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DEVELOPMENT OF A COMFORTABLE LIGHT ENVIRONMENT FOR PERFORMING VISUALLY INTENSE WORK – A PROBLEM OF HYGIENE IN INDUSTRIAL LIGHTING

Martirosova V. G.[1], Galinsky A. D.[2], Sorokin V. M.[3]

[1]State Institution «Kundiiev Institute of Occupational Health of the National Academy of Medical Sciences of Ukraine», Kyiv

[2]«AEROPLAST» Scientific and Technical Centre, Kyiv

[3]V. E. Lashkarev Institute of Semiconductor Physics of the National Academy of Sciences of Ukraine, Kyiv

Introduction. Despite the long history of lighting regulation, the question of creation of optimal and comfortable light environment (LI) to ensure a high level of the functional state of the organism and visual system with the least fatigue remains an underdeveloped issue.

The purpose of the study – development of a method for creation a comfortable LI, taking into account the individual needs of a person in the level of illumination.

Materials and methods of research. The studies included a questionnaire survey, physiological studies in production facility and laboratory. The studies were carried out in the Azur-Air office in order to study the reaction of the organism on effects of LI, equipped with a system of general uniform illumination with neutral white LEDS at illumination level of 4000 K (in accordance with current standards) and Tcv 4000 K. The study involved office workers selected for participation in experiment, aged 25–32 years, with work experience from 5 to 8 years, healthy, with visual acuity of 1.0, based on therapeutic and ophthalmological examinations. Office workers performed usual production operations with complex visual tasks at their common pace of work and neuro-emotional strain dealing with the routine responsibility at workplace. 33 office employees participated in the questionnaire survey. Based on the analysis of Eysenck's questionnaires, according to psychophysiological characteristics, participants were divided into 2 groups of 8 people – extroverts and introverts. Studies in each group were carried out for 10 working days (two working weeks) using a set of physiological studies to examine the state of general and visual performance in the dynamics of the working day and working week. Visual performance was studied in terms of function of eye contrast sensitivity using binocular Dashkevich measurer of system visibility. The general condition of the organism was recorded in terms of cardiovascular system and was assessed by heart rate. Laboratory studies were carried out in an experimental department of the institute, equipped with separate chambers fit with general uniform lighting systems using LEDS with a color temperature of 4000 K based on computer simulation of photometric parameters in the DIALux program. Lighting systems of chambers were equipped with controlled dimmable lighting devices with smooth lighting regulators. A laboratory experiment was conducted for 4.5 hours for 2 weeks with the participation of volunteers – students of the NTUU «Igor Sikorsky Kyiv Polytechnic Institute» aged 20–21 years, selected on the basis of an ophthalmological and general examination (8 out of 29 people), healthy, with a visual acuity of 1.0, prepared and trained in research methods and distributed using Eysenck's questionnaires in groups of 4 people – extroverts and introverts. Each person performed visually intense work using special test tables and they individually set levels of illumination in connection with their psycho-emotional state and individual needs for light, using smooth lighting regulators. Illumination levels set by participants were recorded throughout the entire duration of the experiment, the data recorded in protocols and processed according to programs.

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Results. Conducted studies in occupational conditions with illumination of 400 lx (according to norms) among extroverts established instability of the RP in terms of CCH with high amplitude of fluctuations ($p < 0.05$), and in laboratory experiment with self-regulation of the light flux, the performance curve with reliability $p < 0.05$ flattens with illumination established by them at the level of 600 lx. Introverts have stable level of illumination at 400 lx both in occupational and laboratory conditions ($p < 0.05$), which corresponds to the normalized level for this type of work.

Conclusions. Depending on individual adjustment to the needs of light level and taking into account different psychophysiological characteristics, the employees were divided into two groups – photoabundant and photosensitive. A lighting device has been developed based on the ability to self-regulate the level of illumination and color temperature to create a comfortable light environment to maintain the health and performance of employees and is recommended for visually intense professions.

Key words: light environment, comfort, experimental studies, physiological methods, self-regulation, lighting device

Introduction

The current standards for lighting workplaces and industrial plants (DBN B. 2.5-28:18) were approved in 2018 [1], which coincided with the 90th anniversary of the first state standards on lighting with incandescent lamps in 1928. The latest current norms are the ninth revised version of the norms, taking into account the use of LED light sources (LEDS) in Ukraine. The list of State Standards on lighting (from incandescent to LED light sources) are listed in Table 1.

Table 1 shows that lighting standards for high-precision work were periodically revised, mainly upwards (until 1971), depending on the country's energy capacity and the intensive development of the lighting industry, which developed and introduced new light sources into production.

In the 1990s, the normalized light levels for works of varying accuracy were considered close to optimum, and therefore it was assumed that further increases cannot be economically justified,

Table 1

List of State Standards on lighting (from incandescent to LED light sources)

No.	Normative documents and year of entry into force	Upper limit of rated illumination, lux		
		with incandescent lamps	with gas discharge lamps	with LED lamps
1	Artificial lighting regulations 1928 100	100	–	–
2	Artificial lighting rules 1933 200	200	–	–
3	GOST 3825-47 Artificial lighting of industrial enterprises (incandescent lamps) 500	500	–	–
4	Construction rules and regulations (chap. III-V.6 SNiP) 1955	500 1000	1000	
5	Construction rules and regulations (changes No. 1 to chapters II-B.6 SNiP) 1959 1500 3000	1500	3000	
6	Construction norms and regulations (chap. II-A.9-71 SNiP) 1971	4000 5000	5000	
7	Construction norms and rules (chapters II-4-79 SNiP) 1980	- 5000	5000	
8	DBN V.2.5-28-2006 - 5000	–	5000	
9	DBN V.2.5-28-2018 - 5000 5000	–	5000	5000

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since the increase in labor productivity may be accompanied by significant visual fatigue, which is unacceptable.

However, in modern conditions requirements to sensory systems and especially to visual systems have increased, because a class of works with complex visual tasks (perception of small objects of distinction at low contrasts with the background, at uneven brightness distribution, presence of direct and reflected glossiness, factors interfering and complicating the eye, etc.) appeared [2].

It should be noted that the light environment (LES) (lighting) at workplaces and production facilities is created in accordance with current regulations, a system of combined lighting of general and additional local using different types of table lamps. Existing lighting systems, according to current state standards, provide for the use of fixed ceiling lights, providing constant brightness and color temperature, which creates a monotonous effect on the psycho-emotional state of workers and is an additional factor in the development of fatigue.

The lack of opportunities to change the color temperature and brightness, as well as the inability to zoning (local change in light parameters) significantly reduces the comfort of visual perception of the SS, reduces the visual performance (PD) of employees, which is a disadvantage of such lighting. The use of local light fixtures does not correct this drawback, as it creates a limited light spot, glare and glare, which requires straining of the adaptation mechanisms of the eye, leads to fatigue of the functional state of the visual organs and depletion of the working potential of the eyes during the working day.

According to the Kundiiev Institute of Occupational Health of the National Academy of Medical Sciences of Ukraine examinations at modern production showed that office workers complain (53.6 % of workers 208) about eye and visual asthenopia (a symptom of visual fatigue) which develops in the process of work, and 31.2 % have been diagnosed with functional and pathological disorders of the visual analyzer in the form of progressive forms of myopia, accommodation spasms, convergence, maculopathies, cataracts, degenerative changes in the retina, etc. [3].

The main concept of normalization of illumination is still the establishment of such a combination of quantitative and qualitative parameters of lighting for each type of industrial activity, taking into account the characteristics and specifics of workers, which should ensure high performance of a person with the least fatigue.

An important and underdeveloped issue is the development of optimal and comfortable norms, ensuring a high level of functional state of the organism and the highest effective work of the visual system during visually strenuous work. This is the most difficult approach, because in world practice, until now, there is no unified point of view on the concept of comfortable lighting and criteria for its justification, although from the physiological and hygienic positions, it is the most effective for maintaining health and psycho-emotional state of a person and his ability to work.

Rationale for the work

Research in the field of creating an optimal and comfortable SS has been conducted from different

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positions by many researchers, scientific studies of some of them are applied and cited to the present day.

A. Kruithof (Kruithof), professor of applied physics at Eindhoven University of Technology, in an experiment (1941) established the ratio of lightness values and color temperature most comfortable for visual perception. In his honor, this curve went down in the history of light engineering and physiology of vision as the «Kruithof curve» (Figure 1, 2).

In Figure 1 and Figure 2 A. Kruithof curves in the original version and established values of illumination in the range of 200–800 lux and color temperature of 3500 K–4000 K are presented, which coincides with the data of experimental studies conducted later [4, 6]. Working toward establishing an optimum of light parameters, Kruithof noted that «there are no standards because everyone is different».

Of great interest are the studies of Hans Jürgen Eysenck, a professor at the Institute of Psychology at the University of London (1955–1983), who analyzed the data from surveys of 700 people and came to the conclusion that the totality of human characteristics is reduced to two main types of psychological and emotional adjustment to environmental signals, namely, extroverts (focused on the world of external objects) and introverts (focused on the inner world). The questionnaires developed by him for distribution of persons according to psycho-emotional characteristics of environment perception are used by us and other researchers up to the present time.

Some authors propose automatic systems for managing a person's neuro-psychological state. For example, Van Bommel developed a lighting lighting system based on a change of color temperatures in the dynamics of the day to stimulate the neuro-emotional state of the person [4].

We traced with the help of multicollinearity method the restorative processes in the functional state of the visual system, presented in Figure 3.

The data presented in figure 3 show the mechanisms of compensatory processes in the visual system, characterized by features and specifics of the work process. It can be seen that there is an automatic switching from the main function to the other one before the period of its

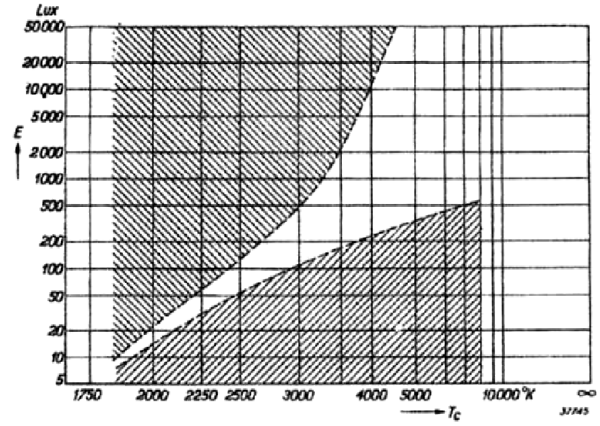

Figure 1. The original curve of A. Kruithof

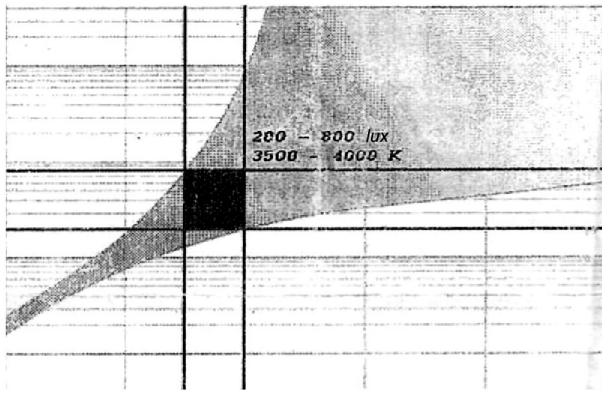

Figure 2. Optimal values of illuminance levels and color temperature (Kruithof)

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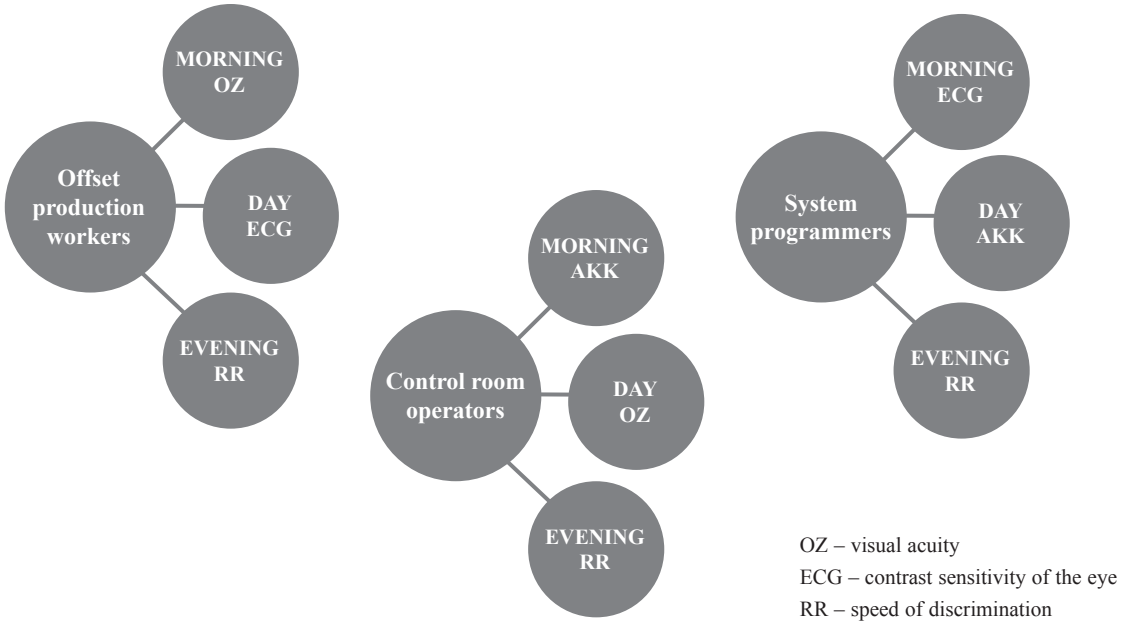

Figure 3. Compensatory processes in the visual system of representatives of different professions in the dynamics of a working day during work operations

reserves exhaustion. Under unfavorable conditions of light environment during visually strenuous work, depletion of function reserves occurs faster.

In our opinion, visual comfort is a harmony between satisfaction of the necessary subjective need for light, which contributes to formation of a high level of functional state of the organism, and ensuring the best visibility of discernible objects with the least fatigue, with creation of a subjective sense of well-being.

Therefore, in all probability, it is possible to provide this psycho-physiological state by the method of organism's self-regulation.

Self-regulation literally translates as «putting in order», i.e. it is a conscious and organized influence of the subject on his/her own psyche in advance in order to change its characteristics in the direction necessary and expected by the organism. It is a peculiar adjustment by an individual of his personal inner world and himself for the purpose of adjustment, which is a property of all biological systems to form, and further to keep at a particular more or less constant level of biological or physical parameters.

The purpose of the study is to develop a way to create a comfortable SS taking into account the individual's need for light levels.

Materials and research methods

The methods and objects of the study were conducted in three main directions:

- Questionnaire survey on the comfort of SS with SDIS;
- Experimental studies of the state of physiological functions in working conditions at work;
- Experimental studies in the conditions of the Kundiiev Institute of Occupational Health of the National Academy of Medical Sciences of Ukraine laboratory to evaluate the method used.

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Production studies were conducted in an office room of Azur-Air company to study the reaction of the body to the effects of SSs, equipped with a system of general uniform lighting with neutral-white LEDS at the illumination level of 400 lux (in accordance with the current standards) and Tcv 4000 K. Office workers, 16 persons selected for participation in the experimental study, aged 25–32 years, with 5 to 8 years of work experience, healthy, with visual acuity 1.0, established on the basis of therapeutic and ophthalmological examinations, participated in the study. The office workers performed habitual production operations with complex visual tasks at their usual work pace and nervous-emotional strain related to the responsibility of the work performed. Thirty-three office workers participated in the questionnaire survey.

Taking into consideration the individual psycho-emotional perception of the CC, the work of G. Eisenk, who divided people into extraverts and introverts according to their psycho-physiological adjustments to the signals of the external environment, was the closest to us.

Based on the analysis of Eysenck's questionnaires, the subjects were divided into two groups of 8 people, extroverts and introverts, according to their psychophysiological characteristics. Research in each group was conducted during 10 workdays (two workweeks) with application of complex physiological research of general and visual workability in dynamics of workday and workweek.

In order to evaluate functional state of the visual system the contrast sensitivity of the eye (CSI) was studied after each hour of work with the help of binocular vision meter of Dashkevich system. The general state of the organism was registered according to the indices of the cardiovascular system and was estimated by heart rate.

Laboratory researches were carried out in the experimental building of the institute, where separate chambers were equipped with general uniform illumination systems with LEDS with color temperature 4000 K based on computer modeling of photometric parameters in DIALux program. The chamber lighting systems were equipped with dimmable dimmable light devices using dimmable dimmers.

The laboratory experiment was carried out in 4.5 hours for 2 weeks with the participation of volunteers, students of the Kiev National Technical University «Kiev Polytechnic Institute named after Igor Sikorsky» aged 20–21, selected on the basis of ophthalmological and general examination (8 out of 29 people), healthy, with visual acuity 1.0, prepared and trained for the research methods and distributed in a group of 4 persons – introverts and extroverts – using the Eiseneck questionnaire. Each subject performed visually strenuous work with the help of special test tables and, in parallel, independently set the levels of illumination in connection with his psycho-emotional state and the necessary individual need for light by means of smooth light regulators during the whole period of the experiment. The levels of illumination set by the subjects were recorded throughout the experiment, the data were recorded in protocols, and processed using a computer program.

The average indices of subjective psychophysiological perception of CC of the office workers

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in the dynamics of the working day (the average for 33 subjects) are presented in Table 2.

From the data shown in Table 2, we can see that psycho-emotional SS office workers perceive differently. Thus, at the beginning of work 51.1 % of workers feel «uncomfortable», then at the end – «uncomfortable» 63.7 % of workers. The color temperature during the working day is also perceived differently. Based on the verbal survey, the majority of workers (75 %) prefer a neutral-white SDIS, while 21.2 % prefer a warm SDIS.

Figure 4 shows the indicators of the state of the studied physiological functions in a comparative aspect, carried out in production and laboratory conditions, Figure 5 presents data on the state of ER by the indicators of the function ECG in the dynamics of performance of production tasks in 2 groups of office workers – extroverts and introverts, under a system of general uniform lighting of their jobs, providing 400 lux in accordance with the current norms.

When considering the data, it is clear that the group of workers – extroverts in the dynamics of the working day traced the instability of the studied function, defined by a high amplitude of fluctuations, and the group of introverts has a somewhat different picture, defined by the course of the performance curve with a moderate fluctuation with a small amplitude.

Using the method of self-regulation of illumination level in extroverts in the dynamics of laboratory experiment made it possible to determine its optimal level of 600 lux, stably set by the workers during 4 hours of continuous experiment. Introverts confirmed the normalized level for work – 400 lux.

On the basis of obtained data Kundiiev Institute of Occupational Health of the National Academy of Medical Sciences of Ukraine together with the Institute of Semiconductor Physics named after V. E. Lashkarev NASU and STC «AEROPLAST» developed one of the ways of creating a complex

Table 2

Average indices of subjective psychophysiological perception of the light environment of office workers in the dynamics of the working day (averages for 33 subjects)

No.	Psychophysiological indicators of the light environment state of LED light sources	Estimated indices	Workday dynamics		
			morning	before lunch break	evening
1	Rating of comfort of the light environment	Comfortable	16	14	12
		Uncomfortable	17	19	21
2	Evaluation of the level of light	Good	33	33	33
		Brilliant	–	–	–
		Insufficient	–	–	–
3	Psychophysiological sensations of the emission spectrum of LED light sources	Warm	7	7	7
		Cold	3	1	1
		Neutral	23	25	25
4	Evaluation of the difficulty of the visual task	Difficult	7	6	7
		Not complicated	26	27	26
5	Characteristics of general body condition	Normal	28	32	27
		Fatigued	5	1	6

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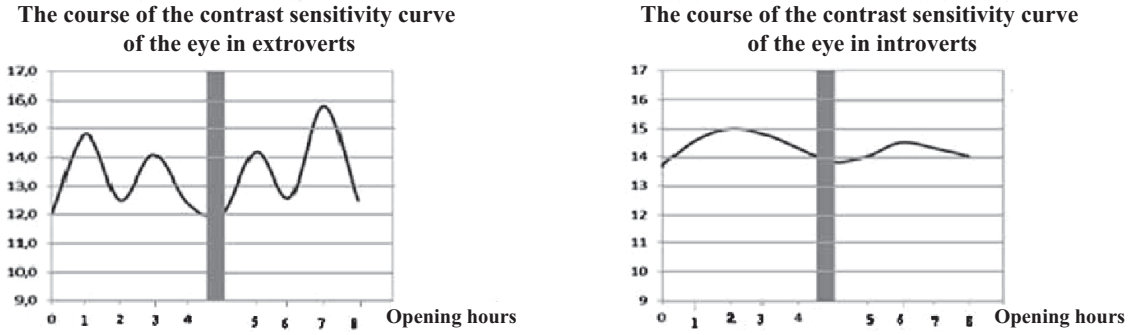

Figure 4. Indicators of the state of contrast sensitivity of the eye in office workers under the conditions of the production experiment in the dynamics of the working day

comfortable light environment for visual and biological representation in the central nervous system of man (Figure 6).

Based on the studies and data obtained, together with STC «Aeroplast» we developed a method of creating a complex SS, which became the basis for creating a lighting device for optimal functioning of the visual and biological representations in the central nervous system of man.

The device is a system of general localized lighting, allowing to create comfortable lighting by changing its parameters using self-regulation method in the workplace according to one's own feelings of comfort and consists of controllable general lighting fixtures with individual control systems.

LED lighting fixtures contain a two-channel driver (power supply), a receiving system that converts the signals from the individual control panel into control signals, by which the driver changes the supply current of the LEDs. This allows the employee to change the brightness and color temperature of the lighting system during the working day, according to his feelings of comfort. Since comfort parameters may vary for each person during the working day, such a system allows to create optimal and comfortable lighting environment for each employee in accordance with his/her physiological, visual characteristics and age requirements. For the developed device the patent for «Corisnu model» № 133710 (UA),

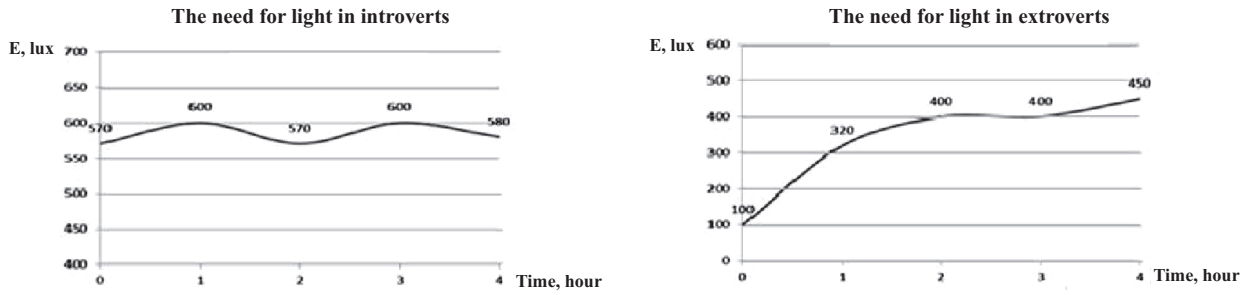

Figure 5. Levels of illumination set by the subjects using self-regulation of the light flux density in the experimental chamber of the institute

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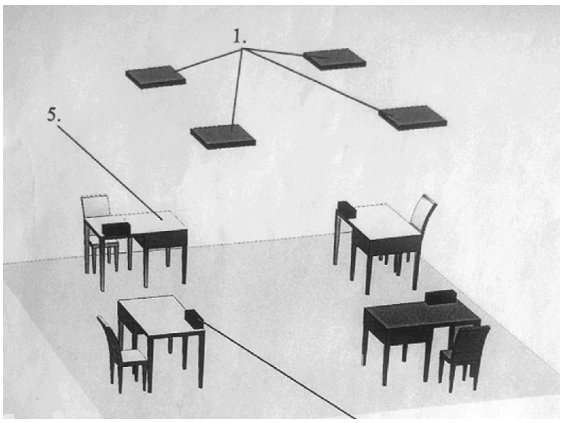

Figure 6. Comfort lighting system

Application № 201808861: application, 21.08.2018: published 25.04.2019. bulletin No. 8.

Conclusions

1. Human perception of SS is determined by the necessary need for light, the main components of which are the brightness of light sources and color temperature. The work of scientists on the establishment of the optimum of light parameters allowed to determine the boundary values, and the Kruithof curves gave practical recommendations for creating comfortable conditions depending on the brightness and color temperature.
2. Due to the individuality of each person on the psycho-physiological and psycho-emotional characteristics, as well as the need for light levels of CC, people can be divided into photosensitive and photosensitive. This is confirmed by the results of experimental studies.
3. With the help of the developed method of creating a complex SS and lighting device created on its basis to create conditions for optimal functioning of visual and biological representations in the central nervous system of a person were carried out experimental studies and obtained dependence of the influence of psychophysiological and psychoemotional characteristics of the examined employees on the light preferences and comfortable illumination.
4. Experimental laboratory studies confirmed the light preference of extroverts, who by self-regulation ensured the comfort of the standardized level of illumination for work performance of 600 lux, and light sensitive introverts confirmed the comfort of the standardized level of illumination for robot work performance of 400 lux.
5. The developed lighting device when using the developed method of creating a complex SS to create conditions for optimal functioning of visual and biological representations in the central nervous system can be recommended for implementation at enterprises in order to create comfortable conditions, improve performance and maintain the health of employees.

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Martirosova V. G. (ORCID ID 0000-0002-2777-1724) – organization and carrying out experimental researches in the production plant, processing of the research data, formulating of the conclusions, participation in development of the patent;
Galinsky A. D. – participation in development of patents, opinion formulation;
Sorokin V. M. – research agenda setting, organization and control of installation of lighting systems at the enterprise.

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Contact person: Martirosova V. G., SI «Kundiiev Institute of Occupational Health of the National Academy of Medical Sciences of Ukraine»,75, Saksaganskogo str., Kyiv, 01033. Tel.: + 38 0 44 289 00 21.