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ABOUT THE EFFECT OF LED LIGHTING AND ITS DYNAMICS ON VISUAL FUNCTIONS AND OVERALL STATE OF A SPECTATOR

Yulia A. Skorik

NIU MPEI, Moscow
E-mail: skorikyulia@gmail.com

ABSTRACT

Constant development of LED light sources (LS) and lighting control systems establish a potential for development of brand new lighting installations (LI) which allow us to increase efficiency of human performance for both short periods of time and for the entire active period of life. For massive development of such LIs, it is necessary to have a methodology for evaluating their efficiency. Such methodology has been developed and tested and has prospects of development requiring constant collection and consideration of new information. In view of this, the article describes experimental evaluations of parameters of visual functions and psycho-emotional and physiological states of spectators in static and dynamic lighting by LED LSs.

Keywords: visual performance, dynamic lighting, comprehensive evaluation of a spectator's state, correlated colour temperature

1. INTRODUCTION

Visual activities of design engineers often imply serious eyestrain. It is especially applicable to transformation of most of documents and drawings into electronic form, which is usually done by using PC. The existing regulatory documents standardise the levels of illuminance in design areas and design bureaus (horizontal illuminance should be of at least 400l x and of 300 lx for offices, vertical illuminance on displays should be 200 lx) [1]. At the same time, the latest data on perception of the level of illuminance and LS radiation spectrum are not taken into account. In the meantime, discoveries have been made in the areas of neuroanatomy and neurophysiology of animal and human vision [2–5], which make it necessary to develop LIs allowing their correlated colour temperature T_{cp} to vary throughout the day [6][1].

Constant enhancement of LED LSs and lighting control systems provides new opportunities in the field of lighting areas for hard visual activities. In particular, works with drawings, transfer of paper information into electronic formats are such types of activity which require speed and scrupulosity of employees' visual activities.

With introduction of light emitting diodes [10], varying of T_{cp} has become easy and adjustable, and the goal of this work (conducted in 2017) was to discover the patterns not only of visual performance (VP) and visual fatigue (VF) but also of psycho-emotional and functional states of spectators involved in hard visual activity at different types of LED lighting (static with different values of T_{cp} and dynamic).

2. PERFORMANCE OF EXPERIMENTS

The work for comprehensive evaluation of vision functions (VF), psycho-emotional and functional states of spectators was performed in a draw-

[1] Both visual perception and the level of circadian efficiency of biological effect of LS radiation remain unconsidered [7, 8]. But human health and psycho-emotional state depend on the level of illuminance and T_{cp} [6]. For instance, with T_{cp} growth in, there is a certain growth in spectator's activity efficiency [9].

ing processing room of one of Moscow office centres. Evaluation was conducted both with static lighting (SL) by white LEDs with different T_{cp} and with dynamic lighting (DL) by LEDs. Implementation of lighting scenarios became possible thanks to use of specialised system *Esylux NOVA Quadro Set*.

To increase objectivity, 2 groups of spectators were formed (the main one and the control one). The main group of spectators included 3 persons aged 30 to 54. The tested activity was regulatory review, i.e. check of drawings. The control group included 4 persons of the same age range. The tested activity was processing of drawings using PC including regulatory review. All spectators had normal sight without colour anomalies, had the same nature of work, the same set of technical means, and did not have differences in lifestyle and chronic diseases.

LED-based lighting devices (LDs) with micro-prism diffusers preventing visual discomfort even in case of work with several PC displays were used for lighting. These LDs were distinctive with capability to change their T_{cp} throughout the day in accordance with a well-known proposition [6]. T_{cp} values of LDs were measured by means of TKA-VD spectrocolorimeter. T_{cp} of LDs was equal to 4230K in the case of neutral-white (NW) lighting, to 2970K in the case of warm-white (WW) lighting, and to 5670K in the case of cold-white (CW) lighting. The levels of illuminance were equal to: 500 lx (G-0,8) and 250 lx (V-1,2). With reflectance of the floor, walls and ceiling equal to 0.5, 0.7 and 0.7 respectively, the discomfort index M was equal to 13, which corresponds to its standard value.

Before starting the series of tests of each new type of lighting, spectators worked with the created scenario of lighting for 2 working weeks. The main group of spectators (and the control group after them) was first tested with SL with different T_{cp} and then with DL (Fig. 1).

Correlated colour temperature was changed automatically by means of software supplied with the LED-based LDs. In the beginning of the working day (9:00), T_{cp} was equal to 5500K. Then it was gradually lowered having become equal to 4000K by the end of the first half of the day (13:00). The second peak of T_{cp} was observed in an hour, closer to the end of lunchtime, and T_{cp} lowered down to 3800K again by the end of the working day (18:00).

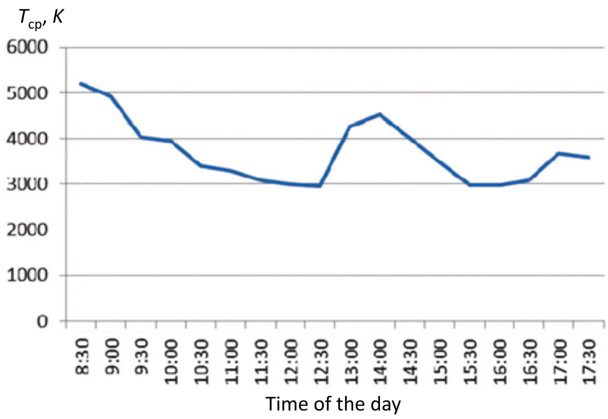

Fig. 1. Correlated colour temperature T_{cp} dependence on the dynamic lighting scenario

During preparation of the test plan, it was taken into account that experimental evaluation (testing) should not take more than 1 hour of working time per day (not more than 15 % of the working time).

Testing was performed at the beginning and at the end of the working day, before and after lunchtime. As a result the following estimations had been made:

– VP by using the programme, which checked Landolt ring with PC [11, 12];

– VF by using the VF estimation programme [9, 13–15];

– Psycho-emotional state, using the answers for test questions in accordance with the Health, Activity and Mood (HAM) method;

– Medical and biological state of a spectator (evaluated by non-invasive analysis method (without taking blood samples)).

Some previous studies [13, 14] allowed us to develop and to test a method of comprehensive evaluation of a spectator's state with different types of lighting. As a part of VP evaluation attention concentration and sustainability (with calculation every 60 seconds during a 5-minute test), attention set-shifting, coefficients of accuracy and performance (calculated using three major methods) as well as the clarified, minimum and maximum paces of work were evaluated. The volume of information being evaluated was rather large and did not allow us to use tests on paper media since it significantly slowed down processing of the results. Therefore, a software product allowing such amount of information to process was developed [11, 12]. At the beginning of the test, a spectator specified his full name, age, and made a note about his sight (for instance, some participants of the experiment were

Table 1. Visual Performance Coefficient (*R*, relative units) with Different Types of Lighting

Time of the day	9:05	13:05	13:55	17:55
WW-SL	0.66±0.06	0.65±0.05	0.69±0.03	0.71±0.05
NW-SL	0.62±0.06	0.67±0.05	0.68±0.06	0.73±0.07
CW-SL	0.64±0.06	0.69±0.06	0.72±0.06	0.74±0.06
DL	0.68±0.05	0.81±0.05	0.81±0.09	0.82±0.06

Table 2. Relative Visual Fatigue (*Ya*, relative units) with Different Types of Lighting

Time of the day	9:05	13:05	13:55	17:55
WW-SL	0.51±0.01	0.49±0.04	0.40±0.04	0.54±0.03
NW-SL	0.54±0.04	0.50±0.03	0.40±0.06	0.45±0.04
CW-SL	0.51±0.01	0.52±0.04	0.42±0.03	0.55±0.03
DL	0.54±0.03	0.40±0.08	0.43±0.04	0.45±0.04

able to indicate that they used glasses or contact lenses during the test). Within 300 seconds, a spectator pointed at a Landolt ring selected randomly by the programme. When the time was up, the test results were saved in an *Excel* file where necessary values were automatically calculated. The result of the VP study was the VP coefficient *R* calculated using the following formula:

$$R = T \cdot d,$$

where *d* is total number of viewed symbols, *T* is the accuracy coefficient calculated as

$$T = \frac{a-(b+c)}{a+b},$$

where *a* is the number of correctly marked symbols, *b* is the number of missed symbols, *c* is the number of mistakes made (incorrectly marked symbols).

VF was also evaluated [9, 13–15] by calculation of relative VF *Ya* using the formula

$$Ya = (1-\frac{t_2}{t_1}) \cdot 100,$$

where t_1 is time of disappearance of the difference in perception of brightness of two halves of a round before the start of the visual fatigue test, t_2 is time of disappearance of the difference in perception of brightness of two halves of a round after the end of the visual fatigue test.

Psycho-emotional state of a spectator was evaluated using the HAM method [16] and medical and biological state of a spectator (to reflect changes of his state) was evaluated by non-invasive analysis (without taking blood samples [17]).

3. RESULTS

The results of the measurements have undergone statistical evaluation based on Student's t-distribution [18]. Measurement error is characterised by a confidence interval where the actual value of measured magnitudes lies with the confidence probability 95 %.

Comparative evaluations of *R* values with illumination under NW-SL, WW-SL and CW-SL, and DL are presented in Table 1; corresponding evaluations of VF are presented in Table 2.

The presented data demonstrate differences in the values at points 13:05 and 17:55 corresponding to the end of lengthy visual workload. This is defined by the end of hard visual activities in the first and the second halves of the working day. It is worth noting, that the value of *R* is much higher by the end and at the beginning of the working day under DL than under CW-SL illumination. Based on the poll of the spectators, it may be explained by positive experience of a spectator's work with DL during the period of adaptation to the new type of lighting or, on the contrary, by negative experience of work with CW-SL. It is this why the data obtained from the spectators are evaluated in a dynamic fashion.

Table 3. Health, Activity, Mood Indexes (relative units) with Different Types of Lighting

Time of the day	9:05	13:05	13:55	17:55
	Health			
WW-SL	0.92±0.03	0.88±0.03	0.84±0.04	0.84±0.11
NW-SL	0.92±0.03	0.89±0.03	0.85±0.03	0.84±0.05
CW-SL	0.91±0.04	0.81±0.03	0.81±0.05	0.84±0.04
DL	0.90±0.05	0.91±0.03	0.84±0.03	0.85±0.03
	Activity			
WW-SL	0.90±0.06	0.79±0.06	0.69±0.06	0.61±0.05
NW-SL	0.85±0.06	0.80±0.04	0.73±0.04	0.67±0.05
CW-SL	0.88±0.06	0.80±0.08	0.68±0.06	0.75±0.04
DL	0.91±0.05	0.90±0.03	0.84±0.06	0.82±0.05
	Mood			
WW-SL	0.92±0.04	0.84±0.05	0.80±0.05	0.77±0.02
NW-SL	0.91±0.03	0.85±0.04	0.81±0.04	0.81±0.02
CW-SL	0.92±0.06	0.83±0.05	0.75±0.04	0.72±0.05
DL	0.89±0.04	0,88±0.04	0.85±0.04	0.85±0.03

The least levels of VF after the end of working day are observed with NW-SL and DL.

The values of parameters of the spectators' psycho-emotional state (Table 3), especially at time points 13:5 and 17:55, confirm better readiness of the spectators for continuous work with DL.

The results of data analysis demonstrate mutually-dependent dynamics of parameters of the spectators' VP and psycho-emotional state. The values of *R* with NW-SL and CW-SL are higher than with WW-SL. At the same time, the mood indicator lowers much more under CW-SL than with WW-SL and NW-SL illuminations by the end of the working day. When it comes to activity, DL turned out to be the most favourable for the spectators. Comparison of the data demonstrates that DL has a number of advantages as compared to SL, especially to CW-SL and WW-SL.

CONCLUSION

The described evaluations demonstrate that application of LED-based sources of NW light is more preferable compared to similar sources of WW and CW light. With increase in T_{cp}, there is an increase in VP with reduction of psycho-emotional characteristics of the spectators, and the levels of relative VF become almost the same with WW-SL and CW-SL by the end of the working day and twice as high as with NW-SL and DL. It is also seen that VF grows along with growth of VP under CW-SL[2].

The presented data testify that the existing method of VF and overall state evaluation is rather developed and may be used further. The following alterations to improve the method are possible:

– Separation of the studies by type: laboratory (more detailed, appropriate for small groups of

[2] It is also worth noting that:

– The area had a distinctive feature (non-availability of natural lighting) that made it possible to collect information strictly at the set level of lighting; this allowed us to conduct a series of experiments in conditions close to laboratory environment, and comprehension of the parameters being studied and analysis of their dynamics throughout the working day substantiate consistency of the collected data;

– Comprehensive evaluation of the spectators' state in different types of lighting provides variability for development of lighting scenarios for specific types of activities and spectators of different ages and professions;

– It is necessary to simplify and supplement such studies to obtain maximum possible amount of useful information for standardisation and design of DL LIs.

spectators) and experimental (less detailed, appropriate for checking the results of laboratory studies with large number of spectators);

– Replacement of complex and expensive medical equipment used in the described experiment (for instance, with EEG or just with measurement of blood pressure and heart rate);

– Application of different methods of a spectator's psychoemotional state evaluation.

It is important to note that complication of the method of comprehensive evaluation of spectators' state with different types of lighting should not expand the time needed for testing.

During the studies, it was shown that work with small groups provides good results. This allows us to speak about possibility to form small experimental groups of spectators of different age, profession, working in different facilities, etc. Such approach will allow us to collect data on the effect of DL on maximum number of categories the spectators may be divided into.

The collected data will allow us to form a base for introducing amendments to regulatory documents which may be further used by designers of DL LI's.

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***Yulia A. Skorik**,*
engineer, graduated from the Lighting Engineering sub-department of MPEI (TU) in 2011, graduated from the post-graduate studies of NIU MPEI by specialty in Lighting Engineering and Light Sources in 2019