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Subjective and objective survey of office lighting: effects on alertness, comfort, satisfaction, and safety

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Abstract

Background: *Lighting is one of the workplace factors that can relevantly impact workers' health, performance, safety, and job satisfaction. Brightness, natural light and color temperature are the factors that affect the quality of lighting. This study involved subjective and objective evaluation of office lighting and its effects on workers' alertness, comfort, satisfaction, safety, and performance in a prominent government office.* **Methods:** *Visual comfort, alertness, performance, safety and satisfaction were assessed subjectively using the questionnaires and rating scales. Moreover, illuminance, color temperature of light sources, and natural light availability were evaluated objectively.* **Results:** *The findings of this study indicated that the use of natural light in the workplace could increase the illuminance and color temperature of light in the workplace and improve alertness, visual comfort, satisfaction and worker's preference.* **Conclusions:** *To improve the quality of lighting in the workplace, factors affecting it, such as the color temperature and the availability of natural light, should be considered.*

Introduction

The administrative workforce is growing, and this group's health has been promoted in recent decades [1]. Among the environmental conditions of an office environment, room lighting plays a crucial role in all aspects of health, especially in the visual system [2-4]. Studies investigating the relationship between health and lighting conditions in office environments show that inadequate lighting may affect various physiological functions and have adverse health effects, including a possible role in several neurobehavioral, psychological and cognitive conditions [2, 3, 5-7]. On the other hand, lighting is directly and closely related to occupational safety and the prevention of injuries and human errors [8].

Mainly due to computer-based technologies and modern technologies, vision and work are very important [4]. Accordingly, the ICOH Scientific Committee on Work and Vision defines ergophthalmology as the scientific field aimed at analyzing, evaluating and designing complex or straightforward working systems about the relationship between work and visual performance. Its primary purpose is to reduce discomfort and eye diseases and increase the efficiency of the visual system through the characteristics of the task, environmental conditions, and individual attributes of ophthalmology [4].

According to the European standard EN12665, visual comfort is defined as the conditions under which a person feels comfortable in the workplace, and the factors affecting it are light sources (natural

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or artificial), illuminance, color temperature, luminance and uniformity of light [9]. All lighting-relevant aspects should be taken into account quantitatively and qualitatively at the workplace so that employees feel more comfortable [10, 11].

By providing light during the day, one can take advantage of sunlight, which has a full spectrum and is well compatible with the human visual system. Studies show that employees prefer natural light and feel more satisfied, healthier, visually more comfortable and more productive [12]. In-office environments, natural light is provided through windows, and because natural light is not always available enough, it is often used with artificial light [13]. The combination of natural light and the desired artificial lighting system moreover make working conditions more satisfactory for employees and increases the efficiency and wellbeing of the workforce [14, 15].

Illuminance level (lux) is another important and influential factor in the desirability of lighting in the workplace. Therefore, it is one of the indicators for assessing the quality of lighting in the workplace, and the illuminating engineering society (IES) has taken into account specific illuminances for each workplace [16]. The illuminance required to perform the task depends on the type of work. Its desirability is directly related to the quality of vision, comfort, health, performance, productivity, and satisfaction of employees in the work environment [17-20].

Another factor affecting the quality of lighting is color temperature. Although less considered in international standards, recent studies have shown that it should be considered and even included in lighting standards as one of the essential elements [6, 21]. The color temperature of light sources in work environments plays a vital role in humans' physiological and psychological functions. Color temperature affects people's awareness, mood, emotions, and feelings, however some studies showed that very high color correlated temperature light is dangerous for photoreceptors [6, 22, 23]. Anyway, choosing the proper color temperature for employees in office environments can improve visual comfort subjectively and reduce sleepiness [21]. There are three main challenges in previous studies: firstly, in most previous studies, only illuminance and other factors, especially color temperature and natural light, which affect the quantity and quality of light, were given less attention. Secondly, in previous studies, the study of lighting in the workplace mainly was based on objective methods and evaluated and judged only from this perspective. Employees' opinions and their effects on them have received less attention [24]. Thirdly, most studies have assessed the impact of lighting in the laboratory or semi-laboratory, so the purpose of this study is to study lighting in a natural office environment objectively and subjectively to meet the above challenges.

Methods

Participants and study design

A descriptive-analytical cross-sectional study was carried out in a large government office (Figure 1). Eighty-five employees, each working in a separate room equipped with conventional and compact fluorescent lamps, were randomly selected for this study with written consent, taking into account inclusion criteria such as no previous history of eye surgery, acute vision problems, and neurological disorders. The objective assessments were carried out on one day, around 10 to noon in winter, and these assessments were performed at the end of the working day.

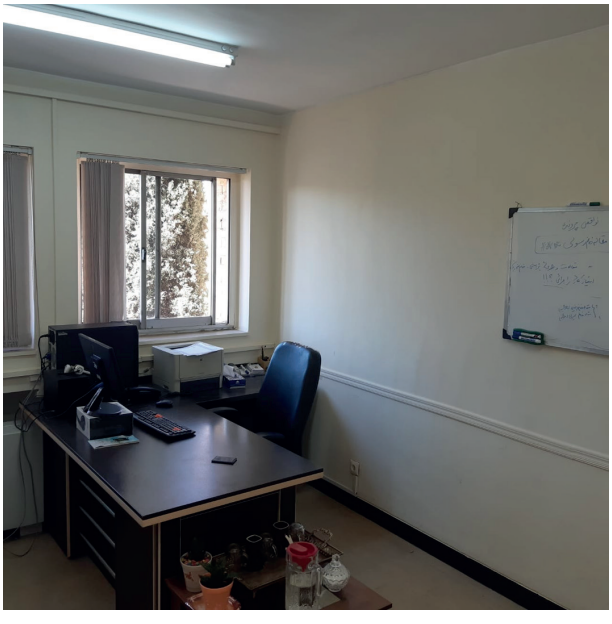

Figure 1. Sample of offices that were studied.

Study materials

Demographic questionnaire

The demographic questionnaire collected general information on age, marital status, job title, current work experience, education, working hours per day, luminance and satisfaction with the workplace lighting. Descriptive findings related to demographic variables are given in Table 1. 71% of the participants in this study were men, and their average age and work experience were 39.3 and 13.3 years, respectively.

Table 1. Demographic Characteristics of participants (n = 85).

Variables		n. (%)
Age (Years)		39.3 (6.8)*
Work experience (Years)		13.3 (7.3)*
Computer working hours per day		5.2 (1.5)*
Exercise hours per week		1.8 (1.1)*
Spectacles use	Yes	47 (55.3%)
	No	38 (44.7%)
Sex	Male	71 (83.5%)
	Female	14 (16.5%)
Marital status	Married	76 (89.4%)
	Single	9 (10.6%)
Education level	Diploma	25 (29.4%)
	B.Sc.	41 (48.2%)
	M.Sc. Or PhD	19 (22.4%)

* Mean (Standard deviation).

Subjective assessment of lighting

Visual comfort assessment: A modified version of the Office Lighting Survey (OLS) was used to assess the visual comfort of respondents with the brightness [25]. The questionnaire consists of two parts; in the first part, which contains questions 1-6, a subjective assessment of the light is carried out, and in the second part, which includes questions 7-12, respondents determine the number of visual symptoms related to the light on a 4-Point Likert scale. The staff filled out this questionnaire in the middle of the working day. The scoring method is shown in Table 2. Before reading this questionnaire, it was translated into Persian and validated. The Cronbach's alpha was 0.76.

Awareness: The Karolinska Sleepiness Scale (KSS) index, which is validated by Electroencephalography (EEG) data [26], was used to assess alertness. This index is a subjective score in which each respondent states their current level on a 9-step scale from very alert [1] to very sleepy [27].

Table 2. Office lighting evaluation questionnaire.

Questions	Score
Preferences	Scale from zero (no) to four (yes)
1. Like the lighting in this office.	Yes: 0
2. In general, the lighting in this office is comfortable.	
3. This color of light allows me to carry out different tasks.	
4. My skin looks natural under the light.	
5. The lighting in this office is too warm.	
6. The lighting in this office is too cold.	
Symptoms	Scale from zero (no) to four (yes)
7. I feel eye strain.	
8. My eyelids are heavy.	
9. My eyes feel dry.	
10. I have burning eyes.	
11. I have a headache working under this CCT of light.	
12. I have difficulties seeing objects on the screen.	

Performance, safety and satisfaction assessment: In this study, safety, satisfaction and performance are assessed using the following three questions, which contain a five-point Likert scale (1 = Very low, 2 = low and ... 5 = Very high):

- Does the low light level in your workstation affect your job performance?
- How satisfied are you with the lighting condition in your work environment?
- Can the light levels in your working environment cause falls or slips?

Objective assessment of lighting

Illuminance and color temperature assessment: Illuminance and luminance were measured using a Hagner Screen Master device. The zero point was used to calibrate it. With this type of calibration, the received energy is reduced to zero by darkening the surface of the receiving cell. The measurement time was moreover in the early hours of the day to minimize the influence of natural light on the measurements. The illuminance was measured according to the Iranian lighting standard, which is derived from the IESNA standard. The operator was asked to keep their normal position during the measurement. The photocell of the device was placed in the visual field of the workers on the keyboard and at the same angle on both sides of the keyboard (45 degree), and then the Illuminance level was read at three points of the station, and the average value of the three measuring points was recorded [16]. The color temperature was assessed using the Kelvin meter model TES 136 at the work surface height (horizon level) from 8 a.m. to 10 a.m.

The survey was conducted in 45 rooms and 85 workstations. It should be noted that 32% of the workstations had no windows, 68% had windows, and their cleanliness was good. All lamps used were fluorescent with a 20-60 watts' power consumption. 90% of the ceiling and walls were white, and 100% of the floor was cream ceramic.

Availability of natural light: The condition of having natural light included having vertical or horizontal windows on the workplace ceiling in any direction of the building, provided that direct or indirect light shines without creating obstacles such as curtains.

Statistical analyses

Descriptive statistics (frequency and percentages tables) were used for the qualitative variables in the data analysis, and central tendency indices such as mean and dispersion indices such as standard deviation were used for quantitative variables. In the inferential statistics section, independent t-test, correlation coefficient and analysis of variance were used to analyze the results. All analyzes were performed using SPSS statistical software version 21.

Results

Objective variables of lighting:

Table 3 lists the average of the three variables illuminance, luminance and color temperature. According to the IESNA standard, the required range of localized illuminance required for office work is 300 to 500 lux [28]. Among the 85 stations surveyed, 50 stations (58.8%) had an illuminance level below the standard of 300 lux, 15 stations (17.6%) had an illuminance level of 300 to 500 lux, and 20 stations (23.6%) had a local illuminance of more than 500 lux. The color temperature of the lighting used in the studied work environments is listed in Table 3. The average color temperature of

Table 3. Objective variables of lighting (n=85).

Light Variable	Min-Max	Mean (SD)	standard
Illuminance (lux)	103-1000	340 (183.90)	**300-500**
Luminance (cd/m^2)	23-200	94 (40.45)	**<1000**
Color temperature (kelvin)	500-8500	5799 (943.71)	**> 4000**

the light sources was 5799 Kelvin. Luminance ratios in the visual field of the workers were about 1:10-1:15. 55% of the participants had natural light, and 45% only worked with artificial light.

Subjective assessment of lighting

Table 4 shows the mean and standard deviation of the studied subjective variables, including alertness, satisfaction with workplace lighting, safety, performance, visual comfort, and preference.

The effect of illuminance on subjective variables

The lighting standard for office environments is 300 to 500 lux [28]. Therefore, in this study, workstations were divided into lighting below 300 lux, i.e. below the standard limit, 300 to 500 lux, i.e. within the standard limit, and above 500 lux, i.e. above the standard limit. Among the studied subjective variables, preference ($p < 0.01$) and satisfaction ($p < 0.02$) were relevantly affected by illuminance. That is, an increase in illuminance increases the participants' preference, and the highest satisfaction was, of course, in the standard range (300 to 500 lux). Illuminance did not affect alertness, safety, visual comfort and performance (Table 5).

Table 4. Subjective variables of lighting (n=85).

Subjective assessment	Min-Max	Mean	SD
Alertness	1-7	3.4	**1.3**
Satisfaction	0-4	2.0	**0.82**
Eye comfort	0-18	9.4	**3.5**
Preference	2-17	8.6	**2.7**
Performance	0-4	2.7	**0.96**
Safety	0-4	1.2	**1.0**

The effect of the color temperature of light sources on subjective variables

This study divided color temperature into two categories below 6000 K and 6000 K and above. Comparison of these two groups showed that the color temperature of light has a significant effect on preference ($p < 0.004$) and has no effect on other subjective variables. In other words, with increasing color temperature, the preference increases (Table 6).

The effect of using natural light on subjective variables:

The study results of the impact of combinational light (presence of natural and artificial light) on subjective variables are shown in Table 7. Based on these results, the use of natural light in the workplace has a positive effect on alertness ($p < 0.036$), visual comfort ($p < 0.001$), preference ($p < 0.001$) and employee satisfaction ($p < 0.001$).

Discussion

Appropriate lighting is one of the factors affecting the performance, safety and health of employees in the workplace but less attention has been paid to its study compared to other risk factors. Some studies and even standards in workplace lighting focus on assessing the illuminance, and other essential lighting factors and subjective indicators have been

Table 5. The association of illuminance on subjective variables (alertness, safety, preference, visual comfort, satisfaction and performance).

	Illuminance (lux)			
Variables	**<300**	**300-500**	**>500**	**p.v**
Alertness	3.5(1.4)	3.1(1.1)	3.3(0.8)	**0.43**
Safety	1.1(1.0)	1.1(1.0)	1.2(0.9)	**0.94**
Preference	9.3(3.0)	7.9(2.5)	7.3(1.8)	**0.01**
Visual comfort	8.8(3.5)	10.3(3.4)	9.9(3.2)	**0.17**
Satisfaction	1.8(0.9)	2.4(0.5)	2.2(0.6)	**0.02**
Performance	2.7(1.0)	2.7(0.8)	2.6(0.9)	**0.98**

neglected [24]. Insufficient light affects the quantity and quality of work and can lead to undesirable results. In Iranian office environments, despite the progress made, a high percentage of workstations suffer from inadequate illuminance. Moreover, other essential lighting factors such as daylight and color temperature were not considered. The results of this study (inadequate illuminance) are consistent with other studies. In 2013, Dianat et al. examined different wards of a hospital in Iran and found that 52% of hospital wards had poor and substandard illuminance [24]. In a study in Tanzania, Katabaro and Yan reported that the illuminance of the horizontal surface and the uniformity of light were lower than standard [29]. Viola et al. found in a study that despite the importance of the color temperature of light sources to human health and performance, many workplace lighting designs neglect the color temperature of light sources, and standards do not emphasize the need to pay attention to it [6].

Table 6. The association of color temperature on subjective variables (alertness, safety, preference, visual comfort, satisfaction and performance).

	Color correlated temperature(k)		
Variables	**>6000K**	**<6000K**	**p.v**
Alertness	3(1.0)	3.5(1.4)	**0.11**
Safety	1.0(0.94)	1.2(1.0)	**0.6**
Preference	7.4(2.2)	9.2(2.8)	**0.004**
Visual comfort	10(3.2)	9(3.6)	**0.40**
Satisfaction	2.2(0.7)	2(0.9)	**0.2**
Performance	2.7(1.0)	2.6(0.9)	**0.8**

The results of this study showed that illuminance is associated with the preference and satisfaction of people so that with improvement in illuminance, employees' choice and satisfaction with lighting increases. This result was consistent with a study by Dianat et al., which showed that only 35.8% of employees reported high and very high levels of satisfaction with their workplace lighting [24]. In the present study, the average illuminance was moderate, which was moreover qualitatively described by the computer workers as moderate. Dianat et al. (2013) found that the employees' perception of light was comparable to the actual illuminance [24].

The results of the present study showed that the color temperature of the light has a significant effect on the preference, which is consistent with the study of Wang et al. [30]. In places where a high level of mental activity or alertness is required, the color temperature of sources in the blue light spectrum should be above 4000 Kelvin [6, 21]. 98.8% of workstations in this study had color temperatures above 4000 degrees Kelvin, which can be attributed to the presence of natural light in workstations.

Visual comfort was assessed using a self-reporting questionnaire to evaluate office lighting as did other studies [25]. Natural light and visual communication with the outside environment in human living spaces, including work, leisure, and education, increase efficiency and productivity, reduce anxiety, improve behavior, comfort, and especially visual comfort of employees [31]. The significant influence of windows on workplace lighting has been widely recommended for proper use in the workplace in various sciences, including architecture and occupational health [31, 32].

Table 7. The association of using natural light on subjective variables (alertness, safety, preference, visual comfort, satisfaction and performance).

	Light condition		
Variables	**Artificial light**	**Combinational light (natural and artificial)**	**p.v**
Alertness	3.8(1.5)	3.1(1.0)	***0.036***
Safety	1.1(1.2)	1.2(0.9)	**0.70**
Preference	10.37(2.80)	7.60(2.30)	**0.001**
Visual comfort	7.60(3.4)	10.20(3.3)	***0.001***
Satisfaction	1.5(1.0)	2.3(0.6)	***0.001***
Performance	2.8(1.0)	2.6(0.9)	**0.2**

In this study, although illuminance was measured in the early hours of the day, it was shown that the presence of windows and, consequently, natural light could relevantly increase eye comfort and illuminance. In similar studies, it has been pointed out that if daylight is not accompanied by intolerable luminance, it can lead to greater visual comfort [32]. The research results of Jamrozik et al. also showed that providing daylight and sufficient visibility in the office environment through modern shading methods to prevent glare can improve cognitive performance and employee satisfaction while reducing eye strain [33]. Moreover, Nicol et al. showed that lighting has a small but significant impact on employee reported productivity, which is even greater when daylight is used in office work environments [34].

Although there was no significant association between color temperature and comfort, windows and natural light could directly affect light color and increase color temperature, thus increasing comfort. Duijnhoven et al. mention illuminance and color temperature as two crucial factors which play an essential role in workers' physical and cognitive health [35].

Limitation

This cross-sectional study using an OLS questionnaire assessed respondents' visual comfort and its relationship with brightness. This type of study has intrinsic limitations related to its design, sampling technique, statistical analysis, evaluation of the variables, and it can be solved in an experimental study. At the same time, some eye diseases such as refraction, ocular motility, ocular surface, chronic degenerative pathologies, and age (presbyopia) could have played an essential role in developing these symptoms that weren't addressed and need to survey in future studies.

Conclusion

The presence of windows and natural light can increase the color temperature of the light and increase visual comfort, alertness, satisfaction, and especially staff preferences. The present study results, which was carried out in a large government office, showed that the illuminance was below IESNA standard in more than half of the evaluated workstations, and only 55% of the people had natural light in their work environment. There was a significant correlation between increased illuminance and people's satisfaction and preference. People preferred increased lighting, and of course, the highest level of satisfaction was observed in the standard lighting range (500-300 lux). People moreover preferred light sources with higher color temperatures. In addition, the findings showed that the use of natural light has a relevantly positive association on alertness, visual comfort, preference and satisfaction of employees so that it can be concluded that in addition to the illuminance, other factors related to lighting are moreover very important and should be given special attention.

Ethics: This article is from a research project with Ethics Code IR.SUMS.REC.1397.1291 at Shiraz University of Medical Sciences.

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Declaration of Interest: The authors declare no conflict of interest.

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