LED WATCH

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EMERGING SPECIFICATION GUIDANCE FOR TM-30

Where we are with the new method for color rendition calculations

It's been a few years since the publication of IES TM-30-15, a method for characterizing color rendition that's more accurate and more comprehensive than older methods. Although TM-30 data for light sources are becoming increasingly available, and specifiers are beginning to incorporate the new tools into their work, there's still a ways to go before TM-30 achieves ubiquity. That's understandable, given that there's considerable inertia to overcome when introducing new standards to a broad user base.

TM-30 describes a calculation procedure, but it intentionally doesn't include any guidance on how to apply the dozens of values and graphics that are generated. Researchers and practitioners have been working to develop that guidance, including establishing criteria to help specifiers, purchasers and end users choose lighting products that make objects appear as natural and pleasing as needed for the application. While the lighting community awaits something more formal along those lines, such as an IES Recommended Practice, it's possible to use a growing body of evidence as the basis for performance criteria to aid specification and technology development.

There are at least three ways to establish performance criteria. One is by benchmarking, or using a set of products that met previous criteria to establish new criteria with different measures. Benchmarking is relatively fast, cheap and straightforward, but it can be misleading if existing sources are not accurately classified or not representative of all possibilities. A second way to establish performance criteria is through the experience of lighting practitioners, which has the advantage of involving real architectural spaces, but relies only on existing sources and is gained gradually. It can be hard to gain experience if no product data or initial guidance are available to facilitate use of new tools. A third option is to conduct human-factors research, which directly reveals users' responses and allows for light-source properties to be varied in many different ways—but also can be time-consuming, costly or misleading (if done improperly). While all methods to establish performance criteria have limitations, better criteria can emerge and be refined over time by combining multiple approaches.

WHY NEW CRITERIA ARE NEEDED

The findings of a recent study ("Human perceptions of color rendition vary with average fidelity, average gamut, and gamut shape"; *Lighting Research and Technology*) demonstrate why a transition to new criteria for color rendition is important. By itself, average color fidelity—especially CIE R_a (CRI)—was found to be a weak predictor of any subjective aspect of color quality (naturalness, vividness or preference), and many of the most-liked lighting conditions had a CRI ≤ 73, indicating that the common practice of using CRI ≥ 80 as a cutoff point may exclude many preferred light sources—a deficiency that's been recognized by the CIE itself. The use of CRI ≥ 80 as a criterion began back when fluorescent lamps were the most-efficient lighting products available. A CRI of 80 delineated between older halophosphate technology and newer and more efficient tri-phosphor technology, which was generally considered to have superior color quality. The implementation of CRI ≥ 80 by Energy Star, combined with practitioners' experience with those two types of light sources, likely led to what's become a de-facto standard for interior architectural lighting. For many years, this cutoff was reasonably effective for differentiating the color quality of available light sources—but only because the pool of light sources under consideration had little variation in overall color-rendition characteristics beyond average color fidelity. Because the spectrum of solid-state lighting (SSL) can easily be tuned to provide a wide variety of color-rendition characteristics, the technology has exposed both the scientific inaccuracies and the limitations in scope of CRI, which may now be more of an impediment to technology development than a useful design aid.

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THE SCIENTIFIC EVIDENCE

No experimental evidence has been published in a peer-reviewed journal to support the implementation of CRI ≥ 80 as a means to ensure preferable or acceptable lighting color quality for SSL products. Combined with TM-30's inclusion of scientifically accurate measures for numerous objective qualities of color rendition—including average color fidelity (R_f), gamut area (R_g), local chroma shift ($R_{cs,hj}$), local hue shift ($R_{hs,hj}$) and local color fidelity ($R_{f,hj}$)—spectrally tunable LED systems have enabled more-effective research experiments. By systematically varying different aspects of color rendition, it is possible to better understand what influences subjective evaluations.

Pacific Northwest National Laboratory (PNNL) has conducted two such experiments, the results of which indicate that criteria of IES TM-30-15 $R_f \geq 75$, $R_g \geq 98$, $-7\% \leq R_{cs,h1} \leq 15\%$ are effective for identifying light sources with high acceptability, preference and naturalness ratings—with $R_{cs,h1}$ values between 0 and 8% being

ALL ABOUT RED?

All research to date has highlighted the importance of IES $R_{cs,h1}$ or IES $R_{cs,h16}$, which are measures of red chroma shift derived from adjacent hue-angle bins. This new type of measure reveals whether reds will be made more vivid (positive values) or more dull (negative values), and either measure works well as part of a set of specification criteria.

The combination of multiple IES TM-30-15 values, including red chroma shift, is analogous to the current practice of augmenting CRI (R_a) with R9 to address the particular importance of the color red to lighting color quality. However, red chroma shift is more informative than R9 because it indicates both the direction and magnitude of the shift.

most preferred ("Human perceptions of colour rendition at different chromaticities"; *Lighting Research and Technology*). Another recent study ("Toward a unified model for predicting color quality of light sources"; *Applied Optics*), conducted at Zhejiang University in China, also found that the parameters of R_f, R_g and $R_{cs,h1}$ were the most effective for predicting ratings of naturalness, vividness and preference. Although no specific thresholds were proposed by the authors, those derived from the work at PNNL are very effective at distinguishing the top performers. A fourth recent study ("Models of colour quality over a wide range of spectral power distributions"; *Lighting Research and Technology*), conducted at Penn State University, found that the most preferred quartile of lighting conditions had $R_g \geq 100$ and $R_{cs,h16} \geq 0\%$.

The largely congruent results of these experiments are supported by a recent benchmarking study that led to the U.S. Department of Defense's *Unified Facilities Criteria* (UFC)*, Design: Military Medical Facilities* (UFC 4-510-01). Based on a set of acceptable fluorescent light sources that had been used in such facilities, new criteria were developed using IES TM-30-15 values: $R_f \geq 80$, $R_g \geq 98$, $-9\% \leq R_{cs,h1} \leq 9\%$, and $R_{f,h1} \geq 78$.

While there are some minor differences in specific values, these five studies collectively point to average color fidelity (R_f), gamut area (R_g) and especially red chroma shift ($R_{cs,h1}$ or $R_{cs,h16}$) being three important values to specify. Some of the differences can be attributed to how and where the criteria are intended to be used. For example, the criteria in UFC 4-510-01 are intended for medical facilities, while the reported criteria arising from the four experiments generally focus on generic object-viewing environments. Whenever criteria are chosen for a specific project or for a general performance specification, considering the purpose of the criteria can help further refine the thresholds. Experience gained going forward may help in this regard.

Minimum color quality standards are necessary, because the light sources most efficient at producing lumens are impractical for use in architectural lighting, due to poor color rendition. Thus, accurate measures of color rendition and accompanying performance criteria are essential for helping technology developers and users balance trade-offs between energy efficiency and lighting quality. Setting higher color-rendition criteria while maintaining use of CRI (e.g., CRI ≥ 90) may filter out some unacceptable light sources, but also filters out many highly desirable light sources and requires a greater trade-off with energy efficiency. In contrast, specifying color rendition using TM-30 R_f, R_g, and $R_{cs,h1}$ has been shown to be effective for differentiating desirable sources while maintaining flexibility for technology development and energy efficiency.

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