LEDucation
Trade Show and Conference

Designers Lighting Forum

Not All The Reds Are The Same.

Challenges Of Specifying Color Changing LED

Ellie Motevalian, Toranj Noroozi
03/08/2023

CONTINUING EDUCATION AIA

leducation.org

Learning Objectives

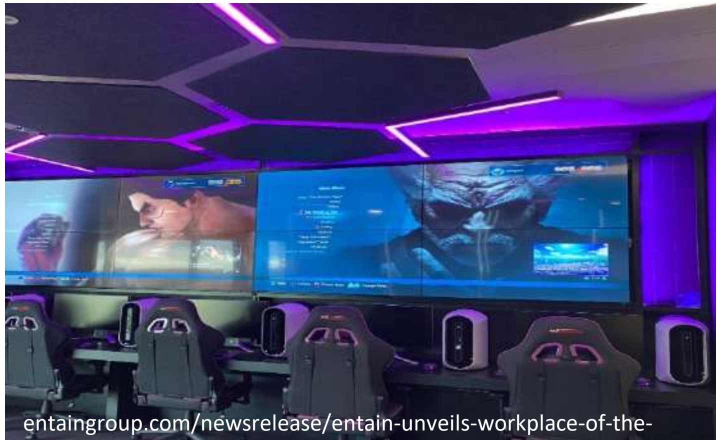
At the end of this course, participants will be able to:

1. This course describes the challenges of using white light illumination metrics for color-changing sources due to differences in human perception of colored and white lights
2. This course identifies the shortcomings of current calculation software and metrics in having consistent and clear measurements to compare the light source's color properties from different manufacturers.
3. This course explores recommendations on the information that the lighting specifiers can include in their fixture specifications to ensure that the final purchased fixtures are the true or close equivalent of the initial design.
4. This course investigates various possibilities that the lighting manufacturers can provide information on the color properties in an effort to create a consistent metric that allows the specifiers to compare different fixtures effectively.

Not all reds are the same!

Applications where we use RGB in architectural lighting:

- Branding
- Entertainment
- Mood or Atmosphere
- Way finding



Not all reds are the same!

Applications where we use RGB in architectural lighting:

Semi-Conductor Manufacturing Amber Light

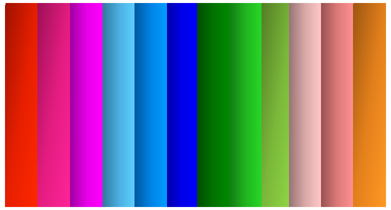
Surgical Rooms – Green Lights

Public Restrooms– Blue Lights

Not all reds are the same!

- Finding The Right Fixture
- Illumination Level Study
- Rendering
- Mockup

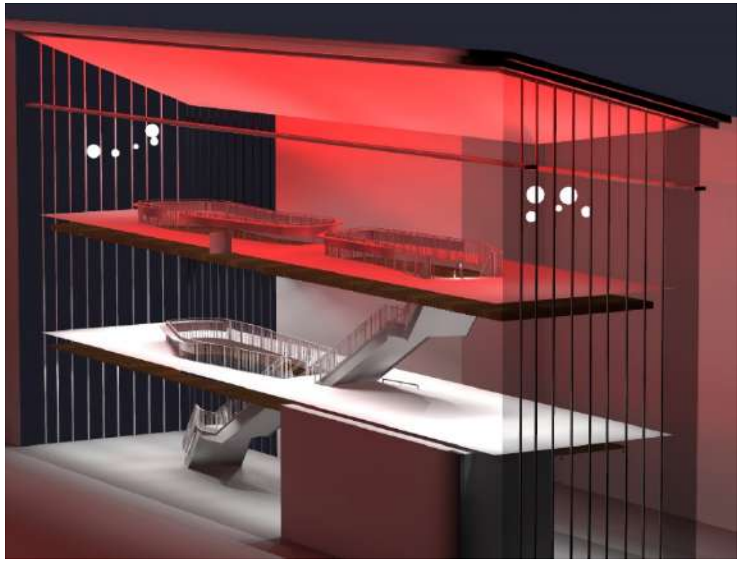
Specifying RGB



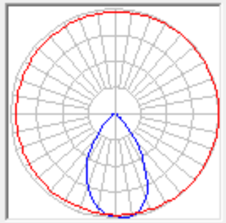
- How to write the spec
- Keeping the spec
- The Right Alternate
- Original vs Alternate

Not all reds are the same!

- Rendering
- Mockups
- Cutsheets
- IES File



Metrics



Roadway Classification	Type VS
Longitudinal Classification	Very Short
Upward Waste Light Ratio	0.00
Indoor Classification	Direct
Luminaire Efficacy Rating (LER)	42
Maximum UGR	14.2
BUG Rating	B2-U1-G0
Cutoff Classification (deprecated)	N.A.

Not all reds are the same!

- The Perception of Color

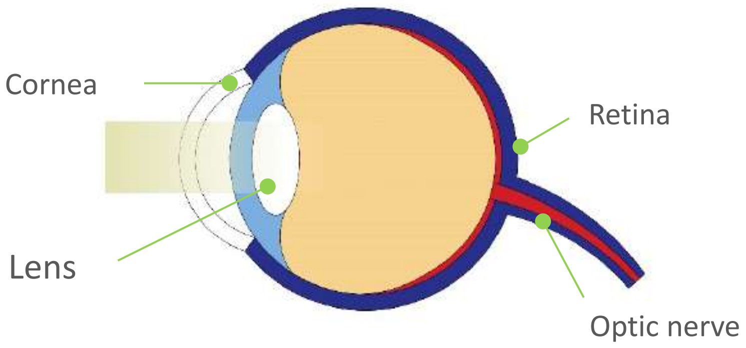
How human eyes see colors:

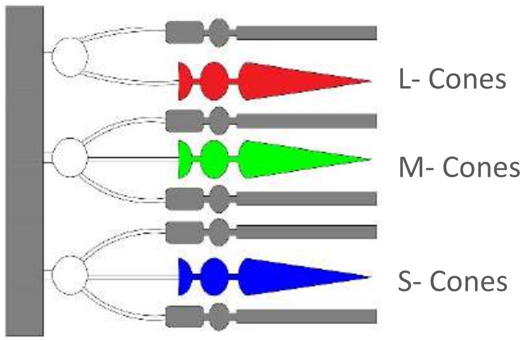
Cones: Lower sensitivity to light and responsible for color and Photopic vision.

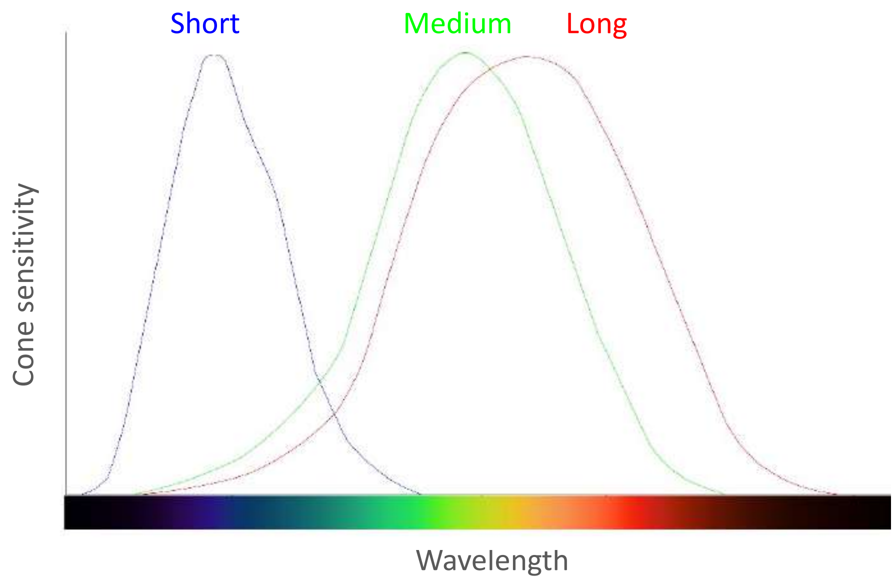
Rods: Higher sensitivity to light and responsible for scotopic vision. Do not mediate color vision

Three different cones types and their sensitivity to each wavelength:

- Long wavelength: L cones
- Medium wavelength: M-cones
- Short wavelength: S-cones







Not all reds are the same!

- The Perception of Color

Our vision doesn't respond equally to all wavelength.

Under photopic vision, peak brightness is at bout 555 nm or pale yellow-greenish

The brightness decrease toward red and violet of the spectrum.

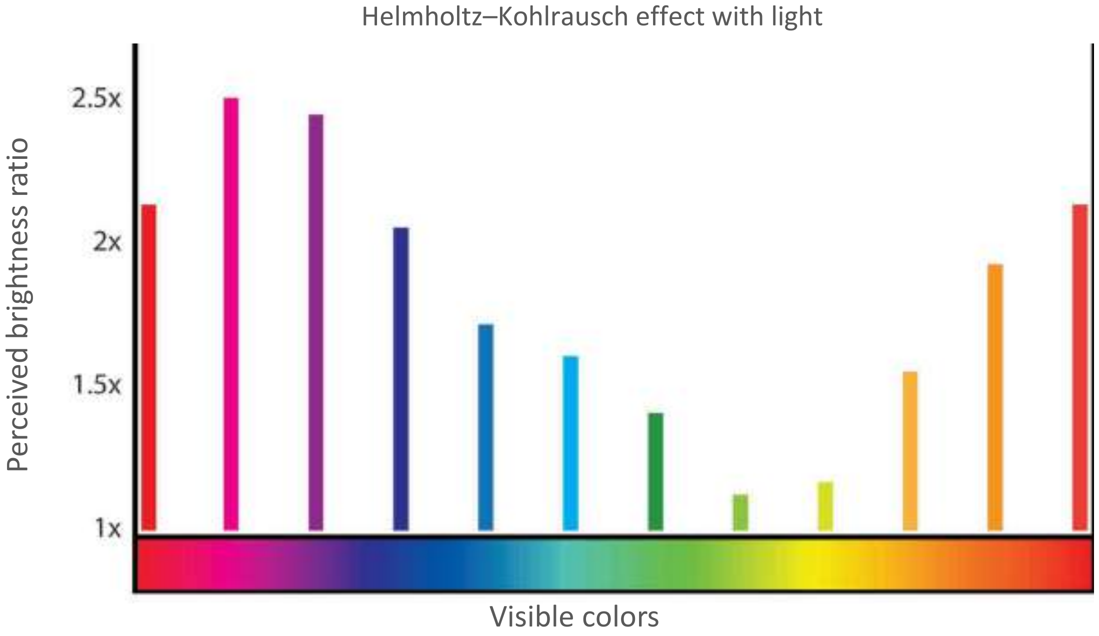
Not all reds are the same!

- The Perception of Color

Helmholtz–Kohlrausch Phenomenon

Colored stimulus (light reflected from an object or colored light) appears brighter than a white stimulus of the same luminance.

The more saturated the stimulus, the brighter it appears to human eyes.



Source: ANSI/IES LS-5-21 Lighting Science: Color

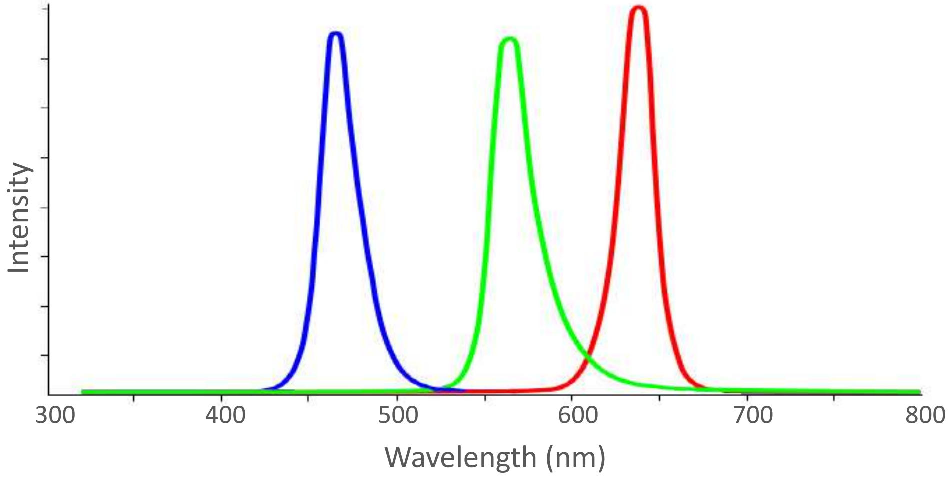
Not all reds are the same!

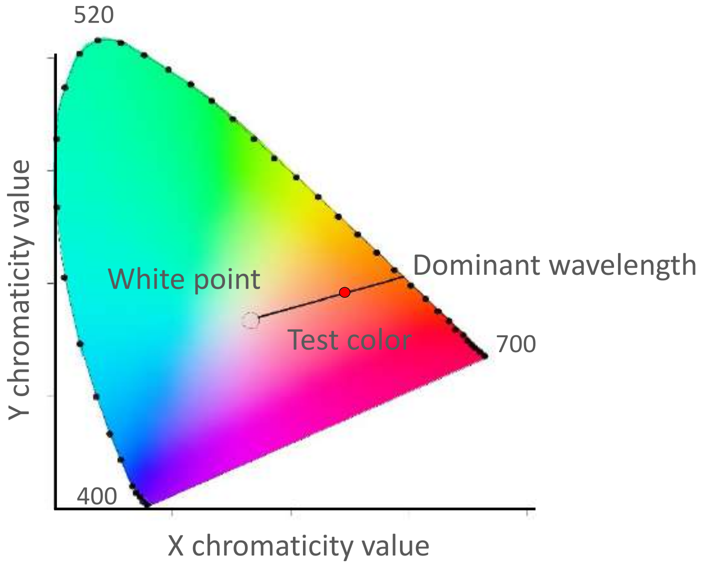
- Peak Wavelength

  The wavelength at which the maximum value occurs in a spectral power distribution. (Peak value measured by a spectrometer)

- Dominant Wavelength (DW)

  The dominant wavelength is characterizing a color's hue. (Eye response to a single wavelength that describes what the light source looks like)





Not all reds are the same!

IES File or Lumens Information for Each Color

Spectral Distribution/ CIS Tristimulus Values

Optic And Color Mixing Technology

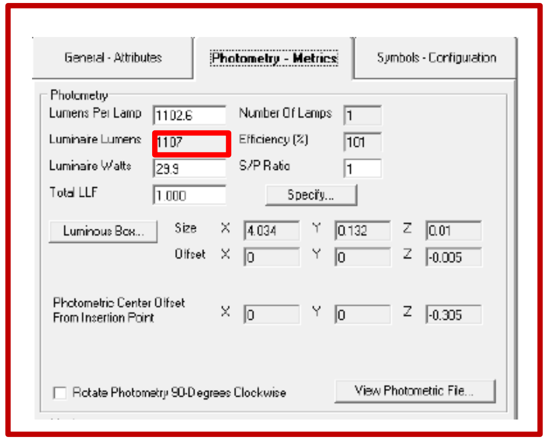
Not all reds are the same!

- What information is available on manufacturers websites and cutsheets

  Out of more than 20 manufacturers:

  - 30% shows lumen output for each color on their cutsheet.
  - 35% has IES file for each color
  - Only 10% have information about dominant and peak wavelength on their cutsheet

Luminous output	1 FT at 12W	4 FT at 12W
FULL	650 lumens	2600 lumens
RED	290 lumens	1160 lumens
GREEN	580 lumens	2320 lumens
BLUE	120 lumens	480 lumens

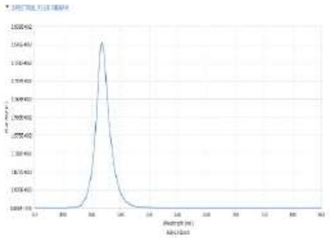


Fixture Image	Lumen output for each color	IES file for each color	Color mixing	Peak and dominant wavelength
	NO	NO	With RGBW/RGBA color mixing, the available electrical power of the projector is normally distributed evenly across all four channels. This means that a maximum of	NO
	NO	NO	Using Nitro Color Technology with they Quad Cluster LED Configuration: 20% of total power per channel	NO
	Yes	YES	High efficiency LED emitter with individual color diodes.	NO
	NO	YES	RGBA Color Mixing 36 LEDs per 12 in (18x tri-color LEDs, 18x amber LEDs)	NO
	NO	NO	RGBW	NO
	NO	NO	RGBW	NO
	YES, IT HAS MULTIPLIER	NO	RGBW	NO
	NO	YES	RGBW ,RGBA, RGBWA IN SOME FIXTURES	NO
	NO	NO	RGBW	NO
	NO	No	Color Mixing: Using proprietary technology, colors are efficiently blended together through an internal mixing chamber. The one-color output	LED Die Colors: Red (620-635nm), Green (520-535nm), Blue (450-465nm) and
	Yes	YES	Each LED module contains 4 LED dies: Red, Green, Blue and White. These are given unique DMX addresses at the factory increasing by four from one module to the next as shown below in the example of a 48" fixture	NO
	YES	YES	RGBW	NO
	NO	No	in a family with Chromasync technology. During the manufacturing process a calibrated light measurement device creates an algorithm to define a common color gamut for an entire family of LED luminaires. When	NO
	luminous output: 1 ft at 12W4 ft at 12W FULL:650 lumens2600 lumens RED:290 lumens1160 lumens	YES	Graze QUAD models feature homogenized color mixing with 8 LEDs/ft and an integrated color boosting feature for full-powered illumination of a single color or mixed colors. Each unit is factory calibrated for	NO
	NO	NO	RGBW	NO
	YES	NO	RGBW, RGBA Full power for each color	YES
	NO	No	RGBW	NO
	NO	NO	RGBW	NO
	NO	YES		NO

Not all reds are the same!

- Sample Of Peak/ Dominant Wavelength

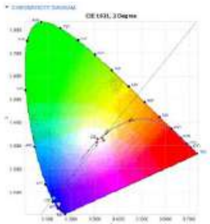
Most manufacturers only share this data upon request.



Spectral Response

Photometric Test Results

Luminous Flux (Lumens)	81.5
Efficacy (Lumens/Watt) (I/O)	8.14/15.59
Color Temperature (CCT K)	22,000
Color Rendering Index (CRI)	-47.4
R_9 Value	-312.9
Radiant Flux (W)	1.0
Chroma u' / Chroma v'	0.1401 / 0.1846
Duv	N/A
RGB Ratio (%)	12.17



Chromaticity Diagram
Tristimulus Values: x / y = 0.1275 / 0.0747

Electrical Test Results

Input Power (Watts) (I/O)	10.02/5.23
Input Voltage (Volts) (I/O)	120.02/119.84
Input Current (Amps) (I/O)	0.130/0.045
Power Factor (I/O)	0.644/0.961
Input Frequency (Hz)	60.0
Stabilization Time	60 minutes
Ambient Temperature	25.1°C
Max ITHD (%)	48.78

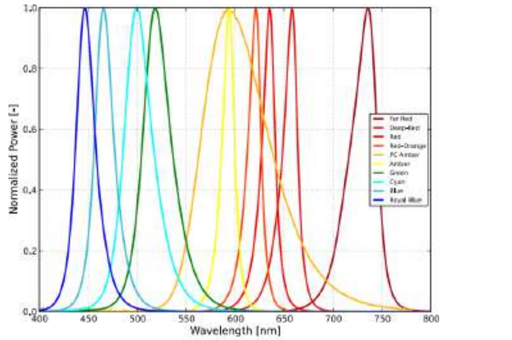
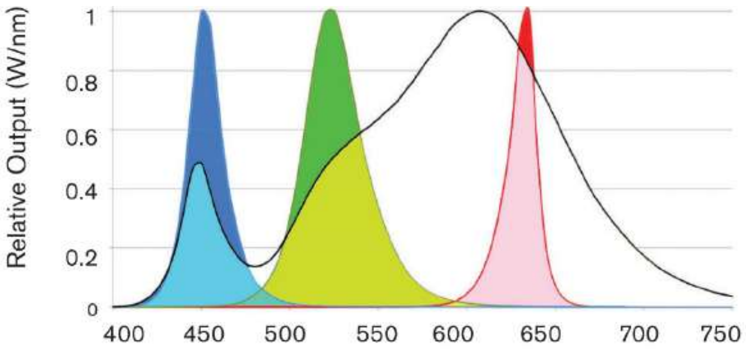
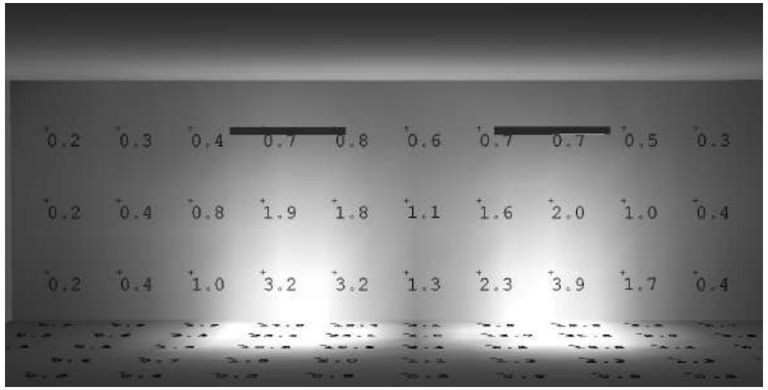


Figure 1a. Typical normalized power vs. wavelength for LUXEON Rebel Far Red, Deep Red, Red, Red-Orange, PC Amber, Amber, Green, Cyan, Blue and Royal Blue at test current, T_J=25°C.

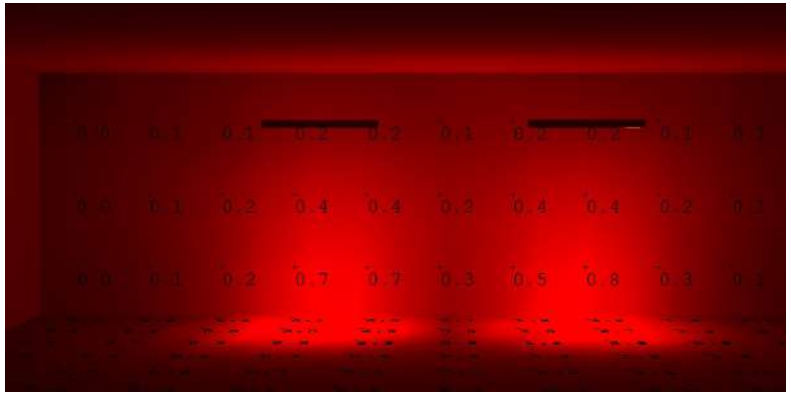


LEDucation Trade Show and Conference

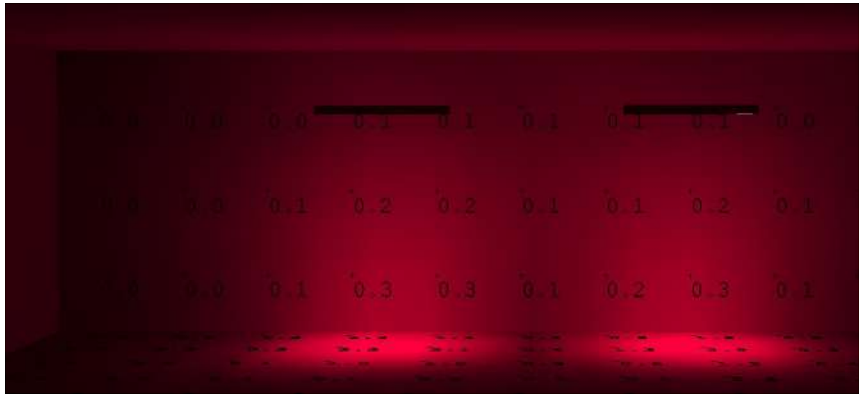
Not all reds are the same!



photometric study using red IES file
no filter



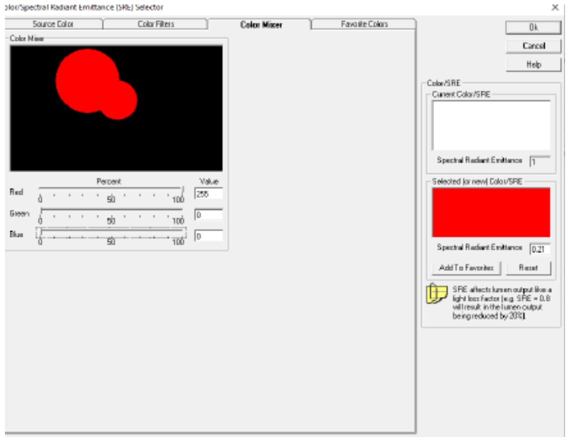
photometric study using red IES file
with adjusted color mixing
255 red . 0 green. 0 blue

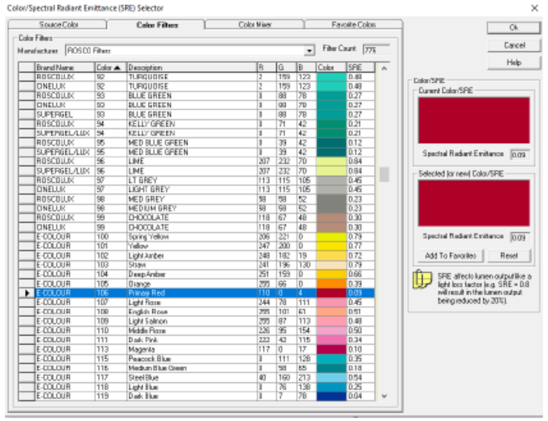


photometric study using red IES file
with Rosco color gel
Primary red

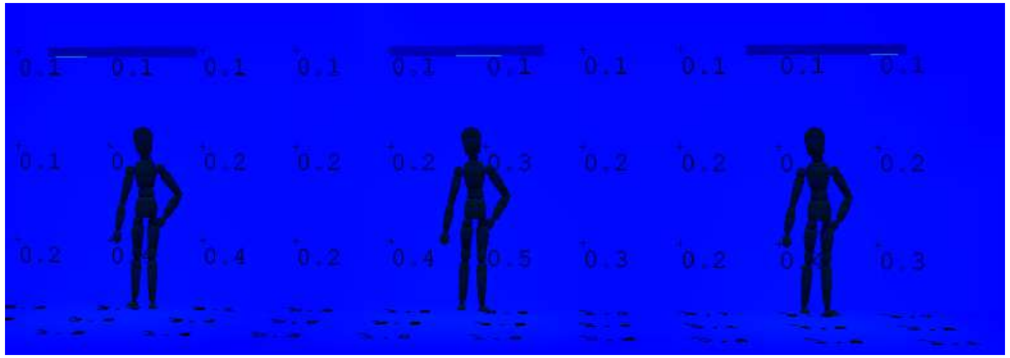
Luminaire Schedule

Symbol	Qty	Tag	LLF	Luminaire Lumens	Luminaire Watts	Total Watts
	1	RED IES File	1.000	1107	29.9	29.9
	1	RED IES File - Color Mixing Red at 255	1.000	1107	29.9	29.9
	1	RED IES File - Rosco Gel 106	1.000	1107	29.9	29.9



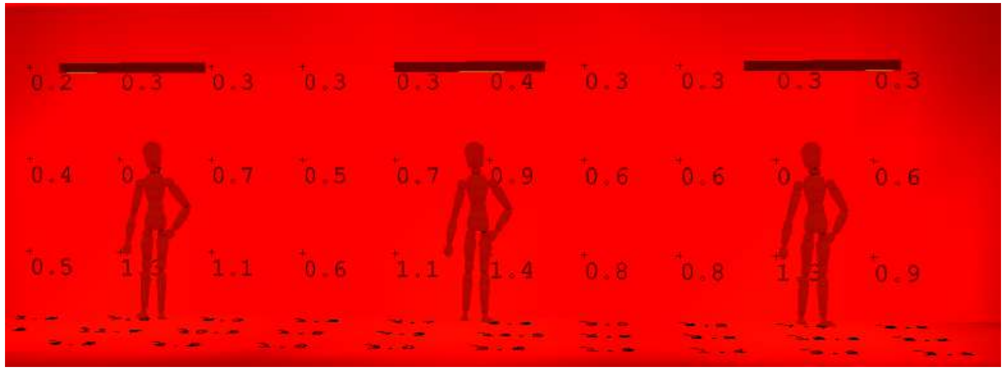


Not all reds are the same!



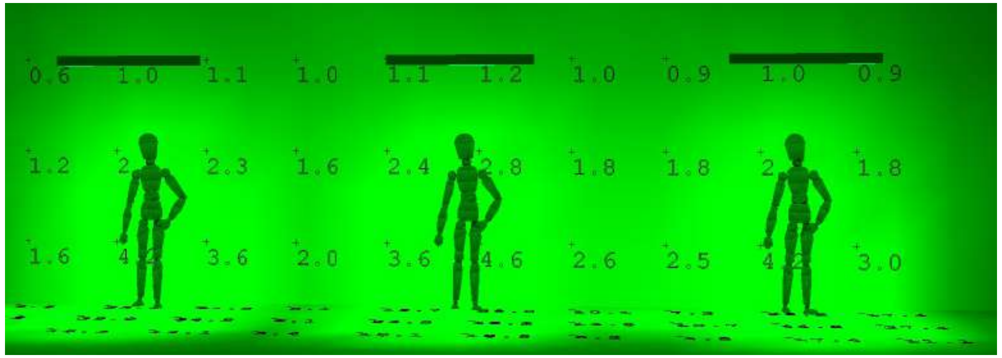
Luminaire Schedule						
Symbol	Qty	Tag	LLF	Luminaire Lumens	Luminaire Watts	Total Watts
	3	Blue Color Mixing	1.000	2494	39	117

Calculation Summary							
Label	CalcType	Units	Avg	Max	Min	Avg/Min	Max/Min
Room Study_Wall_3	Illuminance	Fc	0.21	0.5	0.1	2.10	5.00
Room_2_Floor	Illuminance	Fc	1.73	4.9	0.3	5.77	16.33



Luminaire Schedule						
Symbol	Qty	Tag	LLF	Luminaire Lumens	Luminaire Watts	Total Watts
	3	Red Color Misixng	1.000	2494	39	117

Calculation Summary							
Label	CalcType	Units	Avg	Max	Min	Avg/Min	Max/Min
Room Study_Wall_3	Illuminance	Fc	0.64	1.4	0.2	3.20	7.00
Room_2_Floor	Illuminance	Fc	5.13	14.3	0.8	6.41	17.88



Luminaire Schedule						
Symbol	Qty	Tag	LLF	Luminaire Lumens	Luminaire Watts	Total Watts
	3	Green Color Misixng	1.000	2494	39	117

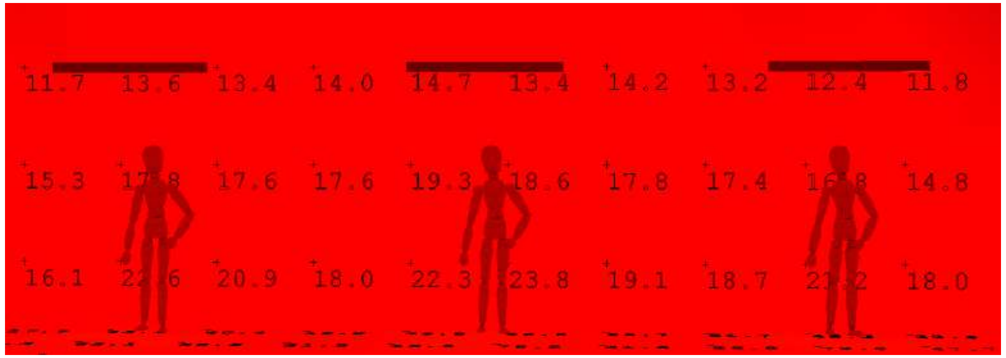
Calculation Summary							
Label	CalcType	Units	Avg	Max	Min	Avg/Min	Max/Min
Room Study_Wall_3	Illuminance	Fc	2.08	4.6	0.6	3.47	7.67
Room_2_Floor	Illuminance	Fc	17.23	48.2	2.7	6.38	17.85

LEDucation
Trade Show and Conference

Not all reds are the same!

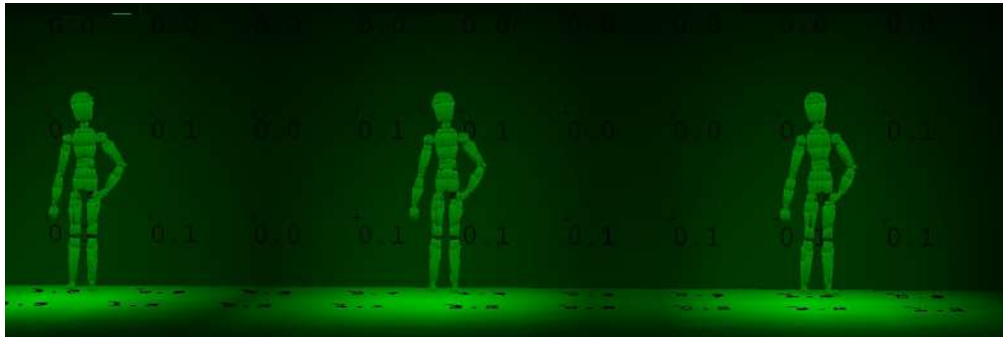
Luminaire Schedule						
Symbol	Qty	Tag	LLF	Luminaire Lumens	Luminaire Watts	Total Watts
	3	Blue Color Mixing	1.000	2494	39	117

Calculation Summary							
Label	CalcType	Units	Avg	Max	Min	Avg/Min	Max/Min
Room_2_Floor	Illuminance	Fc	0.09	0.2	0.0	N.A.	N.A.
Room_2_Wall_3	Illuminance	Fc	0.00	0.0	0.0	N.A.	N.A.



Luminaire Schedule						
Symbol	Qty	Tag	LLF	Luminaire Lumens	Luminaire Watts	Total Watts
	3	Red Color Misixng	1.000	2494	39	117

Calculation Summary							
Label	CalcType	Units	Avg	Max	Min	Avg/Min	Max/Min
Room_2_Floor	Illuminance	Fc	42.31	78.1	19.2	2.20	4.07
Room_2_Wall_3	Illuminance	Fc	17.10	23.7	11.8	1.45	2.01



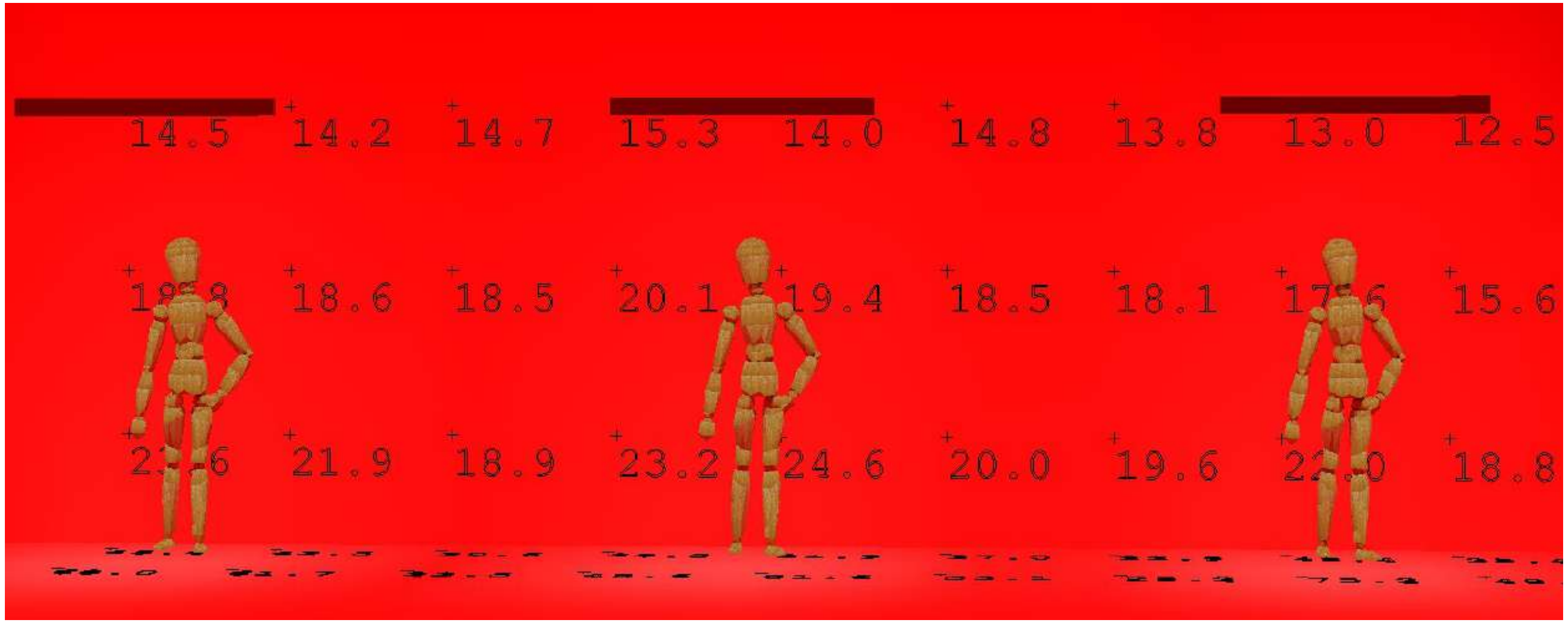
Luminaire Schedule						
Symbol	Qty	Tag	LLF	Luminaire Lumens	Luminaire Watts	Total Watts
	3	Green Color Misixng	1.000	2494	39	117

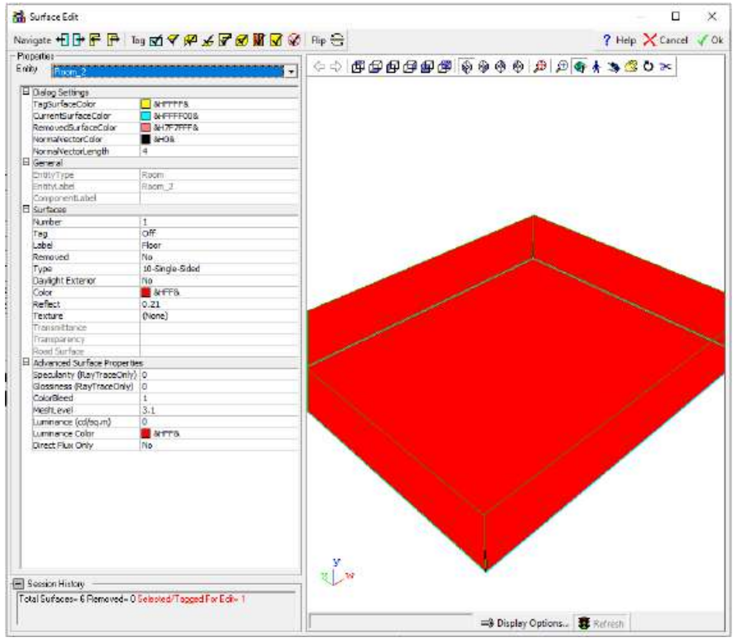
Calculation Summary							
Label	CalcType	Units	Avg	Max	Min	Avg/Min	Max/Min
Room_2_Floor	Illuminance	Fc	0.99	2.2	0.2	4.95	11.00
Room_2_Wall_3	Illuminance	Fc	0.05	0.1	0.0	N.A.	N.A.

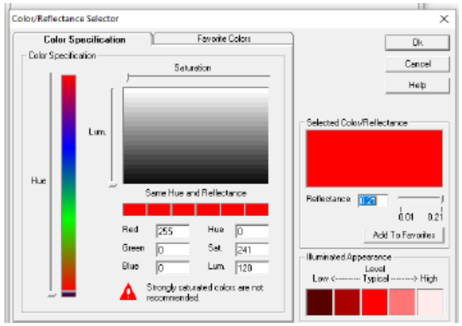
CONTINUING EDUCATION AIA

leducation.org

Not all reds are the same!



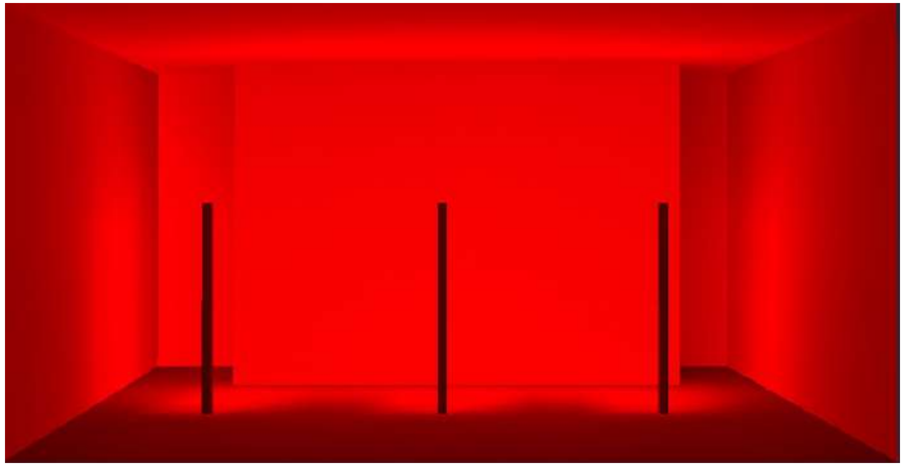




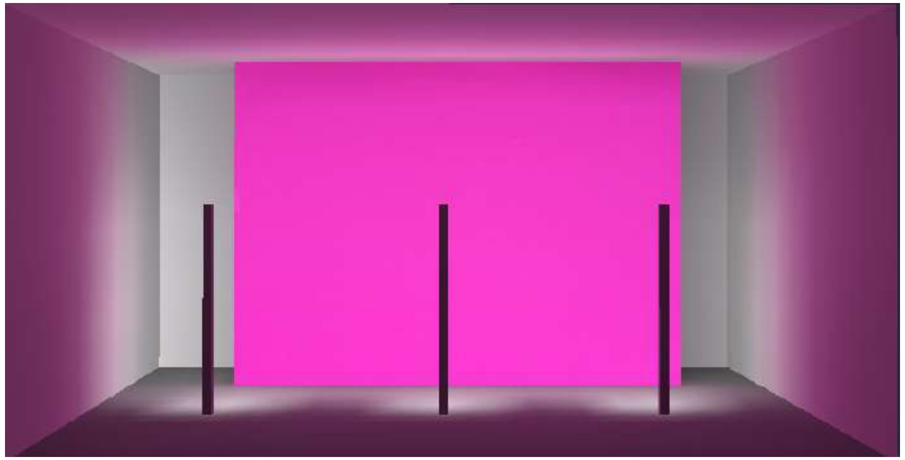
LEDucation
Trade Show and Conference

Not all reds are the same!

Rendering

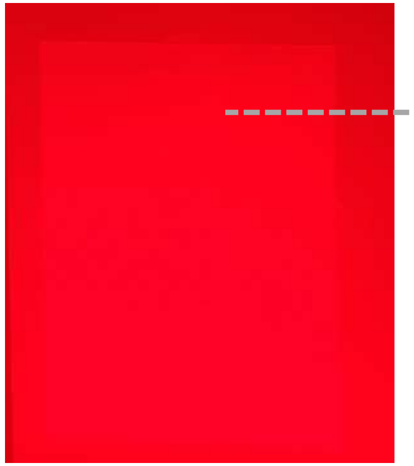


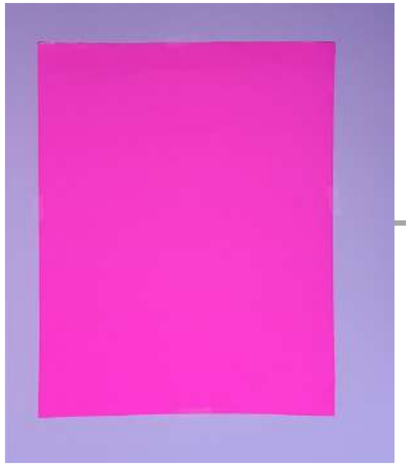
Color mixing: R:0, G:0, B:255



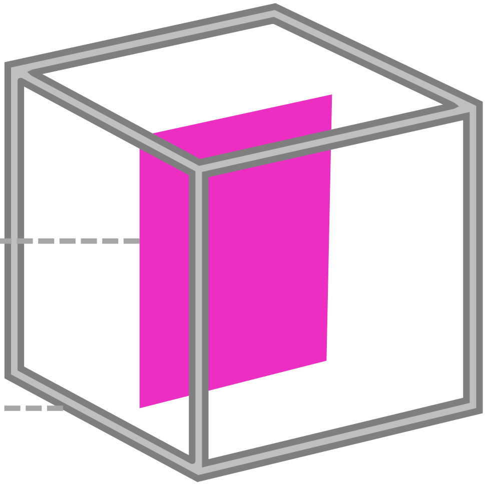
Color mixing: R:255, G:255, B:255

Photo

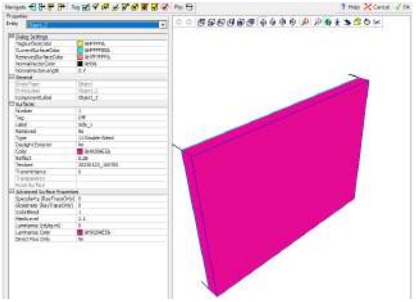




Magenta Object



White Room



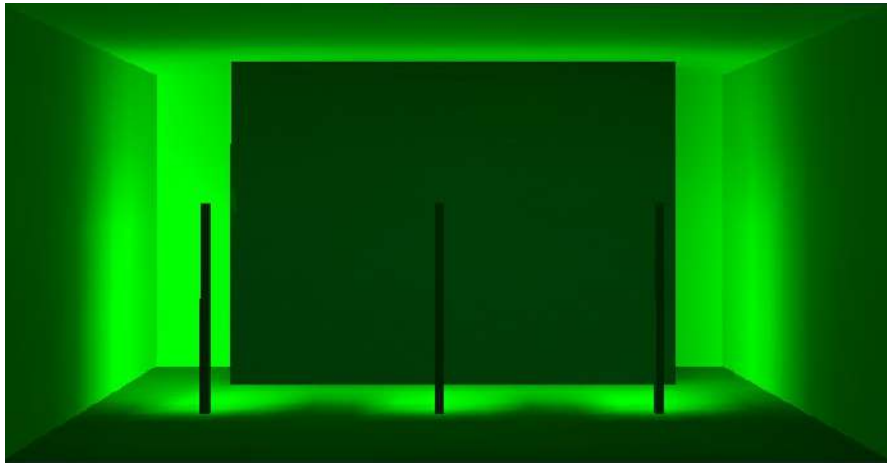
CONTINUING EDUCATION AIA

leducation.org

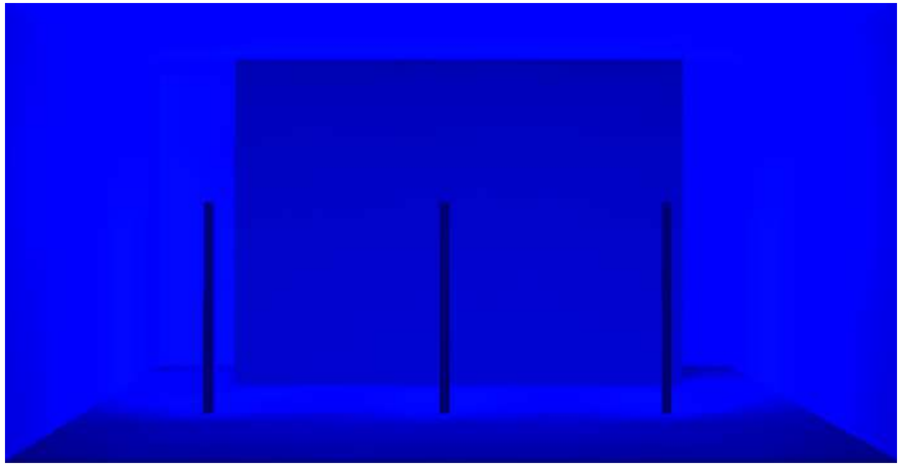
LEDucation
Trade Show and Conference

Not all reds are the same!

Rendering

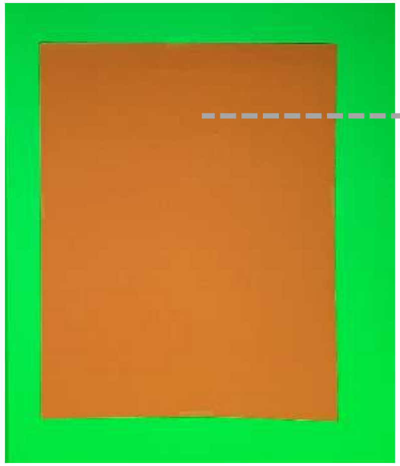


Color mixing: R:0, G:255, B:0

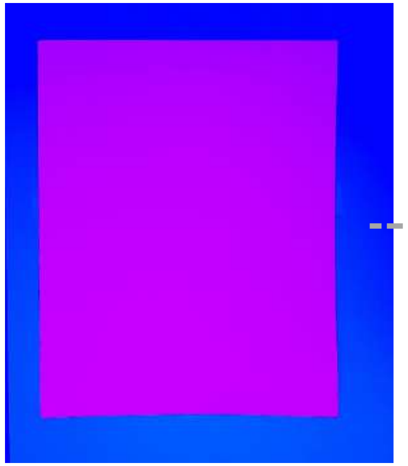


Color mixing: R:0, G:0, B:255

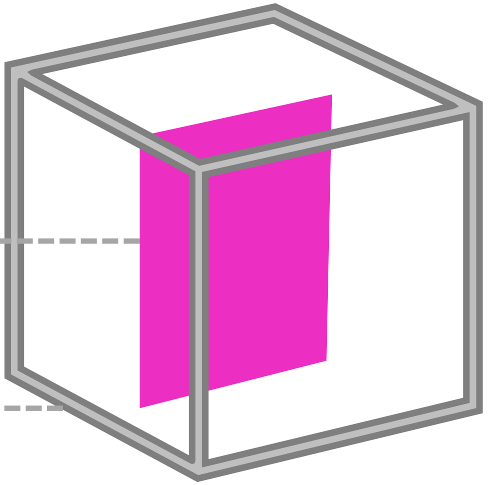
Photo



Full Green at 100



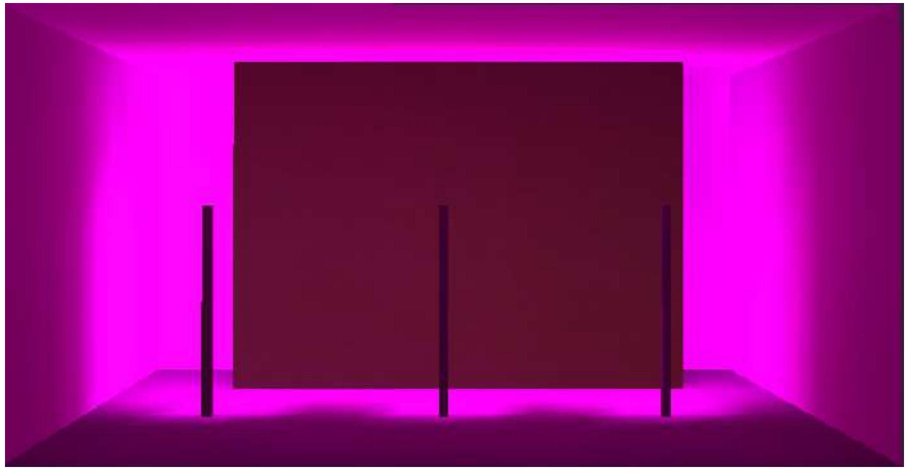
Full Blue at 100



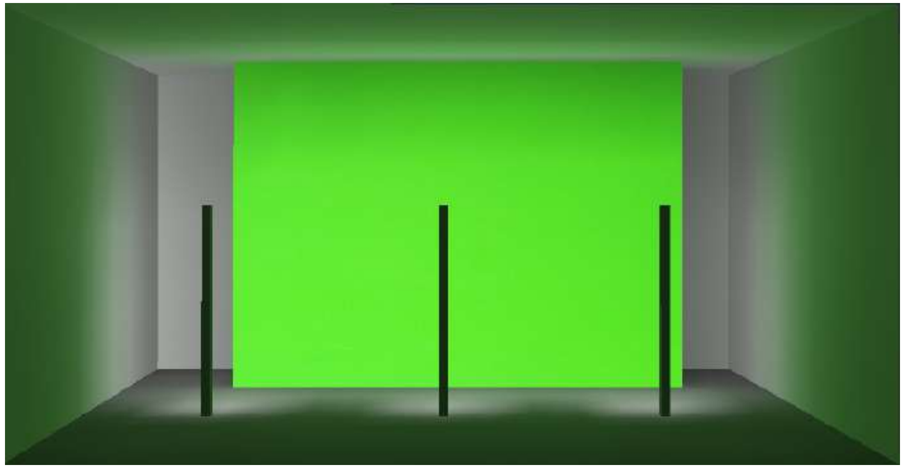
LEDucation
Trade Show and Conference

Not all reds are the same!

Rendering

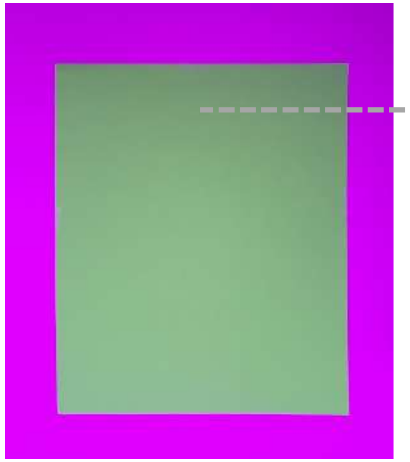


Color mixing: R:255, G:0, B:255



Color mixing: R:255, G:255, B:255

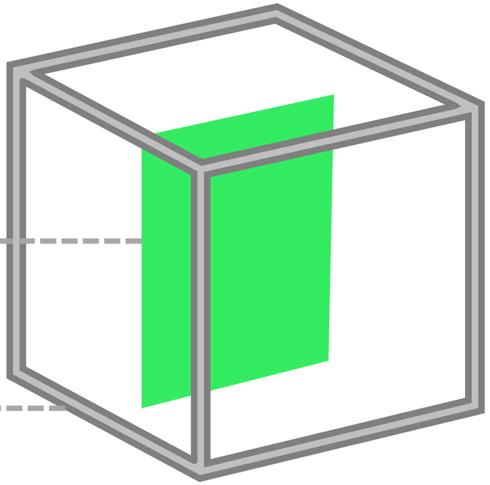
Photo



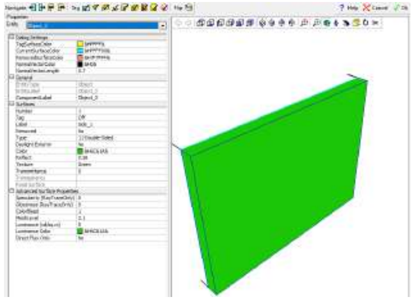
Magenta: Red + Blue at 100

White Light

Green Object



White Room

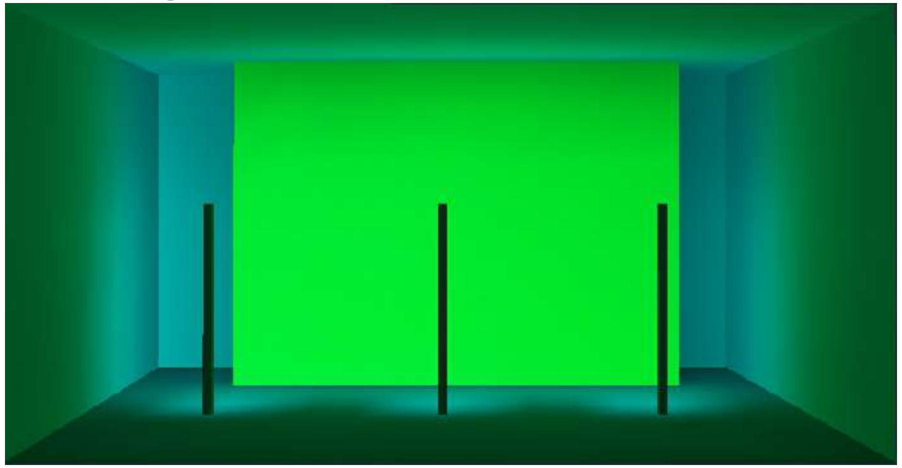


CONTINUING EDUCATION AIA

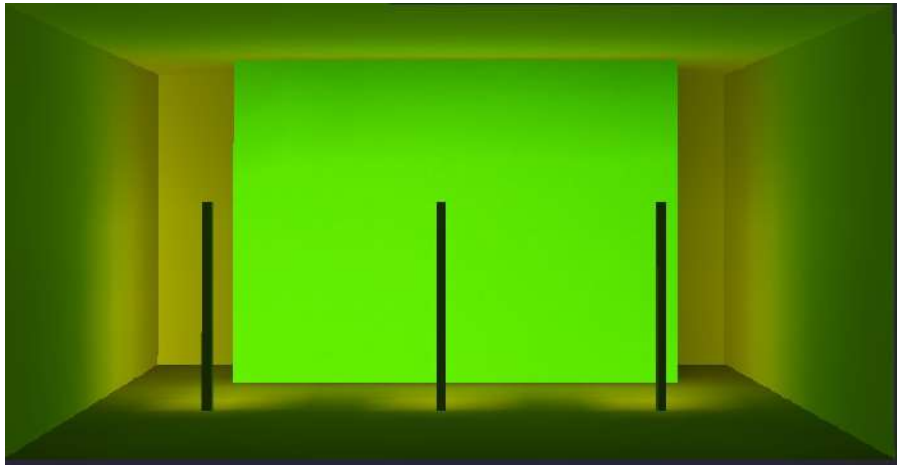
leducation.org

Not all reds are the same!

Rendering

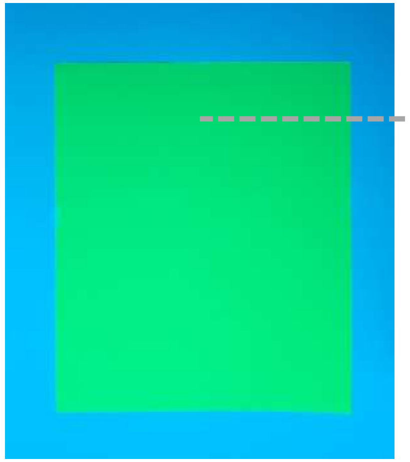


Color mixing: R:0, G:255, B:255

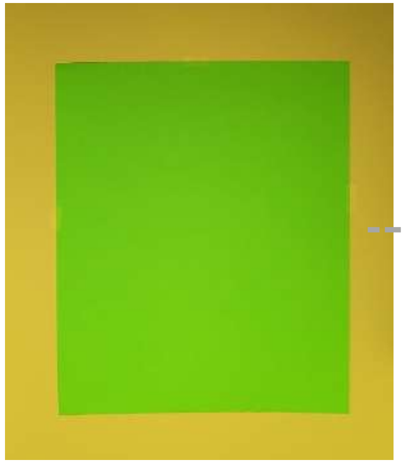


Color mixing: R:255, G:255, B:0

Photo

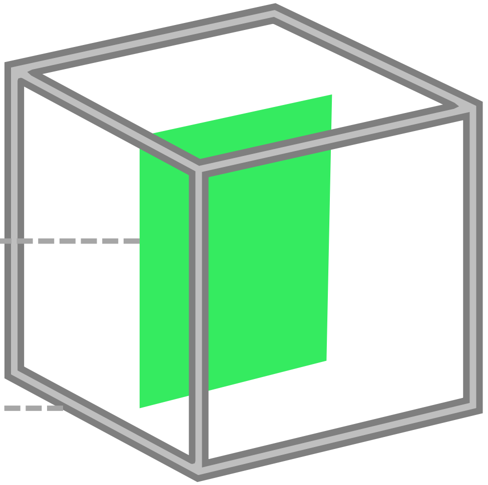


Cyan: Green + Blue at 100



Yellow: Green + Red at 100

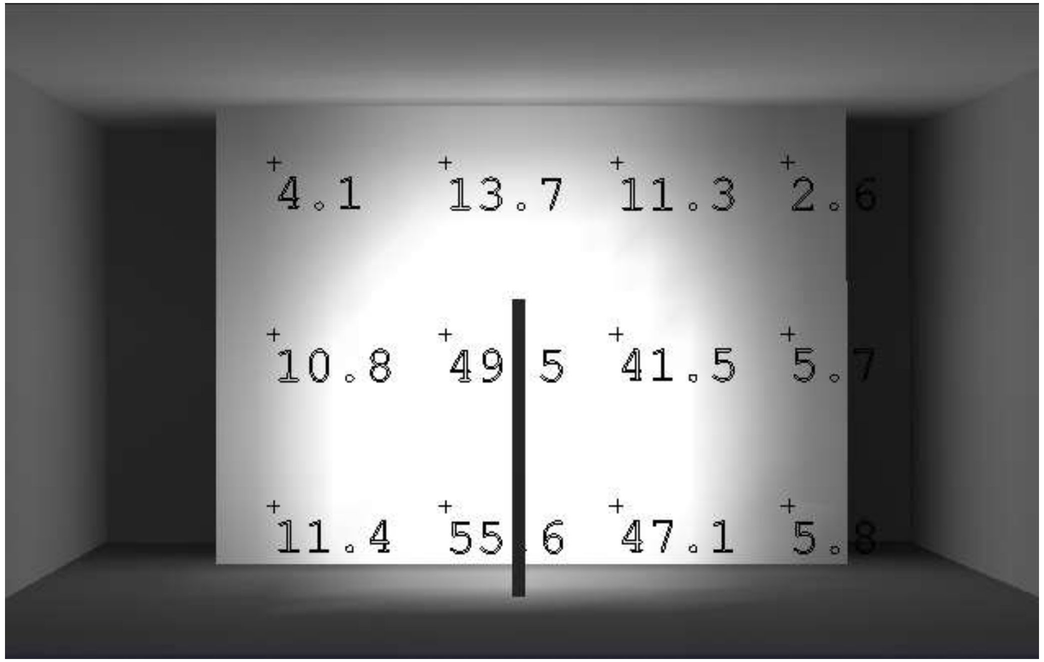
Green Object



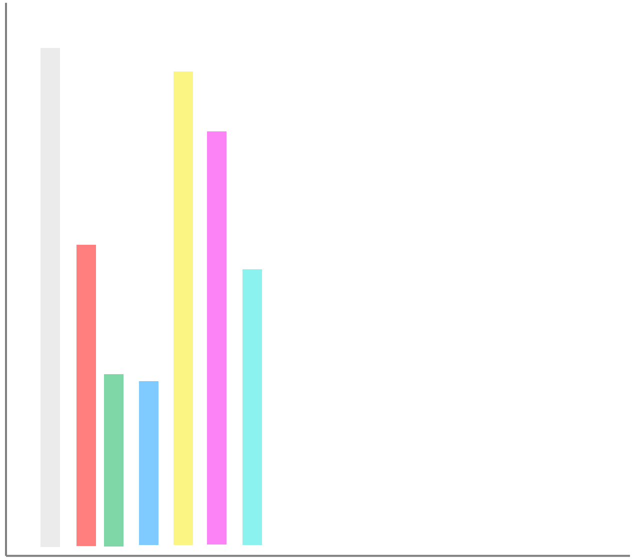
White Room

Not all reds are the same!

- Light Emission Range for RGB Lights

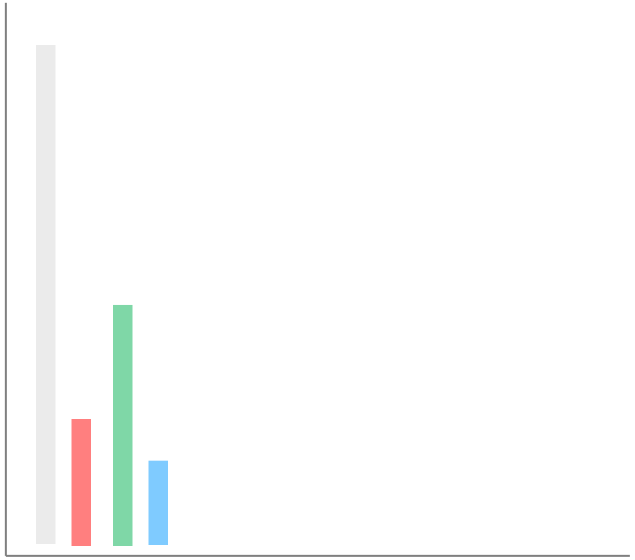


Mockup Test



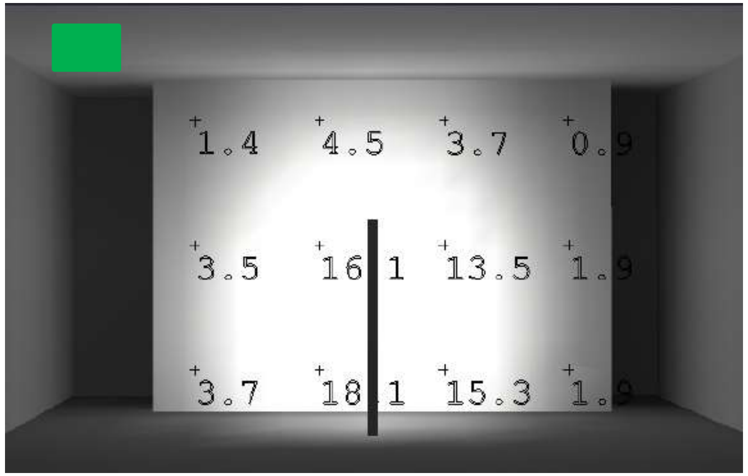
Illuminance % compared to white

Photometric Study

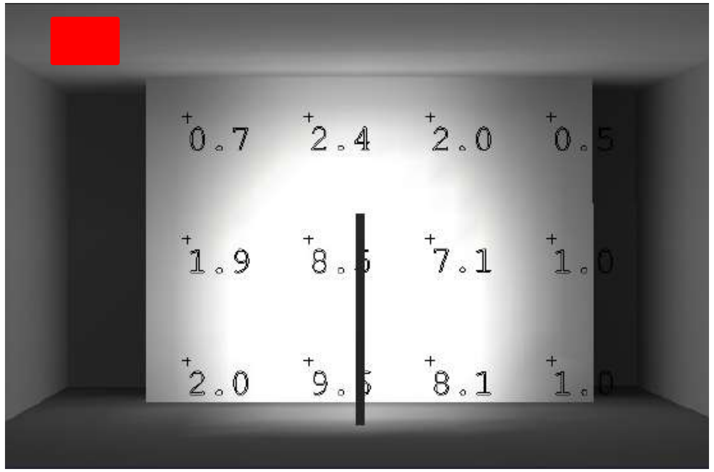


Illuminance % compared to white

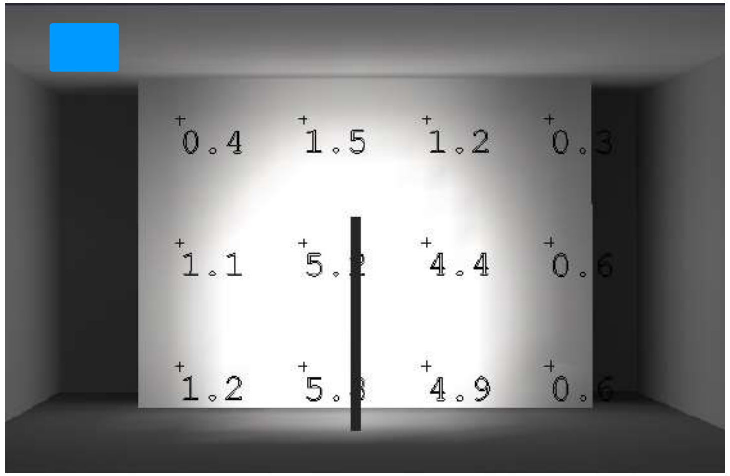
Not all reds are the same!



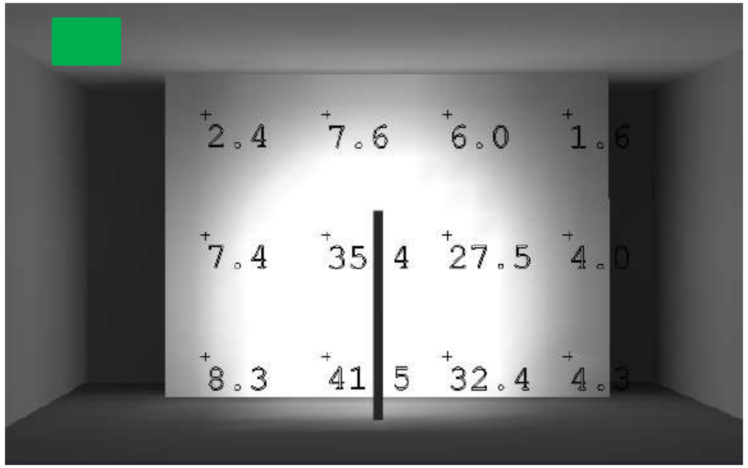
LLF adjusted for Green – 34%



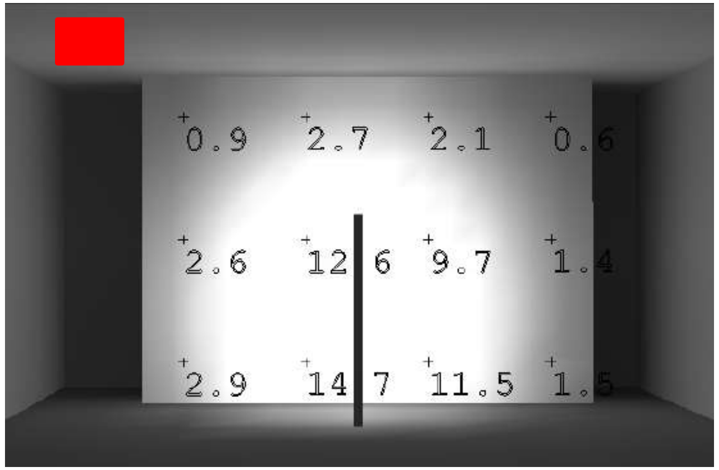
LLF adjusted for Red – 18%



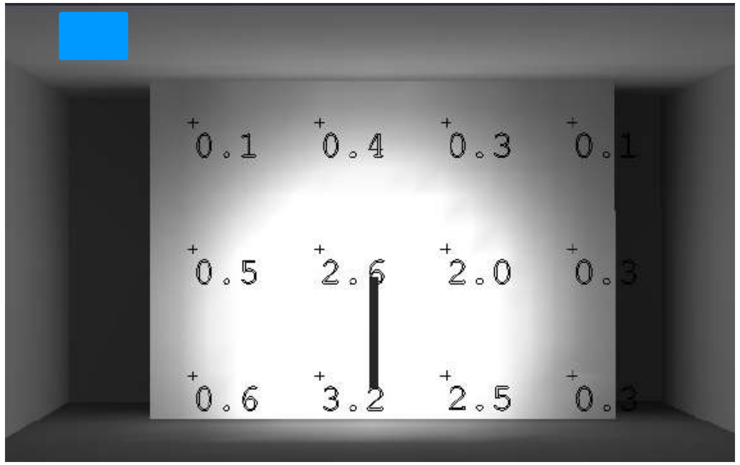
LLF adjusted for Blue – 11%



Green IES File, LLF : 1



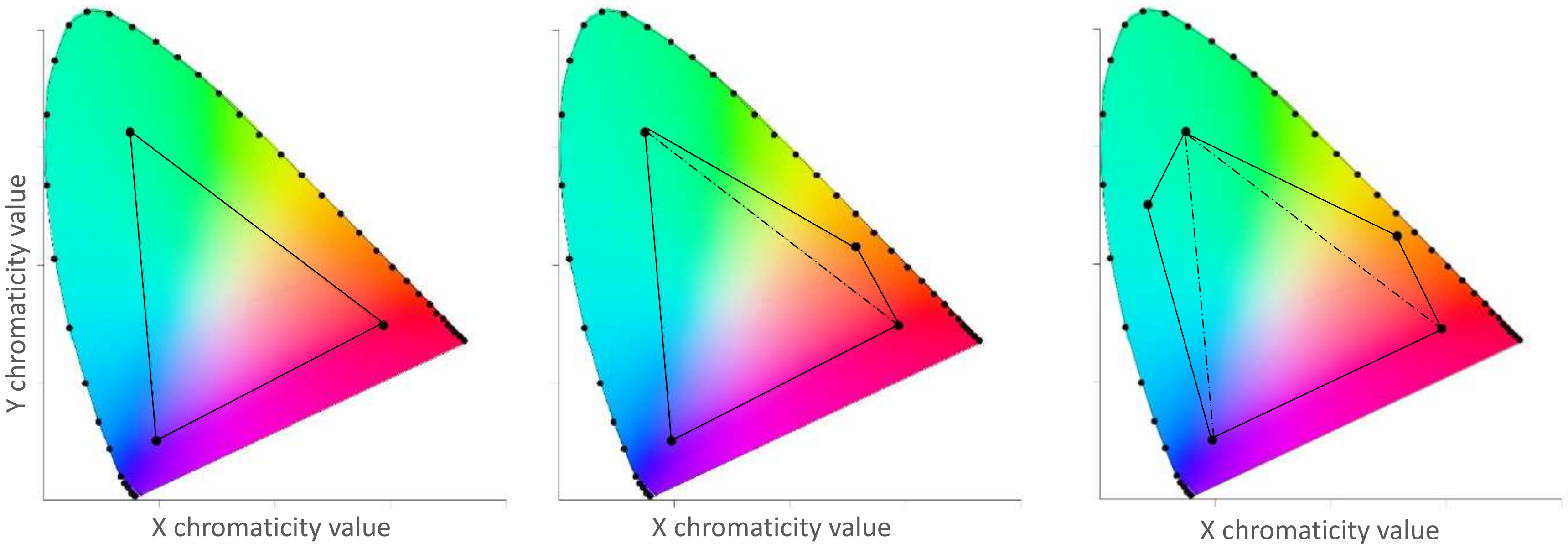
Red IES File, LLF : 1



Blue IES File, LLF : 1

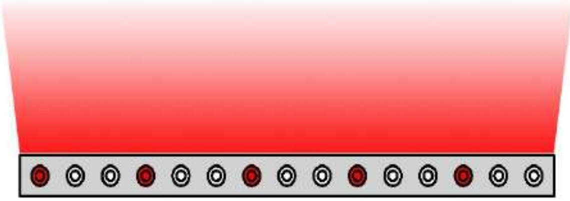
Not all reds are the same!

- Manufacturers technologies
- Additive color mixing
  - RGB, RGBA, RGBW,….
  - Up to 7 color mixing, mainly in theatrical fixtures
  - **Not having the chromaticity values makes it difficult for specifiers to understand what color they can create with RGB fixture**

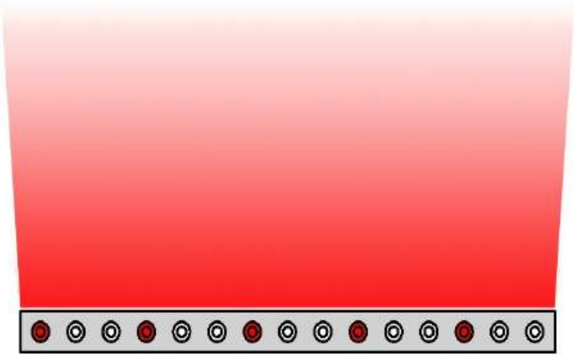


Not all reds are the same!

- Manufacturers technologies
- Power distribution
  - Traditionally, the power is distributed evenly between channels
  - Few manufacturers develop a technology that a single channel can receive even full power
  - **Not having the lumen output for each color or IES file makes it difficult for specifiers to compare fixtures**



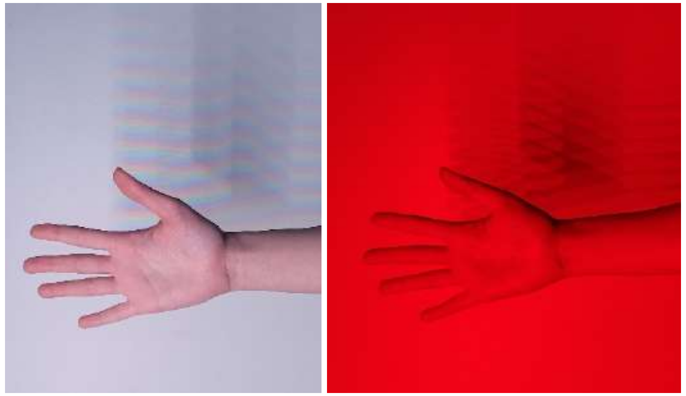
Traditional distribution: Each channel receives 33% of power (or 25% in RGBW, RGBA)

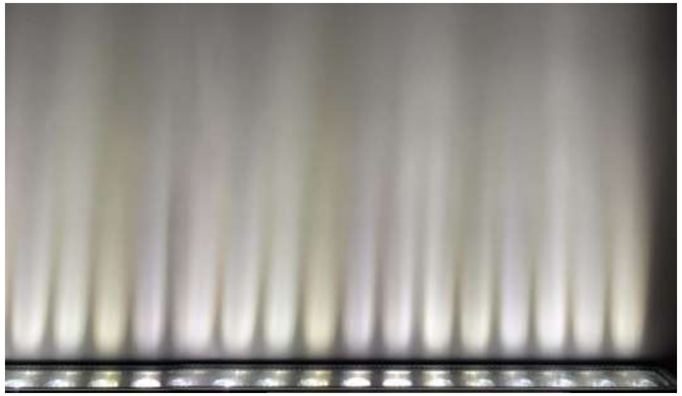


Advance technology: Each channel can receive full power

Not all reds are the same!

- Manufacturers technologies
- Discrete LED vs. Quad chip
  - The luminous efficacy and optical control is higher in discrete LED fixture.
  - Mixing distance in quad chip LED is less compared to discrete LED.
    (how far in front of a fixture it takes to separate colored LEDs to mix and form a single color within the beam of light produced by the fixture)



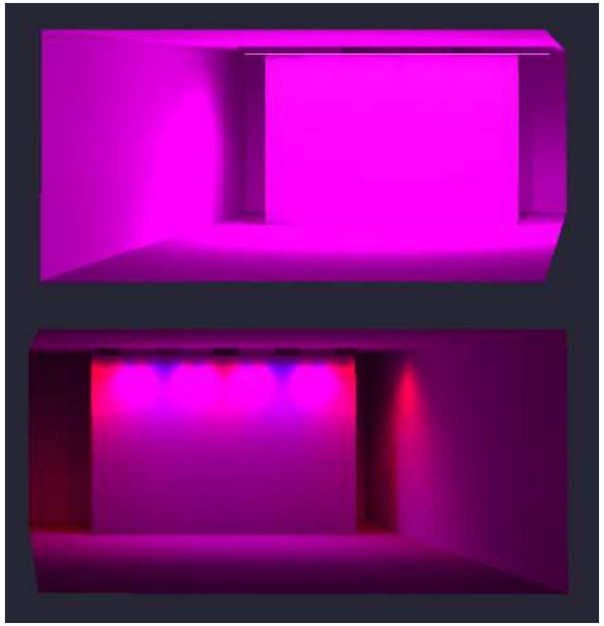


Not all reds are the same!

- Color Mixing

Color changing LEDs with separate emitters and various lenses might look different when mixing colors.

The only way to test the fixture is mock-up.



Quad-chip Multi-chip

Not all reds are the same!

- What specifiers can do?

  Information to include:

  Power distribution for each color.

  Light emission range of Red, Green and Blue.

  Peak and Dominant wavelength for each color.

  x,y,z coordinates on spectral locus or wavelength range.

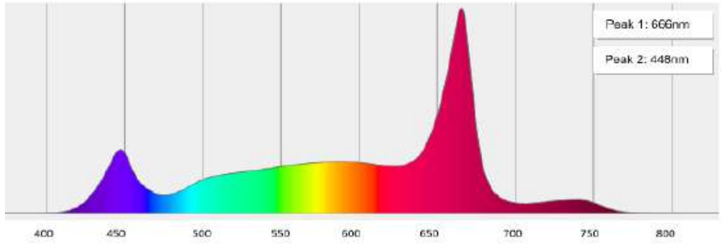
  Don’t trust computer generated renders alone

  Ask for sample: With all the information in many cases, mock-up is still the best way.

FULL	650 lumens	2600 lumens
RED	290 lumens	1160 lumens
GREEN	580 lumens	2320 lumens
BLUE	120 lumens	480 lumens

COLOR OR CCT	RED	GREEN	BLUE	WHITE	RGB40K
DISTRIBUTION	10°X10°	10°X10°	10°X10°	10°X10°	10°X10°
LUMENS	1350.7	3476.6	527.0	3501.9	2437.6
EFFICACY L/W	25.7	56.5	8.49	55.3	38.5

UV 360-399nm			0.007	0.00
Blue 400-499nm	18.9	13.40	18.9	12.68
Green 500-599nm	42.2	29.93	42.2	28.32
Red 600-699nm	79.7	56.52	79.7	53.49
Far Red 700-800nm			8.66	5.81



* This information might change depending on the timeline of the project, but it helps prevent unequal substitution.

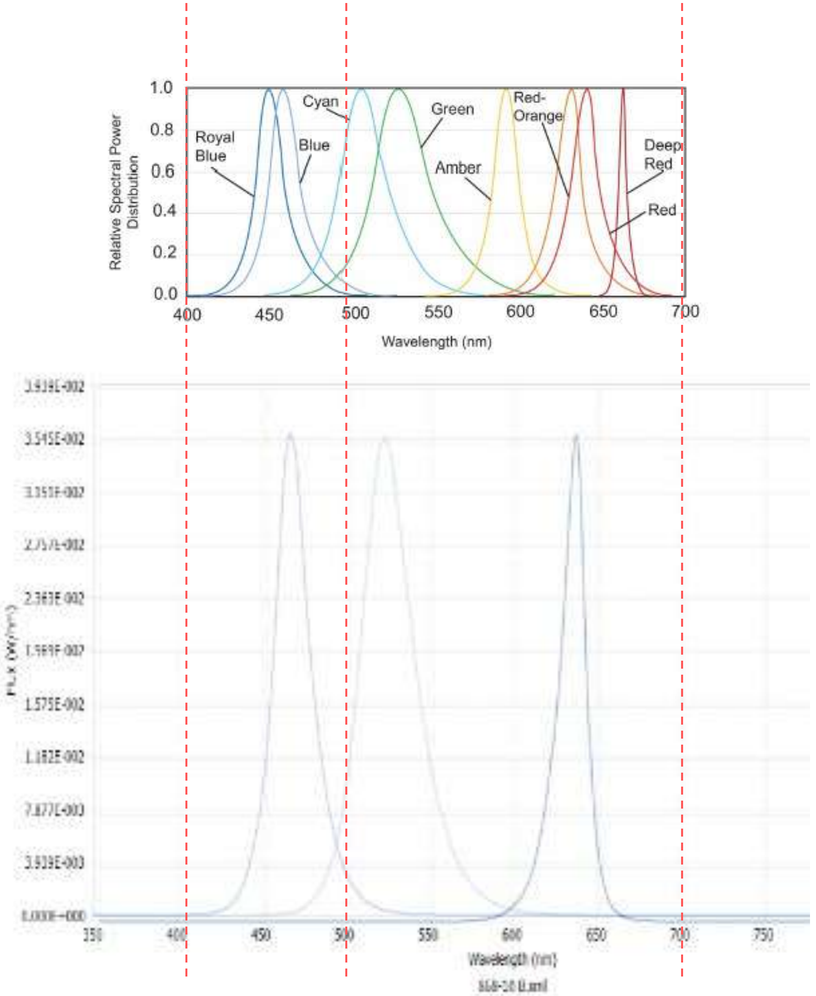
* This information might the available upon request from the manufacturer.

Not all reds are the same!

- What specifiers can do?

  Fixture comparison example

Sample		Total Wattage	Delivered Lumen	Red (Luminous Flux)	Green Luminous Flux)	Blue (Luminous Flux)
#1	RGBW - 4k	41W (48")	1480	52	118	38
#2	RGBW - 4k	74W (48")	2156	121 x / y = 0.1275 / 0.0747	234 x / y = 0.1853 / 0.7190	81.5 x / y = 0.6975 / 0.3019



- Conclusion

  Not all reds are the same!

  Manufacturers need to be more thorough and transparent with the information provided in their spec sheets

  The industry needs to define what typical information should be available to simplify fixture comparison

  (similar to the available standardized information provided for white light)

LEDucation
Trade Show and Conference

This concludes The American Institute of Architects Continuing Education Systems Course