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Evaluation of the durability of selected LED lamps

Małgorzata Zalesińska[1], Julita Zabłocka[1], Andrzej Pawlak[2]✉

[1] Poznan University of Technology, Division of Lighting and Electro Heating Engineering
e-mail: Malgorzata.Zalesinska@put.poznan.pl; julita_zablo@op.pl
[2] Central Institute for Labour Protection – National Research Institute
e-mail: anpaw@ciop.pl
✉ corresponding author

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Abstract

Luminous flux reduction during operation affects the operating lifetimes of LED lamps. Due to the very long lifetimes of LED sources, i.e. tens of thousands of hours, the lifetime declared by the manufacturer is most often determined by forecasting the luminous flux reduction. Lifetime forecasting is performed based on measuring the operating luminous flux reduction within a time frame of at least 6000 hours, every 1000 hours, followed by extrapolating the obtained results with a relevant exponential curve. This article presents the results of measurements of luminous flux changes taking place between 0 and 10,000 operating hours of several LED light sources. The obtained results were analyzed, and the lifetimes of the examined lamps were evaluated.

Introduction

LED lamps are popular light sources that illuminate workplaces both indoors and outdoors. Apart from good photometric and colorimetric parameters, their operating parameters, such as lifetime or their ability to maintain luminous flux during operation, are also very good. Thanks to the dynamic growth of LED technology and the rapid development of new designs, better photometric, colorimetric, and useful parameters have been achieved. Additionally, the lifetimes of LED lamps greatly surpass those of previous light sources. Still, the very long lifetimes and the constantly changing design solutions create major problems for the ongoing control of useful parameters of products available in the market. Additionally, examining operating parameters is very time-consuming and labor-intensive. Consequently, controlling LED lamps' parameters pursuant to EU regulations (No. 1194/2012; 874/2012; 244/2009) is usually limited to evaluating their initial parameters (Zalesińska, 2012; Tabaka, 2015; Pawlak & Zalesińska, 2017; Szwedek, Zalesińska & Górczewska, 2017). The measurement and evaluation of the lumen maintenance factor for 6000 hours (hrs) of operation for lamps are rarely done (Zalesińska, Zabłocka & Wandachowicz, 2018), not to mention the reduction of the luminous flux for longer periods of operation and verifying the declared lifetimes based on this. Thus, the goal of this study was to determine the decrease in the luminous flux of selected LED lamps during 10,000 hrs of operation and to forecast the long-term lumen maintenance for different percentages of the initial lumen output according to the IES Standard.

The lifetimes of LED lamps

The lifetime of a single LED lamp, L_x, is determined by the time over which the LED lamp delivers at least the declared percentage of its initial luminous flux (PN-EN 62612:2013). Given a certain production scatter, the operating parameters of individual lamps may be different, and their electronic elements may become damaged. Therefore, the rated lifetime and useful lifetime are determined for a population of LED lamps. The rated lifetime is determined by combining the effect of a gradual deterioration in the flux, most often due to the degradation of materials, with the sudden damage of electric elements. This constitutes the time during which the percentage of the population of lamps expressed as "y" has at least the declared percentage of lumen maintenance "x" and a percentage of damage less than or equal to the declared one. These parameters are expressed as L_xF_y, e.g., $L_{70}F_{10}$ (PN-EN 62612:2013). This notation means that, according to a manufacturer's declaration, only 10% of the population will have a luminous flux below 70% of the declared value. The values related to lumen maintenance may be different, although these are typically 70%, 80%, or 90%.

Forecasting the luminous flux drop during lighting

In the case of LED lamps, regardless of whether the lifetime of a single lamp or the rated or useful lifetime of a population of lamps is being determined, it is necessary to determine the magnitude of degradation of the luminous flux. Since measuring operating reductions in the luminous flux of LED lamps is time-consuming, a method was developed to forecast luminous flux reductions to serve as a basis for estimating the lifetimes of LED lamps (IES TM-21-11).

The recommended method may also be used to estimate the reduction in the luminous flux for a specific illumination time (e.g. 25,000 hrs or 50,000 hrs).

The recommended method for projecting lumen maintenance is to use a curve-fit to the collected data to extrapolate the lumen maintenance value to the time point where the luminous flux output decreases to the minimum acceptable level (for example, 70% of the initial luminous flux). That time point is the lumen maintenance life. The same curve-fit of the collected data can also be used to determine the luminous flux output level at given future time points (i.e., 25,000 hrs or 50,000 hrs).

The reduction in the luminous flux during operation can be described by an exponential curve (1) in the publication (IES TM-21-11):

$$\Phi'(t) = B \exp(-\alpha\, t) \tag{1}$$

where:
- t – operating time in hrs,
- $\Phi'(t)$ – the relative value of the luminous flux at time t,
- B – projected initial constant,
- α – decay rate constant.

In order to determine the forecasted lumen maintenance life, measurements should be performed for the first 6000 hrs of operation, every 1000 hrs. If the measurements are performed for longer operating periods (also every 1000 hrs), the lifetime can be estimated using all the results of measurements between the mid-point and the end of the examined duration (IES TM-21-11).

The method of forecasting the lifetime of LED lamps, described in (IES TM-21-11), allows the lifetime to be calculated for the assumed percentage reduction in the luminous flux on the basis of dependence (2):

$$L_p = \frac{\ln\left(100 \cdot \frac{B}{p}\right)}{\alpha} \tag{2}$$

where:
- L_p – lumen maintenance life expressed in hrs,
- p – the percentage of the initial lumen output.

The projected lumen maintenance life shall be expressed using the following notation:

$$L_p\ (Dk) \tag{3}$$

where:
- D – is the total duration of the test in hrs, divided by 1000 and rounded to the nearest integer. For example, L_{70}(6k) represents 6000 hrs of test data.

The purpose of measurements and a description of the examination subject

In order to evaluate the real reduction in the luminous flux during 10,000 hrs of lamp operation and to estimate the luminous flux according to the procedure described in (IES TM-21-11), examinations were conducted on several generally available non-directional LED lamps for household use meant to serve as replacements for traditional 60 W bulbs.

Six LED lamps made by various manufacturers were selected for examination. All lamps, as declared by their manufacturers, had luminous fluxes of 806 lm. Figure 1 presents the examined light sources.

Figure 1. The examined LED lamps

The basic information presented on the packaging of the products are presented in Table 1, and the results of measuring the initial parameters of the examined LED lamps are described in a previous publication (Zabłocka, Zalesińska & Górczewska, 2017).

Table 1. The basic information presented on the packaging of the products

Parameters	No. of lamp					
	1	2	3	4	5	6
U [V]	220–240					
P [W]	9	10	10	7.5	7	12
Φ [lm]	806	806	806	806	806	806
CCT [K]	3000	3000	2700	2700	2700	2700
CRI [–]	–	–	80	> 80	> 80	> 80
τ [h]	25,000	15,000	15,000	15,000	10,000	25,000
Energy efficiency class [–]	A	A+	A+	A+	A++	A

Measured luminous flux reduction during illumination

Measurement procedure

The measurement of the luminous flux was conducted on a measuring station consisting of an Ulbricht sphere, a POWER PCR 2000M stabilized power supply unit by Kikusui, a NORMA 4000 power analyser by Fluke, a photo-electric current measuring machine based on a lux meter PHOTOMETR B510 by LMT, with a cell corrected to $V(\lambda)$, and a PC with an interface and software. The measuring station was calibrated using a collective luminous flux standard.

A diagram of the measuring station is shown in Figure 2, and Figure 3 shows the measuring station.

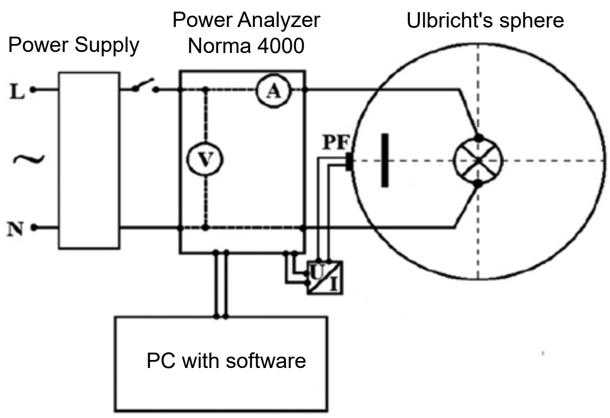

Figure 2. The diagram of the measuring station for measuring the luminous flux

Figure 3. The measuring station for measuring the luminous flux

The first stage of examination involved measuring the initial parameters and the operating luminous flux reduction for up to 3000 hrs of operation, in 1000-hr intervals (Zabłocka, Zalesińska & Górczewska, 2017). Subsequently, measurements were made from 4000 to 10,000 hrs of operation, also in 1000-hr intervals (Zabłocka et al., 2018). Each time, the luminous flux was recorded in the stabilized working conditions of the lamps.

The results of measurements

The measured reductions in the luminous flux of the examined lamps between 0 and 10,000 hrs are presented in Table 2. The relative changes in the luminous flux relative to the initial value are shown in Table 3.

Table 2. The results of measurements of the luminous flux of the examined lamps when illuminated

Working time in [h]	No. of lamp					
	1	2	3	4	5	6
	$\Phi(t)$ [lm]					
0	927	830	797	819	736	889
1000	906	651	758	776	655	884
2000	891	611	742	740	608	874
3000	889	608	753	721	589	885
4000	874	597	732	667	552	872
5000	874	594	731	641	551	872
6000	872	594	731	607	551	870
7000	868	–*	–*	576	548	869
8000	864	–	–	508	539	869
9000	859	–	–	346	537	867
10,000	850	–	–	300	525	864

* the source of light burned out before reaching 7000 hrs of operation.

The measurements showed that lamps No. 6 and 1 had very high luminous flux stabilities. The sources exhibited a luminous flux reduction between 3% and 7% during 10,000 hrs of operation. The analysis of the obtained results also showed that in the case of 3 light sources (lamps No. 2, 4, and 5) the luminous flux reduction was significant, and after 6000 hrs exceeded the permissible values for LED lamps as specified in the EU regulation (874/2012) (≥ 80%). Two of the examined sources of light (No. 2 and 3) burned out after 6000 hrs of operation, thus failing to reach even half of their declared lifetimes.

Table 3. The relative changes in the luminous flux of the examined lamps when illuminated

Working time in [h]	No. of lamp					
	1	2	3	4	5	6
	$\Phi(t)$ / $\Phi(t = 0)$ [lm]					
0	1.000	1.000	1.000	1.000	1.000	1.000
1000	0.977	0.784	0.951	0.947	0.890	0.994
2000	0.961	0.736	0.931	0.904	0.826	0.983
3000	0.959	0.733	0.945	0.880	0.800	0.996
4000	0.943	0.719	0.918	0.814	0.750	0.981
5000	0.943	0.716	0.917	0.783	0.749	0.981
6000	0.941	0.716	0.917	0.741	0.749	0.979
7000	0.936	–	–	0.703	0.745	0.978
8000	0.932	–	–	0.620	0.732	0.978
9000	0.927	–	–	0.422	0.730	0.975
10,000	0.917	–	–	0.366	0.713	0.972

Projecting long-term lumen maintenance lifetimes of LED lamps

The least-squares regression described in the IES Standard (IES TM-21-11) was used to forecast decreases in the luminous flux. This method has become a standard method of working within the lighting industry and is generally used by manufacturers to determine certain parameters of their products. The measured reduction in the luminous flux during 6000 hrs of operation was used to calculate the forecasted lifetime to 70%, 80%, and 90% of the initial luminous flux value. Table 4 presents the results of these calculations. Figure 4 shows the course of the forecasted curves of the luminous flux reduction up to 25,000 working hrs, along with the actual results of measurements.

The forecasted lifetimes were determined for all six examined lamps, despite the fact that two LED lamps (No. 2 and 3) burned out after 6000 hrs. For lamp No. 2, it was impossible to determine the lifetime for the assumed luminous flux reduction to 80% and 90% of the initial value and 90% for lamp No. 5. This was caused by a very significant decrease in the luminous flux at the beginning of its operation. During the first 1000 hrs of operation, the luminous flux of lamp No. 2 decreased by over 21% and by 11% for lamp No. 5. In the remaining cases, the forecasted lifetimes were determined for all three luminous flux reductions most commonly used in practice (70%, 80%, and 90%).

The examined lamps could be divided into two groups based on measurements and calculations. The first group contained lamps with low luminous flux reductions during their operation (No. 1, 3, and 6) and thus a high lifetime. For lamps No. 1 and 3, L_{70}(6k) exceeded 40,000 hrs and even 12,000 hrs for lamp No. 6. However, despite such a good prognosis, lamp No. 3 burned out after only 6000 hrs. Due to the relatively low reduction in the luminous flux after 6000 hrs of operation, this lamp may be placed in a group of good-quality lamps. The second group contains lamps that exhibited significantly reduced luminous fluxes during the first 6000 hrs of operation. In each case, the reduction exceeded 20%, and the lamps failed to satisfy the requirements of the Commission Regulation of EU (1194/2012) with regards to the required lumen maintenance factor after 6000 hrs of operation (≥ 80%). Based on such a significant luminous flux reduction, the forecasted values were much lower than for the other lamps. Nevertheless, lamp No. 2 shows that forecasting the lifetime based on the first 6000 hrs of operation is

Table 4. Results of projecting long-term lumen maintenance lifetimes for different percentages of initial lumen output

Parameter	Lamp No.					
	1	2	3	4	5	6
	The value of the calculated parameter					
α	7.465E-06	1.587E-05	7.328E-06	4.959E-05	3.487E-05	2.780E-06
B	0.9792	0.7755	0.9539	1.0013	0.8952	0.9953
Calculated L_{70}(6k) [h]	44,960	6456	42,231	7220	7053	126,583
Calculated L_{80}(6k) [h]	27,072	–	24,008	4527	3224	78,556
Calculated L_{90}(6k) [h]	11,293	–	7935	2151	–	36,194

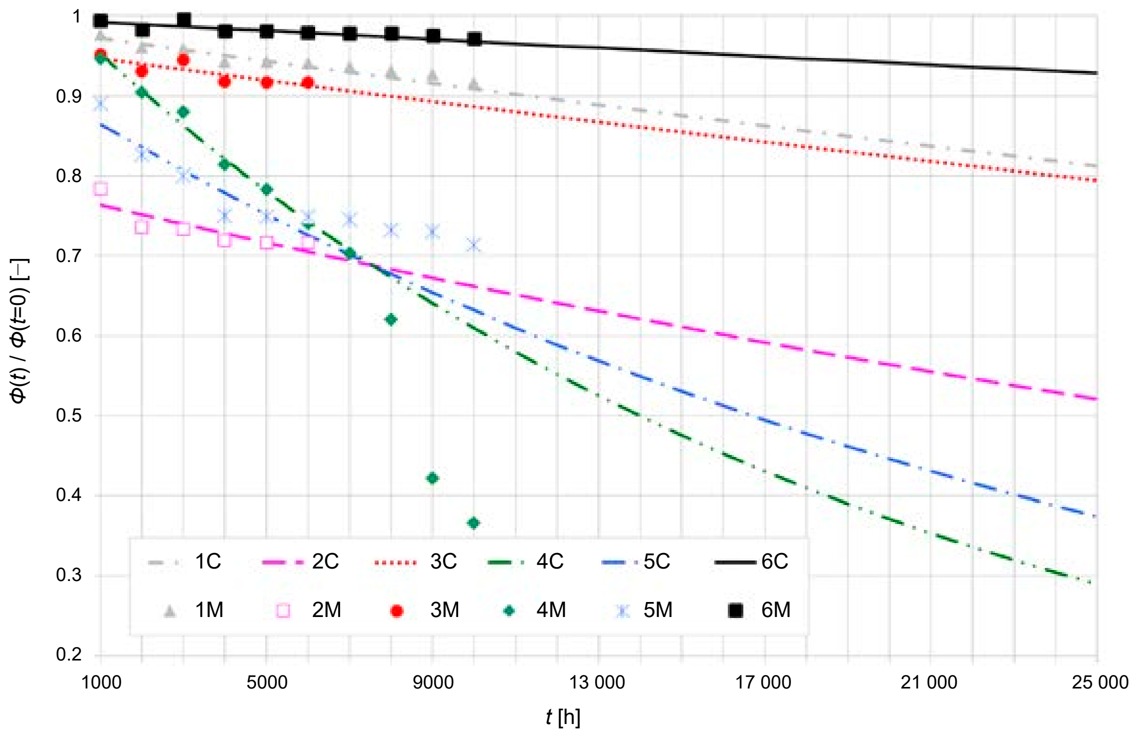

Figure 4. The results of measurements and the curves extrapolated for the obtained results. The letter "C" used in the key indicates the calculations, while "M" refers to the measurements

not always accurate. The measurements for subsequent operating times show that reductions in the luminous flux were much lower than expected from the forecasted values based on 6000 hrs of operation (Figure 4).

Based on the calculations, it is difficult to compare the calculated lifetimes with the manufacturers' declarations because the measurements were only made for single lamps, and none of the manufacturers declared luminous flux reductions for which they also provided lifetime values. Still, the performed measurements and calculations made using dependence (2), allow the luminous flux reduction to be estimated for a lifetime declared by a manufacturer. Such an estimation was done based on the first 6000 hrs of operation. Thus, high consistency can only be expected for lamps No. 1 and 6 for which the results of subsequent measurements coincided with the extrapolation. In the case of lamp No. 2, a lower luminous flux drop should be expected, and in the case of lamp No. 4, a much higher one. For lamps No. 2 and 3 which burned out after 7000 hrs, verification of the estimated values will be impossible in the future. Table 4 presents the results of these calculations.

Table 4. Estimating the luminous flux reduction for the lamps' declared lifetime

Lamp No.	1	2	3	4	5	6
Life declared [h]	25,000	15,000	15,000	15,000	10,000	25,000
Estimated decrease in luminous flux [%]	0.81	0.61	0.85	0.48	0.63	0.93

Conclusions

Measurements of reductions in the luminous flux were only performed on individual lamps and cannot be generalized to an entire population of lamps. Still, the measurements proved that it is necessary to perform ongoing control of the product in the market and especially to examine them after 6000 hrs to fully assess decreases in the luminous flux of LED lamps. As shown in the examination, despite the fact that all lamps satisfied the criterion of the minimal initial value of the luminous flux, only half had a lumen maintenance factor that was higher than that required by EU regulations (No. 1194/2012). The conducted examination also made it possible to calculate the expected lifetime of the lamps based on the initial 6000 hrs of operation and to evaluate the procedure described in publication (IES TM-21-11). Following the analysis of the measurements, we may conclude that limiting the minimum measurement duration to 6000 hrs (IES TM-21-11) to estimate the lamps' lifetime may be insufficient in many cases. To confirm this thesis, the authors must continue the examination and verify the next lifetime of lamps.

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