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ECONOMICAL COMPARATIVE STUDY FOR LIGHTING SYSTEMS USING ENERGY CONSUMPTION FACTOR

A.E.H. Gaballah, E.M. El-Moghazy and Alaaeldin Abdelmageed
Photometry and Radiometry Division, National Institutes of Standards (NIS), Tersa St, Al-Haram, Giza, Egypt
E-Mail: ahmed.gaballah@nis.sci.eg

ABSTRACT

The paper presents a comparative study of some commercial LED lamps for indoor lighting using the energy consumption factor. This article focuses on providing a suitable level of illumination utilizing LED lighting bulbs of various wattages to illuminate a 50-square-meter area, as well as their energy consumption. The CIE publication (S008/E-2001) has recommended an illuminance level of 500 Lux for indoor workplaces such as offices. The study has included three sets of commercial LED lamps purchased from three companies designated as E, T, and V. Each set included three duplicated lamps with different wattages such as 9, 12, and 15 Watt for repeatability. Thus, a summary of the measured photometric and electric parameters for these lamps was measured to assess their energy consumption.

Keywords: LED lamps - luminous flux - energy consumption factor.

1. INTRODUCTION

Energy consumption plays a significant role in our daily lives due to the high energy demand. The shortage of energy supplies, carbon emissions, and environmental changes put the world on edge to search for alternative sources or rationalization of available energy [1,2]. Energy consumption can be improved in several ways, as an example, most governments have accepted the use of LED lighting instead of traditional light sources due to their advantages in saving energy [3-9]. LED illumination is available in a variety of forms including panels, LED bulbs, and luminaires [10-13]. LED bulbs have become widely used for modern lighting especially inside buildings due to their superior advantages as energy efficiency, reduced heat dissipation, high brightness, and low cost when compared to other light sources [14, 15]. Energy efficiency has been of interest to both energy providers and consumers due to its economic impacts, especially in lighting systems [16]. One of the early developed energy indices that reflects the performance of electrical devices is the energy consumption factor (Ec), It has a considerable effect on managing the usage of energy, as well as reducing cost [17,18]. It is most widely used for comparing the performance of energy consumption in buildings [19], the term "energy consumption" refers to the total amount of energy required to perform a task; It can be calculated from a variety of energy sources, but here we will refer to the electrical one. In this paper, the work focuses on providing a suitable level of illumination using LED lighting bulbs of various wattages to illuminate a 50-square-meter area with 500 lux as recommended by CIE according to their energy consumption [20]. Three sets of commercial LED lights from three distinct firms were used in this study, each with a different wattage designated as E, T, or V. For high repeatability, each set contained three duplicated lights with varied wattages such as 9, 12, and 15 Watt.

2. EXPERIMENTAL REALIZATION

The total luminous flux for a given light source can be expressed as:

$$\Phi_v = K_m \int_{380}^{780} \Phi_{e.\lambda} V(\lambda) d\lambda \qquad (1)$$

Where $\Phi_{e.\lambda}$ is radiant power in Watt and Φ_v is the total flux in lumen. The constant K_m is a scaling factor called the maximum spectral luminous efficiency for photopic vision and equals to 683 lm/W and $V(\lambda)$ is the photopic luminosity function which represents the sensitivity of the human eye to light. The luminous flux was measured using an integrating sphere with a diameter of 2.5 meters. A schematic diagram of the available integrating sphere at NIS Egypt is shown in Figure-1, the sphere is equipped with V (λ) - corrected filter, cosine - corrected detector, a baffle screen, auxiliary lamp, and temperature sensor. The LMT standard photometer with an opal glass diffuser is used as the V (λ) corrected detector. The total luminous flux was measured in direct substitution with standard lamps of reasonable flux to the tested lamp. The sphere wall is coated with barium sulfate, which has a diffuse reflectance of about 0.97. The integrating sphere also has a tungsten auxiliary lamp (100 watts) mounted on the sphere wall to measure the bulb's self-absorption effects[21].Aglint 6813B AC power source/analyzers with precise measurements and output voltages up to 300V AC and 10A was used to power the lamps. The measurements were carried out in a controlled setting with a temperature of approximately $24^0C \pm 1^0C$. The lamps were operated at a nominal voltage of 220 V±2. The lamps were normally allowed to steady for around 30 minutes after being turned on, while the lamp current is maintained.

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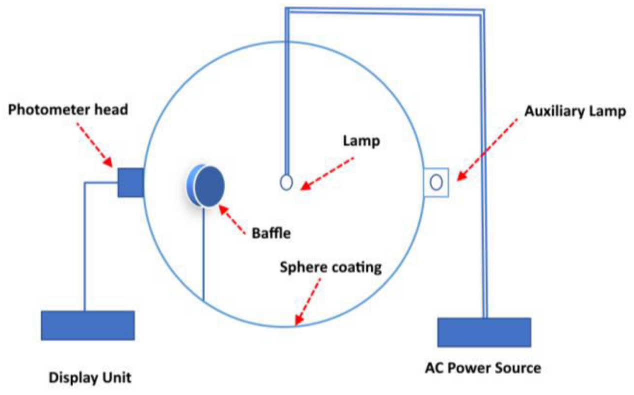

Figure-1. NIS 2.5 m integrating sphere set up for luminous flux measurements.

3. ENERGY CONSUMPTION FACTOR MEASUREMENTS

The study has extended to different types of commercial LED lamps working in the Egyptian market with different watts. The electricity usage depends on the wattage, and the number of hours of usage, thus, the estimation of (Ec) is calculated for a working time of 6 hrs per day. The total luminous flux incident on a given area is defined by:

$$E = \frac{n\Phi}{A} \tag{2}$$

Where E is the illuminance in Lux, Φ is the luminous flux in a lumen, n is the number of lighting units and A is the area in m^2. In order to estimate the total number of lamps required to illuminate an area of approximately 50 m^2 for office lighting purposes [22], the CIE has recommended an illumination level of 500 Lux for indoor workplaces. Table-1 summarizes the output results regarding the total luminous flux for different types of lamps and the equivalent illuminance ina unit of Lux to the light an area of approximately 50 m^2.

ARPN Journal of Engineering and Applied Sciences

Table-1. The total luminous flux for different types of lamps with different Watts and their equivalent Illuminance in Lux to illuminate an area of approximately 50 m^2.

	Lamp	Watt	Flux	Average Flux	Equivalent Illuminance in Lux
Group A	T1	9	835	823	$\frac{30x\ 823}{50\ m^2} = 494$
	T2		828		
	T3		806		
	V1	9	884	887	$\frac{28x\ 887}{50\ m^2} = 497$
	V2		895		
	V3		883		
	E1	9	959	956	$\frac{26x\ 956}{50\ m^2} = 497$
	E2		948		
	E3		961		
Group B	T4	12	1015	1012	$\frac{25x\ 1012}{50\ m^2} = 506$
	T5		1014		
	T6		1007		
	V4	12	884	1208	$\frac{21x\ 1208}{50\ m^2} = 507$
	V5		895		
	V6		883		
	E4	12	959	1240	$\frac{20x\ 1240}{50\ m^2} = 496$
	E5		948		
	E6		961		
Group C	T7	15	1362	1364	$\frac{18x\ 1364}{50\ m^2} = 491$
	T8		1364		
	T9		1366		
	V7	15	1436	1433	$\frac{18x\ 1433}{50\ m^2} = 516$
	V8		1452		
	V9		1412		
	E7	15	1660	1637	$\frac{15x\ 1637}{50\ m^2} = 491$
	E8		1611		
	E9		1641		

The following formula is used to determine the energy consumption factor (E_c) in kWh/1000 h, which is rounded to two decimal places [23].

$$E_c = P * \frac{1000\ h}{1000} \tag{3}$$

or the energy consumption formula is expressed as:

$$E_c = P * \frac{t}{1000} \tag{4}$$

where P is power in Watts, and t is the operating time in hours. The average cost per unit charged by the electric utility is based on the number of hours of usage and the price of Kilowatt-hour. Since every country has different tariff rates, we used a multiplying factor (k) referring to the price of Kilowatt. The consumed power in Watt and the energy consumption factor (Ec) for different LED lampsare seen in Table-2.

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Table-2. The consumed power in Watt and the energy consumption factor (Ec) for different LED bulbs with different Watts.

	Lamps	P (Watt)	Ec	The price of KWh
Group A	T_{9W}	$9x30 = 270$	$\frac{270x6}{1000} = 1.62$	1.62xk
	V_{9W}	$9x28 = 252$	$\frac{252x6}{1000} = 1.52$	1.52xk
	E_{9W}	$9x26 = 234$	$\frac{234x6}{1000} = 1.40$	1.40xk
Group B	T_{12W}	$12x25 = 300$	$\frac{300x6}{1000} = 1.81$	1.81xk
	V_{12W}	$12x21 = 252$	$\frac{252x6}{1000} = 1.52$	1.52xk
	E_{12W}	$12x20 = 240$	$\frac{240x6}{1000} = 1.44$	1.44xk
Group C	T_{15W}	$15x18 = 270$	$\frac{270x6}{1000} = 1.62$	1.620xk
	V_{15W}	$15x18 = 270$	$\frac{270x6}{1000} = 1.62$	1.620xk
	E_{15W}	$15x15 = 225$	$\frac{225x6}{1000} = 1.35$	1.35xk

As shown in Figure-2, the energy consumption factor (Ec) for 15 W lamps of the designated company (E) has a distinct performance when compared to their counterparts with the lowest number of LED bulbs (15 lamps), as shown in Figure-2.

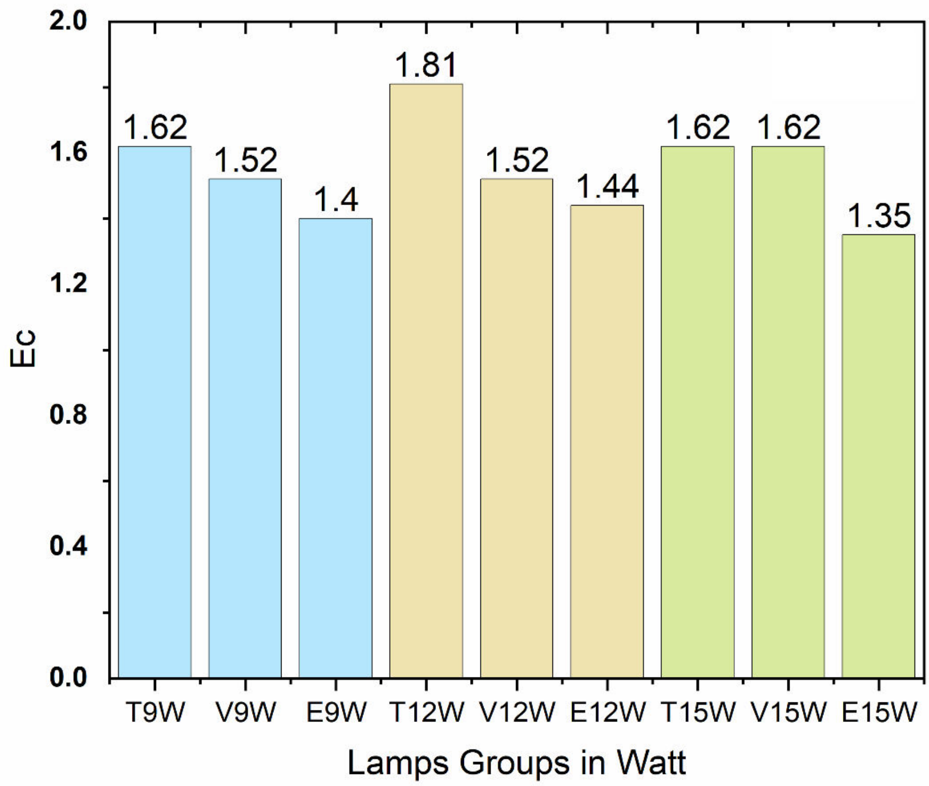

Figure-2. The energy consumption factor (Ec) for different LED bulbs with different Watts.

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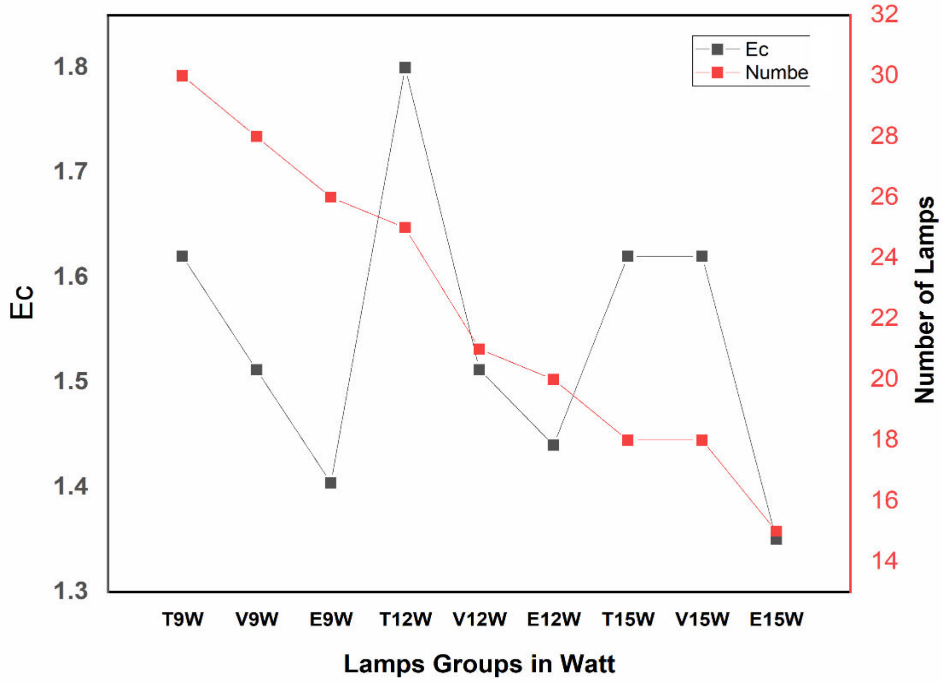

Figure-3. The energy consumption factor (Ec) with the number of utalized lamps.

4. CONCLUSIONS

The energy consumption factor (Ec) that quantifies the performance of electrical devices of three different sets of commercial LED lamps was used; classified to groups A, B and C. Each group contained three identical lamps of the same wattages as 9, 12, and 15 Watt. The results show that the usage of 15-watt lamps is adequate for lighting, based on comparisons between different firms with varying wattages. The daily cost when we use 15-watts lamps is the best from an economic point of view to illuminate a 50-square-meter area with 500 Lux, as recommended by CIE based on energy consumption. It has a significant impact on energy management and cost reduction.

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