ENERGY STAR® Program Requirements for Solid State Lighting Luminaires

Eligibility Criteria – Version 1.0

Draft: 12/20/06

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The rapid pace of SSL performance improvements will require DOE to periodically review and amend the criteria to parallel technological advances and ensure the criteria remain up to date. DOE will develop a strategy that monitors SSL development and, at appropriate intervals, revise the criteria. DOE is sensitive to concerns over frequent revisions and stranded product. Therefore the approach developed will be transparent and involve the input of program stakeholders.

Below are the product criteria for ENERGY STAR® qualified luminaires using solid-state lighting (SSL). The criteria apply to both residential and commercial products. A product must meet all the criteria in order to be qualified as ENERGY STAR.

Scope

The ENERGY STAR criteria cover the requirements for SSL products used for general illumination. Given the nascency of SSL technology development with respect to its application to general illumination, the criteria establish near-term and long-term requirements. The near-term transitional criteria (Category A) are for niche application products offering equivalent or better energy performance relative to fluorescent light sources. The long-term criteria (Category B) are for future products.

The criteria are based upon compliance with existing lighting industry reference standards and test procedures, as well as new or revised standards and test procedures currently being developed by lighting industry organizations. These reference standards and test procedures are listed in the appendix.

General Requirements

The following general requirements apply to both Category A and Category B. Additional requirements for color rendering and luminaire efficacy are listed under Category A and Category B below.

Devices

The chromaticity requirements shown below have been proposed by ANSI C78 Working Group. They are a modification of existing fluorescent lamp standards to reflect the current (and near future) state of SSL technology and color binning capabilities. In the manufacturing process, LEDs are binned for chromaticity. These bins, when superimposed on the CIE color space, take the form of quadrangles, as opposed to ellipses. Six of the eight quadrangles defined below largely correspond to and overlap with the ANSI 7-step MacAdam ellipses (consistent with the current ENERGY STAR lighting criteria), but include additional space in the corners. The proposed quadrangles therefore have the same nominal CCTs as fluorescent lamps. The two additional nominal CCTs, 4500 K and 5700 K, provide color definition for LEDs that would not otherwise be captured by the current six ANSI defined CCTs.

*NOTE: An additional CCT category, labeled “Flexible CCT,” provides manufacturers with an option to select a nominal CCT that falls within the range of the eight fixed CCTs while maintaining the same tolerance.

Device Requirements:		
Correlated Color Temperature (CCT)	The device(s) must have one of the following designated CCTs and fall within the 7-step quadrangles as defined in the Appendix.	
	Nominal CCT[1]	CCT (K)
	2700 K	2725 ± 145
	3000 K	3045 ± 175
	3500 K	3465 ± 245
	4000 K	3985 ± 275
	4500 K	4503 ± 243
	5000 K	5028 ± 283
	5700 K	5665 ± 355
	6500 K	6530 ± 510
	Flexible CCT (2700-6500 K)	T[2] ± ΔT[3]
Color Spatial Uniformity	The variation of chromaticity in different directions (i.e., with a change in viewing angle) shall be within a 4-step ANSI MacAdam ellipse.	
Color Maintenance	The change of chromaticity over the lifetime of the product shall be within a 7-step ANSI MacAdam ellipse.	
LED Useful Life (L_{70})	The device shall have average rated lumen maintenance of at least 70% of initial device lumens at ~~35,000~~ 50,000 hours.	

[1] Six of the nominal CCTs correspond to those in the fluorescent lamp specification: 2700 K, 3000 K, 3500 K, 4100 K, 5000 K, and 6500 K, respectively.

[2] T is chosen to be at 100 K steps (2800, 2900, …., 6400 K), excluding the eight nominal CCTs listed.

[3] ΔT is given by $\Delta T = 0.0000108 \times T^2 + 0.0262 \times T + 8$.

Luminaires

Luminaire Requirements	
Warranty	A warranty must be provided for luminaires, which covers repair or replacement of defective parts of the luminaire housing, device, optics, trim and electronics for a minimum of three (3) years from the date of purchase. For residential products, the written warranty must be included with the luminaire packaging at the time of shipment.
Thermal Management	Luminaire manufacturer shall adhere to device manufacturer guidelines, certification programs, and test procedures for thermal management.

Outdoor Luminaires

Outdoor Luminaire Requirements	
Residential Automatic Daylight Control	Luminaires designated as “residential” and greater than 13 watts must contain an integral photosensor that automatically prevents operation during daylight hours. In addition, the control must automatically reactivate within 24 hours of a manual override or test operation.

Drivers

Driver Requirements	
Power Factor	≥ .90
Minimum Operating Temperature	Driver shall have a minimum operating temperature of ~~-20°~~C. -40°C except battery backup @-20°C
Maximum Measured Driver Case Temperature During Normal Operation Inside Luminaire(s)	Not to exceed the driver manufacturer maximum recommended driver case temperature during in-situ operation. **Note:** This performance characteristic is separate and distinct from thermal requirements established by UL, which governs safety rather than longevity of the driver. All qualified luminaires are expected to meet this requirement, including linear, suspended, close-to-ceiling, IC, ICAT and Non-IC recessed canisters, etc. as well as those luminaires that may be exempt from UL1598.
Electromagnetic and Radio Frequency Interference	• Drivers designated by the manufacturer for residential applications must meet FCC requirements for consumer use (FCC 47 CFR Part 15 Consumer Emission Limits) • Drivers designated by the manufacturer for commercial applications must meet FCC requirements for non-consumer use (FCC 47 CFR Part 15 Non- consumer Emission Limits).
Noise	Driver shall have a Class A sound rating.
Transient Protection	Driver shall comply with ANSI C62.41 Category A for Transient protection.
> L70 Driver shutdown	Timer based or other end of life indicator

Packaging Requirements

Packaging Requirements	
Incompatibility with Controls and Application Exceptions	Included documentation must clearly state any known incompatibility with photo-controls, dimmers or timing devices.

The ENERGY STAR criteria for SSL Luminaires use Luminaire Efficacy to establish performance as defined below:

$$\text{Initial Luminaire Efficacy} = \frac{\text{Luminaire Light Output (includes fixture efficiency and thermal effects)}}{\text{Luminaire Input Power}}$$

The existing ENERGY STAR lighting product criteria use system efficacy defined as the light output of the lamp-ballast system divided by the input power measured in a 25°C environment. Established test procedures for fluorescent sources support this approach. However, the program requirements in this document are based upon luminaire efficacy, instead of system efficacy for the following reasons:

- Measurement of the LED light source separate from the fixture is often not possible due to the nature of the technology. Individual LED devices are often arrayed together in order to provide adequate light. The geometry, configuration and size of the array (if beyond the dimensions of a typical lamp) cannot be accurately measured in an integrating sphere (an apparatus that captures all the light emitted from a source and determines total light output).
- LED performance is significantly affected by elevated temperature. LED devices generate heat that is typically removed by an external heat sink, which may be designed into the luminaire itself. Separating the light source from its heat sink will significantly impact test results.
- In some cases it may be impractical or cost prohibitive to separate the light source from the luminaire. Luminaire manufacturers may integrate LEDs in such a way as to make separation difficult.
- No standards or test procedures exist or are planned in the foreseeable future to measure system efficacy of LEDs. However, standards organizations are aggressively developing a test procedure for photometric measurement of LED luminaires. This test procedure is currently in draft form and scheduled to be final in Spring 2007.

Category A: Near-term Niche Applications

Methodology for Establishing Luminaire Efficacy of Niche Applications:

Determination of the luminaire efficacy thresholds for niche applications stems from an analysis of the currently available fluorescent products in the market, IES design guidelines, photometric modeling and the current performance characteristics of commercial LEDs. The selection of Category A niche applications is based on the following parameters:

- Directed light applications
- Source relatively close to illuminated surface
- Relatively modest illuminance requirements
- Applications in which typical fixture efficiency (with traditional light sources) is 50% or lower

Luminaire efficacy levels are established for each application that assure approved luminaires perform at least as well as typical luminaires using fluorescent light sources. These thresholds are then adjusted by a factor to account for the relationship between LED efficacy and CRI, increasing the required efficacy level for the extent to which required CRI for the application is allowed to be below a CRI of 80. This has the effect of requiring LED systems with lower CRI to perform significantly better than their fluorescent counterparts in terms of efficacy.

Using a commercial recessed downlight as the example:
The typical efficiency of commercial recessed downlight luminaires in the market is approximately 50%. The typical system efficacy for pin-based compact fluorescent lamps and electronic ballast systems is estimated by ASHRAE/IES to be 58 lm/W. Multiplying fixture efficiency of 50% times 58 lm/W system efficacy yields 29 lm/W luminaire efficacy. This number is then adjusted for CRI. The CRI and efficacy of LEDs is strongly interrelated. In order to account for these performance trade-offs, a scaling factor is applied to the niche application luminaire efficacy. This is expressed mathematically below:

$$\text{Luminaire Efficacy} = \frac{\textit{Typical Fixture Efficiency x CFL Efficacy}}{\frac{\textit{Application CRI}}{0.8}}$$

For the commercial recessed downlight example above: $\frac{0.50 \times 58}{\frac{0.7}{0.8}} = 33$ lm/W

Under-cabinet kitchen lighting

Application Requirements	
Minimum Light Output	Luminaire shall deliver a minimum of 150 lumens (initial) per lineal foot. The light output requirement is calculated by the following equation: $\frac{\text{Measured Fixture Length (inches)}}{12} \times 150 = \text{Minimum Required Light Output (lumens)}$
Zonal Lumen Density Requirement	Luminaire shall deliver no more than 75% of total lumens (initial) within the 0-60° zone.
Minimum Luminaire Efficacy	23 lm/W
Minimum CRI	80

Under-cabinet shelf-mounted task lighting

Application Requirements	
Minimum Light Output	Luminaire shall deliver a minimum of 150 lumens (initial) per lineal foot. The light output requirement is calculated by the following equation: $\frac{\text{Measured Fixture Length (inches)}}{12} \times 150 = \text{Minimum Required Light Output (lumens)}$
Zonal Lumen Density Requirement	Luminaire shall deliver no more than 75% of total lumens (initial) within the 0-60° zone.
Minimum Luminaire Efficacy	29 lm/W
Minimum CRI	80

Portable desk task lights

Application Requirements	
Minimum Light Output	Luminaire shall deliver a minimum of 200 lumens (initial).
Zonal Lumen Density Requirement	Luminaire shall deliver a minimum of 85% of total lumens (initial) within the 0-60° zone.
Minimum Luminaire Efficacy	29 lm/W
Minimum CRI	80

Outdoor wall-mounted porch lights

Application Requirements	
Minimum Light Output	Luminaire shall deliver a minimum of 200 lumens (initial).
Zonal Lumen Density Requirement	Luminaire shall deliver a minimum of 85% of total lumens (initial) within the 0-90° zone.
Minimum Luminaire Efficacy	27 lm/W
Minimum CRI	70

Outdoor step lights

Application Requirements	
Minimum Light Output	Luminaire shall deliver a minimum of 100 lumens (initial).
Minimum Luminaire Efficacy	23 lm/W
Minimum CRI	70

Outdoor pathway lights

Application Requirements	
Minimum Light Output	Luminaire shall deliver a minimum of 100 lumens (initial).
Zonal Lumen Density Requirement	Luminaire shall deliver a minimum of 85% of total lumens (initial) within the 0-90° zone.
Minimum Luminaire Efficacy	29 lm/W
Minimum CRI	70

Recessed downlights

Application Requirements	
Minimum Light Output	≤ 4” Aperture (nominal): 300 lumens (initial) > 4” Aperture (nominal): 500 lumens (initial)
Zonal Lumen Density Requirement	Luminaire shall deliver a minimum of 85% of total lumens (initial) within the 0-60° zone.
Minimum Luminaire Efficacy	
Residential:	29 lm/W
Commercial:	33 lm/W
Minimum CRI	
Residential	80
Commercial	70
Reduced Air Leakage	Recessed downlights intended for installation in insulated ceilings shall be IC rated and be leak tested per ASTM E-283 to demonstrate no more than 2.0 cubic feet per minute (cfm) at 75 Pascals (1.57 lbs/ft2) pressure difference. The luminaire must include a label certifying “airtight” or similar designation to show air leakage less than 2.0 CFM at 75 Pascals when tested in accordance with ASTM E283.

Category B: Efficacy Based Performance

Initial **Luminaire Efficacy Requirements:**			
Luminaire Efficacy	2009	2007	2008
CCT ≤ 3000 K	≥ 50* lm/W	30*	40*
3000 < CCT ≤ 5000	≥ 60* lm/W	40*	50*
CCT > 5000 K	≥ 70* lm/W	50*	60*
Device Requirements:			
Color Rendering Index			
Indoor Luminaires	≥ 80		
Outdoor Luminaires	≥ 70		

* = Luminaire efficacy at 50,000 hours must be maintained at 70% or greater of initial luminaire efficacy, calculated using the device manufacturer's depreciation data for the specific luminaire Tj.

Standards and Documentation

Performance Characteristic	Methods of Measurement Reference Standards	Required Documentation
Luminaire Efficacy: Light Output Input Power	IESNA LM-79-XX† ANSI C82.2	Laboratory test results must be produced using the specific device(s) and driver combination that will be used in production. Provide: 1. a test report from a laboratory accredited by NVLAP or one of its MRA signatories. **Note:** If the laboratory used for this test is accredited by NVLAP or one of its MRA signatories it must also have a scope of accreditation that includes the method of measurement reference standard for this performance characteristic.
Power Factor	ANSI C82.77	Laboratory test results must be produced using the specific device(s) and driver combination that will be used in production. Provide: 1. a test report from a laboratory accredited by NVLAP or one of its MRA signatories. **Note:** If the laboratory used for this test is accredited by NVLAP or one of its MRA signatories it must also have a scope of accreditation that includes the method of measurement reference standard for this performance characteristic.
LED Useful Life (L_{70})	LM-80-XX†	Laboratory test results must be produced using the specific device(s) and driver combination that will be used in production. Provide: 1. a test report from a laboratory accredited by NVLAP or one of its MRA signatories.

† Currently being developed by IESNA/ANSI Task Groups in coordination with DOE ENERGY STAR SSL program

Color Rendering Index	IESNA LM-58 CIE 13.3	Laboratory test results must be produced using the specific device(s) and driver combination that will be used in production. Provide: 1. a test report from a laboratory accredited by NVLAP or one of its MRA signatories. **Note:** If the laboratory used for this test is accredited by NVLAP or one of its MRA signatories it must also have a scope of accreditation that includes the method of measurement reference standard for this performance characteristic.
Correlated Color Temperature	IESNA LM-58, LM-16, C78.377A†	Laboratory test results must be produced using the specific device(s) and driver combination that will be used in production. Provide: 1. a test report from a laboratory accredited by NVLAP or one of its MRA signatories. **Note:** If the laboratory used for this test is accredited by NVLAP or one of its MRA signatories it must also have a scope of accreditation that includes the method of measurement reference standard for this performance characteristic.
Noise	Class A sound rating: Driver not to exceed 24 dBA	Self Certification **Note:** A laboratory test report must be submitted upon DOE request.
Luminaire Warranty		Provide copy of the actual 3-year manufacturer luminaire warranty that is included in the packaging.
Safety Portable Fixtures Hardwired Fixtures	 ANSI/UL 153 UL 1598	Provide the cover page of a safety test report or a general coverage statement from an OSHA NRTL laboratory.

† Currently being developed by IESNA/ANSI Task Groups in coordination with DOE ENERGY STAR SSL program

Qualification Process

To be determined at later date.

Quality Assurance Testing

To be determined at later date.

Effective Date

To be determined at later date.

Future Specification Revisions

To be determined at later date.

Appendix

Definitions

A. **A2LA**: American Association for Laboratory Accreditation.
B. **ALA**: American Lighting Association.
C. **ANSI**: American National Standards Institute.
D. **ASSIST**: Alliance for Solid State Illumination Systems and Technologies.
E. **ASTM**: American Society for Testing of Materials.
F. **Automatic daylight shutoff**: A photocell device that automatically prevents operation of a luminaire during daylight hours.
G. **CIE**: Commission Internationale de l'Eclairage (translated International Commission on Illumination).
H. **Color appearance**: The actual color of the lamp is called the color appearance and is defined in terms of the spectral tri-stimulus values (color coordinates) according to the recommendations of the CIE Publication No. 13.3 – 1995. For color coordinates near the black body loci, the correlated color temperature (Kelvin) can be used to define color appearance.
I. **Color rendition**: The effect the spectral characteristic of the light emitted by the LED has on the color appearance of the objects illuminated by it is called color rendition. The color rendering index (CRI) is defined in terms of a comparison of the spectral tri-stimulus values of the objects under test illumination and standard illumination according to the recommendations of CIE Publication No.13.3-1995.
J. **Correlated Color Temperature (CCT)**: The actual color of the LED is called the color temperature and is defined in terms of the spectral tri-stimulus values (color coordinates) according to the recommendations of IESNA LM-16. For color coordinates near the Black Body loci, the correlated color temperature, measured in Kelvin (K), is used.
K. **CSA**: Canadian Standards Association.
L. **Device**: The LED package containing the die, encapsulant, internal optics, electrical connections and heat sinking that delivers light.
M. **Driver**: A device used with light emitting diodes to obtain the necessary circuit conditions (voltage, current, and waveform) for starting and operating.
N. **IEC**: International Electrotechnical Commission.
O. **IESNA**: Illuminating Engineering Society of North America.
P. **Initial performance values**: The photometric and electrical characteristics at the end of the 100-hour aging period.
Q. **LED useful life (L_{70})**: The length of time declared by the manufacturer at which 70% lumen maintenance of any large number of LEDs is reached.
R. **Luminaire**: A complete lighting unit consisting of an LED(s) and driver(s) together with the parts designed to distribute the light, position and protect the LEDs, and connect the LEDs to the power supply.
S. **Luminaire Efficacy**: The luminous flux of the luminaire divided by the input wattage.
T. **Lumen maintenance**: The luminous flux at a given time in the life of the LED and expressed as a percentage of the initial luminous flux.
U. **MacAdam color ellipse**: An elliptical region of chromaticity coordinates that is defined using a centroid, a tilt angle relative to a horizontal axis, and a defined level of variance. Such a region defines what chromaticity coordinates can be acceptably associated with a target Correlated Color Temperature. For these criteria, standardized color ellipses are defined using centroids based upon objective chromaticities (x,y) and tilt angles (è) specified in Table 1 and 2 of ANSI C78.376-2004, and a defined variance of four steps.
V. **Minimum operating temperature**: The minimum temperature at which the driver will reliably operate.
W. **MRA**: Mutual Recognition Arrangement.
X. **NVLAP**: National Voluntary Laboratory Accreditation Program.
Y. **Portable luminaire**: A luminaire whose power supply connection is made by means of a cord with or without a plug.
Z. **Power factor**: The active power divided by the apparent power (i.e., product of the rms input voltage and rms input current of a driver).
AA. **Rated luminous flux or lumen output**: Initial lumen rating (based on the measured 100-hour lumens), which is declared by the manufacturer.
BB. **UL:** Underwriters Laboratories.

Reference Standards and Test Procedures

Standards and Test Procedures in BLUE are currently under development.

Reference Standards and Test Procedures		
Organization	Identifier	Description
ANSI	ANSI C82.XXX	Electronic Drivers for LED Devices, arrays, or systems (In development).
ANSI	ANSI C78.377A	Specifications for the Chromaticity of Solid State Lighting Products (In development).
ANSI	ANSI C82.77 - 2002	Harmonic Emission Limits – Related Power Quality Requirements for Lighting
ANSI	ANSI/IEEE C62.41 - 1991	Recommended Practice for Surge Voltages in Low-Voltage AC Power Circuits
ANSI/UL	ANSI/UL 153 - 2005	Portable Electric Luminaires
ASTM	ASTM E 283 - 2004	Restricted air movement
CIE	CIE Pub. No. 13.3 - 1995	Method of Measuring and Specifying Color Rendering of Light Sources
FCC	FCC 47 CFR	Electromagnetic interference
IESNA	IESNA LM-16	Correlated Color Temperature
IESNA	IESNA LM-58	Color Rendering Index and Correlated Color Temperature
IESNA	IESNA LM-79	Approved Method for the Electrical and Photometric Testing of Solid-State Lighting Devices (In Development)
IESNA	IESNA LM-80	Lumen Depreciation of LED Light Sources (In Development)
NFPA	NFPA 70 - 2005	National Electric Code
UL	UL 1012 - 2005	Power Units Other Than Class 2
UL	UL 1310 - 2005	Class 2 Power Units
UL	UL 1598 - 2004	Luminaires
UL	UL 1838 - 2002	Low Voltage Landscape Lighting Systems
UL	UL 1994 - 2005	Luminous Egress Path Marking Systems

Chromaticity Specification and Tolerance Quadrangles

This chromaticity specification below was developed by ANSI to be as consistent as possible with existing fluorescent lamp standards, and to reflect the current (and near future) state of SSL technology and color binning capabilities. Each of the eight quadrangles as defined below overlap the six current the ANSI 7-step MacAdam ellipses (consistent with the current ENERGY STAR lighting criteria), and thus have the same nominal CCT as ENERGY STAR fluorescent lamps. Two additional CCTs (4500 and 5700K) are included to encompass the additional CCTs available in SSL (see figure 1).

In addition to the fixed CCTs above, a manufacturer defined Flexible CCT is added (see figure 2) to give manufacturers the option to select a nominal CCT that falls within the range of the eight fixed CCTs while maintaining the same tolerance.

	2700 K		3000 K		3500 K		4000 K		4500 K		5000 K		5700 K		6500 K	
	x	**y**	**x**	**y**	**x**	**y**	**x**	**y**	**x**	**y**	**x**	**y**	**x**	**y**	**x**	**y**
Center point	0.4578	0.4101	0.4338	0.4030	0.4073	0.3917	0.3818	0.3797	0.3611	0.3658	0.3447	0.3553	0.3287	0.3417	0.3123	0.3282
Tolerance quadrangle	0.4813	0.4319	0.4562	0.4260	0.4299	0.4165	0.4006	0.4044	0.3736	0.3874	0.3551	0.3760	0.3376	0.3616	0.3205	0.3481
	0.4562	0.4260	0.4299	0.4165	0.3996	0.4015	0.3736	0.3874	0.3548	0.3736	0.3376	0.3616	0.3207	0.3462	0.3028	0.3304
	0.4373	0.3893	0.4147	0.3814	0.3889	0.3690	0.3670	0.3578	0.3512	0.3465	0.3366	0.3369	0.3222	0.3243	0.3068	0.3113
	0.4593	0.3944	0.4373	0.3893	0.4147	0.3814	0.3898	0.3716	0.3670	0.3578	0.3515	0.3487	0.3366	0.3369	0.3221	0.3261

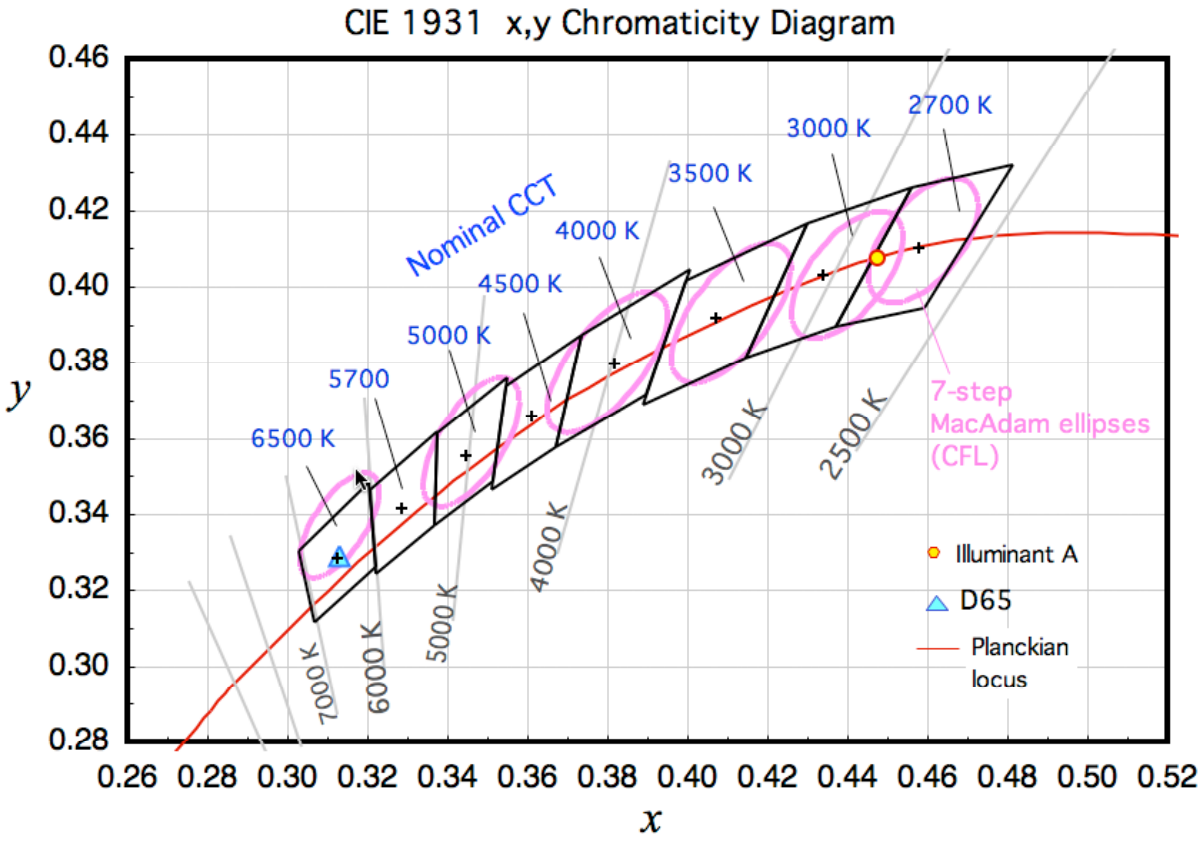

Figure 1. CIE 1931 chromaticity diagram showing the eight nominal CCT Quadrangles

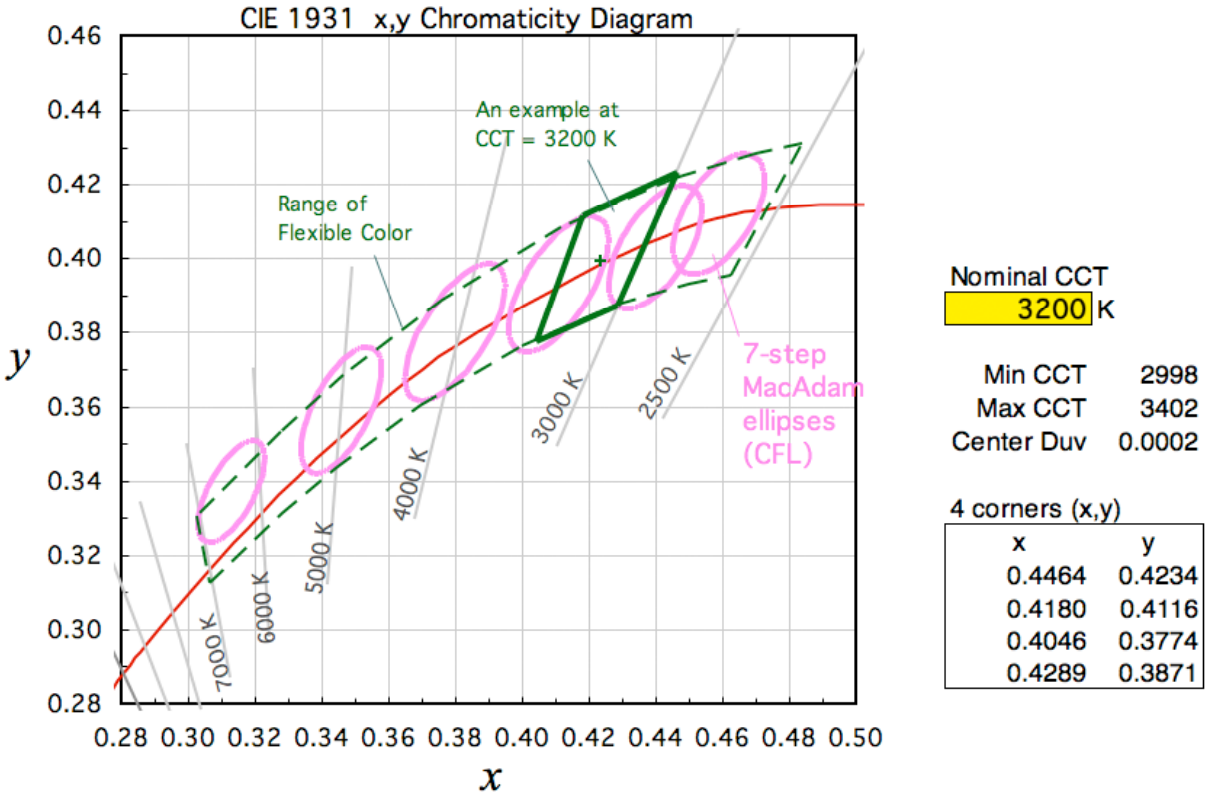

Figure 2. An example of chromaticity tolerance of Flexible CCT at nominal CCT of 3200 K.