Radiation Protection Dosimetry (2008), pp. 1–5 doi:10.1093/rpd/ncn234

TECHNICAL NOTES

OPTICAL RADIATION EMISSIONS FROM COMPACT FLUORESCENT LAMPS

M. Khazova* and J. B. O'Hagan
Health Protection Agency, Chilton, Didcot, OX11 0RQ, UK

Received June 11 2008, revised July 25 2008, accepted August 2 2008

There is a drive to energy efficiency to mitigate climate change. To meet this challenge, the UK Government has proposed phasing out incandescent lamps by the end of 2011 and replacing them with energy efficient fluorescent lighting, including compact fluorescent lamps (CFLs) with integrated ballasts. This paper presents a summary of an assessment conducted by the Health Protection Agency in March 2008 to evaluate the optical radiation emissions of CFLs currently available in the UK consumer market. The study concluded that the UV emissions from a significant percentage of the tested CFLs with single envelopes may result in foreseeable overexposure of the skin when these lamps are used in desk or task lighting applications. The optical output of all tested CFLs, in addition to high-frequency modulation, had a 100-Hz envelope with modulation in excess of 15%. This degree of modulation may be linked to a number of adverse effects.

INTRODUCTION

There is a drive to energy efficiency to mitigate climate change. Lighting is responsible for ~14% of the European Union's electricity consumption, and new energy efficient lighting technology can reduce this factor by as much as 80%[1]. To meet this challenge, the UK Government has proposed phasing out incandescent lamps by 31 December 2011 and replacing them with energy efficient fluorescent lighting, including compact fluorescent lamps (CFLs) with integrated ballasts[2].

This paper presents a summary of an assessment conducted by the Health Protection Agency in March 2008 to evaluate the optical radiation emissions of CFLs currently available in the UK consumer market.

PREVIOUS RESEARCH

CFLs generate ultraviolet radiation (UVR) from a discharge in mercury vapour. The energy in the ultraviolet photons is converted into visible optical radiation in the phosphor coating inside the glass envelope of the lamp. Ideally, the conversion would be 100% efficient. However, in reality, some UVR is transmitted through defects in the phosphor coating and the glass envelope.

The Artificial Optical Radiation Directive[3] requires businesses, including home-base businesses, to limit exposure to optical radiation below the exposure limits in the Directive, including exposure to UVR hazards from general lighting.

Whillock *et al.*[4] in the 1990s concluded that, under normal use, the UVR emission from CFLs would not constitute a significant UVR hazard, when assessed at 65 cm. The assessment was made against exposure limits recommended by the American Conference of Governmental Industrial Hygienists (ACGIH) and against a minimum erythemal dose of 300 J m^{-2} effective[5].

A study by Sayer *et al.*[6] on contemporary lighting found that both daylight and cool-white fluorescent lamps may emit UVA and UVB radiation as short as 280 nm; 254 nm emission was also detected. They concluded that for a general, normally responding, population the UVR risk from these sources remains very low. However, they advised that the condition of photo-sensitive patients may be exacerbated by exposure to selected fluorescent lamps and that further investigation into UV exposure from lamps used at short distances (e.g. desk or task lamps) may be warranted.

Earlier studies[7,8] of fluorescent lamps in occupational environments showed that the brightness of these sources is not an accurate predictor of their UV emission and of their potential for adverse health effects.

A number of research studies[9–13] also pointed out that there is a modulation of optical output (flicker) from fluorescent lighting at relatively low frequencies (up to 160 Hz). This is claimed to cause eyestrain, fatigue, affect visual performance and aggravate repetitive behaviour in autistic patients[14].

For many applications, including domestic lighting, the optical radiation emission in the visible spectral range is important for colour perception. Colour quality is usually characterised by the colour rendering index (CRI). However, it is well known[15,16] that CRI does not have good correlation with subjective colour quality for the light sources with emission

*Corresponding author: marina.khazova@hpa.org.uk

wavelength spectra that contain prominent peaks, such as fluorescent lighting or LEDs as opposed to broadly emitting sources like incandescent lamps.

SAMPLES AND MEASUREMENT PROCEDURES

Seventy-three CFLs were purchased from the UK major retailers within 3 days in March 2008 in the same geographical area. The CFLs were manufactured by nine manufacturers, including branded names and retailer owned brands. The majority of the CFLs were marked as 11 or 12 W; with bayonet or Edison screw fitting. All of the lamps contained integral electronic ballasts and were labelled as Energy Saver. Details are given in Table 1 and Figure 1.

Twenty of the tested samples were double envelope bulbs (Figure 2a); the remainder were single envelope (Figure 2b), stick or spiral design. Nine of the tested lamps carried Energy Saving Recommended accreditation. Details are summarised in Table 2.

Three sets of CFL characteristics were measured:

(1) UV emission (200–400 nm);
(2) emission in visible spectral range (400–700 nm);
(3) temporal modulation of optical output (flicker).

The UV spectral irradiance was measured using a scanning double grating Jobin–Yvon Model D180 spectroradiometer with a measurement interval of 1 nm and calibrated by reference to a deuterium discharge and tungsten halogen lamps traceable to the UK National Physical Laboratory. Measurements were performed at a distance of 200 mm from the CFL as representative of foreseeable long-term exposure from task lighting (hands under desk lamp) and in close proximity to the bulb as representative of worst-case accidental exposure.

Table 1. Tested CFL samples.

Manufacturer	A	B	C	D	E	F	G	H	I
Number of samples	17	18	11	9	1	10	4	1	2

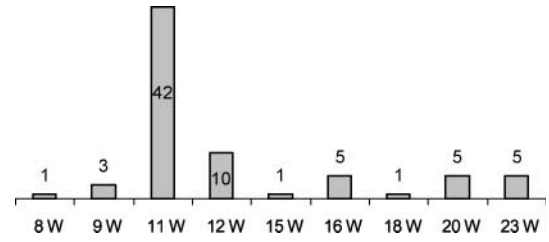

Figure 1. Number of CFLs at each labelled output.

Spectral irradiance in the visible spectral range was measured using a Bentham scanning double spectroradiometer Model DM150 with a measurement interval of 1 nm and calibrated by reference to a tungsten halogen lamp traceable to the UK National Physical Laboratory.

Temporal modulation of the optical output was measured using a ThorLab high-speed silicon biased detector DET36A with a rise time of 20 ns using a National Instruments USB-6211 DAQ with a 250-kHz sampling rate.

RESULTS

Assessment of UV hazard

The UV spectral irradiance for three CFLs is shown in Figure 3 for a double envelope lamp (1) and for single envelope lamps (2 and 3). 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 (e.g. Lamp 3) emit in the UVB and UVC (254 nm) regions, probably due to defects in the phosphor coating.

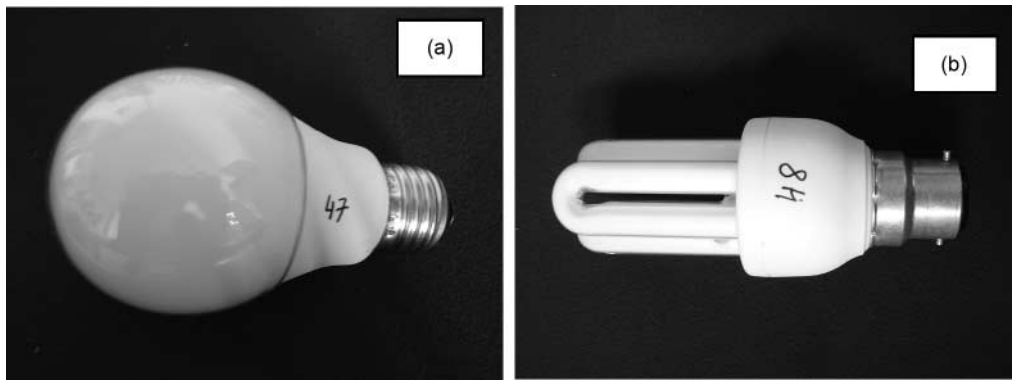

Figure 2. Construction of CFL: (**a**) double envelope and (**b**) single envelope.

Table 2. Construction and energy saving accreditation of tested CFLs.

Energy saving recommended accreditation		Construction of bulb	
Yes	No	Single envelope	Double envelope
9	64	53	20

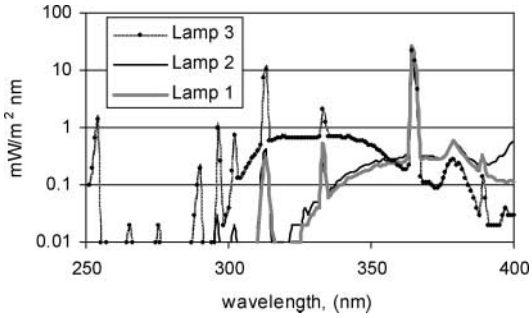

Figure 3. UV emission spectra of three CFLs (lamp 1, double envelope lamps; lamps 2 and 3, single envelope).

Nine out of 53 single envelope CFLs and none of the double envelope lamps emitted UVC at 254 nm. Emission at 313 nm from double envelope bulbs was considerably lower compared with single envelope samples, as illustrated in Figure 4: 80% of all tested double envelope lamps have emission at 313 nm below 1 mW m^{-2} nm^{-1}, and none at all above 5 mW m^{-2} nm^{-1}; whereas 25% of all single envelope lamps emitted above 10 mW m^{-2} nm^{-1} at this wavelength.

The measured spectral irradiance was used to assess the exposure level and compare it with exposure limit values (ELVs) recommended by the International Commission on Non-Ionizing Radiation Protection (ICNIRP)[15]. Long-term eye exposure at 200 mm from a lamp or in a close proximity to the source is unlikely due to aversion responses to a bright source. However, unintentional long-term skin exposure is foreseeable at close distances from the CFLs, e.g. hands under a desk lamp or short-term activity near the source. For a few of the tested single envelope CFLs, the UV ELVs are likely to be exceeded, as

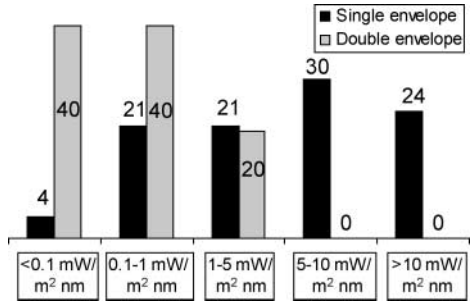

Figure 4. Percentage of tested CFLs with respect to emission level at 313 nm.

summarised in Table 3; it is not expected that the ELVs will be exceeded for double envelope lamps. It should also be noted that exposure level may be substantially increased by reflection from a lamp shade or a luminaire reflector, resulting in further reduction of the time to exceed ELV.

The exposure limits do not take account of persons who may be particularly photosensitive. Therefore, Table 3 may not be appropriate for such groups.

Flicker

The optical output of all tested CFLs was modulated with two carrier frequencies: 15–40 kHz (due to the electronic ballast) and a 100-Hz envelope (due to rectification of the 50 Hz mains supply), as shown in Figure 5. Modulation of the output was calculated as

$$\text{Modulation } (\%) = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}} \times 100\%$$

and the results are summarised in Figure 6.

Colour quality of CFLs

The emission of all the tested CFLs in the visible spectral range consisted of a few narrow peaks (Figure 7) with very low (Lamp 4) or negligible emission (<0.1% of peak emission for Lamp 5) in other parts of the spectrum. The spectral output of Lamp 5 was typical of the majority of the tested lamps and may result in distorted colour perception of an environment

Table 3. Time to exceed UV ELVs for tested CFLs.

	Close proximity to lamp (20 mm)				200 mm from lamp (front end)			
	<10 min	10–15 min	16–30 min	>30 min	<4 h	4–8 h	8–10 h	>10 h
Single envelope (%)	20.7	15.1	18.9	45.3	0	7.5	13.2	79.3
Double envelope (%)	0	0	0	100	0	0	0	100

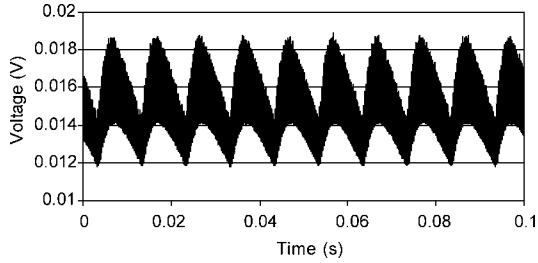

Figure 5. One hundred Hertz modulation envelope of optical output.

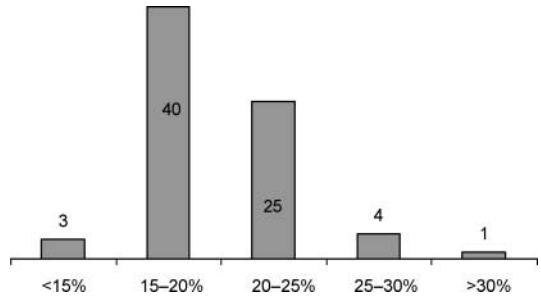

Figure 6. Output modulation of tested CFLs: number of samples.

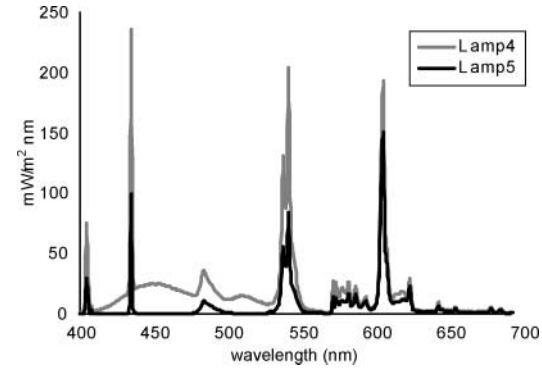

Figure 7. Visible spectra emission of CFLs.

illuminated by these CFLs as stated previously[15,16]. Furthermore, such a low emission in wide parts of the spectra may require an increase in CFL brightness to perform similar visual tasks compared with other sources, including tungsten-halogen lamps.

CONCLUSIONS

(1) The optical emissions of 73 CFLs from the UK consumer market were tested in March 2008.
(2) The UV emissions of the tested lamps are not expected to present a realistic hazard for eyes due to aversion responses to bright sources.
(3) The UV emissions from a significant percentage of the tested CFLs with single envelopes may result in foreseeable overexposure of the skin when these lamps are used in desk or task lighting applications. In addition, some groups of individuals may be particularly photosensitive to emission of these wavelengths.
(4) The optical output of all tested CFLs was modulated at a frequency between 15 and 40 kHz, representing the frequency of the electronic ballast. In addition, all had a 100 Hz envelope with modulation in excess of 15%. This degree of modulation at this frequency may be perceived and has been linked to a number of adverse effects.
(5) The visible spectrum emissions from the tested CFLs consisted of a series of discreet narrow peaks with low or negligible emission between peaks. This may compromise colour perception and may require an increase of brightness to perform similar visual tasks.

ACKNOWLEDGEMENTS

The authors wish to thank Dr J. Meara and Dr A. F. McKinlay for their continuing support and valuable advice. The assistance of Miss K. Grainger with the measurements is gratefully acknowledged.

REFERENCES

1. Make the Switch. The ELC Roadmap for Deploying Energy Efficient Lighting Technology across Europe. Available on http://www.elcfed.org.
2. Defra Press Release, 27 September 2007 (Reference 328/07).
3. Directive 2006/25/EC of the European Parliament and of the Council of 5 April 2006 on the Minimum Health and Safety Requirements Regarding the Exposure of Workers to Risks Arising from Physical Agents (Artificial Optical Radiation). Official Journal of the European Union, L114/38-L114/59, 27 April 2006.
4. Whillock, M., McKinlay, A., Kemmlert, J. and Forsgren, P. *Ultraviolet radiation emission from miniature (compact) fluorescent lamps*. Lighting Res. Technol. **22**(3), 125–128 (1990).
5. McKinlay, A. and Diffey, B. *A reference action spectrum for ultraviolet induced erythema in human skin*. CIE J. **6**(1), 17–22 (1987).
6. Sayre, R., Dowdy, J. and Poh-Fitzpatrick, M. *Dermatological risk of indoor ultraviolet exposure from contemporary lighting sources*. Photochem. Photobiol. **80**, 47–51 (2004).
7. Cole, C. *et al.* Effect of indoor lighting on normal skin. Ann. N Y Acad. Sci. **453**, 317–327 (1985).

8. Harber, L. *et al. Photosensitivity diseases related to interior lighting*. Ann. N Y Acad. Sci. **453**, 305–316 (1985).
9. Wilkins, A. and Clark, C. *Modulation of light from fluorescent lamps.* Lighting Res. Technol. **2292**, 103–109 (1990).
10. Jean, M. *et al. Office workers visual performance and temporal modulation of fluorescent lighting*. Leukos, **1**(4), 27–46 (2005).
11. Wilkins, A. J., Nimmo-Smith, I. M., Slater, A. and Bedocs, L. *Fluorescent lighting, headaches and eyestrain*. Lighting Res. Technol. **21**(1), 11–18 (1989).
12. Bergman, S. *et al. Human electroretinogram responses to video displays, fluorescent lighting and other high frequency sources.* Optom. Vis. Sci. **68**(8), 645–662 (1991).
13. Brundrett, G. *Human sensitivity to flicker.* Lighting Res. Technol. **6**(3), 127–143 (1974).
14. Colman, R. *et al. The effect of fluorescent and incandescent illumination upon repetitive behaviour in autistic children*. Journal Autism Child. Schizophr. **6**(2), 157–162 (1976).
15. Ohno, Y. *Optical metrology for LED and solid state lighting*. SPIE **6046**, 604625-1–6046625-8 (2006).
16. Davis, W. *Measuring colour quality of light sources.* Proc of SPIE **6337**, 93370L1 (2006).
17. ICNIRP. *Guidance on limits of exposure to ultraviolet radiation of wavelength between 180 nm and 400 nm (incoherent optical radiation)*. Health Phys. **87**(2), 171–186 (2004).