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Comparison of Visible and Ultra-Violet Radiations for Commercial Compact Fluorescent and Light Emitting Diode Lamps in the Saudi Market

Manal A. Haridy[1,2,*], and Samar Alanzy[1]
[1]Physics Department, College of Science, University of Hail (UOH), Hail, Kingdom of Saudi Arabia (KSA).
[2]Photometry and Radiometry Division, National Institute of Standards (NIS), Giza, Egypt.
***** Corresponding Author

Abstract: The present paper aimed to measure Ultraviolet radiation and Illuminance (visible) and some important lighting parameters such as the safe parameter of UVA power to illuminance values (K) of some useable commercial Compact Fluorescent Lamps (CFLs) and Light Emitting Diode (LED) Lamps in the Saudi Market. Also, evaluating the relationships between UVA radiation and illumination levels. As the use of Compact Fluorescent Lamps (CFLs) becomes rapidly far flung and also increases the concerns relating to their mercury content and the associated hazards. While the risk associated with individual CFLs, the cumulative impact of millions of lamps does however become a more important issue and could represent a potential risk to the human health. The parameters such as ultra violet irradiance quantity, ratio of UVA irradiance to electrical power (η) and the safe parameter of UVA power to luminous flux (K) are studied and calculated for the two types of lamps to dedicate their performance. A set up based on UVA/B silicon detector for irradiance measurements in UVA region. The setup is consisting of Sper Scientific UVA/B Light Meter (Model 850009C) is calibrated at National Institute of Standard and Technology (NIST), USA for absolute irradiance measurements. The absolute irradiance in W/m^2 in UVA region of the lamps and their accompanied standard uncertainty are evaluated. Another set up based on Luxmeter is used for measuring illuminance. The set up based on TM-201Lux Luxmeter are used for measuring illuminance for all lamps. For all two groups under study k parameter remains less than the safe limit for human health. Light emitting diode (LED) lamps have smaller ratio (η) than CFLs. We recommended using Light emitting diode (LED) lamps than CFLs at any distance. Also, we recommended using CFLs for short distance in table lamps or other application and the distance more than 50cm. The Data were analyzed, performed and calculated to determine the uncertainty model which have all parameters affect on the measurements and the final results.

Keywords: UVA Radiation, Irradiance, Illumination Levels, Human Health, Compact Fluorescent Lamps (CFLs), Light Emitting Diodes, Uncertainty Analysis.

1. Introduction

Light is necessary in all activities in our life. Some characteristics of light sources and ultraviolet radiation have significant roles on visual and non- visual health effects of lighting [1]. All common light sources, like light bulbs give out her forms of radiation in ultraviolet and infrared radiations. Ultraviolet radiation (UV) is the most potential damaging form of energy and the damage it causes is cumulative. So when lighting an area where important or valuable works are housed, it is essentially to minimize the potential for damage. We must also provide a safe and comfortable working and viewing environment for people. To achieve that it is important to have basic understanding to UV radiation and what levels of illumination are required for various activities [2].

To emphasis on use of energy saver Lamps, it is necessary to analyze the effect of radiation especially Ultra violet radiation (UV) on human health. Ultra violet radiation (UV) is non-ionizing part of electromagnetic spectrum. It produced either by heating a body to incandescent temperature or by passing an electric current through a gas which produces Ultra violet radiation (UV). Ultra violet radiation (UV) has three regions of wavelengths as shown in Figure 1. Which divided to: UVA from 315 nm to 400 nm, UVB from 280 nm to 315 nm, and UVC from 100 nm to 280 nm [3-5]. The UVC has the greatest health effects of UV radiation.

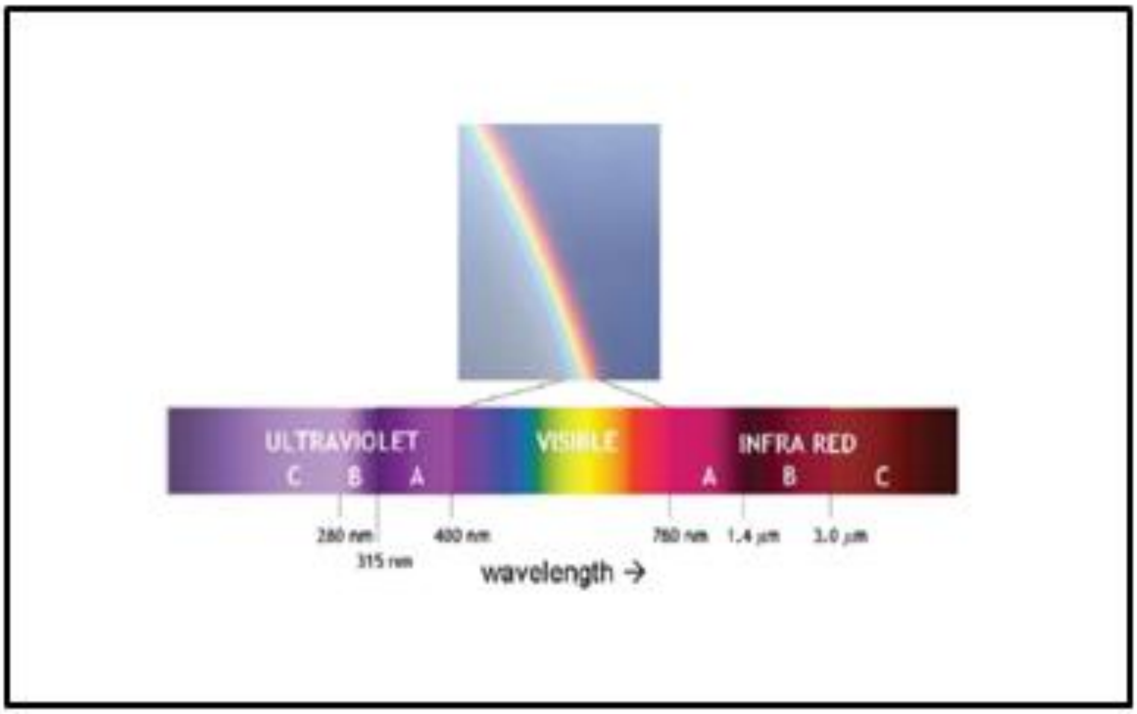

Figure 1. Types of UV radiation [6]

Light output in the Fluorescent Lamps is influenced by the mercury vapor pressure inside the lamp; if the pressure is either greater than or less than optimal, light output declines, and change in contain mercury vapor can change light output [7]. Under normal use, the Ultra violet (UV) emission at distance 65 cm from Tubular Fluorescent Lamps would not produce a significant Ultra violet radiation (UV) hazard [8].

Lighting energy can be saved in many ways, including improving the efficiency of the light source, improving the efficiency of the specific component of lighting system, typically the ballast and, improving the efficiency of the luminaries [9-11]. Replacing technology can occur at a very low cost and provide immediate results [12].

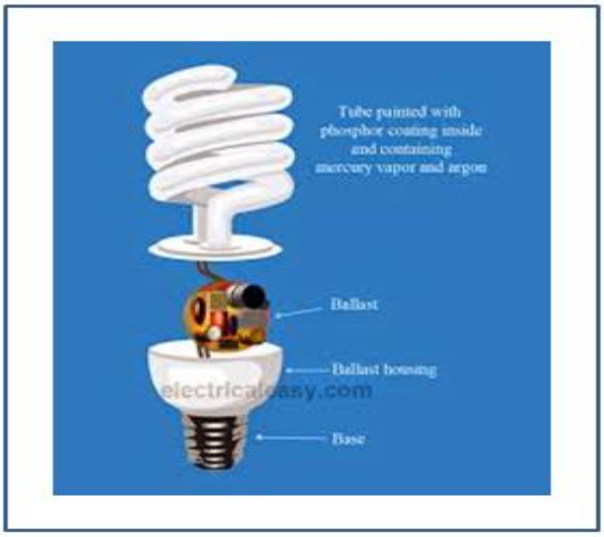

Figure 3. Schematic Diagram of Compact Fluorescent Lamp [15]

Replacing incandescent lamps with compact fluorescent lamps (CFLs) which have played an important role in both industrial and domestic lighting is one of the most obvious and easiest methods to achieve energy efficiency [13]. On comparing with incandescent bulbs, compact fluorescent lamps (CFLs) are approximately four times as efficient i.e. a 25 Watt CFL will have the same light output as a 100 Watt incandescent bulb. They also possess high longevity i.e. 10 times longer, meaning that the life of a standard CFL is comparable to 10 incandescent bulbs. But, a CFL gives off light that looks just like a standard incandescent [14]. Compact fluorescent lamps are usually compounded of two parts as shown in Figure 3. One is plastic cover with holes for pipe and bills. Tube is agglutinated to it. Second much bigger piece has slots for bills from the inner side. Inside is printed circuit board with components and wires from tube.

The widespread use of Compact Fluorescent Lamps is followed by people concerns about their light qualities and health risks. One of the disadvantages of Tubular Fluorescent Lamps emits higher acceptable levels of UV radiation [16]. Compact Fluorescent light bulbs contain mercury, and the inside of the tube is coated with phosphors; the mercury gas inside the tube becomes excited when the electric current is switched on which emits UV radiation. This UV radiation then interacts with the chemicals on the inside of the bulb to generate light. Ideally, conversion of UV to visible light should be 100%; however, due to the defect in phosphor it contains trace amount of UV radiation [17].

Today, the solution for a better lighting system seems to be the use of LEDs. The light-emitting diodes, LEDs, have been known for many years. They are based on the electroluminescence, which is the production of light by the flow of electrons. This phenomenon was discovered in 1907 by H.J. Round of Marconi Laboratories, who used a crystal of silicon carbide (SiC) and a cat's-whisker detector to show it [18]. To produce white light, as shown in Figure 2, most currently available LED luminaire employ phosphor coated blue LEDs or, less commonly, various combinations of red, green and blue (RGB) LEDs. Although performance varies widely among available general service LED lamps, the technology continues to improve even as the price per lumen decreases.

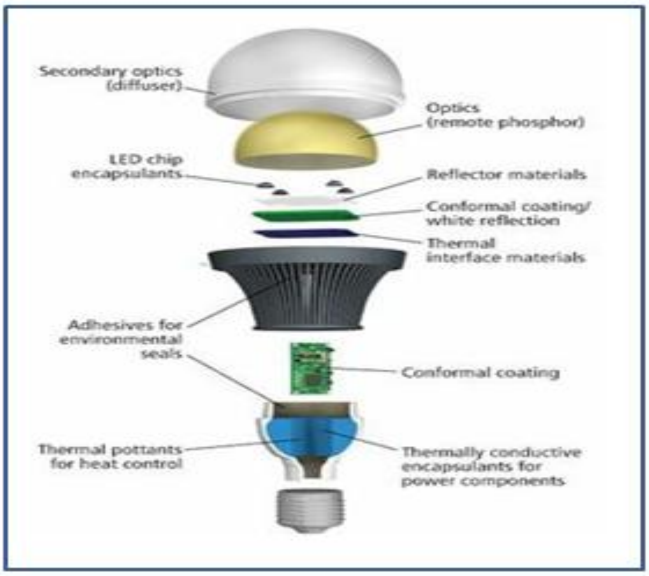

Figure 2. Structure of LED Lamps [19]

Some LED products have already demonstrated equivalence to the ubiquitous 60 Watt incandescent light bulb, and higher output alternatives to 75 Watt and 100 Watt incandescent. When chosen carefully, LED products can offer substantial energy savings without compromise to the quantity or quality of illumination, while also saving money in the long run. [20]. This is the result of radiative recombination of electrons and holes, where the excited electrons release energy as photons [21]. Photometric measurements with LEDs require greater care than such measurements with conventional light sources. Commission Internationale de l0Eclairage (CIE) has recommended guidelines for LED photometric measurements, which deal with measurement geometry, detector requirements, calibration procedure, etc. [22]. Light-emitting diode (LED) lighting offers many potential benefits over incandescent. Serving as a long-life solid-state lighting source, LEDs have been proposed to replace the light sources in some special applications of the automotive, lighting, display and new lighting developments [23]. Recently, colored and white LEDs are used as possible standard sources in the photometric or spectrophotometric areas of the optical metrology [24-26].

2. Theoretical Principles:

The following equation describe the relation between intensity of tested lamp and the illuminance quantity:

$$E = \frac{I \cos \theta}{d^2} \quad (1)$$

where
E : is the quantity of illuminance,.
I : is the intensity of the tested lamps.
d : is the distance from the tested lamp to the surface of the detector.
θ : is the angle between the normal of the receiving surface and the direction of emission [27].

The Spectral irradiance in the part of ultraviolet radiation in class A (UVA) is defined as the electromagnetic radiation power divided by area in ($W/m^2/nm$) hence,

$$I_\lambda(\lambda) = \int_{\lambda_1}^{\lambda_2} I_i(\lambda)\, d\lambda \quad (2)$$

where,
$I_\lambda(\lambda)$: is the spectral irradiance in ($W/m^2/nm$).
$I_i(\lambda)$: is the intensity.

It is obvious that the spectral power distribution of any light source describes the power divided by area per unit of wavelength of illumination. In other words, the concentration is a function of wavelength to any radiometric and photometric quantities [28].
To determine and calculate the ultraviolet radiation in class A (UVA) it will be helpful to use the following equation [3]:

$$\eta = \frac{\int_{\lambda_1}^{\lambda_2} E_{irr}(\lambda) d\lambda}{P} \quad (3)$$

Where,
$E_{irr}(\lambda)$: is the ultraviolet irradiance.
P : is the electrical lamp power.

To make a better comparative study between two different artificial light sources, it is necessary to determine the safe parameter (k).

$$K = \frac{\int_{\lambda_1}^{\lambda_2} E_{irr}(\lambda)\, d\lambda}{k_m \int_{380nm}^{780nm} E_{irr}(\lambda)\, d\lambda V(\lambda)\, d\lambda} \quad (4)$$

$E_{irr}(\lambda)$: is the spectral distribution of the radiant flux W/nm
$V(\lambda)$: is the spectral human eye response (CIE response curve).
k_m is photometric radiation constant and equal ($683 lm/W$).
From equation (1) k is also defined as:

$$K = \frac{\int_{\lambda_1}^{\lambda_2} I_\lambda(\lambda) d\lambda}{k_m \int_{380nm}^{780nm} I_\lambda(\lambda)\, d\lambda V(\lambda)\, d\lambda} \quad (5)$$

This parameter can help to determine which type of these artificial light source emit less ultraviolet radiation to the lumen. The following equation can calculate the safe parameter. It is depending on the distance between the lamp and the area exposure [3]

3. Method

In the present work, a comparative ultraviolet irradiance and illuminance study made it to two different artificial light sources which are the most usable lamps in the Saudi market. These artificial lamps are three compact fluorescent lamps (CFLs) with different watts and three Light Emitting Diode Lamps (LEDs) with different watts. The comparative study was to dedicate their performance and also to analyze and calculate the uncertainty budgets for the measurements [16, 29, 30]. All lamps were seasoned up to 50 hours in the vertical position in base down [27]. Different parameters determined for the types of lamps such as ultra violet irradiance (UVA), ratio of UVA irradiance to electrical power (η) and ratio of UVA power to luminous flux (K) at different distances. Measurements were performed in a conditioned black box around the set up of the measurements according to the International Commission on Non-Ionizing Radiation Protection (ICNIRP) recommendations [31] and the temperature was maintained at $(25 \pm 2)^{o}C$. The photometric bench consists of Sper Scientific UVA/B Light Meter (Model 850009C) is calibrated at National Institute of Standard and Technology (NIST), USA as shown in Figure 4. The UVA detector was mounted on a translation stage and positioned at the same height as the light source on the optical bench as shown in Figure 4. Before taking measurements, each Lamp was warmed up to 15 minutes. Measurements were repeated for each lamp and were finally averaged out and the uncertainty in irradiance measurements is calculated.

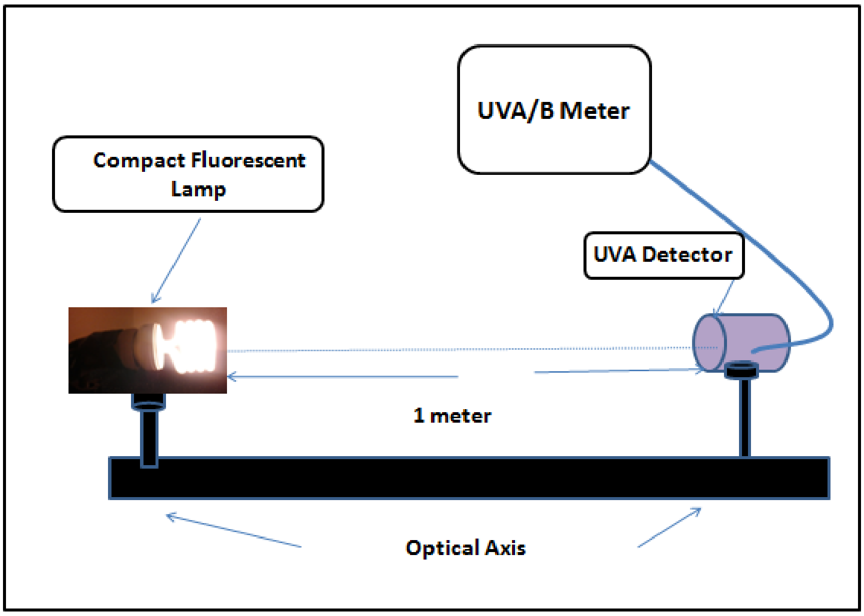

Figure. 4. A Set up diagram for measuring UVA irradiance

The illuminance of each lamp is measured using a Luxmeter TM-201Lux. The Luxmeter was mounted on a translation stage and positioned at the same height as the artificial light source on the optical bench as shown in Figure 5. Before taking measurements, each lamp was warmed up to 15 minutes. Measurements were repeated for each lamp and were finally averaged out and the uncertainty in irradiance measurements.

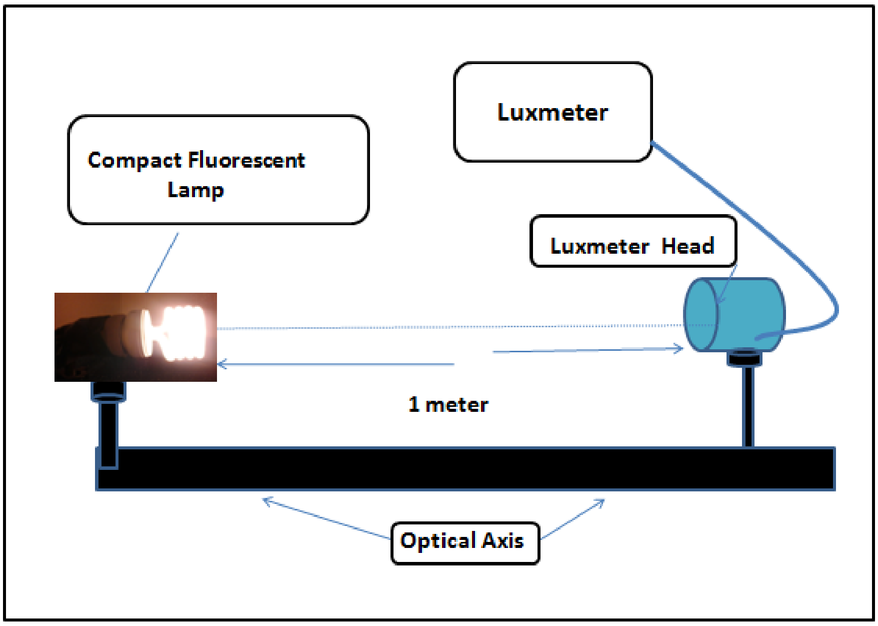

Figure. 5. A Set up diagram for measuring illuminance

4. Results and Discussions

UVA irradiance and illuminance were measured at the different distance for Compact Fluorescent Lamps (CFLs) and Light Emitting Diode (LED) Lamps. At the distance of 25 cm that was considered to be the closest distance that people would be exposed to the lamp especially in desk-top application. For analyzing the UV content at the short distance, the measurements were conducted at the distance of 25 cm. The description of the compact fluorescent lamps is UOH-CFL-1(15 watt), UOH-CFL-2 (20 watt) and UOH-CFL-3 (26 watt). These lamps are designed to emit their power in the visible region. In fact, they emit almost of their energy in the visible region but part of their energy is emitted in the UV region. The description of the light emitting diode lamps is UOH-LED-1(16 watt), UOH- LED -2 (12 watt) and UOH- LED -3 (9 watt). Negligible amounts of UVA and UVB were detected at 150 and 200 cm from compact fluorescent lamps (CFLs). Therefore, only data relating to the UVA irradiance measured at 25, 50, and 100 cm were analyzed in this study.

Figure 6 shows the comparison of UVA irradiance level between Compact Fluorescent Lamps (CFLs) and Light Emitting Diode lamps (LEDs) at distance of 25, 50, and 100 cm. Each lamp measured at distances of 25, 50, and 100 cm from its central vertical axis respectively using Sper Scientific UVA/B Light Meter (Model 850009C) which calibrated at National Institute of Standard and Technology (NIST), USA.

The UVA irradiance at distances of 25cm, 50cm, and 75cm for all lamps varies from 0 to $18\,\mu W/m^2$. Our results showed that the LEDs lamps have zero values of the UVA irradiance. Also the highest value of the UVA irradiance was from UOH-CFL-3 (26 Watt) at 25 cm distance.

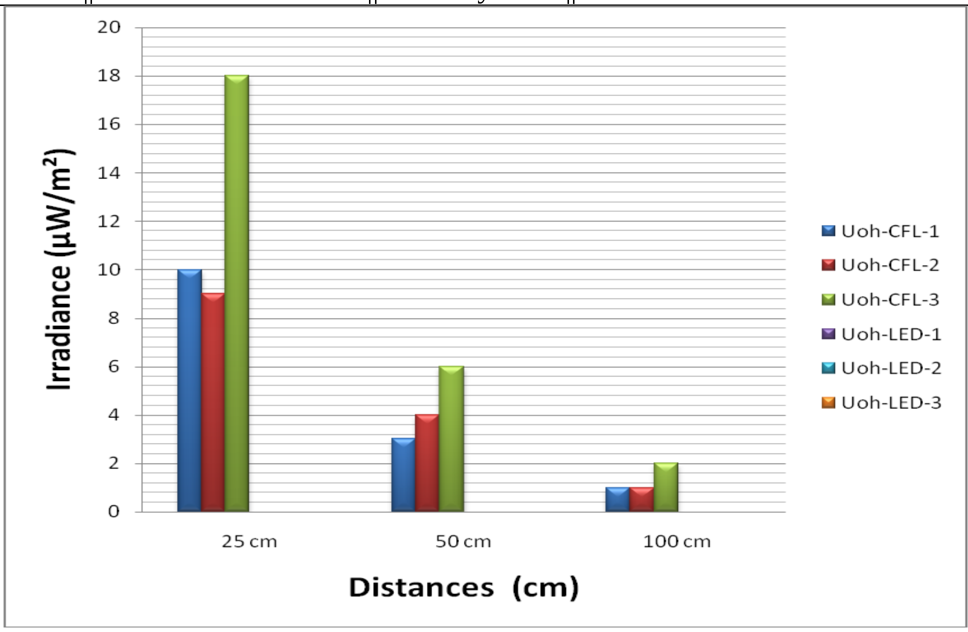

Figure. 6. Comparison measurements of UVA absolute irradiance levels between Compact Fluorescent Lamps (CFLs) and Light Emitting Diode lamps (LEDs) at different distances

Figure 7 shows the comparison of illuminance level between Compact Fluorescent Lamps (CFLs) and Light Emitting Diode lamps (LEDs) at distance of 25, 50, and 100 cm. Each lamp measured at distances of 25, 50, and 100 cm from its central vertical axis respectively using Luxmeter TM-201Lux. The illuminance level at distances of 25cm, 50cm, and 100cm for all lamps varies from 107 lux to 2500 lux. Our results showed that LEDs lamps have higher values of the illuminance level than the compact Fluorescent lamps.

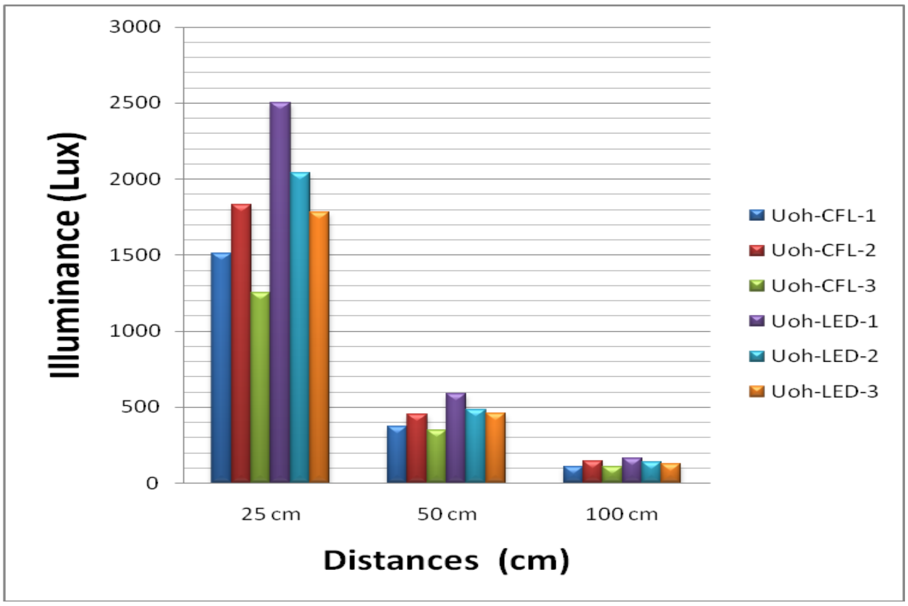

Figure. 7. Comparison measurements of Illuminance levels (Lux) between Compact Fluorescent Lamps (CFLs) and Light Emitting Diode lamps (LEDs) at different distances

It would be more appropriate to analyze UVA irradiance per electrical wattages (η) as shown in Figure 8. For warm white compact lamps, the value of (η) should remain invariant, provided the phosphor and the mercury content used in CFLs are in the same proportion [3]. Also, large variation may due to non-uniformity in coating of phosphor. Smaller value of (η) is safe for human being. Figure 8 show the histogram for comparison of UVA absolute irradiance levels per electrical power of (η) at distances of 25cm, 50cm, and 100cm for all types of studied lamps which varies from $zero$ to $0.69\,m^{-2}$.

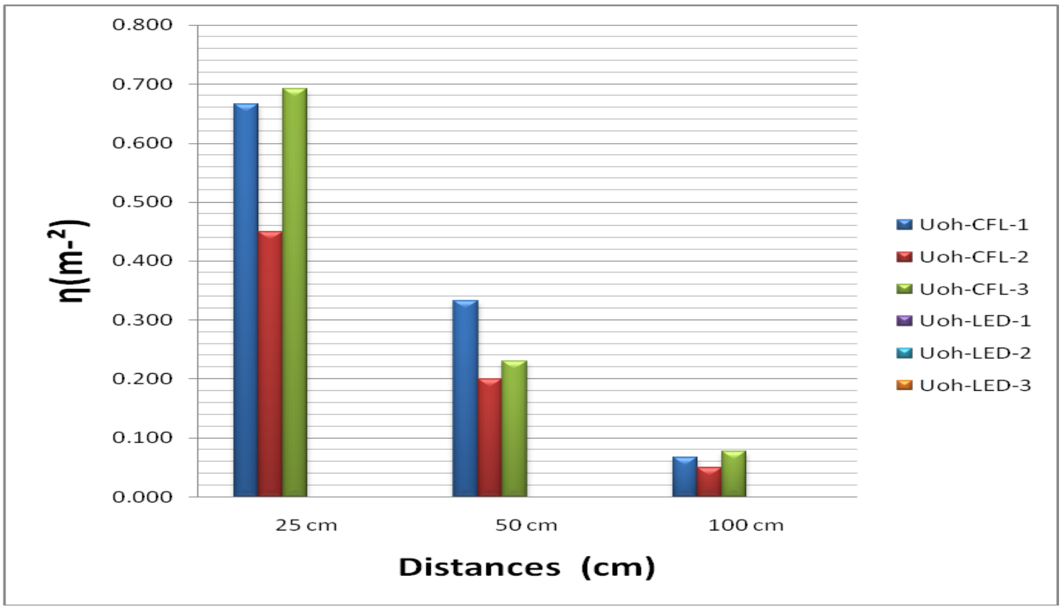

Figure. 8. Comparison measurements of UVA absolute irradiance levels per to electrical power (η) between Compact Fluorescent Lamps (CFLs) and Light Emitting Diode lamps (LEDs) at different distances

To make a better comparison in UVA concentration to illuminance ratio (K), is of more interest for analyzing the lamps radiation characteristics as shown in Figure 9. It shows the histogram for comparison of UVA concentration to illuminance ratio (K) at distances of 25cm, 50cm, and 100cm for all types of studied lamps which varies from $zero$ to $0.0144\,\mu W/lm$.

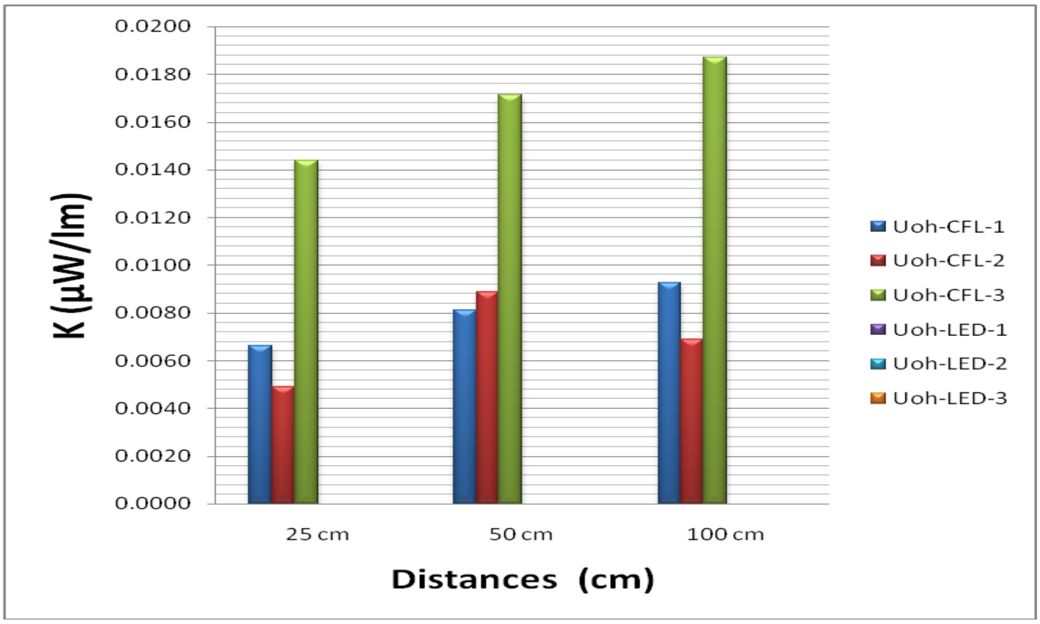

Figure 9. UVA absolute irradiance levels per illuminance values (K) Between Compact Fluorescent Lamps (CFLs) and Light Emitting Diode lamps (LEDs) at different distances

The maximum detected value $0.0144\,\mu W/lm$ is less than the safe limit for human health at different distances. [3]. All of light sources emitted UV in regions UVA ; the amount of emissions varied randomly between different bulbs. According to occupational exposure limited (OEL), occupational UVB and UVA exposure should be limited to an effective irradiance of $3\mu W/m^2$ and $1.04166\,W/m^2$ in an 8 hr period, respectively [32,33]. It is important to consider the effect of compact fluorescent lamps because the risk of death in middle-aged adults from occupational exposure to fluorescent lighting for basal and squamous cell carcinomas is 1 in 2.5 million per year [34].

5. Uncertainty analysis

When reporting the result of measurement of any quantity, it must be quantitative indication of the quality of the result be given so that those who use it can assess its reliability. With such an indication, measurement results can be compared. The ideal method for evaluating and expressing the uncertainty of the result of a measurement should be universal which means that the method should be applicable to all types of measurements and all kinds of input data used in measurements [35]. The uncertainty in the result of a measurement consists of several components which may be grouped into two categories. According to the way in which their numerical value is estimated. Type A those which are evaluated by statistical method and type B those which are evaluated by other means. The components in type A are characterized by the estimated variances s_i^2 (or the estimated "standard deviation" s_i) and the number of degree of freedom v_i . The components in type B should be characterized by u_j^2, which may be considered as approximations to the corresponding variances, the existence of which is assumed. The quantities u_j^2 may be treated like variances and the quantities u_j like standard deviations. The combined uncertainty should be characterized by the numerical value obtained by applying the usual method for the combination of variances. The combined uncertainty and its components should be expressed in the form of "standard deviations" [36]. Expanded uncertainty is termed overall uncertainty. It is quantity of an interval about the results of a measurement that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand. Coverage factor is numerical factor used as a multiplier of the combined standard uncertainty in order to obtain an expanded uncertainty [36].

Evaluation of the uncertainty is done by the Guide to the expression of uncertainty in Measurement (GUM) method. This method is adopted and described in details by International Organization for Standardization (ISO) [35]. The standard uncertainty $u(x_i)$ to be associated with input quantity is the estimated standard deviation of the mean [35,37]

$$u(x_i) = s(\bar{X}) = \left(\frac{1}{n(n-1)} \sum_{k=1}^{n} (X_{i,k} - \bar{X})^2 \right)^{1/2} \qquad (6)$$

The combined standard uncertainty $u(x_i)$ is obtained by combining the individual standard uncertainties u_i these can be evaluated as Type A and Type B. That is,

$$u_c^2(y) = \sum_{i=1}^{N} (\frac{\partial f}{\partial x_i})^2 u^2(x_i) \qquad (7)$$

Uncertainty model used for the determination of the UVA irradiance $E_{UVA}(\lambda)$ is [14]

$$E_{UVA}(\lambda) = E_S(\lambda) + \delta E_l + \delta E_r \qquad (8)$$

where, $E_S(\lambda)$ = uncertainty due to reference spectral irradiance UVA standard radiometer (obtained from the calibration certificate).

δE_l = uncertainty due to distance effect on the irradiance measurements (calculated by using the inverse square law).

δE_r = uncertainty due to repeatability of the measurements (standard deviation of repeated 5 times).

The uncertainty must be quoted whenever the results of a measurement are reported, it tells us about the precision with which the measurements were made. The uncertainty budget of the absolute irradiance and illuminance measurements are shown respectively in Table 1 and Table 2 with expanded uncertainty with confidence level 95% (coverage factor ***k***=2). Finally, UVA irradiance, and illuminance measurements are calculated.

Table (1). Estimated Uncertainty budget of UVA irradiance for Lamps

Uncertainty Component	***Relative Standard Uncertainty (%)***
Irradiance responsivity calibration of standard radiometer	5.2
Distance measurements	0.02
Repeatability	0.03
Relative Expanded Uncertainty (*k*=2)	**10.4**

Table (2). Estimated Uncertainty budget of illuminance for lamps

Uncertainty Component	***Relative Standard Uncertainty (%)***
Illuminance responsivity calibration of standard photometer	6
Distance measurements	0.02
Repeatability	0.04
Relative Expanded Uncertainty (*k*=2)	**12**

6. Conclusion

UVA emission and illuminance were measured from commercial Compact Fluorescent Lamps (CFLs) and Light Emitting Diode (LED) Lamps on the Saudi Market. UVA emission were studied to assess their unwanted output in the UVA region. Various parameters such as ultra violet irradiance (UVA), ratio of UVA irradiance to electrical power (η) and ratio of UVA power to luminous flux (K), for the two types of lamps are studied to dedicate their performance. The higher values were measured in Compact Fluorescent Lamps (CFLs) than Light Emitting Diode (LED) Lamps. The Light Emitting Diode (LED) Lamps appeared to be zero value of (η) which is safe for human. Data analysis was performed. Uncertainty model includes all parameters accompanied with the measurements are studied. The accompanied uncertainty in the absolute UVA irradiance measurements (10.4 %) and in the illuminance measurements (12%) are calculated respectively in Table. 1 and Table. 2 with confidence level 95% (*k*= 2). According the results of this research, we recommended using Light Emitting Diode (LED) Lamps. Also, we recommend using Compact Fluorescent Lamps (CFLs) at short distance in table lamps or other desk-top application.

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