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COMFORT LIGHT ENVIRONMENT UNDER NATURAL AND COMBINED LIGHTING: METHOD OF THEIR CHARACTERISTICS DEFINITION WITH SUBJECTIVE EXPERT APPRAISAL USING

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ABSTRACTS

Light comfort in the room is characterized by the conditions of visual work, which are determined by the levels of illumination of the workplace and the saturation of the entire room with light. The related problems were solved mainly for artificial illumination. The article examines the results of research in our country and abroad by determining the criterion for the comfort of lighting rooms with artificial and natural light. It is pointed out that such studies are obviously insufficient, and suggestions are given on their development.

Keywords: expert evaluation, comfort, light environment, psychophysical methods, room lighting, visual work, room light saturation, subjective assessment, observers

1. INTRODUCTION

Requirements for the light environment in buildings are characterized by the levels of illumination sufficient for performing visual work, as well as high light saturation, providing light comfort. In addition, light comfort is ensured by the uniform distribution of light flows in the interiors and by the absence of sharp contrasts in the field of view. The listed parameters are static characteristics. However, numerous studies prove that a constant light environment in the room has a negative effect on people's health [1]. Human being accustomed to the dynamics of lighting for thousands of years. Change of day and night affects the production of hormones in the human body, affecting the state of wakefulness and fatigue [2]. These studies conducted in Russia and abroad showed the advantages of natural lighting. However, only natural lighting of interiors is impossible in principle, since at low levels of outdoor natural illumination it is necessary to include artificial light. Even at high levels of external natural illumination, one cannot avoid the use of artificial light. Modern production requires high levels of illumination, which in high-rise multi-storey buildings can not be provided at the expense of one natural light. In such premises, most part of a day natural and artificial light act together.

2. THE CONCEPT OF PERMANENT SUPPLEMENTARY ARTIFICIAL LIGHTING OF INTERIORS (PSALI)

This is the first concept of the combined effect of artificial and natural light, developed by R. Hopkinson back in 1959. [3, 4]. Prerequisites for this concept were the contradictions that arose during the normalization of artificial illumination of that time for school classes and offices in the UK. Normalized levels of illumination (160–200) lx caused a sharp contrast between the dark interior surfaces in the deep-most area of the premise and the bright sky, visible through the windows. In order to avoid this unpleasant phenomenon, it was necessary to increase the levels of additional artificial illumination. Moreover, this increase should correspond to an increase in the external natural illumination.

2.1. The Concept of Automatically Adjustable Supplementary Artificial Lighting (AASAL)

Modern means of regulation of artificial illumination have allowed putting on forward the second concept of the combined illumination. This is automatically adjusted combined illumination. The main idea of this concept is the addition of natural light to the normalized value under artificial illumination in areas with insufficient natural light. In this case, the premise is divided into zones according to the levels of D.F. (day light factor), which change their area and location, depending on the change in the external illumination. In these zones, photodetectors are located in specially designated areas, fixing the illumination in these zones and sending signals to automat that turn on and off the luminaires, thus increase or decrease the luminous flux of these luminaires so that the total illumination from natural and artificial light is within the normative standard. Photodetectors can also be placed on the windows, with protecting them from direct sun exposure. In this case, it is necessary to elaborate a program for changing the zone with sufficient natural illumination, depending on the change in ambient light, and to turn on and off the rows of lighting fixtures in accordance with this program. In order to calculate the energy savings for artificial lighting in such systems, it must be assumed that the rows of lamps are parallel to the windows in such remises. It is believed that the levels of internal natural light, at which it is necessary to turn on or off the rows of lamps, must correspond to the normative requirements for artificial lighting. If a premises has a uniform distribution of natural light, for example in large halls with skylights evenly distributed on the roof, then the regulation of additional artificial lighting is carried out by switching on or off groups of luminaires that create the same levels of artificial illumination depending on the amount of external illumination (discrete regulation). Modern technology can also provide a smooth (continuous) regulation of the luminaires luminous flux.

The second concept is also not modern and does not meet the needs of a person. It is largely mechanistic. At the modern level of the science of lighting, we can calculate the levels of illumination and other lighting parameters in any room. But we know almost nothing about the needs of a person relating to the indoor light environment. For example, we do not know what is best for a person: discrete or continuous regulation. Continuous – creates a constant level of illumination at low levels of outdoor lighting. Discrete – supports in some measure the natural dynamics of natural light.

The design of combined lighting should solve two problems: creating the necessary conditions for visual work at the workplace and creating a light environment in a premise that would be characterized by people who are in it, as comfortable. It is believed that this can be achieved by recreating the psychological and aesthetic sense that the interior is flooded with natural light [5]. The provision of the required conditions for visual work is a necessary, but not sufficient requirement. A requirement representing the result of linking the solution of two tasks to each other is sufficient. The first problem is solved with reference to the combined lighting in the Research Institute of Building Physics of the RAASN [6], in the All-Russian Scientific Research Lighting Institute (VNISI) and in the Research University – the Moscow State University of Civil Engineering [7]. The second task is devoted to the work carried out in the laboratory of building physics at the Moscow State University of Civil Engineering, the methodology of which we tried to present in general terms in this article.

3. RESEARCH OF NATURAL AND COMBINED LIGHTING WITH USING CRITERION OF THE LIGHT ENVIRONMENT COMFORT IN WORKING PREMISES

Comfort of the light environment is a subjective concept. Physical quantities, which we learned to calculate, are secondary, leading to normalization. But first you need to determine – is what the person needs, what parameters of the light environment are comfortable for most people. In the second half of the twentieth century, a new approach to the design of natural lighting of premises using the method of subjective expert appraisal was outlined and gradually developed [8–14]. This method is based on subjective assessment by observers of the quality of the light environment. At the same time, emphasis is placed on higher quality parameters of natural light in comparison with artificial light. These parameters are the spectral composition of natural light and the dynamics of its change. In addition, an important role in the subjective perception of natural light is played by the information link with the outdoor environment, which can only be carried out with side or, to a lesser extent, the roof light openings. At the same time, most of the qualitative parameters can recede to the background in comparison with the view from the windows. Through the skylights of the roof natural light system, information is received only about the weather and the time of the day. For some types of skylights, information on the season year due to the condition of the snow cover of the roof and the presence of snow on the glazing is added too. This is the minimum requirement for communication with the outdoor environment. Authors have revealed this during the installation of roof lights in the work shop of steel wire production of the Cherepovets Steel Mill and in the weaving shop of the Kherson Textile Mill by method of questionnaires conducted in the 1970 years.

In the domestic practice, the questions of the subjective evaluation of the light environment have been considered and are considered not sufficiently. Episodic studies that have been conducted in our country since the middle of the last century (in NIISF RAASN, MISI–MSCIU) unfortunately could not lay the fundamentals of this new scientific direction [15–19]. Therefore, this article aims to attract attention of domestic researchers in the field of architectural and building lighting technologies to the relevance of this scientific direction, which can effectively combine the results of engineering developments with the results of developments in the field of psychology, hygiene, etc. The method of subjective expert evaluation must pass from the category of auxiliary and testing to the category of the main one, which operates not so much with objective data on the working capacity of people, but also with data on their subjective preferences. This approach fully corresponds to the current world trend in the priority of individual interests, assessments and requests.

Studies on the subjective appraisal of the lighting environment in the premises, conducted at the Department Architecture of Civil and Industrial Buildings of the Institute for Civil Engineering named after V.V. Kuibyshev (now the Moscow State University for Civil Engineering) at the end of the last century were based on the works of leading Russian scientists, psychologists, hygienists, lighting engineers. In particular, the main influence on this was based on the theory of adaptation, developed by H. Helson (USA) [20]. The formula he proposed, determines the level of adaptation, depending on the focus, background and residual stimuli and their weighting factors.

$$A = X^p B^q P^r, \quad (1)$$

where A is the level of adaptation of the system, upon which the most complete acceptance of the stimulus occurs and its greatest correspondence to the human responses is achieved. X, B and P are, respectively, focal, background and residual stimuli, p, q and r are weighing coefficients taking into account the intensity of the influence of the corresponding stimuli. For some studies in the field of natural and artificial lighting, one can use a simplified version of the Helson formula:

$$A = X^p B^q. \quad (2)$$

Here, the residual stimulus is taken into account in the values of the background stimulus. The conditions of illumination and the research tasks determine the values of the focus and background stimuli. For example, in studies of the required conditions for performing visual work, the focus stimulus (X) is the amount of illumination, at which the highest operability and the lowest fatigue occur. The background stimulus (B) is the amount of total illumination in the interior to which the subject adapts. For artificial lighting, X is the level of local illumination and B is the level of general lighting. For natural lighting, X is the level of natural light, at which maximum performance and minimal fatigue are observed. B is the average level of natural illumination in the premise. However, under natural lighting, these parameters change all the time, and it is required to switch on and turn off artificial light. Therefore, with combined lighting, X is the level of natural illumination at a given time, with the addition of the necessary amount of artificial light to ensure maximum performance and minimal fatigue in this visual work. B is the level of additional artificial illumination.

The weighing coefficients p, q and r in formula (1) can vary in their significance, depending on the situations being evaluated. The focal stimulus in one case, may be background or residual for

Table 1. Values Assigned to the Rating Scale

№	Characteristics	Score in points				
		1	2	3	4	5
1	Overall appraisal of the light environment	Very bad	Bad	Satisfactory	Good	Very good
2	Predominance of natural or artificial ligh	Artificial	More artificial than natural	Equally	More natural than artificial	Natural
3	Combination of natural and artificial light	Very bad	Bad	Satisfactory	Good	Very good
4	Feeling of Twilight	No	Minor	Average	The twilight presents	Large
5	Contrast between windows and wall piers	Very Small	Small	Average	big	Very big
6	Distribution of brightness over the room	Monotone	Almost Monotone	pleasant	Almost Contrast	Contrast

another situation. So, for example, when assessing lighting conditions in the workplace, lighting in the workplace is considered a focal stimulus, the overall light environment is a background one, and the residual stimulus is characterized by past experience and observer habits. When assessing the light environment of the premise as a whole, the background stimulus passes into the focus category. The complete adaptation is indicated by neutralization of the applied energy and that is the best estimation of the stimulus.

For example, in administrative offices, focus and background stimuli can be estimated by weight coefficients p and q equal to 0.5. This is determined on based of on the analysis of working time of the office employees. Complete adaptation is based on the results of questionnaires with A = 600 lx. Normalized artificial illumination (we shall consider it as the background stimulus) B = 300 lx. According to formula (2), the saturation degree of the interior X with light (we shall consider it as a focal stimulus) can be determined from the expression:

$$600 = X^{0.5} \times 300^{0.5};\ X = 1200\ lx. \quad (3)$$

This suggests that for full adaptation, i.e. feeling of comfort of the light environment, it is necessary that the levels of illumination in the workplaces in total with the overall level of illumination in the premise should be summed up.

In the studies conducted, the subjective appraisal of the light environment in the rooms was carried out by the most common method – a ball score, based on a given scale. The assignment of scores to one or another characteristic was the coding of visual sensations. For example, the evaluation of an explored feature with a maximum score indicates that a "comfort zone" has been reached. With a decrease or increase in the parameters of the evaluated feature, the score decreases, which indicates discomfort of the sensations (Table 1 and Fig. 1) [20]. The complete adaptation is indicated by neutralization of the applied energy that is the best estimate of the stimulus. There is an optimal value of the stimulus, which in psychophysics is expressed by the so-called "U-hypothesis". This hypothesis

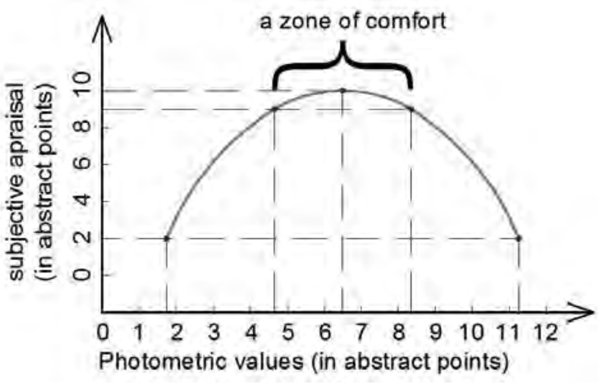

Fig. 1. Scheme of the dependence of the subjective appraisal of the light environment on the change in the photometric value

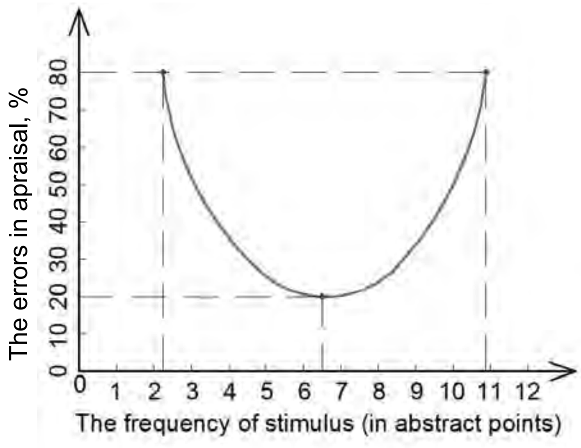

Fig. 2. "U" – functional dependence

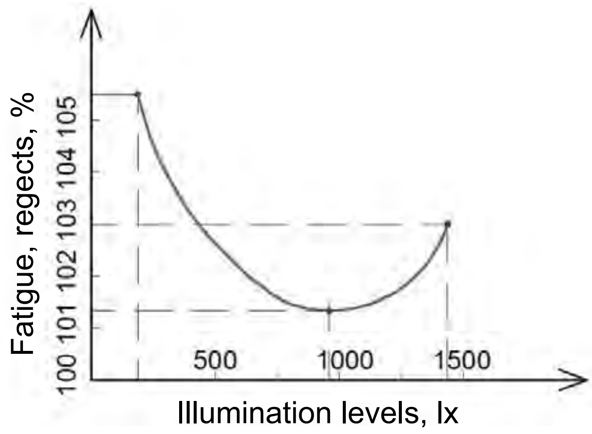

Fig. 3. Dependence of the amount of rejects on levels of artificial illumination

assumes that the character of the process change is described by the graph of the frequency of the stimulation in form of the Latin letter "U". The optimal value of the stimulus is the range of minimal erroneous solutions, where the minimum is at the point that is the adaptation level of the system under consideration (Fig. 2) [21–22].

The principal use of the main provisions of the theory of adaptation, which confirms the "U-functional" relationship between stimuli and reactions, can be traced in the basic works of foreign and domestic researchers since the end of the last century. Thus, Fig. 3 represents a graph showing the change in the amount of rejects in the work due to fatigue of the workers when the illumination levels change, similar to the graph in Fig. 2. The graph in Fig. 4 shows that when the illumination is increased to a certain limit, the productivity of labour increases, which is also the analogy of the graph in Fig. 1.

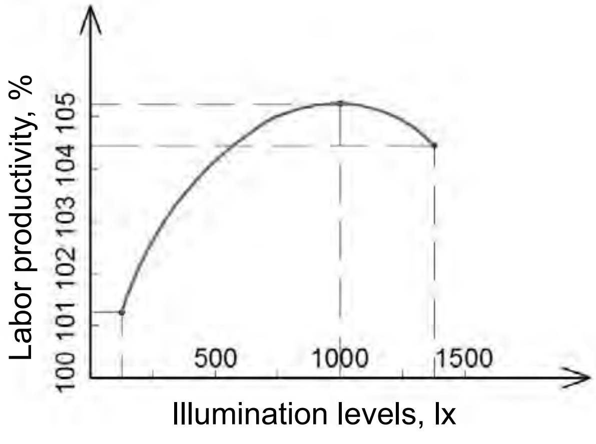

Fig. 4. Dependence of labour productivity on levels of artificial illumination

Objective data on the change in the degree of fatigue and labour productivity when the illumination in the workplace is changing correspond to a subjective evaluation of the overall light environment for the premise which was obtained in a series of studies conducted later on, according to the method of expert evaluation. The basics of this technique are the following actions, namely:

1. Selection of a group of observers by quantity;
2. Selection of a group of observers for quality;
3. Determination of the objectives of the experiment and the formulation of the corresponding tasks;
4. Correct processing of experimental results.

The necessary number of observers (n) should be determined in accordance with the selected values of the feature, which estimates the accuracy of the experiment by the formula of G.F. Lakin [23]:

$$n = (t_z^2/z^2) + 3, \quad (4)$$

where t_z is the normalized deviation from a given level of significance, z is the auxiliary value for estimating the values of the correlation coefficient, and it is determined from the table [23]. To obtain more reliable statistics, a group of observers should consist of persons of different sex, age, vocational training, fatigue conditions of, visual analyzer, etc. It is necessary to develop a special manual (the so-called "introduction to the experiment"), with which observers are introduced before the beginning of observations. The purpose and objectives of the experiment largely determine the methodology for conducting it. Therefore, this item should be worked out with great care. Finally, correct processing of the results of observations should be en-

Table 2. The Composition of the Expert Group (75 observers, 99 sessions of observations)

<table>
<tr><th>№№</th><th>Number of observations</th><th>Classification</th><th colspan="9">Subgrouping</th></tr>
<tr><td rowspan="2">1</td><td rowspan="2">99</td><td rowspan="2">Gender</td><td colspan="4">Men</td><td colspan="5">Women</td></tr>
<tr><td colspan="4">66</td><td colspan="5">33</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">99</td><td rowspan="2">Professionalism</td><td colspan="3">Experts</td><td colspan="2">Specialists</td><td colspan="4">Amateurs</td></tr>
<tr><td colspan="3">22</td><td colspan="2">33</td><td colspan="4">44</td></tr>
<tr><td rowspan="2">3</td><td rowspan="2">99</td><td rowspan="2">The state of the visual analyzer</td><td colspan="2">Normal</td><td colspan="2">Myopia</td><td colspan="3">Hyperopia</td><td colspan="2">Astigmatism</td></tr>
<tr><td colspan="2">47</td><td colspan="2">26</td><td colspan="3">18</td><td colspan="2">8</td></tr>
<tr><td rowspan="2">4</td><td rowspan="2">99</td><td rowspan="2">Age</td><td><20</td><td colspan="2">20–30</td><td>30–40</td><td>40–50</td><td colspan="3">50–60</td><td>>60</td></tr>
<tr><td>9</td><td colspan="2">37</td><td>31</td><td>11</td><td colspan="3">7</td><td>4</td></tr>
<tr><td rowspan="2">5</td><td rowspan="2">99</td><td rowspan="2">Degree of fatigue</td><td colspan="3">Minimum</td><td colspan="2">Average</td><td colspan="4">Maximum</td></tr>
<tr><td colspan="3">33</td><td colspan="2">48</td><td colspan="4">18</td></tr>
<tr><td rowspan="2">6</td><td rowspan="2">99</td><td rowspan="2">Time of the experiment</td><td colspan="2">9 a.m. – noon</td><td colspan="2">noon – 3 p.m.</td><td colspan="2">3 p.m.– 6 p.m.</td><td colspan="3">6 p.m.– 9 p.m.</td></tr>
<tr><td colspan="2">16</td><td colspan="2">41</td><td colspan="2">30</td><td colspan="3">12</td></tr>
</table>

sured with the help of modern electronic methods of mathematical statistics [24, 25]. In particular, as an example, the composition of the expert group with which the experiment was conducted on the subjective evaluation of the light environment on models of premises, in which levels and zones of additional artificial lighting in premises with side light openings were determined, could be cited as an example. With a total number of observers 99, men were 66 and women – 33. This ratio was chosen as a real one in accordance with the specific task of the experiment to determine the levels of additional artificial lighting in the premises of design organizations. Those with normal vision were 47 people. The number of observers by age groups varied as follows: Individuals under 30 years old – 46, from 30 to 50 years – 42, over 50 years – 11 observers.

The further development of the methodology for conducting psychophysical experiments using questionnaires and an interactive method, when the subjects themselves establish the desired parameters of the light environment, was obtained during a number of full-scale experiments conducted by the new generation of young researchers at the Chair of Architecture, and then the Chair of Design of Buildings and Structures NRU MGSU. An example is the last study carried out by former postgraduate student of the Department of Design of Buildings of the Moscow State University of Civil Engineering, N.A. Muraviova [26]. She established the dependence of the subjective appraisal of the quality of the natural light environment on the value of the daylight factor of cylindrical illumination (DFCI). As studies have shown, this factor, which is the ratio of natural cylindrical illumination in the centre of the room to simultaneous outdoor illumination on a horizontal plane, characterizes the light field around the observer. Having determined this value, at which observers regard the light environment as comfortable, one can proceed to normalize Daylight factor or spatial characteristics of the light field in the premise.

4. CONCLUSIONS

1. The development of modern building physics poses new challenges for researchers, which can be successfully solved only on the basis of using the basic principles and methods, which are characteristic for other fields of science. In particular, in recent years, methods of subjective expert evaluation of both the internal light environment in the premise as a whole and its individual parameters are increasingly widely and actively used, which are the prerogative of psychophysics.

2. The current state of lighting engineering makes it possible to determine and calculate any characteristics of the light environment. Technical

capabilities using mathematical formulas and modern computer technology ensure high accuracy of calculations. However, we almost do not know what is required for a person when creating a light environment in the premises. Studies of the light environment in the workplace allowed us to normalize the levels of artificial illumination for performing certain visual tasks. Visual workability was also studied under natural light. Scientific works on the study of a comfortable light environment in the entire premise were conducted only a few. Now there is a need to conduct such studies that will allow obtaining data for the normalization of natural light in premises where visual work is not determinative, and the comfort of the natural light environment is the determining one.

3. The methodology for carrying out studies by the method of expert evaluation largely depends on the goals and objectives set in the specific work. Therefore, the general methodology for researching coverage issues by expert evaluation method does not make sense. Here we proposed only the fundamentals of the methodology. A specification should be for each individual task, which will be presented in the future.

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