

To: Richard Karney
DOE Energy Star Product Manager
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From: Ian Ashdown, FIES
Senior Research Scientist
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Re: ENERGY STAR Program Requirements for Solid State Lighting Luminaires
Draft 12/20/06

Dear Mr. Karney:

I have reviewed the ENERGY STAR Program Requirements for Solid State Lighting Luminaires (Draft 12/20/06) that was brought to my attention through my membership in the CSA C866 Technical Subcommittee on Performance of Light Emitting Diodes. My comments are as follows:

1. I am puzzled by the equation on page 6 that derates the luminaire efficiency according to the CRI. I have never seen this equation before, and I cannot understand how it might have been derived.
2. The text states that “the CRI and efficacy of LEDs is strongly interrelated.” In the absence of any references, I must strongly dispute this claim. Efficacy is a physical measurement involving electrical power and luminous flux; the CIE General Colour Rendering Index metric (CRI) is based on psychophysiological phenomena. There is no relation between the two.

I am aware of work done by Drs. Sam Berman and Moji Navvab that indicates that visual performance improves with increasing color temperature, but this also has no relation to CRI.

3. The proposed minimum luminaire efficacies are quite aggressive, even for near-term niche applications. As evidence of this, I refer to the DOE Solid-State Lighting Commercial Product Testing Program Summary of Results: Pilot Round of Product Testing (Update – December 2006), where the SSL manufacturers overstated their product luminous efficacies by factors of 2.3 to 3.4. (The report does not identify the products, but I believe I judged them as part of the 2006 Lighting for Tomorrow competition.)

I do however agree that these minimum luminaire efficacies should be competitive with existing CFL-based luminaires. As such, the ENERGY STAR requirements will likely represent targets for future products for at least another year.

4. I must question the proposed minimum CRI values for four reasons:
 - i) LED modeling performed by NIST¹ has shown that typical RGB LED clusters have CRIs of ~27, whereas cool white LEDs have CRIs of ~72 and warm white LEDs have CRIs of

¹ W. Davis and Y. Ohno, “Towards an improved color rendering metric,” *Proc. Solid State Lighting V*, SPIE Vol. 5941, 2005.

~85. Our own published research² has shown that RGB LED clusters vary in CRI from 25 at 3000 K to 40 at 6500 K. Adding amber LEDs increases this to between 50 at 3000 K and 72 at 6500 K.

While it is unlikely that near-term niche applications will use RGB or RGBA LED clusters rather than fixed CCT phosphor-coated white light LEDs, this is not necessarily the case for Category B Efficacy Based Luminaires³.

- ii) There have been numerous papers published that question the applicability of the CIE Colour Rendering Indices (and in particular the General Colour Rendering Index, colloquially known as “CRI”) to solid state lighting products. A comprehensive bibliography has been prepared by CIE Technical Committee 1.62, “Colour Rendering of White LED Light Sources.” The metric has also been called into question as being thoroughly outdated⁴.

The CIE has recently initiated TC 1.69, “Colour Rendition by White Light Sources,” to modernize the CRI metric. (A recent proposal by NIST called the Color Quality Scale¹ is an attempt to do this.)

Given that the CIE will likely deprecate the current CRI metric in favour of a new color rendering metric, it is questionable whether proposed standards should continue to reference it.

- iii) Current high-end SSL products based on RGB LED clusters have received critical acclaim, even for demanding applications such as museum lighting. This is in agreement with a 2002 study by the Lighting Research Center – while RGB LED clusters may have low CRIs, observers still rank them highly in terms of color preference.
- iv) I do not understand how the specification of color rendering fits within the mandate of the ENERGY STAR program with its focus on energy efficiency.

If color rendering is indeed an issue, then I must object to the overly lax CCT limits of seven MacAdam ellipses. While I appreciate that these limits likely acknowledge the technical limitations of CFL manufacturing, they result in painfully obvious chromaticity differences between light sources.

The ANSI requirements for linear fluorescent lamps is a more reasonable four MacAdam ellipses, with most manufacturers managing to maintain two to three MacAdam ellipses with their quality control. Even so, chromaticity differences are alleviated by the large physical size of these light sources. Viewing white light LEDs side-by-side in arrays makes color binning a much more critical issue, even when the LEDs are diffused. (This was painfully obvious when we were judging the Lighting for Tomorrow submissions last October.)

The maximum seven MacAdam ellipse requirements make sense in terms of the ENERGY STAR mandate. It is likely however that consumer expectations will enforce

² Speier, I., and M. Salsbury. 2006. “Color Temperature Tunable White Light LED System,” *Proc. Solid State Lighting VI*, SPIE Vol. 6337, 2006, available from <http://www.tirsys.com/pdf/resources/technical-papers/Color-Temperature.pdf>.

³ In the interests of full disclosure, TIR Systems is currently developing RGB LED-based luminaires for general illumination.

⁴ van Tright, C. 1999. “Color Rendering, A Reassessment,” *Color Research & Application* 24(3):197-20.



stricter binning requirements for all but the least expensive products. By the same token however, I believe that consumers should be given the choice of CRI performance, rather than it being mandated for no particular reason through ENERGY STAR labeling.

5. Regarding standards and documentation for CCT (p. 11 and 13), IESNA LM-11 has been deprecated by the IESNA. The appropriate reference is CIE 15:2004, Colorimetry, Third Edition (pp. 26-27).

Also, IESNA LM-58 is titled "IESNA Guide to Spectroradiometric Measurements," and has no information on Color Rendering Index and Correlated Color Temperature (p. 14). The appropriate reference is CIE 13.3-1995, "Method of Measuring and Specifying Colour Rendering Properties of Light Sources." (This publication details the mathematical procedures; the related physical measurements are the subject of CIE 63-1984, "The Spectroradiometric Measurement of Light Sources.")

Yours truly,

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