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OPHTHALMOLOGICAL AND LIGHTING PROBLEMS OF CREATING A RATIONAL LIGHTING ENVIRONMENT FOR OFFICE WORKERS AT UKRAINIAN ENTERPRISES

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Introduction. Despite the huge number of light-technical lighting devices with different characteristics of types and colour temperatures, there are still no specific hygienic recommendations for their use to create an optimal lighting system.

The aim of the study is to develop hygienic and lighting recommendations for creating an optimal lighting environment, taking into account the types, spectral characteristics and colour temperatures of light sources.

Materials and methods of research. The research was conducted in industrial conditions at the computer centres of the Pension Fund of Kyiv, equipped with fluorescent light sources, and the office of the «Azur Air» company, equipped with LED light sources. Office workers, a total of 148 people (81 and 67) with visual acuity 1.0 participated in the research, on the basis of an ophthalmological examination during work throughout the working day with an hour break in the middle. To assess the functional state of the visual system, physiological and psycho-physiological methods of functional indicators were used: visual acuity, accommodation and its potentials, contrast sensitivity of the eye, achromatic dysparopia, visual performance, heart rate, peripheral blood pressure (systolic and diastolic), short-term memory.

Results. The experimental studies carried out in industrial conditions based on the main indicators of the functional state of the workers showed that when working under the influence of radiation generated by fluorescent lamps at T_{cv} – 4100 K against the background of minor fluctuations in the indicators of the state of accommodation reserves and the stability of the accommodation function, the fluctuating nature of visual performance indicators is observed ($p < 0.005$) indicators of short-term memory decrease by 50 %, and heart rate from 57.9 beats. Increases to 146 units. min. and then normalizes until the end of the work. When working under the influence of radiation generated by LED light sources at T_{cv} – 4500 K, the indicators of the level of the functional state of workers are more stable when the level of the investigated functions fluctuates with a small amplitude.

Conclusions. When working under the influence of radiation generated by LED light sources at T_{cv} – 4500 K, the levels of indicators of the functional state of workers have a more stable character when the level of the investigated functions fluctuates with a small amplitude. The instability of the main investigated functions was established in the working office in the light environment equipped with fluorescent lamps, while under LED lighting the investigated functions have a stable character during the working day. Recommendations have been developed taking into account ophthalmic hygiene and lighting requirements for creating an optimal lighting environment for office workers, the implementation of which will contribute to increasing visual performance and prevention of visual impairments.

Key words: light environment, experimental studies, physiological methods, lighting device

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Introduction

When designing efficient lighting systems for workplaces and production facilities, attention should be paid not only to lighting levels in accordance with current regulations, but also to the choice of light sources that contribute to the creation of quality lighting environment parameters that affect visual performance levels.

A particularly important approach to the creation of an optimal lighting environment, i. e. the optimal combination of quantitative and qualitative parameters, is necessary for professions involving complex visual tasks in case of demanding tasks, where no mistakes can be made [1–3].

As there is now a large variety of different types of light sources in the lighting arsenal, managers of office buildings (employers) often decide on the choice of light sources on their own without taking into account the specific visual tasks, the characteristics of colour temperatures, heights of luminaires and other parameters of lighting systems.

In the case of complaints about the development of visual fatigue of office workers, managers address the Institute for recommendations on the rational design of lighting systems for workplaces and production facilities. Therefore, we faced the task of organizing and conducting research in working conditions in order to study the functional state of the body of workers under the influence of generated radiation from fluorescent and LED light sources using objective and subjective research methods in order to develop recommendations for creating an optimal lighting environment.

Development of ophthalmohygienic recommendations for lighting workplaces and workrooms for workers of different industries is established on the basis of conducted scientific research and, as a rule, is focused on visual performance status [2–4].

Visual performance is an integral indicator of the interaction of physiological functions when performing work tasks of varying degrees of complexity. The importance of production lighting is particularly important because the visibility of objects of distinction determines the quantitative and qualitative performance of workers and contributes to maintaining a high level of performance. Properly organized industrial lighting, which is tailored to the specific visual tasks, helps to prevent visual fatigue and visual impairment.

To a greater extent, this applies to the work with complex visual tasks, characterized by the need for long fixation of the gaze on small objects of distinction at small contrasts with the background, at reduced brightness of the background, the need to look at floating and flickering objects, located on vertical, horizontal and inclined. planes.

However, no less important is the choice of light sources in industrial lighting systems, which create a luminous environment with quantitative and qualitative parameters. In modern factories today mainly compact and tubular fluorescent lamps and LED light sources with different spectral characteristics and colour temperatures are used [4].

Figures 1 and 2 show the spectra of light sources used in production facilities.

Materials and methods of research

The main purpose of the study was to determine the peculiarities of psychophysiological reactions in office workers when performing work operations with complex visual tasks under the action of radiation from two types of light sources – fluorescent and LED in a comparative analysis on the basis of subjective and objective indicators in the studied to develop measures of their application.

The study was conducted in working conditions at the computing centres of the Pension Fund in

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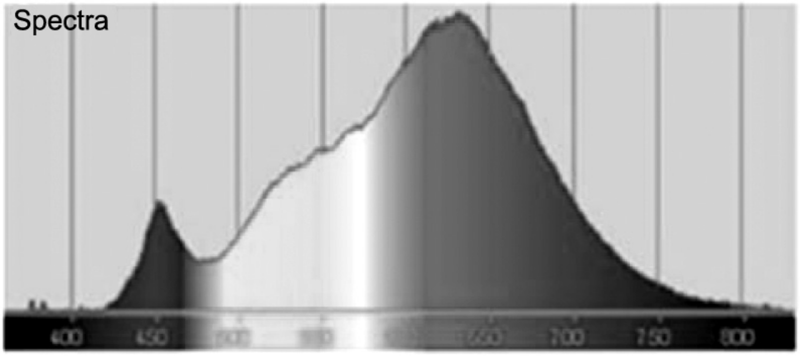

Figure 1. The spectrum of an LED lamp

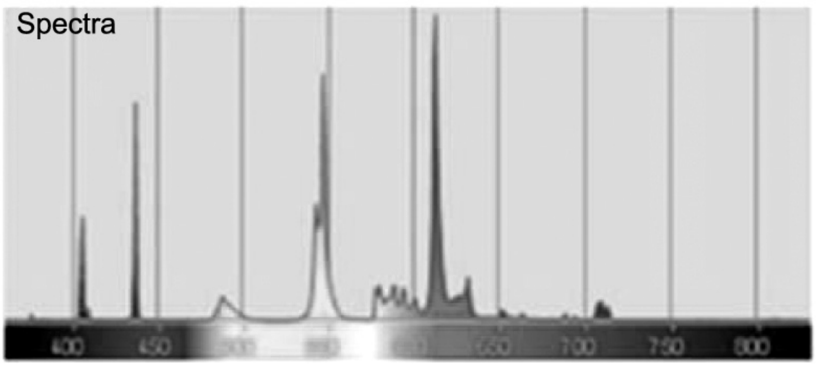

Figure 2. The spectrum of a fluorescent lamp

Kiev, equipped with fluorescent lamps (FL), and the office of Azur Air, equipped with LED light sources (LEDS). The study involved office workers, 148 persons in total (81 and 67) with visual acuity 1.0 based on ophthalmic examination while working with Noutbuk during the whole working day with a 1-hour break in the middle of the day [1, 2].

In order to carry out the work, requirements for a general uniform lighting system in office areas were developed for a production experiment to investigate the effects of testing from LLVs and LEDSs. Based on this, the following tasks were carried out: computer modelling of photometric parameters of the production room in DiaLux software was carried out; a scheme of luminaire placement in lighting installations in production facilities was developed, providing a norm of illumination at the workplace – 400 lx and colour temperatures of 4100 K and 4500 K respectively. In order to assess the functional state of the visual system, physiological and psychophysiological research methods have been used, taking into account their adequacy to the task, which allows to estimate correctly the visual perception and quality of visual information processing [3].

In this study, a complex of psychophysiological methods was used to assess brightness and contrast of the visual system channels under the influence of radiation from the SDDS, functional state of the rods and cones systems, as well as information transmission to the central sections of the visual analyzer, primary and secondary visual centres [3].

In order to solve the above tasks, the following methods of investigation of functional indicators were applied: visual acuity, accommodation and its

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potentials, contrast sensitivity of the eye, achromatic adisparopia, visual performance, heart rate, peripheral BP (systolic and diastolic), short-term memory.

The visual acuity or eye resolution of the subjects we studied is one of the main criteria for evaluating the ability to visually analyse the shape, size, structure and orientation of objects in space, and visometry refers to the obligatory methods of functional studies of the visual organs.

Visual performance was studied by us using Landolt ring tables, reflecting the integral index of visual acuity function, contrast sensitivity and resolution rate.

The achromatic adaptation method we use reflects the functional state of the contrast sensitivity function of the eye. It is based on inequality aversion of the two contrast-contrasting fields.

After preconditioning adaptation to a set background luminance, the observer fixed a point in the centre at the boundary of the two fields. The time threshold for adaptation was determined by the time from the observer's fixation of the test object until the clear boundary between the contrasting fields was broken when the contrast $K \geq 0.5$ or until the contrast between the contrasting fields disappeared with $K \leq 2$.

The hourly threshold of adisparopia, which characterises functional visual stability, was measured in seconds.

Taking into account the psycho-emotional nature and peculiarities of human perception of light, we developed a questionnaire with a table for subjective evaluation of the comfort of the light environment according to 5 indicators, which can be used for office workers.

The questionnaires were designed to conduct a production experiment in office workers three times per workday: in the morning before lunch break and at the end of the work shift under the conditions of adaptation to the light environment equipped with LLs and LEDS [3].

Obtained data of conducted researches were worked out with computer programs.

Own research. Experimental physiological studies we conducted in production conditions are presented in Figures 3–6, which show their levels in the dynamics of the working day and during the working week of office workers under lighting conditions with different light sources.

From the data ($p < 0.05$) we can see that against the background of insignificant fluctuations of function in terms of adysparopia and accommodation reserves, the oscillating character of visual performance and contrast sensitivity of the eye with a large amplitude, resulting in a significant reduction of function from the beginning to the end of the working day is observed. At the same time, short-term memory values decrease significantly (by 50 %), and the heart rate increases to 146.0 bpm from 57.9 bpm until the middle of the working day. Visual performance according to the integral index within the working day doubles, and by the end of the working day it decreases to the initial value, while the number of mistakes made increases by 11.6 %.

Thus, Figures 3–6 show that during work under influence of radiation generated by fluorescent lamps at colour temperature 4100 K, against the background of insignificant fluctuations of indicators of the state of accommodation reserves and stability of accommodation function, fluctuating character of indicators of visual performance with high amplitude is observed ($p < 0.005$), indices of short-term memory decrease on 50 %, and heart rate increases from 57.9 beats/min up to 146.0 beats/min and then slightly normalizes by the end of work.

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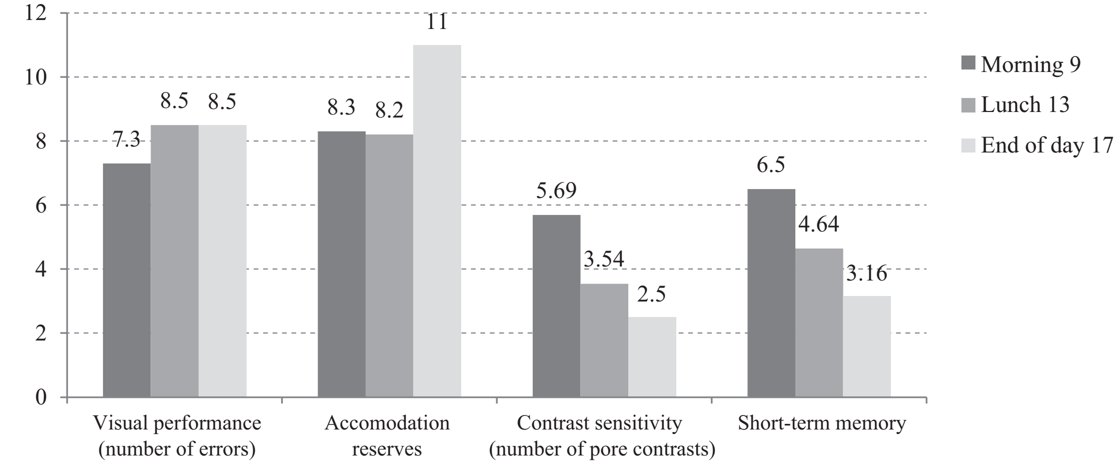

Figure 3. Indices of the level of psychophysiological functions (visual performance, accommodation reserves, contrast sensitivity, short-term memory) of office workers in the dynamics of the working day and during the working Sunday in a light environment equipped with fluorescent light sources – E 400 lx, T_{cv} 4100 K

When working under the influence of radiation generated by SDDS at colour temperature T 4500 K, indicators of the level of functional state of workers are more stable with fluctuations of the level of functions studied with a small amplitude.

The average indices of subjective psychophysiological perception of the light environment of the employees in the office of the Pension Fund in Kiev and Kiev region under illumination of LL at E 400 lx and colour temperature T 4100 K are presented in Table 1.

The survey data (Table 1) showed that when working under LL lighting conditions, workers rated the light environment as comfortable – 43.3 %, and as uncomfortable – 56.7 %. The level of illumination is assessed as «good» by 56.7 %, «brilliant» by 11.9 % and «insufficient» by 31.3 %. Researchers prefer cold colour temperatures – 55.2 %,

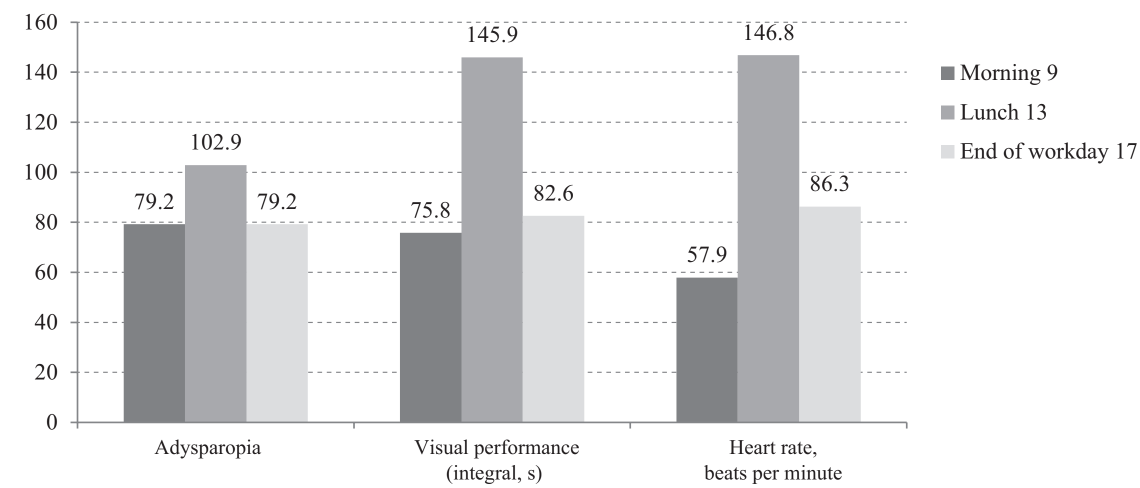

Figure 4. Indices of the level of psychophysiological functions (adysparopia, visual performance, heart rate) in office workers in the dynamics of the working day and during the working Sunday in a light environment equipped with fluorescent light sources – E 400 lx, T_{cv} 4100 K

ISSN 2223-6775, Ukrainian Journal of Occupational Health, 2022, 18 (2), 119–129

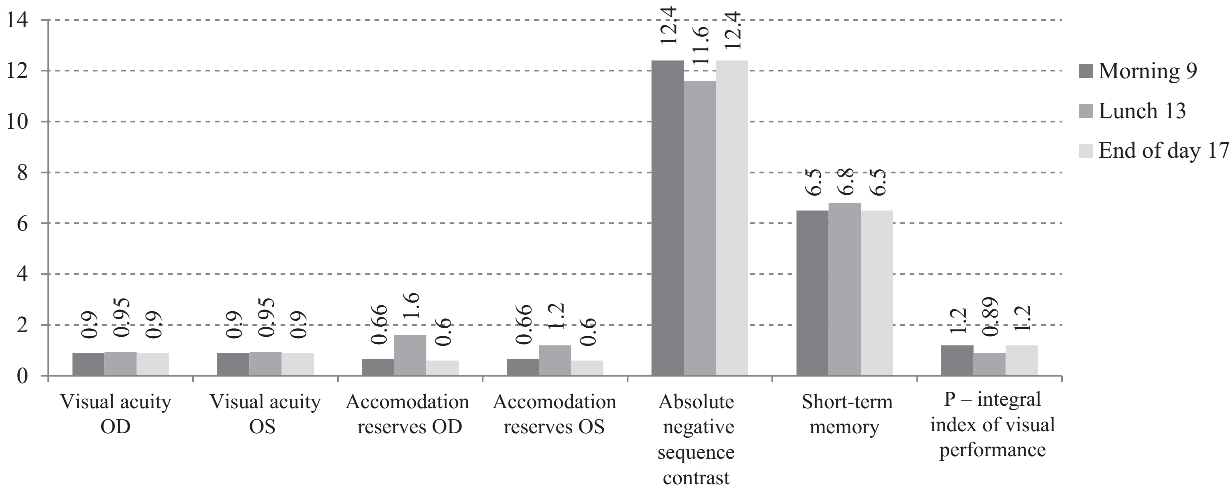

Figure 5. Indices of the level of psychophysiological functions (visual acuity, accommodation reserves, absolute negative serial contrast, short-term memory, integral index of visual work capacity) of office workers in dynamics of the working day and during working Sunday in the light environment equipped with 4500 K LED light sources

warm – white – 28.3 % and neutral – 16.4 %. Workers assessed the work done as «not difficult» – 56.7 %, and as «complicated» – 43.2 %. General condition of the body is assessed as «normal» by 53.7 % and «tired» by 46.2 %.

The average indices of subjective psychophysiological perception of the light environment of workers in Handling Company's office in the dynamics of the working day during a working Sunday at illumination with SDDS at E 400 lx and colour temperature 4500 K are presented in Table 2.

The survey data (Table 2) showed that the majority of employees rated the lighting environment as «comfortable» – 82.7 %, and as «not comfortable» – 17.3 %. The level of lighting is rated as

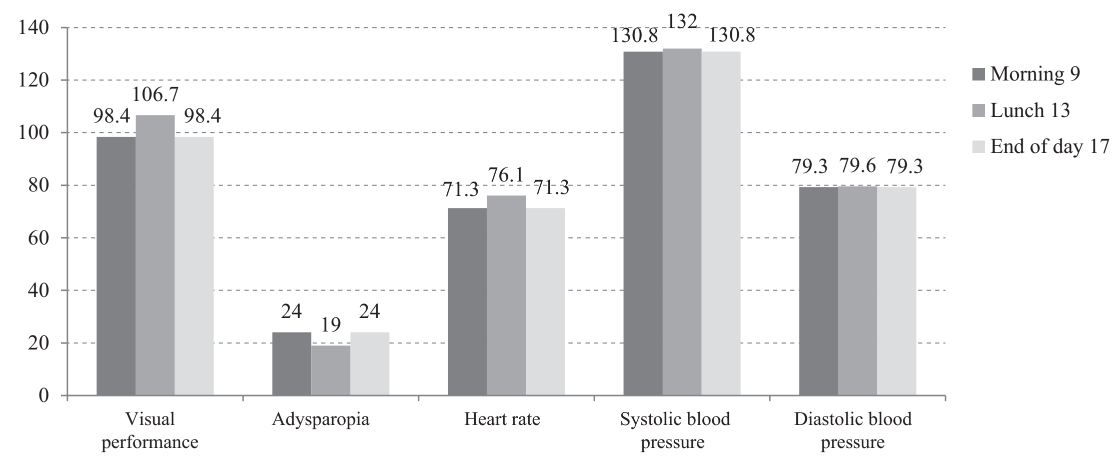

Figure 6. Indices of the level of psychophysiological functions (visual performance, adysparopia, heart rate, systolic blood pressure, diastolic blood pressure) in office workers in the dynamics of the working day and during the working Sunday in the light environment equipped with LED light sources – T_{cv} 4500 K

ISSN 2223-6775, Ukrainian Journal of Occupational Health, 2022, 18 (2), 119–129

Table 1

The average indexes of subjective psychophysiological perception of the luminous environment of the employees in the office of the Pension fund in Kiev and Kiev region when illuminated by fluorescent light sources at E = 400 lux, colour temperature 4100 K

No.	A psychophysiological indicator of the state of the light environment	Evaluation indicator	Absolute average
1	Evaluation of a comfortable lighting environment	Comfortable Not comfortable	29 38
2	Assessment of the level of illumination	Good Brilliant Insufficient	38 8 21
3	Psychophysiological perception of the radiation spectrum	Warm Cold Neutral	19 37 11
4	Assessment of the complexity of the visual task	Complicated Simple	29 38
5	Characteristics of the general state of the body	Normal Tired	36 31

Table 2

The average indices of subjective psychophysiological perception of the lighting environment of the employees in the Handling Company's office in the dynamics of the working day during the working Sunday at illumination with LED light sources of E 400 lx, 4500 K colour temperature

No.	A psychophysiological indicator of the state of the light environment	Evaluation indicator	Absolute average
1	Evaluation of a comfortable lighting environment	Comfortable Not comfortable	67 14
2	Assessment of the level of illumination	Good Brilliant Insufficient	67 6 8
3	Psychophysiological perception of the radiation spectrum	Warm Cold Neutral	25 19 37
4	Assessment of the complexity of the visual task	Complicated Simple	45 36
5	Characteristics of the general state of the body	Normal Tired	70 11

«good» – 82.7 %, and as «brilliant» – 7.4 %. Most workers (45.6 %) perceive the colour temperature well in the neutral-white range, with cold-white being 23.4 % and warm-white being 30.8 %. Those surveyed describe their work as «complicated» – 55.5 %. The general condition of the body is assessed as «normal» by 86.4 % of those surveyed, and as «tired» by 13.58 %.

Workplaces and production facilities are lit using different light sources. The invention of a new light

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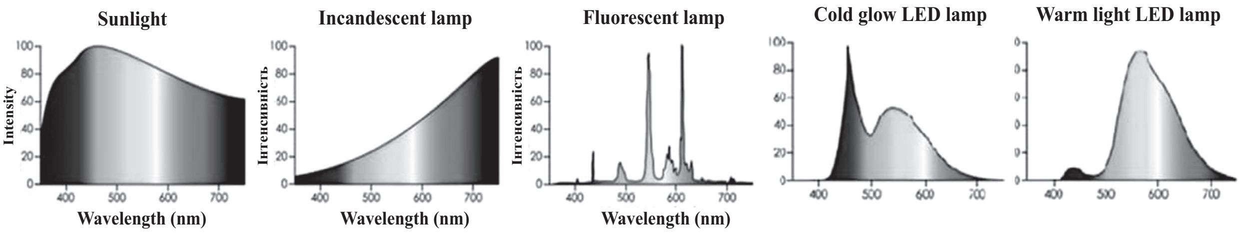

Figure 7. Spectra of modern light sources in use

source has always been perceived as a new era of perfection in the science of lighting, and has always been of great significance for the development of the economy of all countries of the world. This was the case with Thomas Edison's invention of the incandescent lamp in 1879, Henry Round's invention of the fluorescent lamp in 1930 and finally Heath Kamura's invention of the LED light source in 2000. Each light source invented has differed from the previous one in terms of improved properties and disadvantages.

Figure 7 shows the spectra of all light sources used in lighting systems compared to solar radiation.

When looking at the range of light sources, it can be seen that they are different. LL, for example, generates mainly infra-red radiation in a large range and is characterised by a «lumpy» spectrum and emits ultraviolet radiation, which is dangerous to the eye. The spectrum of SDDS is characterised by emission in the 420–460 nm range, with blue light emitted at colour temperatures above 3500 K [6, 7].

SDDS with colour temperature up to 3500 K generates radiation with a pleasant yellow tint and relaxing effect on the functional state of human body, which leads to loss of attention and productivity. The 3500–5000 K radiation range (neutral-white light) generates the «ideal radiation» for all work, which is conducive to a high level of body function and performance. Cold-white LED light (above 5000 K) generates a high flux of blue light, promotes high concentration of eye function and general body condition to a high level, which causes exhaustion and leads to a decrease in their level, which is not suitable for use in office space in enterprises [7].

The lighting and ophthalmohygienic characteristics of light sources used in modern workplaces are given in Table 3.

Recommendations for the optimum lighting environment created by a lighting system using an SDDS for office space are shown in Table 4.

Table 4 presents the results of our own ophthalmic and lighting studies to create an optimal lighting environment for office buildings.

Conclusions

1. In the majority of modern office facilities lighting of workplaces and workrooms is provided by general lighting system using LL and LEDs, their colour temperature, suspension height and other parameters of lighting system to create an optimal lighting environment, which causes complaints of workers about fatigue and reducing their general and visual performance.
2. Our psychophysiological studies and questionnaire survey of office workers – 148 people – have shown that at the same level of workplace illumination – 400 lux and colour temperature 4100 K and 4500 K (neutral-white light), the prevalence of positive reactions. with subjective research methods.

ISSN 2223-6775, Ukrainian Journal of Occupational Health, 2022, 18 (2), 119–129

Table 3

Lighting and hygiene characteristics of light sources used

The name of the light source	**Incandescent lamp**	**Positive qualities**	1. Generates scattered radiation, pleasant for perception with a yellowish tint
	Incandescent lamp	**Negative qualities**	1. Emits 3–7 % visible light, the rest is in the infrared range, so it is called a «heat emitter» 2. The tungsten heating filament often burns out 3. Consumes a lot of electricity, so it is not efficient 4. Glass flask 5. Fire hazard 6. Short-range infrared radiation can cause cataracts
	Compact and tubular fluorescent lamp	**Positive qualities**	1. Generates light in a wide spectral range 2. The large area of the tubular bulb reflects diffused light
	Compact and tubular fluorescent lamp	**Negative qualities**	1. Contains mercury and phosphorus 2. High pulsation of light flux 3. Generates ultraviolet radiation 4. Starters and chokes create unpleasant noise and inconvenience during use 5. The «needle spectrum» has a negative effect on the psycho-physiology of the eye 6. It is necessary to dispose of mercury
	Led lamp	**Positive qualities**	1. Generates 100 % visible light 2. High energy saving 3. Has a wide spectral range (warm white – up to 3500 K) (neutral white – 3500–5000 K) (cold white – more than 5000 K) 4. The period of use is more than 50.000 hours or more 5. Fireproof, consists of crystals 6. Works in a high temperature mode (+ 45 °C) (- 45 °C) 7. The range of application is wide, etc
	Led lamp	**Negative qualities**	1. Brilliant light source, should be used with a lamp for uniformity of contrast and uniform distribution of light flux 2. In the range of more than 5000 K, it generates blue light, which is dangerous for the eye

ISSN 2223-6775, Ukrainian Journal of Occupational Health, 2022, 18 (2), 119–129

Table 4

Recommendations for an optimum lighting environment created by an LED lighting system for office spaces

Factor/problem to be solved, unit	Recommended action		Measurement method
	engineering	normative	
1. Intensity of luminous flux, lx	600	From the system of general uniform illumination	Photometer TES-0693
2. Constant angle, degree	Not less than 90	DsanPin 3.3.2.007-98	Transparency and square
3. Overall brightness Luminaires shall be equipped with light diffusers reducing luminance of LED lamps to the above values, cd/m^2	Not more than 5000	DBN B.2.5-28-2018	Photometer TES-0693 Luminance meter
4. Allowed irregularity of output brightness	$L_{max} : L_{min}$ not more than 5 : 1	DSTU-P IES/PAS 62722-2-1:2014	Photometer TES-0693 Luminance meter
5. Correlated colour temperature, K	2700 3000 4000 4500	DSTU-P IES/PAS 62722-2-1:2014 DSTU- IES/PAS 62612:2012	According to manufacturer's data – by marking on products and their packaging
6. Colour rendering index, R_a	Not less than 80	DSTU-P IES/PAS 62722-2-1:2014 DSTU- IES/PAS 62612:2012	According to manufacturer's data – by marking on products and their packaging
7. Luminous flux pulsation coefficient, %	Not more than 5	DsanPin 3.3.2.007-98	DSTU B B.2.2-6-97

3. On the basis of ophthalmohygienic and light engineering data of our studies recommendations were developed to ensure the optimum lighting environment created by LEDS in workplaces and office space in terms of light intensity, protective angle, ambient brightness, allowable non-uniform colour temperature, light pulsation colour index.
4. To create an optimal lighting environment for office workers, our recommendations should be used to help maintain visual and general performance, prevent visual fatigue and preserve the health of workers.

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ORCID ID of co-authors and their contribution to the preparation and writing of the article:
Martirosova V. G. (ORCID ID 0000-0002-2777-1724) – organization and carrying out experimental research at work, processing the research data, formulating the conclusions;
Sorokin V. M. – setting of aims of the research, organization and control over the installation of lighting systems at the manufacture.

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