positive impact on several aspects of human well-being, such as spatial perception, emotional state, and biological rhythm [6][7][8]. Although the lighting environment is influenced by numerous complicated parameters, the two main characteristics are correlated color temperature (CCT) and illuminance, which have been researched in many previous studies [9][10][11]. With the development of lighting research, the academic topic of building environment has not only focused on the impact of daylight and artificial lighting on building performance but also expanded to the effect of lighting on comfort, health, and work productivity [12][13][14].

Furthermore, no uniform quantitative standard is available for CCT and illumination values in office buildings. For example, in Taiwan, the lighting standard CNS 12112 stipulates that the average illumination of the workspace in an office for writing, typing, reading, and data processing should be at least 500 lux, which is similar to the international standard CIE S 008/E-2001 [15][16]. However, in Japan, the illuminance is required to be in the range of 500 to 750 lux in ordinary offices, while the British Institute of Lighting Engineering recommends 750 lux for designing and typing in offices. The WELL building standard is a health building-design standard for different categories issued by the international WELL building institute in 2014 [17]. WELL also has many regulations for lighting, such as visual lighting design, circadian lighting design, low-glare design, etc. In WELL, for all workstations, electric lights need to maintain illuminance on the vertical plane facing forward (to simulate the view of the occupant) of 150 equivalent melanopic lux (EML) or greater. According to the International Commission on Illumination (CIE), the illuminance produced by light-emitting diode (LED) lamps needs to consider the spectral mismatch correction factor (SMCF) [18][19]. It can correct the measurement error of the luxmeter because the spectral sensitivity of the luxmeter does not completely match the required one and may vary with different instruments [20]. Meanwhile, when evaluating LED lamps, not only CCT but also chromaticity point and binning should be considered [21].

2. Research on the Impacts of Lighting

Numerous studies have shown that a light environment can directly influence work efficiency through visual effects while indirectly affecting people's attention, enthusiasm, and arousal level. Sun et al. [22] found that the illumination on the work plane had the most significant impact on visual comfort, and the CCT of the light ranks second. Ishii et al. [23] found that the task performance of the subjects under high CCT (6200 K) was better than that of normal CCT (5000 K). Figueiro et al. [24] suggested that appropriate light application could promote circadian rhythm and improve alertness. Chraibi et al. proposed that the sensor-triggered lighting control strategy could solve the problem of energy-saving use of electric lighting without affecting the user experience. Huang et al. [25] found that subjects preferred whiter illumination when the CCT value was between 2500 K and 5500 K. Furthermore, Dangol et al. [26] found that in an office, workers preferred 500 lux rather than 300 lux illuminance for working and a CCT of 4000 K rather than 6500 K under the lighting condition of 500 lux.

Jihyun et al. [27] proposed that the illuminance level of 406 lux for the work surface reaches the best satisfaction level in contemporary office environments. Hviid et al. [28] changed the lighting situation from 2900 K–450 lux to 4900 K–750 lux and found that the processing speed, concentration level, and mathematical skills of pupils improved significantly. Shamsul et al. [29] indicated that their subjects preferred the CCT of 4000 K, but the best subjective attention level, including the correct rate of typing and execution ability, was at a CCT of 6500 K. Houser et al. [30] pointed out that when designing light strategies, circadian rhythm, neuroendocrine, and neurobehavioral responses were as important to human health as visual responses. Zhai et al. [31] indicated that illumination had a greater impact on visual perception than CCT. Islam et al. [32] proposed that staff tended to have task illuminance of 500 lux to 300 lux and CCT of 4000 K to 6500 K. Veitch et al. [33] pointed out that higher-quality office lighting could make subjects have more pleasant mood and happiness. Ye et al. [34] suggested that the subjects showed better performance and the higher alertness under the illumination of higher CCT range. Park et al. [35] indicated that the occupants prefer a different CCT according to the function of the space, as well as that a changeable CCT was better than a fixed CCT for subjects.

The relationship between physiological changes and the light environment has also been studied by many researchers. The electroencephalograph (EEG) and electrocardiogram (ECG) have been widely applied in subjective sensory and cognitive tasks, which can be used as an objective index to support traditional subjective methods and productivity evaluation [36][37]. Baek et al. [38] found that blue light (short wavelength) significantly reduced EEG alpha activity but increased work productivity after lunch. Michal et al. [39] confirmed that short-wavelength light could enhance cognitive efficiency in task-specific scenarios. Eroglu et al. [40] proposed that the types and luminance of visual stimuli can be revealed by changing the activity power of the brain. Yosuke et al. [41] suggested that the power in the alpha frequency range of brain waves decreased significantly after half an hour of exposure to both short- and long-wavelength light. Lasauskaite et al. [42] increased CCT from 2800 K to 6500 K and found that the average heart rate decreased by almost 1.5 beats per minute (bpm). Omidvar et al. [43] compared different CCT conditions and indicated that the activation of non-visual photoreceptors could lead to melatonin inhibition, thus increasing heart rate and warmth. Other recent research is summarized in **Table 1**, including experimental details and research points.

Table 1. Representative experiments in lighting research literature.

Ref.	CCT (K) Illuminance (lux)	Experiment Method	Physiological & Psychological Measurement	Productivity Measurement	Conclusions
[44]	**1 CCT (5000) 3 illuminances (200, 500, 1000)**	**Fixed lighting/3 groups**	**1. EEG 2. heart rate 3. skin temperature 4. engagement level**	**1. number addition 2. visual search 3. digit recall**	- The influence of lighting level on work engagement varies across different individuals.
[45]	**3 CCTs (3000, 4500, 6000) 1 illuminance (300)**	**Fixed lighting/3 groups**	**1. ECG 2. thermal sensation and comfort 3. light satisfaction and comfort**	**1. short-term memory test**	- CCT can change thermal sensation of environment when the temperature difference is less than 2 °C.
[46]	**3 CCTs (3000, 4000, 6000) 5 illuminances (75, 100, 200, 300, 500)**	**Fixed lighting/15 groups**	**1. ECG 2. luminance 3. color authenticity 4. fatigue 5. relaxation**	**1. reading**	- CCT affects reading efficiency significantly. - Illuminance affects the response of the vision.
[47]	**3 CCTs (2800, 5000, 6700) 2 illuminances (150, 300)**	**Fixed lighting/6 groups**	**1. luminance 2. security sense 3. pressure 4. positive feelings 5. fatigue**	**1. reading**	- Higher CCT relates to higher spatial luminance. - Security sense was influenced by CCT rather than illumination.

Ref.	CCT (K) Illuminance (lux)	Experiment Method	Physiological & Psychological Measurement	Productivity Measurement	Conclusions
[48]	5 illuminances (300, 500, self-adjust)	Fixed and adjustable lighting/5 groups	1. visual perception 2. self-rated productivity 3. satisfaction level	-	- Memory mode is better than forgetting mode. - Regardless of conflicts, controllable is better than uncontrollable.
[49]	2 CCTs (3000, 6500) 2 illuminances (100, 1000)	Fixed lighting/4 groups	1. KSS 2. Psycho-motor vigilance test	1. Go/No-go test 2. Flanker test 3. working memory task	- Fatigue was reduced at 6500 K and 1000 lx. - Reaction was highly increased in 1000 lux compared to 100 lux.
[50]	9 CCTs (2500–6500) 1 illuminance (200)	Fixed lighting/9 groups	1. six different jeans 2. color preference 3. color discrimination	-	- CCT affects color recognition of subjects.
[51]	2 CCTs (2700, 5800) 2 illuminances (5, 1200)	Fixed lighting/4 groups	1. core body temperature 2. skin temperatures 3. energy expenditure 4. thermal perception 5. visual comfort	-	- Changes in visual comfort and thermal comfort were related. - Lighting can partially compensate for thermal discomfort.
[52]	CCT (4000) illuminances (variable)	Adjustable lighting/9 groups	1. visual perception 2. comfort level	1. typing 2. reading 3. look at clock and tree	- The difference of light environment is small and better.
[53]	2 CCTs (2700, 6000)	Fixed lighting/4 groups	1. Electro-dermal activity (EDA) 2. ECG 3. visual experience 4. comfort level	1. image response 2. number operation 3. find fault 4. image change	- CCT is the most important factor affecting the mood, but no obvious effect on health, psychology, productivity.
[54]	2 CCTs (2700, 6500)	Fixed lighting(from 20 to 24 °C)/2 groups	1. thermal perception 2. personal acceptability 3. affective assessment	-	- Participants feel colder at high CCT. - Participants have high comfort level at lower CCT.
[55]	4 illuminances (self-adjust)	Adjustable lighting/4 groups	1. visual perception 2. comfort level	1. reading 2. identify difference	- The default value is better than the preferred value.
[56]	4 CCTs (2700, 4300, 6500), 1 illuminance (500)	Fixed lighting/3 groups	1. visual perception 2. comfort level	1. Chu attention test	- CCT affects concentration, especially 4300 k.

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