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Functional features and hygienic aspects of LED lamps

Cechy użytkowe i aspekty higieniczne lamp ledowych (LED)

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[b)] *measurements and laboratory tests*
[c)] *data collection*
[d)] *data analysis*
[e)] *text and references*

Summary

Aim of the study: The aim of this study was to identify characteristics of the LED lamps and their influence on perceptual abilities and feeling of a human. **Materials and methods:** Technical parameters of ten chosen LED sources of light were determined. The sources varied among each other, according to the shape, colour temperature, colour rendering index and also name of the manufacturer. For each of the analysed sources of light, the illuminance, lighting uniformity, lighting luminance and degree of glare were determined. Moreover, also a subjective evaluation of the lighting conditions created by those lighting sources was performed. **Results and conclusions:** The study results have shown that the majority of the analysed sources of light provided their users with a good visibility and comfort of vision, but on the other hand, if used in an inappropriate way, they may be the reason for the unaccepted glare. It has been stated that the appropriate use and earlier – the well-thought-out choice of the LED sources of light are crucial. One has to consider the luminous flux, the colour temperature, the shape, as well as the manufacturer, who guarantees the quality and the safety class of the LED source of light.

Key words: LED lamp, lighting conditions, Correlated Colour Temperature, glare, blue light

Streszczenie

Cel badań: Celem badań było poznanie właściwości ledowych źródeł oświetleniowych i ich wpływu na możliwości percepcyjne człowieka oraz jego samopoczucie. **Materiał i metodyka badań:** Określono parametry techniczne dziesięciu, wybranych źródeł LED, różniących się między sobą kształtem, mocą, temperaturą barwową, wskaźnikiem oddawania barw, a nawet marką producenta. Dla każdego, badanego źródła wyznaczono natężenie oświetlenia, równomierność oświetlenia, luminancję świetlną oraz stopień olśnienia, a także dokonano subiektywnej oceny warunków oświetlenia, stwarzanych przez te źródła. **Wyniki i wnioski:** Wykazano, że większość z badanych źródeł LED zapewnia dobrą widoczność i wygodę widzenia, ale jednocześnie przy nieprawidłowym stosowaniu może być powodem nieakceptowalnego olśnienia. Stwierdzono, że bardzo istotne jest prawidłowe użytkowanie oraz wcześniej – przemyślany wybór źródła LED, biorący pod uwagę strumień świetlny, temperaturę barwową, kształt, a także markę producenta, która gwarantuje jakość i klasę bezpieczeństwa źródła LED.

Słowa kluczowe: lampa LED, warunki oświetleniowe, temperatura barwowa, olśnienie, światło niebieskie

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1. Introduction

The LED lamps are the modern sources of light which are gradually supplanting the traditional sources. Energy saving constitute the greatest advantage of this kind of lighting sources. The lighting effectiveness of the LED lamps available nowadays on the market equals 50 – 140 lm/W, which allows to obtain 80% of energy saving in comparison with light bulbs and 30% of energy saving in comparison with compact fluorescent lamps [1]. Another advantages of this kind of sources, which are enumerated by the manufacturers, are the high quality, independent of the frequency of turning on and turning off the light, the resistance to vibrations, high durability (25,000 – 50,000 h), the scarce amount of the ultraviolet radiation. On the other hand, the light emitted by the LED lamps is produced in a different way than it is done in the incandescent or gas-discharge sources of light. What is more, it is characterized by the radiation spectrum with a greater amount of the blue light (400 – 500 nm) and higher lighting luminance than, for example, fluorescent lamps. The light produced by the LED lamps may thus influence a human being in a slightly different way than the light emitted by the traditional bulbs or fluorescent lamps. Hence the questions: does the LED light provide people with the appropriate perception, what kind of visual sensations does it evoke, and, can it have a negative influence on a human's health?

Although the prospective dangers can be attributed to the opportunity of causing the phenomenon of glare, the influence of the blue light on the eye's retina, and even electromagnetic fields generated by the LED power-supply systems, the study aimed at the first place to determine optic features of the LED sources, currently available in the Polish market, as well as to describe the prospective influence of the light emitted by the LED sources on a human, and especially on the human's perceptual abilities. The investigation of this problem is very important because of the fact that in the near future the LED sources of light are going to be the universally applied sources to light rooms at homes and workplaces, and so far their properties have not been investigated in detail.

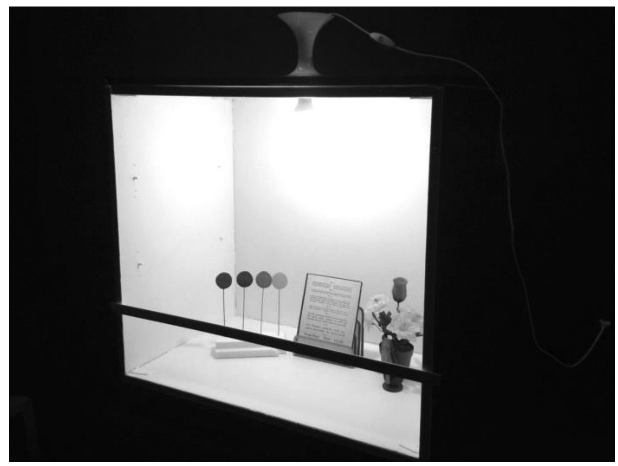
2. Material and methods

2.1 LED sources

Ten LED lamps of various construction and from different manufacturers marketed in Poland were studied. Their technical data, provided by the manufacturers, are reported in Table I. The sources were numbered consecutively from I to X and were referred to by these numbers in the subsequent text and tables.

2.2 Subjective assessments of the lighting quality

Eleven volunteers with proper vision, familiar with similar testing procedures, participated in the study. Volunteers were between 23 and 65 years old (mean age 41.5 years). Volunteers were asked to evaluate the light quality for visual work and to assess subjective feelings of the lighting conditions provided by the studied sources, trice for each of the light source compared.. They evaluated: visibility of the printed text, visual comfort of reading, glare, impression of colour and relaxing influence of light. They read a text from the Snellen's chart for near vision and observed colours of the presented objects: four discs, coloured red, green, blue and yellow, and a composition of flowers. The tests were performed in an experimental chamber installed in a photometric darkroom, that is shown in Photograph 1. The lighting conditions were evaluated using the scales presented in Table II.



Photograph 1
The experimental chamber lit by one of the evaluated LED lamp
Komora doświadczalna oświetlana przez jedno z badanych źródeł LED

2.3 Measurement of the lighting parameters

The second part of the study consisted in the measurements of the lighting parameters, created by the compared sources, i.e. the illuminance on the chosen horizontal planes, the uniformity of the lighting, the lighting luminance, and the level of glare, which may occur if the source is installed in a wrong way.

The measurements were performed in the same photometric darkroom as applied in the subjective assessments. The illuminance was measured with the illuminance meter L-51 manufactured by Sonopan. The illuminance level was determined at the distance of 20 cm from each of the evaluated lamps. Moreover, the distance between the lamp and a point where the illuminance level was equal to 500 lx was determined for each lamp. The luminance of the each source was measured with the luminance meter ML-20 manufactured by Sonopan. The measurements were performed according to the standards PN-83/E-04040.03 [2], PN-83/E-04040.04 [3] and PN-84/E-02033 [4]. Uniformity of the lighting U_0 was calculated from the illuminances measured at the lower, horizontal plane of the experimental chamber, using the following formula:

$$U_0 = E_{min}/E_{av}, \quad (1)$$

where E_{min} and E_{av} are the minimum and average illuminances, respectively.

The level of glare was calculated according to the standard PN-EN 12464-1 [5]:

$$UGR = 8\log_{10}\left[\frac{0,25}{L_b}\sum\frac{L^2\omega}{p^2}\right] \quad (2)$$

where: L is the luminance of the source of light, i.e. the source of glare [cd/m^2], ω is the angular size of the source of glare [sr], L_b is the background luminance [cd/m^2], p is the position index proposed by Luckiesh and Guth, characterizing the position of the glare source in relation to the line of vision of the observer [6].

The angular sizes of the lighting sources were determined according to the formula:

$$\omega = S/r^2 \quad (3)$$

where: S is the lighting area of the lighting source, r is the distance of the lighting source from the observer's eye.

In this study, the UGR factors were calculated for the source of light located at the distance of 50 cm from the observer's eyes, 30 cm sidewards from the line of vision, and 20 cm above it. For this arrangement, the position index p equal to 2.5 was taken from the Luckiesh-Guth chart [6]. The background luminance applied in the calculations was 300 cd/m^2.

3. Results

3.1 Subjective evaluation

The results of the subjective evaluation of the lighting conditions provided by the compared sources of light are reported in tables III and IV and in figures 1 and 2. In table III, the numbers in columns 3 – 7 are the arithmetic

Table I

Basic information and technical data of the LED lamps as stated by the manufacturers
Podstawowe informacje i dane techniczne lamp LED, deklarowane przez producentów

ID #	Lamp name and manufacturer	Glass bulb / lamp cap type	Power[a] /luminous flux	CCT[b] / R_a[c]	Other information
I	LED Star glob Daylight MANUF. A	Classic A40 E27	7 W (40W) 470 lm	6500 K Ra=80	220-240 V 50/60 Hz –20°C-40°C t=15000h
II	LED Star glob Warm white MANUF. A	Classic A40 E27	7 W (40W) 470 lm	2700 K Ra=80	220-240 V 50/60 Hz –20°C-40°C t=15000h
III	Glob MANUF. B Warm white	E27	6 W (40W) 470 lm	2700 K Ra>80	220-240 V t=15000h
IV	„Sweetcorn" SMD 5050 White MANUF. C	GU10	4 W (40W)	3000-3500 K	220-240 V 50/60 Hz T=60000h
V	„Sweetcorn" 15 led SMD Intensive 5050 Warm white MANUF. D	G9	3.3 W	2700 K	230 V, 50 Hz t=50000h lighting angle 120°
VI	1-chip White MANUF. B	GU10	4 W (35 W) 245 lm	3000 K Ra>80	220-240 V, 50 Hz t=15000h lighting angle 36°
VII	6-chip Warm white MANUF. B	GU10	4.5 W 345 lm	2700 lm Ra>80	220-240 V t=15000h lighting angle 36°
VIII	Many chips LED SMD JDR SMD CW-250 Cool white MANUF. E	E14	3.5 W (36 W) 250 lm	6400 K Ra>80	220-240 V, 50 Hz –20°C-40°C t=25000h lighting angle 120°
IX	Many chips 22 SMD Daylight MANUF. F	GU10	5 W (35W) 390 lm	6000 K Ra=80	230 V, 50 Hz t=30000h lighting angle 120°
X	Many chips 22 SMD Warm white MANUF. F	GU10	5 W (35W) 390 lm	2700 K Ra=80	230 V, 50 Hz t=30000h lighting angle 120°

[a]in parentheses power consumption of the traditional incandescent lamp of equivalent luminous flux
[b]CCT – Correlated Colour Temperature
[c]R_a – Colour Rendering Index

means of the scores granted by all 11 participants. The „mean rating" column 8 contains averaged values of numbers from the columns 3 – 7.

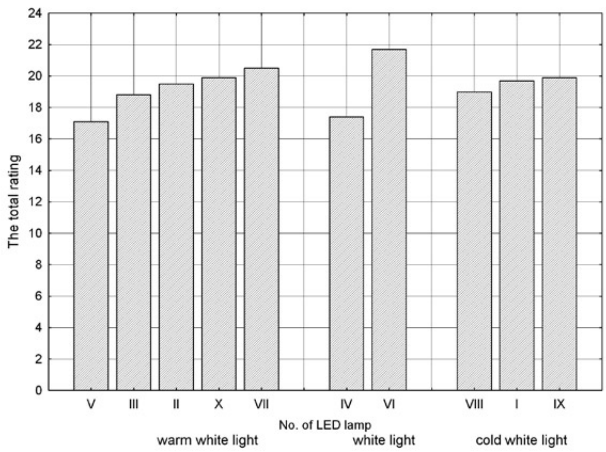


Figure 1
The total value of the subjective ratings of each of the evaluated LED lamps
Suma średnich ocen subiektywnych uzyskanych dla każdego badanego źródła LED

The subjective ratings were converted into numerical values using the relations reported in Table II. Then, descriptive statistics were calculated f or all parameters obtained in that way. Calculations were performed for different kind of the light (warm white, white and cool white/daylight – and additionally for natural light) for the subjects divided into the two groups of age. The subjects of 23 to 34 years old constituted the group of younger people, while those of 49 to 65 years old – the group of older ones. Statistically significant differences between the scores in the two groups were found. In the evaluations, the analysis of variance (ANOVA) for the repetitive results was applied. In the case of the lack of the sphericalness (Mauchley's test $p < 0.05$), the multivariate analysis of variance MANOVA was applied. The variance analysis was complemented with the post hoc analysis according to the Bonferroni procedure.

The multivariate analysis of variance MANOVA showed the statistical importance of differences between the ratings for certain LED lighting sources, for example I and VI, IV and VIII. The total ratings, i.e. the sums of scores, for the cold and warm lights were close to one another, equal to 19.5 and 19.2, respectively. The multivariate analysis of variance MANOVA for repetitive results showed that the difference in the ratings for the sources of different correlated colour temperatures is rather low, with the significance level of $p=0.23025$. On the other hand, the analysis of the mean values for the particular scores showed that the results for the light of higher correlated colour temperature were slightly better (Table IV). The warm white light was rated higher than the other ones only as the light suitable for the relax rather than for the activity.

Table II

The grade scales applied in the estimation of the lighting conditions
Skale stosowane do subiektywnych ocen warunków oświetlenia

Evaluated parameter	Grade scale	
	Descriptive	Numerical
Visibility of the printed text	very bad bad average good very good	1 2 3 4 5
Visual comfort of reading	The lack of comfort Not sufficient comfort Average comfort Good comfort Very good comfort	1 2 3 4 5
Glare	Unbearable Great, disturbing vision Quite big, uncomfortable Average, on the verge of comfort small imperceptible	1 2 3 4 5 6
Relaxing influence of light	Unacceptable Unpleasant Neutral Pleasant Very pleasant	1 2 3 4 5
Perception of colours	Depressing A little sad Normal Quite energetic Stimulating	1 2 3 4 5

The evaluation of the lighting sources emitting the cold and warm light by the younger and older volunteers shows Figure 2.

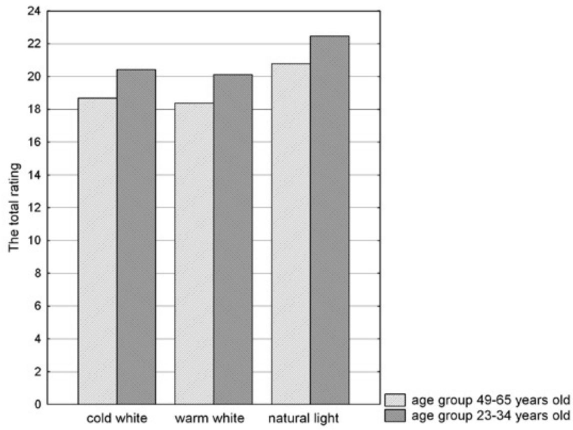


Figure 2
Ratings of the sources of cold and warm light assessed by the younger and older volunteers
Oceny źródeł LED o zimnej i ciepłej barwie światła, uzyskane przez młodych i starszych wolontariuszy

The cold light were rated for 20.4 by the young volunteers, while for 18.7 by the older people. The difference of the results was statistically significant, as was evidenced by p<0.05. Similarly significant difference was observed for the natural light, with the mean values of the total scores equal to 22.5 and 20.7 for the two groups. Respective total ratings of the warm light were 20.1 and 18.4 (but the difference was statistically not significant in the latter case).

3.2. Measured characteristics of the light sources

Measured parameters of the lighting supplied by the compared LED sources and the calculated unified glare ratings (UGR) are reported in Table V.

Discussion

The compared LED sources are widely marketed in Poland. The manufacturers are worldwide known companies, such as PHILIPS and OSRAM, as well as Polish firms of locally established reputation as POLUX, ANS-lighting and EKOLIGHT. Some products bear brands which are difficult to recognize. All the products were made in China, as stated on the packagings. In this research, the products of different designs were compared. The sources numbered from I to III had the spherical shape (so called „globe"), the sources numbered from IV to V had the shape of a cylinder (so called „sweetcorn"), and the sources numbered from VI to X were spotlights. Nine out of the ten evaluated sources of light had their own optical system, designed to provide the appropriate light flux distribution. In three sources, numbered from I to III, the lighting chips

Table III
Means of the subjective evaluations of the lighting conditions
Wartości średnie subiektywnych ocen warunków oświetlenia

ID #	Light characte-ristics	Text visibility	Glare	Visual com-fort	Relaxing influence	Perception of colours	Mean rating	Sum of scores
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
I	Daylight	4.4	4.8	3.8	2.8	3.8	3.9	19.7
II	Warm white	4.1	5.1	3.7	3.1	3.6	3.9	19.5
III	Warm white	3.9	5.1	3.2	3.3	3.3	3.8	18.8
IV	White	3.6	5.1	2.9	3.5	2.2	3.5	17.4
V	Warm white	3.4	5.6	2.5	3.5	2.1	3,4	17.1
VI	White	4.3	5.6	4.2	4.0	3.6	4.3	21.7
VII	Warm white	4.2	5.4	3.5	3.8	3.6	4.1	20.5
VIII	Cool white	4.2	5.2	3.7	3.1	2.8	3.8	19.0
IX	Daylight	4.2	5.1	3.8	2.9	3.5	3.9	19.6
X	Warm white	4.1	5.3	3.6	3.4	3.5	3.9	19.9

Table IV
Averaged subjective ratings for LED sources of different colour temperature
Średnia ocen uzyskanych dla źródeł o różnych temperaturach barwowych

ID #	Light characteristics	Text visibility	Glare	Visual com-fort	Relaxing influence	Perception of colours	Mean rating
II, III, V, VII, X	Warm white	3.9 good	4.8 small	3.3 average	3.4 neutral	3.2 normal	3.7
IV, VI	White	4.0 good	5.4 small	3.6 good	3.8 pleasant	2.9 normal	3.9
I, VIII, IX	Cool white / Daylight	4.3 good	5.0 small	3.8 good	2.9 neutral	3.4 normal	3.9

were not visible because of the frosted lightbulbs, in three sources (numbers IV, VI and VII) the lighting chips were hardly visible through the matte lightbulbs, and in two sources (numbers IX and X) the lighting chips were clearly visible through the transparent bulbs. The source number V did not have its own optical system, that is the lighting chips were not covered. Each source belonged to one of the three groups according to the correlated colour temperature, named: „warm white", CCT =2700 K, „white", CCT =3000-3500 K, or „cool white"/"daylight", CCT =6000-6500 K. Almost all of the evaluated sources of light claimed very good colour rendering index Ra ≥80 and very good durability from 15,000 to 50,000 hours. For the spotlight LED sources, the manufacturers report the lighting angle: narrow – 36^0 or wide – 120^0.

The manufacturers declare the LED lamps of power varying from 4 to 7 W as the substitutes of traditional light bulbs of 35 – 40 W. It was found, however, that the LED sources differ in terms of e.g. the luminous flux (245 – 470 lm), the lighting luminance and the possibilities to provide the user with expected level of illuminance. The sources numbered I, II, III, VI, VIII, IX, X may serve as the examples (cf. Tables I and V). Thus, the sources of various manufacturers which are characterized by the similar declared power values and luminous flux, differ in terms of the luminance and the illuminance which they may provide, e.g. the sources II and III. Similarly, the sources of light supplied by the same manufacturer and characterized by the same power values, but of different correlated colour temperatures, show different luminances and the illuminance. That is in the case of sources I and II, as well as IX and X.

Another question is the shape of the light beam emitted by the source. An interesting example is the source number VI. Although it is characterized by a smaller luminous flux than the other sources, it is a high-luminance-source (1990 kcd/m^2) effectively ensuring a high level of illuminance. At the same time, it shows relatively low lighting uniformity, equal to 0.74. Indeed, it is a spotlight emitting the white light within a narrow angle of 36^0. The research has proven that these characteristic features comprise both the source's advantages and drawbacks.

It is worth noticing that while choosing or evaluating the LED lamps, one should take into consideration not only the power value declared by the manufacturer, as it was sufficient in the case of the traditional light bulbs. The characteristics of a LED source involve its shape, the luminous flux, the colour temperature and may even depend on the manufacturer. In order to facilitate the choice of the substitute, some manufacturers report the approximate power values of the traditional light bulbs emitting the same luminous flux as the proposed LED source. The example of such approximate relation between the luminous flux and power is given in Table VI [1].

Table VI
The LED substitutes of the traditional light bulbs
„Zamienniki" ledowe tradycyjnych żarówek

Luminous flux of the LED lighting source [lm]	Power of the corresponding, traditional light bulb [W]
136	15
249	25
470	40
806	60
1055	75
1521	100

The analysis of the subjective assessments evidenced that six lighting sources were rated higher than the remaining four, with the total score of 19.5 and above (cf. Table III). Different types of the sources, shown in Photograph 2, belong to this group: spotlights (numbers VI and VII), „globes" (I and II), and those with multiple chips (IX and X). These sources provided appropriate levels of illuminance, good print visibility,

Table V
Lighting parameters of the evaluated LED sources
Parametry oświetleniowe badanych lamp LED

ID #	Illuminance in distance of 20 cm from lamp [lx]	„500 lx" distance[a] [cm]	Luminance [kcd/m^2]	Lighting conditions		UGR	Glare assessment
				Mean illuminance [lx]	Uniformity		
I	2600	51	77.6	874	0.98	34	unbearable
II	2860	54	103	1004	0.97	36	unbearable
III	1890	44	53	784	0.98	31	unbearable
IV	240	13 (< 20)	15.5	397	0.99	24	big
V	200	12 (< 20)	11	133	0.98	12	small
VI	16700	115	1990	1849	0.74	64	unbearable
VII	16900	115	1950	2147	0.75	54	unbearable
VIII	2340	48	60	558	0.98	32	unbearable
IX	3000	54	57	832	0.98	30	unbearable
X	2400	51	71	707	0.96	31.5	unbearable

[a]the distance between the lamp and the point where the illuminance level is equal to 500 lx

little glare (if installed properly), normal reception of colours and comfortable vision.

Lamp VI: 

Lamp I: 

Lamp IX: 

Photograph 2
Examples of three types of the LED sources which were rated best by the subjects
Przykłady trzech źródeł LED, które uzyskany najlepsze oceny wolontariuszy

The lighting sources number VIII, IV, V and III scored worse. The source number V with the declared power of 3.3 W did not provide sufficient level of illuminance. The comfort of vision and/or the colour reception was poor in the light of the sources numbered V, IV, VIII, III. Generally, the cold lighting sources were rated slightly better, as is illustrated in Figure 2. However, different light sources seemed to be suitable for different purposes:

– the lighting sources of the „daylight" type, provided good colour perception,
– the visibility of the printed text was better at the cold light („daylight", „cool white") and at the white light,
– the cold light („daylight" and „cool white") ensured higher comfort of vision,
– the „white" and „warm white" light colour were preferred when „relaxing influence of the light" was considered.

The visual work conditions were generally rated slightly lower by the group of older volunteers than by that of the younger ones. That might result from the lower transparency of the eye's optical centres of older people in comparison with that of young ones. The effect is stronger for the short waves of the visible spectrum (as in spectrum of LED lamps), because while getting older, the yellowish lens becomes a filter for the short-wave radiation [7].

The measured luminance of the studied LED lamps ranged from 11 to 1999 kcd/m^2. The lowest luminance of 15 – 15 kcd/m^2 provided the „sweetcorns" (numbers IV and V), then 120^o-angle spotlights (VIII, IX and X) – 57-71 kcd/m^2 and the „globes" (I to III) – 53-103 kcd/m^2. Significantly higher luminances showed 36^o-angle spotlights (VI and VII) – 1950-1999 kcd/m^2. Thus, the highest levels of luminance are attained by the sources characterized by rather narrow angle of the luminous flux. These values are high in comparison with those of the fluorescent lamps, ranging from a few to several dozen kcd/m^2.

One of the highly unwanted effects caused by the light sources is glare. The estimated UGR factors reported in Table V were calculated for a desktop lamp, situated close to the user, with a coverless LED lamp directed towards the user's eyes. It is evident that in nine of ten cases, the glare was pronounced. Applying the scale of the subjective perception of the glare reported in Table VII, the glare could be described as unbearable for the LED sources number VI, VII, I, II, III, VII, IX and X or big (for IV). Only the low-luminance source V caused small glare.

Table VII
The UGR values and corresponding conventional description of the glare, according to [6]
Wartości UGR i odpowiadający im opis słowny olśnienia, wg [6]

UGR	Glare description
28	unbearable
23-27	big
22	quite big
17-21	average
16	rather small
11-15	small
10	hardly noticeable

The problem of glare due to high luminance level LED lighting sources is ignored by some researchers, who are of opinion that the experience gained from the usage of the traditional lamps is sufficiently ample for the use of the LED sources [1]. On the other hand, serious reservations have been raised concerning the method of evaluation the glare according to the lighting standards, i.e. by the UGR factor given by eq. 2. Although successfully applied to other types of the lighting sources previously, is seems to be not appropriate for the LED sources [8, 9]. For example, the real glare surface in the LED source is sometimes difficult to define, as it has not been decided yet whether the surface of one chip or the total surface of all the chips should be regarded as the lighting surface affecting the human eye.

However our results clearly show that the high-luminance LED sources must be placed outside the direct field of vision and they should be equipped with appropriate protective covers or shades. The latter is especially important for the spotlights.

Conclusions

The obtained results led to the following conclusions:

a) modern LED lamps may provide good visibility of the printed text and objects of visual work, and adequate colour perception, as well as sufficient comfort of vision and good mental and physical state of humans subjected to their influence;

b) subjective evaluations suggest that the cold light LED sources are slightly better for visual work than the warm light ones, the latter are suitable rather for the places of relax;

c) some LED lamps, characterized by high luminances, could easily cause unacceptable glare if improperly installed, thus the problem of proper choice of places of installation and of suitable protective covers demands minute considerations;

d) a LED lamps for a particular purpose should be chosen taking into account its shape and correlated colour temperature of the emitted light, apart from its power/luminous flux that was the only criterion for the majority of traditional light sources; moreover, the products of recognized manufacturers seem to be worthy of recommendation, because of the product quality and durability, and of reliably stated safety class.

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