



AN EXPERIMENTAL EVALUATION OF PHOTOMETRIC PERFORMANCE AND POWER QUALITY OF LED LAMPS IN DIFFERENT OPERATING CONDITIONS

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ABSTRACT

Due to the global interest of Light Emitting Diode (LED) Technology, LED lamps manufacturers and academic researchers are doing great efforts to study different aspects of LED lamps performance. This paper investigates the photometric and electrical properties of LED lamps. The effect of temperature on the output light emitted from the LED lamps has been studied and a model of LED lamp is simulated and presented in this manuscript. The presented model has been implemented experimentally to investigate the lamp performance. Experimental results show that the effect of aging test on photometric parameters of LED lamp such as luminous flux, correlated color temperature (CCT), color rendering index (Ra). This study enables to understand and well control the features of the visible light emitted from LED lamps. The value of CCT is an important parameter in many applications such as lighting, videography, photography, publishing, horticulture, and manufacturing. It is desirable to achieve a high CRI light in color-critical applications such as neonatal care in hospitals). Experimental results also demonstrate that PF of LED lamp driver decrease when the lamp is operated in high ambient temperature.

Keywords: *LED indoor lighting, Energy saving, Energy efficiency, Photometric characteristics, Aging test, Power quality.*

1. INTRODUCTION

Light Emitting Diode or LED is a P-N junction diode, which emits light when activated. Today, LEDs are commonly used in different applications (lamps, TV's, camera flashes, traffic lights, displays, etc.) [1] [2].

Nowadays, LED lights have become an applicable lighting solution for indoor and outdoor applications [3]. Furthermore, with the technology advancements, all traditional lamps (incandescent bulbs, compact fluorescent lamps (CFLs), high intensity discharge lamps (HIDs), etc.) has been replaced with LEDs [4]. LED lamps consume only about 10% of the energy that

incandescent lamps require [5]. Moreover, mass manufacturing has resulted in a significant drop in production cost of LEDs. LEDs have many advantages such as long lifetime, low power consumption and high efficacy [6].

Lighting purposes represent about 25% of world electricity consumption. Hence, LED lamps contribute to save the Earth's resources [7].

In Egypt, residential, and street lighting sectors consume 50.5%, and 4%, respectively, of Egypt's total electricity consumption [8]. Lighting represents the largest proportion of household electricity consumption, as shown in Fig.1 and Fig.2.

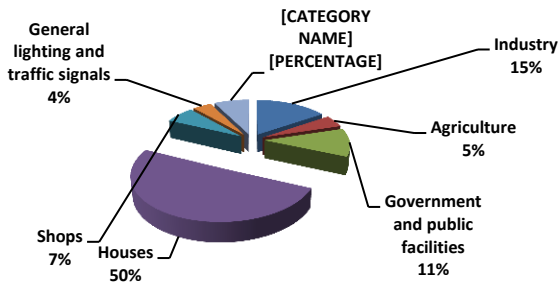


Fig.1. Percentage of electricity consumption in Egypt over different purposes (2016/2017).

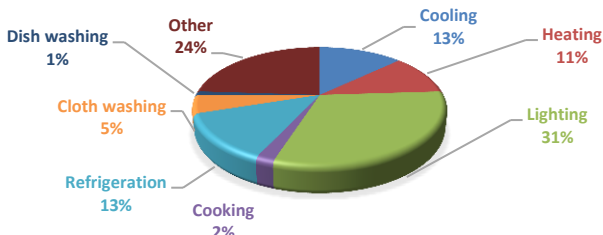


Fig.2. Percentage of electricity consumption in Egypt in residential sector.

There is an interest from countries around the world to use LED lamps. For example, in the first quarter of 2015, Ministry of Electricity and Renewable Energy in Egypt released an international tender to supply 13 million LED lamps with various power (4W, 6W, 9W) to be sold to customers through Electricity Distribution Companies (EDCs) in different governorates of Egypt [9] in order to replace traditional lamps to LEDs.

As LEDs spread and becoming more and more popular, their characteristics getting well understood and considered. Study and investigation of LED performance under different conditions have been focused in many previous researches. However most of these handled the LED lamp as a separate unit: Some of these papers studied LED as P-N junction concept [10-14], and other studied the LED lamp driver itself [15-17]. In this work, it is considered that LED lamp as a compact unit. However, the archival content of LEDs investigations and experimental tests is still limited. In this paper, the aging test is used to evaluate the reliability of LED lamps with

respect to their output light` performance characteristics. The following points are investigated in this paper:

- The relationship between DC LED current and luminous flux emitted from LED.
- The behavior of luminous flux versus time aging of LED lamps.
- The rate of change of correlated color temperature (CCT) with time aging of LED lamps.
- The behavior of color rendering index (Ra) versus time aging of LED lamps.
- Power factor analysis of LED lamps with change of temperature.
- Construction and simulation of a proposed LED model.

This work is organized as follows: Section II presents the theoretical frame work. Section III provides experimental works. Section IV studies the relationship between luminous flux of LEDs and current. Luminous flux versus time is presented in section V. The effect of time on two major parameters: correlated color temperature and color rendering index is discussed in sections VI and VII, respectively. Finally, section VIII investigates the impact of increasing temperature on power factor of LED lamp driver.

2. THEORETICAL FRAMEWORK

2.1. Current versus luminous flux

Luminous flux of LEDs is function of forward current according to the following equation [17]:

$$Lm(I) = 0.0001I^2 + 0.3093I + 3.647 \quad (1)$$

where Lm refers to the luminous flux of LED and I refers to the forward current of LED (Technical Datasheet DS56, Power Light Source Luxeon Rebel, Philips Lumileds Lighting) [17]. This Equation can be drawn as in Fig.3; which shows light output versus current of a similar LED.

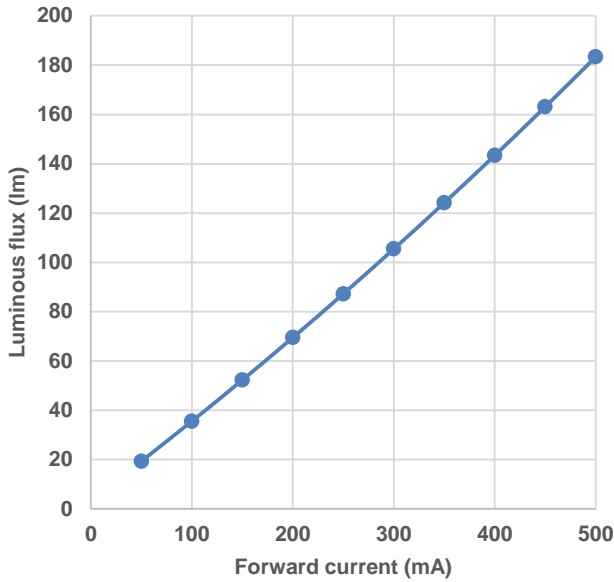


Fig.3. Light output versus current.

2.2. Temperature versus current and luminous flux

The forward current of LED is affected seriously by environment temperature according to the following equation [17]:

$$I(V, T) = \exp(-5.75564 + 3.6398V - 0.003(T-25)) \quad (2)$$

where:

I refers to the forward current of LED.

V refers to the forward voltage of LED.

T refers to the LED temperature.

And by changing temperature in this model from 0°C to 100°C, the results can be obtained as shown in Fig. 4.

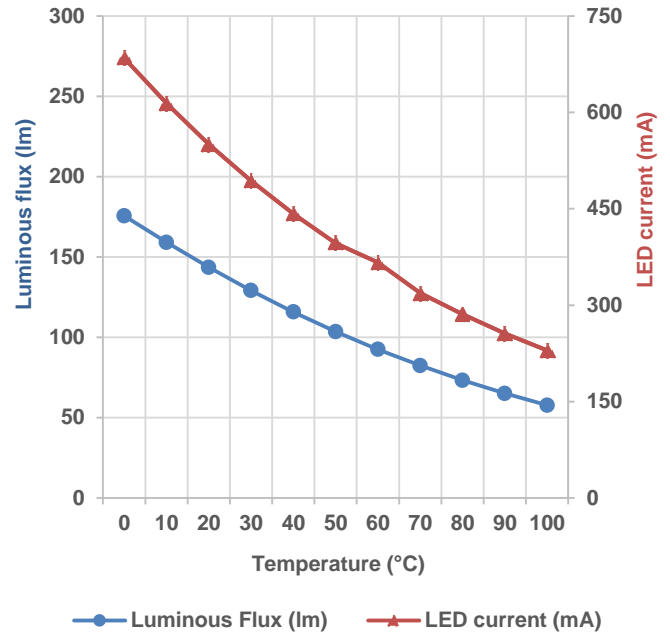


Fig.4. Luminous flux and LED current vs. temperature.

From the previous results, it has proved that luminous flux of LED is inversely proportional to temperature. This means that by increasing temperature, the luminous flux coming from LED will decrease. In other meaning, the forward current of LED has to be compensated in order to keep the luminous flux as desirable value.

3. EXPERIMENTAL WORK

Experimental Setup:

An experimental setup has been achieved to investigate the features under study. The setup includes the following devices:

- 1- Spectrophotometer "Volnic FMS-3000".
- 2- Photometer "HP200".
- 3- Digital power meter "HP105".
- 4- Constant current (DC power supply) "WP502".
- 5- AC power source "FDP-500".
- 6- Constant temperature and humidity chamber "JY-K-100T".
- 7- Heater.
- 8- Temperature sensor.

Spectrophotometer is used to measure LED photometric parameters such as lumen, correlated color temperature (CCT), color rendering index (Ra) and the efficacy [18]. This device consists of a sphere and control unit to analyze the lamp luminous flux as shown in Fig. 5.

Digital power meter is used to measure electrical performance parameters (power, voltage, current, power factor) as shown in Fig. 6.

- DC power supply is turned on and adjusted to constant 50V DC (according to lamp label).
- The lamp is left turned on for about 20 minutes to stabilize the luminous flux.
- Flux calibration is processed using the software "FMS-3000".
- Calibration is completed and then results are saved.

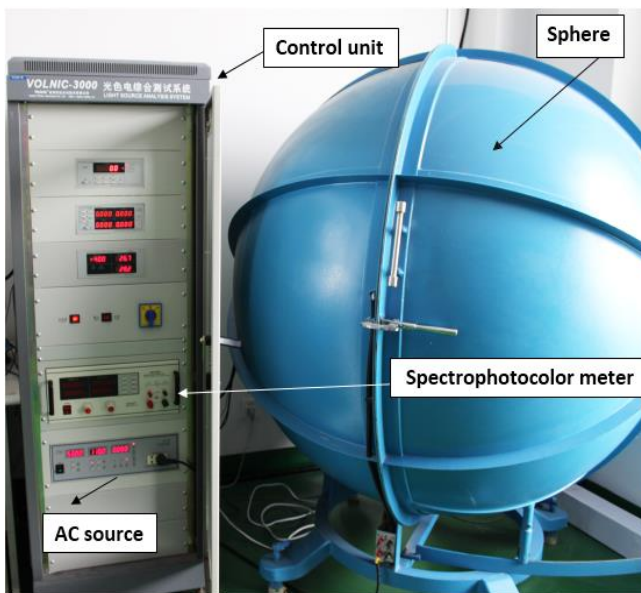


Fig.5. Volnic FMS-3000 spectrophotometer.



Fig.6. Digital power meter "HP105".

Calibration procedures

Before testing, calibration should be done, as follows:

- Calibration lamp is inserted inside the sphere.

Fig.7 shows a humidity test chamber, where both temperature and humidity can be controlled in range from 0°C to 100°C.



Fig.7. Temperature and humidity test chamber.

Lamps under-test

Two types of lamps have been tested: 60cm 9W LED tube lamp and 6W LED bulbs with different brands. These brands were chosen as they are the most popular ones in the Egyptian market. The lamps under test have different specifications (lumen, CCT and CRI) values.

LED lamp components

The main components of LED lamp are chip, driver and heat sink. There are some other secondary components of LED lamp such as housing and lamp base.

LUMINOUS FLUX VS. CURRENT

In this experiment, LED lamp 60cm (Model 2835 (SMD) LEDs), operates with DC

voltage is tested.

A constant DC voltage (50V) is applied to the LED lamp and the current fed into the lamp is manually controlled and the change in luminous flux emitted from the lamp is noticed, measured, and recorded as shown in Fig. 8.

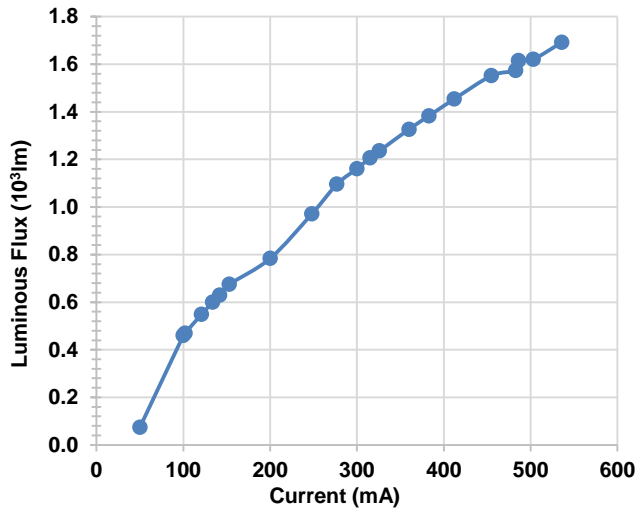


Fig.8. Experimental luminous flux vs. current.

LUMINOUS FLUX VS. TIME

In this experiment, six Watt LED bulbs with different brands are tested.

The samples are operated for 100 hours continuously and the change of luminous flux is observed, measured, and recorded, as shown, in Fig. 9.

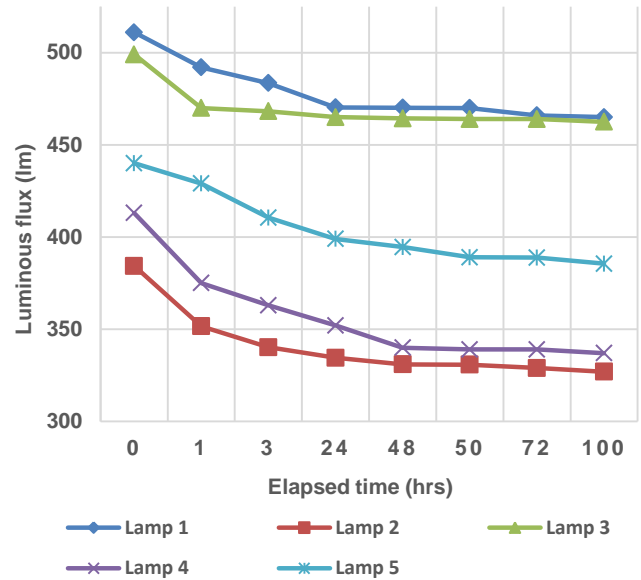


Fig.9. Luminous flux vs. Time.

CORRELATED COLOR TEMPERATURE (CCT) VS. TIME

The Correlated Color Temperature (CCT) is a more specific term used to describe the color of a light emitted by a light source. CCT is defined in Kelvin degrees; a warm light like sodium lamps is around 2700K, warm white is around 4000K, cool white is from 5000K to 6500K, and the more than 6500K is the blue light [1] [19], as shown in Fig. 10.

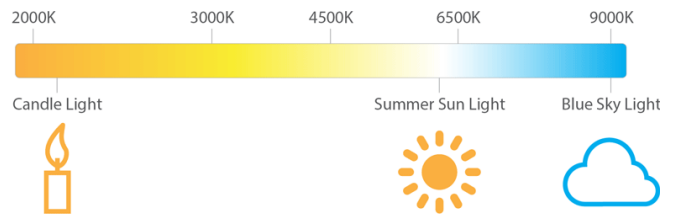


Fig.10. Correlated color temperature chart [20].

Color temperature is an important concept when purchasing a light source [21]. Selecting the right color temperature can make a big difference in choosing the suitable lamp for the area to be illuminated [22]. In this experiment, the samples are operated for 100 hours continuously. The change of CCT is observed, measured, and recorded, as shown in Fig. 11.

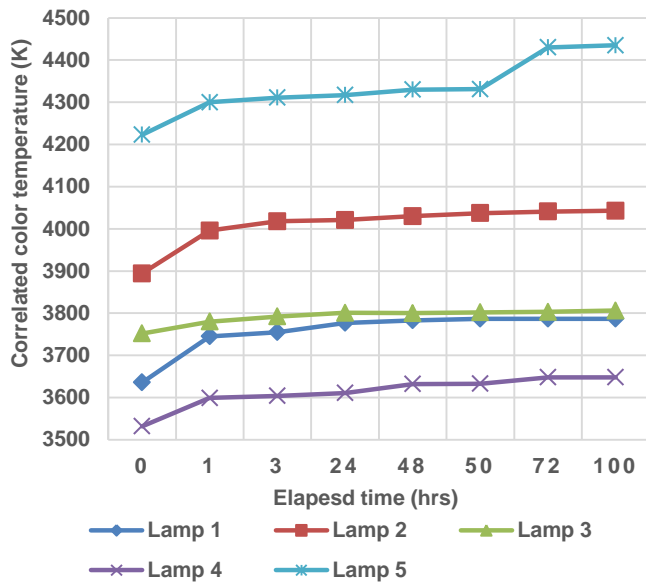


Fig.11. Correlated color temperature (CCT) vs. operating time.

The results obtained in this experiment reveals that CCT of LED lamps increases with the passage of time. This means that the color of light emitted from lamps changes. This may have an effect on the design of lighting in color-sensitive places where light color is important such as intensive care rooms in hospitals as well as in archaeological sites and museums.

COLOR RENDERING INDEX VS. TIME

Color Rendering Index (CRI) is an important parameter means a scale that measures the ability of a light source to faithfully reproduce color when compared to an ideal light source such as the sun and tungsten lamp. It shows how the color of an object appears to human eyes.it is a scale from 0 to 100 [23].

By operating the samples for 100 hours continuously, the change of CRI is observed, measured, and recorded.

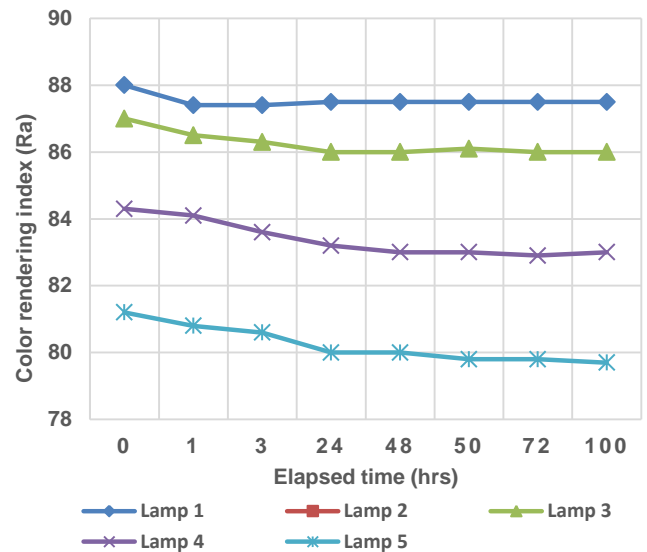


Fig.12. Color rendering index vs. operating time.

The experimental results, shown in Fig. 12, indicate that on the change in the CRI of the LED lamps is minor.

EFFECT OF TEMPERATURE ON POWER FACTOR

Power factor (PF) is a key parameter in selecting the lamps [24]. Power factor is defined as the ratio of real or active power (in Watts) to apparent power (in VA);i.e. the lower power factor the higher drawn current of the load [25]. By inserting the samples in temperature test chamber, changing the chamber temperature from 5°C to 90°C, measuring the power factor of LED lamp driver by using digital power meter "HP105" and then recording the results as shown in Fig. 13 and Fig. 14.

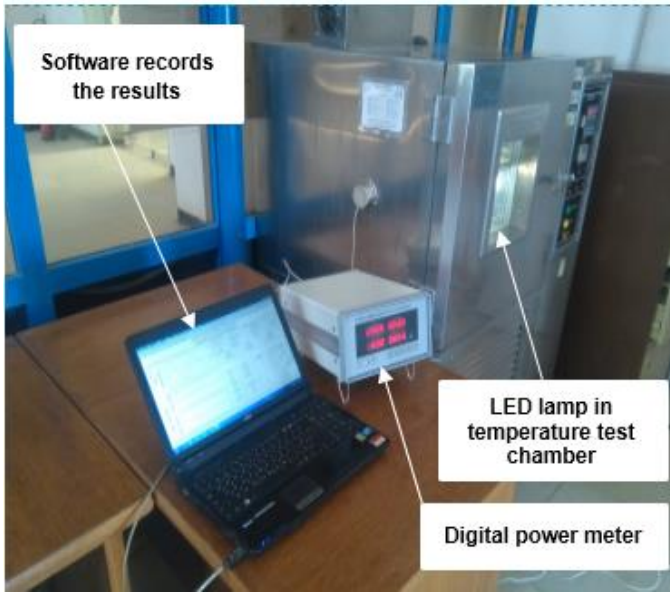


Fig.13. The chamber temperature uses for measuring the power factor of LED lamp.

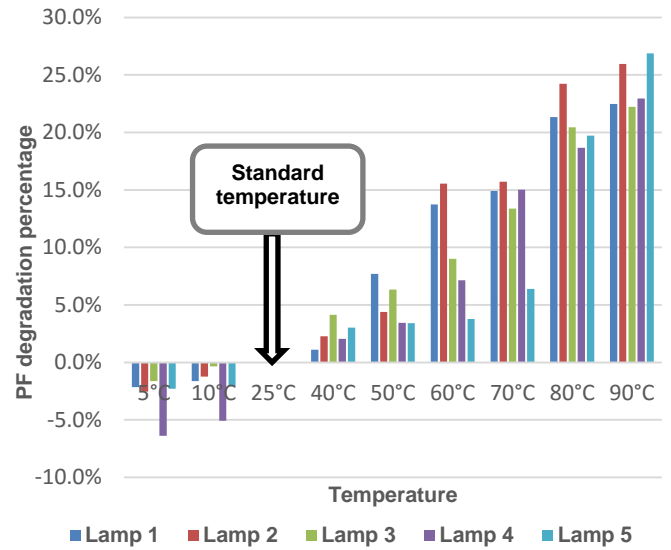
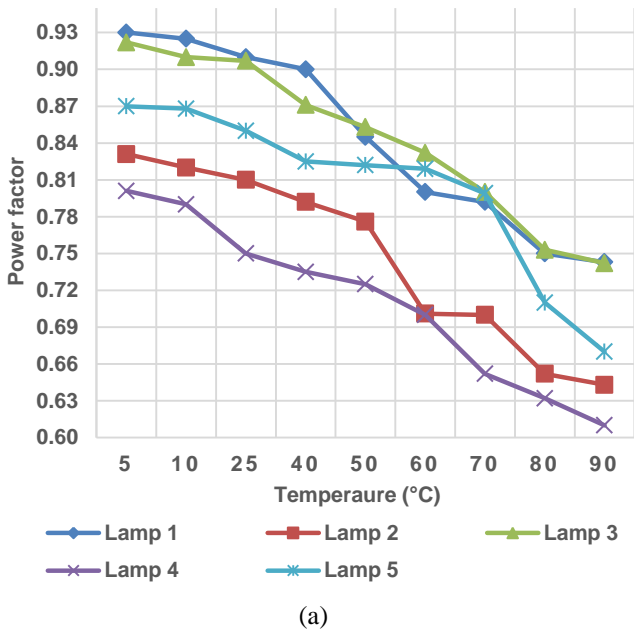


Fig.14. Effect of operating temperature on power factor of LED lamp driver: (a) PF vs. temperature, (b) PF degradation percentage from its value at standard temperature (25°C).

From the previous experiment, it is shown that power factor of LED lamp driver decreases from about 1% to 26% over the temperature range of 5°C to 90°C.

In some factories, especially heavy industries such as steel and cement factories, production lines are illuminated by LED lamps and these lamps work continuously at high temperatures. High temperature leads to a change in the characteristics of electronic components of the driver circuit. This leads to reduction of the power factor of the lamps as noticed in the previous experiment. In such case, power factor should be compensated to avoid the poor PF penalty imposed by the electricity company on big consumers [26]. Furthermore, in long transmission lines decreased PF may lead to unacceptable voltage drop at the receiving end and leads to electricity grid stability complications. Hence, LED lamps operating power factor is usually considered by heavy consumers as well as electric grid operators.

4. CONCLUSION

Several experimental investigations have been conducted in this research to explore and evaluate LED Lamps performance. Experimental results proved that when the DC forward current increases, luminous flux emitted from LED increases and vice-versa. Moreover results showed that by running LED lamps continuously and observation versus elapsed operating time, the LED lamps luminous flux is degraded, the correlated color temperature increases, and on the contrary, the color rendering index is approximately constant. Experimental results also showed that PF of LED lamp driver decreased when operating temperature increases.

This research recommends that luminous flux and CCT of LED lamps should be checked periodically to make sure that their values are still within acceptable limits. It is recommended to employ current compensation controllers such as boost converters to maintain luminous flux as desired. Furthermore, the authors recommend to use a power factor correction technique to compensate the degraded power factor due to the increased temperature working environment.

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تقييم معلمي للأداء الضوئي وجودة القدرة للمبات الصمامات الثنائية الباعثة للضوء في ظروف تشغيل مختلفة

نظرًا للاهتمام العالمي بتكنولوجيا الإضاءة الباعثة للضوء (LED) ، يبذل مصنعو لمبات LED والباحثون الأكاديميون جهودًا

كبيرة لدراسة كل جانب من جوانب أداء هذا النوع من المبات.

تبحث هذه الرسالة في الخصائص الضوئية والكهربائية للمبات LED. وقد تمت دراسة تأثير درجة الحرارة على الضوء المنبعث

منها، وتم محاكاة نموذج لمبات LED في هذه الرسالة. كما قدمت أيضا الرسالة نتائج تجريبية لتأثير اختبار التقادم (مرور الزمن)

على المتغيرات الضوئية للمبات LED مثل التدفق الضوئي ودرجة حرارة اللون (CCT) ومؤشر تقديم اللون (CRI).

تمكن هذه الدراسة من فهم ومراقبة الضوء المرئي المنبعث من لمبات LED وتعد مهمة في العديد من التطبيقات حيث أن

معامل درجة حرارة اللون (CCT) معامل هام في مجالات الإضاءة والفيديو والتصوير الفوتوغرافي والصناعة كما أنه من المرغوب

فيه أيضا تحقيق قيمة عالية في مؤشر تقديم الألوان (CRI) وذلك في التطبيقات الحساسة للون مثل العناية بالأطفال حديثي الولادة

في المستشفيات.

وقد أثبتت النتائج التجريبية أيضًا أن معامل القدرة للمبة LED ينخفض إلى نسبة تصل إلى 26% تقريبًا عن قيمته المقننة

عند تشغيله في درجات حرارة عالية.