A Two-metric Proposal to Specify the Color-rendering Properties of Light Sources for Retail Lighting

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A two-metric proposal to specify the color-rendering properties of light sources for retail lighting

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ABSTRACT

Lighting plays an important role in supporting retail operations, from attracting customers, to enabling the evaluation of merchandise, to facilitating the completion of the sale. Lighting also contributes to the identity, comfort, and visual quality of a retail store. With the increasing availability and quality of white LEDs, retail lighting specifiers are now considering LED lighting in stores. The color rendering of light sources is a key factor in supporting retail lighting goals and thus influences a light source's acceptance by users and specifiers. However, there is limited information on what consumers' color preferences are, and metrics used to describe the color properties of light sources often are equivocal and fail to predict preference. The color rendering of light sources is described in the industry solely by the color rendering index (CRI), which is only indirectly related to human perception. CRI is intended to characterize the appearance of objects illuminated by the source and is increasingly being challenged because new sources are being developed with increasingly exotic spectral power distributions. This paper discusses how CRI might be augmented to better use it in support of the design objectives for retail merchandising. The proposed guidelines include the use of gamut area index as a complementary metric to CRI for assuring good color rendering.

Keywords: color rendering, saturation, vividness, naturalness, gamut area index, LED

1. INTRODUCTION

Since the early days of electric light sources, lighting has played a major role in supporting retail operations, from setting the atmosphere of the store to helping customers evaluate the products for sale.[1][2] The color rendering and light color appearance of light sources are key factors in supporting retail lighting goals and thus influence a light source's acceptance by users and specifiers. For almost 50 years, the lighting industry has used primarily one metrics to describe the color rendering capabilities of light sources, color rendering index (CRI).[1][3] CRI is intended to describe the appearance of objects illuminated by the light source. This metrics was developed to precisely describe the physical properties of light sources but is only indirectly related to human perception; thus, it has a limited ability to predict color appearance and can be misleading.[4][5] Furthermore, designers and specifiers have indicated that the color properties of a light source are often more important than the luminous efficacy of the source, especially in retail lighting, and that they rely heavily on CRI to compare and specify light sources.[4][5][6]

With the increasing availability and quality of white LEDs, retail lighting specifiers are now considering the use of LED lighting in stores. As a result of the increasing number of LED source options in the market, CRI is now being challenged more than ever before because of the new spectral compositions offered by LED sources, often unfamiliar to specifiers. Not surprisingly, the lighting industry is in need of better ways to characterize the color-rendering properties of light sources so that designers and specifiers can be reasonably confident that the light sources they recommend will meet the expectations of the end users. To address this need, the Alliance for Solid-State Illumination Systems and Technologies (ASSIST) has developed a recommendation on how CRI might be augmented to better use it in support of the design objectives of retail merchandising.[4][5] This paper summarizes ASSIST's recommendations to specify the color rendering properties of light sources. Full details of ASSIST's recommendations are available online (www.lrc.rpi.edu/programs/solidstate/assist/recommends.asp) for free download in two relevant *ASSIST recommends…* documents.

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2. BACKGROUND

Color rendering is a general term for describing the ability of a light source to provide color information to an observer when objects are illuminated by the source. In the context of interior illumination, color information can take several meanings. In 1948, Bouma[7] articulated the ideal color rendering abilities of any light source based on his observations of daylight. Based on Bouma's observations, it is reasonable to expect that a light source with good color rendering abilities should make objects appear vivid and natural, it should provide good discrimination between subtle differences in hue, and should not distort colors.[4]

To date, color rendering index is the most widely used measure of the color rendering abilities of a light source.[6] CRI was developed in the 1960s as a measure of how "true" colors were rendered by electric light sources in comparison to a reference source.[8][9] In developing CRI, daylight and incandescent lights were chosen as references because they were the most familiar sources at the time. The general CRI, also denoted as Ra, is derived from the net change in color space of the coordinates of eight standard color chips under two light sources of the same CCT, one being the reference and the other the light source being evaluated. The CRI method results in a high score, capped at 100, when there is small or no shifts in chromaticity of the color chips. Large shifts are penalized and result in a lower Ra value.[3] In general, Ra values above 80 are considered to represent good color rendering and is the typical value recommended for retail applications.[1] However, it must be emphasized that CRI was not designed to measure all of the good color rendering expectations described by Bouma. Instead, CRI was designed to measure only color fidelity, or how "undistorted" a light source renders colors with respect to the reference. Unfortunately, over time CRI has become the only measure of color rendering and has been erroneously associated with the other dimensions of good color rendering described by Bouma. Given the clearly stated intent of CRI, it is not surprising that a body of work has demonstrated that CRI cannot predict a source's ability to provide good hue discrimination, subjective impressions of vividness, and preference.[10]-[20] Shortly after CRI had been developed, Judd argued that in order to better describe the color rendering abilities of a light source, more than one metric was needed.[9] However, Judd's proposal to augment CRI with a flattery index was not adopted. Over the past few years several other attempts to improve CRI have been made; [11]-[20] however, these attempts have not yet been adopted perhaps because a single metric cannot fully describe all of the fundamentally different aspects of color rendering.

In the early 1970s, Thornton developed the concept of gamut area as an alternative measure of color rendering.[21]-[24] Thornton's work attempted to addressed perceived color saturation and hue discrimination, two important aspects of color rendering not previously addressed by CRI. Thornton's approach was fundamentally different from CRI as he was interested in the absolute separation of the chromaticity of the eight color chips rather than in the relative shift with respect to a reference. The gamut area defined by Thornton corresponds to the area within a polygon in chromaticity space. The corners of the polygon are the chromaticity coordinates of the eight standard color chips when illuminated by the test source. Figure 1 shows the gamut areas of traditional light sources. Thornton showed that greater gamut areas corresponded to greater perceived hue saturation. As expected, Thornton also showed that in general, the greater the gamut area, the greater the discriminability between object colors. One caveat to the concept of gamut area is that a light source with too large a gamut area could make objects appear overly saturated and thus unnatural.

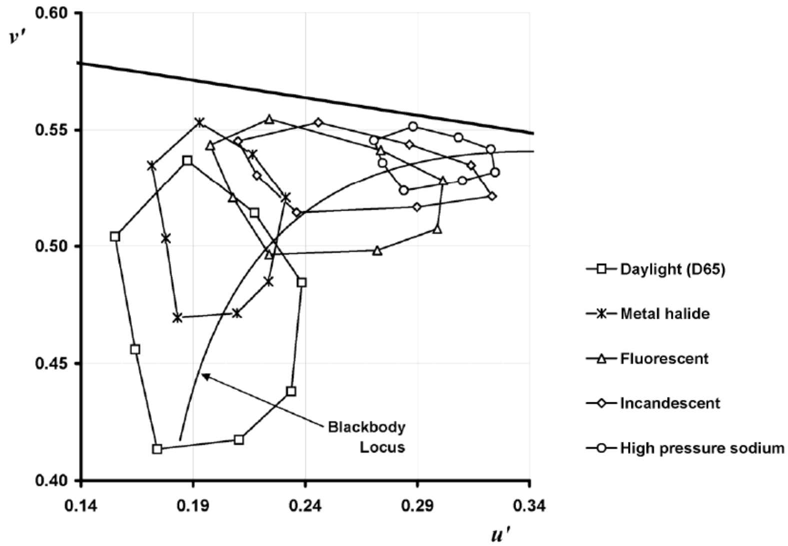

Figure 1. Gamut areas of metal halide, high-pressure sodium, fluorescent, incandescent, and CIE D65 standard illuminant simulating daylight of 6500 K (after Thornton 1972[24] and Boyce 2003[25]).

3. RECOMMENDATION FOR SPECIFYING COLOR-RENDERING PROPERTIES

Recently, following the principles laid out by Bouma,[7] Judd,[9] and Thornton,[24] Rea and Freyssinier[26][27] proposed a two-metric approach by complementing CRI with a measure of gamut area (gamut area index) as a practical approach to specify the color-rendering properties of light sources. The rationale behind the approach is that CRI and gamut area are indicative of fundamentally different, but relevant, aspects of color rendering. CRI is a metric that emphasizes the stability of colors with respect to a familiar source, i.e., a high CRI score means that the light source renders object colors similar to the reference, whereas gamut area is sensitive to hue saturation and hue discriminabilty. Gamut area index (GAI)[28] was defined in terms of the same eight test color chips used in the CRI calculation. For any given source, its gamut area is defined by the eight chromaticity coordinates of the standard color chips in the CIE u'v' color space. An equal energy spectrum was arbitrarily assigned a GAI value of 100, and the gamut area of all other light sources is scaled accordingly to derive their GAI. Given this definition, GAI values greater than 100 are possible.

Recent work by Rea and Freyssinier[26] showed that GAI is a better predictor than CRI of the scores of a standardized color discrimination test known as the Farnsworth-Munsell 100-hue test.[29][30] In their work, Rea and Freyssinier also showed that GAI is a good measure of subjective impressions of hue saturation and confirmed that light sources with too large a GAI value can render object colors overly saturated and affect subjective ratings of acceptability. Based on their work and initial recommendations by Figueiro et al.,[31] Rea and Freyssinier recommended a lower (80) and an upper (100) limit to GAI.[5][27]

Perhaps more importantly, Rea and Freyssinier[27] tested the two-metric hypothesis and were able to show that when GAI is used to complement CRI, high values of both metrics (CRI ≥80 and 80≤GAI≤100) seem to ensure positive subjective impressions of naturalness and vividness, both considered important aspects of color rendering in retail applications. Additionally, sources meeting the CRI and GAI criteria seem to be generally preferred over sources with only high CRI or only high GAI when used to illuminate a multicolored display. The results are applicable to warm and cool correlated color temperatures (CCT~3000 K and CCT~5000 K).

Based on these findings, ASSIST recommends that light sources intended for retail lighting applications should meet two criteria in order to have increased chances of providing good color rendering under most conditions: a CRI ≥80 and 80≤GAI≤100. Table 1 shows a partial list of available light sources that meet the criteria of the two-metric approach proposed.[5][27] Figure 2 shows graphically the target criteria for CRI and GAI of the sources listed in Table 1.[5][27]

Table 1. Partial list of commercially available light sources meeting the criteria of CRI ≥80 and 80≤GAI≤100.

	Light source	Manufacturer	Product Model	CCT (K)	CRI	GAI
1	Xenon	OSRAM SYLVANIA	1000W	5853	97	91
2	PC-LED	Cree	XRE lamp	4154	84	82
3	PC-LED	Sharp	Zenigata	5097	95	99
4	RGB-LED	Various	Peak wavelengths of 465 nm, 545 nm, and 614 nm	4000	89	82
5	T8	General Electric	F32T8SPX50	4751	87	86
6	T8	Lumiram	Lumichrome 1XX	5960	93	95
7	T8	Verilux	F32T8VLX	6369	85	96
8	T12	OSRAM SYLVANIA	Design50, 40W	4861	90	84
9	T12	General Electric	Sunshine F40C50	4944	92	87
10	T12	Duro-Test	Vita-Lite 5500	5159	88	90
11	T12	Lumiram	Lumichrome 1XC	5207	92	93
12	T12	Philips	Colortone 75	6217	90	85
13	T12	Duro-Test	DAYLITE 65, 40W	6588	93	95
14	MH	Philips	CDM100W/4K	4075	93	80
15	MH	Philips	CDM150W/4K	4197	92	83
16	Daylight		CIE D50	5000	100	88
17	Daylight		CIE D65	6500	100	98

PC-LED: phosphor-converted white light-emitting diode
RGB-LED: red, green and blue LEDs mixed to create white light
T8: linear fluorescent, 25 mm diameter
T12: linear fluorescent, 38 mm diameter
MH: metal halide

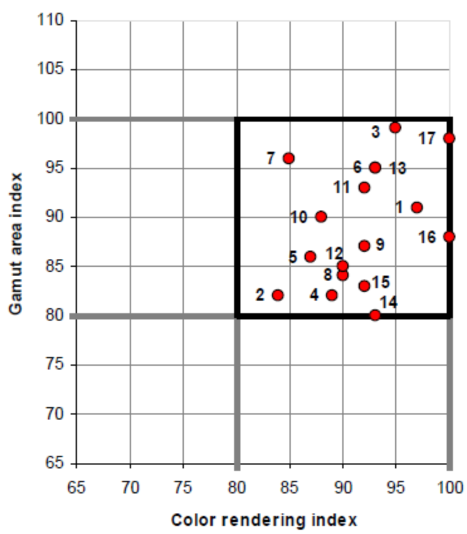

Figure 2. CRI and GAI of the light sources listed in Table 1. The black square shows the target zone for light sources that have both high CRI and high GAI.

4. CONCLUSIONS

The lighting industry is in need of ways to characterize the color rendering properties of light sources so that designers and specifiers can be reasonably confident that the light sources they recommend will meet the expectations of the end users. CRI was developed to measure only one aspect of color rendering—color fidelity—under the assumption that high CRI values can be generally taken to mean that a light source renders object colors similarly to the reference, and thus naturally. However, color rendering is a concept that encompasses several orthogonal dimensions, including color fidelity, naturalness, saturation, and hue discrimination, that cannot be characterized by any single metric. This paper summarizes a recent recommendation by ASSIST in which two metrics, each measuring fundamentally different aspects of color rendering, are needed to provide the information needed for the specification of retail lighting. Rea and Freyssinier have shown that GAI is a good measure of saturation and is a better predictor of color discrimination than CRI. Recent laboratory experiments have consistently shown that when GAI is used to complement CRI, high values of both metrics (CRI $\geq$80 and 80$\leq$GAI$\leq$100) seem to ensure positive subjective impressions of naturalness and vividness, both considered important aspects of color rendering in retail applications. Additionally, sources meeting the CRI and GAI criteria seem to be generally preferred over sources with only high CRI or only high GAI. The two-metric approach presented here is a practical solution to ensure good color-rendering properties of electric sources for interior lighting, including retail applications.

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