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Full Spectrum and LED Office Lighting

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Prepared by:
Ron Wardell, BA, MASc, CCPE
Ph.: 780-436-0024
www.ewiworks.com

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INNOVATIVE ERGONOMIC SOLUTIONS

Corporate Office:
Unit 201, 5677-99 Street
Edmonton, Alberta, T6E 3N8

Tel: +1 (780) 436-0024
Fax: +1 (780) 436-0092

Email: info@ewiworks.com
www.ewiworks.com

Executive Summary

Full spectrum fluorescent lighting (FSFL) is claimed to have significant benefits over regular fluorescent lighting. LED lighting is also claimed to have advantages over other light sources. This report is a summary of literature evaluating these claims. There is no published review that uses the criteria of evidence-based research. Research that is independent of manufacturers has been conducted by the National Research Council of Canada Institute for Research on Construction (NRCC/IRC) and by the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute. The latter operates the National Lighting Product Information Program (NLPIP) in the USA to provide objective information about lighting systems.

There is no commonly accepted definition of full spectrum and standards organizations have not agreed upon a metric. FSFL sources should produce light across the full visible spectrum, have a colour temperature (CCT) of 5000K or greater, and have a colour rendering index (CRI) of 90 or better. Not all sources marketed as FSFL meet the LRC criterion for full spectrum, while some fluorescent lamps not labelled as FSFL do meet the criterion. In spite of the common labeling, FSFL does not in fact emulate the intensity and colour spectrum of daylight.

NRCC/IRC reviews published in 1994 and 2001 concluded that research was generally of poor quality and there was a lack of evidence for benefits from FSFL for performance, mood, or health. LRC reported in 2005 that FSFL does not improve performance or health. In spite of the lack of biophysical evidence, LRC found that over 70% of lighting specifiers felt that FSFL has a positive effect on mood. Tasks such as graphic design or colour matching, which require good colour discrimination, benefit from lighting that has higher CRI and CCT, whether that lighting is labelled full spectrum or not.

LED lighting is still under development. White light can be produced by either a combination of red, green, and blue LEDs, or, more commonly, by using a blue LED to excite a mix of phosphors. The colour rendering properties of phosphor-based white LED sources are questionable. RGB mix sources are recommended for reading and task lighting. Because LED sources are inherently directional, they should be evaluated by the amount of illuminance on the surface rather than the light output from the source.

The choice of light source technology is only part of lighting design. Ergonomically, the task and environment are critical to determine the amount and quality of ambient and task lighting to achieve productive and comfortable levels of contrast and colour rendering while avoiding glare. Whatever light sources are used, their layout, fixtures, furniture system, and architectural context all need to be considered for good lighting design.

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Lighting design requires attention to economics, energy and environment, aesthetics and interior architecture, however, this report will focus on the ergonomic considerations of human performance, health, and mood or affect. Lighting has been studied in many different contexts, but this report will be limited to office environments.

Lighting Spectrum

Lighting may affect human performance, health, and mood or affect. The characteristics of light sources that produce these effects are the amount of light and the distribution of energy over light wavelengths. The effects of the light source are moderated by the design of the light fixture, luminaire, or architectural presentation (for example, direct and indirect lighting, cove lighting, troffer fixtures, surrounding surface colour and finishes), however, we will focus on the sources themselves. The amount of light is measured either by luminance, which is the quantity of light coming from the source in units of lumens, or by illuminance, which is the quantity of light falling on a surface in units of lux. The distribution of light energy over the colour spectrum is most completely measured by the spectral power distribution (SPD) which plots the relative amount of energy at each wavelength. The spectral characteristics can be indicated by the correlated colour temperature (CCT), which is the temperature in degrees Kelvin of a black body radiator that would appear to be the same tint of white. The spectral characteristic is also indicated by the colour rendering index (CRI) which is a measure of how well a colour sample maintains its hue when illuminated by the source, as compared to a reference source such as the sun or an incandescent lamp.

Full Spectrum Fluorescent Lighting

Fluorescent sources produce light by electrically stimulating the phosphors which cover the inside of the tube. The spectral properties of the source can thus be controlled by varying the phosphor materials. A source which is full spectrum has phosphors that produce light in a broader distribution over the spectrum than a source that is not full spectrum.

Daylight

Full spectrum sources are sometimes associated with daylight; however, this is misleading since the spectral power distribution of daylight varies strongly with time of day, latitude, season, and atmospheric conditions[1]. Daylight is therefore a moving target and it is more accurate to characterize full spectrum sources as producing a fuller spectrum than other sources[2]. The daylight comparison is attractive for

[1] NLPIP. (March 2005a) “How can full-spectrum light sources be compared?” *NLPIP Lighting Answers.* Vol.7, No.5. http://www.lrc.rpi.edu/programs/nlpip/lightingAnswers/fullSpectrum/comparisons.asp Retrieved 26/06/2013.
[2] Stefan Graf, as quoted by Garris, Leah B. (November 2005) “Full-spectrum lighting: nothing but the truth.” *Buildings*. Vol.99, No.11. ABI/INFORM Complete. pg. 56

marketing purposes and is part of the evolutionary theory that humans evolved in natural light and therefore are healthier under daylight, but no fluorescent source has the intensity or spectral distribution of daylight[3]. Figure 1 compares a claimed full spectrum fluorescent and daylight at 5500K (daylight varies at least from 5000K to 20000K[4]).

Ultraviolet

What constitutes a full spectrum is also open to debate. Some manufacturers claim benefits from sources that include UV wavelengths. The NRCC/IRC includes some UV emission in its definition of full spectrum fluorescent lighting[5]. The Lighting Research Centre (LRC) disputes these claims on the grounds that the amount of UV exposure from such sources is too small to have any appreciable effect on human health[6]. They further argue that full spectrum sources should be evaluated against a theoretical uniform source radiating in the visible spectrum between 380 and 730 nm[7].

When is a source full spectrum?

Full spectrum and daylight are marketing terms, which raises the question of how to determine whether a source is actually full spectrum. Figure 2 compares two T12 fluorescent lamps, one of which is labelled full spectrum and the other is not so labelled. Although the U.S. prices differ markedly, the SPDs are very similar. LRC proposes a new metric to compare sources[8]. The Full Spectrum Index (FSI) is calculated from the difference between a lamp's SPD and a theoretical uniform source over the visible spectrum. Their conclusion is:

Based on an arbitrary cutoff of FSI = 2.0, the following light sources can be categorized as full-spectrum: natural daylight from 4000K to 11000K, xenon lamps, some fluorescent T12 lamps marketed as full-spectrum, some T12 fluorescent lamps not marketed as full-spectrum, and some ceramic metal halide lamps. At the time this report was written, the following T12 lamps marketed as full-spectrum met the FSI = 2.0 cutoff: Duro-Test Daylight 65, Duro-Test Vita-Lite 5500K, Lumiram Lumichrome 1XC, and Verilux VLX fluorescent lamps.

Since manufacturers may not provide SPD data for fluorescent lamps, the finding that some lamps marketed as full spectrum do not meet the LRC criterion is troublesome. There is no commonly accepted definition of full spectrum and standards organizations have not agreed upon a metric.

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[3] McColl, S.L., and Veitch, J.A. (2001) "Full-spectrum fluorescent lighting: A review of its effects on physiology & health." NRCC-43097. . http://archive.nrc-cnrc.gc.ca/obj/irc/doc/pubs/nrcc43097/nrcc43097.pdf Retrieved 27/06/2013. A version of this document is published in *Psychological Medicine*, v. 31, no. 6, August 2001, pp. 949-964.

[4] NLPIP (March 2005a) *op. cit.*

[5] Veitch, J.A., and McColl, S.L.(2001) "A Critical examination of perceptual and cognitive effects attributed to full-spectrum fluorescent lighting." NRCC-42840. http://www.cyberlux.de/deutsch/articles/l-h/beleuchtung/ahmet-cakir/images/nrcc42840.pdf Retrieved 27/06/2013. A version of this document was published in *Ergonomics*. 2001 Feb 20. Vol.44. No.3. Pp.255-79.

[6] NLPIP. (March 2005b) "Is ultraviolet radiation production important?" *NLPIP Lighting Answers.* Vol.7, No.5. http://www.lrc.rpi.edu/programs/nlpip/lightingAnswers/fullSpectrum/production.asp retrieved 27/06/2013.

[7] NLPIP. (March 2005a) *op.cit*.

[8] NLPIP. (March 2005a) *op.cit*.

Color Temperature

In the absence of SPD data, colour temperature can be used as an indicator of spectral characteristics. Full spectrum sources have ratings of 5000K or greater[9,10].

CRI

In addition to colour temperature, the colour rendering index is an indicator of spectral characteristics. A higher CRI shows that the source has a more even distribution across the colour spectrum. Full spectrum sources have CRI scores of 90 or greater[11,12]. Because CRI is measured at set colour points, a high CRI does not necessarily mean that the light distribution is without peaks and valleys.

How valid are claims for full spectrum fluorescent lighting?

If a source qualifies as being full spectrum, then the question is whether it provides benefits for human performance, health, comfort, and mood or affect. There have been many studies, but they have many weaknesses[13]. A 1994 review by the NRCC/IRC concluded that:

In general, the quality of the research is poor, making it difficult to determine whether or not treatment effects may legitimately be attributed to light source spectral power distribution. A few rigorous investigations of full-spectrum fluorescent lighting have demonstrated small effects; however, few researchers have taken up the challenge to replicate their work. These small effects do not support the claims that full-spectrum fluorescent lighting will produce better performance, mood, or health in the general population.[14]

Performance

A NRCC/IRC review published in 2001 reached conclusions of poor research quality and lack of evidence for visual, perceptual, and cognitive effects of fluorescent lamp type[15]. In general, LRC reported in 2005 that: “Full-spectrum light sources will not provide better visual performance than other light sources, under most circumstances.”[16] Lighting design needs to consider the tasks being performed. Tasks such as graphic design or colour matching, which require good colour discrimination, benefit from lighting that has higher CRI and CCT, whether that lighting is labelled full spectrum or not[17,18]. Such lighting also improves visual

[9] Garris *op. cit.*
[10] Veitch and McColl (2001) *op.cit*.
[11] Garris *op. cit.*
[12] Veitch and McColl (2001) *op.cit*.
[13] Robert Gifford. (1994) “Scientific evidence for claims about full-spectrum lamps: Past and future.” In J. A. Veitch (Ed.)., *Full-spectrum lighting effects on performance, mood, and health.* IRC Internal Report No. 659. National Research Council of Canada Institute for Research in Construction. Pp.37-46. http://www.megavolt.co.il/articles/gifford.pdf retrieved 27/06/2013.
[14] J.A. Veitch and S.L. McC oll. (1994) “Full-Spectrum Fluorescent Lighting Effects on People: A Critical Review.” In J. A. Veitch (Ed.)., *Full-spectrum lighting effects on performance, mood, and health.* IRC Internal Report No. 659. National Research Council of Canada Institute for Research in Construction. Pg. 53. http://archive.nrc-cnrc.gc.ca/obj/irc/doc/pubs/ir/ir659/veitch_mccoll.pdf retrieved 22/07/2013.
[15] Veitch and McColl (2001) *op.cit*.

[16] NLPIP. (March 2005c) “How valid are the claims regarding full-spectrum light sources?” *NLPIP Lighting Answers.* Vol.7, No.5. http://www.lrc.rpi.edu/programs/nlpip/lightinganswers/fullspectrum/claims.asp Retrieved 27/06/2013.
[17] NLPIP. (March 2005c) *op.cit.*
[18] Garris *op. cit.*

acuity if that is a performance variable[19], although laboratory results showing this improvement have not been found in field studies under normal viewing conditions[20].

Full spectrum lamps output less light than cool-white fluorescent lamps of similar wattage. For example, the 30 watt Philips F30T12 Cool White with a CRI of 62 and CCT of 4100K has a design output of 1900 Lm, whereas the 40 watt Philips F40T12 DX ALTO Daylight Deluxe with a CRI of 90 and CCT of 6500 K has a comparable design output of 2025 Lm. The implication is that to maintain the same task illuminance, a lighting system with full spectrum lamps must accommodate higher wattage service.

As for visual comfort, full spectrum lighting fundamentally is about colour spectrum and there are other pertinent lighting design issues such as glare, contrast ratio, and uniformity.

Health

The health benefits claimed by manufacturers for full spectrum lighting are not supported by independent research[21]. A NRCC/IRC review published in 2001 reached conclusions of poor research quality and lack of evidence for physiological and health effects[22]. LRC has also concluded that "Full-spectrum light sources will not provide better health than most other electric light sources."[23] This conclusion includes the claimed benefits for circadian rhythm and therapeutic use for seasonal affective disorder.

Mood and Affect

The positive mood or affect that is commonly associated with natural lighting may also be associated with full spectrum lighting. As previously mentioned, full spectrum lighting does not in fact emulate the varying characteristics of daylight. Heschong *et al.* state that: "Although positive psychological benefits from full-spectrum light sources may have been observed in some circumstances, there appears to be no biophysical explanation for those observations."[24] In spite of these conclusions, the marketing of full spectrum lighting as natural lighting is persuasive. A survey of lighting specifiers conducted by the LRC found that over 70% felt that full spectrum lighting has positive effect on mood[25].

[19] Garris *op. cit.*
[20] Jennifer A. Veitch. (1997) Choosing the right light: The benefits of full-spectrum lighting continue to be researched and debated. NRCC-44747. http://www.iar.unicamp.br/lab/luz/ld/Sa%FAde/Choosing%20the%20right%20light.pdf Retrieved 27/06/2013.
[21] Liebel, quoted by Garris *op. cit.*
[22] McColl and Veitch (2001) *op.cit*.
[23] NLPIP. (March 2005c) *op.cit.*.
[24] Heschong, Wright & Okura, 2000, as cited by NLPIP. (March 2005c) *op.cit.*
[25] NLPIP. (March 2005d) "What benefits are claimed for full-spectrum light sources?" *NLPIP Lighting Answers.* Vol.7, No.5. http://www.lrc.rpi.edu/programs/nlpip/lightinganswers/fullspectrum/benefits.asp Retrieved 25/07/2013.

Conclusion

Veitch[26] concludes:

"Although the popular media continue to promote the notion that full-spectrum fluorescent lighting is beneficial to people...the experimental evidence does not support these claims. Facilities managers, when faced with complaints about office lighting, should resist the temptation to look reflexively to the lamp as the source of lighting problems. The evidence does not support changing fluorescent lamp type as a solution to occupants' problems with fluorescent lighting. Field and laboratory studies have more consistently identified other aspects of the lighting system, such as the flicker rate...and luminaire design...as levers for solutions to problems with interior lighting." Pg. 260

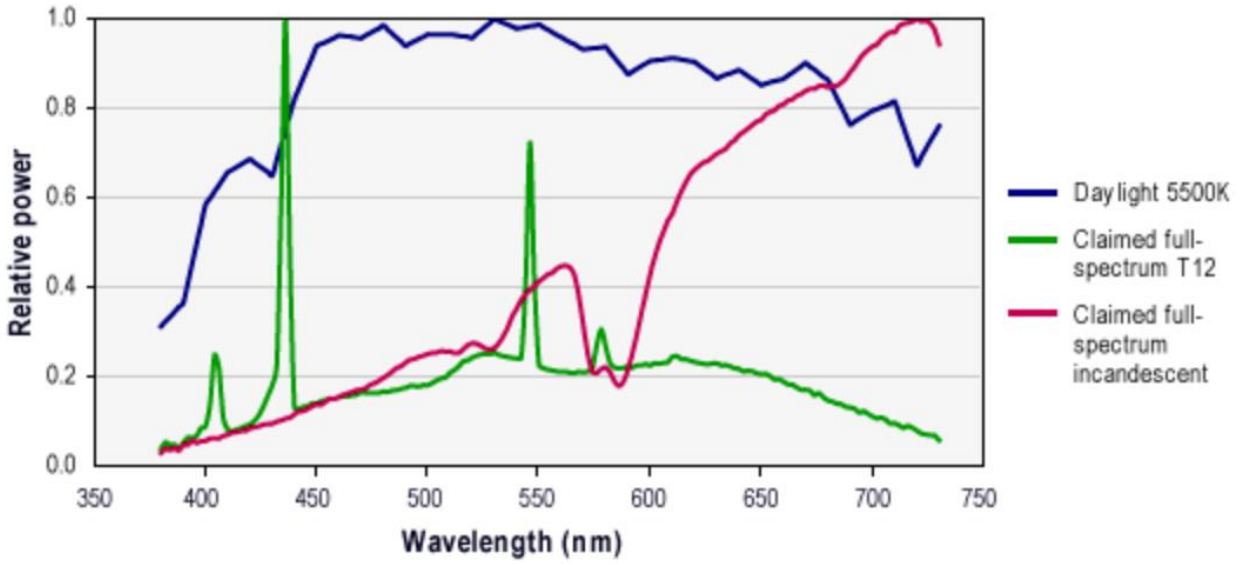

Figure 1. © 2003 - 2005 Rensselaer Polytechnic Institute. NLPIP. (March 2005e) "What are full-spectrum light sources?" *NLPIP Lighting Answers.* Vol.7, No.5. http://www.lrc.rpi.edu/programs/nlpip/lightingAnswers/fullSpectrum/lightSources.asp September 2003 (revised March 2005)

[26] Veitch, J.A.. (1997) "Revisiting the performance and mood effects of information about lighting and fluorescent lamp type." *Journal of Environmental Psychology.* 17, 253–262

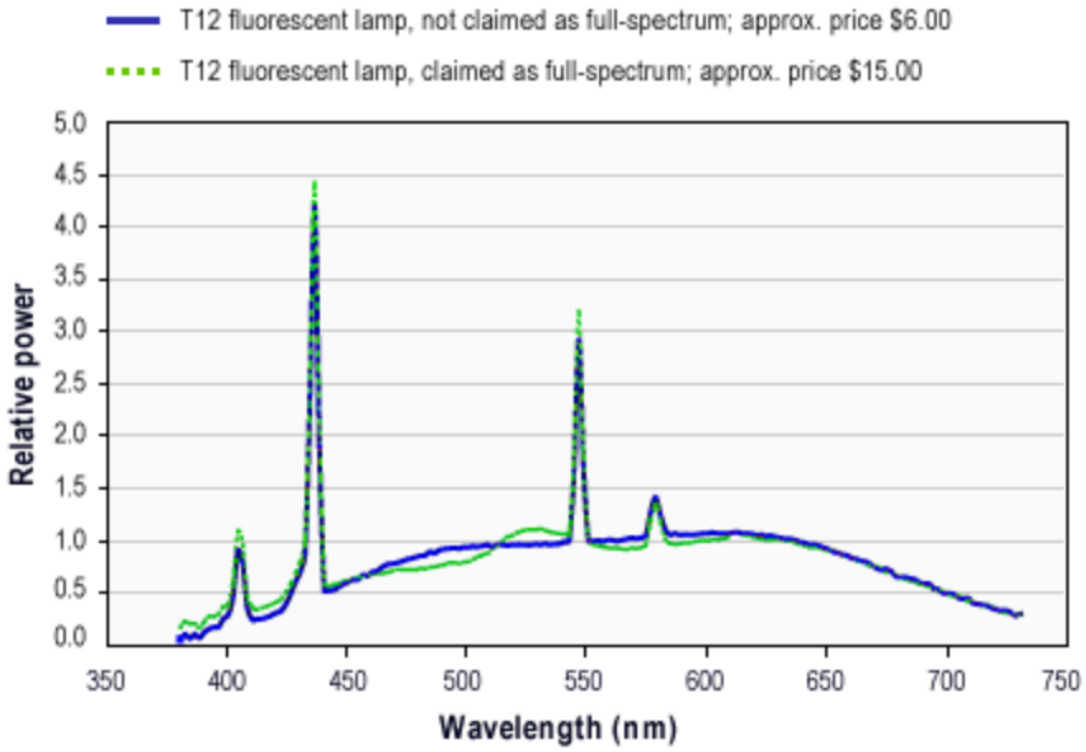

Figure 2. © 2003 - 2005 Rensselaer Polytechnic Institute. NLPIP. (March 2005f) "What are the disadvantages of full-spectrum light sources?" *NLPIP Lighting Answers.* Vol.7, No.5. http://www.lrc.rpi.edu/programs/nlpip/lightingAnswers/fullSpectrum/disadvantages.asp September 2003 (revised March 2005)

White LED

White LED lamps differ from fluorescent sources in SPD, CRI, flicker, and directionality.

LED lamps commonly produce white light by using a blue LED to excite a mixture of phosphors that emit a range of colour wavelengths that in combination appear white[27]. It is possible to generate white light by combining red, green, and blue LEDs, but for manufacturing reasons this is rarely done. Like fluorescent lamps, the phosphors can be chosen to produce a desired tint of white. Figure 3 shows the spectral power distribution of LED sources at three colour temperature ranges; namely, warm white from 2600 to 3700K, neutral white from 3700 to 5000K, and cool white from 5000 to 10000K.

[27] Lenk, R., and C. Lenk. (2011) *Practical Lighting Design With LEDs*. First Edition. The Institute of Electrical and Electronics Engineers, Inc. John Wiley & Sons, Inc.

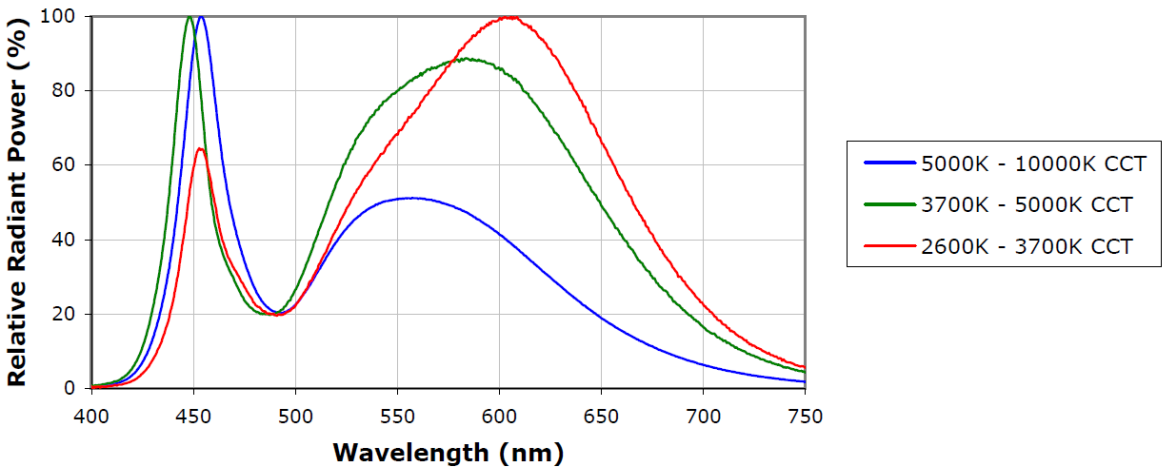

Figure 3. Relative spectral power distributions of Cree® XLamp® XR-E LED. http://www.cree.com/~/media/Files/Cree/LED%20Components%20and%20Modules/XLamp/Data%20and%20Binning/XLamp7090XRE.pdf Retrieved 08/07/2013.

From the figure, it is clear that although LED sources can be produced to colour temperatures comparable to a full spectrum fluorescent source, the SPD has two strong peaks around the wavelengths of the blue LED and the phosphor. Because of this, the CRI is inferior to a full spectrum fluorescent source. LRC reports a representative white LED with CCT of 5000K and CRI of 78[28]. Their evaluation gives a full spectrum index of 5.2, which does not meet their criterion for full spectrum lighting.

Performance

LED lighting is a new technology and there have been few ergonomic studies of its effectiveness. Narendran and Deng of the LRC found that LED reading lights were preferred over halogen and incandescent light sources for overall colour appearance, although flesh tones were rated poorly under phosphor-based LED lighting[29]. They recommend RGB mix white LEDs for reading or task lights. CRI was found to be a poor predictor of user preference. The LRC has proposed alternative metrics for solid state lighting[30]. The U.S. National Institute of Standards and Technology (NIST) is developing a Color Quality Scale (CQS) with input from the lighting industry and the CIE (International Commission on Illumination)[31]. Until the question of color rendering metrics is resolved, Philips recommends that "you should observe LED sources with low CRI scores in person to evaluate how well they render color."[32]

Pulse width modulation is used to control the light output of LED systems, which raises the possibility of unacceptable perceived flicker. Flicker can be detected directly by eye or indirectly by its stroboscopic effect

[28] NLPIP (March 2005f) *op.cit.*
[29] Narenden, N., and Deng, L. (2002) "Color rendering properties of LED light sources." *Solid State Lighting II: Proceedings of the SPIE*. 4776: 61-67 http://www.lrc.rpi.edu/programs/solidstate/pdf/CRIForLED.pdf Retrieved 26/07/2013.
[30] LRC. (2013) Understanding White Light Source Color Rendering and Appearance. http://www.lrc.rpi.edu/programs/solidstate/colorResearch.asp Retrieved 26/07/2013.
[31] NIST. (October 2, 2012) "Color rendering of light sources." http://www.nist.gov/pml/div685/grp03/vision_color.cfm Retrieved 27/07/2013.
[32] Philips Solid-State Lighting Solutions, Inc. (2010) LED Lighting: Getting It Right. http://www.ledlightingexplained.com/led-lighting-myths/led_lighting_Getting_It_Right.pdf Retrieved 27/07/2013.

on moving objects in the field of view. The detection and acceptability of flicker are functions of frequency, duty cycle, and the amount of modulation of flicker. In a simulated office setting with a laptop computer, Bullough *et al.* found that flicker was acceptable at a frequency of 100Hz[33], meaning that systems driven from AC line frequency and modulated at 120 Hz will not generate directly perceptible flicker either when looking at or looking away from the source of illumination. Flicker perception at frequencies of 1000Hz or higher is independent of the degree of modulation and generally acceptable[34]. By comparison, fluorescent lamps on conventional magnetic ballasts flicker at 120 Hz and on modern electronic ballasts in the range 20-60 kHz[35].

LED sources are inherently directional whereas fluorescent and incandescent lamps output light in all directions. The implication of this is that an LED lamp may deliver the desired level of illumination in a given direction with a total lumen output that is lower than another source that radiates in all directions, losing light in the surroundings and fixture[36]. LED lighting should be designed for the light delivered to a surface (illuminance) rather than luminance output from the source.

Conclusion

LED lighting is still under development. The color rendering properties of phosphor-based white LED sources in particular are questionable and need to be evaluated with the actual lamp *in situ*. LED lighting systems need to be designed with the task and total environment in mind.

[33]Bullough, J.D., K. Sweater Hickcox, TR Klein and N. Narendran. (2011) Effects of flicker characteristics from solid-state lighting on detection, acceptability and comfort. *Lighting Research and Technology*. 43: 337 originally published online 11 July 2011. Downloaded from lrt.sagepub.com at UNIV CALGARY LIBRARY on July 27, 2013.
[34] Bullough, J.D., K Sweater Hickcox, TR Klein, A Lok and N Narendran. (2012) Detection and acceptability of stroboscopic effects from flicker. *Lighting Research and Technology*. 44: 477 originally published online 11 October 2011. Downloaded from lrt.sagepub.com at UNIV CALGARY LIBRARY on July 27, 2013.
[35] Veitch and McColl, 2001, *op. cit.*
[36] Philips Solid-State Lighting Solutions, Inc. (2010) Evaluating Light Output. http://www.colorkinetics.com/support/whitepapers/evaluating_light_output.pdf Retrieved 08/07/2013.