Is Full-Spectrum Lighting Special?

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Definition

There is no "official" definition of full spectrum lighting. What there is, is a de facto definition related to the use of full- spectrum fluorescent lamps. Specifically, full-spectrum lighting consists of interior lighting provided exclusively by full-spectrum fluorescent lamps. Such lamps are designed to mimic daylight. They have spectral emissions in all parts of the visible spectrum and some emission in the ultra-violet, mainly the near ultra-violet. Quantitatively, they have a correlated colour temperature greater than 5000 K and a CIE General Colour Rendering Index of greater than 90. The correlated colour temperature specifies the apparent colour of light emitted by the lamp; the higher the colour temperature, the cooler (or more blue) the apparent colour of the light. The CIE Colour Rendering Index quantifies the ability of the lamp to render colours as well as a standard lamp with the same colour temperature. The CIE General Colour Rendering Index has a value of 100 when the match between the test lamp and the standard is perfect. Therefore, the full-spectrum fluorescent lamp is cool in colour appearance and has good colour rendering properties.

Claims

Lighting using full-spectrum fluorescent lamps has been the subject of many claims. The level of support for these claims varies. For example, full-spectrum lamps have repeatedly been shown to be effective in the treatment of seasonal affective disorder (Rosenthal & Blehar, 1989) . Less well established are the effects of working under full-spectrum fluorescent lamps on fatigue, task performance and mood; some authors achieving statistically significant improvements under full spectrum lighting (Maas, Jayson & Kleiber, 1974) while others fail to find any effects (Berry, 1983; Boray, Gifford & Rosenblood, 1989). Even more controversial are studies of the effects of full-spectrum lighting on hyperactivity in children (Mayron, Ott, Nations & Mayron, 1974; O’Leary, Rosenbaum & Hughes, 1978a; Mayron, 1978; O’Leary, Rosenbaum & Hughes, 1978b)

The result of this diversity of findings is that the whole field of full-spectrum lighting has become clouded with controversy. The objective of this symposium is to clarify some of the arguments involved in this controversy and to set down what steps are needed to resolve it.

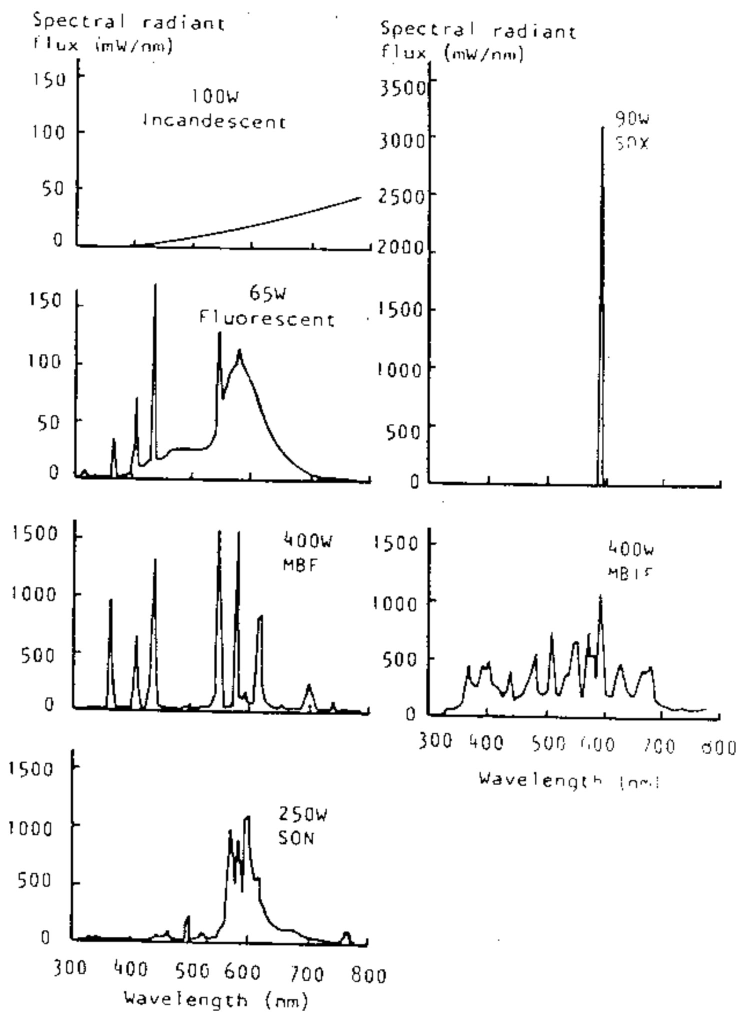
The objective of this presentation is to place full-spectrum fluorescent lamps in context with other light sources available to the lighting designer and to predict what would be expected from full-spectrum fluorescent lamps on the basis of current knowledge.

Full-Spectrum Fluorescent Lamps in Context

There are two broad classes of electric light sources available for interior lighting; incandescent light sources and discharge light sources. Incandescent light sources produce light by heating a filament, the spectrum of the light being determined by the temperature of the filament. Discharge light sources produce light by passing an electric current through an ionized gas; the spectrum of the light being determined by the gas used, the gas pressure, the other elements in the discharge and the presence or absence of a phosphor coating. Full-spectrum fluorescent lamps are low pressure, mercury discharge lamps with a phosphor coating. The discharge in the mercury atmosphere produces mainly ultra-violet radiation. This ultra-violet radiation is largely absorbed by the phosphor coating lining the walls of the discharge tube and reradiated as light. Incandescent lamps have a continuous spectrum in the visible region, dominated by the long wavelengths (see Figure 1). Discharge lamps typically have a spectrum consisting of strong single wavelengths amongst a continuous background (see Figure 1). The spectrum emitted by one type of full-spectrum fluorescent lamp is shown in Figure 2.

Figure 1
Spectral radian flux distributions for some widely used light sources.

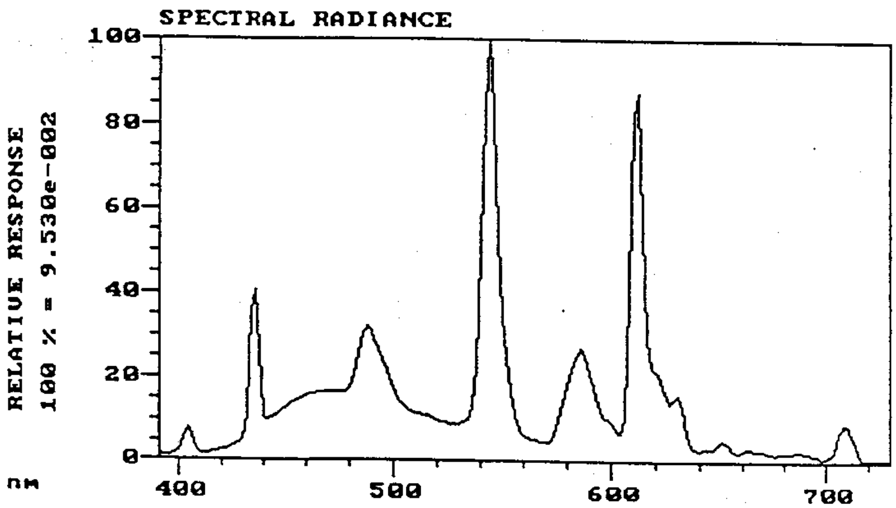
The light sources shown are a 100 W incandescent lamp, a 65 W White low pressure mercury (fluorescent) discharge lamp, a 90 W low pressure sodium (SOX) discharge lamp, a 400 W high pressure mercury (MBF) discharge lamp, a 400 W high pressure mercury metal halide (MBIF) discharge lamp and a 250 W high pressure sodium (SON) discharge lamp. Note the different scales on the ordinates.



It is the emission spectrum which defines each lamp type. Different lamp types have different luminous flux outputs but these can be compensated by adjusting the number of lamps used in an installation. The spectral emission cannot be compensated in this way. Figure 1 shows emission spectra, over the visible spectrum, for a number of light sources. All the light sources shown are commonly used for lighting in homes, offices, factories and on roads. It should be apparent from

Figure 1 that there are many diverse types of lamps available from which the lighting designer can choose.

Figure 2
Relative Spectral Radiance of a full-spectrum fluorescent lamp over the visible region.



Even if only fluorescent lamps are examined, there are several which have a similar visible spectrum but which are not commonly called full-spectrum lamps. The visible lamp spectrum can be characterized by two numbers, the correlated colour temperature and the CIE General Colour Rendering Index. Table 1 shows the manufacturer's name, the correlated colour temperature and the CIE General Colour Rendering Index for a number of fluorescent lamps with comparable lamp spectra. Vitalite and Vitalite-plus are the lamps usually identified as full-spectrum fluorescent lamps. It can be seen from Table 1 that, as regards the CIE General Colour Rendering Index and the correlated colour temperature, the full- spectrum fluorescent lamp is actually part of a family of fluorescent lamps. The fluorescent lamps in Table 1 are typically used where very good colour rendering is essential such as in the graphic arts industry or for display lighting.

Table 1
Manufacturer, lamp name, correlated colour temperature (CCT) and CIE General Colour Rendering Index (CRI) for fluorescent lamps with visible spectra suitable for full-spectrum lighting.

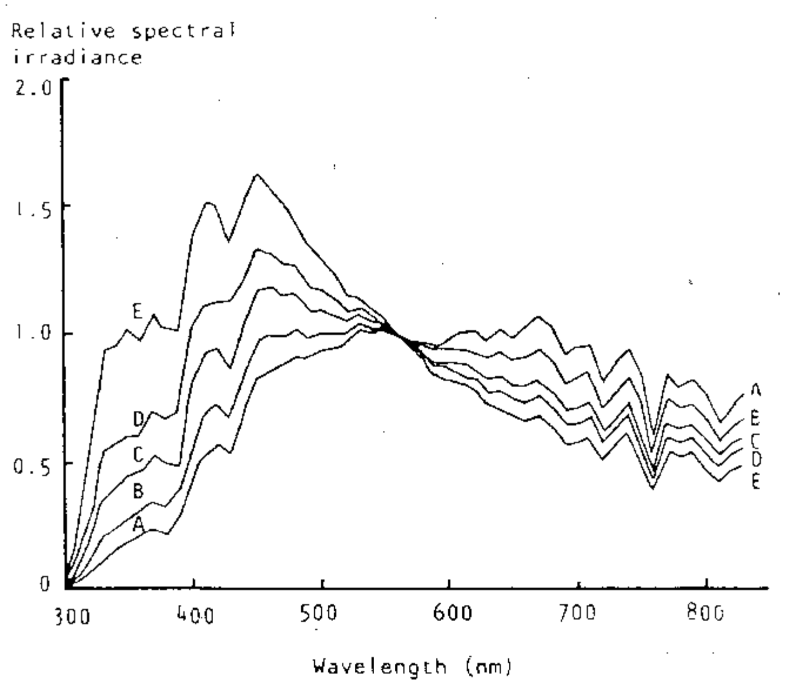
Manufacturer	Lamp Name	CCT (K)	CRI
General Electric	Chroma 50	5000	90
General Electric	Chroma 75	7500	92
Philips	Colortone 50	5000	92
Philips	Colortone 75	7500	95
Osram Sylvania	Octron 900	5000	90
Osram Sylvania	Design 50	5000	90
Duro-test	Vitalite	5500	91
Duro-test	Vitalite plus	5500	91

The only element of the full-spectrum fluorescent lamp spectrum which is not included in the quantities presented in Table 1 and which distinguishes it from other fluorescent lamps is the ultraviolet component. This is not included because it does not directly affect the retina, radiation below a wavelength of 380 nm being absorbed by the cornea and lens of the eye. However, it may influence the people through absorption at the skin and by changing the appearance of objects which have fluorescing materials in them.

It should be noted that the extent to which the ultraviolet component is present in an actual lighting installation using full- spectrum fluorescent lamps will depend on the luminaire used. If the luminaire is sealed with a plastic prismatic controller, no ultraviolet radiation may be emitted from the luminaire because some of the plastics used in luminaires are opaque to ultraviolet radiation (McKinley, Harlen & Whillock, 1988). Alternatively, if an open specular reflector is used, then the ultra-violet component will be emitted from the luminaire.

Having compared full-spectrum fluorescent lamps with ether electric light sources it is also desirable to compare them to daylight, the light source which they are designed to mimic. Figure 3 shows the normalized spectral irradiance distributions of daylight. There is more than one spectral irradiance distribution because the spectral content of daylight varies throughout the day and the season depending on the latitude of the location, the elevation of the sun in the sky and the amount of water vapour in the atmosphere. The basis for the comparison of full-spectrum fluorescent lamps to daylight is the high correlated colour temperature, the high CIE General Colour Rendering Index and the deliberate inclusion of an element of near ultra-violet radiation in the spectral emission. However, a comparison of Figures 2 and 3 suggests that the full- spectrum fluorescent lamp is a modest imitation of daylight, even if it is closer to daylight than most other electric light sources.

Figure 3
Relative spectral irradiance distributions of the standard phases of daylight. The distributions are normalised to a value of unity at 560 nm. The standard phases of daylight have correlated colour temperatures of A = 4800 K, B = 5500 K, C = 6500 K, D = 7500 K, E = 10,000 K



Predicted Effects of Full-Spectrum Lighting

Light and ultra-violet radiation can influence people through three paths; the visual system, the hormonal system and the skin.

Light is the medium that allows the visual system to operate. Without light we are blind. With light, we can discriminate detail and colour, perceive form and movement and so feed our higher cognitive functions.

Part of the signal carried by light, received by the eyes and transmitted up the optic nerve reaches the pineal gland. This in turn is connected to the hypothalamus and so to the hormonal control system. The effect of light on the hormonal system is related to the synchronization of circadian rhythms with consequent effects on performance, alertness and fatigue and on phenomena such as seasonal affective disorder and jet lag.

As for the effect on the skin, the incidence of light and ultraviolet radiation on the skin is known to cause chemical changes in the skin. These changes can be both beneficial such as the formation of Vitamin D and detrimental such as the increased frequency of skin cancer after prolonged exposure (McKinley, Harlen & Whillock, 1988)

The direction of effect of radiation from full-spectrum fluorescent lamps in most of these areas can be predicted. However, the magnitude of the effect is more often open to question.

For the visual system, only the visible spectrum is relevant. The strong short wavelength component in the spectral emission of the full-spectrum fluorescent lamp can be expected to produce a smaller pupil size than other fluorescent lamps for the same adaptation luminance. This small pupil size might be expected to allow a slight improvement in visual acuity because of the improved retinal image quality produced by using only the central part of the lens, despite the reduced retinal illumination. Berman et al (1992) have shown that for low contrast, briefly-presented stimuli, there is indeed an improvement in visual acuity.

The fact that the full-spectrum fluorescent lamp has spectral emissions in all parts of the visible spectrum, and the consequent high CIE General Colour Rendering Index, implies that tasks requiring very accurate colour judgements will be performed better under a full-spectrum lamp. Boyce and Rea (1993) have shown that colour sorting performance on a task requiring fine colour judgements is indeed more accurate under full-spectrum lamps in a multi-layer polarizing luminaire than under conventional fluorescent lamps with a CIE General Colour Rendering Index of 73 in conventional luminaires.

The strong short wavelength element in the spectral emission of full spectrum lamps and the high CIE General Colour Rendering index might also be expected to generate an impression of greater visual clarity (Boyce, 1977) and brightness (Luria, 1987; Berman et al., 1990). However, chromatic adaptation may pose a limitation to this perception. Boyce and Rea (1993) have reported a study of the perceptions associated with three rooms lit in three different ways, two with full-spectrum fluorescent lamps in multi-layer polarizing luminaires and one with conventional triphosphor fluorescent lamps in parabolic, specular reflector luminaires. The results failed to show any consistent perceived difference between the three installations, other than an effect of illuminance.

As for the effect of full-spectrum lamps through the hormonal system, with its consequences for circadian rhythm and seasonal affective disorder, most of the early experiments which established the reality of the photobiological effects of light were done using full-spectrum lamps. However, subsequent studies have shown that the effect is not a unique property of full-spectrum lighting (Rosenthal & Blehar, 1989). Therefore, while there is no doubt that full-spectrum lighting, in sufficient amounts, will influence circadian rhythm and seasonal affective disorder, so should many other types of electric lighting.

Finally, as regards the contribution of the ultraviolet component, this has to be treated with caution. This is not to deny that the ultraviolet radiation has effects on the body through absorption at the skin and the eye but rather to point out that these effects can be both helpful and harmful. Ultraviolet radiation is used in the treatment of a range of skin diseases and is known to influence the production of Vitamin D, which beneficially effects the structure of bones (Steck, 1982). It is also implicated in skin aging (Gange, 1986), the incidence of skin cancers (Steck, 1982) and possibly has immunological effects (Gange, 1986) . Fortunately, the amount of ultraviolet radiation emitted by a full-spectrum lighting installation is very small compared with the amount available from daylight over a short exposure time. In this circumstance, it may be doubted if the ultraviolet radiation from a full-spectrum lamp significantly increases the body's total ultraviolet exposure, except in locations where daylight is severely limited by nature (e.g., in northern Canada in winter), or by the type of the work, (e.g., submarine patrols) or by personal factors (e.g., reduced mobility of the very old). However, much remains to be learned about the effects of long term exposure to ultraviolet radiation. Recommendations for quantitatively evaluating the hazard posed by exposure to ultraviolet radiation are published by the American Conference of Governmental Industrial Hygienists (ACGIH, 1986).

Summary

It should now be apparent that, as regards its visible spectrum, the full-spectrum fluorescent lamp is not special. Rather it is just one among several fluorescent lamp types that can and are used for interior lighting. Current knowledge of the interaction of light and vision predicts that the blue-rich visible spectrum and good colour properties of full-spectrum lighting will improve peoples' visual acuity for low contrast stimuli, modify their impressions of an interior and enhance their performance at tasks requiring accurate colour judgements. What does make the full-spectrum fluorescent lamp special amongst florescent lamps is the deliberate inclusion of an ultraviolet component in the spectral emission. Whether this ultraviolet radiation is an advantage or a hazard requires quantitative analysis and much more study.

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