Research Article

Ultraviolet Radiation Emissions and Illuminance in Different Brands of Compact Fluorescent Lamps

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Introduction. Replacing incandescent lamps with compact fluorescent lamps (CFLs), which are three to six times more efficient, is one of the easiest methods to achieve energy efficiency. The present study aimed to evaluate relationships between UV emissions radiated and illuminance CFLs. **Material and Methods.** This pilot study was conducted on 16 single envelope CFLs. The illuminance and UV irradiance of various types of CFLs are measured on a three-meter long optical bench, using a calibrated lux meter and UV meter, and measurement was done in 10, 25, 50, 100, 150, and 200 cm, in three angles, including 0°, 45°, and 90°, at the ages of 0, 100, and 2000 hours. **Result.** UVC irradiance was not observed at the distance of 10 cm in all of lamps. The lowest value of UVB irradiance was recorded in Pars Khazar lamp, while the highest value was recorded in Etehad lamps. UVR values measured at different times showed negligible differences; the highest asset value was detected in zero times. One way ANOVA indicated that relationships between UVA irradiance and illuminance were significant ($P < 0.05$). **Conclusion.** UVB irradiance in most of the lamp in 10 and 25 cm was more than occupational exposure and UVA except for the fact that Pars Khazar 60 watts and Nama Noor 60 watts were less than occupational exposure.

1. Introduction

The amount of energy used for lighting will be 80% higher in 2030 than today [1]. And Lighting is responsible for 19% of the electricity consumption [2]. On the other hand, one of the most important technologies in this century is energy saving that is an important item among the concept of environmental protection, economy, and improved science and technology [3]. There are various energy-saving products and compact fluorescent lamp (CFLs) is one of these products. Lighting energy can be saved in many ways, including (i) improving the efficiency of the light source; (ii) improving the efficiency of the specific component of lighting system, typically the ballast; (iii) improving the efficiency of the luminaries [4]. Replacing incandescent lamps with 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 [5]. Replacing technology can occur at a very low cost and provide immediate results [2]. CFLs are three to six times more efficient than incandescent lamps [6]. Egypt, Iran, Saudi Arabia, and Turkey are the largest consumers of electricity. These four countries consume about 88% of the region's total electricity consumption, who have a very aggressive current program to promote CFLs. In Iran, the Ministry of Energy has developed 20 different strategic goals, including the distribution of 93 million high-efficiency lamps for 21 million households. Using various distribution methods, about 65 million CFLs have been distributed to households up until the year 2009. This resulted in a reduction of 1750 MW (megawatt) of peak load, annual electricity saving of 3.8 Twh (terawatt-hour), and the reduction of 2.7 Mt (million tons) of CO₂ [2].

CFLs have many disadvantages. One of these emits higher acceptable levels of UV radiation [7]. 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 [8–13].

Ultraviolet (UV) radiation is a form of electromagnetic radiation on the electromagnetic spectrum, UV radiation comes between visible light and X-ray. UV radiation is based on its effect on living tissue, and wavelength is divided into three major groups: UVA (320–400 nm), UVB (290–320), and UVC (200–290) [14, 15].

The acute and chronic effects are the normal responses of the skin to UVR; acute reactions considered will be erythema (sunburn) and vitamin D production. Skin aging and skin cancer will be discussed as those reactions produced by prolonged or repeated UVR exposure.

Erythema induced by CFLs is strongly dependent on the wavelength of radiation. At 300 nm an average threshold dose or minimal erythema dose (MED) is about $10\text{--}20\text{ mJ}\cdot\text{cm}^{-2}$ whereas for UVA radiation the MED is about a thousandfold higher. Large doses of UVB may result in oedema, pain, and blistering although blistering never occurs with UVC [16].

Cole et al. demonstrated that CFLs emitted significant levels of UVB and UVC [8]. In 2004, Sayre et al. made quantitative measurements of UV emission from CFLs commonly used at home and in the workplace. His results show that all emitted appreciable levels of UVA and UVB, and several even emitted UVC [10].

Light output in the CFLs 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 [17]. In relation to the illuminance and ultraviolet radiation from compact fluorescent lamps and general lighting service (GLS) a study by Khazova and O'Hagan carried out that the results show in equal illuminance 500 lux for both lamps UVA for CFL and GLS was 0.05 w/m^2 and 0.03 w/m^2 , for UVB in CFL and GLS was 0.004 w/m^2 and 0.001 w/m^2 , respectively [18]. In typical practical conditions, the illuminance under CFLs is 500 lux and 10,000 lux outdoors in natural daylight. In this condition UVA for CFL and natural daylight was 0.05 w/m^2 and 5.4 w/m^2 , for UVB in CFL and natural daylight was 0.004 w/m^2 and 0.08 w/m^2 , respectively. Here the illuminance increases and the amount of UV radiations also increases [18].

Because of increasing the cost of electricity in recent years people use CFLs that consume 3–6 times less energy relative to incandescent lamps and because of nature of produced light in CFLs, ultraviolet radiation is generated and light output in the CFLs is influenced by the mercury vapor pressure inside the lamp, as change in contain mercury vapor can change light output and UV irradiance; the present study aimed to evaluate relationships between UV emissions radiated and illuminance from compact fluorescent lamps.

FIGURE 1: Single envelope CFLs.

FIGURE 2: Shield envelop CFLs.

2. Material and Methods

This pilot study was conducted on 16 CFLs that were randomly purchased from local retail outlets in Isfahan City, Isfahan, Iran. The light sources were manufactured by four manufacturers, including branded names and retailer owned brands. The CFLs were marked as 11, 18, 40, and 60 watts and all of the lamps contained integral electronic ballasts.

In this study, all of light sources were open (or single envelope) CFLs (Figure 1) and “shielded” refers to CFL that was completely enclosed within a bulb-shaped shield during the manufacturing process (Figure 2).

The illuminance and UV irradiance of various types of CFLs are measured on a three-meter long optical bench, using a calibrated lux meter and UV meter (Figure 3), and measurement was done in 10, 25, 50, 100, 150, and 200 cm, in three angles, including 0° , 45° , and 90° , at the ages of 0, 100, and 2000 hours [19]. In the angle 0° the lamps were orientated horizontally so that the tip of the lamp was facing the input diffuser of the UV and lux meter. This was to measure the radiation one might expect to receive if standing directly under a lamp suspended from the ceiling. In the angles 45°

TABLE 1: UVB irradiance ($\text{W}\cdot\text{m}^{-2}$) in different times for four brand CFLs at 90° in Iranian brands.

Brand of CFLs	Distance (cm)	10			25			50			100		
	Measurement time (hour)	0	100	2000	0	100	2000	0	100	2000	0	100	2000
Pars khazar	11 W	0.01	0	0	0.01	0	0	0	0	0	0	0	0
	18 W	0.01	0.02	0.01	0.01	0	0	0.01	0	0	0	0	0
	40 W	0.02	0.02	0.01	0.01	0	0	0	0	0	0	0	0
	60 W	0.01	0	0	0	0	0	0	0	0	0	0	0
Parmis	11 W	0	0.01	0	0	0.01	0	0	0	0	0	0	0
	18 W	0.01	0.01	0.01	0	0	0	0	0	0	0	0	0
	40 W	0.01	0.02	0.01	0	0	0	0	0	0	0	0	0
	60 W	0.01	0	0	0.01	0	0	0	0	0	0	0	0
Etehad	11 W	0	0	0	0	0	0	0	0	0	0	0	0
	18 W	0.01	0.01	0.01	0	0.01	0	0	0.01	0	0	0	0
	40 W	0.01	0.02	0	0.01	0	0	0	0	0	0	0	0
	60 W	0.02	0.02	0	0.01	0	0.01	0.01	0	0	0	0	0
Nama Noor	11 W	0.01	0.01	0	0	0	0	0	0	0	0	0	0
	18 W	0.01	0.01	0	0.01	0.01	0	0	0	0	0	0	0
	40 W	0.02	0.02	0	0.01	0	0	0	0	0	0	0	0
	60 W	0.02	0.02	0.01	0.01	0	0	0	0	0	0	0	0

FIGURE 3: Schematic diagram of experimental set up for illuminance and UV irradiance measurement.

and 90° for UV exposure from lamps used at desk or task lamps.

A type-666230 photometer-radiometer equipped with UVA, UVB, and UVC detectors was used to measure UV irradiance in all the three ranges and for illuminance measurement, a digital photometer types YF-170 was used. Measurements were performed in a dark room, maintaining the temperature at $(26 \pm 2)^\circ\text{C}$ and the relative humidity (45%). Following a 10-minute warm-up period, the emission spectrum of each lamp was measured. Measurements were repeated for each type of CFLs and finally averaged out.

Finally, the information was analyzed using SPSS-20. In order to compare UVA and UVB irradiance and the value and relationships between UV irradiance and illuminance in four brands in three angles, we used one-way ANOVA. A P value less than 0.05 was considered to be statistically significant.

3. Results

UV irradiance and illuminance were measured at the different distance for sixteen types of CFLs of different wattage. At the distance of 10 cm that was considered to be the closest

distance that people would be exposed to the lamp, even in the desk-top application UVC irradiance could not be detected in all the cases. For analyzing the UV content at the short distance, the measurements were conducted at the distance of 10 cm.

Negligible amounts of UVA and UVB were detected at 150 and 200 cm from all CFLs. Therefore, only data relating to the UV irradiance measured at 10, 25, 50, and 100 cm were analysed in this study.

In order to compare UV irradiance in three angles (0, 45, and 90°), one-way ANOVA indicated that difference between three angles was not significant statically ($P > 0.05$). The lowest amount was recorded in 45° ; furthermore, in most cases the highest amount of UV irradiance was detected in 90° but this difference was not significant statically.

Table 1 shows the UVB irradiance for four brands of CFLs; one-way ANOVA indicated that difference between UVB irradiance in the same wattage of four brands of lamps was not significant statistically ($P > 0.05$). The lowest value of UVB irradiance was recorded in Pars Khazar lamp, while the highest value was recorded in Etehad lamps. Table 2 shows the UVA irradiance ($\text{W}\cdot\text{m}^{-2}$) values in 10, 25, 50, and 100 cm for three measurement times, including 0, 100, and 2000 hours; as is obvious, UVA irradiance increased with the increase in lamp electrical wattage and emissions decreased rapidly with distance, but such cases are not found for UVB irradiance. UVR values measured at different times showed negligible differences; the highest values were detected in zero times. One-way ANOVA showed that this value for three times was not significant statistically. Pars khazar with the highest UVA irradiance placed in the first group and other groups were Nama Noor, Parmis, and Etehad, respectively.

To make a better comparison in UVR concentration, it would be more appropriate to compare UVA concentration relative to illuminance in four brands. As shown in Table 2

TABLE 2: UVA irradiance ($\text{W}\cdot\text{m}^{-2}$) and illuminance (lux) in different times for four brand CFLs in Iranian brands.

Brand of CFLs	Power (watt)	Distance (cm)	10			25			50			100		
		Measurement time (hour)	0	100	2000	0	100	2000	0	100	2000	0	100	2000
Pars khazar	11 W	UVA ($\text{W}\cdot\text{m}^{-2}$)	0.29	0.33	0.22	0.05	0.05	0.03	0.02	0.02	0	0.01	0	0
		Illuminance (lux)	6850	6580	6520	982	1012	1099	281	264	316	84	82	93
	18 W	UVA ($\text{W}\cdot\text{m}^{-2}$)	0.68	0.92	0.36	0.16	0.13	0.06	0.06	0.04	0.01	0.02	0.02	0
		Illuminance (lux)	9990	9880	6900	1476	1373	885	371	388	150	105	112	74
	40 W	UVA ($\text{W}\cdot\text{m}^{-2}$)	1.63	1.24	1.05	0.32	0.3	0.19	0.09	0.07	0.07	0.03	0.03	0
		Illuminance (lux)	13440	11490	13250	3320	3440	2890	784	707	689	206	214	166
Parmis	11 W	UVA ($\text{W}\cdot\text{m}^{-2}$)	1.7	1.51	1.41	0.54	0.48	0.4	0.05	0.08	0.07	0.03	0.05	0.02
		Illuminance (lux)	14610	14650	14020	3550	2940	2880	921	731	680	266	209	180
	18 W	UVA ($\text{W}\cdot\text{m}^{-2}$)	0.19	0.13	0.12	0.04	0.04	0.01	0.02	0.02	0	0	0.02	0.01
		Illuminance (lux)	3870	3290	3030	657	598	499	189	165	36	60	49	34
	40 W	UVA ($\text{W}\cdot\text{m}^{-2}$)	0.52	0.34	0.27	0.09	0.08	0.05	0.04	0.04	0.02	0.02	0.02	0
		Illuminance (lux)	9000	9350	8510	1330	1300	1240	501	466	361	142	126	103
Etehad	11 W	UVA ($\text{W}\cdot\text{m}^{-2}$)	0.96	0.87	0.55	0.17	0.26	0.12	0.07	0.05	0.02	0.03	0.03	0
		Illuminance (lux)	12470	12340	12820	3820	3590	2680	837	865	697	243	225	194
	18 W	UVA ($\text{W}\cdot\text{m}^{-2}$)	0.67	0.61	0.46	0.15	0.1	0.1	0.07	0.03	0.07	0.05	0.03	0
		Illuminance (lux)	13090	14590	10230	4253	3590	2660	689	921	587	266	261	167
	40 W	UVA ($\text{W}\cdot\text{m}^{-2}$)	0.07	0.07	0.23	0.02	0.02	0.06	0.03	0.01	0	0.02	0.01	0
		Illuminance (lux)	3500	3170	3090	595	540	512	177	164	151	47	41	35
Nama Noor	11 W	UVA ($\text{W}\cdot\text{m}^{-2}$)	0.36	0.24	0.21	0.1	0.07	0.03	0.07	0.03	0.01	0.03	0.02	0
		Illuminance (lux)	6860	6290	6020	1471	1076	1062	386	326	315	117	92	89
	18 W	UVA ($\text{W}\cdot\text{m}^{-2}$)	0.54	0.38	0.31	0.13	0.12	0.05	0.6	0.04	0.01	0.03	0.03	0
		Illuminance (lux)	12340	10450	8630	3850	3400	3100	910	831	317	260	268	162
	40 W	UVA ($\text{W}\cdot\text{m}^{-2}$)	0.97	0.89	0.26	0.33	0.2	0.15	0.09	0.05	0.03	0.04	0.04	0
		Illuminance (lux)	8050	11600	5220	3490	3060	2860	866	812	801	330	254	225
Etehad	11 W	UVA ($\text{W}\cdot\text{m}^{-2}$)	0.41	0.21	0.13	0.07	0.05	0.04	0.02	0.03	0	0.01	0.02	0
		Illuminance (lux)	2920	2850	1640	520	554	513	210	162	153	56	49	30
	18 W	UVA ($\text{W}\cdot\text{m}^{-2}$)	0.49	0.22	0.27	0.07	0.05	0.01	0.03	0.03	0	0.02	0.02	0
		Illuminance (lux)	3610	2390	2470	541	425	325	176	128	91	45	39	44
	40 W	UVA ($\text{W}\cdot\text{m}^{-2}$)	1.01	0.7	0.27	0.18	0.14	0.04	0.07	0.04	0	0.03	0	0
		Illuminance (lux)	6640	5200	3470	1481	1001	484	378	260	148	100	81	24
Nama Noor	60 W	UVA ($\text{W}\cdot\text{m}^{-2}$)	1.3	1.07	0.46	0.28	0.25	0.13	0.09	0.05	0.01	0.04	0.03	0
		Illuminance (lux)	9490	8460	4860	2560	2230	1057	601	812	328	180	157	40

Pars khazar with the highest value of UVA emission also has the highest amount of illuminance, but Nama Noor with the lowest illuminance placed in second rank in UVA emission. One-way ANOVA indicated that relationships between UVA irradiance and illuminance were significant ($P < 0.05$).

4. Discussion

Measurements of UVR and illuminance irradiance from the CFLs were made in the ultraviolet and visible part of the spectrum (100–780 nm) at distances of 10, 25, 50, 100, 150, and 200 cm. Techniques for the measurement of UVR may be divided into three classes: physical, chemical, and biological. The regions of ultraviolet radiation have widely been differing in physical properties and potential for causing biological

damage [16], including the following: (i) UVA rays, which are the weakest of the UV rays, can cause skin cells to age and indirect damage to cells' DNA. (ii) UVB rays are slightly stronger. They can cause direct damage to the DNA, sunburns, and skin cancers. (iii) UVC rays are the strongest UV rays. Fortunately, they react with ozone do not reach the ground. But they can be found in some man-made sources, such as mercury lamps [20].

The standard for occupational exposure to ultraviolet radiation is based on the threshold limit values (TLV) published by the American conference of Governmental Industrial Hygienists. These TLV are relative to a monochromatic source of radiation at 270 nm. The exposure at this wavelength in 8 h is 30 Jm^{-2} . In our study, measurable values of the UVC irradiance (100 nm–280 nm) were not observed

using UVC detectors at the distance of 10 cm in all of lamps that is consistent to study by Khazova and O'Hagan that stated, "Radiation below 280 nm (UVC) is not received at the earth's surface and is not emitted by tubular fluorescent and incandescent lamps for general lighting purposes." But in another study by Khazova and O'Hagan on 73 CFLs (20 single envelopes and 53 double envelope CFLs) at 2 cm and 20 cm, a result of measurement showed single envelope lamps emitted UVC and they concluded that the UVC irradiance was probably due to defects in the phosphor coating of the glass envelope [18].

As is denoted the lowest and highest UV emission were recorded in 45° and 90° angle, respectively. The similar results reported by Roisin et al. and Safari et al. concluded that CFLs radiate more horizontally (90°) at the expense of the vertical intensity (0°) [13, 21].

All of light sources emitted UV in regions UVA and UVB; the amount of emissions varied randomly between different bulbs and different manufacturers. According to occupational exposure limited (OEL), occupational UVB and UVA exposure should be limited to an effective irradiance of 0.000003 and 1.04166 W·m⁻² in an 8 h period, respectively [22, 23].

At 10 cm distance, measurement UVB irradiance from most of CFLs was more than OEL. The highest value was recorded in Etehad lamp with 0.03 W·m⁻² that was 10000 times more than OEL.

Among sixteen CFLs which was measured at a distance of 10 cm, the UVA output for Pars Khazar 40 and 60 watts was 1.61 W·m⁻² and 1.78 W·m⁻², respectively, and for Nama Noor, 60 W was 1.3 W·m⁻²; this shows that three CFLs would exceed the UVA exposure limit in 8 h at a distance of 10 cm. Study by Mironava et al. indicated that UV irradiance was different between bulbs and different manufacturers, and the result from that study showed UVR in different distance in many cases was exceeded of occupational exposure limited [24].

Rihner and McGrath (1992) conducted a survey of systemic lupus erythematosus (SLE) patients. They reported a substantial number who recalled having experienced symptom flares after exposure to fluorescent light [25]. 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 [26].

5. Conclusion

UV emission (UVA, UVB, and UVC) and illuminance (100 nm–780 nm) were measured from different brands, size, and electrical powers of CFLs. UVC emissions were not observed at the distance of 10 cm in all of lamps. UVB irradiance in most of the lamp in 10 and 25 cm was more than occupational exposure. The highest values were measured in Etehad lamps while of all the bulbs tested, in UVA irradiance, the Etehad appeared to be the safest. Nama Noor with the lowest illuminance has more value of UVA. As is denoted this study carried out on single envelope CFLs; in some cases the amount of UVR was more than OEL; in order to decrease

UVR there are two methods: (i) shielded fluorescent lamps by acrylic diffusers and (ii) double envelope lamp.

As Elwood (1986) noted, it has generally proved impossible even to specify whether the fluorescent lamps were shielded by acrylic diffusers or not; if they were, then the ultraviolet exposure of people in those spaces was negligible because of the absorptive properties of acrylic [27].

In order to compare the UV radiation from double and single envelope a study was conducted by Khazova and O'Hagan in which the double envelope lamp has very low level of UVB emission, with the spectrum cut-off below 313 nm, whereas some of single envelope lamps emit in the UVB and UVC (254 nm) regions, probably due to defects in the phosphor coating [18].

Conflict of Interests

The authors declare that they have no conflict of interests.

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