

INFLUENCE OF ECO-DESIGN POLICY AND ENERGY LABELING ON THE LEVEL OF ENERGY EFFICIENCY AND FUNCTIONALITY OF LED LAMPS

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Considering the light engineering and environmental advantages of light-emitting diode (LED) light sources, lighting systems using LEDs should provide a decisive impact on increasing the energy efficiency of lighting and reducing greenhouse gas emissions. One of the priority directions of the energy saving policy is eco-design, which involves measures to reduce negative impacts on the environment and increase the functionality of LED light sources. The article presents the results of the study of commercial samples of non-directional LED lamps of various brands for compliance with the Commission Regulation European Union (EU) 2019/2020 on establishing requirements for the eco-design of light sources and the Commission Delegated Regulation EU 2019/15 on energy labelling, which came into force in 2021. It is shown that the light output of the studied batches of lamps with a power of 5–12 W is in the range of 90–120 lm/W, which corresponds to energy efficiency classes, accord-

ing to the new rating scale of the Commission Delegated Regulation EU 2019/2015, F and E. Over the past decade, the luminous efficiency of lamps supplied to Ukraine has increased by more than 30 %. Quality indicators of light are also improved: all tested lamps have a general colour rendering index of $R_a > 80$; in five of the 8 batches of lamps, the colour unevenness does not exceed the 3-steps Mac-Adam ellipses, and only in one batch individual lamps exceed the 6-steps ellipse; all tested lamps meet the requirements for the level of flickering (< 1) and the level of visibility of the stroboscopic effect ($SVM < 0.4$). Individual inconsistencies of the lamps with the established requirements have also been noted, in particular lamps with a power of 11 and 12 W do not meet the power factor $\cos \phi$, a number of manufacturers do not fully declare the characteristics of their products; most of the lamps have a low special colour rendering index R_s . Conclusions have been made about the effectiveness of the eco-design policy and energy labelling in increasing the energy efficiency, quality and safety of LED lamps.

Keywords: *Energy efficiency, energy labelling, LED lamps, regulation of the EU Commission.*

1. INTRODUCTION

Lighting consumes 15 % of global electricity consumption, which accounts for 4.6 % of total greenhouse gas emissions during its production [1]. The EU aims at building an economy with zero greenhouse gas emissions by 2050, and to achieve this aim, the task is to increase the energy efficiency of lighting equipment by at least 32.5 % by 2030 [2]. Considering the energy and environmental advantages of LED products, lighting systems using LED technology should have a decisive impact on increasing the energy efficiency of lighting and reducing greenhouse gas emissions. One of the priority areas of the energy saving policy is eco-design, which involves measures to reduce negative impacts on the environment. As a result of the implementation of the EU Commission's regulations on eco-design and energy labelling over the past decades, significant results have been obtained in terms of increasing the efficiency of light sources. The requirements for the eco-design of light sources are becoming stricter regarding the establishment of minimum values of effi-

ciency and functionality parameters, which is confirmed by the constant adoption of new directives and regulations in the EU.

In 2019, the European Commission announced a new EU Commission Regulation 2019/2020 on establishing eco-design requirements for light sources and separate start-up control devices in accordance with Directive 2019/125/EU of the European Parliament and of the Council and on the repeal of EU Commission Regulations No. 244/2009, 245/ 2009 and 1194/2012 [3]. The peculiarity of this regulation is that, in addition to energy efficiency requirements, a number of new indicators for light quality and functionality of LED light sources have been established. In particular, the declared value of energy consumption should not exceed the maximum allowed power, which is determined as a function of the declared useful luminous flux and colour rendering index; established requirements for the quality of colour rendering and colour uniformity (changes in colour coordinates within the 6-steps or smaller Mac-Adam ellipse); new

requirements have been established for the level of flickering brightness of LED light sources, characterised by the short-term and the level of SVM, etc.

The new Commission Delegated Regulation EU 2019/2015 on the energy labelling of light sources [4] entered into force on 1 March 2021. The most important change in this Regulation of the EU Commission has been the return to the A-G rating scale, which sets the maximum and minimum energy efficiency. The scale is designed in such a way that initially only a small number of products have high energy efficiency in order to introduce more efficient products in the future. At present, more and more LED light sources in accordance with the scale established by the previous regulation of the EU Commission [5] have reached classes A, A+, A++, and it is difficult for consumers to evaluate the difference, for example, between classes A and A++. According to the new scale of the EU Regulation Commission [4], the highest indi-

cators of light sources correspond to class D and there is a large margin for adding more efficient products to this scale in the future.

Given that the requirements for energy efficiency and functionality of LED light sources are constantly increasing, and production technologies are being improved, researching commercial samples of products according to established mandatory requirements is crucial. Additionally, informing consumers about the current technical level of products from various manufacturers is also a pressing concern.

This study involves analysing the requirements for the eco-design of LED light sources, conducting experimental studies on non-directional LED lamps entering Ukraine, complying with EU Commission Regulation 2019/2020, and determining the energy efficiency classes of these lamps in accordance with Commission Delegated Regulation EU 2019/2015.

2. ANALYSIS OF REQUIREMENTS FOR ENERGY EFFICIENCY AND FUNCTIONALITY OF LED LIGHT SOURCES

The EU Commission Regulation 2019/2020 [3] sets eco-design requirements for light sources used for general lighting with a luminous flux of 60–82.000 lm and a luminous flux from the projection area of the light-emitting surface of more than 500 lm/mm². The regulation applies to incandescent lamps, low-and high-pressure discharge lamps, inorganic (LED) and organic (OLED) light-emitting diode lamps and luminaires. The regulation contains requirements for energy efficiency and functionality, as well as requirements for providing information and permissible deviations of product parameters from declared values. In this study, only those issues that concern LED lamps of non-directional radiation are

considered.

The Regulation of the Commission Delegated Regulation EU 2019/2015 [4] establishes requirements for the calculation of energy efficiency classes of light sources based on the overall efficiency of the network η_{TM} , as well as for the provision of additional information about light sources.

In the EU, starting from 1 September 2021, the declared energy consumption value of LED light sources P_{on} should not exceed the maximum allowed power $P_{on max}$ (W), which is determined as a function of the declared useful luminous flux Φ_{use} (lm) and the declared colour rendering index R_a accordingly [3]:

$$P_{on\max} = C \cdot (L + \frac{\Phi_{use}}{F \cdot \eta}) \cdot R_a \quad (1)$$

where C is the basic values of the correction factor (plus allowances to C for special characteristics of light sources). For mains powered non-directional LED light sources (NDLS), the base C value is 1.08, and for mains powered directional light sources (DLS) it is 1.23. Additions to the correction factor C for LED light sources are applied only to sources with an anti-glare screen (+0.2) and sources with the ability to

change the colour of light (+0.1);
 η is luminous efficiency (lm/W). For LED light sources $\eta=120$ lm/W;
L is the coefficient of final losses (W). For LED light sources $L=1.5$ W (Table 1);
F is the efficiency factor. For LED non-directional light sources $F=1.0$, and for directional sources $F=0.85$;
 R_a is the coefficient; it is 0.65 for $R_a \leq 25$ and $(R_a + 80)/160$ for $R_a > 25$.

The requirements for the functionality of LED light sources are given in Table 1.

Table 1. Requirements for the Functionality of LED Light Sources [3]

Colour rendering index (R_a)	$R_a \geq 80$
Displacement factor (DF, $\cos \varphi_1$) at power input P_{on}	No limit at $P_{on} \leq 5$ W, $\cos \varphi_1 \geq 0.5$ at $5 \text{ W} < P_{on} \leq 10$ W, $\cos \varphi_1 \geq 0.7$ at $10 \text{ W} < P_{on} \leq 25$ W, $\cos \varphi_1 \geq 0.9$ at $25 \text{ W} < P_{on}$
Lumen maintenance factor X_{LMF} , %	The luminous flux retention coefficient X_{LMF} % after endurance tests shall be at least X_{LMFmin} %, calculated as follows: $X_{LMFmin} \% = 100 \cdot e^{\frac{(3000 \cdot \ln(0.7))}{L_{70}}}$ where L_{70} is the declared $L_{70} B_{50}$ life time (in hours). If the calculated value for $X_{LMF,MIN}$ exceeds 96.0 %, an $X_{LMF,MIN}$ value of 96.0 % shall be used.
Survival factor (SF)	The light sources must be functional after the test.
Colour consistency for LED and OLED light sources	Variation of chromaticity coordinates within a six-step Mac-Adam ellipse or less.
Flicker for LED and OLED MLS	≤ 1.0 at full-load
SVM for LED and OLED MLS	$SVM \leq 0.4$ at full-load

In this Regulation, displacement factor ($\cos \varphi_1$) means the cosine of the phase angle φ_1 between the first harmonic of the network voltage and the first harmonic of the network current; lumen maintenance factor (X_{LMF}) – the ratio of the luminous flux at a given time of the life cycle of the light source to the initial value of the luminous flux; survival factor (SF) is a defined fraction of the total number of light sources that continue to function for a given time under defined conditions.

The method of testing LED light sources for determining X_{LMF} and SF involves the steps described below.

1. Initial measurement of light flux before switching cycles.
2. Switching cycles: The source must be operated for 1200 complete continuous cycles. One complete switching cycle consists of 150 minutes of turning on the light source at full power, after which the source is turned off for 30 minutes. The total operating time (i.e., 3000 hours) includes only the periods of the switching cycle when the source is on. The total test time is 3600 hours.
3. Measurement of light flux after 1200 switching cycles.

4. For each of the sample units that did not fail, you need to divide the measured final luminous flux by the initial one. Determine the average value of all tested samples that did not fail, and calculate the average value of the luminous flux retention coefficient X_{LMF} % according to the formula given in Table 1.
5. The SF after 1200 switching cycles is determined as the number of functioning light sources to the total number of tested ones.

In order to shorten the test period, accelerated methods for estimating the service life of LED light sources have been recommended for the first time in [3]. The service life for these light sources means the time (in hours) from the start of their use until 50 % of the light sources under test have gradually reduced their luminous flux conservation factor (X_{LMF}) to 70 % of the initial value. It is also called $L_{70}B_{50}$ service life. The service life is estimated based on the experimentally determined X_{LMF} retention coefficient after 1200 switches (3000 hours of lamp burning).

“Colour consistency” means the maximum deviation of the initial spatially averaged chromaticity coordinates (x, y) of a separate light source from the central chromaticity point (cx, cy) declared by the man-

ufacturer, expressed as the size (in steps)) of the Mac-Adam ellipse formed around the central chromaticity point (cx, cy). The size of the Mac-Adam ellipse is determined by the number of standard deviation colour matching (SDCM) units between the centre of the ellipse and its border. The method of determining colour uniformity is established in [6], [7].

The indicator of flicker level used in this Regulation is the parameter " P_{st}^{LM} ", where “st” stands for short-term, and “LM” stands for the flicker measurement method defined in standards establishing measurement methods and requirements for devices for accurate perception of voltage fluctuations. Flicker in the frequency range of 0.05 Hz–80 Hz is assessed by the short-term according to [8]. The interpretation of test results is as follows:

- at $P_{st}^{LM} = 1$, the investigated light source has a flickering level that the observer detects with a probability of 50 %, such as in incandescent lamps with a power of 60 W;
- at $P_{st}^{LM} < 1$, the light source has a flickering level lower than that of incandescent lamps with a power of 60 W;
- at $P_{st}^{LM} > 1$, the level of flickering is higher than that of incandescent lamps and it is easy to detect.

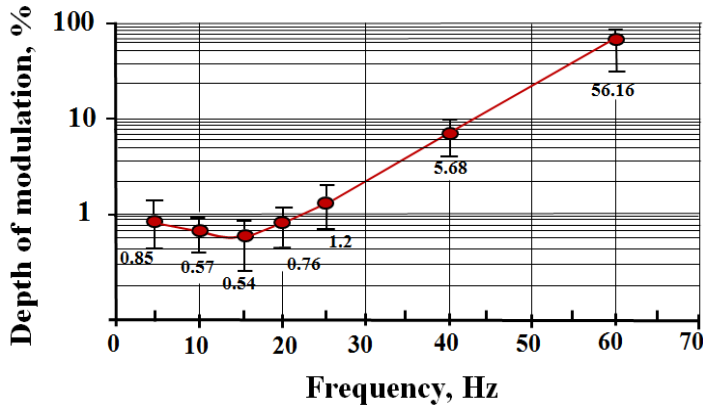


Fig. 1. Threshold values of the depth of brightness modulation at different frequencies [9].

Figure 1 shows the threshold values of the modulation depth depending on the detection frequency with a probability of 50 % [9]. As can be seen from Fig. 1, at a frequency of 15 Hz, an observer can detect a flicker with a relative modulation depth of 0.5 %, while at a frequency of 60 Hz, a modulation depth of almost 60 % is required to detect a flicker.

The resulting modulation values for each frequency are expressed in terms of detection thresholds and denoted as M_{pk} . The perceived modulation corresponding to the threshold value (detected with a probability of 50 %) is taken as one.

At values smaller than one, it is not possible to detect blinking, and at significantly higher values, it is easy to detect. If the blinking in the interval 3–60Hz has different frequencies, then the resulting perception of modulation M_p is determined as:

$$M_p = \sqrt{\sum_k (M_{pk})^2} \quad (2)$$

where $k=1, 2, 3 \dots$

The resulting value of M_p is interpreted in the same way as M_{pk} for individual fre-

quencies: at $M_p=1$, threshold values are detected with a probability of 50 %; at $M_p < 1$, blinks are not visible; at $M_p > 1$, blinking is easy.

As for the estimation of the SVM, the objective method of measuring the indicator of the SVM is proposed in the standard [10]. The conditions for the appearance of the SVM considered in this document are limited to the assessment at illuminances of more than 100 lux and at moderate object velocities (< 4 m/s). SVM does not assess the health effects of flickering and is not a measure to assess unwanted SVM in industry. The method is designed to estimate light flickering at offices, residential premises etc.

Numerical values of SVM can range from 0 to 9. At $SVM = 0$, there is no light modulation of any kind, while at $SVM \approx 9$, rectangular modulation (with infinitesimal pulse duration) is 100 %. SVM is an objective indicator obtained on the basis of laboratory studies and studies on the detection of thresholds for the perception of the SVM by people. The sensitivity to the detection of the SVM at different frequencies is shown in Fig. 2 [10].

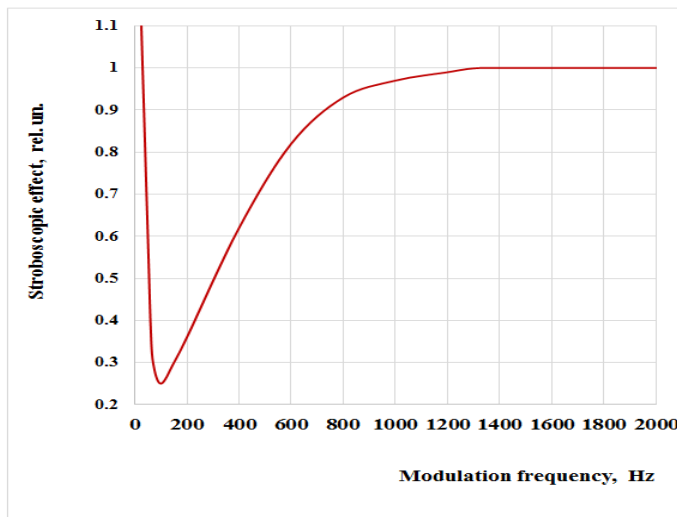


Fig. 2. Dependence of the relative sensitivity of the perception of the SVM on the light modulation frequency [10].

The SVM measurement results can be interpreted as follows:

at SVM =1, the SVM created by light modulation is on the threshold of visibility. This means that the average observer can detect the SVM with a probability of 50 %. If the value of SVM<1, then the detection probability is less than 50 %, and if SVM >1, then the match will be higher than 50 %.

The energy efficiency classes of light sources according to [4] are determined on the basis of the overall network efficiency coefficient η_{TM} , which is calculated by dividing the declared useful luminous

flux Φ_{use} (expressed in lm) by the declared power in full burning mode P_{on} (expressed in W) and multiplied by the F_{TM} coefficient, which takes into account the type of directional and non-directional light sources, as well as types that work in the power network and without it, as follows:

$$\eta_{TM} = \left(\frac{\Phi_{use}}{P_{on}} \right) \cdot F_{TM} \quad (3)$$

The energy efficiency classes of light sources for different network efficiency coefficients η_{TM} are given in Table 2, and F_{TM} coefficients – in Table 3.

Table 2. Energy Efficiency Classes of Light Sources [4]

Energy efficiency class	Total network efficiency η_{TM} , lm/W
A	$210 \leq \eta_{TM}$
B	$185 \leq \eta_{TM} < 210$
C	$160 \leq \eta_{TM} < 185$
D	$135 \leq \eta_{TM} < 160$
E	$110 \leq \eta_{TM} < 135$
F	$85 \leq \eta_{TM} < 110$
G	$\eta_{TM} < 85$

Table 3. F_{TM} Coefficients for Different Types of Light Sources [4]

Light source type	F_{TM}
Non-directional (NDLS) operating on mains (MLS)	1.000
Non-directional (NDLS) not operating on mains (NMLS)	0.926
Directional (DLS) operating on mains (MLS)	1.176
Directional (DLS) not operating on mains (NMLS)	1.089

Energy labelling complements the Ecodesign Directive by providing information on the product energy efficiency. The new energy labeling labels (Fig. 3) have a

QR code, by scanning which consumers can find additional information on the energy-consuming product.

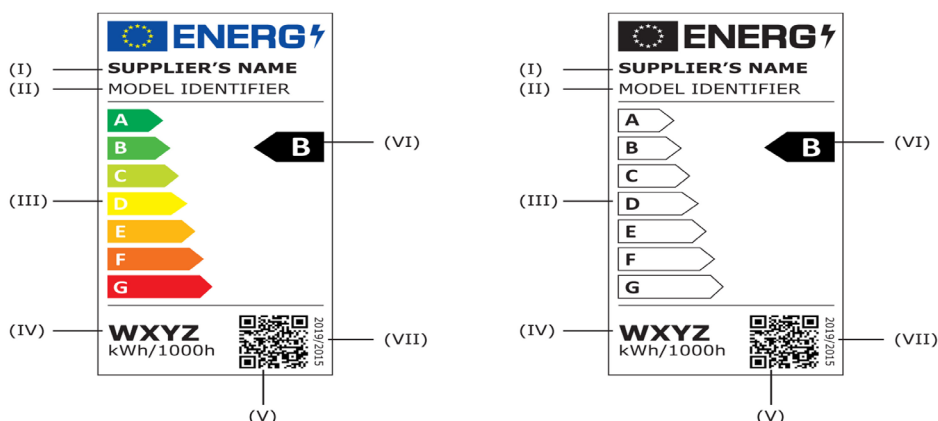


Fig. 3. The general appearance of the label: I – name or trademark of the supplier; II – provider model identifier; III – scale of energy efficiency classes from A to G; IV – energy consumption of the light source in the switched-on mode, expressed in kW of electricity consumption for 1000 hours; V – QR code; VI – energy efficiency class of the source; VII – the number of this regulation is 2019/2015.

In 2019, the European Commission launched a new publicly available database that allows consumers to compare the energy efficiency class of various household products and their other characteristics. The European Register of Energy Product Labelling (EPREL) is breaking new ground by helping EU consumers improve energy efficiency with detailed information on energy-labelled products. Now that the EPREL database is publicly available, consumers have a free online tool that can help them easily find the most energy-efficient lamp models they want to buy and get key information about them in all EU languages.

Energy efficiency and light quality of commercial LED light sources have been studied in many works [13]–[19]. To accelerate the process of saving electricity for lighting, the CALiPER [11] test programme for LED lamps was planned to provide the market with reliable information about the technical level of products. Tests within the framework of this programme showed that already at the first stages of the introduction of LED light sources, most commercial samples demonstrated high energy efficiency indicators, although a significant

part of them (more than 30 %) did not fully correspond to the data declared by the manufacturer. At the end of 2013, the maximum efficiency of the best samples of non-directional LED lamps (categories up to 800 lm) included in the LED Light Facts database [12] was 90 lm/W. In 90 % of such lamps, the total colour rendering index R_a exceeded the value of 80 units, and almost 90 % of the lamps met the new requirements of the ENERGY STAR standard.

The improvement of LED lamp production technology and the introduction of international standards and regulations of the EU Commission regarding eco-design and energy-efficient labelling of light sources contributed to the further rapid increase in energy efficiency and functionality of these lamps. Today, the best commercial samples of non-directional LED lamps have already exceeded the luminous efficiency of 140 lm/W, and the general colour rendering index R_a of almost all manufacturers' lamps exceeds 80 units. The results of the study of energy efficiency and colour parameters are given in [13]–[15], and works [16]–[19] present the results of the study of brightness flickering and the SVM, the photobiological

safety of the light of LED lamps, and the assessment of the compliance of the lamp service life declared by the manufacturer with the test results.

Taking into account that the level of parameters of LED light sources is constantly increasing, the paper presents rel-

evant studies, which relate to LED lamps of non-directional light and the assessment of their compliance with the requirements of the new EU Commission Regulation 2019/2020 on eco-design and the determination of energy efficiency classes according to the EU Commission Regulation 2019/2015.

3. RESEARCH RESULTS

Commercial samples of non-directional LED lamps that were delivered to Ukraine in the period 2021–2023 were studied. The following indicators of LED lamps, regulated by EU Commission Regulations 2019/2020 and 2019/2015, were measured: power consumption, power factor, useful luminous flux, correlated colour temperature, chromaticity coordinates and chromaticity uniformity (change in chromaticity coordinates within 6 SDCM), total color rendering index and special R_g index, short-term flicker index and SVM index.

Based on the measurements and the data declared by the manufacturer, the maximum permissible power was calculated (which was determined as a function of the useful light flux and the declared colour rendering index), the light output and the overall efficiency of the network, the energy

efficiency class according to the EU Commission Regulation 2019/2015. In order to estimate the service life for a batch of LED lamps with a power of 5 W, the luminous flux retention coefficients after testing up to 3000 hours of lamp operation (1200 switching cycles) and SF durability coefficients were determined according to [3]. Measurements of electrical, photometric and colorimetric parameters of LED light sources were carried out in accordance with recommendations [6], [7], [20].

The short-term blinking index and SVM index were determined in accordance with the standards [8], [10]. A spectroradiometer MK350S was used to measure colorimetric parameters and indicators of blinking and SVM [21]. The results of measurements and calculations are shown in Tables 4–6.

Table 4. Results of Measuring Electrical, Light Parameters and Energy Efficiency of Commercial Samples of Non-directional LED Lamps Entering the Market of Ukraine

n/p	Brand, model	Power, W		Maximum permissible power (calculated), P_{onmax} , W	$\cos\varphi_1$, rel.un.		Luminous flux, lm		Luminous efficiency, lm/W		Energy efficiency class	
		declared	measured		declared	measured	declared	measured	declared	measured	declared	measured
1	2	3	4	5	6	7	8	9	10	11	12	13
1	PHILIPS 5W 4000K 470lm 44 mA E14	5	4.74	5.85	0.5	0.56	470	567	94	119.6	F	E
2	PHILIPS 5W 4000K 470lm 44 mA E14	5	4.70	5.85	0.5	0.55	470	559	94	118.9	F	E

n/p	Brand, model	Power, W		Maximum permissible power (calculated), P_{onmax} , W	$\cos\phi_1$, rel.un.		Luminous flux, lm		Luminous efficiency, lm/W		Energy efficiency class	
		declared	measured		declared	measured	declared	measured	declared	measured	declared	measured
3	PHILIPS 5W 4000K 470lm 44 mA E14	5	4.69	5.85	0.5	0.55	470	563	94	120.0	F	E
4	PHILIPS 5W 4000K 470lm 44 mA E14	5	4.73	5.85	0.5	0.56	470	567	94	119.9	F	E
5	PHILIPS 5W 4000K 470lm 44 mA E14	5	4.70	5.85	0.5	0.55	470	563	94	119.8	F	E
6	OPTONICA 6W 6000K 480lm E27	6	6.31	5.94	0.5	0.56	480	654	80	108.3	G	F
7	OPTONICA 6W 6000K 480lm E27	6	6.18	5.94	0.5	0.56	480	618	80	104.0	G	F
8	OPTONICA 6W 6000K 480lm E27	6	6.31	5.94	0.5	0.56	480	654	80	108.3	G	F
9	OPTONICA 6W 6000K 480lm E27	6	6.31	5.94	0.5	0.56	480	658	80	108.8	G	F
10	OPTONICA 6W 6000K 480lm E27	6	6.31	5.94	0.5	0.56	480	658	80	104.7	G	F
11	LightMaster 7W 2700K 540lm 56mA GU10	7	5.95	6.48	---	0.55	540	547	77	91.9	---	F
12	LightMaster 7W 4000K 560lm 56mA GU10	7	5.83	6.66	---	0.55	560	580	80	99.5	---	F
13	ECONOMKA 7W 4200K 580lm 52mA E27	7	6.56	6.84	---	0.58	580	718	83	109.5	---	F
14	ECONOMKA 7W 4200K 580lm 52mA E27	7	6.57	6.84	---	0.58	580	722	83	109.5	---	F
15	ECONOMKA 7W 4200K 580lm 52mA E27	7	6.63	6.84	---	0.57	580	729	83	110.0	---	F
16	NEOMAX NX8B 8W 4000K E27	8	6.13	8.10	---	0.51	720	685	90	111.7	---	E
17	NEOMAX NX8B 8W 4000K E27	8	6.36	8.10	---	0.51	720	697	90	109.6	---	F
18	NEOMAX NX8B 8W 4000K E27	8	6.17	8.10	---	0.51	720	693	90	112.3	---	E

n/p	Brand, model	Power, W		Maximum permissible power (calculated), P_{onmax} , W	$\cos\phi_1$, rel.un.		Luminous flux, lm		Luminous efficiency, lm/W		Energy efficiency class	
		declared	measured		declared	measured	declared	measured	declared	measured	declared	measured
19	NEOMAX NX8B 8W 4000K E27	8	6.34	8.10	---	0.51	720	705	90	111.2	---	E
20	NEOMAX NX8B 8W 4000K E27	8	6.29	8.10	---	0.51	720	697	90	110.8	---	E
21	PHILIPS 9W 3000K 900lm 75 mA E27	9	8.38	9.72	0.5	0.59	900	927	100	110.6	F	F
22	PHILIPS 9W 3000K 900lm 75 mA E27	9	8.76	9.72	0.5	0.60	900	939	100	107.2	F	F
23	PHILIPS 9W 3000K 900lm 75 mA E27	9	8.42	9.72	0.5	0.59	900	892	100	105.5	F	F
24	PHILIPS 9W 3000K 900lm 75 mA E27	9	8.85	9.72	0.5	0.60	900	972	100	104.8	F	F
25	PHILIPS 9W 3000K 900lm 75 mA E27	9	9.03	9.72	0.5	0.60	900	950	100	105.2	F	F
26	MAGNUM BL60 10W 860lm 4100K	10	8.82	9.07	---	0.58	860	797	86	90.4	---	F
27	MAGNUM BL60 10W 860lm 4100K	10	8.70	9.07	---	0.57	860	773	86	88.9	---	F
28	MAGNUM BL60 10W 860lm 4100K	10	8.83	9.07	---	0.57	860	833	86	94.3	---	F
29	MAGNUM BL60 10W 860lm 4100K	10	8.71	9.07	---	0.57	860	781	86	89.7	---	F
30	MAGNUM BL60 10W 860lm 4100K	10	8.74	9.07	---	0.58	860	785	86	89.8	---	F
31	IEK LLE-A60-11-230- 65-E27	11	8.98	10.53	---	0.55	990	1021	90	113.7	---	E
32	IEK LLE-A60-11-230- 65-E27	11	9.22	10.53	---	0.55	990	1047	90	113.6	---	E
33	IEK LLE-A60-11-230- 65-E27	11	9.23	10.53	---	0.55	990	1021	90	110.6	---	E
34	IEK LLE-A60-11-230- 65-E27	11	9.22	10.53	---	0.55	990	1026	90	111.3	---	E

n/p	Brand, model	Power, W		Maximum permissible power (calculated), P_{onmax} , W	$\cos\phi_1$, rel.un.		Luminous flux, lm		Luminous efficiency, lm/W		Energy efficiency class	
		declared	measured		declared	measured	declared	measured	declared	measured	declared	measured
35	IEK LLE-A60-11-230-65-E27	11	9.20	10.53	---	0.55	990	1009	90	109.7	---	F
36	jazzway A60 12W E27 3000K	12	7.98	11.34	---	0.57	1080	741	90	92.9	---	F
37	jazzway A60 12W E27 3000K	12	7.97	11.34	---	0.56	1080	721	90	90.5	---	F
38	jazzway A60 12W E27 3000K	12	7.98	11.34	---	0.57	1080	741	90	92.9	---	F
39	jazzway A60 12W E27 3000K	12	8.25	11.34	---	0.56	1080	757	90	91.8	---	F
40	jazzway A60 12W E27 3000K	12	8.15	11.34	---	0.56	1080	757	90	92.9	---	F

Table 5. Results of Measurement of Colorimetric Parameters and Indicators of Flickering and SVM of Commercial Samples of Non-directional LED Lamps Entering the Market of Ukraine

n/p	Brand, model	CCT, K		Colour coordinates (measured)		SDCM, rel. un.		Colour rendering index R_a , rel.un.		Special colour rendering index R_{sp} , rel.un.	SVM, rel. un.	p_{st}^{LM} , rel. un.
		declared	measured	x	y	declared	measured	declared	measured			
1	2	3	4	5	6	7	8	9	10	11	12	13
1	PHILIPS 5W 4000K 470lm 44 mA E14	4000	4015	0.3805	0.3794	6	0.6	80	84.3	15.7	0.0136	0.1757
2	PHILIPS 5W 4000K 470lm 44 mA E14	4000	3978	0.3813	0.3771	6	2.1	80	84.8	18.3	0.0140	0.1237
3	PHILIPS 5W 4000K 470lm 44 mA E14	4000	4018	0.3799	0.3775	6	1.2	80	84.6	17.1	0.0146	0.3005
4	PHILIPS 5W 4000K 470lm 44 mA E14	4000	4026	0.3796	0.3773	6	1.2	80	84.4	16.6	0.0141	0.1961
5	PHILIPS 5W 4000K 470lm 44 mA E14	4000	3763	0.3918	0.3847	6	6.1	80	84.0	15.0	0.1380	0.1600
6	OPTONICA 6W 6000K 480lm E27	6000	5961	0.3220	0.3451	---	6.3	80	83.4	6.7	0.0060	0.0403
7	OPTONICA 6W 6000K 480lm E27	6000	6133	0.3186	0.3410	---	4.0	80	83.6	7.9	0.0060	0.0697

n/p	Brand, model	CCT, K		Colour coordinates (measured)		SDCM, rel. un.		Colour rendering index R_a , rel.un.		Special colour rendering index R_9 , rel.un.	SVM, rel. un.	p_{st}^{LM} , rel. un.
		declared	measured	x	y	declared	measured	declared	measured			
8	OPTONICA 6W 6000K 480lm E27	6000	5940	0.3225	0.3450	---	6.7	80	82.7	5.6	0.0049	0.0565
9	OPTONICA 6W 6000K 480lm E27	6000	5693	0.3279	0.3512	---	11.5	80	82.6	4.5	0.0045	0.0648
10	OPTONICA 6W 6000K 480lm E27	6000	6030	0.3206	0.3430	---	5.4	80	83.1	6.8	0.0045	0.0649
11	LightMaster 7W 2700K 540lm 56mA GU10	2700	2949	0.4393	0.4028	---	0.4	80	82.8	7.5	0.0216	0.2399
12	LightMaster 7W 4000K 560lm 56mA GU10	4000	4135	0.3745	0.3726	---	2.9	80	84.0	12.4	0.0161	0.0179
13	ECONOMKA 7W 4200K 580lm 52mA E27	4200	3873	0.3889	0.3896	---	4.3	80	82.3	4.1	0.0249	0.3580
14	ECONOMKA 7W 4200K 580lm 52mA E27	4200	3787	0.3908	0.3843	---	5.6	80	83.1	10.0	0.0250	0.2433
15	ECONOMKA 7W 4200K 580lm 52mA E27	4200	3847	0.3889	0.3860	---	4.2	80	83.0	8.6	0.0256	0.1838
16	NEOMAX NX8B 8W 4000K E27	4000	4078	0.3768	0.3738	---	2.4	---	83.4	7.2	0.0087	0.1127
17	NEOMAX NX8B 8W 4000K E27	4000	4069	0.3771	0.3736	---	2.4	---	83.4	7.2	0.0012	0.0804
18	NEOMAX NX8B 8W 4000K E27	4000	4064	0.3774	0.3742	---	2.2	---	83.3	6.8	0.0062	0.1623
19	NEOMAX NX8B 8W 4000K E27	4000	4064	0.3774	0.3742	---	2.2	---	83.2	6.4	0.0013	0.1577
20	NEOMAX NX8B 8W 4000K E27	4000	4025	0.3791	0.3753	---	2.1	---	83.3	6.9	0.0070	0.0751
21	PHILIPS 9W 3000K 900lm 75 mA E27	3000	2937	0.4424	0.4076	6	2.0	80	82.1	5.8	0.0013	0.1183
22	PHILIPS 9W 3000K 900lm 75 mA E27	3000	2977	0.4378	0.4030	6	1.4	80	82.3	5.7	0.0116	0.1024
23	PHILIPS 9W 3000K 900lm 75 mA E27	3000	2895	0.4440	0.4056	6	2.0	80	81.6	2.9	0.0053	0.2003
24	PHILIPS 9W 3000K 900lm 75 mA E27	3000	2929	0.4424	0.4065	6	1.5	80	81.8	4.1	0.0130	0.1963

n/p	Brand, model	CCT, K		Colour coordinates (measured)		SDCM, rel. un.		Colour rendering index R_a , rel.un.		Special colour rendering index R_9 , rel.un.	SVM, rel. un.	p_{st}^{LM} , rel. un.
		declared	measured	x	y	declared	measured	declared	measured			
25	PHILIPS 9W 3000K 900lm 75 mA E27	3000	3002	0.4363	0.4031	6	2.4	80	82.0	4.9	0.0106	0.2205
26	MAGNUM BL60 10W 860lm 4100K	4100	4102	0.3761	0.3742	---	2.3	75	82.5	6.2	0.0402	0.0318
27	MAGNUM BL60 10W 860lm 4100K	4100	4114	0.3760	0.3756	---	2.0	75	82.4	6.0	0.0038	0.0210
28	MAGNUM BL60 10W 860lm 4100K	4100	4067	0.3790	0.3807	---	0.9	75	81.6	2.9	0.0140	0.0324
29	MAGNUM BL60 10W 860lm 4100K	4100	4091	0.3764	0.3139	---	2.3	75	82.8	7.3	0.0055	0.0298
30	MAGNUM BL60 10W 860lm 4100K	4100	4100	0.3764	0.3753	---	1.9	75	82.8	7.1	0.0236	0.0236
31	IEK LLE-A60-11-230- 65-E27	6500	6573	0.3102	0.3373	---	2.8	80	84.0	10.2	0.0156	0.0602
32	IEK LLE-A60-11-230- 65-E27	6500	6707	0.3081	0.3343	---	3.6	80	84.6	12.5	0.0150	0.0337
33	IEK LLE-A60-11-230- 65-E27	6500	6673	0.3088	0.3343	---	3.1	80	84.7	12.6	0.0121	0.0607
34	IEK LLE-A60-11-230- 65-E27	6500	6926	0.3047	0.3311	---	6.0	80	84.7	13.0	0.0124	0.0623
35	IEK LLE-A60-11-230- 65-E27	6500	6716	0.3081	0.3333	---	3.5	80	85.0	15.0	0.0114	0.0314
36	jazzway A60 12W E27 3000K	3000	2962	0.4399	0.4054	---	1.3	80	80.7	-1.1	0.2046	0.0840
37	jazzway A60 12W E27 3000K	3000	2986	0.4378	0.4042	---	1.8	80	80.4	-2.0	0.2836	0.0789
38	jazzway A60 12W E27 3000K	3000	2961	0.4409	0.4074	---	2.0	80	80.5	-2.1	0.2179	0.0852
39	jazzway A60 12W E27 3000K	3000	2959	0.4414	0.4081	---	2.3	80	80.2	-3.2	0.2242	0.0807
40	jazzway A60 12W E27 3000K	3000	2951	0.4405	0.4054	---	1.1	80	80.5	-1.6	0.2465	0.0835

To evaluate the service life of LED lamps, a batch of lamps with a power of 5 W was tested in accordance with the methodology provided in [3]. The average values of the results of measuring the luminous flux after zero hours and after 3000 hours of

operation, the coefficient of preservation of the luminous flux are determined by measurements, and also calculated on the basis of the service life of the lamps declared by the manufacturers (see Table 6).

Table 6. Results of Measurement and Calculation (Based on the Declared Service Life) of the Coefficient of Preservation of the Luminous Flux X_{LMF} for a Batch of Lamps with a Power of 5 W.

The average value of the luminous flux, lm		The coefficient of preservation of the luminous flux X_{LMF} , rel.un.		SF, rel.un.	Service life of L_{70} , declared by the manufacturer, hours
Initial, Φ_0	After test, Φ_{3000}	Determined by measurement	Calculated on the basis of L_{70} declared by the manufacturer according to [3]		
560	530	0.946	0.931	1.0	15000

If the calculated value of the luminous flux conservation coefficient is the same as that determined experimentally or less, then there are reasons to assert that the average service life of the lamps declared by the manufacturer is real. If the calculated value exceeds the value of the coefficient of preservation of the luminous flux determined experimentally, then the declared service life of the lamps is overestimated. In our case, the stated term for lamps with a power of 5 W is real and it can be expected that it will be even higher than the declared value. The coefficient of durability at 3000 hours of lamp operation is 1.0 (there were no lamp failures).

As can be seen from the results obtained for all the investigated batches, the power of the lamps determined by measurements does not exceed the maximum allowed power $P_{on\ max}$ (for the declared luminous flux and colour rendering index). The measured luminous fluxes (for all batches except 12 W lamps) are with tolerances of $\pm 10\%$, not lower than the declared values. The luminous efficiency is in the range of approximately 90–120 lm/W, which corresponds to the energy efficiency classes according to the rating scale of the EU Commission Reg-

ulation 2019/2015 F and E. Over the past 10 years, the luminous efficiency of non-directional LED lamps has increased by more than 30 %. Quality indicators of light have also been improved, in particular the quality of colour rendering and colour uniformity. The total colour rendering index R_a in all the studied batches exceeds 80 units, the colour unevenness in only one batch (6 W) exceeds Mac-Adam's 6-steps ellipse ($SDCM > 6$), and in five of the eight batches it does not exceed 3-steps. All batches of lamps meet the requirements for the level of flickering (< 1) and the level of visibility of the stroboscopic effect ($SVM < 0.4$).

Among the tested lamps, the highest indicators are those of the PHILIPS trade mark.

As for inconsistencies, 11 and 12 W lamps have an understated $\cos\phi_1$ ($\cos\phi_1 < 0.7$), the luminous flux of 12 W lamps is lower than the declared one, and 6 W lamps do not meet the level of colour unevenness. It is also necessary to note the rather low level of the special index R_9 (red colour) in almost the majority of the studied lamps and the lack of declared information about the lamps in a number of manufacturers of batches (energy efficiency classes declared

on the A⁺⁺⁺ – G scale are not included in Table 4).

Despite the mentioned shortcom-

ings, significant progress in improving the parameters of LED lamps over the past decade should be noted.

4. CONCLUSIONS

1. The policy of eco-design and energy-efficient labelling is an important mechanism for increasing the energy efficiency, safety and quality of LED light sources.
2. The EU Commission Regulation 2019/2020 for the first time has established requirements for the maximum power as a function of the declared useful luminous flux and colour rendering index, introduced mandatory requirements for the level of light flickering and the indicator of the SVM, colour uniformity (within 6-steps or smaller ellipses Mac-Adam), as well as estimated the service life based on the measurement and calculation of the luminous flux retention coefficient after 3000 hours of lamp operation.
3. EU Commission Regulation 2019/2015 returned the energy efficiency rating scale A–G instead of A⁺⁺⁺ – G and established a new method of calculating energy efficiency classes. The European register of energy labelling of EPREL products was created.
4. Studies were conducted on LED lamps entering Ukraine for compliance with the requirements of the EU Commission Regulations 2019/2020 and 2019/2015, which entered into force in the EU in 2021. It has been established that most of the parameters of LED lamps meet the requirements of the new regulations of the EU Commission.
5. The following negative aspects were noted:
 - manufacturers of LED lamps do not fully declare the parameters of their products, as required by the regulations;
 - the colour coordinates of the lamps of individual manufacturers go beyond the 6-steps of the Mac-Adam ellipse (SDCM > 6);
 - the power factor of 11W and 12W lamps does not meet the requirements of the Ecodesign Regulation;
 - most of the tested lamps have a low special index R_g .
6. Thanks to the implementation of the requirements of the regulations on eco-design and energy labelling, over the last decade, a significant increase in energy efficiency and quality of LED lamps of non-directional light has been obtained.

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