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THE CAPACITY OF THE GLASS TO ALLOW THE PASSAGE OF LIGHT AS AN INSURANCE FACTOR OF WORKPLACE ERGONOMICS

Laurentiu SLĂTINEANU, Oana DODUN, Mădălin CATANĂ, Margareta COTEAȚĂ, Sergiu OLARU, Adelina HRITUC, Gheorghe NAGÎȚ

Abstract: *The level of illumination of the space where a human operator works is one of the factors considered when evaluating the ergonomics of a workplace. The presence of a glass window can contribute to the absorption of part of the light emitted by a natural or artificial source. To evaluate the extent to which different categories of glass absorb a greater or lesser amount of light energy, experimental research was designed. The input factors were the distance from the optical subsystem corresponding to the light source, the nominal power of the compact fluorescent light bulb, and the supply voltage. The illuminance measured with a photometer was selected as the output parameter. Samples of ordinary glass, sandblasted glass, and decorative glass were considered. The experimental results were mathematically processed using specialized software. Power-type functions were determined, which highlight the intensity of the influence exerted by the input factors on the output parameter considered. It was found that for the experimental conditions considered, the strongest influence is exerted by the energy supply voltage of the bulb, followed by the distance from the light source and the nominal power of the bulb.*

Key words: *workplace lighting, compact fluorescent light bulb, glass, full factorial experiment, lighting distance, bulb nominal power, supply voltage, power type function.*

1. INTRODUCTION

Light is considered electromagnetic radiation, which has characteristics that allow it to be perceived by human beings. It is accepted that the human eye is sensitive to electromagnetic radiation with a wavelength between 400 and 700 nm (a frequency range between 430 and 750 terahertz).

Light has been of particular importance for the development of human society, with most activities requiring a certain level of intensity of light radiation. Higher values of the intensity of light radiation can affect the normal functioning of the eye. In comparison, lower values can generate difficulties in carrying out various activities without affecting the health of the human operator. The possible negative effects of light on the optical receptor of the human being are influenced by the intensity of the light radiation, its wavelength, the tissue to which the light radiation reaches (cornea, lens, vitreous body, retina), and oxygen tension in the eye.

Throughout the evolution of human beings, not only the intensity of light radiation but also the wavelength or the limits of variation of the wavelength that are judged to be convenient for the human operator have been important.

For such reasons, it is considered necessary to know some aspects that characterize the light that can be used in the case of certain workplaces, even more so as the requirements of an ergonomic nature make such knowledge necessary.

For workplace lighting, natural sources of light (the case of sunlight) can be used, as in other situations, it is necessary to use artificial light, thus using lighting designed and made by humans [1-3]. It is preferable, of course, to use natural light (generated by the sun), but when such a condition (that of using natural light) cannot be met, artificial sources are resorted to. The requirements to reduce energy consumption have led, in recent decades, to giving up incandescent artificial light sources in favor of those that use light-emitting diodes.

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It was, therefore, normal for scientific researchers to be interested in ensuring optimal workplace lighting.

Thus, Flimel developed research regarding the requirements for lighting climate from an ergonomic point of view [4]. He considered that the lighting of the workplace should not adversely affect the health of the worker. Flimel proposed the use of an algorithm to characterize the operation of the light climate subsystem in the workplace.

Ghita et al. have appreciated that it is possible to reduce the costs corresponding to lighting in industrial buildings if optimization of the use of light resources is resorted to [5]. In this direction, the use of a theoretical framework based on model predictive control capable of comparing different strategies and ensuring optimal conditions for the use of light sources was proposed.

Enache considered that natural lighting reaches the human operator through windows, doors, or glass walls. Such lighting exerts positive effects on the human operator, but it is not permanently available [6].

It is known that when light passes through the surface separating two media, a phenomenon of *refraction* takes place, characterized by the change in the direction of light propagation. Another phenomenon, in this case directly related to the light passing through a glass wall, is *the absorption of light energy*, which means a decrease in the intensity, I of electromagnetic radiation. This decrease in the intensity of light radiation passing through a certain medium corresponds to the law of absorption (Beer's law):

$$I = I_0 e^{-kx} \qquad (1)$$

where I is the intensity of the wave at distance x from the medium, I_0 is the intensity of the wave penetrating the medium, and k – the light absorption coefficient.

The explanation of the reduction of light intensity when passing through a certain medium considers the absorption of photon energy by the atoms or molecules of the medium. According to equation (1), this decrease in the intensity of light radiation occurs following an exponential function.

In the experimental tests carried out, it was assumed that the illuminance evaluated when using a photometer would decrease with the increase of the distance between the light source and the photometer sensor and would increase with the increase of the nominal power of the bulb and, respectively, of the supply voltage of the bulb with electricity.

In this paper, the possibility of developing experimental research was considered that would highlight the change of illuminance with the variation of the distance from the light source, the nominal power of the bulb, and the voltage supplying the bulb with electricity. A full factorial experiment was used, with three input factors having values on two levels of variation. The experimental results were mathematically processed, and empirical mathematical models of the power-type function were determined for three categories of glass.

2. EVALUATION OF LIGHT ABSORPTION CAPACITY BY GLASS

In principle, measuring the capacity of light absorption by a certain medium makes it necessary to introduce the medium into a vat, then the light radiation emitted by a source is sent through that medium, and an absorbance sensor allows us to obtain some information about the light absorption characteristics by the medium under analysis.

The various devices for evaluating the capacity of light absorption by an environment provide conditions for light radiation with a distribution as uniform as possible to pass through the environment under analysis and, subsequently, reach the surface. A sensor provides information about the part of the light radiation absorbed when passing through the respective environment [6-8].

3. EXPERIMENTAL RESEARCH

3.1. Experimental conditions

The problem of research on the diminution of the intensity of light radiation when passing light through a glass wall was considered. It was appreciated that obtaining additional information in this direction would lead to an enrichment of knowledge regarding the influence exerted by different types of glass on the lighting conditions in the working spaces.

To achieve the objective, it was considered that the optical equipment specific to a photographic enlarger could be used which allowed, some time ago, to obtain photographs by projecting the existing image from a film onto a sheet of photosensitive paper. Later, through developing and fixing operations, the image transferred to the photosensitive paper became visible and stable over time.

In principle, in the case of such a photographic enlarger (Fig. 1), a light source was used (usually an incandescent bulb) whose radiation was passed through an optical condenser that ensured a certain uniformity of the light directed to a rectangular window, with the dimensions of 18 x 24 mm^2, these being the standard dimensions of the existing image on the photographic film. Afterward, the light radiation was forced to pass through one or more lenses, which contributed to an enlargement of the image projected on the photosensitive paper. Subsystems of displacement of the optical subsystem made up of lenses allow us to obtain an image as clear as possible on photographic paper.

Instead of the subsystem supporting the photographic film, a compartment was designed and made in which glass plates with a surface characterized by the dimensions of 100 x 100 mm^2 were inserted. Three categories of glass were used, namely ordinary glass with a thickness of 3 mm, glass sandblasted on one of its surfaces, with a thickness of 4 mm, and, respectively, decorative glass with a thickness of 4 mm.

The choice of these glass categories for the experimental research was carried out with the aim that their levels of transparency were sufficiently different to measure distinct results that would be adequately reflected in the determined empirical mathematical model.

A change in the illuminance generated by the light source was intended by modifying the value of the bulb's supply voltage. Compact fluorescent bulbs are known to involve the production of an electrical discharge in a tube containing a mixture of argon and mercury vapor. An increased efficiency is obtained, in the case of this type of bulb, by covering the inner surface of the tube with a substance that transforms even ultraviolet radiation into visible radiation. In principle, the energy efficiency of compact fluorescent bulbs is slightly lower than that of light-emitting diode (LED) bulbs but still much higher than that of incandescent bulbs. Finding some difficulties in ensuring the operation of LED bulbs at lower voltages, the decision was made to use compact fluorescent bulbs in the intended experimental research.

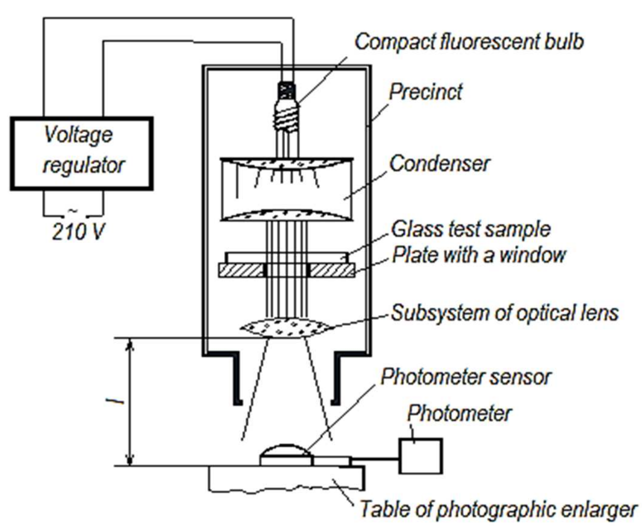

Fig. 1. Schematic representation of the equipment for the evaluation of light absorption by different types of glasses.

Two bulbs from this category were used, with nominal powers of 3 and 15 W, respectively. It was intended to conduct experimental trials following the requirements of a full factorial experiment, with 3 independent variables and two levels of variation of these variables.

As input factors in the lighting process (independent variables), the distance *l* between the optical subsystem of the lenses of the photographic enlarger and the table of equipment on which the photometer sensor was placed, the nominal power *P* of the compact fluorescents' light bulbs and the supply voltage *U* of the bulbs were therefore considered. A distinct, independent variable was the nature of the glass incorporated in the test samples having an area of 100 x 100 mm^2.

Changing the supply voltage *U* of the bulbs was carried out using a voltage regulator that allowed obtaining an alternating current voltage with values of 50-210 V at the output.

The intensity of light radiation reaching a surface at a predetermined distance *l* from the optical subsystem was measured using a photometer of the Light Meter type - Maplin Order Code N76CC (manufactured in the United Kingdom). The sensor of this photometer was placed in the middle of the light spot formed on the table of the photographic enlarger.

It was considered reducing the number of experimental tests necessary to be carried out to determine some empirical mathematical models that highlight the way and the intensity of the luminous intensity variation because of the passage of light through glasses of various categories. As previously mentioned, a planned factorial experiment, with three independent variables and two levels of variation of these variables was used. Moving on to the actual experimental part, it was found that there are some difficulties in ensuring the constancy of the values of the independent variables corresponding to the two levels of variation considered initially. It was thus observed that the supply voltage of the bulbs, which is the voltage of the electricity supply network, is not constant but has a certain variation, for example, between 203 and 210 V, as it was difficult to regulate the voltage provided by the voltage variator, so that this voltage has the initially selected values. The existence of the voltage regulator, however, made it possible to ensure voltages close to those required.

The inclusion of a voltage stabilizer in the experimental equipment could reduce the voltage variations offered by the electrical network. The use of the least squares method for processing the experimental results, however, considers these voltage variations, which will not affect the results of the calculations.

It is also necessary to mention that the nominal power of the bulbs has been considered following that mentioned in the commercial documents without having carried out a check of the real power absorbed by the bulbs. Using an instrument to measure the power absorbed by the bulbs could provide more accurate information regarding this characteristic of the bulbs.

Table 1

Experimental results.

Exp no.	Process input factors			Process output parameter: Illuminance, I, lx			
	Coded value/Real distance l, mm	Coded value/bulb nominal power, P, W	Coded value/Real voltage, U, V	Without glass	Common glass	Sandblasted glass	Ornament glass
Column 1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	1/150	1/3	1/154	39.4	37.8	14.3	15.2
2	2/250	1/3	1/152	17.4	15.5	6.5	6.8
3	1/150	2/15	1/148	47.6	45.2	41.3	42.5
4	2/250	2/15	1/150	20.0	19.6	16.7	16.7
5	1/150	1/3	2/210	47.4	46.4	27.2	29.2
6	2/250	1/3	2/210	21.4	20.2	20.6	22.1
7	1/150	2/15	2/203	75.6	66.5	41.9	46.3
8	2250	2/15	2/203	64.1	56.0	16.2	17.3

The values of the independent variables considered were entered into columns numbered 2-4 in Table 1; in these columns, for each experimental test, a ratio between the coded value (according to the requirements of a full factorial experiment with two levels of variation) and the value assessed as real of the input factor in the investigated process was entered.

3.2. Experimental results

The values of the illuminance *I* at the level of the surface of the photometer sensor (in lux) were entered in columns 5-8 of Table 1, successively, for the situation where there is no glass pane, for the situation when such a glass is an ordinary glass window and respectively for situations when sandblasted glass and decorative glass are used, respectively.

4. PROCESSING AND ANALYZING THE EXPERIMENTAL RESULTS

The values of the input factors and those of the output parameters of the investigated process were processed using specialized software [9], which allowed the determination of some empirical mathematical models designed to highlight the influence and intensity of the influence of the considered input factors in the investigated process on the illuminance sensed by the photometer sensor.

The specialized software uses the method of least squares. It can determine empirical mathematical models such as first-degree polynomials, second-degree polynomials, power-type functions, exponential functions, and hyperbolic functions. The choice of the most appropriate empirical mathematical model among the five types of models mentioned before is made by considering the value of the so-called *Gauss criterion*.

The value of the Gauss criterion is calculated as a ratio where the numerator is the sum of the least squares corresponding to the differences between the measured values and the value determined using the proposed function for the same experimental points. The denominator of the ratio used to calculate Gauss's criterion is the difference between the number of experimental tests and the number of constants included in the proposed empirical mathematical model [9-11].

As previously mentioned, the hypothesis that the illuminance *I* will decrease as the distance *l* increases and increases as the nominal power *P* of the bulb and the supply voltage *U* of the bulb increases is considered. In such conditions, it was decided to determine some empirical mathematical models of the power type function, which correspond to a monotonous variation (without maxima or minima) of the output parameter (illuminance *I*) in relation to the variations of the input factors (distance *l*, nominal power *P* of the bulb, and the supply voltage *U* of the bulb).

By using specialized software, the following empirical mathematical models were developed. For the situation where there is no glass pane:

$$I = 5.124 l^{-1.290} P^{0.322} U^{1.575} \quad (2)$$

where the Gauss criterion has, in this case, a value S_G= 111.1111;

For the situation where an ordinary glass pane is used:

$$I = 8.626 l^{-1.336} P^{0.306} U^{1.513} \quad (3)$$

for which the value of Gauss's criterion is S_G=83.859;

For the situation of using a sandblasted glass window:

$$I = 11.0778 l^{-1.430} P^{0.368} U^{1.433} \quad (4)$$

in which case the value of Gauss's criterion is S_G=45.15544;

For the situation of using a decorative glass window:

$$I = 7.192 l^{-1.469} P^{0.362} U^{1.569}, \quad (5)$$

This is the empirical mathematical model in which Gauss's criterion has a value S_G=46.49361. By considering the empirical mathematical models constituted by equations (2)-(5), the graphic representations included in Figures 2-4 were elaborated.

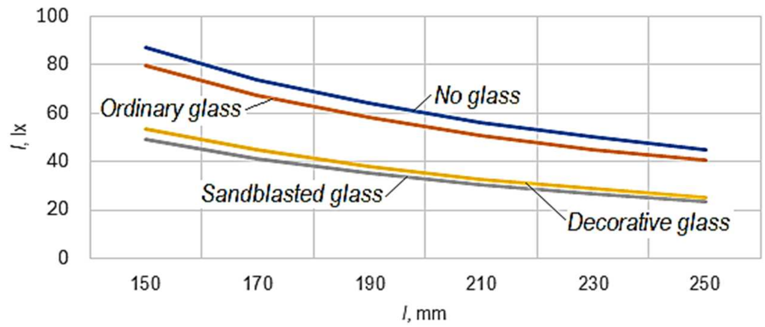

Fig. 2. The influence of the distance *l* between the optical subsystem and the table of the experimental equipment on illuminance *I* for different categories of glass (bulb with a nominal power *P*=15 W, supply voltage of the bulb *U*=219 V).

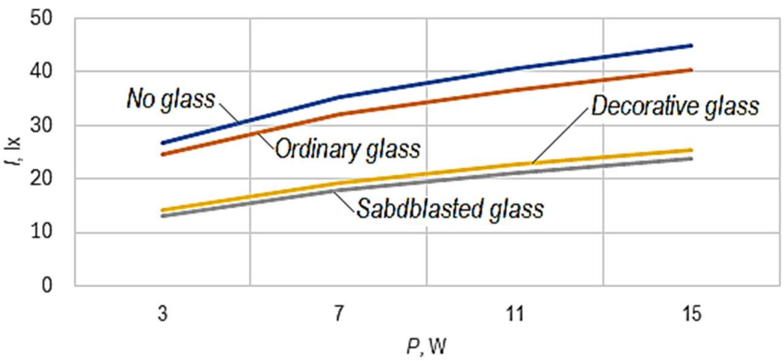

Fig. 3. The influence of the nominal power *P* of the bulb on the illuminance *I*, for different categories of glass (distance *l*=250 mm, supply voltage of the bulb *U*=210 V).

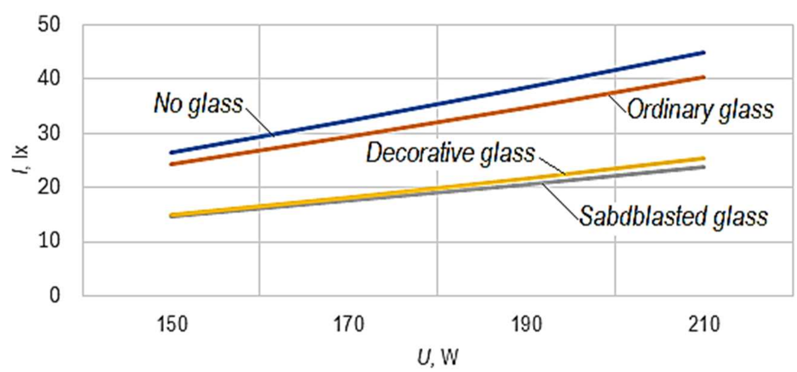

Fig. 4. The influence of the voltage *U* applied to the compact fluorescent bulb on illuminance *I* for different categories of glass (distance *l*=250 mm, nominal power of the bulb *P*=15 W).

The analysis of these graphic representations, as well as the empirical mathematical models corresponding to equations (2)-(5), led to the observations mentioned below.

It is thus found, as expected, that when increasing the distance *l* between the optical subsystem and the photographic enlarger table on which the photometer sensor is placed, there is a decrease in illuminance *I* since the values of the exponents attached to the independent variable *l* in the empirical mathematical models are negative. At the same time, an increase in nominal power *P* of the bulbs and the supply voltage *U* of the bulbs leads to an increase in illuminance *I* since the exponents attached to these independent variables have positive values in the empirical mathematical models.

The greatest influence on illuminance *I* is exerted by the supply voltage *U* of the bulbs since, in the empirical mathematical models, the voltage *U* was assigned the highest absolute value among the exponents corresponding to the independent variables. The distance *l* between the optical subsystem and the table of the equipment exerts a lower influence. Still, the lowest influence corresponds, for the conditions in which the experimental tests were carried out, to the nominal power *P* of the bulb. In the empirical mathematical models, the lowest exponent values were attached to the *P* variable.

It is also confirmed that the ordinary glass pane absorbs the least amount of light compared to the light absorbed by a sandblasted glass pane or a decorative glass pane.

Using the results of the work, to the required lighting and other requirements of the workplace, the window material can be chosen appropriately.

5. CONCLUSIONS

Researching the level of illumination of the space in which the human operator carries out his activity is a problem of interest from an ergonomic point of view. The consultation of specialized literature in this field highlighted the concerns of scientific researchers to accumulate as much detailed information as possible regarding the lighting of the workplace.

On the other hand, it is known that ordinary glass, sandblasted glass, or decorative glass absorbs a certain part of the light emitted by natural or artificial sources. To gain more information on the extent to which different types of glass absorb a greater or lesser amount of the light emitted by a compact fluorescent light bulb source, an experimental study was designed that tracked the variation of illuminance with distance from the optical subsystem of the light source, the nominal power of the bulb, and, respectively, the supply voltage of the bulb.

Through the mathematical processing of the experimental results when using specialized software, mathematical power-type function models were determined, which highlighted the influence of the distance, the nominal power of the bulb, and the supply voltage on the illuminance. It was found that the strongest influence on illuminance is exerted by the supply voltage of the bulb, followed by the distance between the optical subsystem and the photometer sensor and, respectively, by the nominal power of the bulb.

In the future, it is intended to extend the theoretical and experimental research by considering other window materials through which artificial light can reach the workspace area. In addition, sustainability criteria should be considered to develop innovative ergonomic solutions based on the engineering design approach [12–14] .

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Capacitatea sticlei de a permite trecerea luminii ca factor de asigurare al ergonomicității locului de muncă

Nivelul de iluminare a spațiului în care lucrează un operator uman este unul dintre factorii care se iau în considerare atunci când se evaluează ergonomicitatea unui loc de muncă. Prezența unui geam din sticlă poate contribui la absorbția unei părți din lumina emisă de o sursă naturală sau artificială. Pentru evaluarea măsurii în care diferite categorii de sticlă absorb o cantitate mai mare sau mai mică din energia luminoasă, a fost concepută o cercetare experimentală, în cazul căreia factorii de intrare au fost distanța de la subsistemul optic corespunzător sursei de lumina, puterea nominală a becului fluorescent compact și tensiunea de alimentare cu energie electrică a becului. Ca parametru de ieșire, a fost selectată iluminanța măsurată cu ajutorul unui fotometru. Au fost luate în considerare probe din sticlă obișnuită, din sticlă sablată și din sticlă ornament. Rezultatele experimentale au fost procesate matematic cu ajutorul unui soft specializat. Au fost determinate funcții de tip putere, care evidențiază intensitatea influenței exercitate de către factorii de intrare asupra parametrului de ieșire luat în considerare. S-a constatat că pentru condițiile experimentale disponibile, influența cea mai puternică este exercitată de către tensiunea de alimentare a becului cu energie electrică, urmată de distanța de la sursa de lumină și de puterea nominală a becului.

Laurențiu SLĂTINEANU, PhD., Professor, "Gheorghe Asachi" Technical University of Iași, Department of Machine Manufacturing Technology, Blvd. D. Mangeron, 59A, Iași, 700050, Romania, laurentiu.slatineanu@academic.tuiasi.ro, +40723718675.

Oana DODUN, PhD., Professor, "Gheorghe Asachi" Technical University of Iași, Department of Machine Manufacturing Technology, Blvd. D. Mangeron, 59A, Iaşi, 700050, Romania, oana.dodun@academic.tuiasi.ro, +40747144604.

Mădălin CATANĂ, PhD., Associate Professor, National University of Science and Technology Politehnica Bucharest, Manufacturing Engineering Department, 313 Spl. Independentei, București, 060042, Romania, madalin.catana@upb.ro, +40745058752

Margareta COTEAȚĂ, PhD., Associate Professor, "Gheorghe Asachi" Technical University of Iași, Department of Machine Manufacturing Technology, Blvd. D. Mangeron, 59A, Iași, 700050, Romania, margareta.coteata@academic.tuiasi.ro, +40752141598.

Sergiu OLARU, PhD., "Gheorghe Asachi" Technical University of Iași, Department of Machine Manufacturing Technology, Blvd. D. Mangeron, 59A, Iași, 700050, Romania, olarusergiu@gmail.com, +40787840305.

Adelina HRIȚUC, PhD. Student, "Gheorghe Asachi" Technical University of Iași, Department of Machine Manufacturing Technology, Blvd. D. Mangeron, 59A, Iași, 700050, adelina.hrituc@yahoo.com, +40751640117.

Gheorghe NAGÎȚ, PhD., Professor, "Gheorghe Asachi" Technical University of Iaşi, Department of Machine Manufacturing Technology, Blvd. D. Mangeron, 59A, Iași, 700050, Romania, nagit@tcm.tuiasi.ro, +40723936351.