BY **MIKE WOOD**

Those nice bright colors

LAST YEAR IN THIS COLUMN I wrote two articles about color rendering and discussed the pros and cons of CRI (Color Rendering Index) and CQS (Color Quality Scale) as metrics for entertainment luminaires. The conclusion that the PLASA TSP Photometrics Working Group came to on this topic is that CQS suits the needs of our industry better, and accordingly, it is now included as a criteria in the draft E1.41 standard, *Recommendations for Measuring and Reporting Photometric Performance Data for Entertainment Luminaires Utilizing Solid State Light Sources*. This document has just seen the light of day and, as this column goes to press, is in its first public review.

> **"... the RGB 150 may only produce 1,000 lumens in white but look how stunningly bright it is in deep blue ..."**

The draft standard seeks to establish methods for measuring and reporting the performance of luminaires using narrow-band emitters, most commonly LEDs, to allow manufacturers and users to understand how these units compare with the full spectrum emitters we are most familiar with. LED units have been around long enough now that we all understand that there are important differences in the way they perform, and that the simple measurement of the output in white light we have used in the past is inadequate. The goal of the standard is to come up with a series of straightforward measurements that are meaningful and allow direct comparison between units of different types. Color rendering, as mentioned above, is a key metric, but there are a number of others and one in particular, color efficiency, is my topic for this article.

I can be pretty confident that you won't have come across color efficiency as a measurement before and that you won't find it in any textbooks. Why? Well, the working group only invented it last year! The problem is that, with a few notable exceptions, the rest of the lighting world doesn't really care that much about colored light, or how good luminaires are at producing it. They care about white light and white light alone. Color, particularly saturated color, is an area where entertainment lighting walks alone. We care passionately about colored light in all its subtleties, and we care about how good our luminaires are at producing it. We already have a deal of experience in understanding how broad-band white light sources using colored filters, gels, or dichroics perform, and we understand intuitively that subtractive mixing means that the colored light we get from a white light fixture fitted with a filter will be much dimmer than the white we started with. On the other hand, one of the advantages that the manufacturers of additive mixing LED fixtures tout is the improved performance in color. All the manufacturers have their version of the, "Yes, the RGB 150 may only produce 1,000 lumens in white, but look how stunningly bright it is in deep blue," story and I'm sure you've heard it more than once. This isn't just a story as, on the whole, those salesmen are telling the truth, and their luminaires really are much more impressive in mid or deep saturated colors than they are in white. But how much better? How do we measure how good a luminaire is at producing colored light, and can we somehow relate it to a known entity such as an incandescent lamp with a piece of gel, or an HID lamp in a moving light fitted with a dichroic color wheel?

In BSR E1.41 the parameter Color Efficiency was the answer we came up with to try and meet this need. It's a metric designed to indicate how good a luminaire is at producing colored light as compared to white light and is formally defined as:

The ratio of the luminaire efficacy when producing colored light, to the luminaire efficacy when the same luminaire is producing white light at a defined color temperature.

What does this mean? Let's break it down. Luminaire efficacy is the familiar measure, usually expressed in lumens per watt, of the amount of light coming out the front of a luminaire as related to the power it's taking from the supply. For example, if an incandescent luminaire has a 575 W lamp and produces 8,000 lumens, then its efficacy is 8000/575 = 13.9 lum/W.

(Note: This is efficacy and not efficiency—the difference is subtle. If we measured the input and output power in the same units—say watts—then we would call the ratio efficiency. However, in this case, the units are different so we call it efficacy. Watts and lumens are measures of power and the perception of light, respectively; they are related, but they are not the same.)

Now we know what luminaire efficacy is, the definition of Color Efficiency makes more sense. We need to measure the efficacy of the luminaire when producing colored light, and compare that with the efficacy of the same luminaire when producing white light. The better the luminaire is at producing colored light, then the higher the result will be. This seems to make sense, but it leaves some questions open. Firstly, what colors should we use? We clearly need to agree on the colors for the measurements, and we need a way to precisely define what those colors are. It would also make sense to pick colors from every part of the spectrum so that any color bias can be averaged out. The first thoughts were to perhaps pick a range of gel colors from one or more swatch books, but that isn't ideal. Putting aside the potential political issues of choosing gels from one manufacturer or another, gels aren't really the best solution anyway. Their hue is well defined but their spectra less so, and you run the risk of someone using an equivalent gel color which, although matching in hue, has a very different spectrum. It's also better not to include proprietary products in a standard if you can avoid it. Overall, it would be better to find another set of colors. Fortunately the solution was close at hand. The draft standard already proposed the use of CQS as a measure of color rendering, and CQS uses a defined set of 15 mid to heavily saturated colors (shown in **Figure 1**) chosen to be evenly spaced around the color chart. They also are extremely well defined in terms of spectrum.

(Take a look back at this column in the Spring 2010 issue of *Protocol* to see discussion on why those colors were chosen.)

The appearance of a color varies depending on the white point that is chosen as the reference, and **Figures 2** and **3** show the 15 CQS color points with a 3200 K (incandescent) source, and a 5600 K (daylight) white source respectively.

You can see that the 15 colors fall neatly within the normal gamut of a standard RGB based LED luminaire indicated by the dashed triangle, and so most LED luminaires should be capable of producing them. It's no use picking standard colors

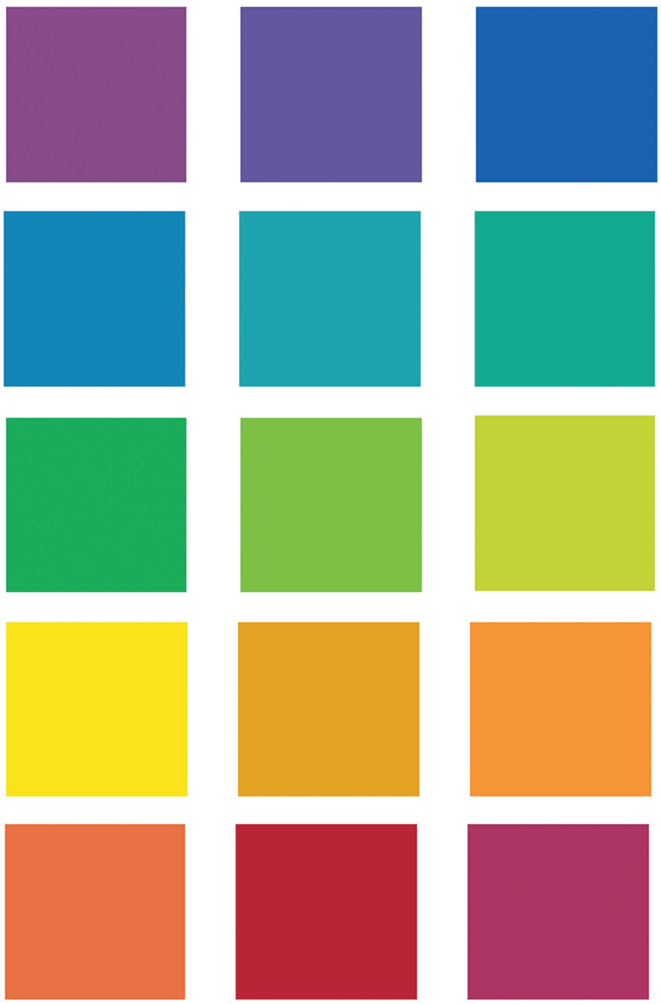

Figure 1 – CQS colors

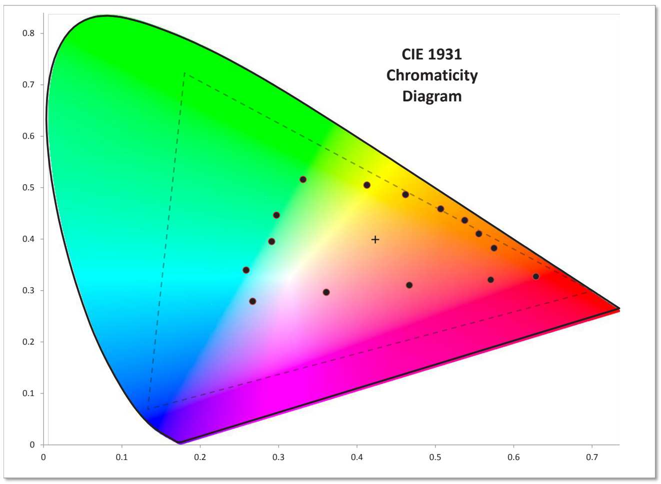

Figure 2 – CQS colors with a 3200 K source

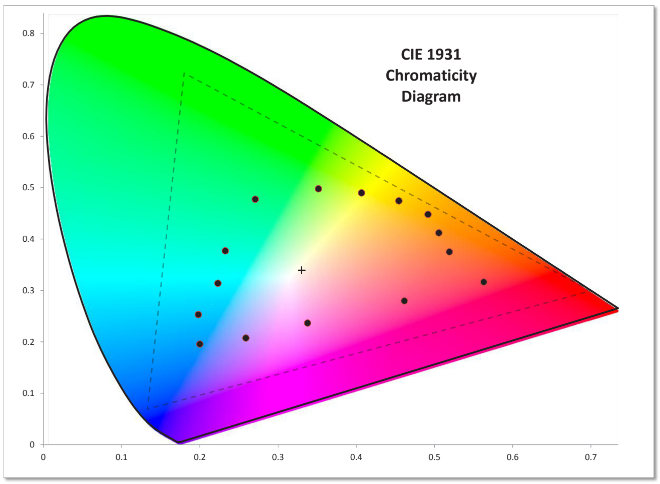

Figure 3 – CQS colors with a 5600 K source

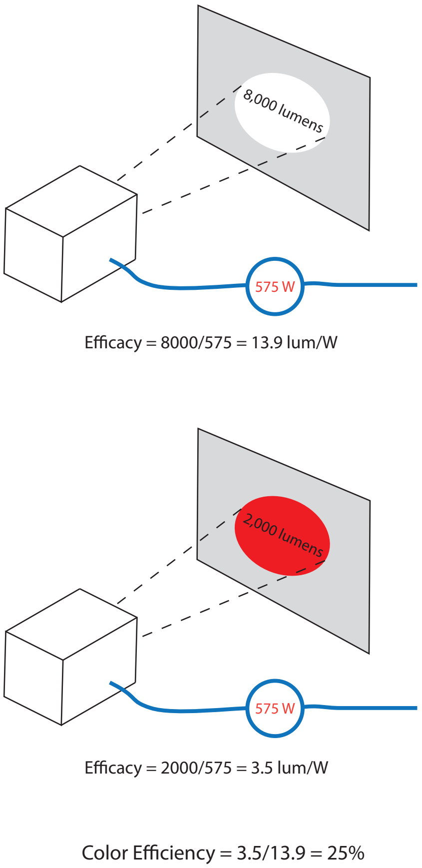

Figure 4 – Incandescent luminaire with subtractive color

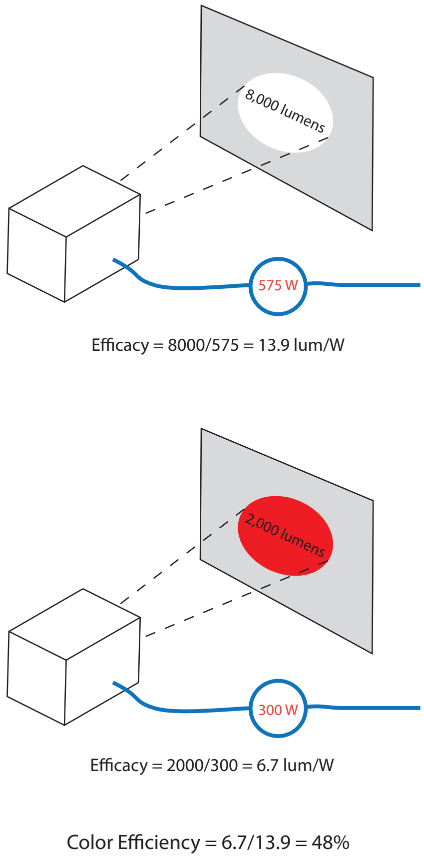

Figure 5 – LED luminaire with additive color

that the target luminaires can't produce!

Figures 4 and **5** illustrate how this might work with real products. **Figure 4** represents an incandescent luminaire that uses gel for color. It is first measured in open white with no gel and, in this example, produces 8,000 lumens with a power consumption of 575 W. That equates to an efficacy of 8,000/575 = 13.9 lum/W. It is then measured with a red gel. The lamp remains at full power, so we are still consuming 575 W, but our output is now reduced to 2,000 lumens. This time we get an efficacy of 2,000/575 = 3.5 lum/W. The Color Efficiency can now be calculated as 3.5 / 13.9 = 25%.

Figure 5 represents an LED based luminaire using RGB emitters; in this hypothetical example we get the same 8,000 lumens from 575 W in white, leading to an efficacy of 13.9 lum/W. However, when producing red light with this luminaire, we are able to reduce power to the blue and green emitters, reducing the total power consumption, so that only 300 W is needed to produce 2,000 lumens. This time we have an improved efficacy of 2,000/300 = 6.7 lum/W. The net result is, as expected, a higher Color Efficiency of 6.7 / 13.9 = 48%.

Although I've illustrated the process here with real luminaires and real filters and you could indeed measure it like that, in practice the measurements probably will be made computationally using the defined spectra for the test colors and the measured characteristics of the light source. I've also only shown one color, but measurements would be taken for all 15 colors and the results averaged. The full process looking something like this:

a.) Choose a color temperature at which to carry out the test from the standard values 3200 K, 5600 K, and 6500 K.

b.) Adjust the color of the luminaire to match the first CQS color at the color temperature chosen.

c.) Measure the lumen output of the luminaire.

d.) Measure the electrical power consumed in watts.

e.) Calculate the color efficacy in lm/W using these values for lumen output and power.

f.) Repeat steps b through e for the remaining 14 CQS colors.

g.) Average the resultant 15 color efficacies.

h.) Measure the lumen output and electrical power consumed when the luminaire is producing white light of the color temperature chosen in step a.

i.) Calculate the white light efficacy using these values for lumen output and power.

j.) Color Efficiency may now be calculated as the ratio of the average color efficacy calculated in step g divided by the white efficacy calculated in step i.

It sounds complex but the important thing is that the result is very simple: a single number that can go on the data sheet representing the Color Efficiency (CE) of the luminaire.

> **"How do we measure how good a luminaire is at producing colored light?"**

The standard also offers one further refinement, Color Ratio. Color Ratio takes the concept of Color Efficiency one step further and compares the Color Efficiency of the luminaire under test to that of a theoretical perfect Planckian (black body) luminaire using colored subtractive filters. It is intended to give an approximate real world comparison to the discharge and incandescent sources we are familiar with that use subtractive gels and dichroic filters.

To get the comparison values the

theoretical Color Efficiency of our perfect source is calculated with the following assumptions:

- The light source is a perfect Planckian emitter at the designated color temperature.
- The transmission curves of the subtractive color filters are determined by the spectra of the CQS colors.

Continuing the example used above, I've calculated that the Color Efficiency of a perfect 3200 K Planckian locus source is 27.3%, and thus the Color Ratio (CR) of the LED luminaire shown in **Figure 5** is 48/27.3 = 1.76. As a user, if you saw a data sheet reporting a Color Ratio of 1.76, you could infer that the luminaire was 1.76 times more efficacious at producing colored light than a hypothetical black body source using subtractive color filters. That should give some idea of how good it might be for the task, particularly if deep colors are needed.

Color Efficiency and Color Ratio are not perfect metrics, but the Photometrics Working Group members hope they will fill a need and give the user and specifier some useful information to help evaluate products. They should also allow you to check whether the salesman's, "It's much brighter in colors," pitch has any truth to it! ■

Mike Wood runs Mike Wood Consulting LLC which provides consulting support to companies within the entertainment industry on product design, technology strategy, R&D, standards, and Intellectual Property. A 30-year veteran of the entertainment technology industry, Mike is the current chair of the PLASA Governing Body, and Treasurer of PLASA North American Regional Board. Mike can be reached at mike@mikewoodconsulting.com.