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Correspondence: In support of the IES method of evaluating light source colour rendition

It is well known that the colour of illuminated surfaces can look different under different light sources. In the mid-20th century, as the diversity of light sources began increasing, the Commission Internationale de l'Eclairage (CIE) developed a metric for assessing colour fidelity called the colour rendering index, or CRI. Since 1965, CIE CRI has estimated the colour fidelity of a light source for 14 selected sample surfaces, and also an average accuracy, R_a, for an eight-sample subset.[1]

CRI has been a helpful aid in light source selection, but CIE has never claimed that a lamp with a higher R_a value is necessarily the more appropriate source for illumination. That is, in part, because it is inefficient to provide perfect colour fidelity; there is generally a tradeoff between the R_a value for a source and other important factors such as luminous efficacy, cost, and lifetime.[2] More generally, colour fidelity is only one aspect of colour rendering—colour fidelity does not always correlate with application-specific considerations, such as colour preference or colour discrimination, and does not take into account other aspects of colour appearance such as the influence of illuminance. Lighting design is both an incomplete, complex science, and an art, and the selection of optimum light sources is a key component of that work. Ultimately, designers must make their best judgments, and understandably they seek practical tools to help them do so. Ideally, such metrics would provide more information about the nature of colour shifts of various surfaces and would present the information in ways that would help guide designers.

CRI has not been updated significantly since 1974,[3] and it is now known to have limitations that are problematic for some sources that have narrow spectral features. This has become more pressing with the advent of narrow-band LED sources.[4] In short, there has been a need for a more accurate index of colour fidelity, and the need to supplement that index with much more information. Recently, the Illuminating Engineering Society of North America (IES) set up the Color Metrics Task Group. Building on previous work at the CIE, the Color Metric Task Group has made significant progress in both these areas, leading to the publication of TM-30-15.[5,6] Based on this work, accuracy improvements for the CIE CRI are being considered by CIE Technical Committee (TC) 1-90, and suggestions for much more colour shift information are being considered by CIE TC 1-91.

While we hope that CIE will introduce recommendations for updating CIE CRI and also provide additional measures of colour quality, there is no need to wait. We believe that IES TM-30-15 can fulfill many of these needs now. It is the first new method for evaluating light source colour rendering approved by an appropriate authority since CIE CRI, and we believe it is a significant advance. TM-30-15 is an assimilation of a significant international body of research that has accrued from steady progress over the last few decades. This warrants a very brief summary here.

Soon after the introduction of the CIE method, there was growing recognition that

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failure to supplement CIE CRI would impede the spectral design of light sources for the purpose of optimizing human well-being.[7–18] In response, scientists around the world proposed over 25 additional ideas for evaluating the influence of light source spectra on colour appearance, beyond CIE CRI's assessment of colour fidelity. These have been called "preference" (usually referring to what observers tend to choose in short term comparisons between light sources), "discrimination" (the ability to discern small colour differences), and quantification of colour shifts in terms of saturation and hue [for reviews, see references 17, 19 and 20]. These measures and the research that led to them advanced the scientific understanding of many aspects of colour shifts and human responses to them. However, not one of these measures has been adopted by an appropriate lighting authority. In the last decade, there has been an especially strong push to improve the accuracy of CIE CRI and to supplement it,[21] including numerous new studies and proposals.[5,15,22–29] These recent works, in particular, are the basis of the conceptual framework and scientific backbone for the IES TM-30-15 method.

The TM-30-15 method includes a fidelity index (R_f) that is basically a more accurate version of the CIE R_a, a relative-gamut index (R_g), that estimates the average extent to which a light source increases or decreases the saturation of surface colours, and, very importantly, colour vector and distortion graphics that visually present information about hue and saturation. The improved accuracy of R_f is achieved with the use of a modern colour difference calculation and an improved set of 99 colour evaluation samples. The system also includes individual fidelity scores for each of the 99 samples, measures of fidelity and saturation change for specific hue angle bins of these samples, and a fidelity measure for skin tones. All of these components combine to form a cohesive system, based upon a single, self-consistent underlying calculation framework, in a computational format that is fast and simple to use.

While simple to use, the TM-30-15 system can also provide an expert user with sophisticated and detailed information. For the simplest applications, R_f and R_g, together with the colour vector and distortion graphics, provide useful information without requiring the user to be an expert on colour science. Experts may also wish to study the colorimetric calculations and secondary sub-indices that are nested within the system. In this way, TM-30-15 offers a replacement for CIE R_a while also providing a suite of other measures that will assist manufacturers with the spectral design of light sources, and assist designers with lighting specifications.

Calculations for the IES method occur in CAM02 uniform colour space, which is an improvement over the outdated U*V*W* colour space used in the CIE method. The intrinsic CIECAM02 chromatic adaptation transform replaces the outdated von Kries transform employed in the CIE method. Calculations are performed using the CIE 1964 10° colour matching functions, which are more representative of general viewing than the CIE 1931 2° colour matching functions which are used in the CIE method. The 2° CMFs are retained in the IES method only for the computation of correlated colour temperature since that is recommended by CIE.[30]

TM-30-15 uses a newly-developed set of reflectance functions, comprising 99 colour evaluation samples. These were down-selected from 105,000 real object samples and are uniformly distributed in colour space and wavelength space. Uniform distribution in colour space means that the samples fairly represent the range of object colours that may be encountered in architectural interiors, something not achieved by the eight pastel test-colour samples of CIE R_a. The test-colour samples of CIE R_a have also been criticized because they permit selective optimization[27,31] which allows CIE R_a scores to be increased or decreased by adjusting the wavelengths of light emission, with a potentially unrelated change in perceived colour fidelity. This new set of evaluation samples shows little preference for any wavelength. Consequently, they prohibit the selective optimization of R_f and R_g scores through spectral engineering.

R_f is a measure of colour fidelity; it characterizes average similarity to a reference source. IES R_f is an improved version of CIE R_a and can be employed as a replacement. R_f has a range of 0 – 100, with higher scores indicating greater similarity to the reference source. R_f is somewhat more stringent than CIE R_a because it does not disadvantage any wavelength bands with respect to the visual system's natural sensitivity to spectral distortion, unlike the CRI R_a, which causes certain visible distortions to be under-represented.

R_g is a measure of relative colour gamut; it characterizes the average amount of saturation or desaturation in an objects' colour appearance in comparison to a reference source. When R_f is greater than 60, R_g will be within the range of about 60 to 140. Values greater than 100 indicate an average increase in saturation relative to the reference; values less than 100 indicate an average decrease in saturation.

R_f and R_g together form a two-measure system in which the whole is greater than the sum of the parts; likely together they will be more useful than either alone in classifying and predicting the value to end-users in various settings. This is possible because R_f and R_g share a common set of colorimetric formulae and colour samples, and also because they employ the same reference source, which is always at the same CCT as the source being evaluated. This establishes a cohesive system compatible with the typical lighting design process, where colour temperature is most frequently decided before colour rendering is considered.

It is important to remember that the colour vector and distortion graphics provide very useful depictions of hue and saturation changes of all colours simultaneously, which can be a quick and useful way to evaluate performance beyond averages. On the colour distortion graphic, if the test-source line plots outside a reference circle, then saturation is increased by the test source. Conversely, when the test-source line plots inside the reference circle, saturation is decreased. The colour vector graphic adds vectors to indicate the approximate direction of hue shifts. For example, a vector may show that orange colours will appear redder and more saturated. Of course any simplified representation of complex data is necessarily incomplete. The graphic tools don't show that some sources will create different colour shifts in objects that have the same chromaticity, but different spectral reflectance functions (an effect called object metamerism), but to some extent those issues are apparent when examining the colour shifts of the individual 99 test samples. Hue and saturation shifts can be in any direction for source SPDs, and simultaneously comparing many sub-index values can be challenging, hence the need for and use of graphics to complement the numerical measures.

Undoubtedly, the process of crafting the ideal system for evaluating colour rendering is not completed by the publication of TM-30-15. On the contrary, there is still much to study, especially related to optimizing sources for maximum human well-being in various settings, establishing appropriate criteria for R_f and R_g, and how context-dependent issues might relate to various combinations of R_f and R_g and the other information provided by TM-30-15. Some of these important considerations about what lies next are discussed by Royer.[32]

In summary, TM-30-15 includes IES R_f as a simple and accurate replacement for CIE R_a. It also provides a suite of other measures and graphics to assist manufacturers with the spectral design of light sources and the design community with lighting specifications. CIE R_a will be with us for some years to come because it is a part of some codes and standards, although we hope that in the near future CIE will upgrade it along the lines of R_f. However, we do not need to wait for that to happen, because, for the first time, a prominent and appropriate lighting authority has agreed upon an alternative: an accuracy upgrade for the CIE CRI along with critically important supplementary information to assess colour rendering beyond fidelity. Adoption of the IES TM-30-15 method for evaluating light source colour rendering is, at root, a choice. We invite you to make the right choice and join us in putting TM-30-15 into practice.

References

1 Commission Internationale de l'Eclairage. CIE Publication 13-1965 *Method of Measuring and Specifying Colour Rendering Properties of Light Sources*. Paris: CIE, 1965.
2 Papamichael K, Siminovith M, Veitch JA, Whitehead L. High color rendering can enable better vision without requiring more power. *Leukos* 2015 [Online before print.]
3 Commission Internationale de l'Eclairage. CIE Publication 13.2. *1974 Method of Measuring and Specifying Colour Rendering Properties of Light Sources*. 2nd edition. Vienna: CIE, 1974.
4 Commission Internationale de l'Eclairage. CIE. Publication 177:2007 *Colour Rendering of White LED Light Sources*. Vienna: CIE, 2007.
5 David A, Fini P, Houser KW, Ohno Y, Royer MP, Smet KAG, Wei M, Whitehead L. 2015. Development of the IES method for evaluating the color rendition of light sources. *Optics Express* 2015; 23(12): 15888–15906.
6 Illuminating Engineering Society of North America. 2015. IES TM-30-15 *IES Method for Evaluating Light Source Color Rendition*. New York: IES, 2015.
7 Judd DB. A flattery index for artificial illuminants. *Illuminating Engineering* 1967; 62: 593–598.
8 Thornton WA. 1972. Color-discrimination index. *Journal of the Optical Society of America* 1972; 62(2): 191–194.
9 Jerome CW. Flattery vs color rendition. *Journal of the Illuminating Engineering Society* 1972; 1: 208–211.
10 Jerome CW. The flattery index. *Journal of the Illuminating Engineering Society* 1973; 2: 351–354.
11 Thornton WA. 1974. A validation of the color-preference index. *Journal of the Illuminating Engineering Society* 1974; 4: 48–52.
12 Walter W. How meaningful is the CIE color rendering index?. *Lighting Design and Application* 1981; 11(2): 13–15.
13 Seim T. In search of an improved method for assessing the colour rendering properties of light sources. *Lighting Research and Technology* 1985; 17(1): 12–22.
14 Houser KW. Lighting for quality. *Lighting Design and Application* 2002; 32(11): 4–7.
15 Narendran N, Deng L. 2002. Color rendering properties of LED light sources. Solid State Lighting II. *Proceedings of the SPIE* 2002; 4776: 61–67.
16 Worthey JA. Color rendering: asking the question. *Color Research and Application* 2003; 28(6): 403–412.
17 Guo X, Houser KW. A review of colour rendering indices and their application to commercial light sources. *Lighting Research and Technology* 2004; 36(3): 183–199.
18 Rea M, Freyssinier-Nova JP. Color rendering: a tale of two metrics. *Color Research and Application* 2008; 33(3): 192–202.
19 DiLaura DL, Houser KW, Mistrick RG, Steffy GR (Eds). 2011. *The Lighting Handbook: Reference and Application* 10th edition, New York: The Illuminating Engineering Society of North America, 2011.
20 Houser KW, Wei M, David A, Krames MR, Shen XS. 2013. Review of measures for light-source color rendering and considerations for a two-measure system for characterizing color rendering. *Optics Express* 2013; 21(8): 10393–10411.

21 Royer MP. Color rendering metrics: An overview of ongoing work. Retrieved 13 July 2015 from http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/royer_rendering_lightfair2014.pdf.
22 Sandor N, Schanda J. Visual colour rendering based on colour difference evaluations. *Lighting Research and Technology* 2006; 38(3): 225–239.
23 Davis W, Ohno Y. Approaches to color rendering measurement. *Journal of Modern Optics* 2009; 56(13): 1412–1419.
24 Davis W, Ohno Y. Color quality scale. *Optical Engineering* 2010; 49(3): 033602.
25 Rea M, Freyssinier JP. Color rendering beyond pride and prejudice. *Color Research and Application* 2010; 35(6): 401–409.
26 Smet K, Whitehead L. Meta-standards for color rendering metrics and implications for sample spectral sets. *Proceedings of the 19th Color and Imaging Conference*, San Jose, CA, USA, 2011.
27 Smet K, Ryckaert WR, Pointer MR, Deconinck G, Hanselaer P. Correlation between color quality metric predictions and visual appreciation of light sources. *Optics Express* 2011; 19(9): 8151–8166.
28 de Beer E, van der Burgt P, van Kemenade J. 2015. Another color rendering metric: do we really need it, can we live without it? *Leukos* 2015; Online before print.
29 Smet K, Whitehead L, Schanda J, Luo MR. Toward a replacement of the CIE color rendering index for white light sources. *Leukos* 2015; Online before print.
30 Ohno Y. Practical use and calculation of CCT and Duv. *Leukos* 2014; 10(1): 47–55.
31 Smet KAG, David A, Whitehead L. Why colour space uniformity and sample set spectral uniformity are essential for color rendering measures. Leukos 2015; Online before print. http://dx.doi.org/10.1080/15502724.2015.1091356
32 Royer MP. IES TM-30-15 is approved—now what? Moving forward with new color rendition measures. *Leukos* 2015; Online before print.

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