ANSI E1.41 – 2016

Recommendations for Measuring and Reporting Photometric Performance Data for Entertainment Luminaires Utilizing Solid State Light Sources.

Photo/2010-5002r2

Approved as an American National Standard by the ANSI Board of Standards Review on 16 September 2016.

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Interest category codes

CP	Custom-market producer	U	User
MP	Mass-market producer	G	General interest
DR	Dealer or rental company	DE	Designer

Table of Contents

1 Scope and Purpose

Most conventional methodology in the entertainment industry for the measurement of the photometric parameters of luminaires is based around an assumption of the use of broad band or full spectrum emitters. The introduction of solid state narrow band emitters, particularly LEDs, has posed a problem for the industry in characterizing luminaires utilizing such emitters. In particular the industry needs methods for measurement which are defined, repeatable, and defensible to allow the manufacturer to produce marketing material and for the user to be able to use the published data for product comparison. This standard is intended to be used for the presentation of photometric data for luminaires employing solid state light sources used in the entertainment and performance industries. This standard defines photometric data that may be presented on documents purporting to accurately describe the photometric performance of these luminaires when producing both white and colored light.

This standard does not supersede or replace, and should be read in conjunction with, ANSI E1.9 – 2007 (R2012), Reporting Photometric Performance Data for Luminaires Used in Entertainment Lighting.

2 Definitions

For the purposes of this standard the following terms shall be defined as:

2.1 Correlated Color Temperature: The temperature of a Planckian black body radiator at which the hue of it, and the target illumination source appear to match, expressed in Kelvin (K)

2.2 luminaire efficacy: The ratio of a luminaire's total lumen output divided by the power consumed, expressed in units of "lumens per watt."

2.3 luminaire: A complete lighting unit, consisting of a lamp or lamps, together with all the parts that are needed to position and protect the lamp or lamps, distribute the light, and connect the lamp or lamps to the power supply.

3 Requirements for White Light Measurement

In addition to the requirements stated in ANSI E1.9 – 2007 (2012), photometric data reports for entertainment luminaires utilizing solid state light sources shall include the following additional information for white light measurement. If the luminaire utilizes more than three color primaries then all measurements should be taken at the mix of those primaries that produces the highest lumen output at the specified white.

3.1 Generic Requirements

The following generic items must be included as part of any reported data detailed in Specific Requirements 3.2.

3.1.1 Correlated Color Temperature

The correlated color temperature (CCT) in Kelvin shall be reported. If a luminaire has variable CCT, then the measured CCT may be reported at multiple CCT values. CCT values used for measurement should be selected from the following list: 2700 K, 3200 K, 4500 K, 5600 K, and 6500 K. The preferred reporting values are 3200 K and 5600 K. The target value chosen from the list of preferred reporting values, the actual value as measured, and the tolerance if available shall be reported.

Informative notes to 3.1.1:

Examples of CCT reporting:
3225 K +/- 15K when set to 3200 K target
5700 K +/- 50K when set to 5600 K target

3.1.2 Delta(u,v)

For each CCT value a Delta(u,v) value shall be reported showing the deviation of the measured color coordinates from the black body or Planckian locus. Delta(u,v) should be reported conventionally as a distance on the u,v chromaticity chart, and should be reported as a positive value for points above the Planckian locus and as a negative value for those below.

3.1.3 Ambient Temperature

The ambient temperature in degrees Celsius while the photometric measurements were made shall be reported. The luminaire shall be operated at its maximum lumen output for 15 minutes in this ambient temperature environment before the photometric measurements are made.

3.2 Specific Requirements

3.2.1 Lumen Output

The lumen output as specified in ANSI E1.9 -2007 (R2012) Clause 3.1.6, when producing white light of a reported CCT, shall be reported.

3.2.2 Luminaire Efficacy

The luminaire efficacy when producing white light of a reported CCT shall be reported. Luminaire efficacy is calculated as the total lumen output of the luminaire in lumens divided by the power consumption of the luminaire in watts and is reported in lm/W. This figure is sometimes called the "wall-plug efficacy."

The point in the electrical system where the power consumption was measured, and whether the supplied voltage was AC or DC shall be reported.

If the luminaire being characterized is an automated luminaire, then measurement should be taken with all functions of the luminaire stationary, except for fans and other moving devices required to provide essential cooling for the luminaire.

Informative notes to 3.2.2:

Examples of luminaire efficacy reporting:
50 lm/W with power consumption measured at the 110 V AC input to the luminaire
15 lm/W with power consumption measured at the 24 V DC output from a remote power supply

3.2.3 Dimmer Efficiency

The dimmer efficiency when producing light of a reported CCT shall be reported. Dimmer efficiency is calculated as the ratio of the average of the luminaire efficacy values when the luminaire is dimmed to produce 50%, 25% and 12.5% output lumens to the efficacy at 100% output lumens. It is reported as a percentage.

$$\text{Dimmer Efficiency} = \frac{(\text{luminaire efficacy at }50\%) + (\text{luminaire efficacy at }25\%) + (\text{luminaire efficacy at }12.5\%)}{3 \times (\text{luminaire efficacy at }100\%)} \times 100$$

3.2.4 Quiescent Power Consumption

The power consumption of the luminaire in watts and the associated power factor when producing no light output shall be reported.

If the luminaire being characterized is an automated luminaire then measurement should be taken with all the functions of the luminaire stationary, except for fans and other moving devices required to provide essential cooling for the luminaire.

3.2.5 Fidelity Index

The Fidelty Index (R_f) when producing white light of a reported CCT shall be reported. The Fidelity Index reported shall be as defined in IES TM-30-15, IES Method for Evaluating Light Source Color Rendition.

3.2.6 Gamut Index

The Gamut Index (R_g) when producing white light of a reported CCT shall be reported. The Gamut Index reported shall be as defined in IES TM-30-15, IES Method for Evaluating Light Source Color Rendition.

3.2.7 Modulation Frequency

The modulation frequency in Hz of the luminaire when measured at 100% output lumens and 50% output lumens shall be reported.

4 Requirements for Colored Light Measurement

In addition to the requirements stated in ANSI E1.9 – 2007 (R2012), photometric data reports for entertainment luminaires utilizing solid state light sources shall include the following additional information for colored light measurement. If the luminaire utilizes more than three color primaries then all measurements should be taken at the mix of those primaries that produces the highest lumen output at the specified color.

4.1 Ambient Temperature

The ambient temperature in degrees Celsius while the photometric measurements were made shall be reported. The luminaire shall be operated at its maximum lumen output for 15 minutes in this ambient temperature environment before the photometric measurements are made.

4.2 Specific Requirements

4.2.1 Color Gamut

The color gamut area shall be reported as the area enclosed on the CIE 1976 (u',v') chromaticity diagram by a polygon whose vertices represent the individually controllable colors that the luminaire can produce. This chromaticity diagram is also known as the CIE 1976 UCS (uniform chromaticity scale) diagram.

4.2.2 Color Efficiency

The color efficiency shall be reported for any luminaire offering continuous color mixing. The color efficiency shall show the relative luminaire effectiveness in producing a color as compared with the same luminaire when producing white light of a specific CCT. The color efficiency is defined as:

$$\text{Color Efficiency (CE)} = \frac{\text{Lumens in Color(n)}}{\text{Power consumed for Color(n)}} \times \frac{\text{Power consumed for White}}{\text{Lumens in White}} \times 100$$

Which is equivalent to:

$$\text{Color Efficiency (CE)} = \frac{\text{Luminaire Efficacy in Color(n)}}{\text{Luminaire Efficacy in White}} \times 100$$

4.2.2.1 Color Efficiency - CE_{3200}

CE_{3200} shall be reported. CE_{3200} is the CE value as compared to a light source of 3200 K on the Planckian Locus. The reported CE value shall be presented as the average CE value for a defined set of 15 colors, Color(n), as listed in Table 1. These colors are derived from the colors used for the CQS value when illuminated with a 3200 K Planckian emitter and are provided here as x,y color coordinates in the CIE 1931 x,y chromaticity space.

Color(n)	x	y		Color(n)	x	y
VS1	0.47	0.31		**VS9**	0.46	0.49
VS2	0.36	0.30		**VS10**	0.51	0.46
VS3	0.27	0.28		**VS11**	0.54	0.44
VS4	0.26	0.34		**VS12**	0.56	0.41
VS5	0.29	0.40		**VS13**	0.57	0.38
VS6	0.30	0.45		**VS14**	0.63	0.33
VS7	0.33	0.52		**VS15**	0.57	0.32
VS8	0.41	0.50				

Table 1: Color Efficiency colors for 3200 K

If any of the color points VS1 to VS15 are outside of the gamut of the luminaire, those points shall be omitted from the Color Efficiency calculation and a note listing the omitted points shall be included in the report.

Informative notes to 4.2.2.1:

Lumens in Color(n) - The lumen output when the luminaire is adjusted to produce the x,y chromaticity coordinates specified in Table 1.

Lumens in White – The lumen output when the luminaire is adjusted to produce light of 3200 K on the Planckian locus. Equivalent to x,y chromaticity coordinates of 0.4234, 0.3989

Power consumed for Color(n) – The power consumption of the luminaire in watts when the luminaire is adjusted to produce the x,y chromaticity coordinates specified in Table 1.

Power consumed in White – The power consumption of the luminaire in watts when the luminaire is adjusted to produce light of 3200 K on the Planckian locus. Equivalent to x,y chromaticity coordinates of 0.4234, 0.3989

4.2.2.2 Color Efficiency - CE_{5600}

CE_{5600} shall be reported. CE_{5600} is the CE value as compared to a light source of 5600 K on the Planckian Locus. The reported CE value is presented as the average CE value for a defined set of 15 colors, Color(n), as listed in table 2. These colors are derived from the colors used for the CQS value when illuminated with a 5600 K Planckian emitter and are provided here as x,y color coordinates in the CIE 1931 x,y chromaticity space.

Color(n)	x	y		Color(n)	x	y
VS1	0.34	0.24		**VS9**	0.41	0.49
VS2	0.26	0.21		**VS10**	0.45	0.47
VS3	0.20	0.20		**VS11**	0.49	0.45
VS4	0.20	0.25		**VS12**	0.51	0.41
VS5	0.22	0.31		**VS13**	0.52	0.37
VS6	0.23	0.38		**VS14**	0.56	0.32
VS7	0.27	0.48		**VS15**	0.46	0.28
VS8	0.35	0.50				

Table 2: Color Efficiency colors for 5600 K

If any of the color points VS1 to VS15 are outside of the gamut of the luminaire, those points shall be omitted from the Color Efficiency calculation and a note listing the omitted points shall be included in the report.

Informative notes to 4.2.2.2:

Lumens in Color(n) - The lumen output when the luminaire is adjusted to produce the x,y chromaticity coordinates specified in Table 2.

Lumens in White – The lumen output when the luminaire is adjusted to produce light of 5600 K on the Planckian locus. Equivalent to x,y chromaticity coordinates of 0.3302, 0.3391

Power consumed for Color(n) – The power consumption of the luminaire in watts when the luminaire is adjusted to produce the x,y chromaticity coordinates specified in Table 2.

Power consumed in White – The power consumption of the luminaire in watts when the luminaire is adjusted to produce light of 5600 K on the Planckian locus. Equivalent to x,y chromaticity coordinates of 0.3302, 0.3391

4.2.2.3 Color Efficiency - CE_{6500}

CE_{6500} shall be reported. CE_{6500} is the CE value as compared to a light source of 6500 K on the Planckian Locus. The reported CE value is presented as the average CE value for a defined set of 15 colors, Color(n), as listed in table 2. These colors are derived from the colors used for the CQS value when illuminated with a 6500 K Planckian emitter and are provided here as x,y color coordinates in the CIE 1931 x,y chromaticity space.

Color(n)	x	y		Color(n)	x	y
VS1	0.32	0.22		**VS9**	0.40	0.49
VS2	0.24	0.19		**VS10**	0.44	0.47
VS3	0.19	0.18		**VS11**	0.48	0.45
VS4	0.19	0.24		**VS12**	0.49	0.41
VS5	0.21	0.30		**VS13**	0.51	0.37
VS6	0.22	0.36		**VS14**	0.55	0.31
VS7	0.26	0.47		**VS15**	0.44	0.27
VS8	0.34	0.49				

Table 3: Color Efficiency colors for 6500 K

If any of the color points VS1 to VS15 are outside of the gamut of the luminaire, those points shall be omitted from the Color Efficiency calculation and a note listing the omitted points shall be included in the report.

Informative notes to 4.2.2.3:

Lumens in Color(n) - The lumen output when the luminaire is adjusted to produce the x,y chromaticity coordinates specified in Table 3.

Lumens in White – The lumen output when the luminaire is adjusted to produce light of 6500 K on the Planckian locus. Equivalent to x,y chromaticity coordinates of 0.3136, 0.3237

Power consumed for Color(n) – The power consumption of the luminaire in watts when the luminaire is adjusted to produce the x,y chromaticity coordinates specified in Table 3.

Power consumed in White – The power consumption of the luminaire in watts when the luminaire is adjusted to produce light of 6500 K on the Planckian locus. Equivalent to x,y chromaticity coordinates of 0.3136, 0.3237

4.2.3 Color Ratio

The Color Ratio shall be reported. The Color Ratio is a measure providing the ratio between the Color Efficiency value of the luminaire and the Color Efficiency value of a standard Planckian locus source using colored subtractive filters.

$$\text{Color Ratio} = CE_{3200} / (\text{CE of 3200 K Planckian locus source})$$

Or

$$\text{Color Ratio} = CE_{5600} / (\text{CE of 5600 K Planckian locus source})$$

Or

$$\text{Color Ratio} = CE_{6500} / (\text{CE of 6500 K Planckian locus source})$$

Where:

CE of 3200 K Planckian locus source = 27.3%

CE of 5600 K Planckian locus source = 26.6%

CE of 6500 K Planckian locus source = 26.5%

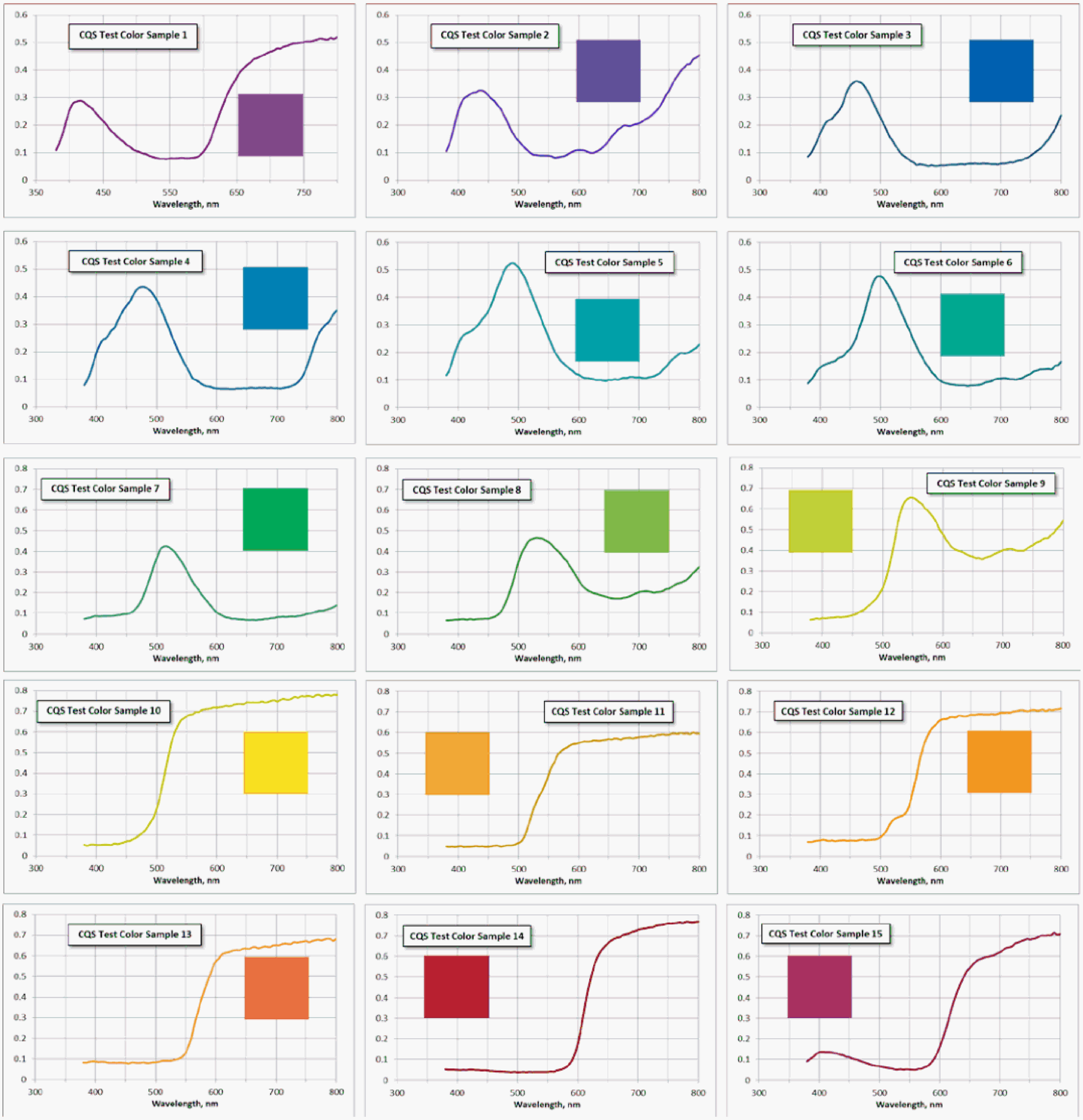
Appendix A (informative, not normative)

A.1 Munsell Designations for the 15 CQS Sample Colors

Color(n)	Munsell	Color(n)	Munsell
VS1	7.5P 4/10	**VS9**	2.5GY 8/10
VS2	10PB 4/10	**VS10**	5Y 8.5/12
VS3	5PB 4/2	**VS11**	10YR 7/12
VS4	7.5PB 5/10	**VS12**	5YR 7/12
VS5	10BG 6/8	**VS13**	10R 6/12
VS6	2.5BG 6/10	**VS14**	5R 4/14
VS7	2.5G 6/12	**VS15**	7.5RP 4/12
VS8	7.5GY 7/10		

Table A1: Munsell designations for the 15 CQS sample colors

A.2 Spectra of the 15 CQS Sample Colors



A.3 Explanation of Color Efficiency and Color Ratio

A.3.1 Color Efficiency

Color Efficiency is a metric designed to indicate how good a luminaire is at producing colored light as compared to white light. It is 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.

The colors used for the measurement are chosen to be the same 15 colors used for the CQS value. These are mid to highly saturated colors in a wide range of hues as can be seen from the data in Appendix A.2 and Figure A1.

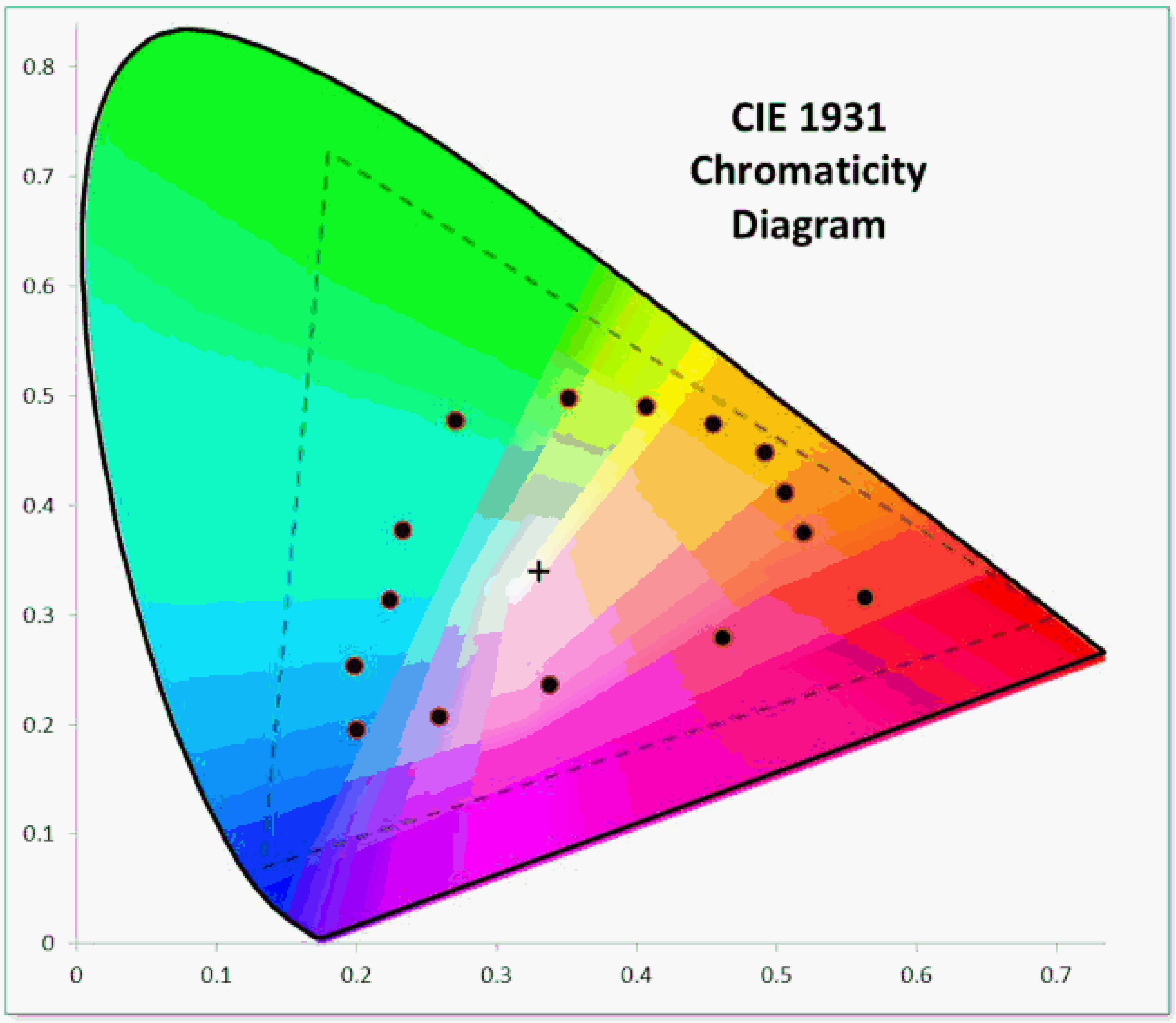


Figure A1: CQS colors with a 5600 K source

One methodology for establishing the CE of a luminaire might be as follows:

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 x,y color coordinates of CQS color VS1 at the color temperature chosen in step a as given by the appropriate table 1, 2 or 3 from this standard.

c. Measure the lumen output of the luminaire.

d. Measure the electrical power consumed in watts.

e. Calculate the color efficacy in lm/W of the luminaire 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.

For example, an LED luminaire with RGB emitters may produce 1,000 lm in white light at 5600 K and consume 50 W to do so. The white light efficacy would then be 1000/50 = 20 lm/W.

In one of the CQS colors the same luminaire may produce 450 lm and consume 30 W, thus having an efficacy in that color of 15 lm/W. The average efficacy for all 15 colors may be 18 lm/W.

Thus the Color Efficiency of that luminaire at 5600 K (CE_{5600}) is 18/20 x 100 = 90%

Note: if the luminaire utilizes more than three color primaries then it may be possible to mix the colors in steps b and h in more than one way. In that case all measurements should be taken at the mix of those primaries that produces the highest lumen output at the specified color.

A.3.2 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) emitter using colored subtractive filters. It is intended to give an approximate real world comparison to the discharge and incandescent sources we are familiar with using subtractive gels and dichroic filters.

For each of the three standard color temperature values; 3200 K, 5600 K and 6500 K, the Color Efficiency has been calculated with the following assumptions:

a. The light source is a perfect Planckian emitter at the designated color temperature.

b. The transmission curves of the subtractive color filters are determined by the spectra of the CQS colors as shown in Appendix A2.

With those parameters the CE values for 3200 K, 5600 K and 6500 K are tabulated in 4.2.3 of the standard.

Continuing the example used in A.3.1, the CE of a 5600 K Planckian locus source is 26.6% and thus the Color Ratio of our luminaire is 90/26.6 = 3.4. This suggests that our test luminaire is 3.4 times more efficacious at producing colored light than a hypothetical Planckian source with subtractive color filters.

A.4 Explanation of Modulation Frequency

This standard requires reporting of modulation frequency in section 3.2.6. It is understood that, for some SSL based luminaires, this may not always be possible or appropriate. Rather than having to use a single, prescribed, testing method, the reporter should make best efforts to report a modulation frequency appropriate to the technology being used. For example, a tester of an LED based luminaire using PWM to control the intensity of the LEDs should report that PWM frequency. If this frequency varies or a spread spectrum system is used then the range of variation should be reported. Other modulation or control methodologies may require reporting of other parameters. In all cases, it is the frequency of modulation of the output light intensity, not the electrical signals causing that variation, that is to be reported.

