Measurement of Optical Exposures and Determination of Safe Distances Of Common Artificial Radiation Sources Used in Homes and Workplaces in Nigeria

[1]Olowookere, C.J.,[2]Oluwadamilare, O.B.,[2]Alade, A.O., and[3]Adeyemi, F.O.

[1] Department of Physics, University of Medical Sciences, Ondo City, Ondo.
[2] Department of Physics, AjayiCrowther University University, Oyo.
[3] Department of Physics, Ondo State University of Science and Technology.

(Received May 11, 2021; Revised July 03, 2021; Accepted October 23, 2021)

Abstract

Lighting in homes and workplaces is essential especially in places like basement and reading rooms during the day and night time. Artificial light sources such as incandescent bulbs (IBs), energy saving bulbs (ESBs) and LED lamps are common today because they are part of man lighting systems. Energy bulbs and LED lamps appear to be effective because of their low energy consumption, low heat output and optimal light output even at low wattage. This study examines the exposures arising from common bulbs used in Nigeria in the recent times. It also explores the possibilityof determining the safe distance (SD)of users from each bulb to prevent overexposure. Measurement of optical radiation (Lux) was carried out onseven energy saving bulbs (ESBs) and three incandescent bulbs (IBs) (wattage range of 15-200 W) at room temperature by using calibrated Digital Luxmeter at different distances which range between 0.10 m and 1.70 m from the source. The measurement was done in a darkroom pre-tested and found to be light-proofed. Results of the investigation show that at a distance of about 0.50 mfrom the light sources, the optical radiations of all the bulbs to the eyes are within the safe limit for offices, hospitals and schools. It is evident from the measurement carried out on bulbs of the same wattage, but of different manufacturer that the exposures produced are different under the same condition.ESB saves four times as much energy as IB. Lower wattage ESBs produce more exposures than higher wattages IBs.

Keywords*: optical exposure, optical radiation, energy saving bulb, LED bulb, incandescent bulb, lux, artificial radiation, safe distance*

1. 0 Introduction

Visible light is part of electromagnetic spectrum that can be detected by the eyes through the sensation of vision. It falls within the wavelength of 400 nm and 750 nm. A human eye is extremely sensitive to light and colour and the many kinds of information they convey. Life of many plants and animals depend on the visible light to find food and to produce their food. With very few exceptions, living creatures depend on light for their existence. Most of the visible lights come from the natural sources-the sun [1]. The sun's high temperature produces light of every wavelength. Light can be produced at high temperature by the process of incandescence. Hot material produces light of different colours because of the various temperatures.

Aside thethe sun, other natural sources of incandescent light strongly affect life on earth. Stars, lightning and fire produce natural visible light through luminescence. This does not require high temperature needed for incandescence. The production of light by living organism is called bioluminescence. This occurs in most cases by the process of chemical reaction reaction rather than from intense heat. Bioluminescence produces little heat. Research on bioluminescence led to the development of light emitting diode (LED [2].

*Corresponding author email: colowookere@unimed.edu.ng

ABC Publications Incorporated

Artificial sources of visible light that use fire include candles, natural gas lamp. Those that use electricity are; incandescent (3500^{o}C- produces more infra red light than visible light) bulb, halogen bulb and fluorescence bulb. A fluorescent bulb is filled with a mixture of mercury vapour and other gases that give off ultraviolet light when an electric current passes through them. One of the fastest growing sources of visible light is the light emitting diode (LED). Light emitting diode do not involve bulb filament or gases. Instead they produce light electronically-it converts electrical energy directly into visible light. The device produces bright light, it does not break easily, uses little energy, produces little heat and can last for a long time. As a result of its high comparative advantages over other artificial light sources, it penetrates into a wide range of consumer products including toys[3]. Being compact and versatile light source, LEDs offer new opportunities in the design of toys, to introduce new functionality and to improve visual appeals to a child. LEDs can be used as indicator for (children to stare at) communication sources or for illumination.

Other artificial light sources include energy bulb and laser. The visible spectrum is located between the infra red ray and ultraviolet rays. The region of wavelength which the visible light especially those produced from artificial sources is of great concern because of the safety of human subjects. The artificial lights are used in offices and homes for lighting and reading.

Different bulbs used in homes fall under the incoherent optical radiation from artificial sources. The wavelength range of electromagnetic waves between 1x 10^{2}nm and 1mmis known as optical radiation. This consists of ultraviolet (UV) (100-400 nm), visible (380-780 nm) and infra redradiation (IR) (780- 1 mm). There is an overlap of wavelength (380 and 400 nm) between visible and ultraviolet radiations [4].

Energy saving bulbs and incandescent bulbs are used in homes workplace, operating theatres, reading lamps and hospitals for lighting in the recent times. This is as a result of its energy saving ability and less heat is generated during use. Ocular diseases, including cataract, eyelids malignancies, uveal melanoma, photokeratitis, droplet keratopathy, and macular degeneration are triggered by exposure to solar ultraviolet radiation (UVR) and visible blue light[5, 6, 7]. Earlier reports have shown a strong relationship between UVR exposure and skin and eye diseases ([8, 9, 10]. The blue light photochemical hazard is considered as dominant risk of retina damage for long time exposures.

In the UV spectral range, the risk of adverse health effect to the eyes and the skin increases significantly with shorter wavelengths, especially below 315 nm, and it is generally recommended to avoid needless exposure to UVR. It is recommended that LEDs emitting below 315 nm should not be used in children's toy[3]. Ultra violet transmittance of crystalline lens is much higher in infants under two years of age than in older children [11]. An attempt to account for the increased risk of adverse effects for very young children, it is suggested that Ultra Violet A and visible light accessible emission limits for LEDs emitting below 440 nm (within the visible spectrum) should be reduced by a factor of ten for toys aimed at children below three years of age [3].

In the recent times, a diverse range of artificial sources of optical radiation emitting in the wavelengthrange 180-3000 nm are found throughout modern hospitals and homes. Some are also seen in shops and boutiques. These include office lighting, operating theater lighting, special dermatologic and ophthalmic examination lamps, and sources used to provide ultraviolet (UV), photodynamic (PDT) and neonatal blue-light therapies, along with a large number of lasers [12]. Workplace exposures to coherent and incoherentoptical radiation from such sources are now regulated in Great Britain under the Control of Artificial Optical Radiation (AOR)2010, that implement the Physical Agents (Artificial Optical Radiation) Directives (AORD) 2006//25/EC [13].Excessive UV light may predispose children to cataract, pterygia, and muscular toxicitylater in adult life**.**

This paper reports the result of optical exposures measured from common artificial radiation sources (energy saving bulbs and incandescent bulbs) used in Nigeria. Safe distances (SDs) for different bulbs in homes and other environments were also determined.

2.0 Materials and Methods

Ten commonly used radiation sources were selected from the market for this work. These consist of seven energy saving bulbs (ESB) and three incandescent bulbs (IB). The voltage ratings of all the bulbs lie between 220 and 240 volts. The wattages of the ESB considered range between 15 and 85 W and those of IB range between 60 and 200 W as shown in Table 1. The measurement was done in a pretest light- proofed darkroom of Physics Department, AjayiCrowther University, Oyo.A light-proofed darkroom was prepared and tested using a factory calibrated Digital Luxmeter (photodetector).

Each bulb was suspended from a rigid body at a distance of 3.5 m from the floor and a measuring tape was hanged vertically beside it to measure source-detector distances. A factory calibrated Digital Lux Meter whose calibration was still valid at the time of the measurement.The digital Luxmeter was placed directly in the path of the beam below (facing the bulb) the bulb and the illuminance at different heights (interval of 10 cm) were measured and recorded for each bulb. Temperature of the bulbs during measurement ranged between 15^o and 180^ocelsius. The measurement was done between a voltagerange of 220 – 240 volts.

Table 1: Artificial Sources Parameters

Bulb Type	*Wattage (W)*	*Manufacturer*	*Voltage Range (V)*
ESB1	15	AKT (China)	220-240
ESB2	18	Everlite (China)	220-240
ESB3	20	Damaplus(China)	220-240
ESB4a	26	AKT (China)	220-240
ESB4b	26	Damaplus(China)	220-240
ESB5	40	AKT (China)	220-240
ESB6	85	Feto (China)	220-240
IB1	60	P2SEO (China)	220-240
IB2	100	JUNGSEN (China)	220-240
IB3	200	JUNGSEN (China)	220-240

ESB : Energy Saving Bulb, IB: Incandescent Bulb

3.0 Results and Discussion

Table 2 shows different types of bulbs examined in the study and the range of exposures measured during the study. The third column shows that the range is large and appreciable. This is an indication that between 10 and 100 cm exposures are appreciable for all the bulbs. However, the range of exposure between 110 cm and 170 cm are relatively low, and in some cases zero. This shows that at distances at above 100 cm exposures may not have effects on the users, but useful for the comfort of the eyes.

Table 2. Different Bulbs and Wattages and Range of Exposure for different range of Length

Bulb Type	*Wattage (W)*	*Range of Exposure (lx) (between 10-100cm)*	*Range of Exposure (lx) (between 110-170cm)*
ESB1	15	5-350	2-4
ESB2	18	1-80	0
ESB3	20	1-65	0
ESB4a	26	4-420	1-4
ESB4b	26	1-108	0
ESB5	40	7-468	2-5
ESB6	85	5-913	2-4
IB1	60	2-160	0
IB2	100	10-756	4-8
IB3	200	16-1064	5-12

Figures 1, 2 and 3show the relationship between exposure distances of the source from the target. Figure 1 shows that the exposure to a certain degree depends on the manufacturer for the same wattage. It is expected that higher exposure will be obtained from bulbs with higher wattage, but this work has shown that this was possible for the product from the same source. Bulbs from different sources (manufacturers) have different exposures under the same condition. It is evident that certain products (such as AKT) with lower wattages have higher exposures than other products with higher wattage. This abnormality could be as a result of the material from which the bulbs (Danaplus and Everlite) were made or the current in the bulb. It is important to consider the manufacturer in the choice of electric bulb for a certain purpose. Figures 2 and 3 demonstrate the pattern of exposure for different

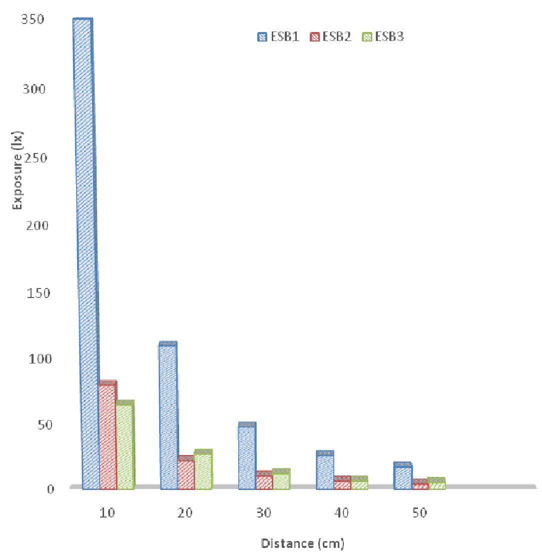


FIGURE 1: EXPOSURE VERSUS DISTANCE (15, 18 AND 20 W -ESB)

ESBs and IBs. The trends show that, they followed the fundamental pattern of radiation exposures. Radiation exposure is expected to follow an inverse square law, that is, the intensity is inversely proportional to square of distance from the source (ie. $E_w = kD^{-\lambda}$ *where* $\lambda = 2$) This study shows that the relationship between exposure (E) and distance (D) from the source for different wattages assume the forms shown in Table 3. These are the pattern of best fitted equations.

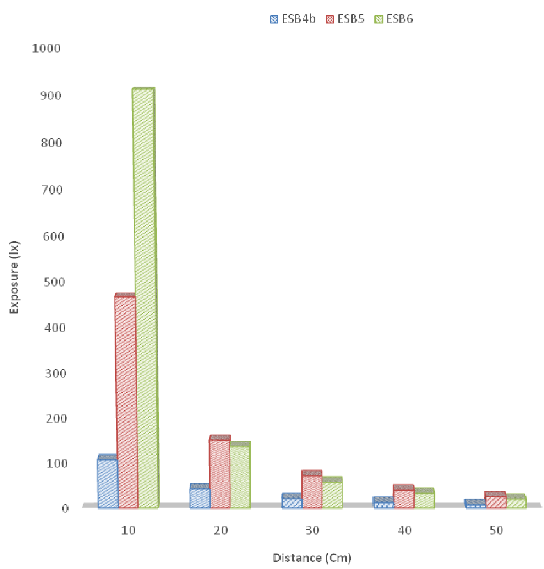
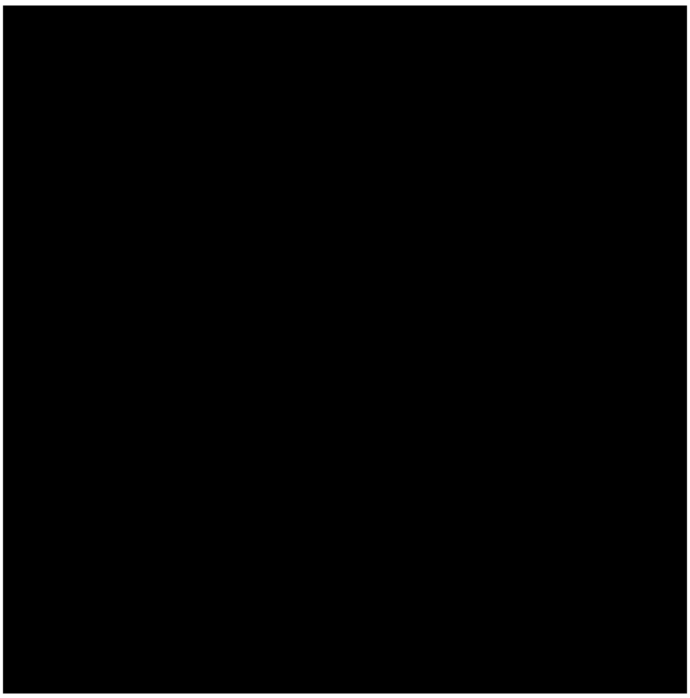


FIGURE 2: EXPOSURE VERSUS DISTANCE (26, 40 AND 85W- ESB)

Table 3: Relationship between exposure (E (lx)) and distance of target from the source (D (cm)) for selected ESB and IB bulbs

Bulb Type	Wattage (W)	Equations Parameter		R^2
		k (10^4)	λ	
ESB1	15	2.7038	1.87	0.998
ESB4b	26	4.7757	2.03	0.999
ESB5	40	3.9468	1.88	0.998
IB1	60	1.8335	1.88	0.963
IB2	100	6.4769	1.90	0.998
IB3	200	8.6977	1.85	0.997

The value of λ ranges between1.85 (IB3) and 2.03 (EB4b), and the values of k ranges from1.8335 x 10^4 (IB1) and 8.69 x 10^4(IB3). The



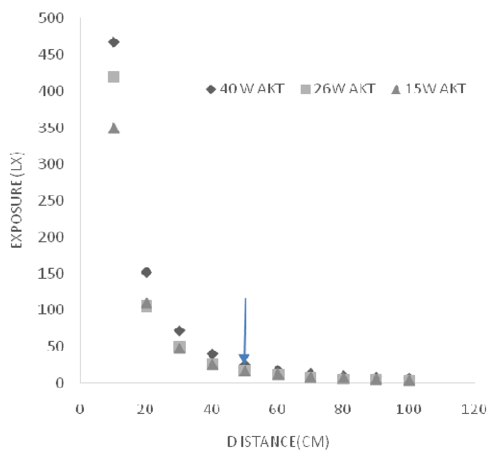


FIGURE 4. PLOT OF EXPOSURE (E) AGAINST DISTANCE (D) FROM THE SOURCE (ESB)

results of IB1 to IB3 shows that the value of k increases with wattage. This is the case of ESB1 and ESB5 (AKT products). The value of k increases from 2.7038 x 10^4 (ESB1-15 W) to 3.9468 x 10^4 (ESB1-40 W)

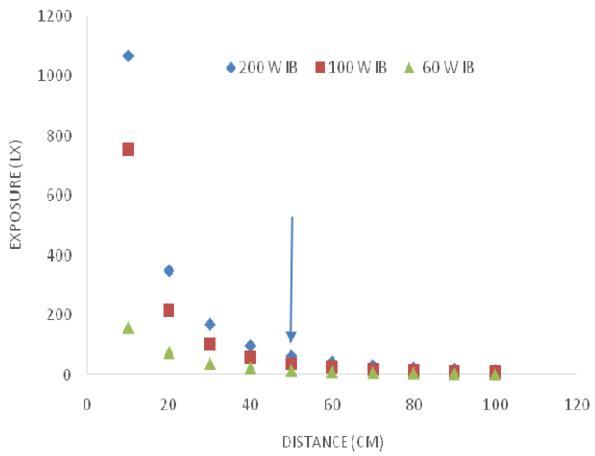


FIGURE 5: PLOT OF EXPOSURE (E) AGAINST DISTANCE (D) FROM THE SOURCE (IB)

Figures 4 and 5 are the plot of exposure against distance of the source from the target. The results indicate that at a distance of about 50 cm, exposure values of all the bulbs apparently approach unity.

Table 4 shows the results of safe distances determined from the exposure levels in school reading room. This was determined based on the acceptable limit recommended by international regulatory body. The safe distance is the distance between the sources of optical radiation for which the exposure is within the acceptable limit.

Determination of Safe Distance (SD) is necessary because the eyes and skin are the organs most susceptible to damages by optical radiation. The type of effects, injury threshold and damage mechanism vary significantly with wavelength [14].In this study, exposure recorded at the smallest distance forESB2 and ESB3 in the school reading room, auditorium and hospital fall within the recommended value.

Table 4. Estimated Safe Distance (SD) for School and Hospital

Bulb Type	Wattage (W)	Equations Parameter		R^2
		k (10^4)	λ	
ESB1	15	2.7038	1.87	0.998
ESB4b	26	4.7757	2.03	0.999
ESB5	40	3.9468	1.88	0.998
IB1	60	1.8335	1.88	0.963
IB2	100	6.4769	1.90	0.998
IB3	200	8.6977	1.85	0.997

SD: Safe Distance, WAL: Within Acceptable Limit

This implies that the eyes of a subject, especially pediatrics should not be close to the source of optical radiation below the Safe Distance.

Knowledge of Safe Distance (SD) prevents children fromoverexposure to visible light. Though the focusing characteristic of a children eyes are still developing and 200 mm (20 cm) as the worst case exposure distance may not be appropriate [15]. It should be noted that non-laser sources do not emit enough power in the wavelength region above 3 x

10^3 nm to cause health hazard other than the possibility of heat stress [16]. Additionally, people with certain medical conditions may be at risk from exposures that are otherwise innocuous [14].High energy visible (HEV) light otherwise called "Blue Light" lies between the wavelength of approximately 381and 500 nm (runs from ultraviolet spectrum and overlaps into visible light). Thesehigh illumination-light have been shown to cause irreversible cell damage in some individuals. Elevated exposure to Blue Light may increase the risk of macular degeneration disease where an affected person loses their central vision. It has been reported that exposure to Blue Light comes through computers, televisions and cell phones. To avoid exposure to HEV light, blue blocker lens could be used by a subject or could keep a reasonable distance from the source of radiation. The blue blocker lens alters the appearance of blue and green colors [17]. Photochemical damage can be classified as Type II or photochemical retinal damage. The photochemical retinal damage resulting from chronic exposures to bright light is called Type I photochemical retinal damage [18]

Effectiveness of different bulbs was investigated. Two bulbs (AKT-26W and DanaPlus-26W) with the same wattage were examined (Figure 6) and they were found to produce different illuminance (lux) under same condition (220-240 V, 50 Hz). This difference might be attributed to the nature (resistance) of material used in DanaPlus product. The resistance of the material must have affected the current supplied to the bulb, and hence the attendant exposures produced. The exposure from AKT is higher than that of DanaPlus under the same wattage

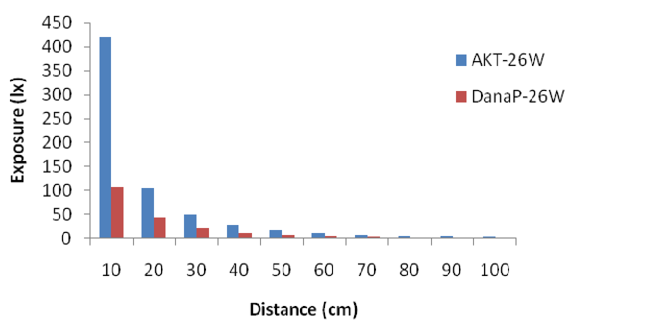


Figure 6. Comparison of Exposures of two products (manufacturers) of the same wattage

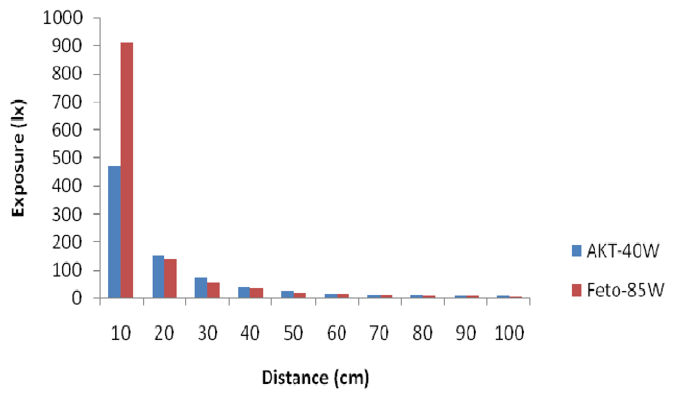


Figure 7. Comparison of two products (bulbs) of different wattages

by factors which range from 2.46 to 4.00 units. Knowledge of this fact is important in the selection of a product for a particular purpose. If higher exposure is required, AKT product could proof useful, and if lower exposure is desired especially where children will be exposed, soft and lower exposure might be desirable.

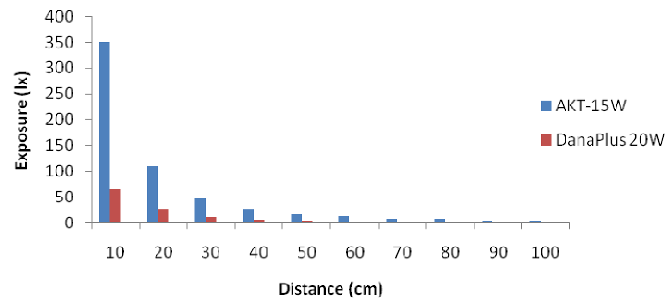


Figure 8. Comparison of two products (bulbs) of different wattages

Results of exposure of light bulbs from different manufacturers under different wattage was also examined. Figures 6 and 7 show that AKT bulb at lower wattages produces higher exposure than Feto and DanaPlus products. This may perhaps be as a result of the material from which the two products were made. This is an indication that AKT produces more exposure at lower wattage than other two products on the market. This informs the need for the manufacturers of the other products to examine the reason for the differences. The two results showthe necessity for further investigation into the reason for higher exposure at a lower wattage than other products. The variation of different products at different voltages and currents can also be investigated. It is evident from this study that, higher exposure can still be achieved if desired, by choosing a product that performs better at lower wattagesthan higher wattages in other products in order to save energy consumed per unit time.

Table 5 shows a comparison of wattage and exposure of ESB with IB. Results show that the illuminance of ESB at a relatively lower wattage is higher than the exposure of higher wattage IB. At a distance of 10 cm, the exposures are higher by factors which range between 1.21 to 2.93 units, and the range of factors by which lower wattage bulbs exposure are greater than higher wattage at 20 and 30 cm range between 1.32 and 2.03 units.It is clear from Table 5 that ESB bulbs (AKT) has a higher exposure levels than incandescent bulbs, even at a lower wattage. Exposure level of 40 W ESB is higher than that of 60 W incandescent bulb by a factor of 2.93 at a distance of 10cm. The trend shown in Table 5 is an indication that a 40 W (ESB) bulb would produce almost thrice the exposure of 60 W (IB), and a 15 W (ESB) produces more than twice the exposure of a 60W (IB).

Table 5: Comparison of exposure levels between ESB and IBat different wattages

ESB Wattage (Exposure--lx)	IB Wattage (Exposure-lx)	Factor by which ESB exposure is greater than IB	Distance from the source
40(468)	60 (160)	2.93	10
85 (913)	100 (756)	1.21	10
15 (350)	60 (160)	2.19	10
40 (152)	60 (75)	2.03	20
15 (110)	60 (75)	1.46	20
40 (72)	60 (38)	1.89	30
26 (50)	60 (38)	1.32	30

The results in Table 5 shows that ESB (AKT) can save as much as four times energy per unit time required to power the IB bulb to produce twice the exposure at a distance of 10 cm. In addition, 40 W (ESB-AKT) bulb saves about 1.5 energy per unit time to produce twice the exposure of 60 W bulb at a distance of 20 cm from the object. This is an indication that ESB bulb(especially AKT) product saves a great deal of energy per unit time. ESB bulb could be very useful where the power sourceis solar energy.

However, it is important to use lower wattage ESB bulbs when lighting children (newborns and toddlers) rooms and hospital wards to ensure that the high intensity light does not damage (sensitive part of their retina) their eyes. Exposure to optical radiation in the wavelength range of about 300-400 nm might affect the eyes and the skin.

4.0 Conclusion and Recommendations

In this study exposure level of ten common artificial light sources used in Nigeria were examined. Exposure level of each bulb was measuredat different distances from the source, and the corresponding Safe Distances from the subject were determined. The study shows that the exposure levels of ESB are generally higher (at lower wattage) than the exposure levels of IB. Energy Saving Bulbs (ESBs) proved to be more effective than the Incandescent Bulbs (IBs) in terms of illumination and power consumption to produce the same illumination. Extensive work on both ESB and IB under different physical conditions may be undertaken to ascertain their effects on the eyes of human and animal subjects.

Acknowledgments
All authors would like to thank the staff of Electronic and Communication Laboratory, Department of Physics, AjayiCrowther University Oyo for providing the Lux Meter used, and made available their Optics Darkroom (laboratory) for the investigation.

References

[1] J. Volchko, Visible light spectrum: fro a lighting manufacturer's perspective. Lumitex 440-
345-8882, April 19, 2014, pp1-10, Accessed on13/11/2019 at

http://www.lumitex.com/blog/visible-light-spectrum.
[2] McDougal Little Physical Science, McDougal Little, a division of Houghton Mifflin Company,2005, pp 88-92..
[3] M. Higglet, J.B.O' Hagan and M. Khazova "Safety of emitting diode in toys." J. Radiol. Prot. Vol 32, pp.51-72, 2012.
[4] CIE. ILV: International lighting Vocabulary Vienna: CIE ;2011.
[5] WHO (World health Organisation0 Solar and ultraviolet radiation, World Health Organisation, London, 1992.
[6] B.K. Armstrong, A. Kricker. "The epidemiology of UV induced skin cancer" J Photochem Photobiol. B 2001 vol 63, pp. 8-18.
[7] R. Lucas, A.J. McMichael Solar and ultraviolet radiation-Global burden of disease from solar ultraviolet radiation. World Health Organisation (WHO), editor, Geneva:WHO, 2006.
[8] B.L. Diffey "Solar ultraviolet radiation effect on biological systems" Rev Phys Med Biol. 1991 vol 36, 299-328.
[9] J.C. Yam, A.K. Kwok "Ultraviolet light and ocular disease"IntOphthalmol, 2014 vol 34, pp. 383-400.
[10] C. Beckes, A. Religi, L. Moccozet, F. Behar-Cohen, L. Vuillemier, J.L. Bullard, D. Vernez Sun exposure to the eyes: predicted uv protection effectiveness of various sunglasses" J Exposure Sciences & Environmental Epidemiology, Springer, 2018,
[11] ICNIRP Guidelines on limit of exposures to broadband incoherent optical radiation (0.38 to 3µm) Health Physics: vol 72, pp. 539-540, 1997.
[12] A. Coleman, F. Fedele, M. Khazova, P. Freeman and R. Sarkany, "A survey of the optical hazard associated with hospital ligbt sources with breference to the control of artificial optical radiation at work reguloation of 2010," J Radiol. Prot, vol 30 (2010), pp. 469-489.
[13] AOR. Applied Optical Radiation. Directive 2006/25/EC 2006 on the maximum health and safety requirement regarding the exposure of workers to risk arising from physical agents (artificial optical radiation) Off. J. Eur. Union LI 14/38-59 https://eur/ex.europa.eu/LexUriserv/LexUr.serv.do?uri=uri=OJ:L8 006:114:0038:0059:EN:PDF.
[14] ICNIRP. ICNIRP Guidelines on limits of exposure to Incoherent visible and infrared radiation. Health Physics 105 (1):74-96, 2013.
[15] M.P. Higglet, J.B. O'Hagan and M. Khazova . Safety of light emitting diode. J. Radiol. Prot. 32 (2012) 51-72.
[16] ICNIRP. Revision of laser radiation for wavelength between 400 nm and 1.4 µm. Health Phy 79: 131 186;2000.
[17] B.J. Lund. Laser retinal thermal damage threshold: impact of small-scale ocular motion. J Biomed Opt 11:064033:2006.
[18] J. Mallero. Light veffects on the retina. In principles and practice of ophthalmology. 1994: 1326-1345.