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Initial Investigation into the Energy and Operational Parameters of LED Modules

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***Abstract*—The paper presents an initial investigation into the energy and operational parameters of three LED modules produced by a little-known producer. The paper considers the requirements of Standards TM-21-11 and LM-80-08 applicable in measuring lumen maintenance life, as well as the requirements for temperature in measuring illuminance. The investigation introduces the structural schemes for measuring the efficiency coefficient of the AC/DC converter of LED modules and provides the obtained measurement results. The performed measurements show that the efficiency coefficients of the AC/DC converters of the examined LED modules amount to 52 %±3.5 %. According to the experimental results obtained after measuring illuminance, the established average lumen maintenance life L_{70} is 2,817 hours.**

***Index Terms*—AC-DC powers converters; data collection; least squares approximation; light emitting diodes; photo thermal effects.**

I. INTRODUCTION

LEDs are known for considerable advantages over traditional incandescent lamps. In comparing LED module parameters with incandescent or fluorescent elements of illuminance, LEDs are distinct for their ecology and low exploitation price [1], [2]. The success of LEDs in the illuminance market has also been determined by the broad spectrum of emitted light. LEDs are known for high efficiency – approximately 15 %–35 % of electrical energy in a diode is converted into light, and 65 %–85 % of energy is dissipated as heat energy. In high power illuminance modules, this can result in heat flow distribution of approximately 300 W/cm^2 [3], [4], which, in its turn, leads to reduced electricity costs. The maintenance life of LEDs (up to 100,000 hours), as indicated by producers, can in ten times exceed the maintenance life of incandescent lamps [4]. Therefore, LEDs have become more acceptable both in economic and environmental protection (ecological) terms.

Due to the indicated advantages, LEDs are being chosen by an increasing number of producers and consumers. Their demand in the market is continuously growing and increasing competence among their producers. Seeking larger economic benefits, not all producers are fair in indicating true parameters of their products. The parameters of the offered products, if they could be objectively assessed in accordance with the established standards and recommendations, could allow a supplier not only to choose reasonably, but also to avoid consumer dissatisfaction and the related losses due to poor-quality products. On the other hand, investigation methods applied to LEDs are relatively new, and they differ from methods applied to conventional lightning sources (incandescent, fluorescent, high intensity discharge lamps, etc.). In order to obtain reliable data, it is important to clarify the differences existing in the standards and recommendations that are specifically applicable to the testing of LEDs [5]–[7], as well as to follow the established guidelines.

The purpose of this investigation is, thus, to define the requirements deriving from the standards applicable to the testing of LEDs, and to carry out initial measurements of the main parameters of the chosen three LED modules.

II. REQUIREMENTS OF APPLICABLE STANDARDS

One of the most important parameters of LEDs is nominal life, which can be determined by measuring decrease in illuminance during a certain period of maintenance. Standard TM-21-11 provides that the lumen maintenance life of LEDs used for main indoor lightning must be such during which illuminance is over 70 % of the initial value (L_{70}). In cases of accent and decorative lighting, illuminance can decrease to 50 % (L_{50}). Due to the long life-span of LEDs, the minimum 6,000-hour testing time-span recommended by Standard LM-80-08 makes it virtually impossible to determine lumen maintenance life (L_{70}). Therefore, the common practice to determine L_{70} or L_{50} values is to obtain approximate data for illuminance degradation during 6,000 hours. For the approximation of experimental data, the least squares method is applied [8]

$$\Phi(t) = B \times e^{-\alpha \times t}, \tag{1}$$

where t is operating time in hours; $\Phi(t)$ – averaged normalized luminous flux output at time t, B – projected initial constant derived by the least squares curve-fit; and α – decay rate constant derived by the least squares curve-fit.

Accordingly, lumen maintenance life can be determined as follows [5]

$$L_{70}(Dk) = \frac{\ln\left(\frac{B}{0,7}\right)}{\alpha}, \tag{2}$$

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where L_p is lumen maintenance life expressed in hours, where p is the percentage of initial lumen output that is maintained, and Dk – total duration time divided by 1,000 and rounded to the nearest integer.

Standard LM-80-08 recommends that illuminance testing be carried out at three temperatures of LED p-n junction – 55 °C, 85 °C and the temperature indicated by the producer.

The temperature of a LED module will have an impact on direct voltage drop on the LED, illuminance intensity, the emitted light spectrum and the optical efficiency coefficient [9]. The findings show the reverse dependency between junction temperature and luminous efficacy [10], [11]. Therefore, it is important to examine whether the LED module is operating in optimal thermal conditions and whether appropriate cooling is ensured therein. Standard LM-79-08 recommends that the environmental temperature at a 1-meter distance from the tested module be 25 °C±10 °C.

III. EXPERIMENTAL SETUP AND RESULTS

The present investigation comprised the testing of the electrical parameters of three LED modules produced by a not widely known producer, as well as the examination of illuminance and temperature during the time-span of 2,500 hours. The number of nine LEDs (three modules each containing three LEDs) met the minimum requirements set by Standard TM-80-08. The illuminance and temperature measurements were carried out every second day during the whole maintenance period.

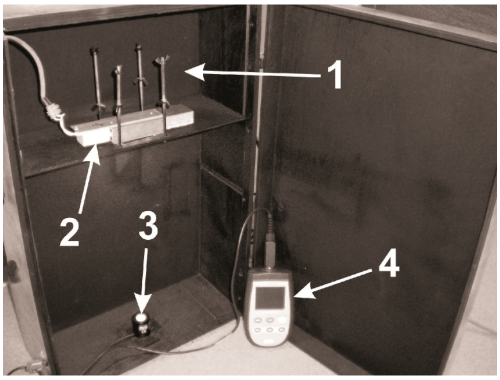

Fig. 1. Experimental setup: 1 – darkened camera; 2 - LED module; 3 – photo probe LP471; 4 - photo radiometer HD 2302.0.

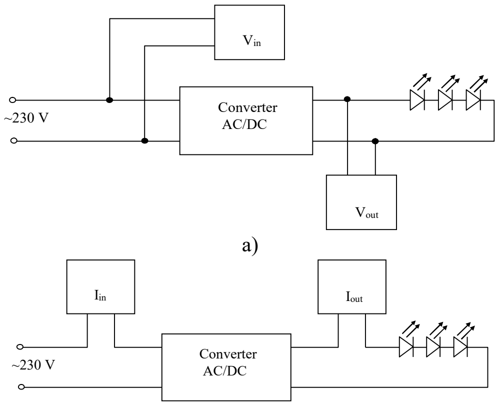

Fig. 2. Structural measurement scheme of the electrical parameters of the LED module: voltage measurement (a); current measurement (b).

As required by Standard LM-79-08, the examination was performed by using a thermally and optically isolated environment – a darkened camera (Fig. 1). The inside of the camera, painted in dark colour, was mechanically equipped at its upper part with a tested LED module, while a photo probe LP471 of a photo radiometer HD 2302.0 was installed at the bottom of the camera. For the temperature measurements of the LED modules, an infrared camera Mikroshot B was used. The electrical parameters and characteristics of the AC//DC converter of the LED modules were obtained in accordance with the requirements of Standard LM-79-08. Currents and voltages were measured by a true-value RMS millivoltmeter CMM-40. The structural scheme of measurements is provided in Fig. 2.

Table I shows the comparative data on the electrical parameters of the converters as these parameters are indicated by the producer and as determined during the measurements. The efficiency coefficient of the AC/DC converter of the LED modules is calculated as follows

$$\eta = \frac{V_{out} \times I_{out}}{V_{in} \times I_{in}} \times 100\ \%, \tag{3}$$

where V_{out} and V_{in} – respectively, voltage at the converter output and input; I_{out} and I_{in} – respectively, current at the converter output and input.

TABLE I. ELECTRICAL PARAMETERS AS INDICATED BY THE PRODUCER AND AS OBTAINED DURING MEASUREMENTS.

Parameters		**Module No.**			**Measu-rement tool error**	**Measu-rement results error**
		1	2	3		
Input voltage, (RMS,V)	measured	217	217	217	1	1.98
	indicated	110-240			-	-
Input current, (RMS, mA)	measured	24.5	24.1	25.09	1.5	2.57
Output current, (RMS, mA)	measured	310	310	317	1	1.3
	indicated	350				
Output voltage, (RMS, V)	measured	8.9	8.95	9	0.06	0.31
	indicated	12			-	-
Efficiency coefficient, (%)	measured	52±3.5	53±3.5	52±3.5	-	-

The confidence interval of the efficiency coefficient is found through logarithm of (3)

$$\ln \eta = \ln V_{out} + \ln I_{out} - \ln V_{in} - \ln I_{in}. \tag{4}$$

After differentiating (4), the following is obtained

$$\frac{\Delta \eta}{\eta} = \frac{\Delta V_{out}}{V_{out}} + \frac{\Delta I_{out}}{I_{out}} - \frac{\Delta V_{in}}{V_{in}} - \frac{\Delta I_{in}}{I_{in}}. \tag{5}$$

Then, the uncertainty of the efficiency coefficient is determined as follows

$$\delta_\eta = \sqrt{\left(\frac{\Delta V_{out}}{V_{out}}\right)^2 + \left(\frac{\Delta I_{out}}{I_{out}}\right)^2 + \left(\frac{\Delta V_{in}}{V_{in}}\right)^2 + \left(\frac{\Delta I_{in}}{I_{in}}\right)^2} = \\ = 3.5\ \%. \tag{6}$$

It was noticed that the 2nd module current through the LED diodes grows as operation time increases. Figure 3 shows the dependency of the 2nd module current on time.

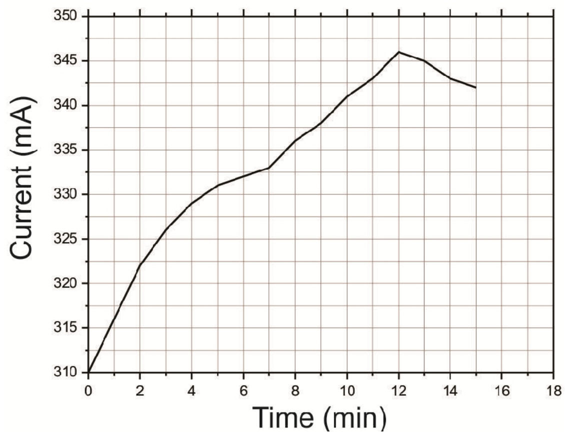

Fig. 3. Dependency of the current through the LED on operation time.

The chart shows that the current initially grows but, in 12–14 minutes, comes to the steady regime.

In examining the dependency of the efficiency coefficient on operating time, it was established that, with growing operation time, the changes of the efficiency coefficient are analogous to the observed dependency of the module current (Fig. 4).

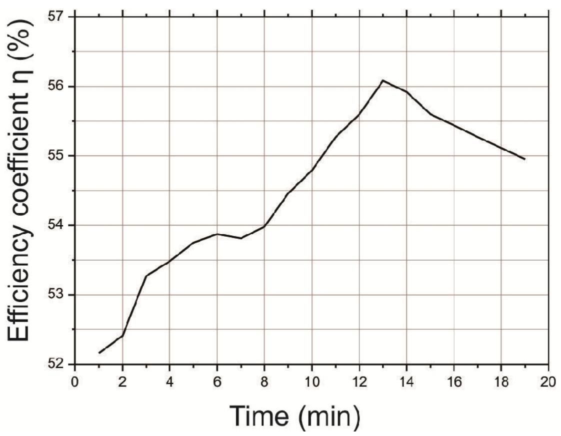

Fig. 4. Dependency of the efficiency coefficient on operation time.

The change in the network current was measured as the operation time was changing. In this case, it was established that stabilization time is reached in 6 minutes when the current obtains the stable value of 25.3 mA.

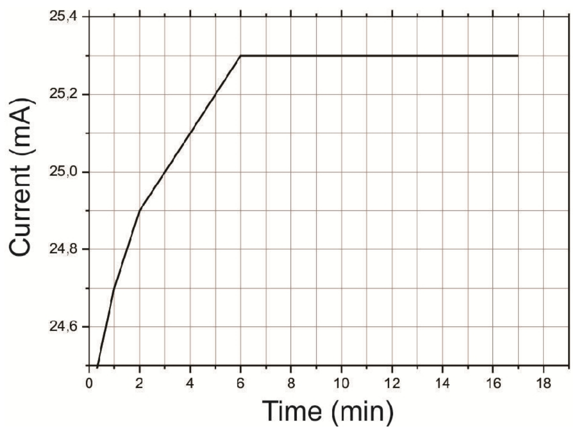

Fig. 5. Dependency of network current on operation time.

The illuminance examination results are provided in Fig. 6, Fig. 7 and Fig. 8. The measurement results were approximated according to (1). According to (2), the curve parts exceeding the duration of the investigation (the curve parts continuing after a break) were extrapolated.

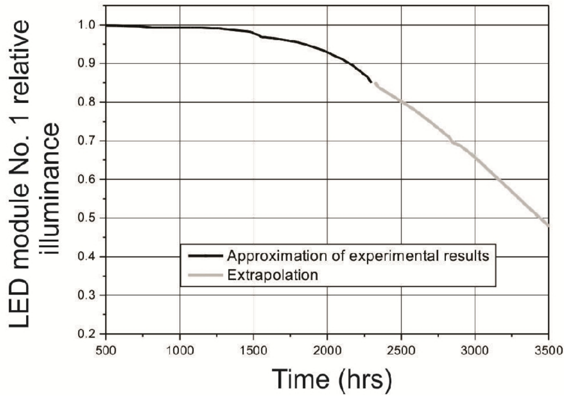

Fig. 6. Illuminance change in time in LED module No. 1.

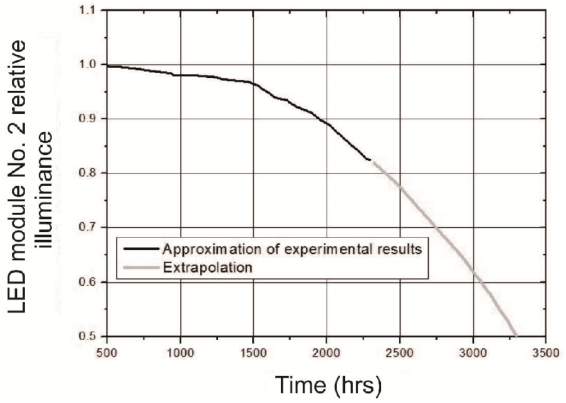

Fig. 7. Illuminance change in time in LED module No. 2.

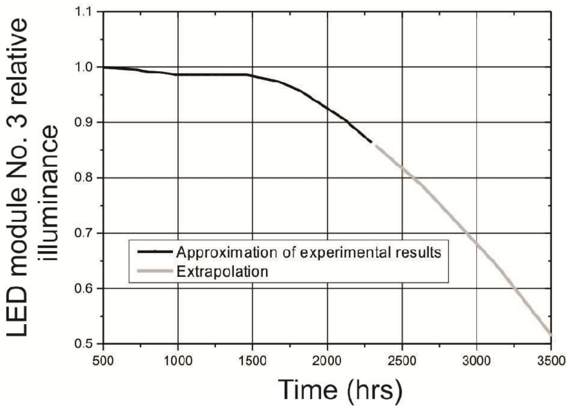

Fig. 8. Illuminance change in time in LED module No. 3.

According to (2), the lumen maintenance lives were estimated to be 2,800, 2,750 and 2,900 hours for LED modules No. 1, No. 2 and No. 3, respectively. As required by Standard LM-21-11, the initial 500 maintenance hours were not included in calculation. Coefficient of determination (R^2) [12] was used to assess the quality of approximations. R^2 were estimated to be 0.8864, 0.9464 and 0.8651 for LED modules No. 1, No. 2 and No. 3, respectively.

Temperature measurements during the initial 500 hours for LED module No. 1 are provided in Fig. 9. The temperatures of the LED diode p-n junction, radiator and the environment at a distance of 1-meter from the LED module were measured.

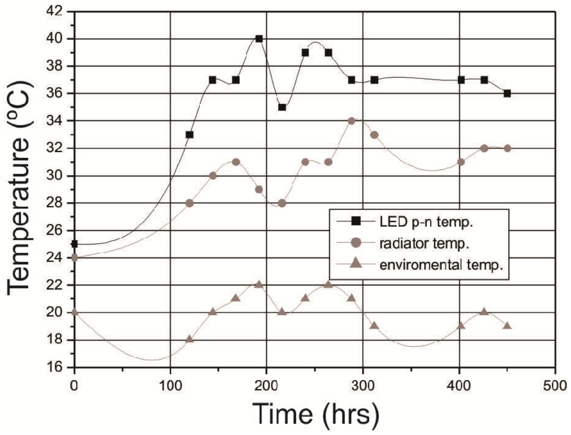

Fig. 9. Temperature changes in time for LED module No. 1.

After the initial 200 hours, the values of temperatures stabilised and only minor fluctuations were observed. Temperature curves of a similar nature were determined for all examined modules. The environmental temperature of 25 °C±10 °C, as required by the standard, was ensured during the measurements.

IV. CONCLUSIONS

The investigation included the performance of initial measurements of the main energy and operational parameters of three LED modules. The measurements of electrical parameters produced a relatively low (52.33 ± 3.5) efficiency coefficient of AC/DC converters. For the majority of converters, the efficiency coefficient amounts to 80 %–85 % [1]. The established dependency of the efficiency coefficient on operation time shows that the efficiency coefficient can still decrease if a LED module is used in the switch mode, i.e. it is repeatedly switched on and off. All this indicates poor energy qualities of the examined modules.

The average lumen maintenance life (L_{70}) is estimated to reach only 2,817 hours.

The temperature measurements demonstrate that the examination was carried out within the environmental temperature limits recommended by the applicable standards. It should be emphasised that the temperature of a LED module is an important factor, which determines degradation in the light emitted by the module and, consequently, the life-span of the module itself. A longer lumen maintenance life can be achieved by improving heat dissipation in LED modules [13]. Without removal of excessive thermal energy, reliability of LEDs can considerably be undermined. The most obvious problem is broken soldered joints, which cause critical module deterioration. Inappropriate thermal protection similarly increases illuminance degradation and leads to spectrum shift. A negative temperature impact is conditioned by increase in thermal electron-hole recombination. During thermal electron-hole recombination light is not emitted and, as the LED temperature grows, illuminance flux decays. Thus, the LED temperature is the main factor that determines degradation in the light emitted by the module and, consequently, has an impact on the life-span of the module itself. Therefore, a fully valid investigation into LED modules must be carried out at three temperatures of LED p-n junction, as recommended by the applicable standard.

In order to obtain statistically reliable results, the measurement of illuminance and temperature must continue not for 2,500, but at least 6,000 hours, as recommended by the standard. Nevertheless, given approximately one-month duration for such an examination, provided it is carried out including three temperatures of LED p-n junction, as recommended by the standard, could be considered as rather long, *i.e.* it could take more than 24 months.

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