Eaton Lighting

Provider Number: J413

The Value of Color Tuning

Save energy and enhance space experience and flexibility with this unique LED lighting capability.

Course Number: XXX

Course Credit

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Copyright Materials

Course Description

Color tuning is a relatively new feature enabled by the versatility of LEDs. This course will explain how color tuning works, identify the different types of LED color tuning solutions now available and compare and contrast their performance. The objective measurement of color tuning and its benefits as it relates to energy savings, broadcasting quality, and experience will also be discussed.

Learning Objectives

1. Explain how color tuning with light-emitting diodes (LEDs) is more energy efficient than the conventional lighting solutions previously used.

2. Use color tuning to dramatically enhance the involvement and experience of attendees at entertainment venues.

3. Describe how color tuning in office buildings and healthcare environments is being used to maintain circadian rhythms and improve mood.

4. Compare and contrast the performance of various color tuning systems available today.

Agenda

- LEDs and the Color of Light
- Introducing Correlated Color Temperature (CCT)
- LEDs and CCT
- Introducing Color Tuning
- Benefits of Color Tuning with LEDs
- Methods of Color Mixing and Control
- Compare and Contrast the Performance of Color Tuning Systems
- Measuring Color Tuning Performance
- Case Study: Color Tuning at Bridgestone Arena
- Conclusion

LEDs and the Color of Light

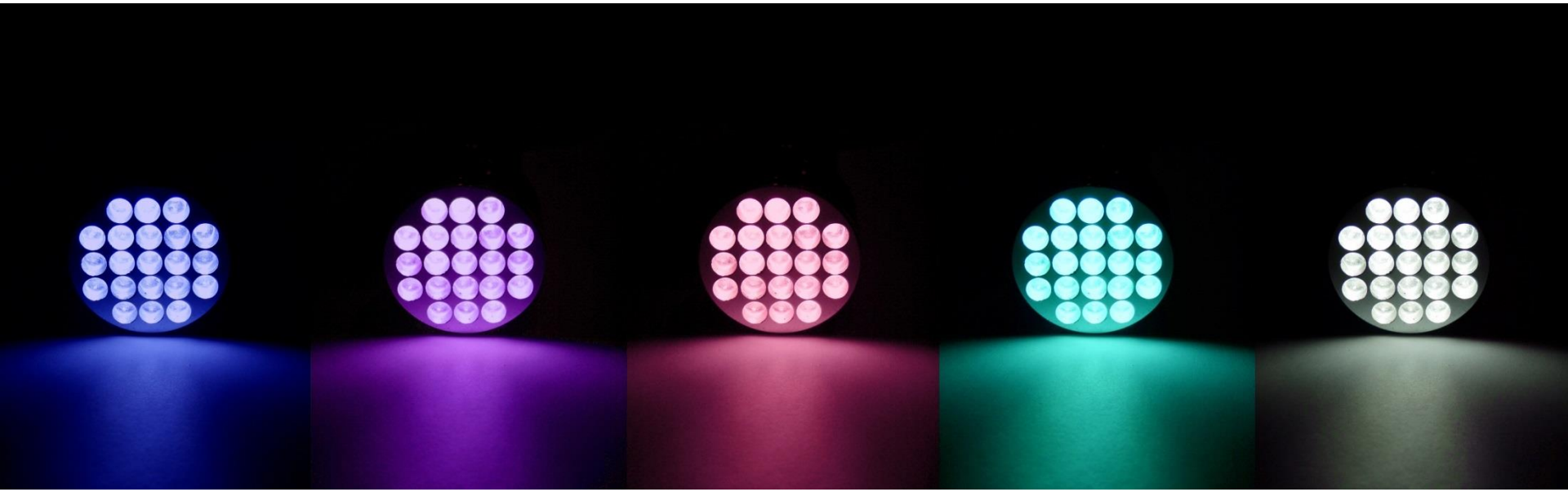
LEDs and the Color of Light

Anatomy of an LED

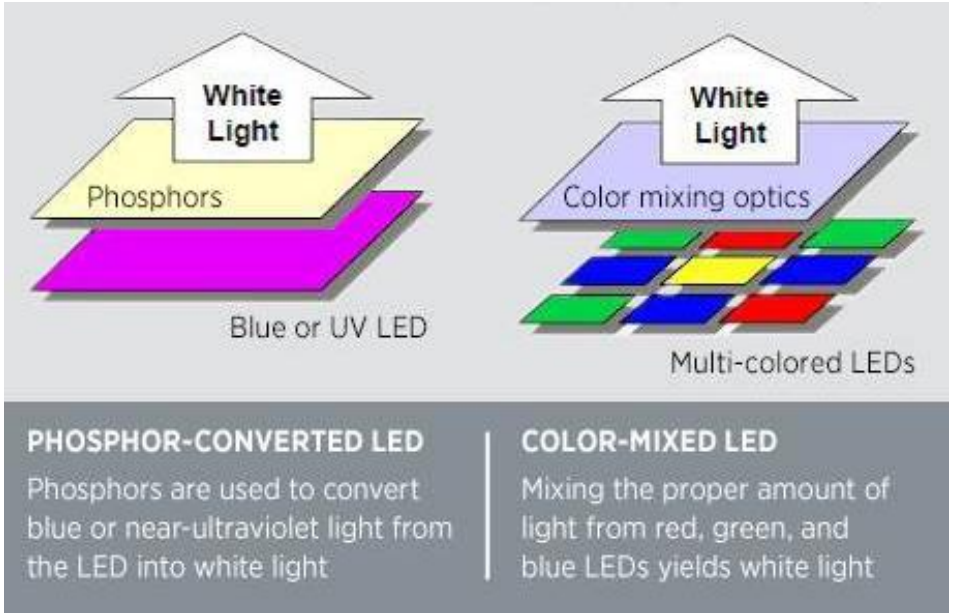
- LED chip (or many LED chips)
- Driver converts incoming alternating current (AC) to direct current (DC) used by the LED chip.
- Heatsink
- Optical system to distribute the light emitted by the LED chip.

LEDs and the Color of Light

The color emitted by the LED diode is determined by the semiconductor materials and the phosphor coating applied over the LED chip.



LEDs and the Color of Light



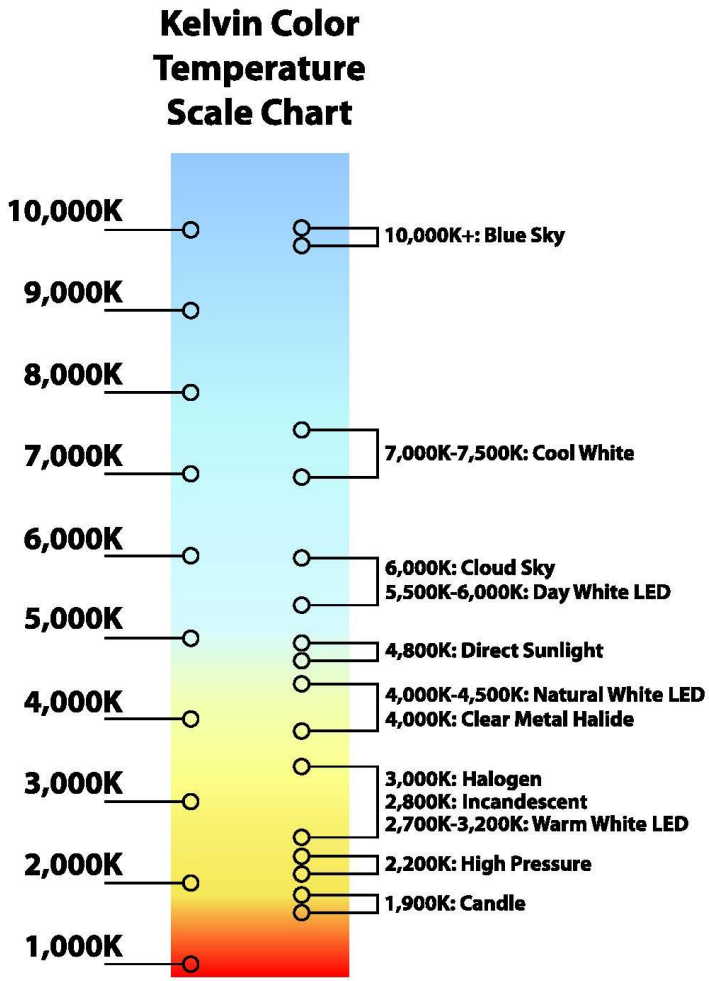
White light is produced by an LED fixture in two ways:

- Phosphor-converted LED
- Color-mixed LED

Ref: http://energy.gov/eere/ssl/led-basics

Correlated Color Temperature (CCT)

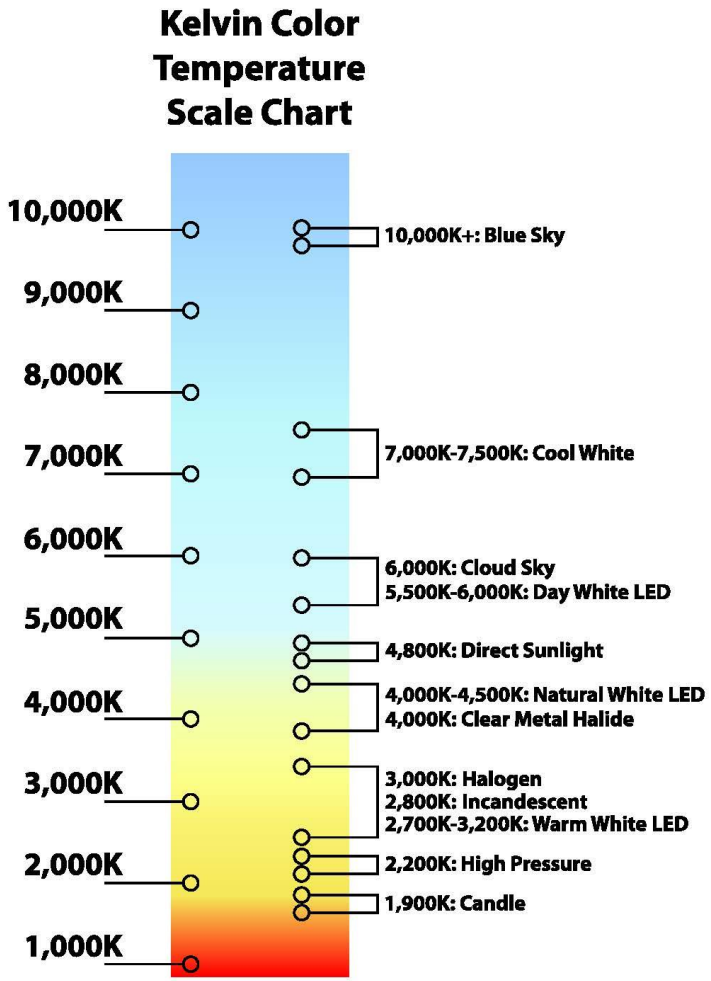
Correlated Color Temperature (CCT)



- The color temperature of a light source is measured in Kelvin (K).
- The K value of a light source indicates the color of the white light.
- White light with a lower K value is considered warmer.
- White light with a higher K value is considered cooler.

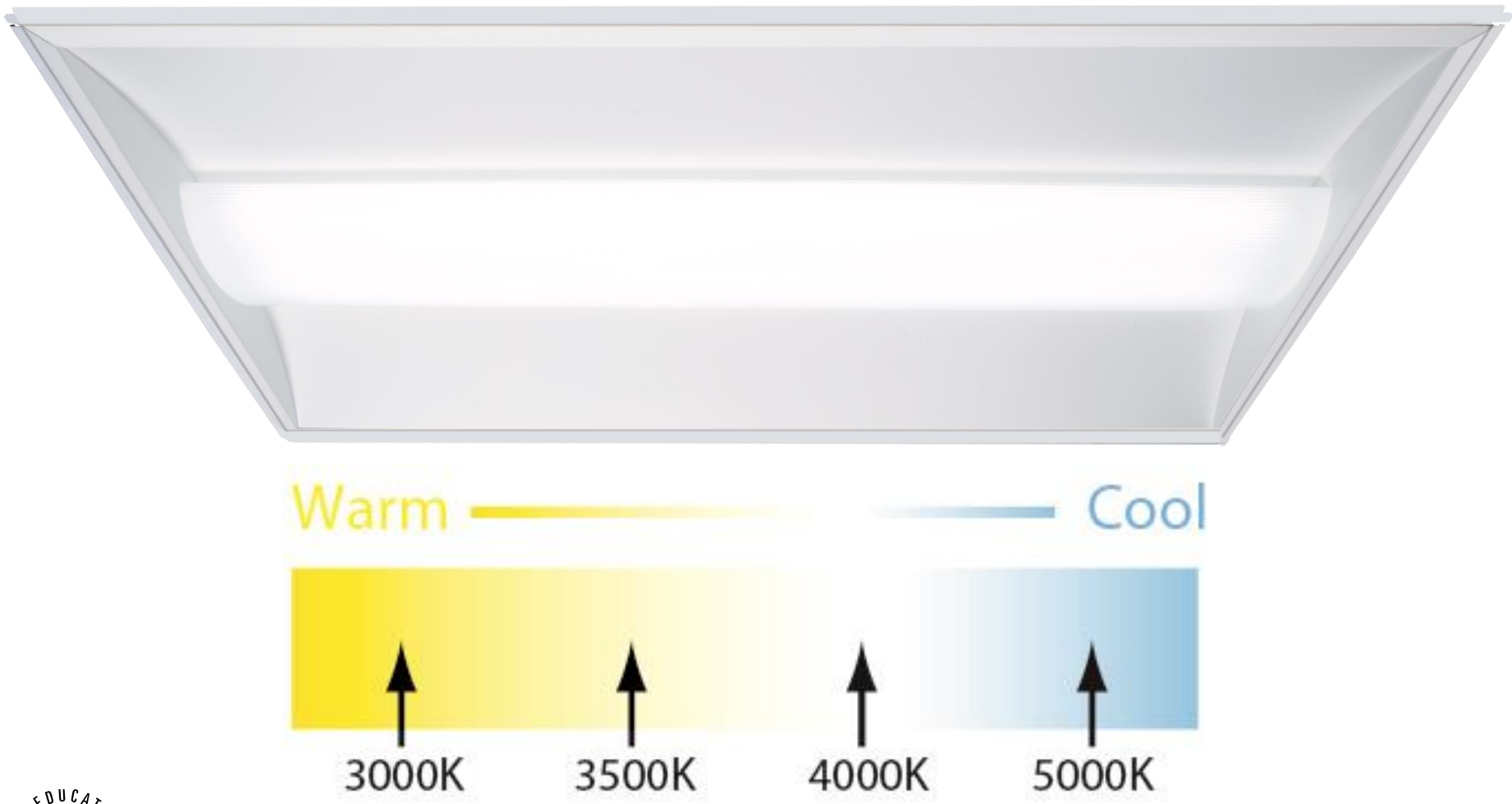
LEDs and CCT

LEDs and CCT

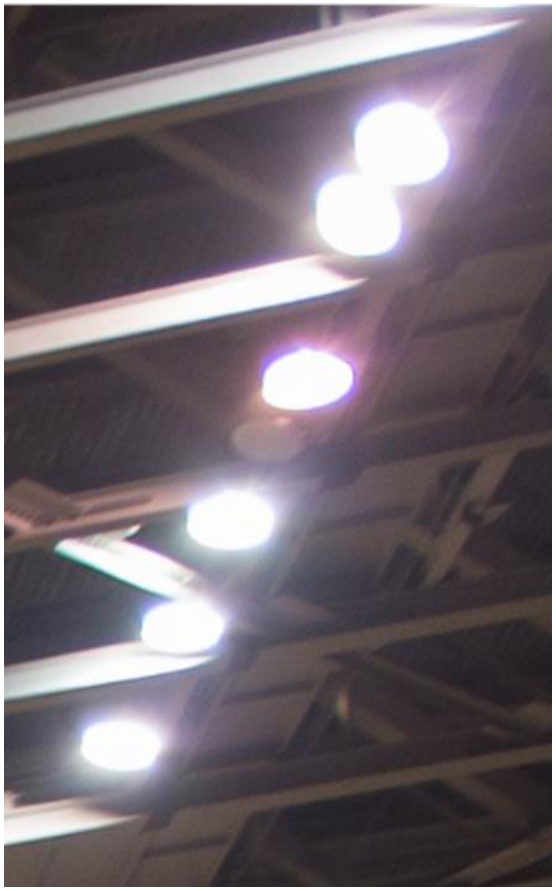


- Conventional light sources have a single set CCT.
- Depending on the type of light, CCT values can change as the source degrades or dimming controls are applied.
- White LEDs in any desired color temperature are available and LEDs maintain their CCT value over the life of the fixture.

LEDs and CCT

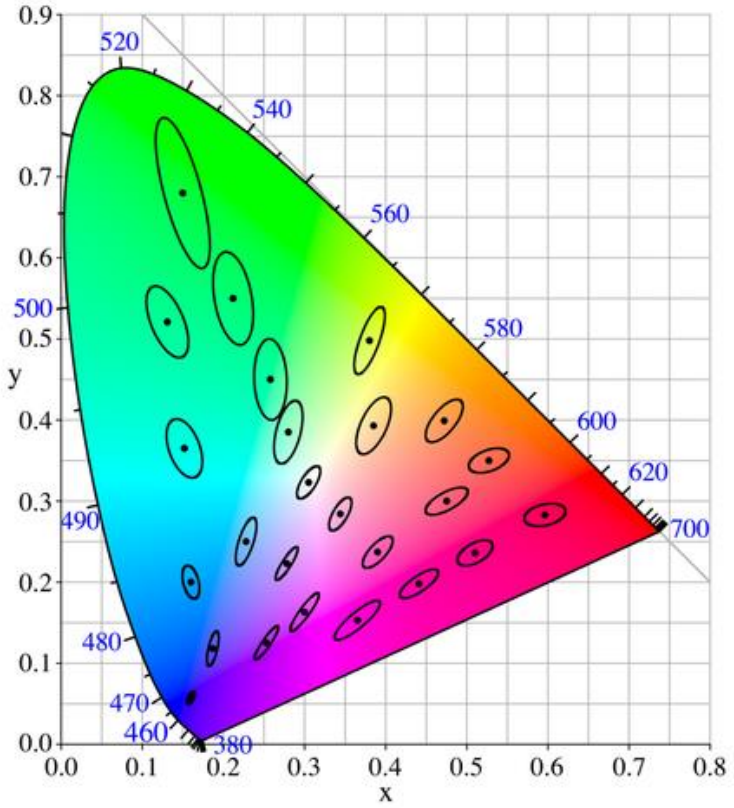


LEDs and CCT



- The variability in the color of light produced by LED chips can compromise the uniformity of the white light across fixtures.
- LED fixtures that produce noticeably different colors of white light create an inconsistent and uncoordinated ceiling aesthetic.
- Manufacturers protect against this phenomenon by organizing LED chips by color.
- This practice is called binning.
- Chips with similar CCT are binned together, so luminaires manufactured with these similarly-colored chips should provide a uniform light color.

Binning for Consistent Light Color



- MacAdam Ellipse defines the range of indiscernibility as 3 standard deviations from the reference color, often called the 3-step MacAdam ellipse.
- 3-step binning organizes LED chips within this range.
- Current industry standards allow LEDs to be considered as having the same nominal CCT within a seven-step MacAdam ellipse.
- Fixtures with LEDs that are binned to a 7-step tolerance may provide in a noticeably different white light.

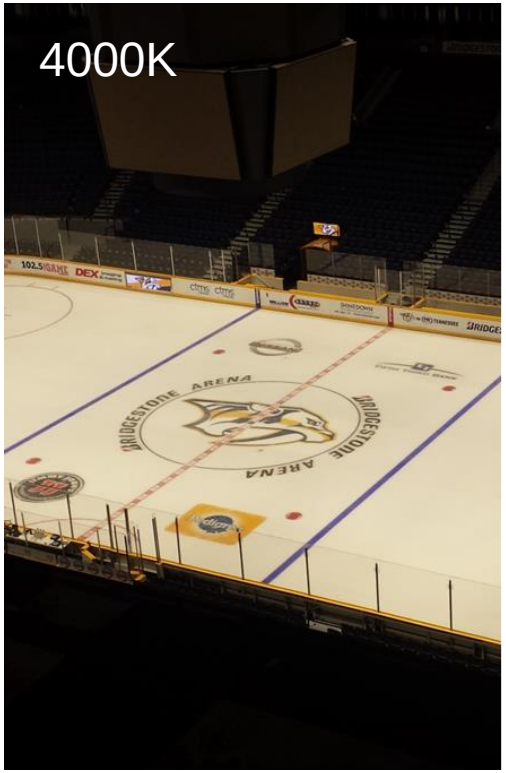
Introducing Color Tuning

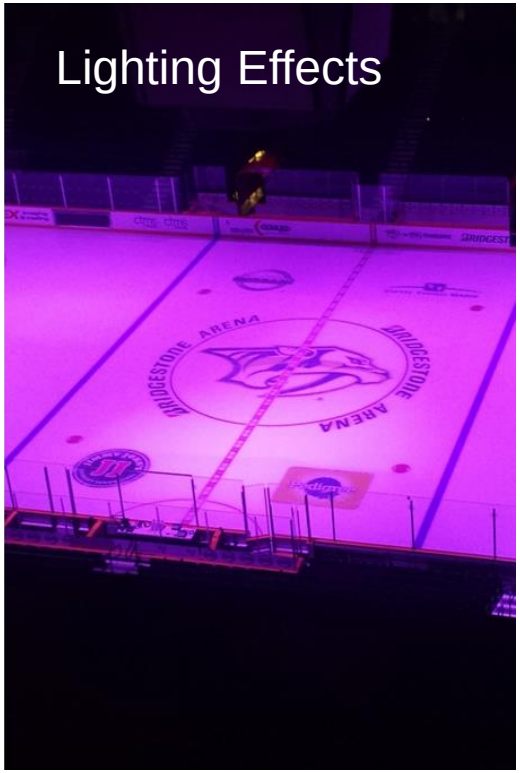
LED Luminaires with more than one CCT

- Conventional light sources are not capable of emitting light with different CCT values.
- Technological advancements in LED materials, design and controls have made it possible for one LED fixture to emit different colors of light.
- LED lighting can combine smaller LED sources with different CCTs into a single luminaire, allowing the end user to adjust the CCT to the desired point within a given range.
- This fixture can deliver white light in the range of 3500K-6500K.

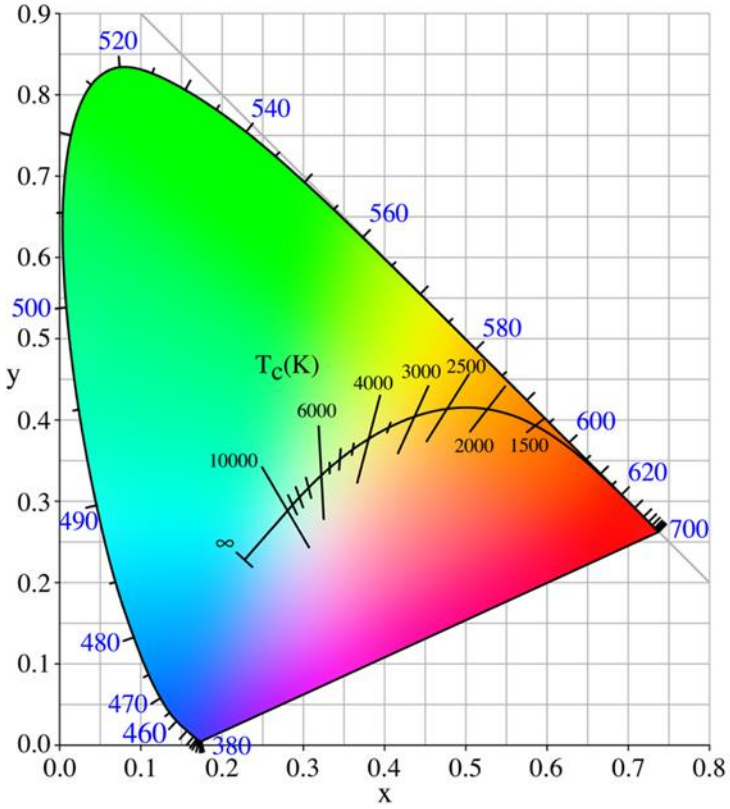
Color Tuning

Color tuning is the ability to adjust the color temperature of an individual luminaire or light source.



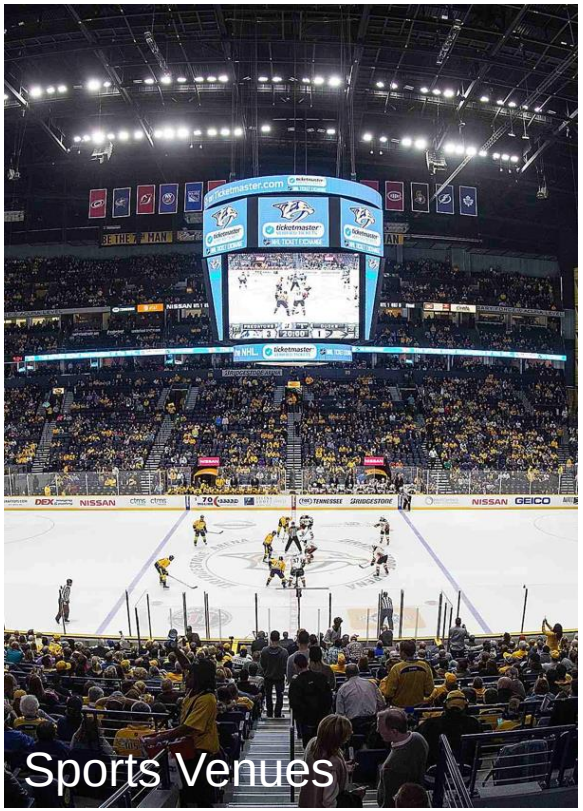


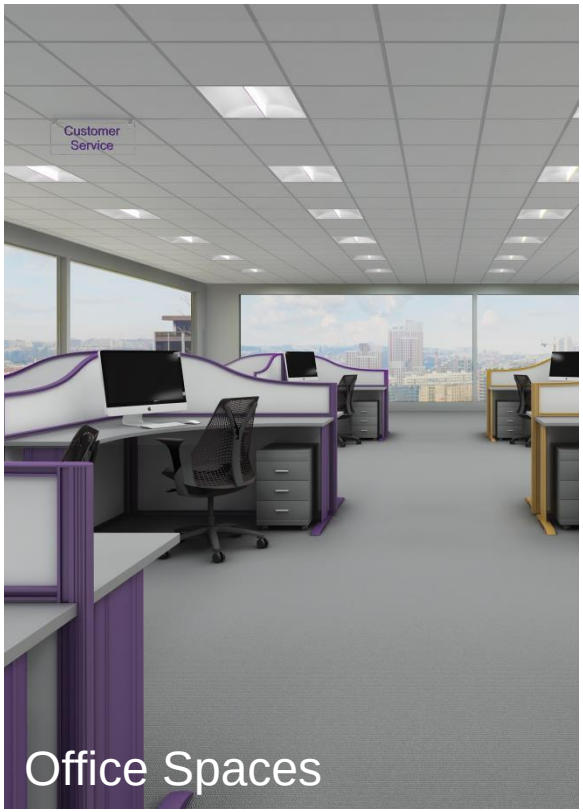
Types of Color Tuning



1. **Stepped White Tuning**
   - Example: Static set points of 3500K, 4000K, 4500K, 5000K
2. **Continuous White Tuning**
   - Example: Infinite set points anywhere from 3500K – 5000K
3. **Dim to Warm**
   - Example: Set at 4000K at full output, drops to 3000K as intensity is dimmed
4. **Full Color Tuning**
   - Example: Continuously variable in X and Y along a triangular path between red, green and blue

Applications for Color Tuning





Benefits of Color Tuning with LEDs

Benefit: Energy Savings

SCENARIO 1	Source Type	SYSTEM Lm/W*	Lifetime (kHrs)	Efficacy vs. LED	Example Case* kWh difference
LED vs. conventional sources	Halogen	10	2	-170%	33,460
	Incandescent	13	1	-160%	25,030
	Metal Halide	30	15	-120%	9130
	Fluorescent	50	8	-82%	4260
	High Pressure Sodium	80	18	-40%	1520
	LED	120	100	Reference	Reference

SCENARIO 2	Source Type	SYSTEM Lm/W*	Lifetime (kHrs)	Efficacy vs. LED	Example Case* kWh difference
LED (single CCT) vs. LED (color tuning)	LED – 3000K	100	100	-33%	1040
	LED – CT (3000/6000K)**	130	100	Reference	Reference

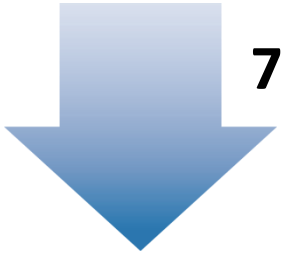
*Case assumes a venue with 125,000 total lumens (about 50 T8 troffers) running 8 hours a day, 365 days a year

**Assumes 50% use of both CCTs

Benefit: Energy Savings (Example)

Multi-Use Arena application:

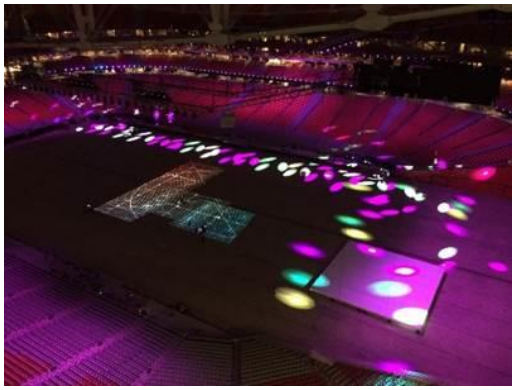
	Hockey	Basketball
Metal-Halide	150- 1500W Metal-Halide 5000K	60- 1500W Metal-Halide 5000K & 20- 1000W HPS
Total	Total Fixtures: 170 Total Wattage Hockey: 225 kW	Total Fixtures: 170 Total Wattage Basketball: 110 kW
Current Energy Use	100 hockey games/year x 12 hours of light operation = 1200 hrs x 225 = 270,000 kWh	50 basketball games/year x 12 hours of light operation = 600 hrs x 110 = 66,000 kWh
Total	336,000 kWh	
LED Replacement	100- 600W Color Tuning Fixtures Hockey- 100 Fixtures: 60 kW x 1200 hours = 72000 kWh	100- 600W Color Tuning Fixtures Basketball- 60 Fixtures: 36 kW x 100 hours = 21600 kWh
Total	93,600 kWh	



72% decrease in kWh

Benefit: Enhanced Attendee Experience

More vivid and custom environments enhance the attendee experience in the space.



Benefit: Optimal HDTV Broadcasting

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4K ULTRA HD

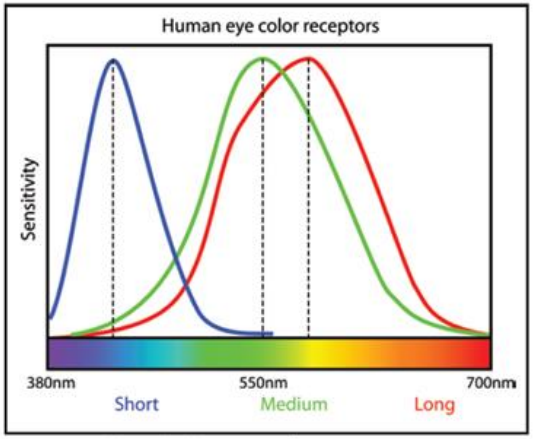


Figure 1 – Human eye color response curves

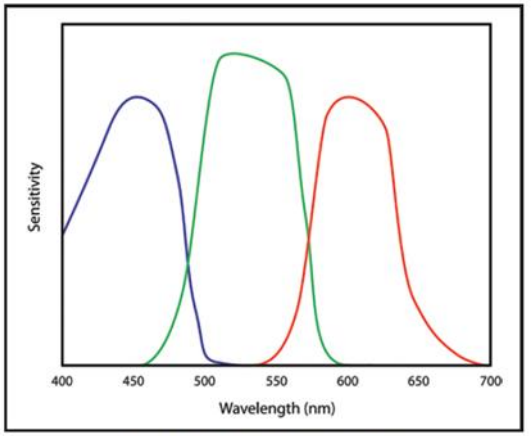
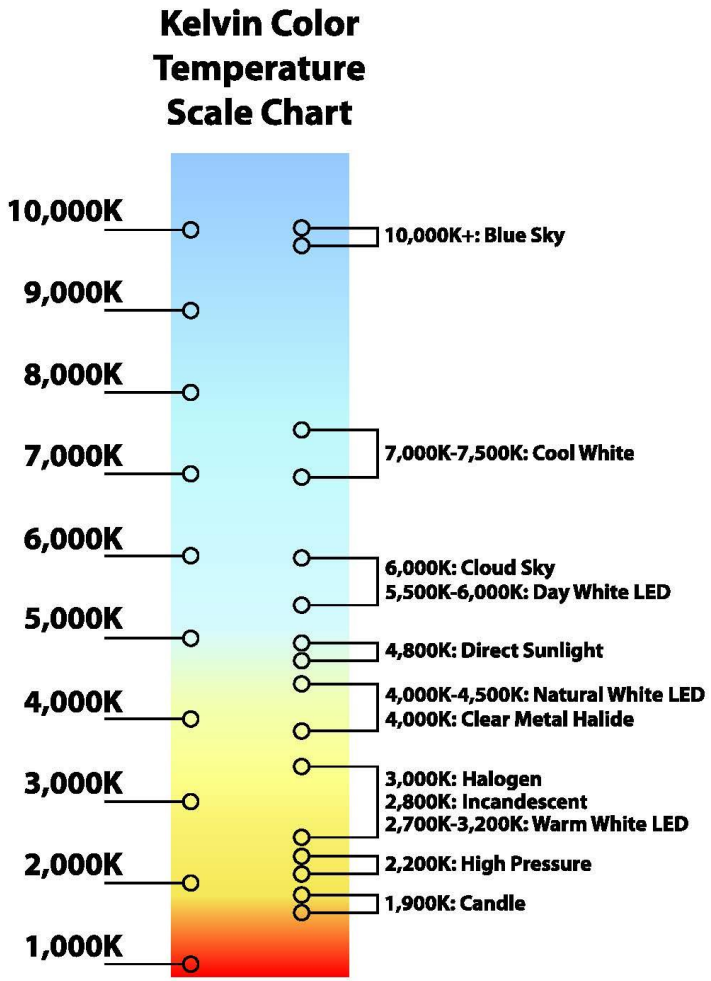


Figure 2 – CCD Camera response curves

Benefits: Optimal HDTV Broadcasting



Cameras are designed around the daylight CCT of 5600 K.

Metal halide is lower and more yellow.

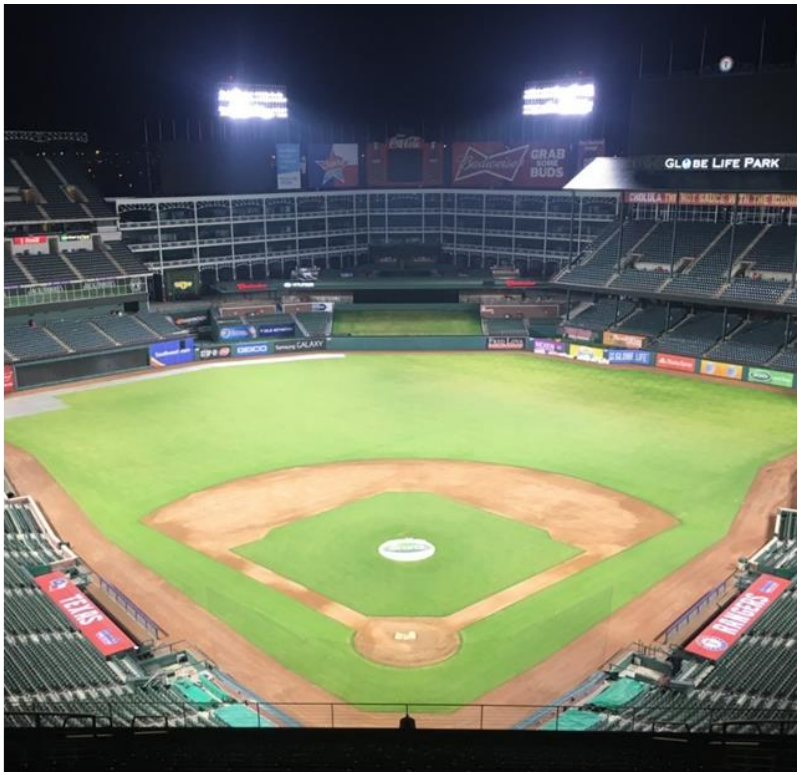
LEDs can provide light that meets the 5600 K target.

Video can be adjusted for color temperature, at a cost of image noise.

No/few adjustments needed with LED.

Benefit: Optimal HDTV Broadcasting

Color temperature tuning allows the color of the lighting to more accurately replicate changing ambient lighting conditions.



Benefit: Optimal HDTV Broadcasting

No flicker, no video loss, better depth of field, and most cameras gain 3 f/stops.

Benefit: Improve Health and Mood

- "There is increasing evidence that the brightness and wavelength of ambient light can have a strong non-visual biological effect, regulating the human circadian system and impacting the biological clock, mood and alertness."
  - Source***: "The effect of high correlated color temperature office lighting on employee wellbeing and work performance"***
  - Journal of Circadian Rhythms, 2007, 5:2, published online 2007 Jan 11.
  - Peter R Mills (et. al)

Benefit: Improve Health and Mood

- The color temperature of sunlight and its intensity change throughout the day.
- Important internal processes are triggered and synchronized by the dynamic presence and character of sunlight.
- White color tuning is a lighting control strategy that helps to maintain circadian rhythms and improve mood.
- The light level and color temperature of LED luminaires are automatically adjusted throughout the day to mimic the natural transition of sunlight.

6 a.m. to 9 a.m., CCT range: 3000-4000K, Intensity: medium to high.

9 a.m. to 12 p.m., CCT range: 4000-6000K, Intensity: high

12 p.m. to 3 p.m., CCT range: 5000-3000K, Intensity: high to medium

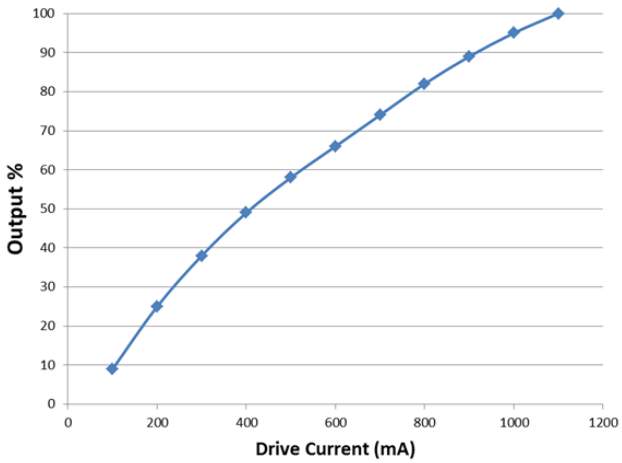
3 p.m. to 6 p.m., CCT range: 4000K-3000K, Intensity: medium

6 p.m. to 9 p.m., CCT range: 3000-2400K, Intensity: medium to low

9 p.m. to 12 p.m., CCT range: 2400-2200K, Intensity: low to none

Methods of Color Mixing and Control

Methods of Color Tuning



Method 1 – Analog: Constant Current Reduction (CCR)

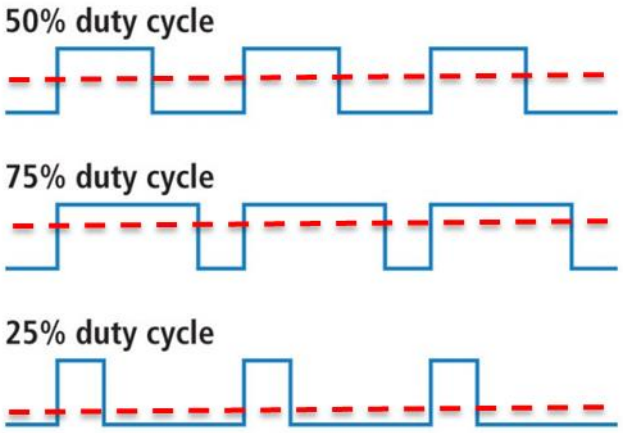
- LEDs are inherently dimmable as a constant current source
- CCR reduces the current amplitude to one CCT, while providing the difference to the other CCT
- Total output current of the driver would remains the same, but current to each LED varies with the adjustment
- Can be done through the driver, or simple control circuitry
- Relies on the balance of current between strings
- Retrofits can use a simple control circuit from an existing constant current source

Note: These methods refer to the control of tuning within the fixture, not the type of dimming control

Methods of Color Tuning

Method 2 – Digital: Pulse Width Modulation

- Current through an LED is switched on and off at a high frequency
- The resultant light emitted is average of the amount time the LED is on
- Total current in the “on” state remains the same
- Can be achieved with both constant-current drivers and constant-voltage drivers



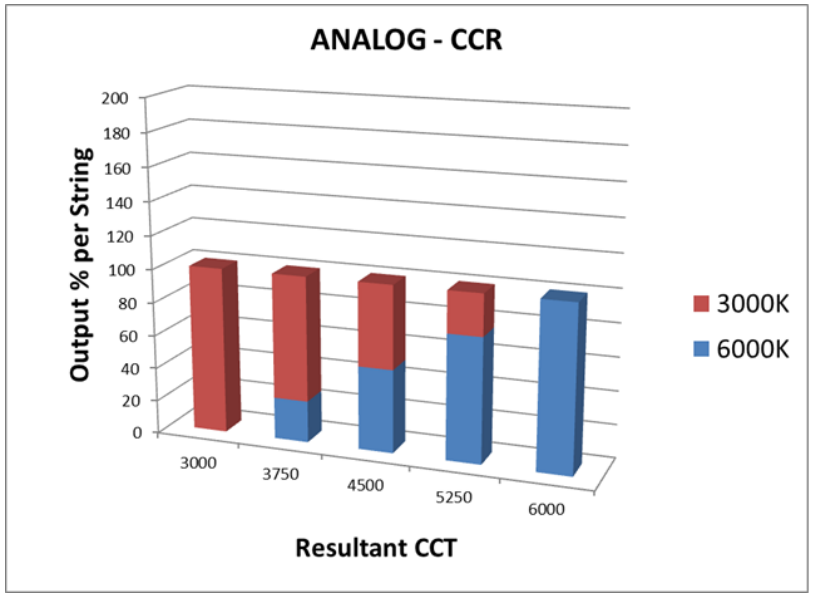
Methods of Color Tuning

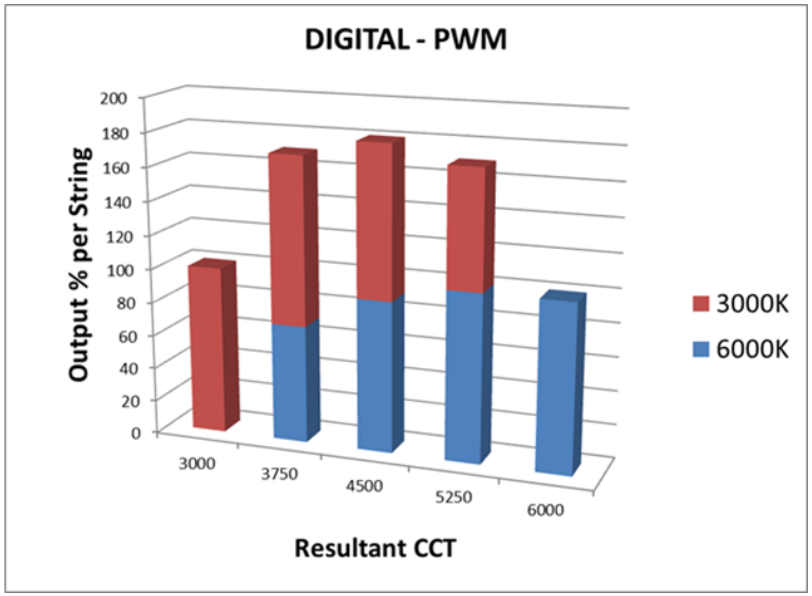
	Analog (CCR)	Digital (PWM)
Efficiency	High	Moderate – High
Complexity	Low	Moderate – High
Dimming Range	10%-100%	<1% - 100%
Color Shift	Can shift up to 20% at low current	Constant
Capacity	3 strings maximum	Unlimited
Adjustment between strings	Proportional	Individual
Other	Drivers can be remotely located	Rapid switching prone to EMI. If frequency is too low, prone to flicker

Comparison of Analog and Digital

- Current is steered to one string or the other, proportionally

- Current is separated to each string by itself, individually
- Can be controlled to provide a constant lumen output in the range





Methods of Controlling Color Tuning

- Daylight Matching
- Continuously adjustable tuning
  - DMX
  - DALI
  - Custom Apps or software
- Schedule System
- CCT scene-based control
- Dimmer switches

*The ability to use a certain control type is manufacturer dependent.

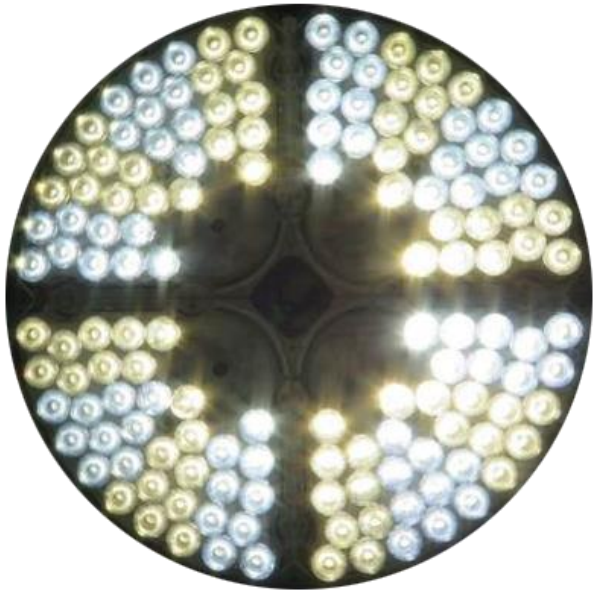
Color Mix Method: Chamber Mixing

Azy—if we can use this image, can we buy it and put a tag under the bluer lamp on left that says 5600K and a tag under yellow lamp that says 4000K?

istock #577344438

- Different CCT LEDs are mixed at the source, under a diffuse optic
- Looking at the source appears to have a single color temperature
- Good for general applications where a wide throw of low-intensity light is preferred
- Reduced optical efficiency (-20% or more) due to the blending of trapped light within the body

Color Mix Method: Targeted Mixing



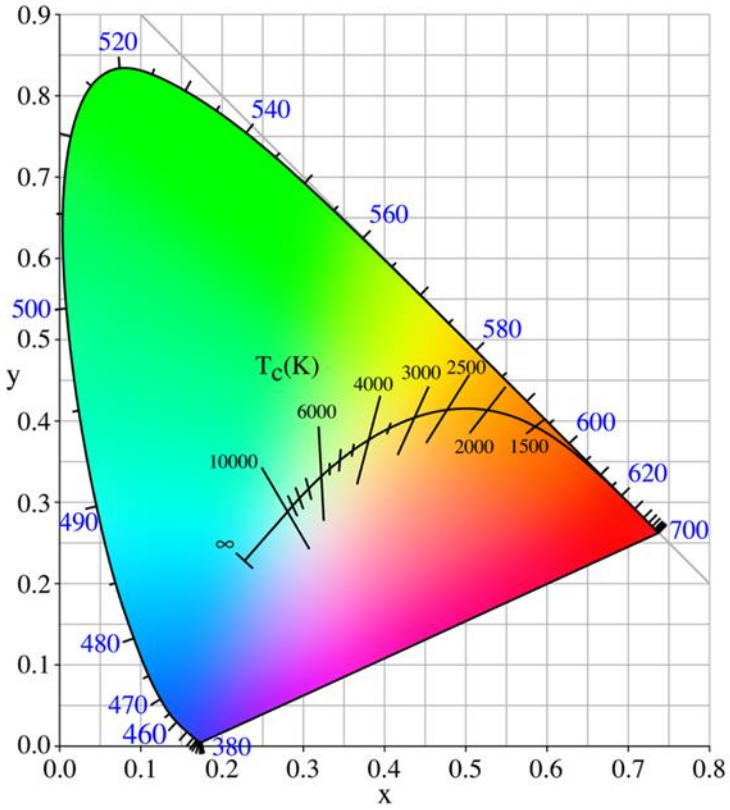
- LED arrays are comprised of individual strings or sets of different CCT chips
- Can see the different CCTs when looking at the source, but the resultant light on the target surface is a single blended CCT
- Allows use of precise optics to aim light, for applications that require exacting cutoffs and beam widths

Color Tuning System

- There are a wide variety of possibilities when selecting a color tuning LED system:
- Type of Color Tuning
- Color Tuning Method (CCR or PWM)
- LED selection (bins, 2 strings, 3 strings)
- Chamber mixing vs. Targeted mixing
- Type of Color Tuning Control

Measurement of Color Tuning

Measurement of Color Tuning



Direct Adjustment:

- Intensity / Lumen Output
- Color Temperature

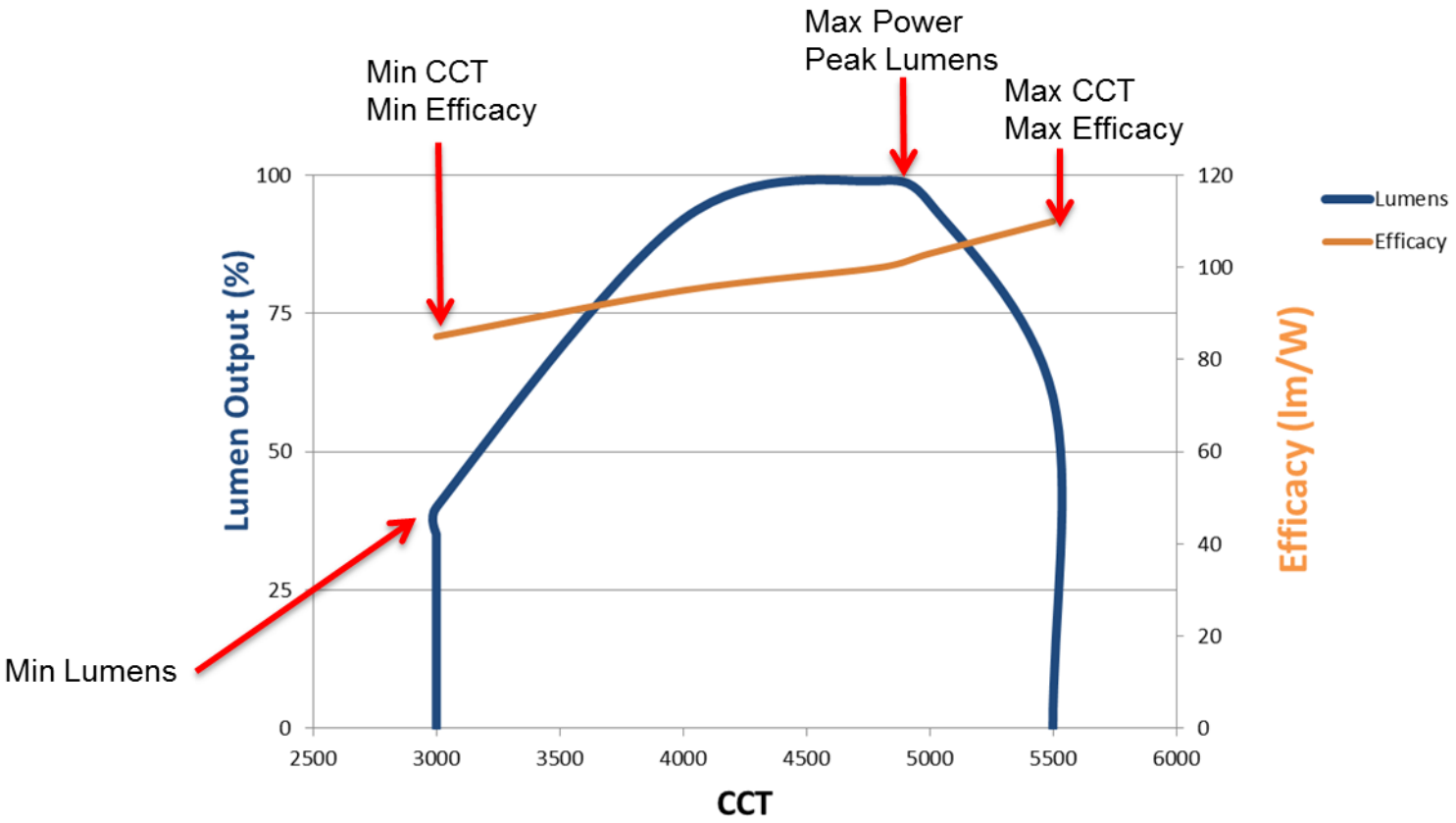
Indirect Adjustment:

- Efficacy – how to identify worst case?
- CRI (?)
- THD / PF
- Temperature – impact to LED and driver

- At what point is light no longer white?
- System performance is ultimately user dependent
- Testing exhaustively over the full range can be costly

Future Development: Standardized Measurement

Rather than a nominal point, characterize the nominal range “A:B” of a color-tuning system



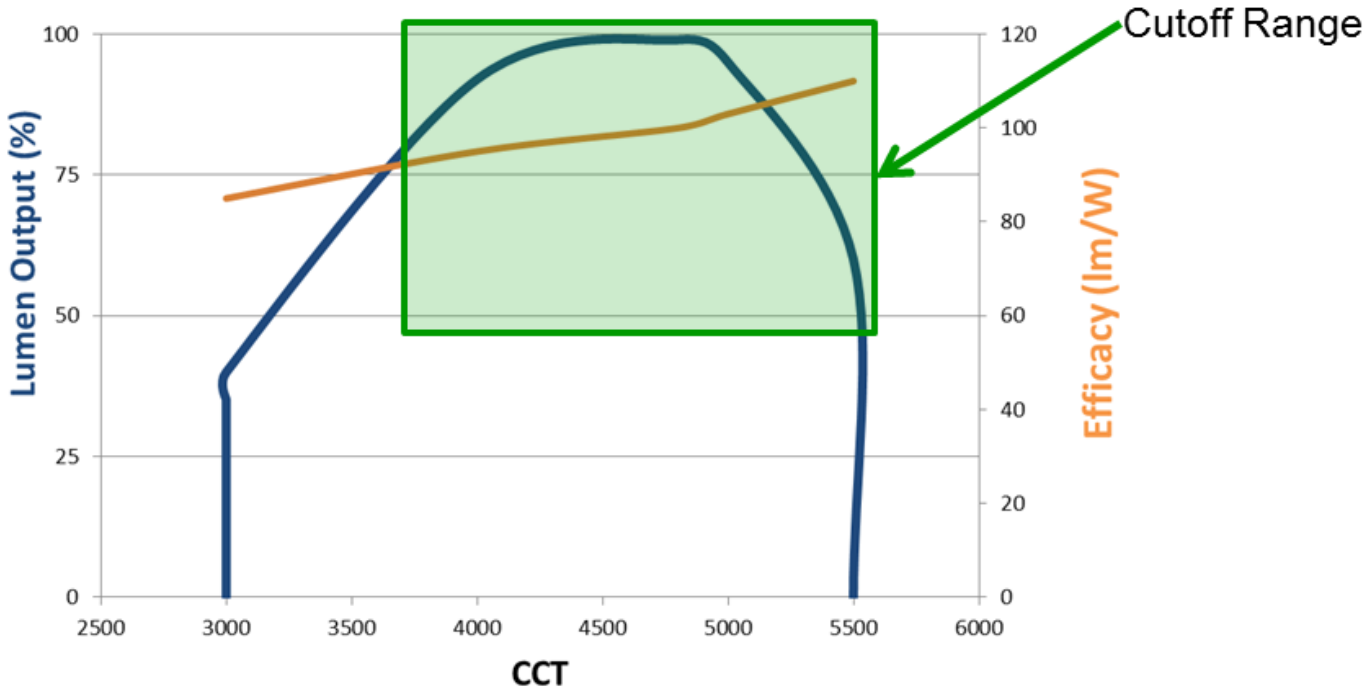
Measurement of Color Tuning

Characterize smallest available dimming module (array/control) in sphere

- Capture CCT/CRI/Lumens/Efficacy at several points along the range
- Start with a broad sweep, refine as needed
- Identify worst case points
- Scale or retest at full fixture level at critical points:
  - Minimum: Lumens, CCT, CRI, PF, Efficacy
  - Maximum: CCT, THDi, drive current, thermal performance

- Identify a “cutoff range” wherein the fixture meets current performance requirements
- Measurements to define worst case still must show: lowest & highest drive current, highest watt-density, least efficient optics

Measurement of Color Tuning



Case Study: Color Tuning at Bridgestone Arena

Color Tuning at Bridgestone Arena

CASE STUDY **BRIDGESTONE ARENA** NASHVILLE, TN | NHL HOCKEY ARENA

Conclusion

Conclusion

This concludes The American Institute of Architects Continuing Education Systems Course.