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Hygienical Evaluation of LED Lighting Systems

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Abstract

The article outlines experimental investigations of LED lighting hygienic efficiency. A comprehensive methodology for psychophysiologic and hygienic assessment of the LED lighting equipment which (the methodology) was elaborated by the authors was used in the course of the experiments. The experiments were carried out by means of a designed experimental research facility ensuring variation of luminescent (basic) and LED lighting. There were selected the indicators of the visual organ state which are the most optimal and complying with the investigational tasks. The article describes the most significant results of the experimental investigations. A practical relevance of the received experimental material at time of designing lighting systems based on the LED lighting sources was demonstrated.

Keywords: Light-emitting diodes (LEDs), Lighting, Integrated methodology, Experimental research facility, Visual functions, Visual fatigue, Psychophysiologic image.

Contents

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1. Introduction

One of the important tasks of the light engineering is creation of a favorable light-and-color environment suggesting use of light for satisfaction of a range of the human needs: ergonomic, psychophysiologic, psychological and ecologic. On the other hand the problems of saving energy consumed for lighting purposes are as well of current concern. It is possible to solve the mentioned problems by means of use of LEDs which are considered to be the most effective and challenging light sources (LSs) nowadays.

However if energy saving in the lighting equipment due to use of LEDs and high luminous efficiency of the same is quite obvious [1, 2], the possibility of LEDs use for ensuring comfortable lighting conditions requires tangible evidence that can be obtained by comprehensive studies of the effect of LED lighting on the visual organ and the body as a whole. The Russian and foreign scientists in their works mention about certain results of studying the effect of LED lighting on the visual functions and visual performance. The results of the said investigations are contradictory and ambiguous [3-7]. It gives ground to considerations that the experimental investigations aimed at hygienic and psychophysiologic evaluation of LED lighting would have importance.

2. Methodology

Taking into account the theoretical and experimental material covering the effect of factors relating to the lighting conditions on visual performance and fatigue we have elaborated a comprehensive methodology for psychophysiologic and hygienic evaluation of the LED lighting equipment. In this sense the investigations of the visual organ functional state and of visual fatigue progression under the LED lighting conditions were of specific concern since the rated features of the lighting equipment are primarily connected with the visual functions. Given the nature of the visual activity we have chosen the most responsive indicators of the visual organ state:

- Absolute accommodation extent and time of achromatic asthenopia (accommodative-muscular system);
- Distance visual acuity, projected blind spot area, chromatic vision acuity (receptor system);
- critical flicker fusion frequency (CFFF) (central division).

The integral evaluation of LED lighting efficiency was carried out on the basis of the visual fatigue indicator measured after completion of visual activity:

$$A = (1 - \frac{t_j}{t_i}) \cdot 100\%$$

where t_j – time of achromatic asthenopia after activity completion; t_i – time of achromatic asthenopia before activity start.

For the purpose of investigations there was designed and installed a general-lighting experimental research facility (ERF) ensuring LED lighting and luminescent lamp lighting variants realization. The variants with LL lighting are regarded as basic when compared with LED lighting. The investigations were performed at various illumination intensity levels: 200, 400 and 1000 lx and various correlated color temperature values (T_c) of the illumination sources: 3000, 4000 and 5000 K.

3. Main Body

A group of volunteer students aged between 20 and 25 years who passed a preliminary clinical examination took part in the experiments. The clinical examination of the visual organ included measurement of refraction and vision acuity; computer-aided tomography of the retina. All of the enrolled observers had predominantly emmetropic refraction, acuity of vision for the both eyes – 1.0; no abnormalities in color perception. The enrolled observers totaling to 60 persons were randomized into two panels each containing 30 of them: a reference panel which participated in the experiment being subject to luminescent lamp (LL) lighting and a primary panel which was subject to LED lighting. The number of observers and the number of experiments was determined based on the requirements to obtain statistically reliable data. Schedules of activity of each panel allowed for the human circadian biorhythms.

Before the investigations start the observers had a research techniques training course until obtaining stable results. After that a 60-day-long series of laboratory experiments was carried out. After its completion the observers were repeatedly examined under clinical conditions in order to determine the where there was any negative effect of LED lighting on the visual organ. It worth mentioning that the physicians were not aware of the light sources used in the course of the observer's activity. Prior to start and after completion of each experiment the observers were examined for distance visual acuity (these measurements were taken twice a week and only before start of activity in order to control this visual function), chromatic thresholds - uniocularly for the both eyes by means of anomaloscope AN-59, projected blind spot area – uniocularly for both eyes by means of a campimeter. Under the studied lighting conditions the observers passed the following tests: uniocular determination of the nearest distinct vision point for each eye, calculation of the absolute accommodation extent (AAE), binocular measurement of the time of achromatic asthenopia and measurement of the CFFF by means of KPFK-99 "Psychomat".

During the investigations a one-and-a-half hour long visually intensive proofreading activity with an intellectual element was used as a functional load. The investigation results were recorded to the special protocols data from which was used for statistical analysis (Statistica 6.0) and for making conclusions on the lighting conditions efficiency. Studies of the AAE showed that its values decrease in the course of strenuous work under every lighting condition variant concerned (Table 1).

The results of determining of the AAE change significance after visual workload according to the Student's t-test allowed to acknowledge that significant changes in the state of AAE ($r < 0.05$) nevertheless not exceeding the boundaries of natural variations for this indicator (0.5 – 1.5 diopter) were observed nearly in all lighting variants. Evaluation of the effect of the lighting spectral distribution at the fixed illumination intensity level according to the

Student's t-test was performed for the compared variants at T_c 4000 K for every illumination intensity level and at T_c 5000 K for 200 and 400 lx.

Table-1. Change of absolute accommodation extent after visual workload under various lighting conditions

Illumination intensity, lx	**Correlated color temperature, K**	**LED lighting**		**LED lighting**	
		Correlation index		**Correlation index**	
		***r* (between, before and after activity)**	***p*(*r*)**	***r* (between, before and after activity)**	***p*(*r*)**
200	3000	0,7458	p < 0,05	0,7287	p< 0,01
400		0,8505	p < 0,01	0,6942	p< 0,05
1000		0,7261	p < 0,05	0,7362	p< 0,01
200	4000	0,6749	p < 0,05	0,6872	p< 0,05
400		0,6536	p < 0,05	0,7667	p< 0,01
1000		0,1433	-	0,8513	p< 0,001
200	5000	0,7932	p < 0,05	0,6345	p< 0,05
400		0,6598	p<0,05	0,8301	p< 0,001
1000		0,6272	p<0,05	0,7175	p< 0,05

The highest AAE value both prior to work start and after its completion was recorder under LED lighting conditions. The value of AAE after the work completion under LED lighting conditions exceeded the basic variant value by 0.6 – 0.7 diopter (6.3 – 8.4 %) at T_c 4000 K within the illumination intensity range from 200 to 1000 lx; 0.5 – 0.7 diopter (6.0 – 8.0 %) at T_c 5000 K within the illumination intensity range from 200 to 400 lx. In other words it was ascertained that the visual organ accommodated better under LED lighting which could be explained by the higher ciliary muscle activity and is obviously connected with biological necessity in the LEDs radiation spectrum [6].

In the course of the experimental investigations it was discovered that the higher visual fatigue leads to the lower achromatic asthenopia time threshold which is used to determine the eye muscles state. Significance of the achromatic asthenopia time threshold change due to visual activity was found out in all of the lighting variants ($p < 0,05$). Influence of the radiation spectral distribution under the fixed illumination intensity conditions on the achromatic asthenopia time change is characterized by a high degree of relevance. The achromatic asthenopia time both prior to the work start and after its completion had longer duration under LED lighting conditions. This evidences favorable effect of LED lighting on the muscle function of the visual analyzer: usual muscle tone was achieved with the reduced muscle efforts. Therefore LED lighting ensures better working conditions for the accommodative-muscular system of the visual organ.

In the course of study of the projected blind spot area it was ascertained that the retinal fatigue evaluated by the peripheral vision state leaded to the positive increase of the physiological blind spot area after completion of intensive visual activity. The range of increase as compared to the initial value for LL lighting variants made 6.57 □ 12.06 %; for LED lighting variants – 3.87 – 10.77 %. It was determined that in the course of visual workload at T_c 3000 K LED lighting facilitates lower visual fatigue as compared to luminescent lighting ($r < 0.05$). For the variants with T_c 5000 K the differences between LED and luminescent lighting as related to the studied indicator were not significant ($r > 0.05$).

In the course of study of the chromatic vision acuity there was detected an uneven pattern of change of the chromatic thresholds depending on different lighting variants. Analysis of the obtained results demonstrates that at time of visual activity under luminescent and LED lighting the retina state was not similar which was obviously connected with photochemical reaction in the retina which may slow down or become more intensive under action of radiation within the different portions of the visible spectrum. However the spectral distribution influence was detected only in regard to c-receptor of the retina: for radiation with T_c 4000 K (1000 lx) and T_c 5000 K (400 and 1000 lx). For the other studied conditions the spectral distribution influence was insignificant which can be explained by the nature of visual tasks – work with achromatic objects not connected with determining of color differences as well as by the qualitative lighting characteristics – favorable radiation spectral distribution, absence of light flux flicker.

Assessment of the state of the visual organ central division was made by means of the critical flicker fusion frequency (CFFF) method. Analysis of the CFFF absolute values as of the time prior to the work start and after its completion didn't allow to determine the most preferable radiation structure: the Student's *t*-test did not confirm significance of the differences within the studied range of illumination intensity and Tc. I.e., the CFFF index under LED lighting conditions is not lower then under LL lighting. The investigation results led to the inference that LED lighting did not have suppressive effect on the CNS status. The CFFF decrease in the course of experiment is pertaining to the intensive visual activity being performed, this process has a reversible nature – by the start of the next day the indicators of the initial values reestablished.

According to the results of clinical examination of the retina status (be means of a computer-aided tomography) and the eye-lens status it was ascertained that both in the reference and in the primary panels after completion of the experiment the vision acuity of the both eyes remained the same and made 1.0, the refraction was also predominantly emmetropic within the physiological standard limits; the foveola profile didn't change, the retina architectonics wasn't affected, the optic disk was of normal size, the disk rim extent and area had no abnormalities; the physiologic excavation extent was normal, the area was not enlarged; correlation of the optic disc excavation area to the optic disc area were within normal limits: for the reference and the primary panels 0.029 ± 0.02 and 0.28 ± 0.02 correspondingly; the peripapillary nerve fibers were not damaged. Statistical analysis of the investigation results both for the primary and the reference panels didn't reveal significant differences between the studied indicators ($r > 0.05$

according to the Student's t-test). In other words the observers' retina state did not undergo significant changes and was not harmfully affected at time of intensive visual activity under both LL and LED lighting conditions.

Values of the visual fatigue indicator are given in Table 2, data of which evidence decrease of the visual fatigue with increase of the illumination intensity level. Such decrease is not significant at 1000 lx at any level of T_c both for LL and LED lighting conditions.

Table-2. Visual fatigue indicators

Illumination intensity, lx	**T_c, K**	**Visual fatigue indicator, %**	
		LED lighting	**LL lighting**
200	3000	15,18	20,39
400		12,17	18,27
1000		6,45	16,67
200	4000	14,91	19,23
400		11,21	17,14
1000		6,40	9,4
200	5000	14,16	18,27
400		11,97	17,14
1000		8,66	9,57

It was ascertained that during the one-and-a-half hour long visually intensive activity LED lighting induced lower visual fatigue. Significant influence of the spectral distribution on the visual fatigue indicator was proved for all of the studied lighting variants with $r < 0.05$ according to the Student's t-test.

Analysis of the obtained results allowed making the conclusion that the light environment created by means of LEDs enabled to ensure the lower visual fatigue and correspondingly the higher visual performance as compared to LL. LED lighting may be considered as more favorable from the point of view of hygiene at time of intensive visual activity by contrast to the basic lighting variant.

4. Conclusion

In the course of the experimental investigations it was ascertained that LED lighting does not entail harmful effect on the visual organ and the human body as a whole. The reported changes in the studied functional indicators of the visual organ in the course of visual activity are within the set boundaries of the physiological variations and have a reversible nature.

5. Findings

The elaborated comprehensive methodology for psychophysiologic and hygienic evaluation of the LED lighting conditions effect on the status of the visual organ and the human body as a whole may be used both for investigation of LEDs or any other LSs lighting conditions and for studying the lighting effects on various age and gender groups. The undertaken research efforts allows elaborating the scientifically based recommendations for use of LED light fittings (with due account for the spectral distribution) in the public and administrative, accommodation and production premises. Use of LED LSs creates opportunities for the visual activity efficiency increase under the studied lighting conditions at time of intensive visual works performance (up to 15%). The material obtained in the experimental investigations may be taken into account during designing of the lighting equipment with LED light fittings aimed both for newly constructed buildings and for remodeling of the existing lighting systems. In this case replacement of LL lighting fixtures by LED ones will ensure significant decrease of the extent of electric power consumed for lighting purposes.

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