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Revisiting Practical Guidelines for use of Light-Emitting Diodes for Lighting of Public and Administrative Buildings

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ABSTRACT

The work outlines experimental psychophysiologic and hygienic investigations aimed at studying the effect of light-emitting diodes (LED) lighting on the visual organ and the human body as a whole. The work includes an analysis of the research results in regard to the indicators of the human mental, physical and immune status, a hormonal profile and visual efficiency under the conditions of LED lighting. There were elaborated scientifically based recommendations for design of the artificial lighting installations that would be safe for the visual system and the general state of the organism.

Key words: light-emitting diode (LED) lighting, visual performance, visual fatigue, physical status, mental status, immune status, hormonal profile, lighting efficiency, recommendations.

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INTRODUCTION

A lot of attention now is paid to ensuring a favorable light-and-color environment [1–2] which supposes use of light both for visual activity and for satisfaction of an entire range of the human needs – psychophysiologic, psychological and ecologic. The problem of saving electricity consumed for lighting needs is equivalently significant. Use of the LED light sources (LS) which are considered to be the most effective nowadays could assist in solving the above problems. The spheres of application of the LED-based illumination equipment are constantly extending. Nevertheless various specialists state that the effect of LED lighting on the quality of human life could not be evaluated as unambiguous [3–9]. The possibility to use LEDs for creation of favorable lighting conditions requires tangible evidence that can be obtained by comprehensive studies of the LEDs lighting effect on the visual organ and the body as a whole.

MAIN PART

There was elaborated an integrated methodology for efficiency evaluation of the lighting equipment (LE) with the LED LSs from the point of view of psychophysiology and hygiene [10, 11], which was tested in a series of experimental investigations aimed at studying LED lighting effect on the visual organ and the human body as a whole. Dynamics of visual performance (VP) and of definite indicators of the functional state of human body were assessed [12]. Prior to the investigation start a group of observers aged between 20 and 25 years who voluntarily participated in the experimental investigations was subject to clinical examination. The examination in the republican ophthalmological hospital included: refractionometry; eidoptometry; computer-assisted 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 examination in the republican mental health hospital included: psychical function analyses; electrocardiographic examination (ECG) (Fig. 1); electroencephalography of brain functional activity (EEG) (Fig. 2); echoencephalography of brain (ECHO-EG) (fig. 3); examination of the immune status and the hormonal profile (fig. 4).

Fig. 1 – Electrocardiographic examination

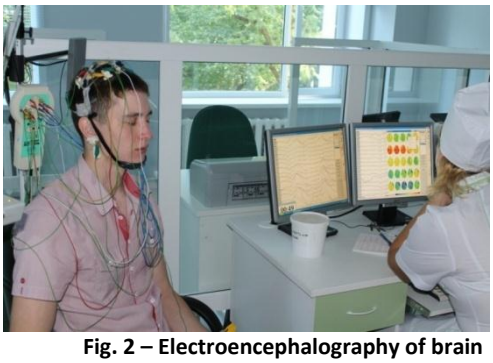

Fig. 2 – Electroencephalography of brain

Fig. 3 – Echoencephalography of brain

Fig. 4 – Examination of the immune status and the hormonal profile

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.An experimental research facility [13] complying with the regulations SP 52.13330.2011 was designed and implemented for the purposes of the experimental investigations. Light fittings of the following manufacturers were chosen: Joint Russian-Korean Enterprise LLC "Nepes Rus" (Cap Flat 66-16) and OJSC "ASTZ" (DVO12-38-001 Prizma and LVO04-4x14-041 PRS, LVO04-4×18-041 PRS). Electrical, photometric, spectral and colorimetric parameters of all of the light fillings were measured. The value of correlated color temperature (Tc) of the light fittings: 3000, 4000 and 5000 K.

Before the experimental investigations start the observers had a research techniques training course until obtaining stable results. Upon completion of the investigations the both panels passed the clinical examinations one more time in order to determine the negative effect of LED lighting on the visual organ as well as on the mental and physical status of the human body. The investigation design envisaged a 15-minutes' period for the observers' adaptation to the lighting conditions, visual functions analysis, diastolic and systolic pressure measurement, heart rate measurement, 2-minutes' visual acuity test. After that the observers accomplished visual activity (category A-2) upon completion of which they entered the subjective estimates into the inquiry forms and were subject to repeated measurements [11].

The subjective estimates method was used in a set of investigations of the human body mental status. Moreover the subjective estimates were helpful in the course of evaluation and justification of new requirements to the quality of lighting. The resulting material based on the inquiry forms with the subjective estimates did not allow determining advantages of any of the variants. It was only determined that the observers preferred LED lighting at Tc 3000 K and 4000 K in the process of evaluation of a plant leaf color reproduction which can be explained by LED spectrum and high values of the special color rendering indices R_{14}. Evaluation of the body physical status under LED lighting conditions was performed relying on the dynamics of such indicator as a "double product" index (DPI) measured before and after the visual workload, as well as on the brain ECG, EEG and ECHO-EG indicators (measured on the 1^{st}, 30^{th} and 60^{th} days of the investigation).

It was ascertained that in the course of visual workload DPI decreased nearly for all of the explored variants of lighting. The calculations showed that there was a weak interconnection between the DPI results before and after the visual activity for the following variants of LL lighting: at Tc 3000 K and the illumination intensity of 200 and 400 lx, at Tc 4000 K and 1000 lx; at Tc 5000 K and 400 and 1000 lx (correlation index: $r < 0.5$). For the following LED lighting variants there was detected a weak interrelationship between the DPI results before and after the visual activity: for Tc 3000 K and the illumination intensity of 200 lx; for Tc 4000 K and 1000 lx (correlation index: $r < 0.5$).

The investigations showed that the values of systolic arterial pressure and heart rate in the course of the experiment didn't exceed the limits of physiological variations ($r < 0.05$). The minimum DPI values were detected under LED lighting conditions at Tc 3000 K which is possibly connected with more favorable effect of warm-white radiation on the human physical state as compared to cold-white or daylight. Thus it was discovered that LED lighting ensured more high spare capacities of the human body then LL lighting.

Analysis of dynamics of ECG indicators (on the 1^{st} and the 60^{th} days) for the reference and the primary panels showed that heart rate and ECG time intervals of the observers were within the physiological standard. It was ascertained that EEG indicators in the primary and the reference panels also were within the physiological standard. The reference panel on the 30^{th} and the 60^{th} days showed some suppression of alpha-rhythm activity which evidenced slightly higher nervous system fatigue in case of LL lighting. ECHO-EG indicators of the brain functioning for the reference and the primary panels were within the physiological standard as well, no significant changes were detected. In other words the explored lighting conditions (LL and LED) are equivalent in regard to ECHO-EG indicators.

In the course of study of immune responses at the level of functioning of the whole system the observers from the reference and the primary panels demonstrated no interruption of relationship between the immunity elements on the first day of the experiment as compared to the corresponding indicators from the healthy donors. Under LL lighting conditions during the whole observation period the immune system indicators, namely the load index, the T-cell index, the immune regulation index remained within the

physiological standard. Individual humoral and cellular characteristics of the immune status in the explored panel demonstrates the following dynamics: comparatively to the healthy donors by the 60th day of observation there was recorded some increase in the number of smaller circulating immune complexes (CIC) up to 99.77 ± 6.24 c. u., there was also observed a tendency to decrease of the oxygen-dependent neutrophil systems activity.

The primary panel (in LED lighting conditions) in the course of the investigation showed increase in the number of smaller CIC as well as in the functional activity of neutrophils. Simultaneously the studied parameters of CIC, phagocytic and metabolic function of the cells remained within the physiological standard notwithstanding the statistically significant differences as compared to the indicators on the 1st day of observation. Neutrophilic granulocytes with high and moderate activity towards latex particles and sufficient renewal rate of nitro blue tetrazolium (Neutrophils activation index 0.27 ± 0.03 c.u., NBT 19.5±0.59 %) were predominant in the blood smears. It was ascertained that the immune status indicators in the reference and the primary panels in the course of the investigations were consistent with the physiological standard parameters except for the smaller CIC the level of which was positively growing ($r < 0.05$). In the reference panel there was observed increase of neutrophilic activity evidenced by phagocytosis, HBT-test and activation index which were indicative of stimulation of nonspecific immunologic resistance factors which was possibly conditioned by a favorable LED lighting spectral distribution.

Analysis of the hormonal profile survey results leads to the conclusion that the hormonal profile change is consistent with mildly marked stress disorders which is possibly caused by an academic load of the observers which started simultaneously with the investigation start. The reference panel demonstrated more severe changes evidenced by increased concentrations of such hormones as cortisol, free thyroxine, somatotrophic hormone, adrenocorticotropic hormone. No corrections for the mentioned disorders were made for the reference panel. According to the investigative data a partial correction of the hormonal profile indicators took place in the primary panel. The primary panel only demonstrated an elevated level of free thyroxine.

The integral LED lighting efficiency indicators were evaluated based on visual performance. Analysis of the VP investigation results by means of the visual acuity test revealed the advantages of LED lighting from the point of view of ensuring more high VP level. The highest VP index under LED lighting conditions was reported at Tc 4000 K; its relative value was higher then under LL lighting conditions by 11.8 % at the illumination intensity of 200 lx, 14.9 % – at 400 lx, 12.4 % – at 1000 lx. It is necessary to be noted that the paired correlation index r proved ($r < 0.05$) existence of a positive interrelationship between the absolute accommodation extent and the VP index after the visual activity. This allowed coming to a conclusion that the VP index increase under LED lighting conditions was to the certain extent due to the better work of the accommodative-muscular system of the visual organ.

The results of work performance quality investigation under different lighting conditions showed that with duration of the visual workload its indicator was going down. However significant decrease of the acuity index according to the Student's t-test was detected only under LED lighting conditions at Tc 4000 K (illumination intensity 400 and 1000 lx); at Tc 5000 K (400 lx). Differences in performance quality after comparison of LED and LL lighting variants were found to be insignificant.

CONCLUSION

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 human body in the course of visual activity are within the set boundaries of the physiological variations and have a reversible nature. LED radiation creates the light environment with high psychophysiologic and hygienic indicators which maintain the VP.

FINDINGS

The obtained experimental material allowed elaborating the scientifically based recommendations for use of the LED light fittings in the public and administrative, accommodation and production premises for ensuring the safe light environment. LED lighting may be recommended for use at time of fulfilling the visual activity requiring the limited light flux pulsation factor (illumination intensity): during intensive visual and

mental work; during activities connected with non-strict requirements to color sensitivity. Use of LEDs for creation of comfortable and safe light environment conditions is effective in the mixed lighting systems, for example along with LL. LED and LL mixed lighting systems may be recommended for use in the lighting equipment in the premises where mental and visual activity is performed with achromatic objects or where the works with low color sensitivity requirements are performed.

The lower boundary of the work surface luminance range should be set to 100 – 150 Cd/m^2. Variance of luminance (illumination intensity) at the work surface in case of LED lighting is recommended to be at the level of 1 : 3. In LED lighting design process it is necessary to control the luminance non-uniformity at a light hole of an light fitting, the value should be $L_{max} / L_{min} \leq 5:1$. It is recommended to cover the general light fittings by light diffusers in order to achieve the necessary luminance uniformity at a light hole or to use the light fittings made according to a "remote phosphor" technology. In case of use of the LED light fittings made according to the "remote phosphor" technology it is necessary to practice an incoming inspection for the same in order to detect ultraviolet light.

The LED light fittings with high general color rendering index Ra and high special color rendering index (R13, R14) may be recommended for illumination of the premises where the A-B category visual activity with high color sensitivity requirements is carried out. Use of the LED light fittings for the lighting equipment being designed or remodeled will allow achieving an economic benefit lying in reduction of lighting power consumption costs no less then by 30% and increase of visual work efficiency up to 15% under the recommended lighting conditions.

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