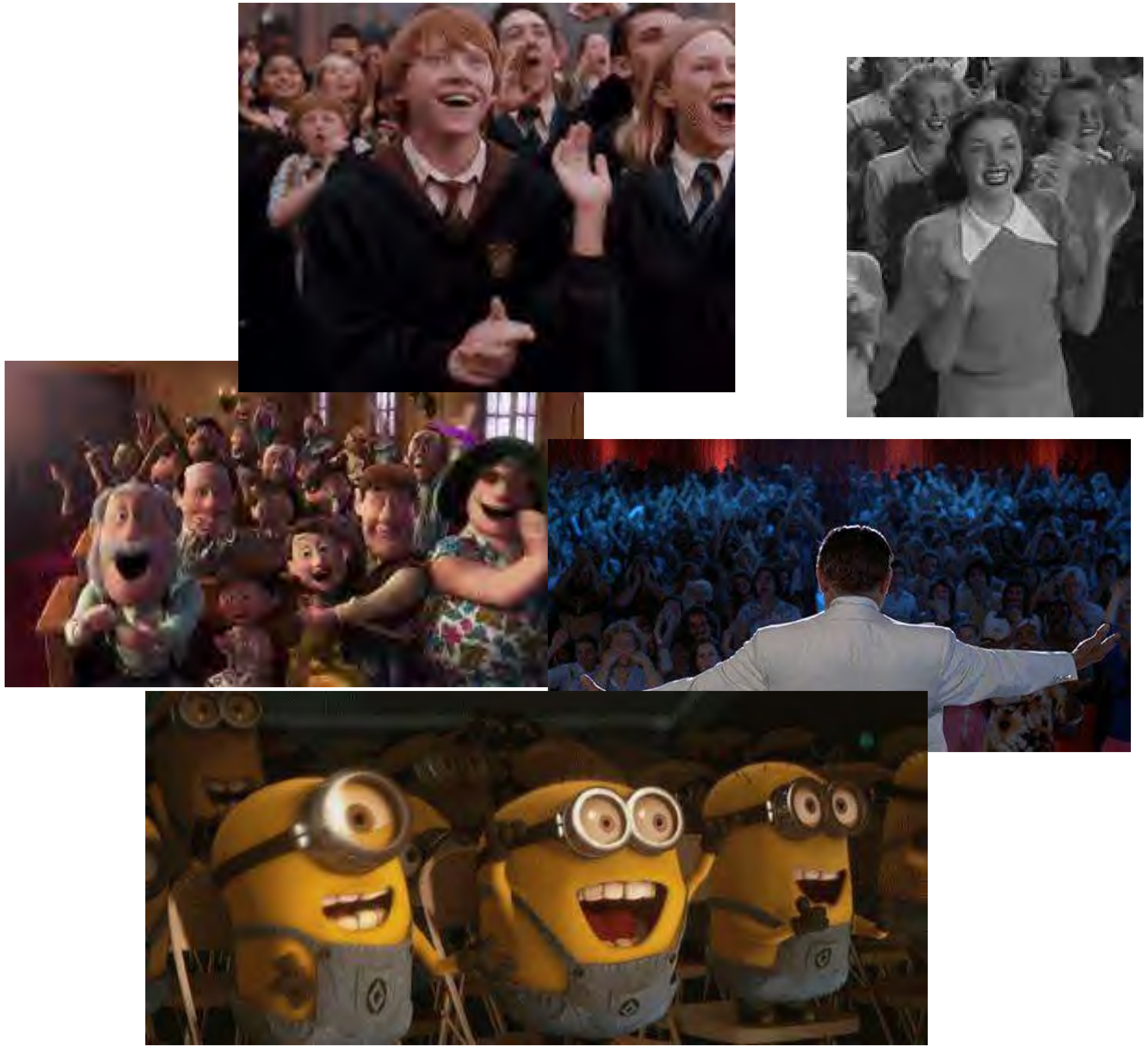
Battle of the Sources

LED
vs.
Fluorescent

Tale of the Tape

The Challenger - LED

- Around since 1960s
- General illumination since mid 1990s
- Two methods to deliver with light;
  - RGB Mix
  - LED “Pump” with Phosphors
- Multiple CCTs
- Mid-High CRI
- Excellent Efficacy

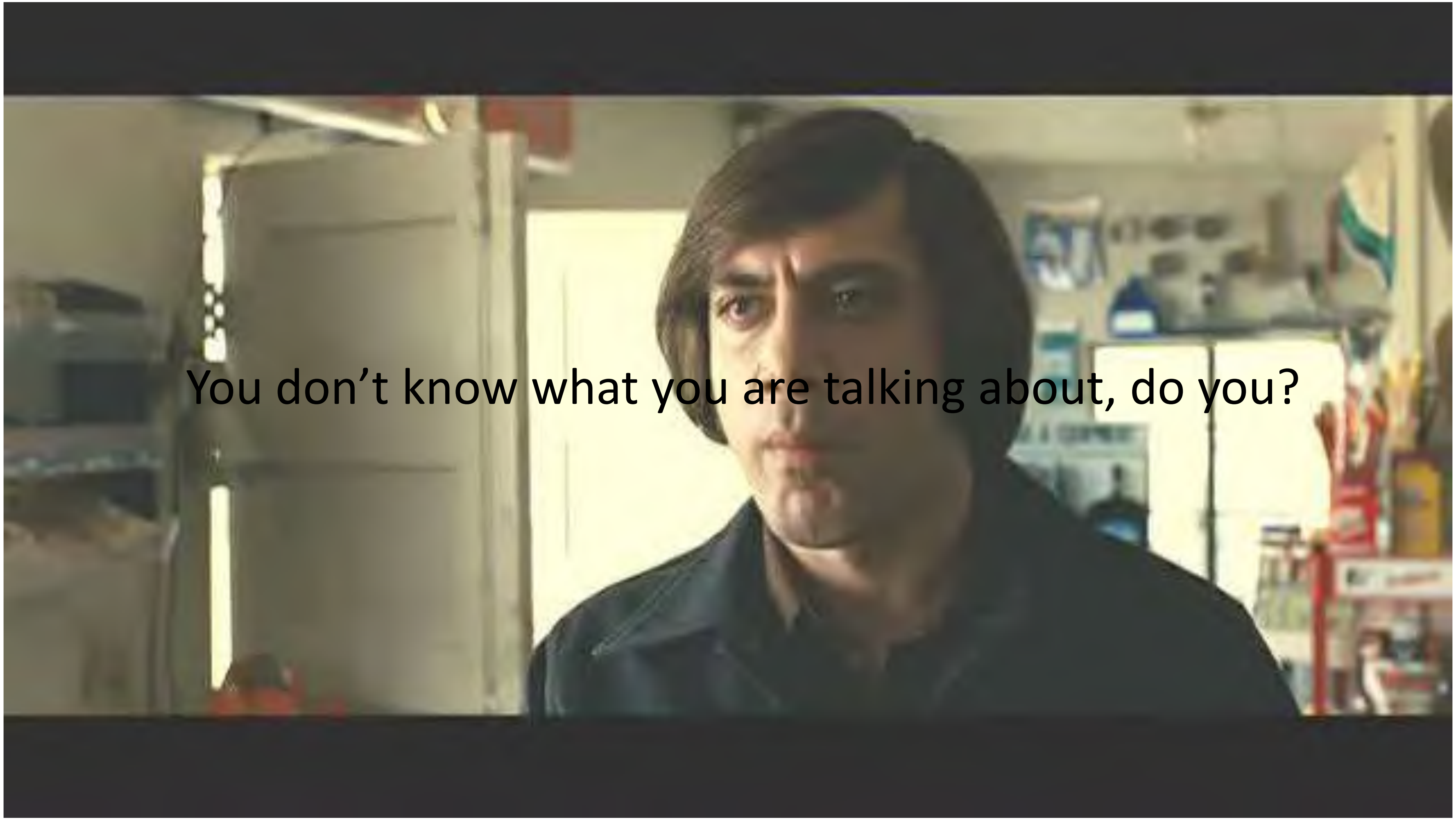


The Incumbent - Fluorescent

- Introduced 1938
- Uses UV energy to excite phosphors to deliver light
- Multiple CCTs
- Mid-High CRI
- Excellent Efficacy

“I’m working on a job and it has to be LED.”

“I’m working on a job and it has to be LED.”



8 Rounds

- Light Generation
- Correlated Colour Temperature Options
- Colour Consistency
- Colour Rendering Index
- Life
- Temperature Issues
- Environmental Impact
- Energy Efficiency

Round 1

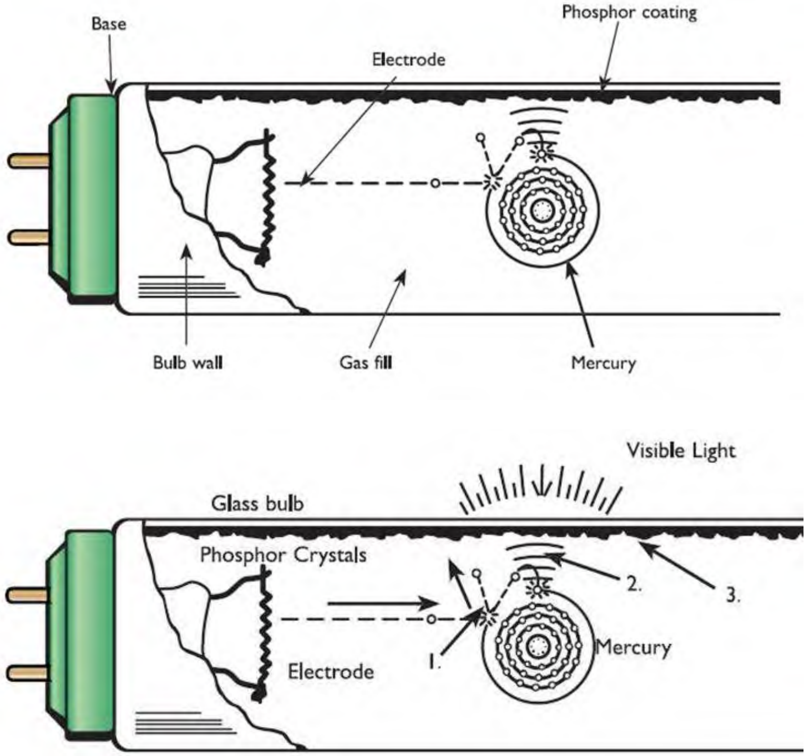
Light Generation

Light Generation - Fluorescent

Operation

When started, the electrodes at each end of the lamp emit electrons.

1. The electrons travel through the tube in the form of an electrical current. The electrons collide with the mercury atoms contained in the glass bulb.
2. After the collision, the mercury atom releases invisible ultraviolet energy.
3. The ultraviolet energy strikes the phosphor coating and the phosphor converts the ultraviolet to visible light.



Light Generation - Fluorescent

Rare Earth Phosphors

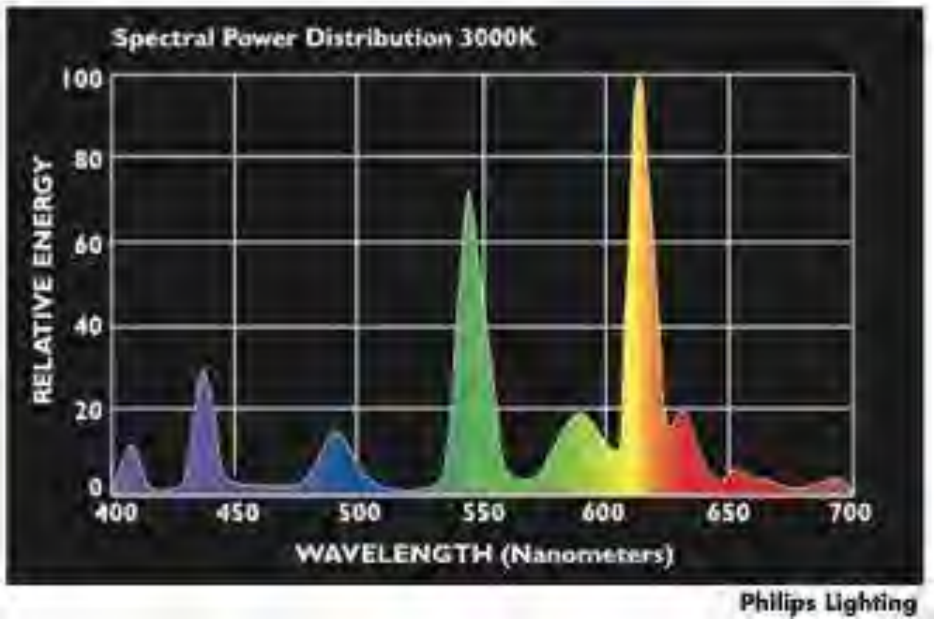
- Rare Earth Phosphor elements such as Cerium, Europium, Terbium, Yttrium are used in fluorescent lamps such as; T8 and T5 lamps, high CRI T12 lamps, and all compact fluorescent lamps
- Rare Earth Phosphors make up 85% of the phosphors used in fluorescent lamps

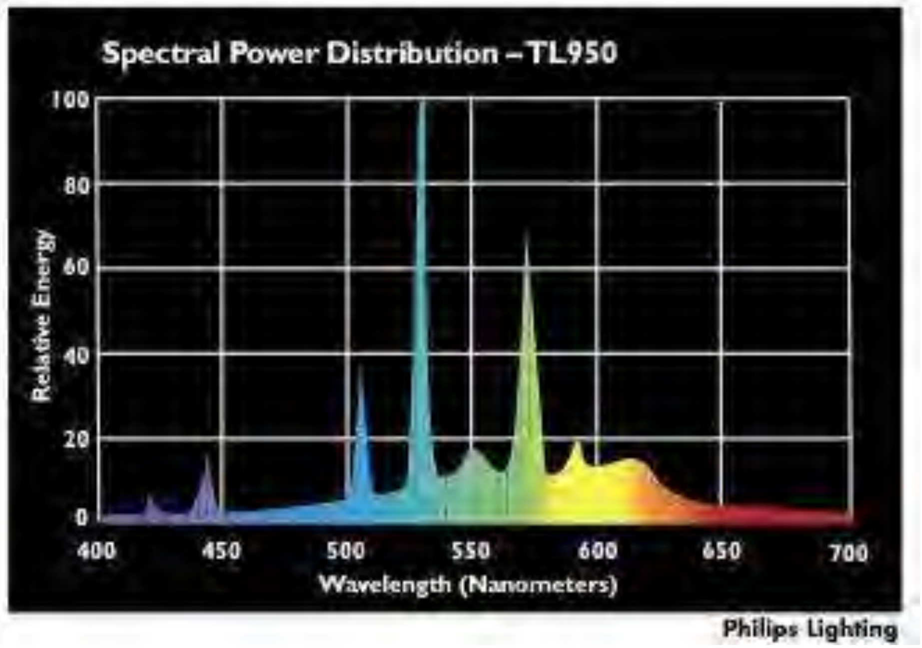
Light Generation - Fluorescent

Under Visible Light

Under Ultraviolet Light

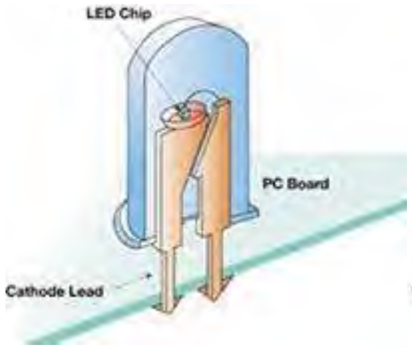
Light Generation - Fluorescent

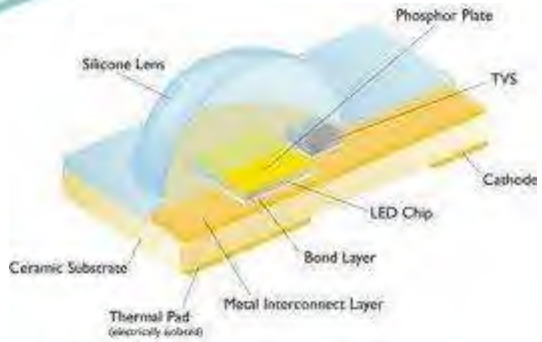


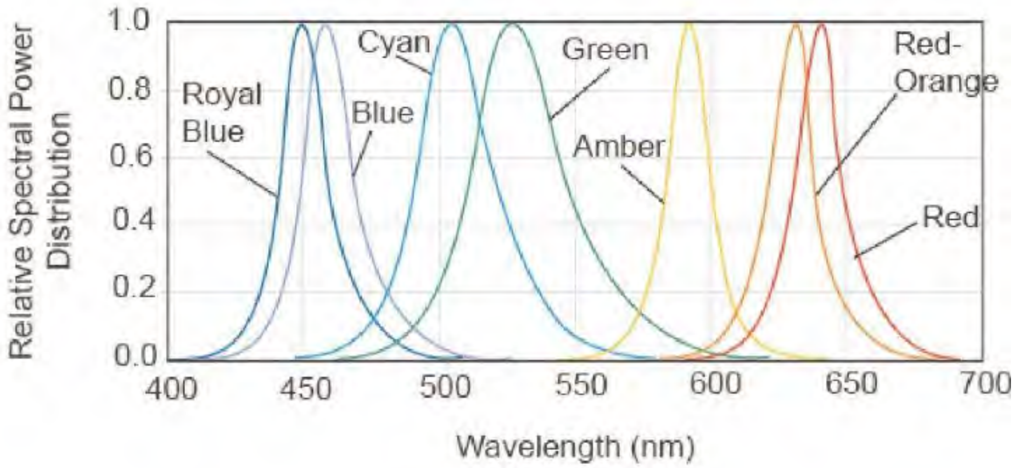


Light Generation - LED

- **LED = Light Emitting Diode**
- A semiconductor device that converts electricity (electrons) into light (photons)
- The light from an LED has an inherently narrow spectrum

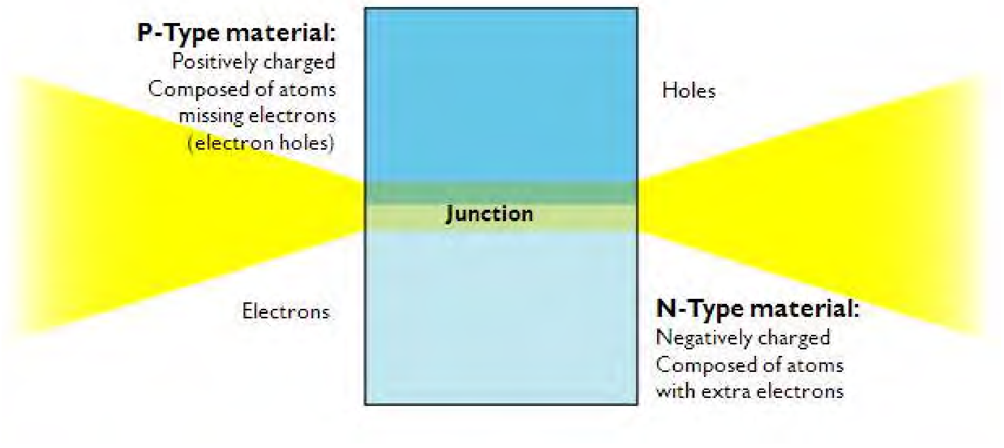




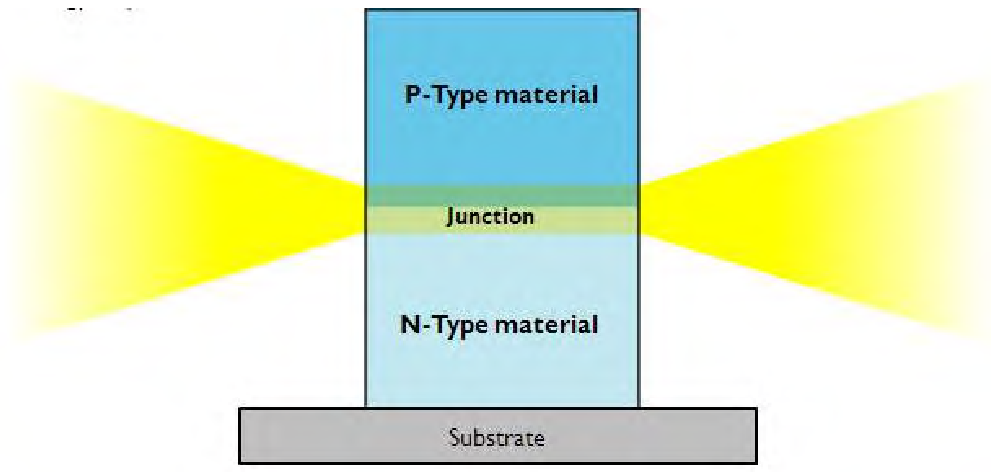


Light Generation - LED

- LEDs like other diodes, consist of a single **P-N** semiconductor junction.

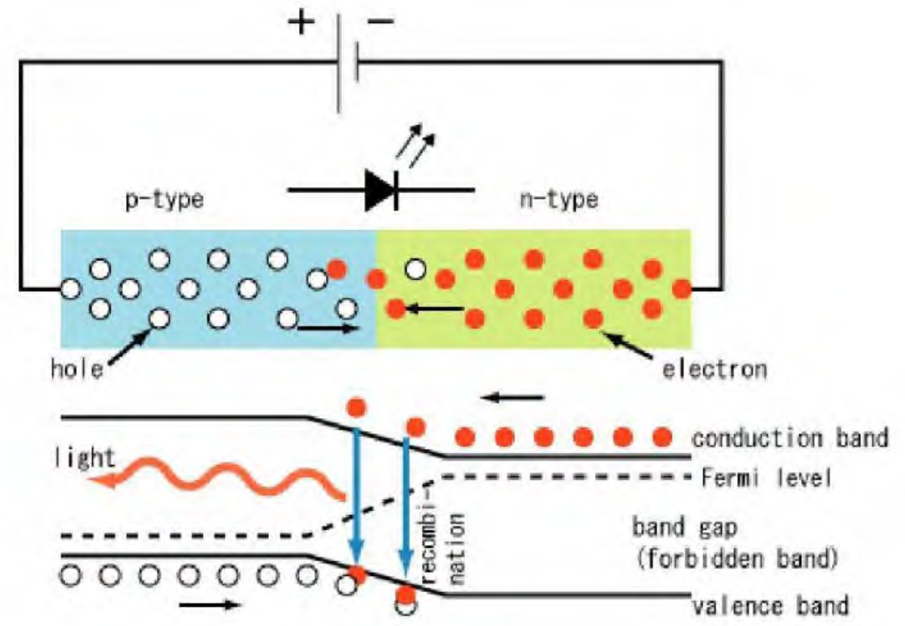


- The **P-N** materials are then placed on a substrate.



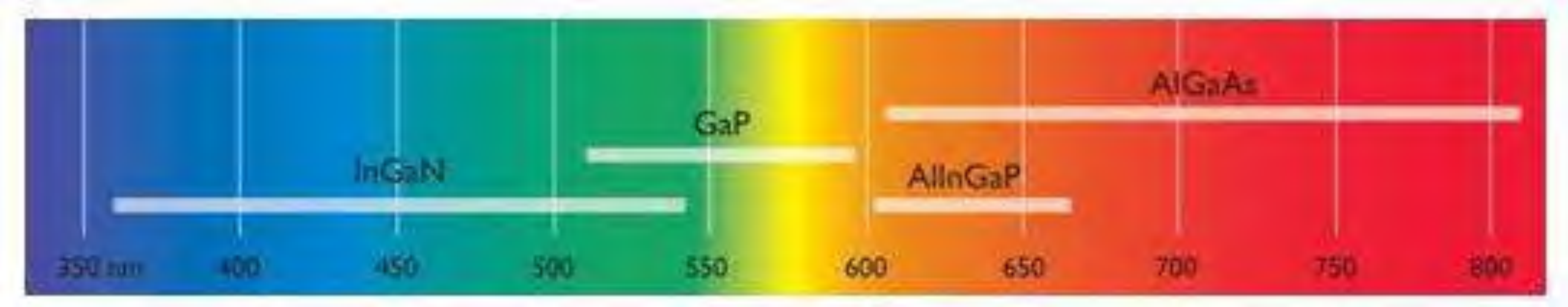
Light Generation - LED

- A negative charge is applied to the n-type side causing current to flow towards the p-type side.
- Extra electrons in the n-type fall into holes in the p-type releasing energy in the form of photons

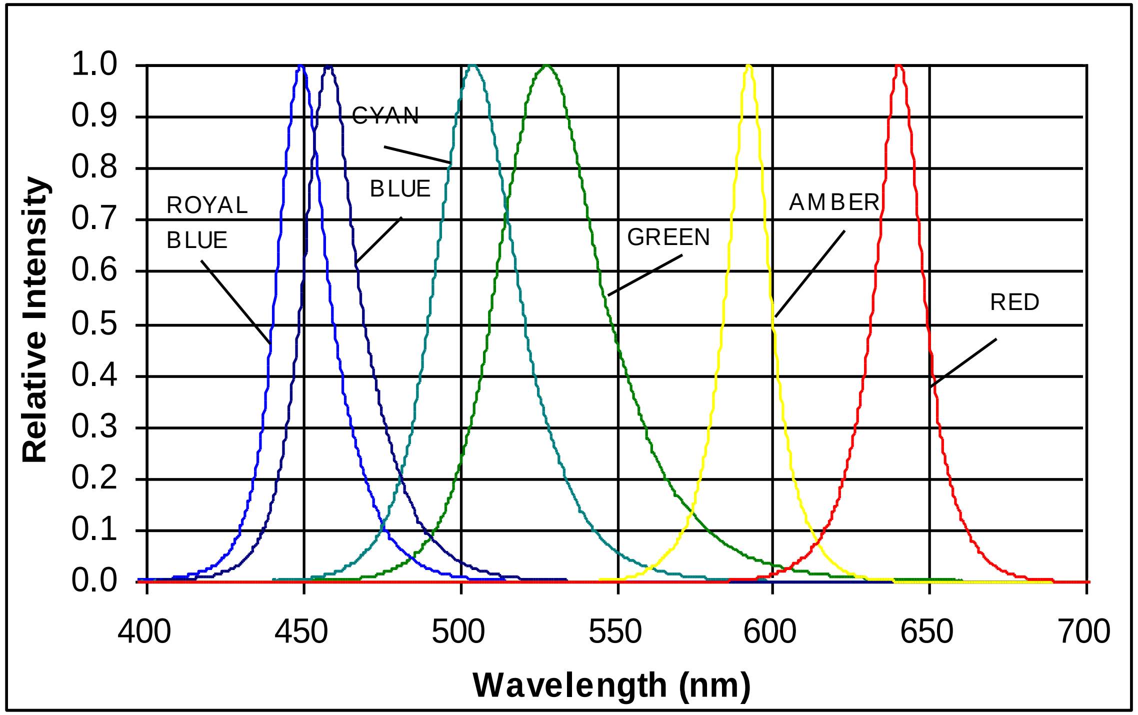


Light Generation - LED

- **Two main chemistries are currently used**
- **InGaN** (Indium Gallium Nitride)= **Green and Blue**
- **AlGaInP** (Aluminum Gallium Indium Phosphide and Aluminum Indium Gallium Nitride)= **Red and Amber**

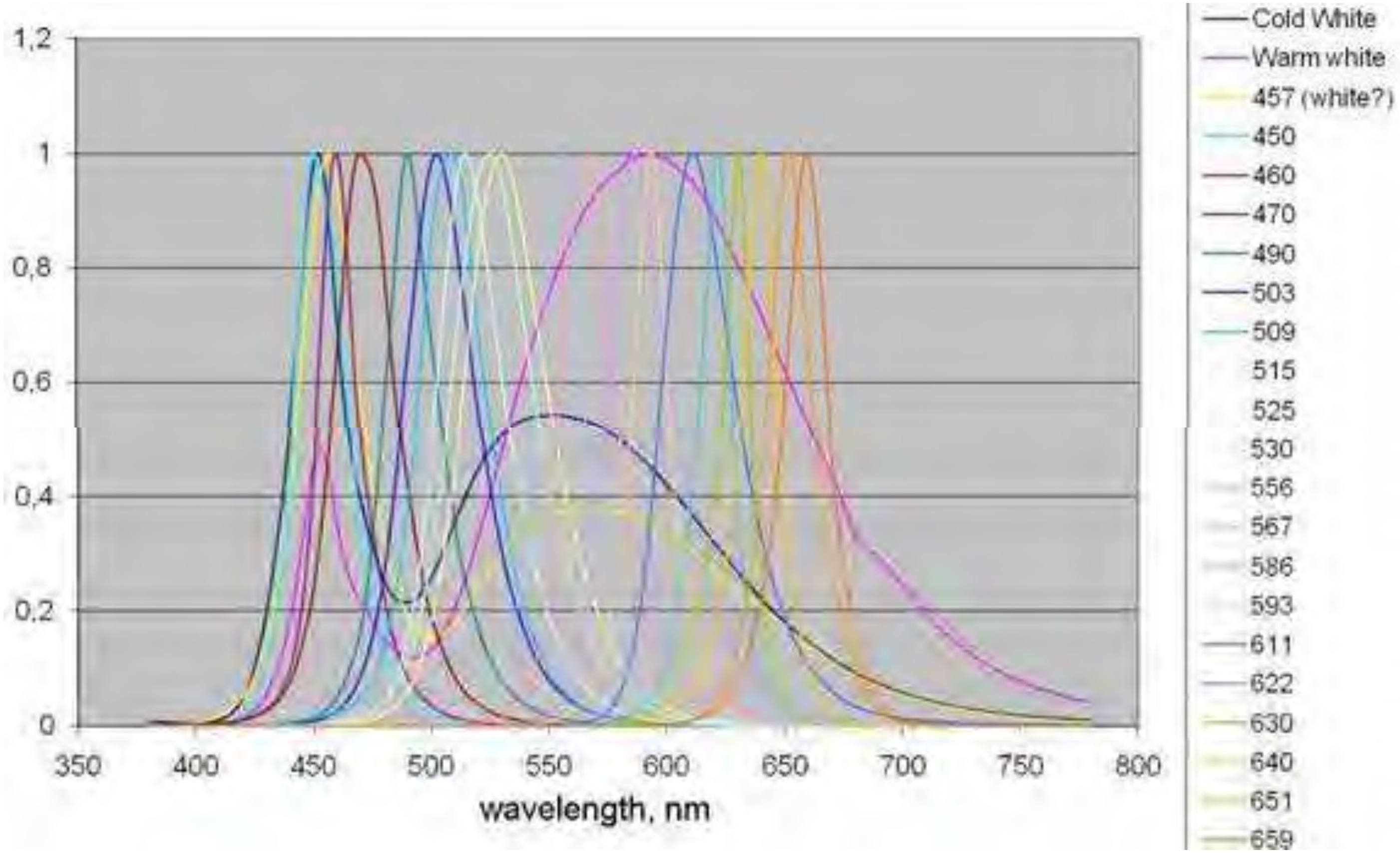


Light Generation - LED

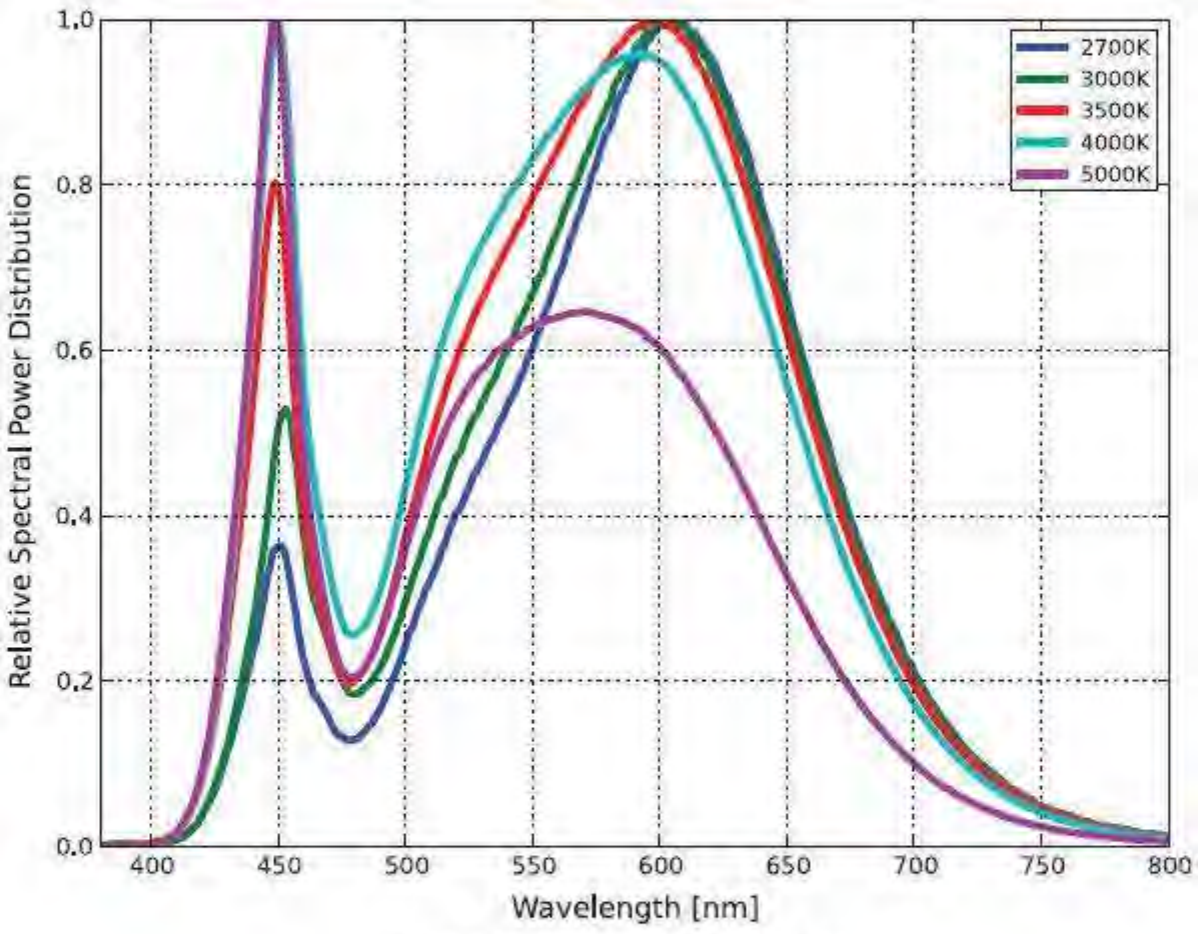


Colour	Wavelength
Royal Blue	440 (peak)
Blue	470
Cyan	505
Green	530
Amber	590
Red-Or	617
Red	625

Light Generation - LED



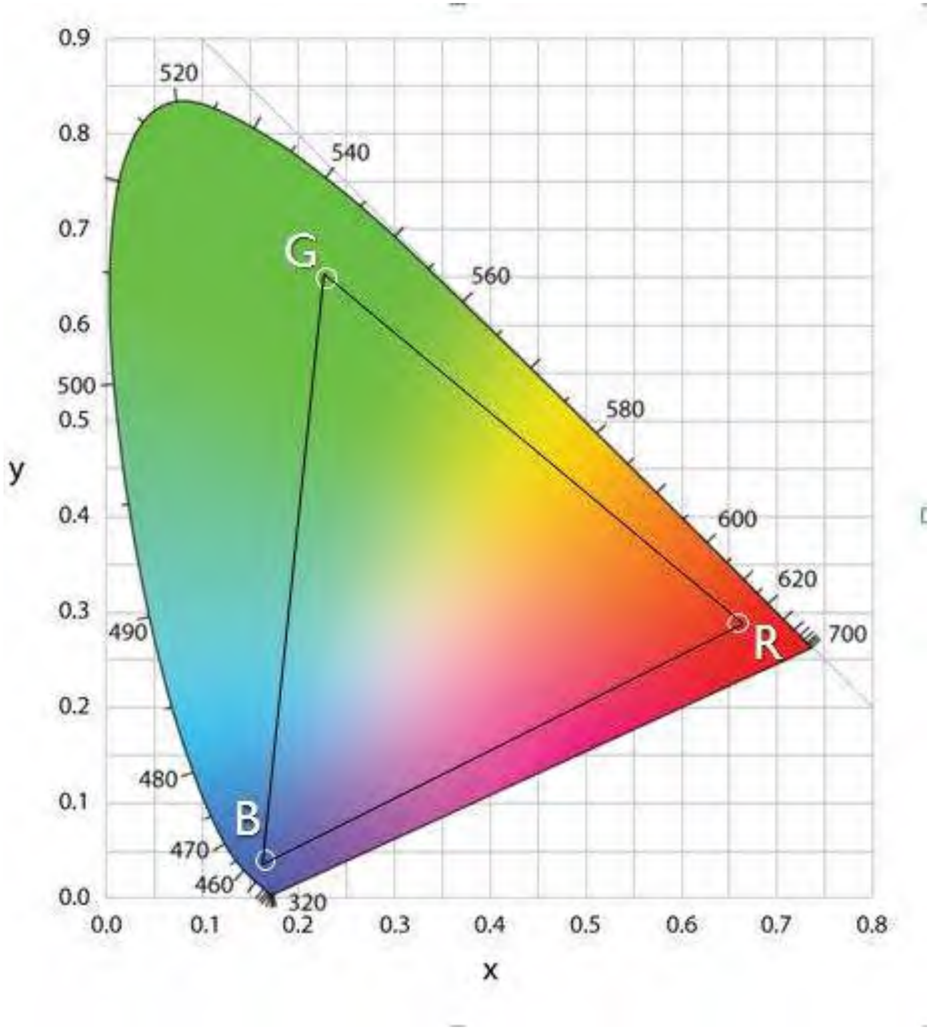
Light Generation - LED



Color Spectrum of LXHc-FWxx.

Philips LumiLeds

Light Generation - LED



LED – 10

Fluorescent – 9

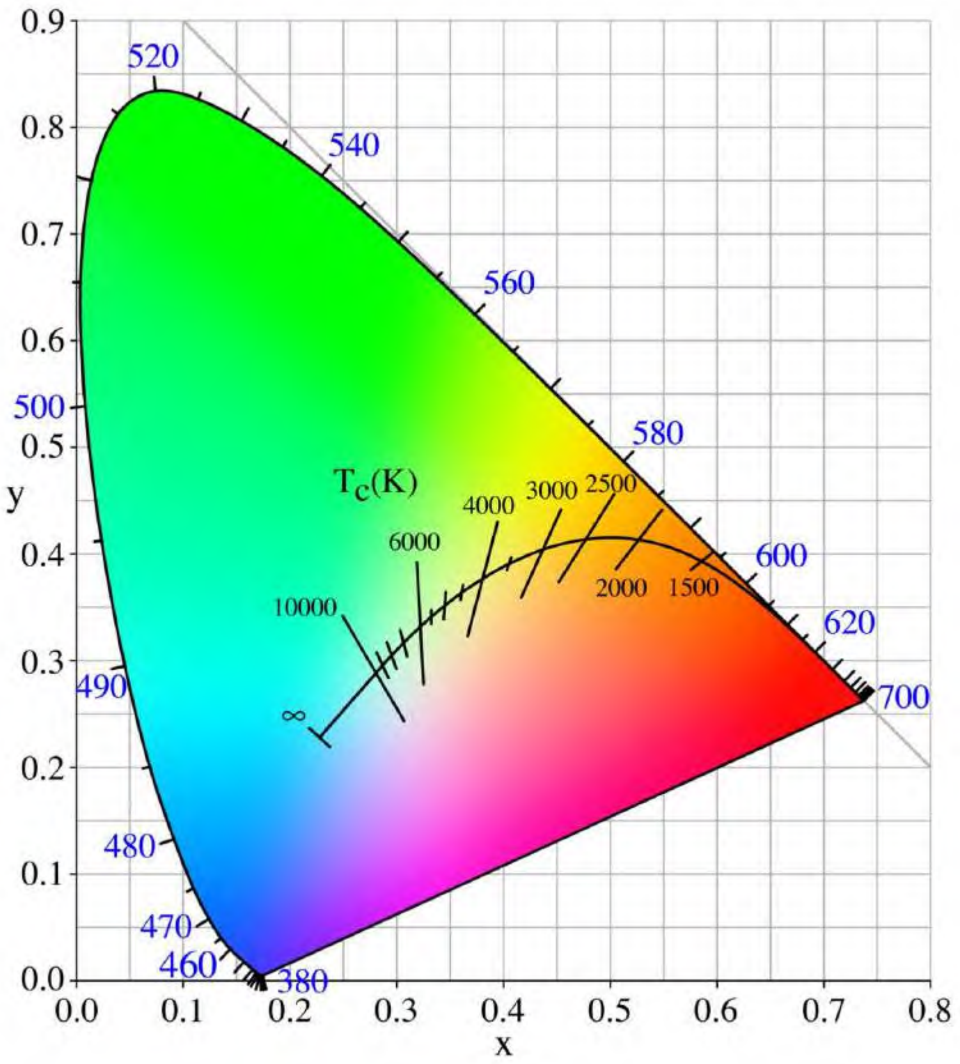
Round 1

Light Generation

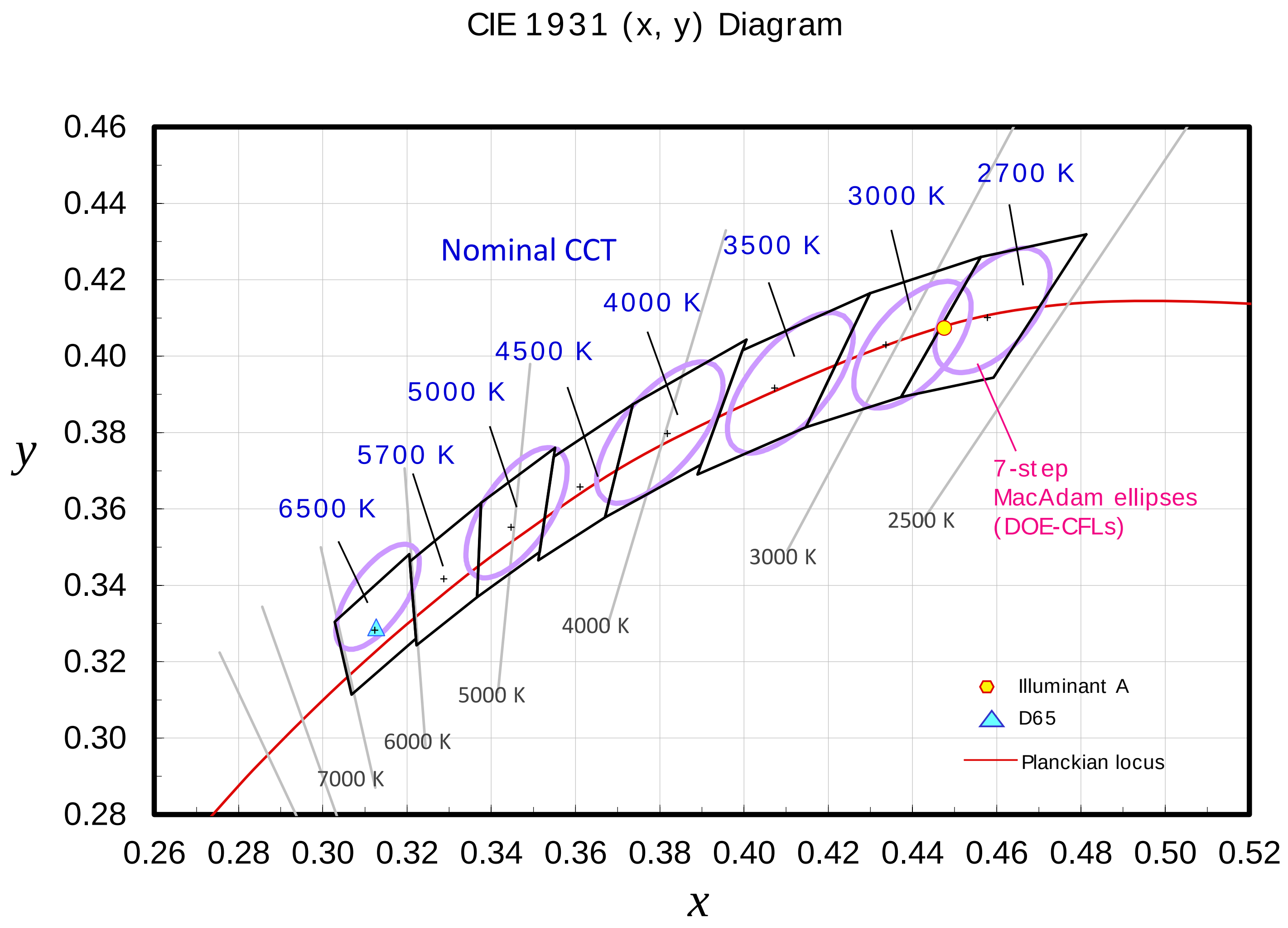
Round 2

Correlated Colour Temperature Options

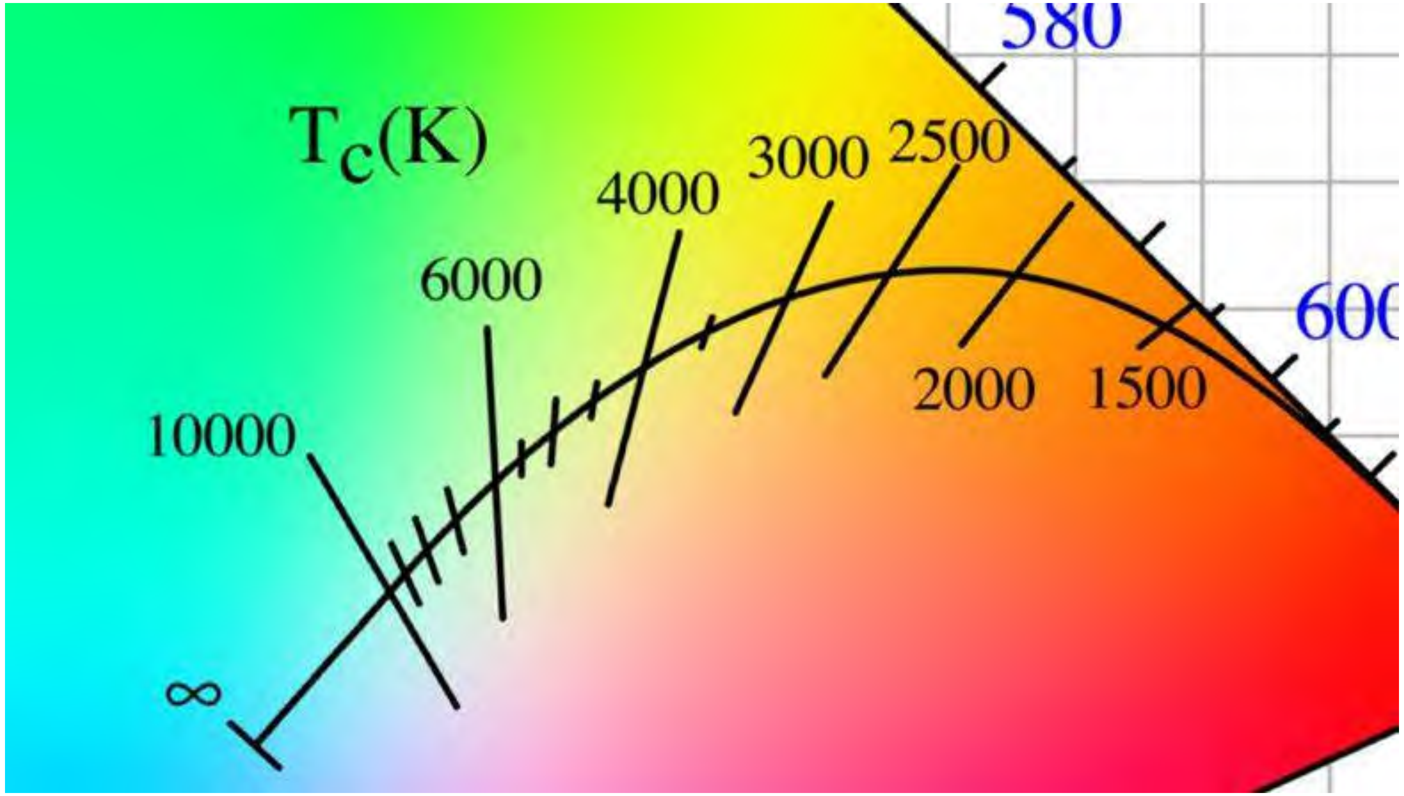
Correlated Colour Temperature



Correlated Colour Temperature



Correlated Colour Temperature



LED – 10

Fluorescent – 9

Round 2

Correlated Colour Temperature Options

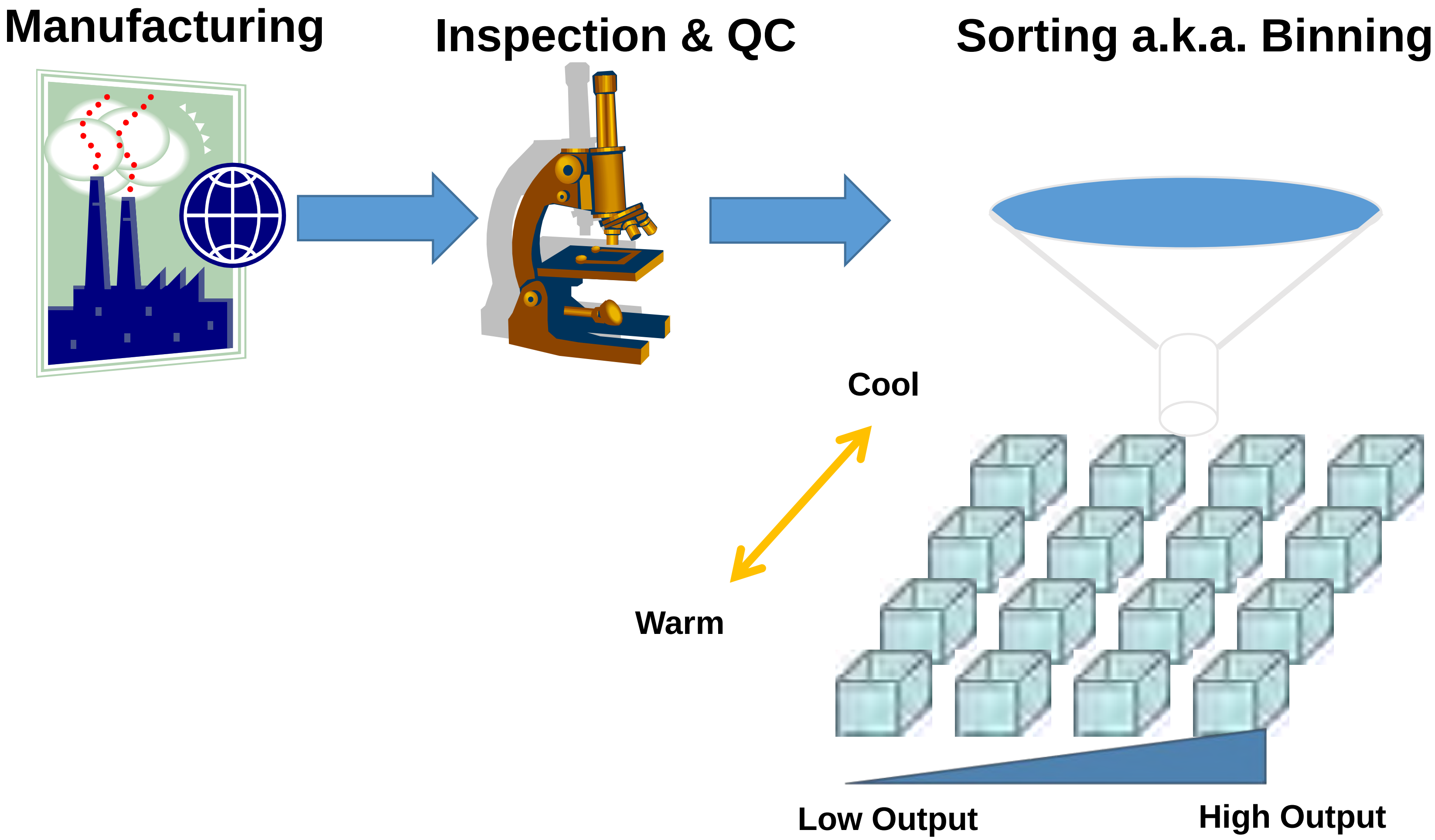
Round 3

Colour Consistency

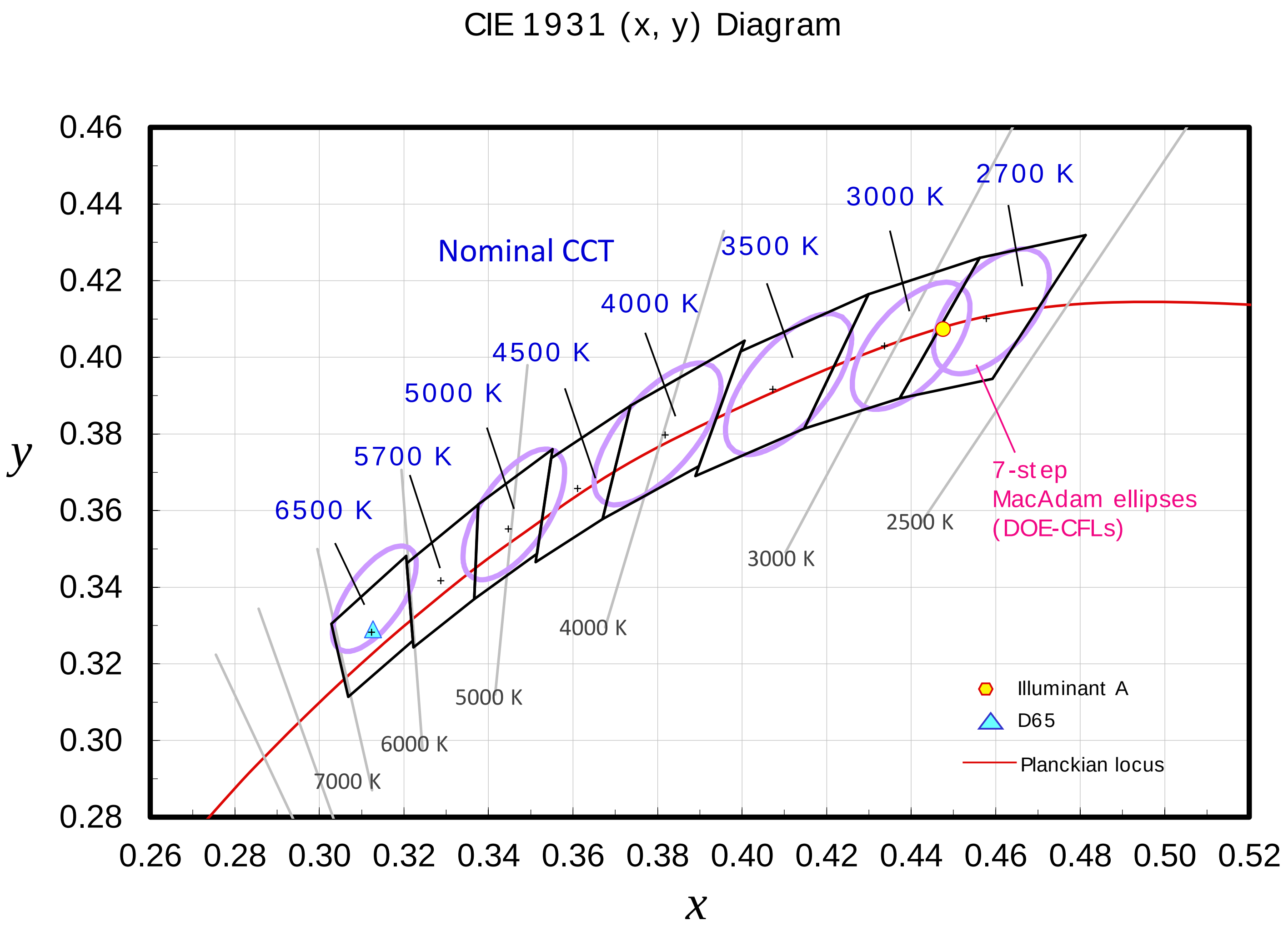
Colour Consistency

Colour Consistency

Binning Example – Ultra Simplified!



Colour Consistency

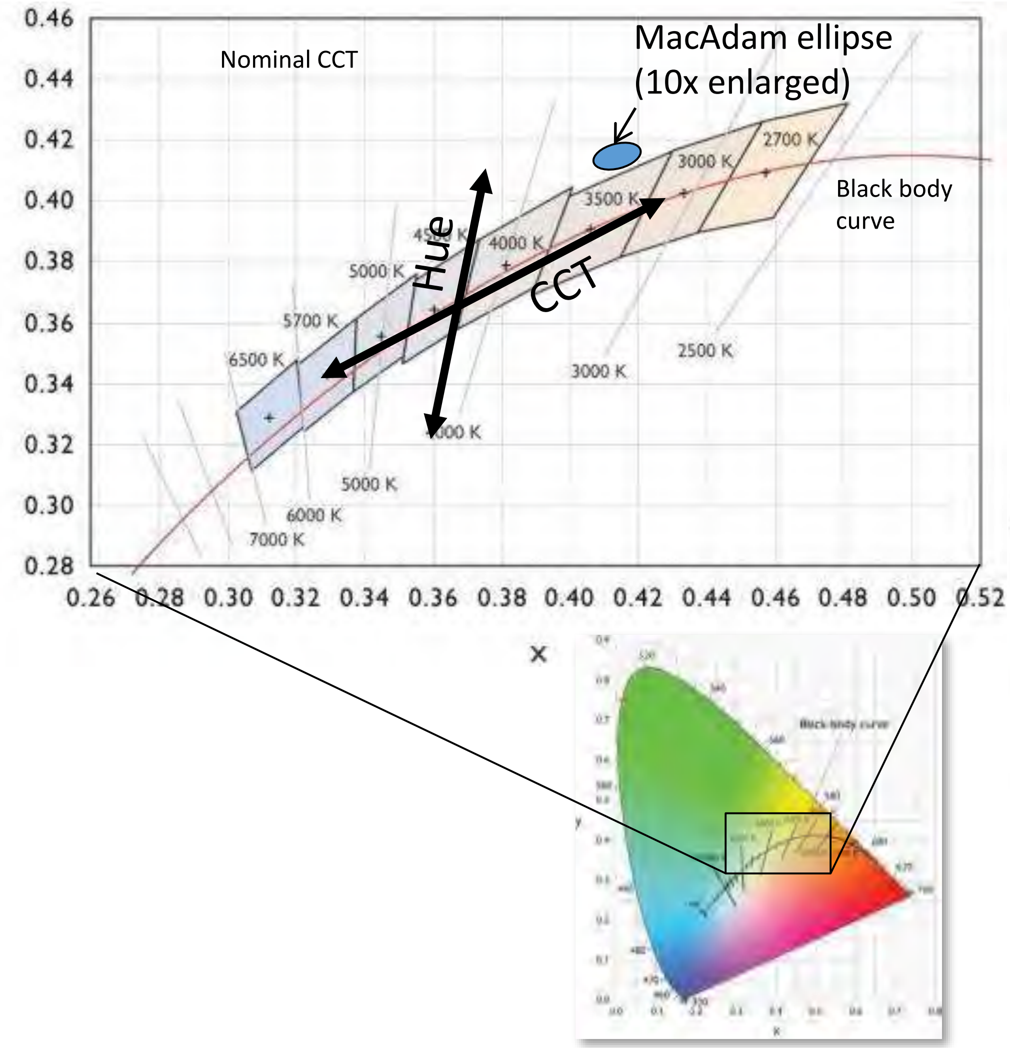


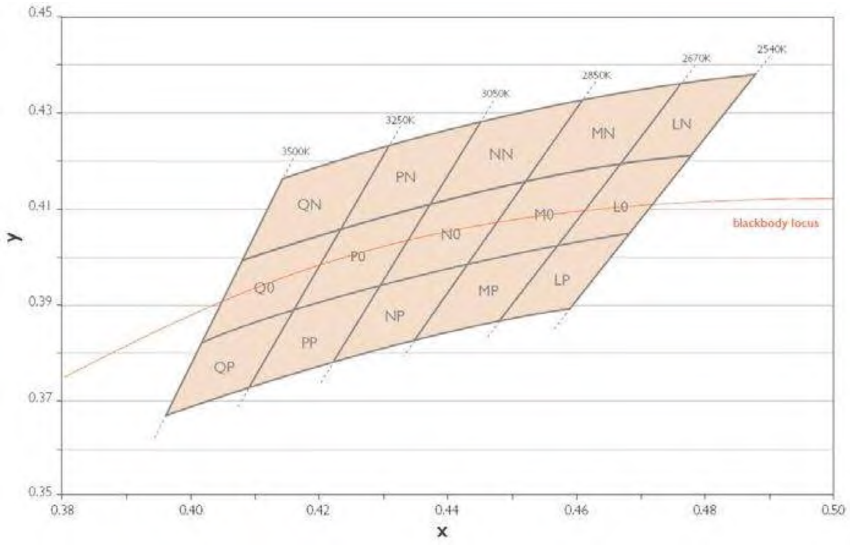
Colour Consistency

Luminaire Requirements:		
Correlated Color Temperature (CCT)	The luminaire must have one of the following designated CCTs and fall within the 7-step chromaticity 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

ANSI / Energy Star Bin Definitions:
Key driver for General Illumination

Colour Consistency





LED – 7

Fluorescent – 9

Round 3

Colour Consistency

Round 4

Colour Rendering Index

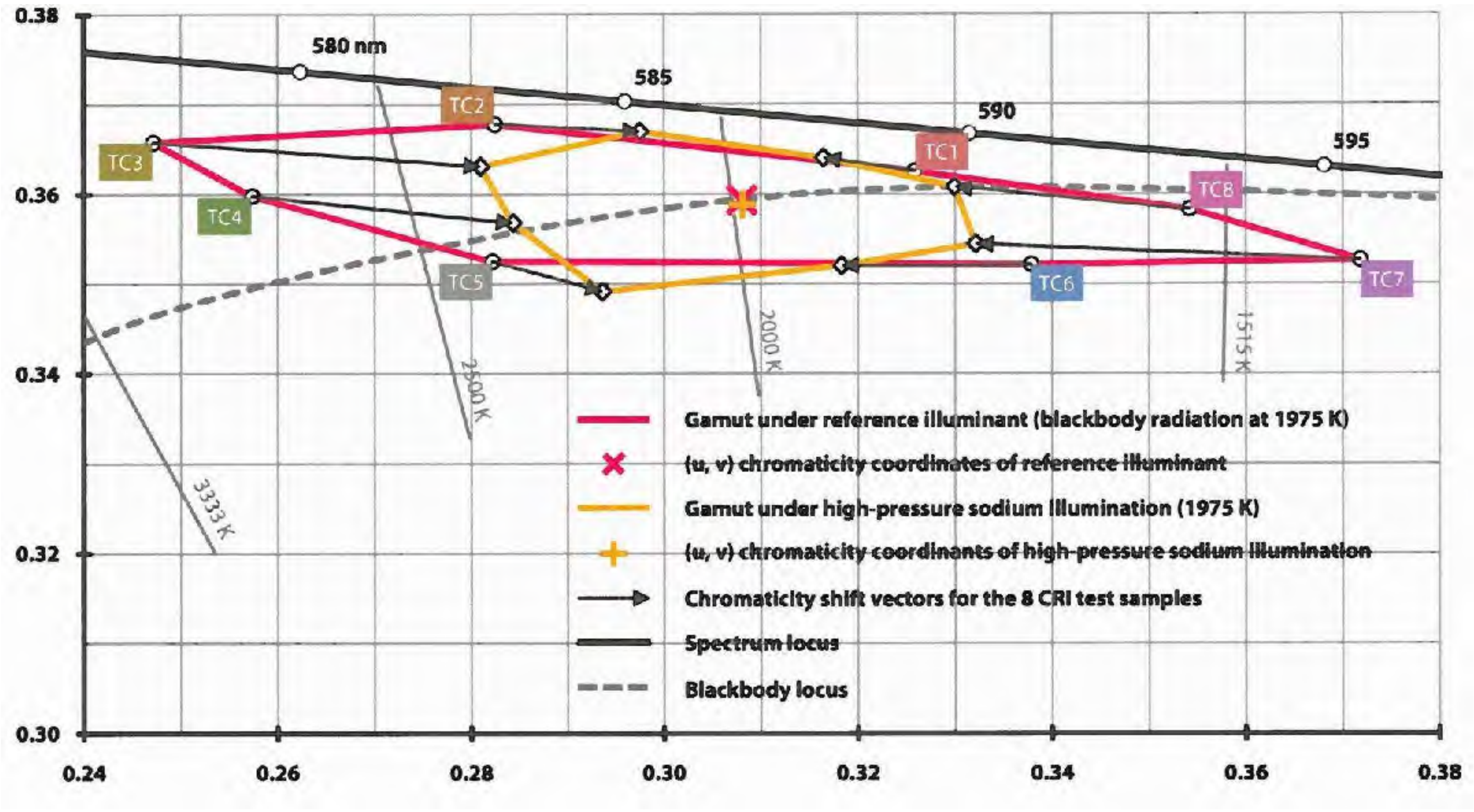
Colour Rendering Index

The Colour Rendering Index asks one basic question:

How closely does the appearance of these eight color patches illuminated by your light source match the same colour patches rendered under the reference light source?

100 is a perfect match

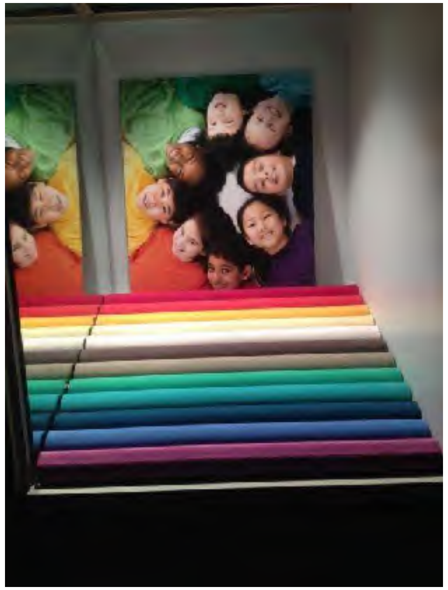
Colour Rendering Index



Colour Rendering Index

100 CRI

85 CRI



100 CRI

86 CRI

Colour Rendering Index

85 CRI 72 CRI

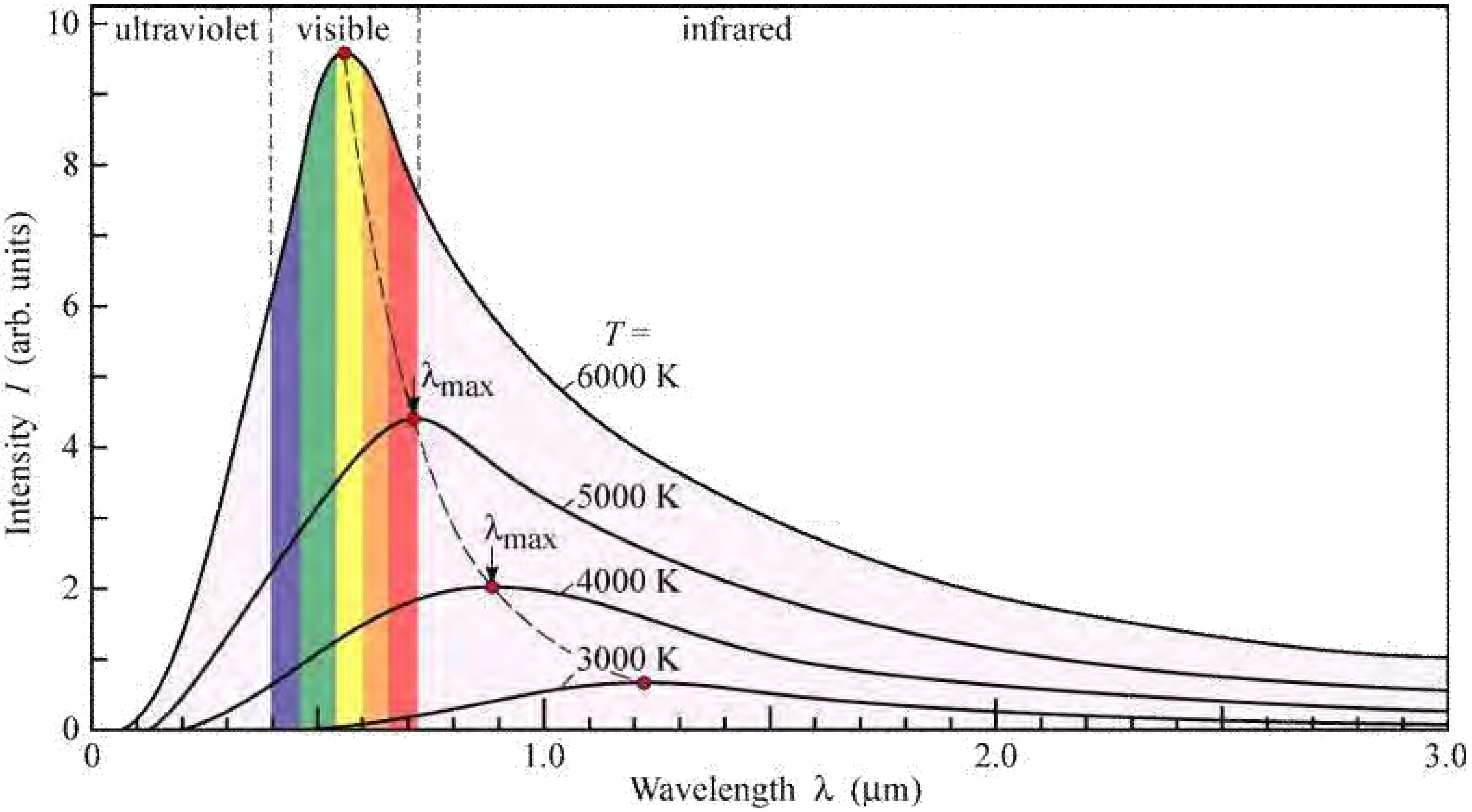
85 CRI 72 CRI

B.I.Q

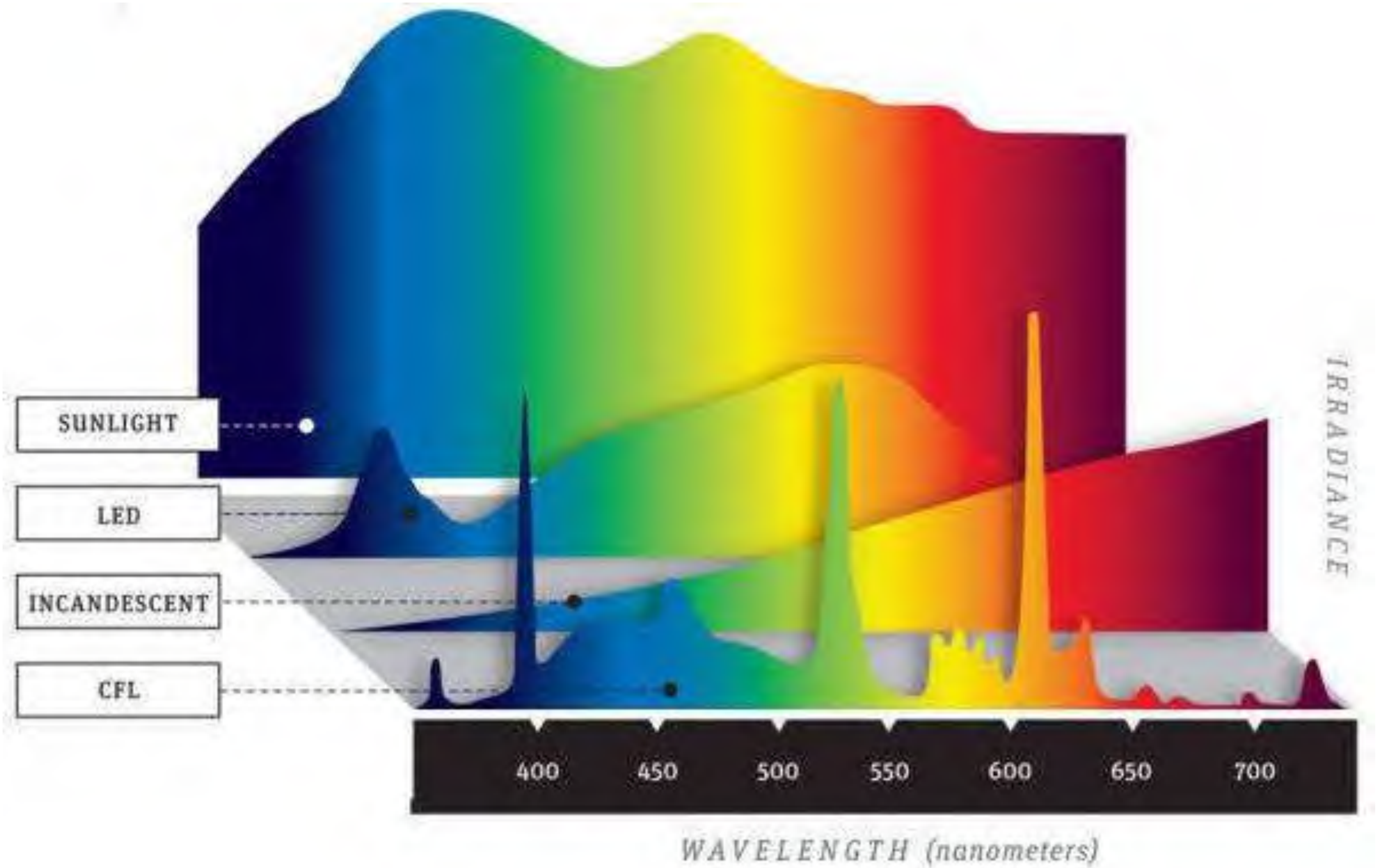
- What is the latitude of Toronto?
- What is the 8th element in the periodic table?
- In what language was Oh Canada written?
- Name the 3 stars in the constellation Orion's belt.
- Who is the only basketball coach in the history of the University of Kansas with a losing record?

- 43.7° N
- Oxygen
- French
- Alnitak, Alnilam, Mintaka
- Dr. James Naismith

Colour Rendering Index



Light Source SPDs



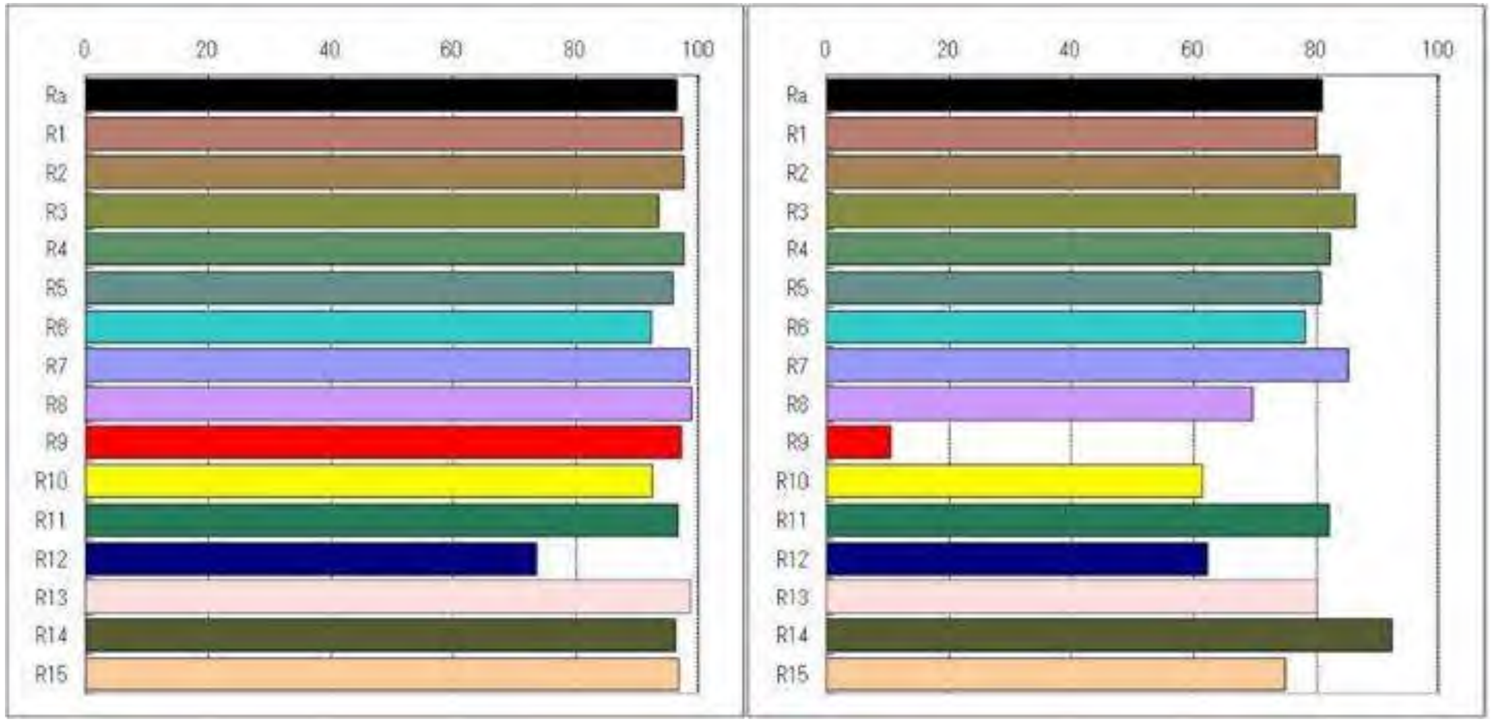
Colour Rendering Index

Test Color # (R_1-R_{14})	Munsell Notation	CIE Specification x	y	Y	ISCC-NBS Name	Approximate Appearance
1	7.5 R 6/4	0.375	0.331	29.9	Light grayish red	
2	5 Y 6/4	0.385	0.395	28.9	Dark grayish yellow	
3	5 GY 6/8	0.373	0.464	30.4	Strong yellow green	
4	2.5 G 6/6	0.287	0.4	29.2	Moderate yellowish green	
5	10 BG 6/4	0.258	0.306	30.7	Light bluish green	
6	5 PB 6/8	0.241	0.243	29.7	Light blue	
7	2.5 P 6/8	0.284	0.241	29.5	Light violet	
8	10 P 6/8	0.325	0.262	31.5	Light reddish purple	
9	4.5 R 4/13	0.567	0.306	11.4	Strong red	
10	5 Y 8/10	0.438	0.462	59.1	Strong yellow	
11	4.5 G 5/8	0.254	0.41	20	Strong green	
12	3 PB 3/11	0.155	0.15	6.4	Strong blue	
13	5 YR 8.4	0.372	0.352	57.3	Light yellowish pink (Caucasian complexion)	
14	5 GY 4/4	0.353	0.432	11.7	Moderate olive green (leaf green)	

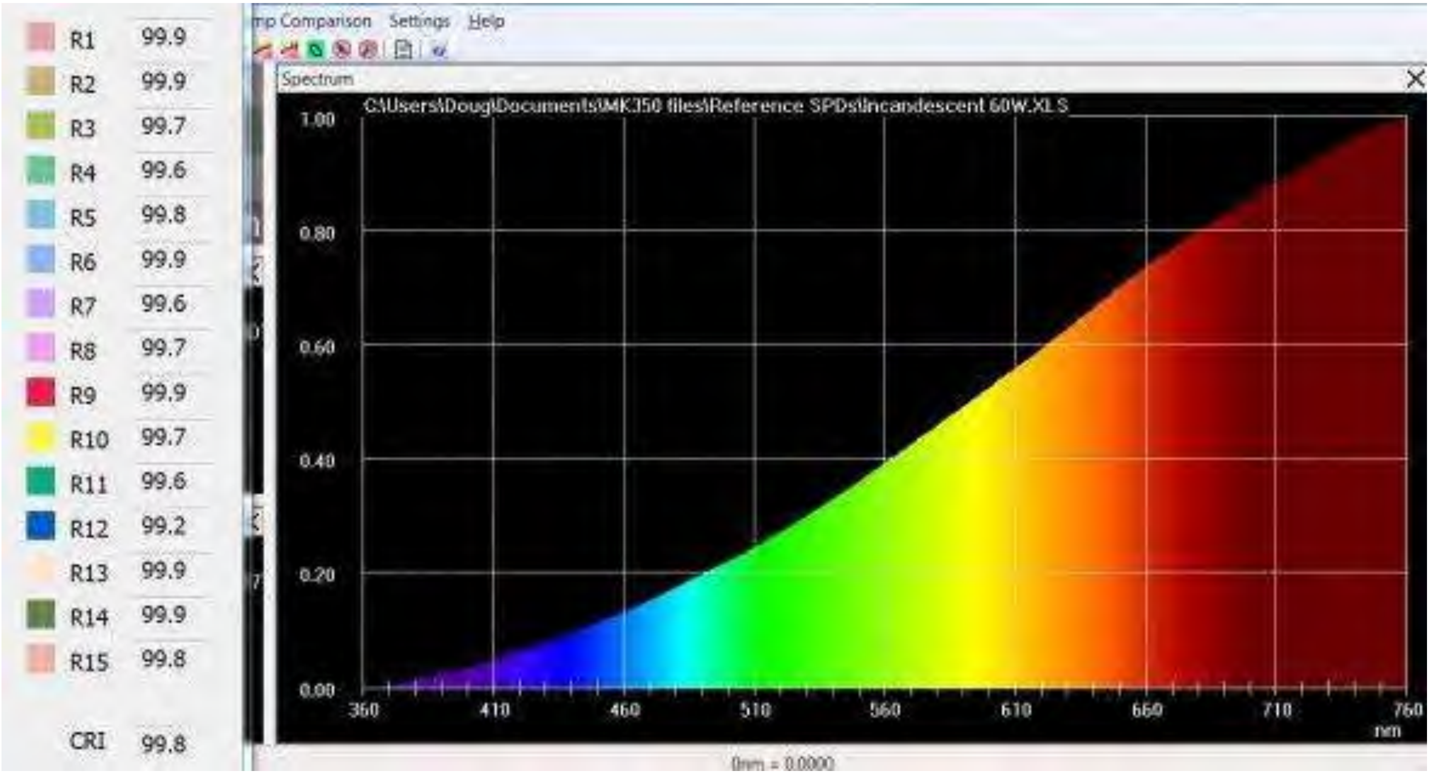
Colour Rendering Index

- Additional R9 values are not included in CRI
- Decent R9 values can be as low as 10
- Excellent R9 >20

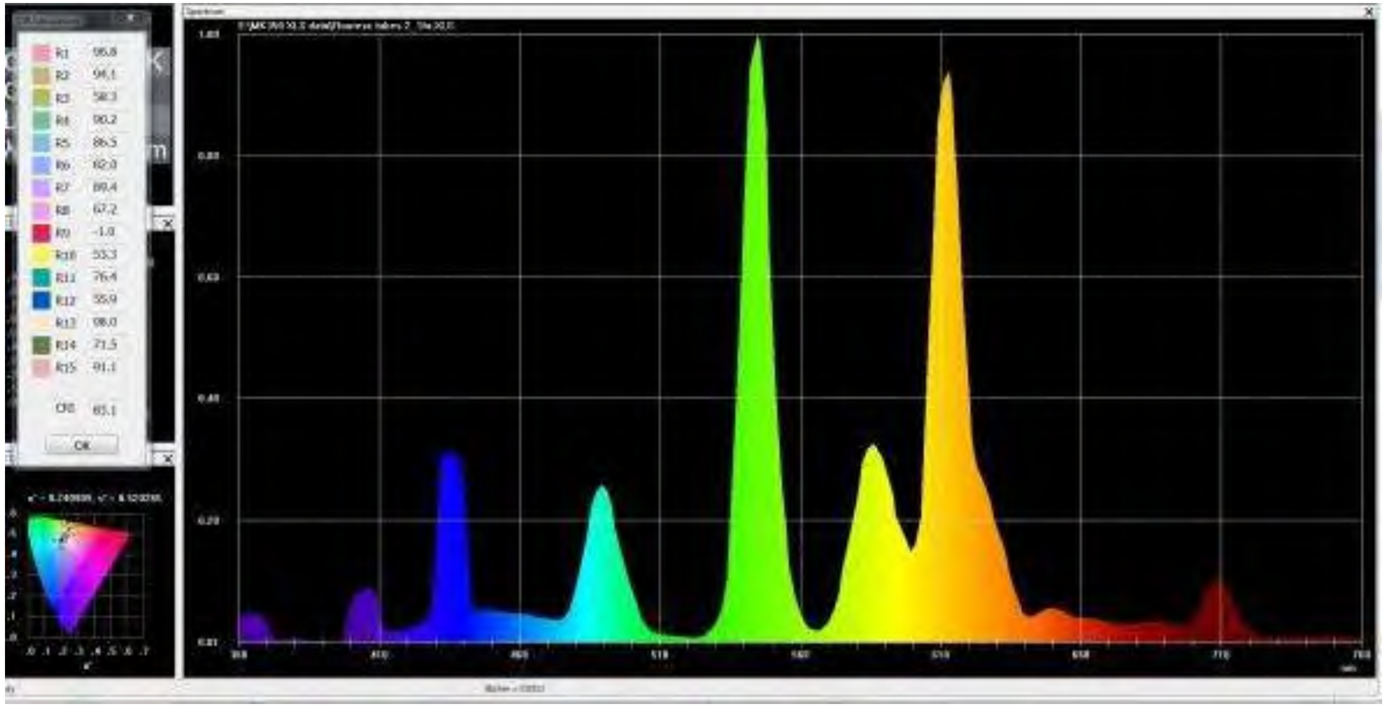
Colour Rendering Index



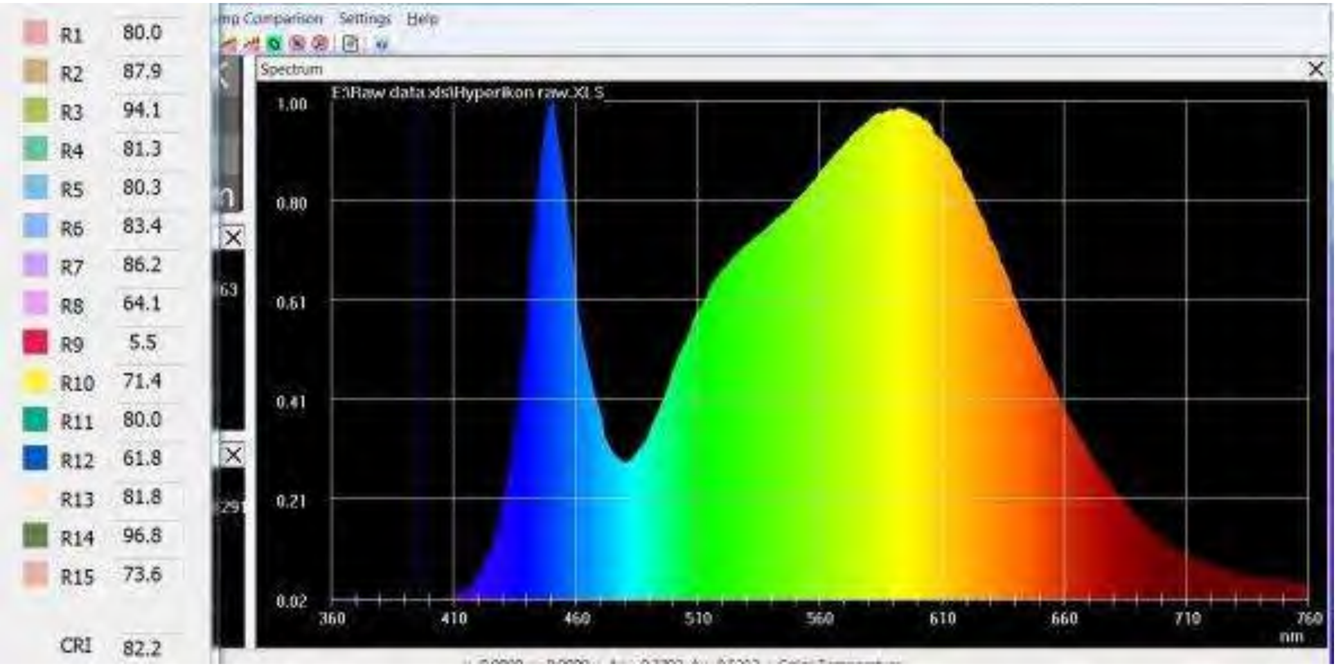
Colour Rendering Index



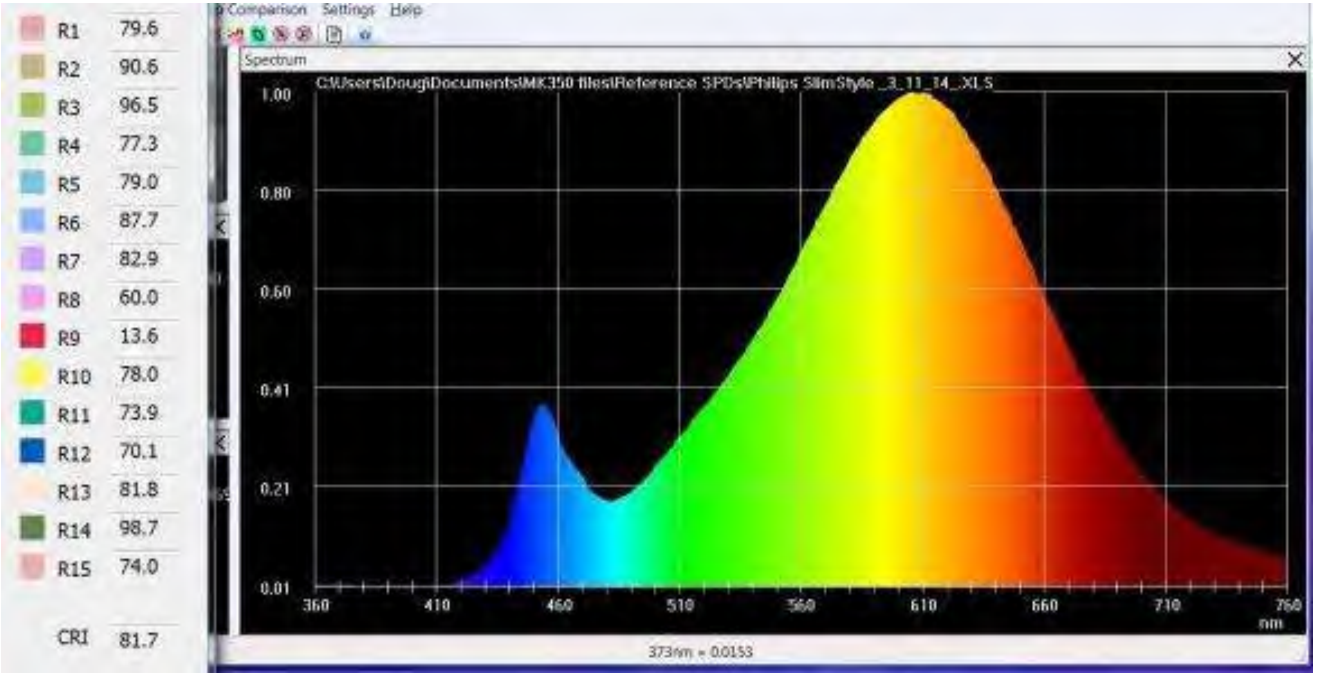
Colour Rendering Index



Colour Rendering Index

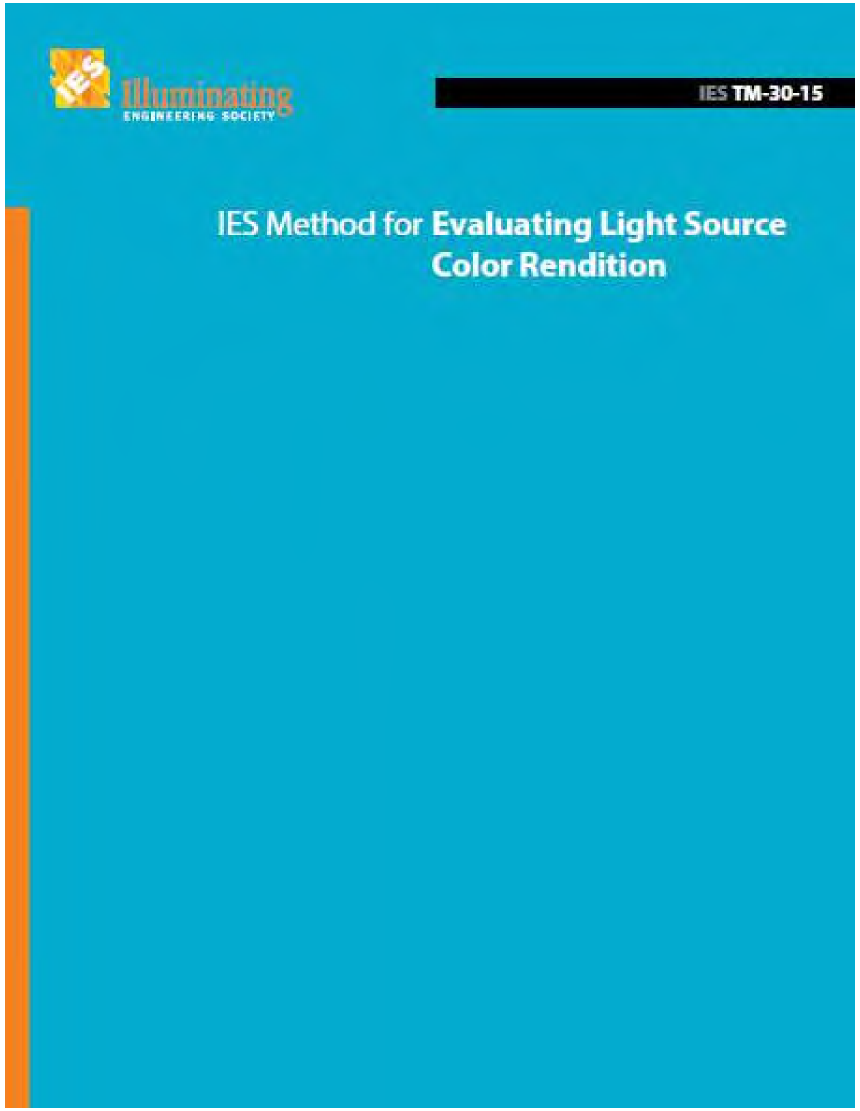


Colour Rendering Index



Colour Rendering Index

- TM-30-15
  - 3 prong approach
  - Fidelity Index – R_f
  - Gamut Index – R_g
  - Colour Vector Graphic



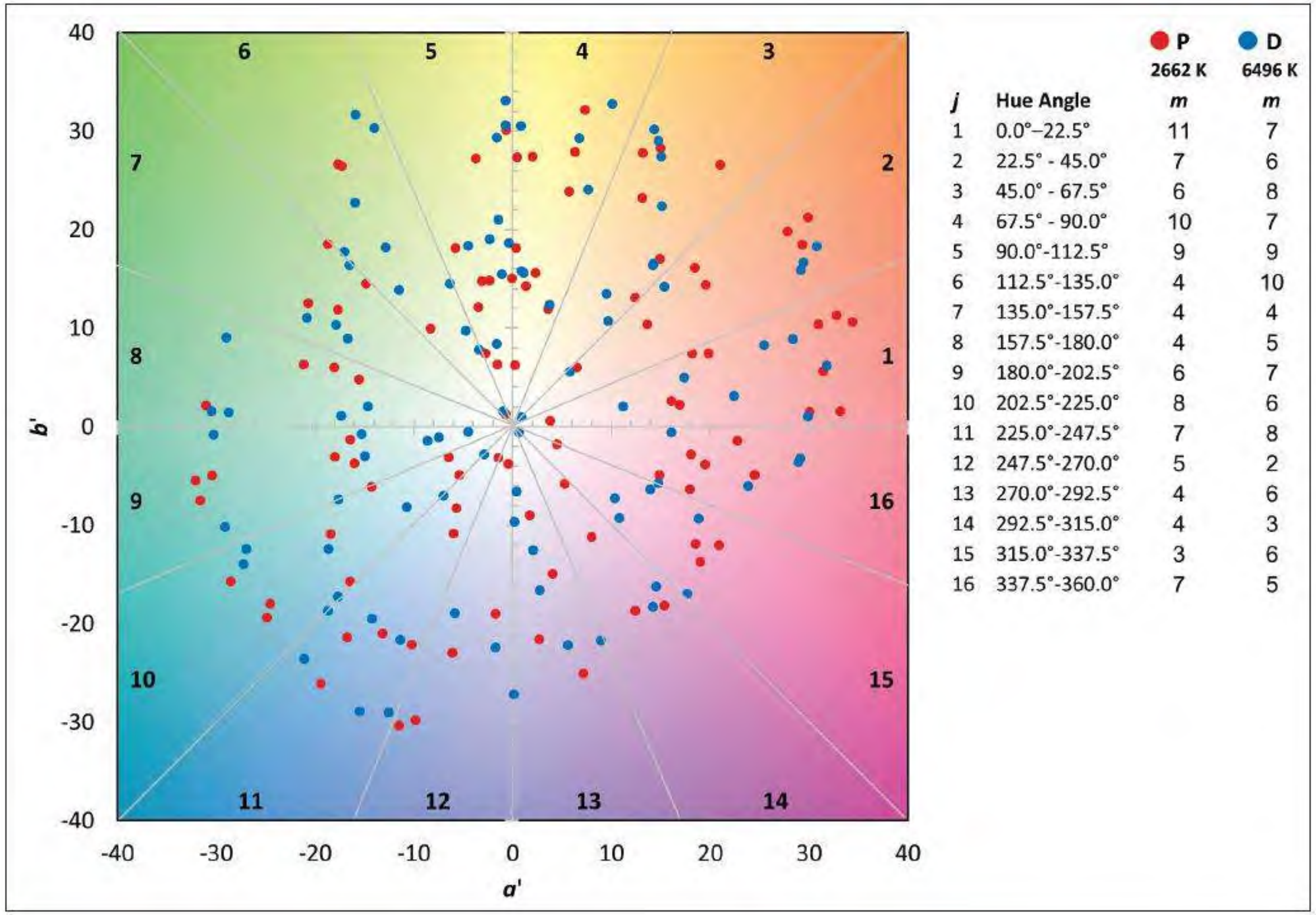
Colour Rendering Index

- TM-30-15
- 99 CES

  (Colour Evaluation Samples)

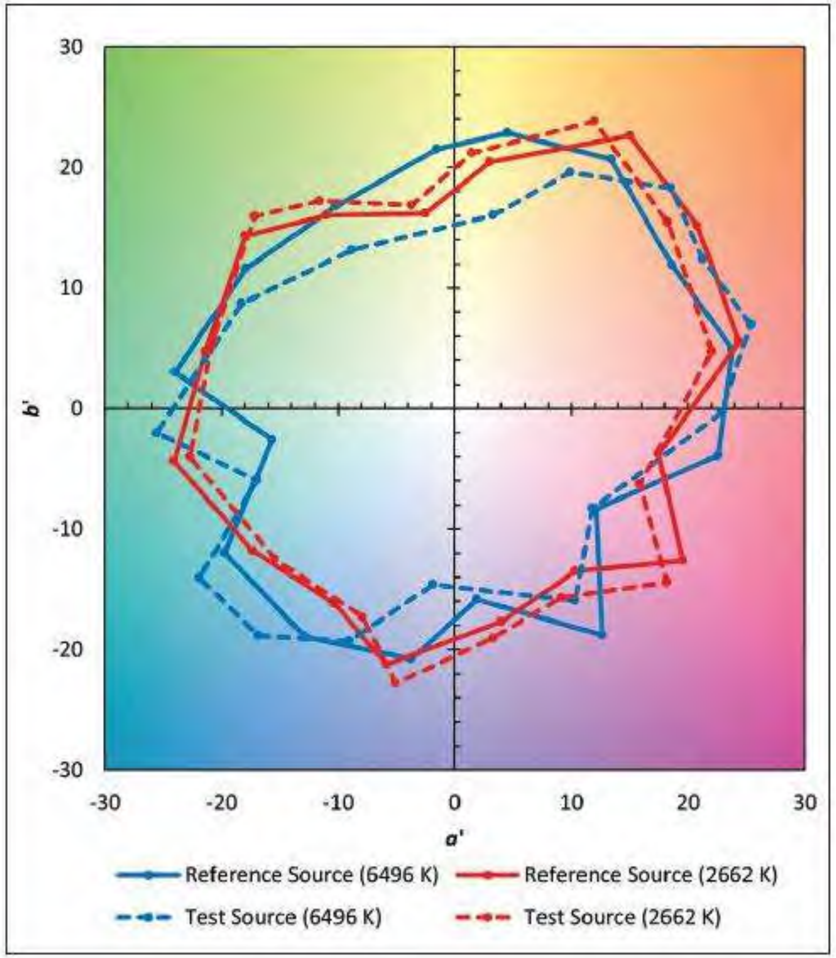
Colour Rendering Index

- TM-30-15
  - 16 Hue angle bins
  - Used to construct gamut



Colour Rendering Index

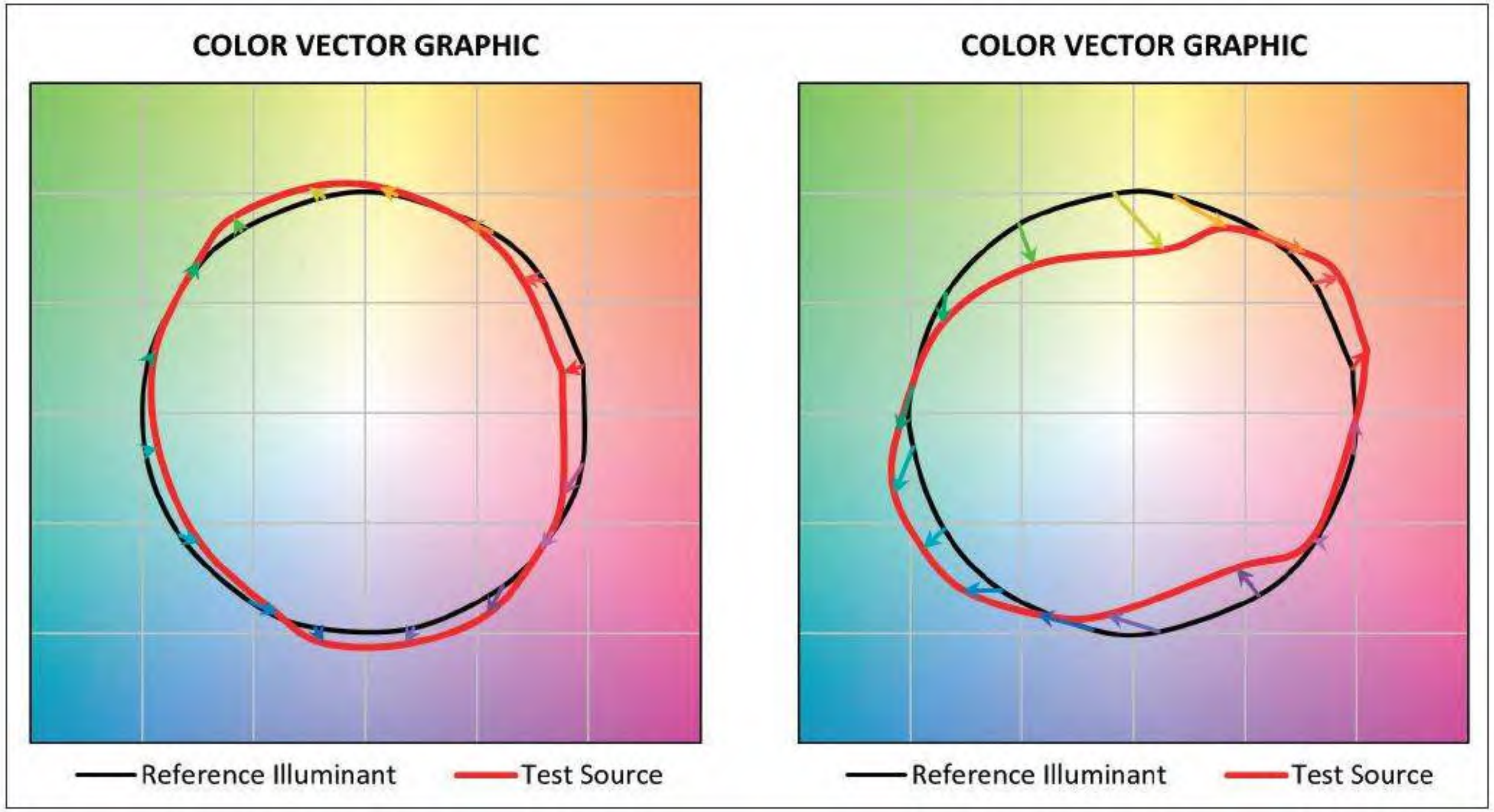
- TM-30-15
  - Gamut Area Polygons



Lower CCT = 99 R_g Higher CCT – 91 R_g

Colour Rendering Index

- TM-30-15
  - Colour Vector Graphic



LED – 8

Fluorescent – 8

Round 4

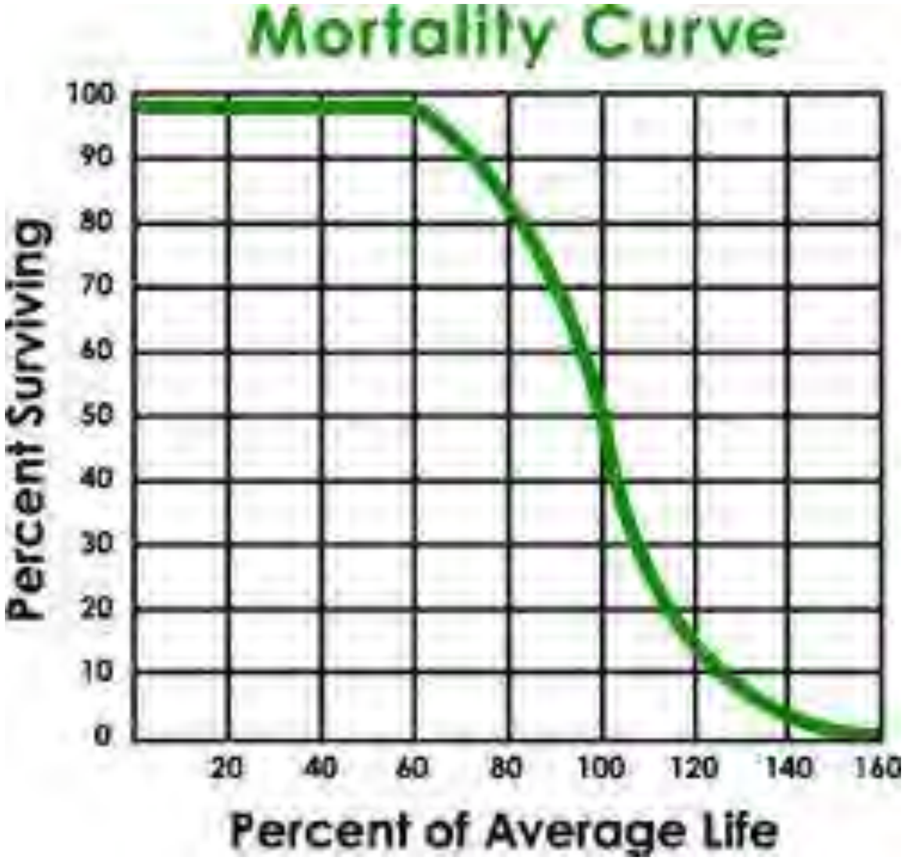
Colour Rendering Index

Round 5

Life

Lamp Life

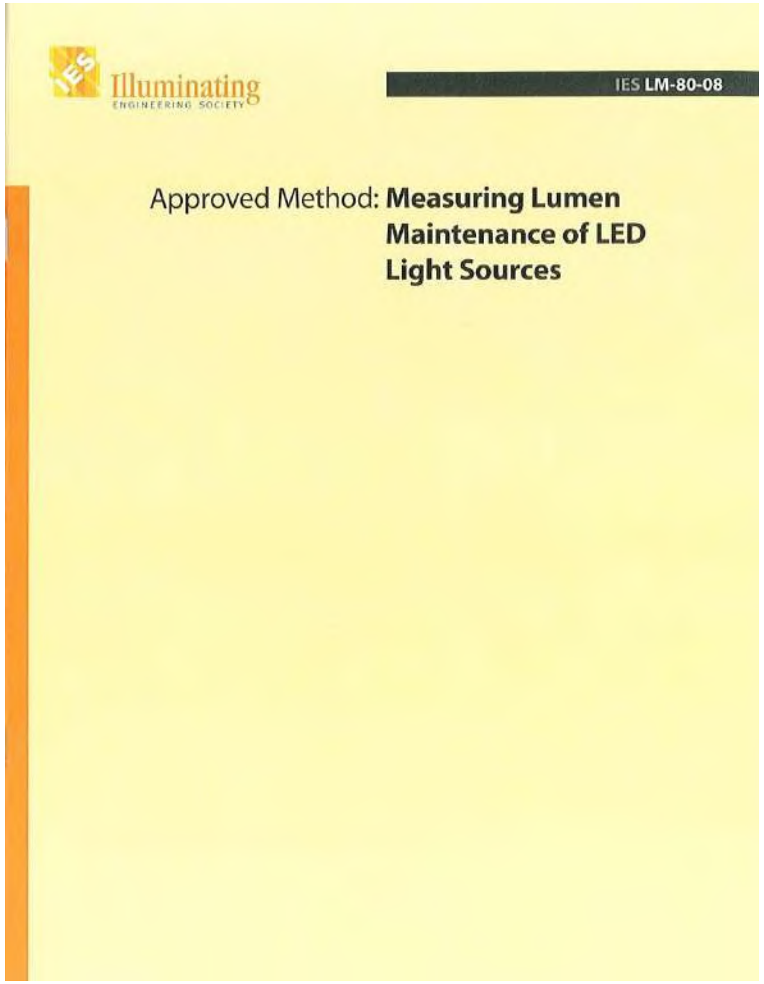
- For Traditional Light Sources life is reported as "mean" time to failure
- Average time for a percentage of lamps to fail (typically 50%)

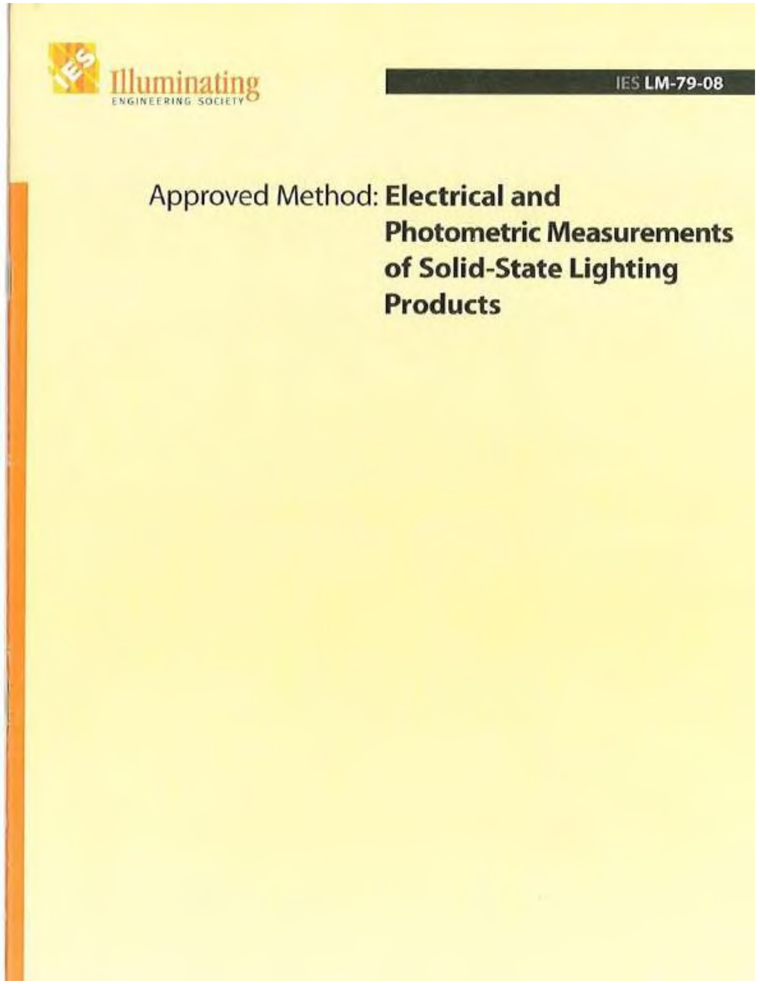


Lamp Life

Manufacturer	Lamp Type	Lumens (Initial)	Efficacy (LPW)	Instant Start		Programmed Start		Hg Content (mg)
				Rated Average Life				
				3hrs/start	12hrs/start	3hs/starrt	12hrs/start	
800 Series								
A	F32T8/SPX	2,925	91	21,000	30,000	30,000	36,000	3.0
B	FO32/800	2,950	92	24,000	28,000	30,000	36,000	3.5
C	F32T8 800	2,850	89	24,000	30,000	30,000	36,000	1.7
Long Life								
A	F32T8/XL/SPX	2,925	91	25,000	36,000	40,000	45,000	3.0
B	FO32/XP	3,000	93	24,000	40,000	40,000	42,000	3.5
C	F32T8/XEW	2,950	92	30,000	36,000	38,000	44,000	1.7
Extra Long Life								
A	F32T8 SXL	2,850	89	31,000	40,000	55,000	60,000	3.0
B	FO32/XP/XL	2,960	92	36,000	52,000	65,000	67,000	3.5
C	F32T8/XLL	2,950	92	46,000	52,000	60,000	70,000	1.7
High Lumen								
A	F32T8/XL/SPX/HL	3,100	97	25,000	36,000	40,000	45,000	3.0
B	FO32/XPS	3,100	97	24,000	40,000	40,000	42,000	3.2
C	F32T8/ADV	3,100	97	24,000	30,000	30,000	36,000	1.7
Energy Saving 28W								
A	F28T8/XL/SPX	2,675	96	24,000	34,000	45,000	50,000	3.0
B	FO28/XP/SS	2,725	97	24,000	40,000	40,000	42,000	3.2
C	F32T8/ADV/EW	2,725	97	32,000	38,000	38,000	44,000	1.7
Energy Saving 25W								
A	F32T8/25W/SPX	2,500	100	36,000	40,000	50,000	55,000	3.0
B	FO32/25W/XP/SS	2,500	100	24,000	40,000	40,000	42,000	3.2
C	F32T8/ADV/XEW	2,500	100	32,000	38,000	38,000	44,000	1.7
Extra Long Life - Energy Saving 28W								
B	FO28/XP/XL/SS	2,600	93	50,000	75,000	80,000	84,000	4.2
C	F32T8/ADV/XLL 28	2,675	94	60,000	68,000	80,000	90,000	1.7
Extra Long Life - Energy Saving 25W								
B	FO32/25W/XP/XL/SS	2,400	96	50,000	75,000	80,000	84,000	4.2
C	F32T8/ADV/XLL 25	2,400	96	60,000	68,000	80,000	90,000	1.7

Lamp Life

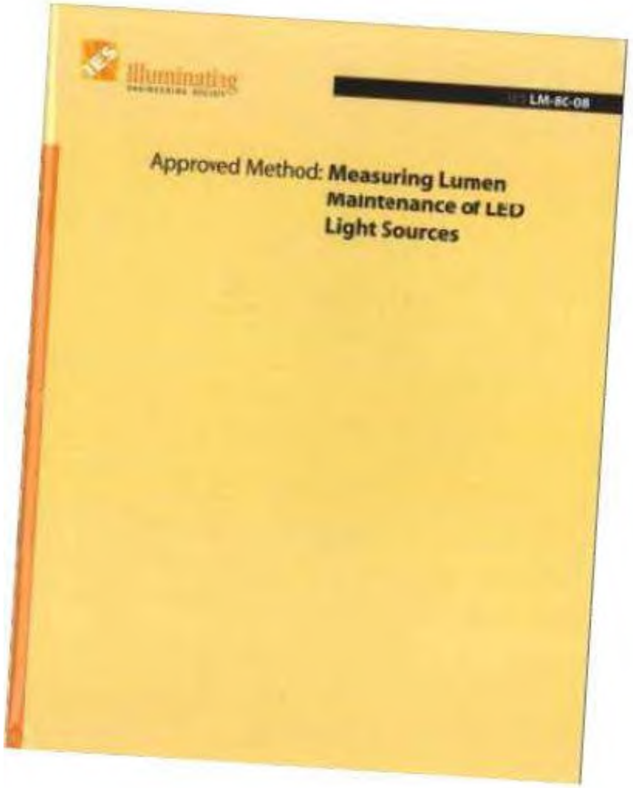

IES
Illuminating
ENGINEERING SOCIETY
IES LM-80-08
Approved Method: Measuring Lumen Maintenance of LED Light Sources


IES
Illuminating
ENGINEERING SOCIETY
IES LM-79-08
Approved Method: Electrical and Photometric Measurements of Solid-State Lighting Products

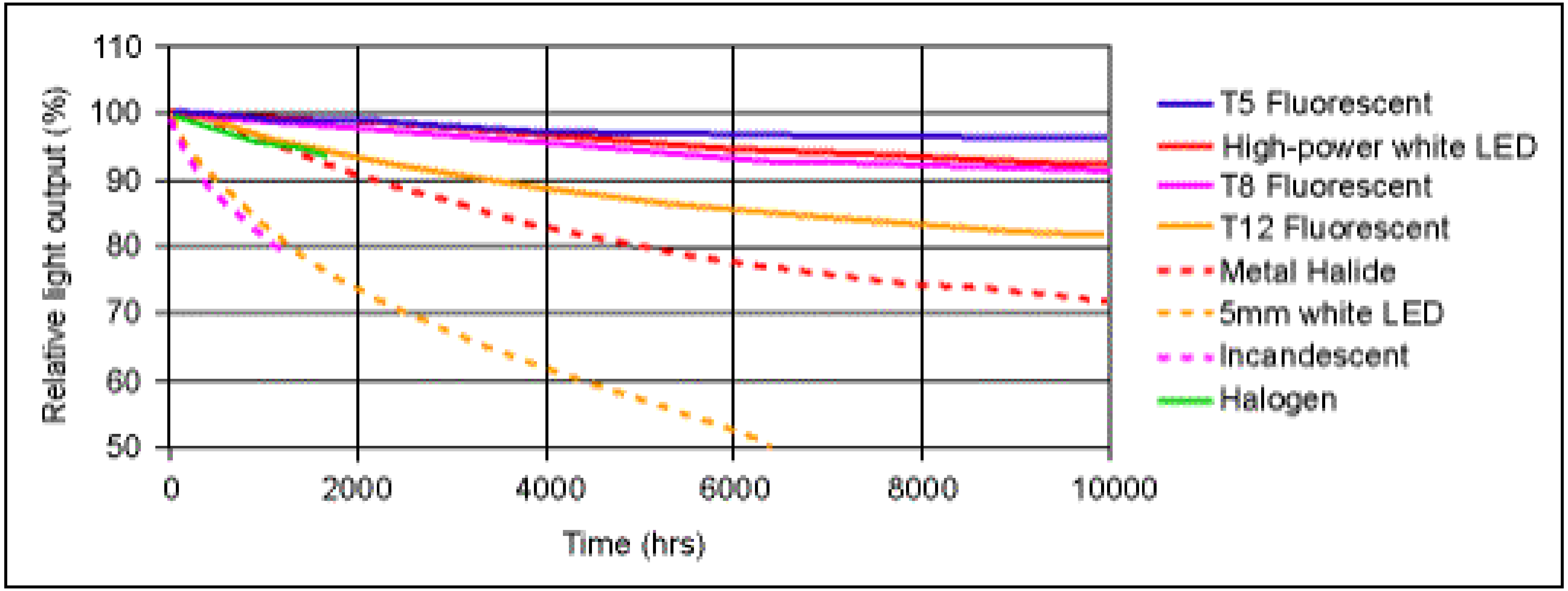
Lamp Life

- Requirement for measuring LED life
- L70 – Time elapse to 70% of initial lumen output
- L50 – Time elapse to 50% of initial lumen output

* Keep in mind many drivers are rated at 60,000 hrs.



Lamp Life



Relative light output (%)
110
100
90
80
70
60
50
0
2000
4000
6000
8000
10000
Time (hrs)
T5 Fluorescent
High-power white LED
T8 Fluorescent
T12 Fluorescent
Metal Halide
5mm white LED
Incandescent
Halogen

Lamp Life

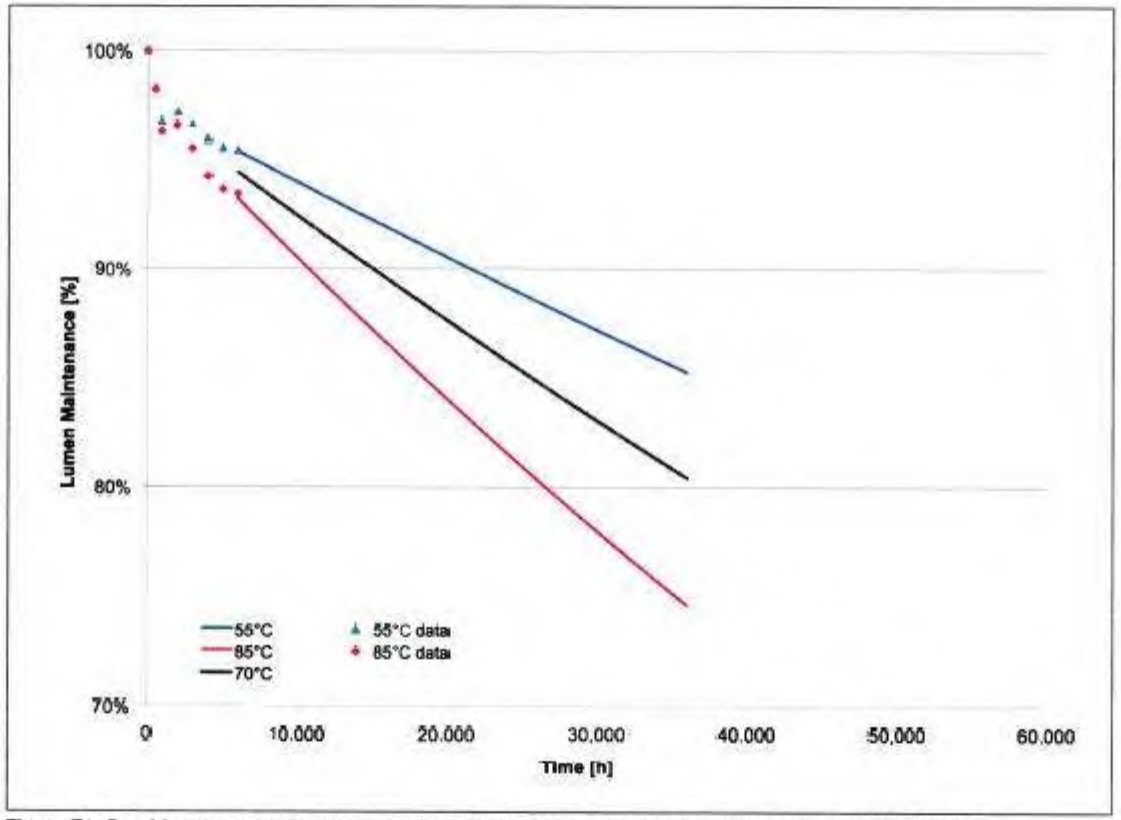


Figure E1. Graphic representation of lumen maintenance life projection using 6000 hours of LM-80-08 data

Lamp Life

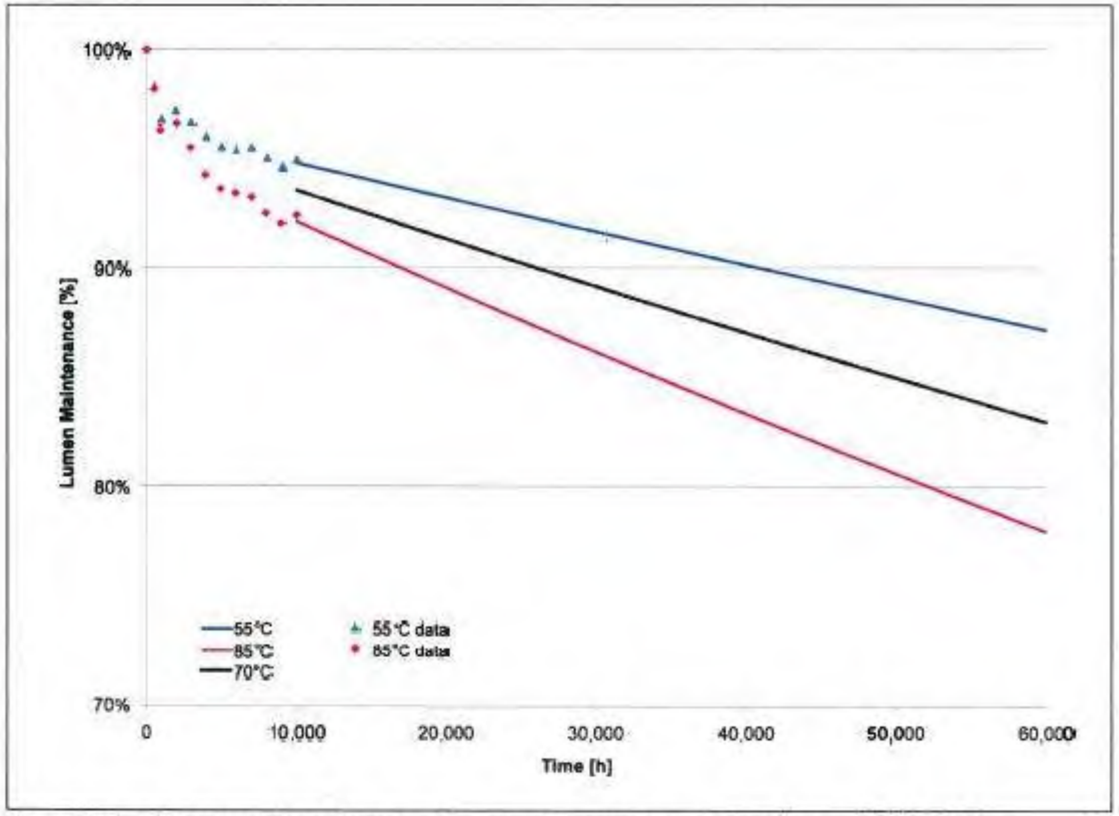
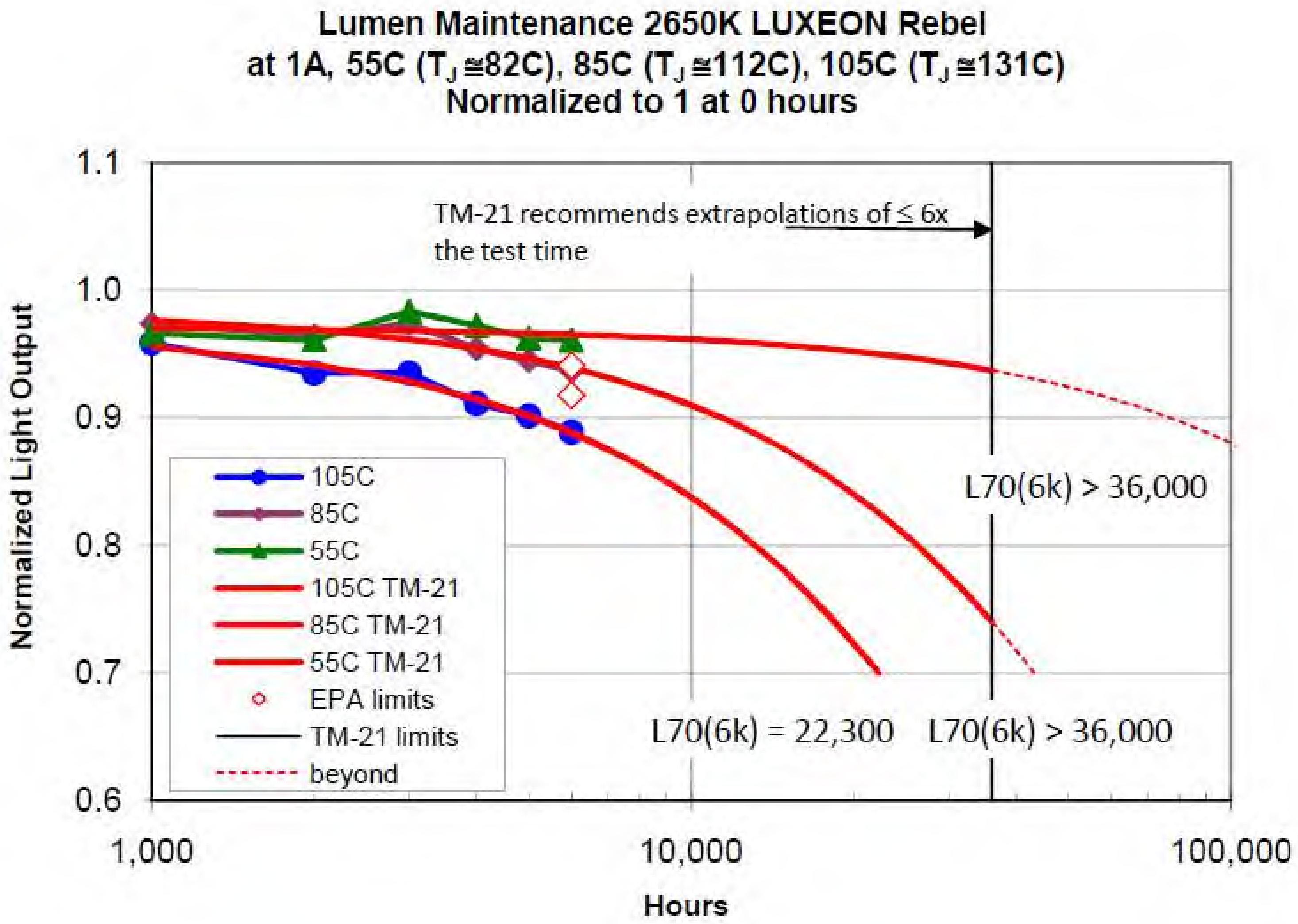


Figure E2. Graphic representation of lumen maintenance life projection using 10000 hours of LM-80-08 data

Lamp Life



Lumen Maintenance 2650K LUXEON Rebel
at 1A, 55C (T_J≅82C), 85C (T_J≅112C), 105C (T_J≅131C)
Normalized to 1 at 0 hours
TM-21 recommends extrapolations of ≤ 6x the test time
L70(6k) > 36,000
L70(6k) = 22,300
L70(6k) > 36,000
105C
85C
55C
105C TM-21
85C TM-21
55C TM-21
EPA limits
TM-21 limits
beyond
Normalized Light Output
1.1
1.0
0.9
0.8
0.7
0.6
1,000
10,000
100,000
Hours

LED – 9

Fluorescent – 9

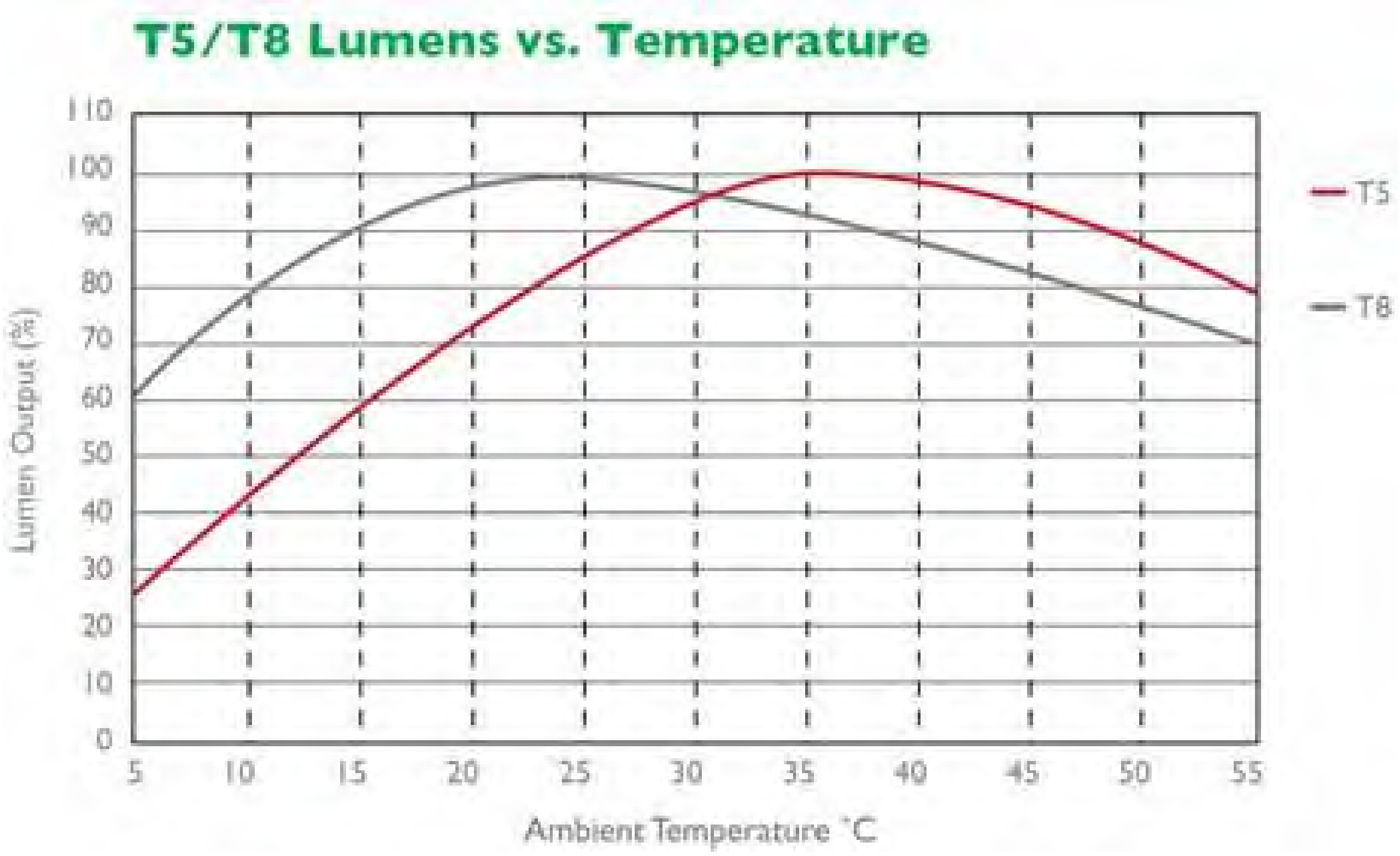
Round 5

Life

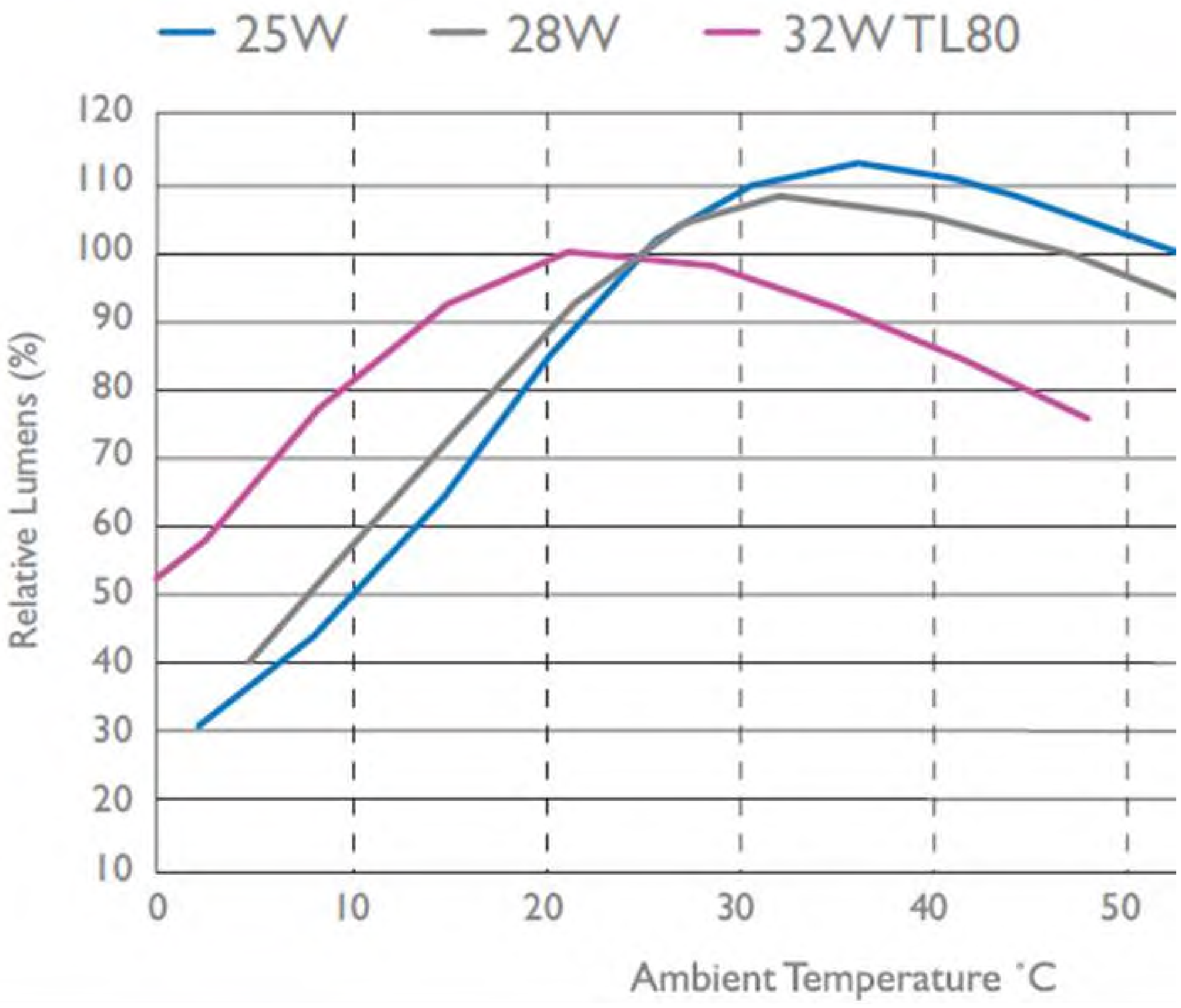
Round 6

Temperature Issues

Temperature Issues



Temperature Issues



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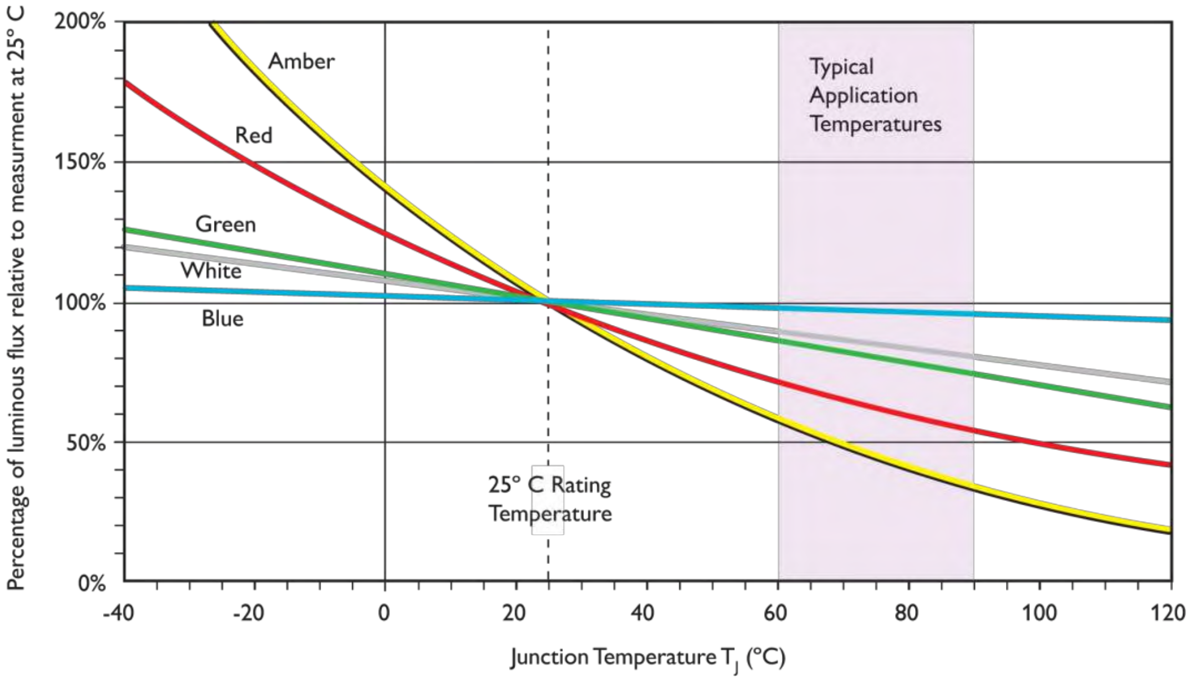
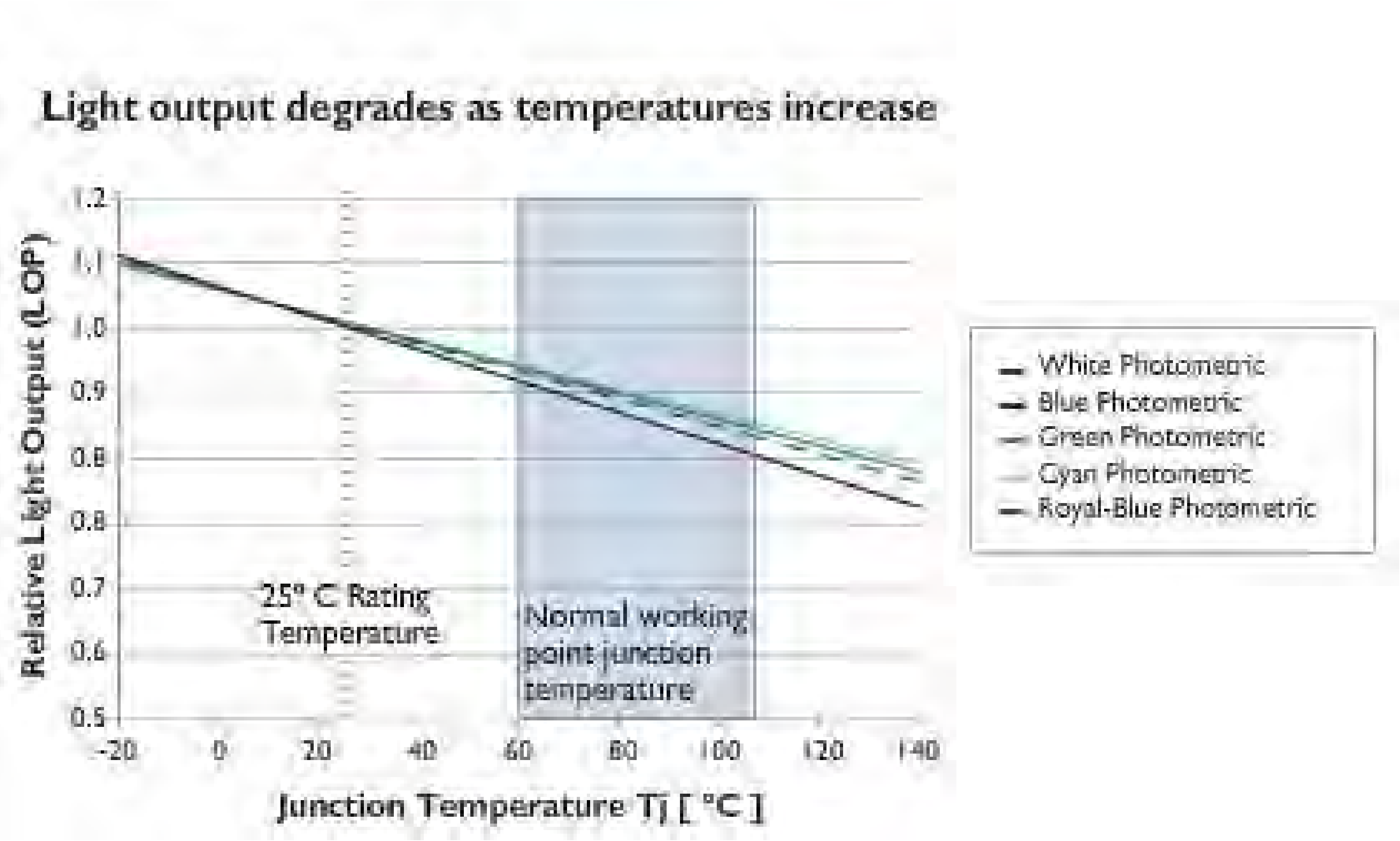


- Each color has a different sensitivity to temperature
- Each color degrades at a different rate
- In general, warmer colors are more temperature sensitive and degrade faster than cooler ones
- The degradation rate increases with increased junction temperature

Temperature Issues



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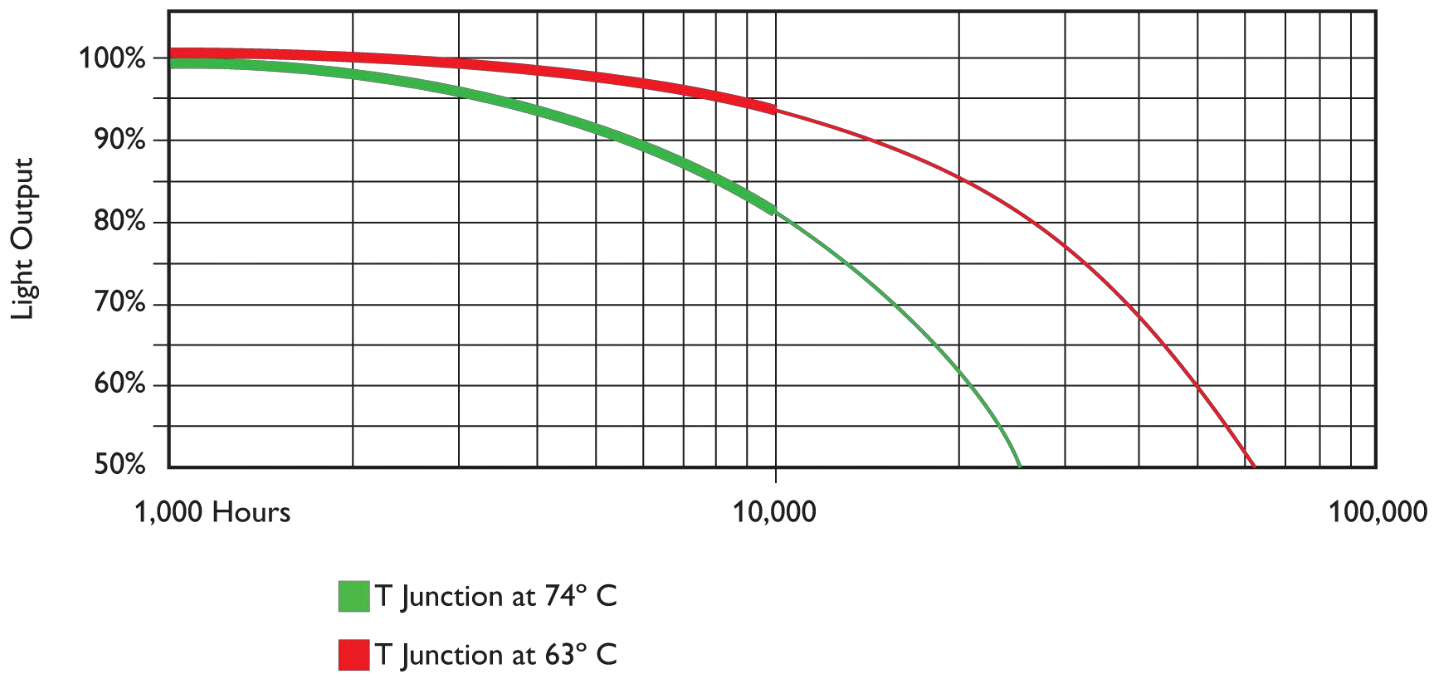


- Heat seriously reduces LED life.
- At 63º C life is 60,000 hrs – L50: 40,000 hrs – L70
- At 74º C life is 25,000 hrs – L50; 16,000 hrs – L70

LED – 7

Fluorescent – 8

Round 6

Temperature Issues

Round 7

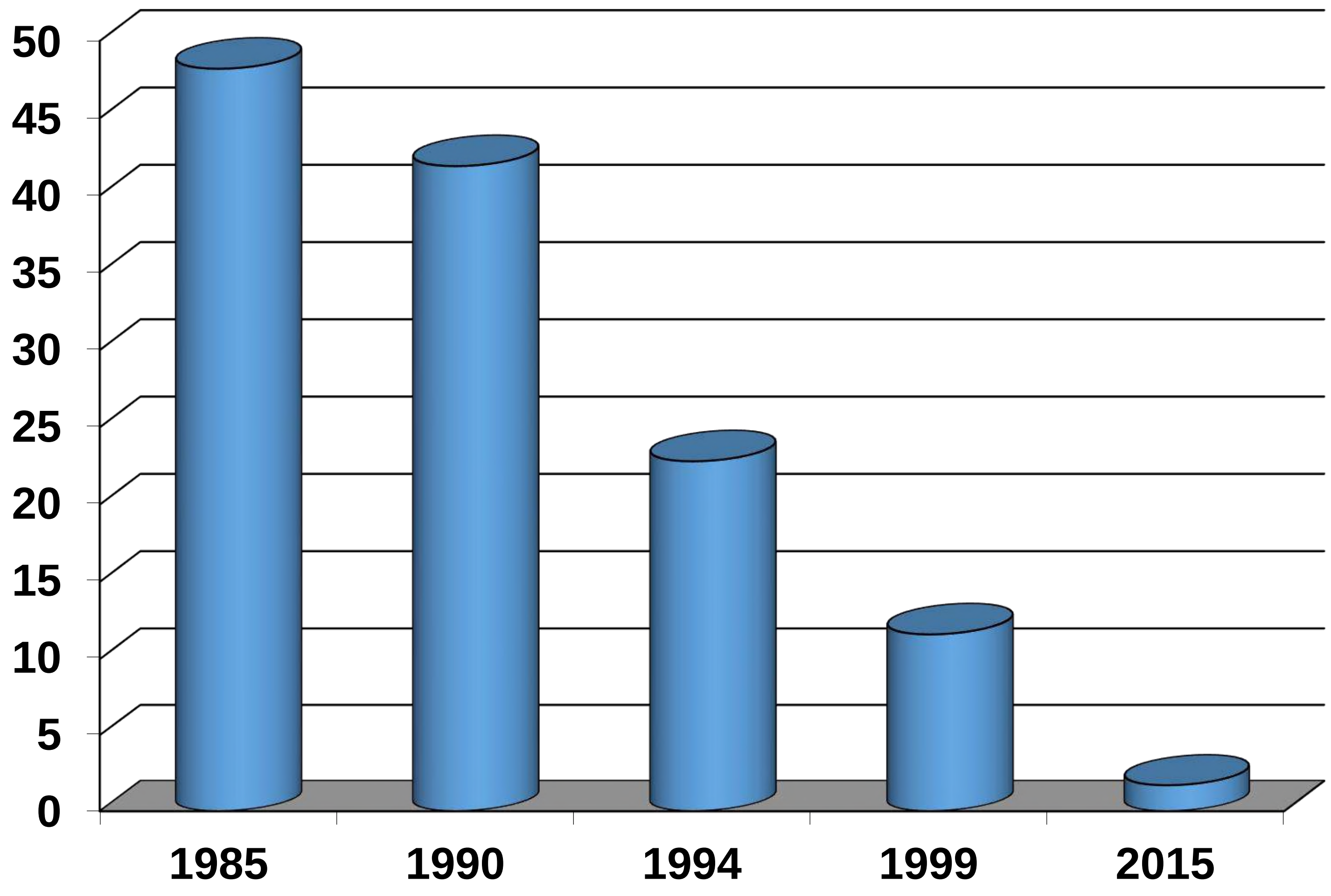
Environmental Impact

Environmental Impact

Fact: Fluorescents have mercury. LEDs do not.

Myth: LEDs are therefore better for the environment.

Environmental Impact



Milligrams of Mercury in 4’ Fluorescent tube

Environmental Impact

Manufacturer	Lamp Type	Lumens (Initial)	Efficacy (LPW)	Instant Start		Programmed Start		Hg Content (mg)
				Rated Average Life				
				3hrs/start	12hrs/start	3hs/starrt	12hrs/start	
800 Series								
A	F32T8/SPX	2,925	91	21,000	30,000	30,000	36,000	3.0
B	FO32/800	2,950	92	24,000	28,000	30,000	36,000	3.5
C	F32T8 800	2,850	89	24,000	30,000	30,000	36,000	1.7
Long Life								
A	F32T8/XL/SPX	2,925	91	25,000	36,000	40,000	45,000	3.0
B	FO32/XP	3,000	93	24,000	40,000	40,000	42,000	3.5
C	F32T8/XEW	2,950	92	30,000	36,000	38,000	44,000	1.7
Extra Long Life								
A	F32T8 SXL	2,850	89	31,000	40,000	55,000	60,000	3.0
B	FO32/XP/XL	2,960	92	36,000	52,000	65,000	67,000	3.5
C	F32T8/XLL	2,950	92	46,000	52,000	60,000	70,000	1.7
High Lumen								
A	F32T8/XL/SPX/HL	3,100	97	25,000	36,000	40,000	45,000	3.0
B	FO32/XPS	3,100	97	24,000	40,000	40,000	42,000	3.2
C	F32T8/ADV	3,100	97	24,000	30,000	30,000	36,000	1.7
Energy Saving 28W								
A	F28T8/XL/SPX	2,675	96	24,000	34,000	45,000	50,000	3.0
B	FO28/XP/SS	2,725	97	24,000	40,000	40,000	42,000	3.2
C	F32T8/ADV/EW	2,725	97	32,000	38,000	38,000	44,000	1.7
Energy Saving 25W								
A	F32T8/25W/SPX	2,500	100	36,000	40,000	50,000	55,000	3.0
B	FO32/25W/XP/SS	2,500	100	24,000	40,000	40,000	42,000	3.2
C	F32T8/ADV/XEW	2,500	100	32,000	38,000	38,000	44,000	1.7
Extra Long Life - Energy Saving 28W								
B	FO28/XP/XL/SS	2,600	93	50,000	75,000	80,000	84,000	4.2
C	F32T8/ADV/XLL 28	2,675	94	60,000	68,000	80,000	90,000	1.7
Extra Long Life - Energy Saving 25W								
B	FO32/25W/XP/XL/SS	2,400	96	50,000	75,000	80,000	84,000	4.2
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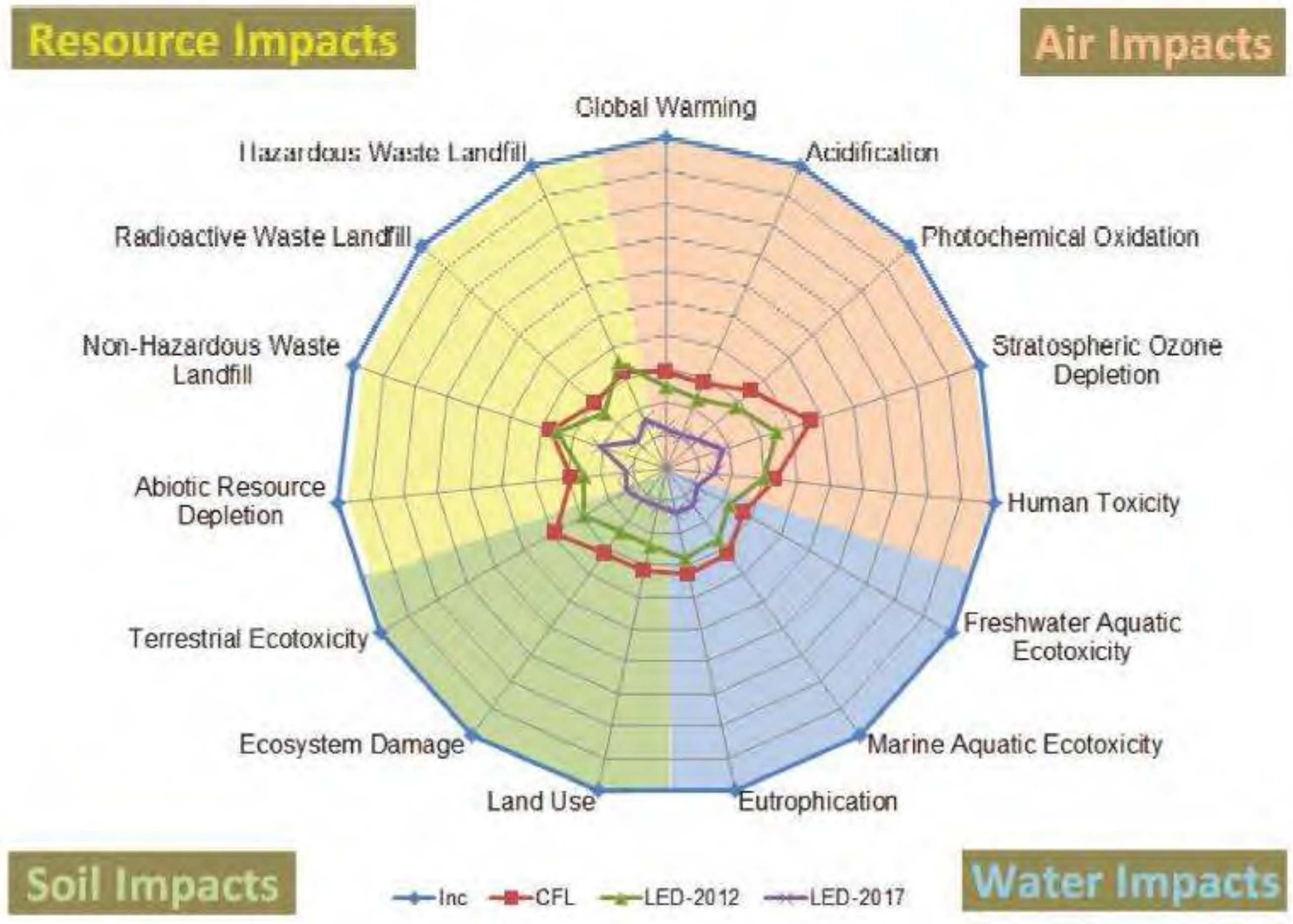
Environmental Impact



Environmental Impact

Light-emitting diodes (LEDs) are advertised as environmentally friendly because they are energy efficient and mercury-free. This study aimed to determine if LEDs engender other forms of environmental and human health impacts, and to characterize variation across different LEDs based on color and intensity. The objectives are as follows: (i) to use standardized leachability tests to examine whether LEDs are to be categorized as hazardous waste under existing United States federal and California state regulations; and (ii) to use material life cycle impact and hazard assessment methods to evaluate resource depletion and toxicity potentials of LEDs based on their metallic constituents. According to federal standards, LEDs are not hazardous except for low-intensity red LEDs, which leached Pb at levels exceeding regulatory limits (186 mg/L; regulatory limit: 5). However, according to California regulations, excessive levels of copper (up to 3892 mg/kg; limit: 2500), Pb (up to 8103 mg/kg; limit: 1000), nickel (up to 4797 mg/kg; limit: 2000), or silver (up to 721 mg/kg; limit: 500) render all except low-intensity yellow LEDs hazardous. The environmental burden associated with resource depletion potentials derives primarily from gold and silver, whereas the burden from toxicity potentials is associated primarily with arsenic, copper, nickel, lead, iron, and silver. Establishing benchmark levels of these substances can help manufacturers implement design for environment through informed materials substitution, can motivate recyclers and waste management teams to recognize resource value and occupational hazards, and can inform policymakers who establish waste management policies for LEDs.

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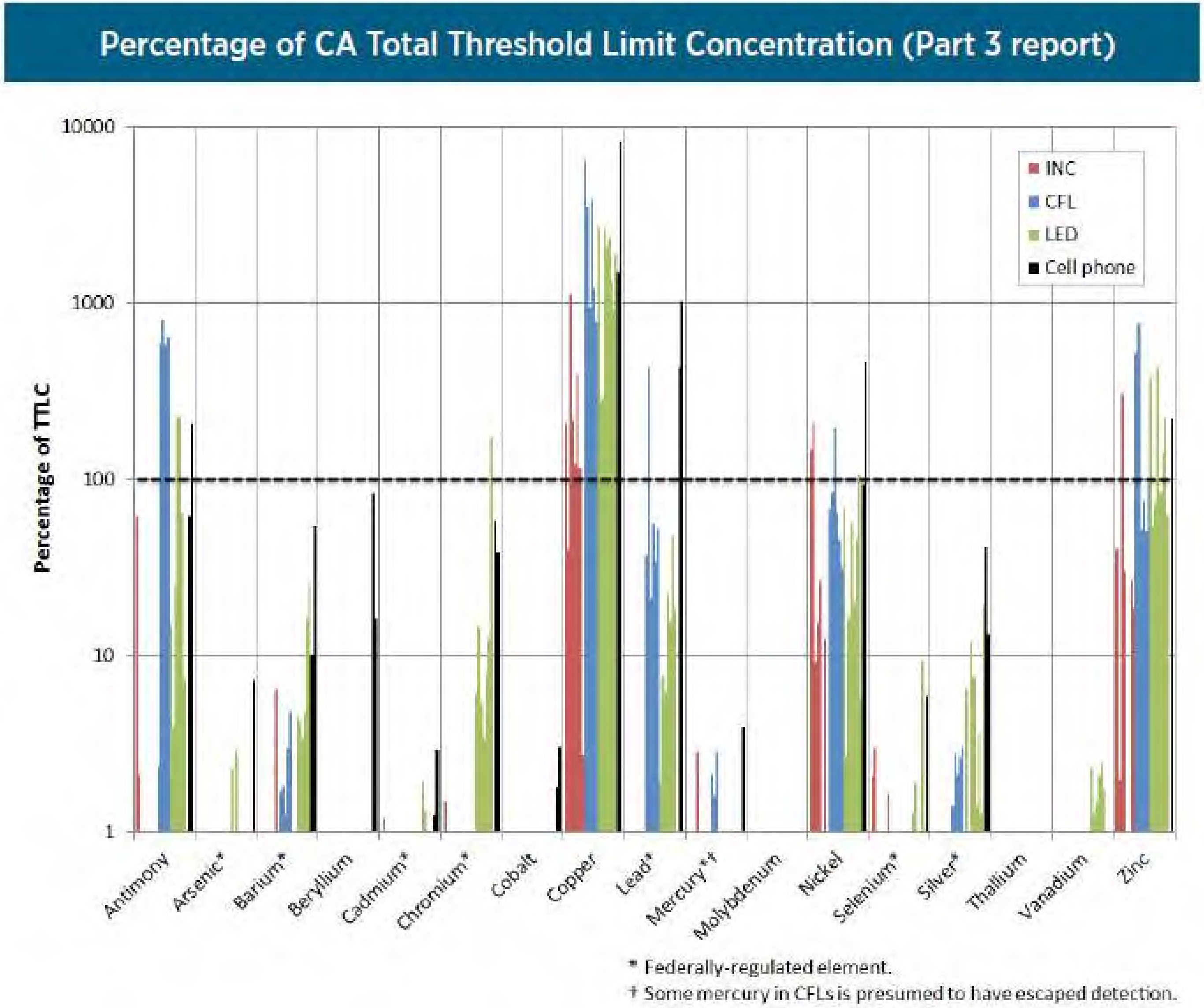
Environmental Impact



LED – 7

Fluorescent – 7

ALL LAMPS MUST BE RECYCLED!

Round 7

Environmental Impact

Round 8

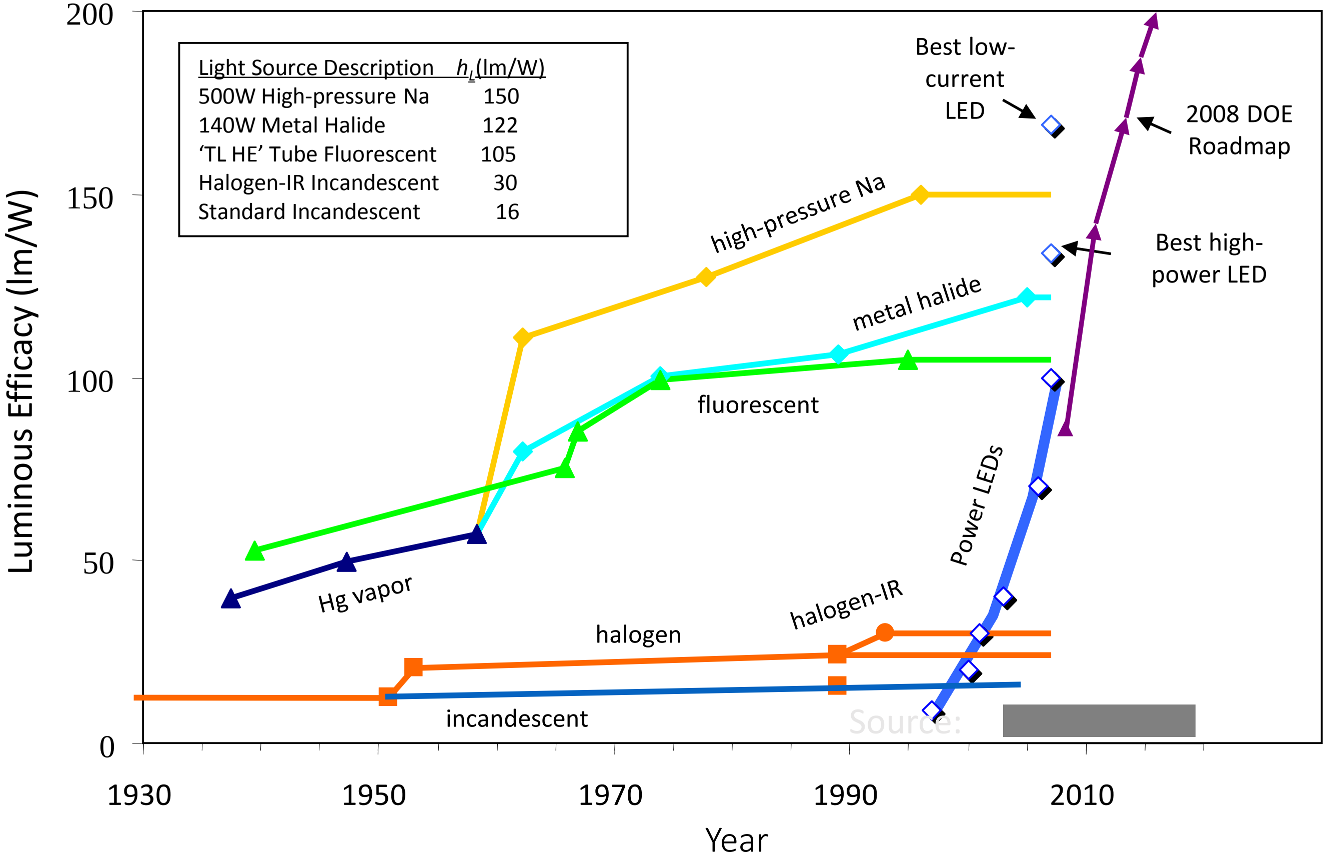
Energy Efficiency

Efficacy

Efficacy

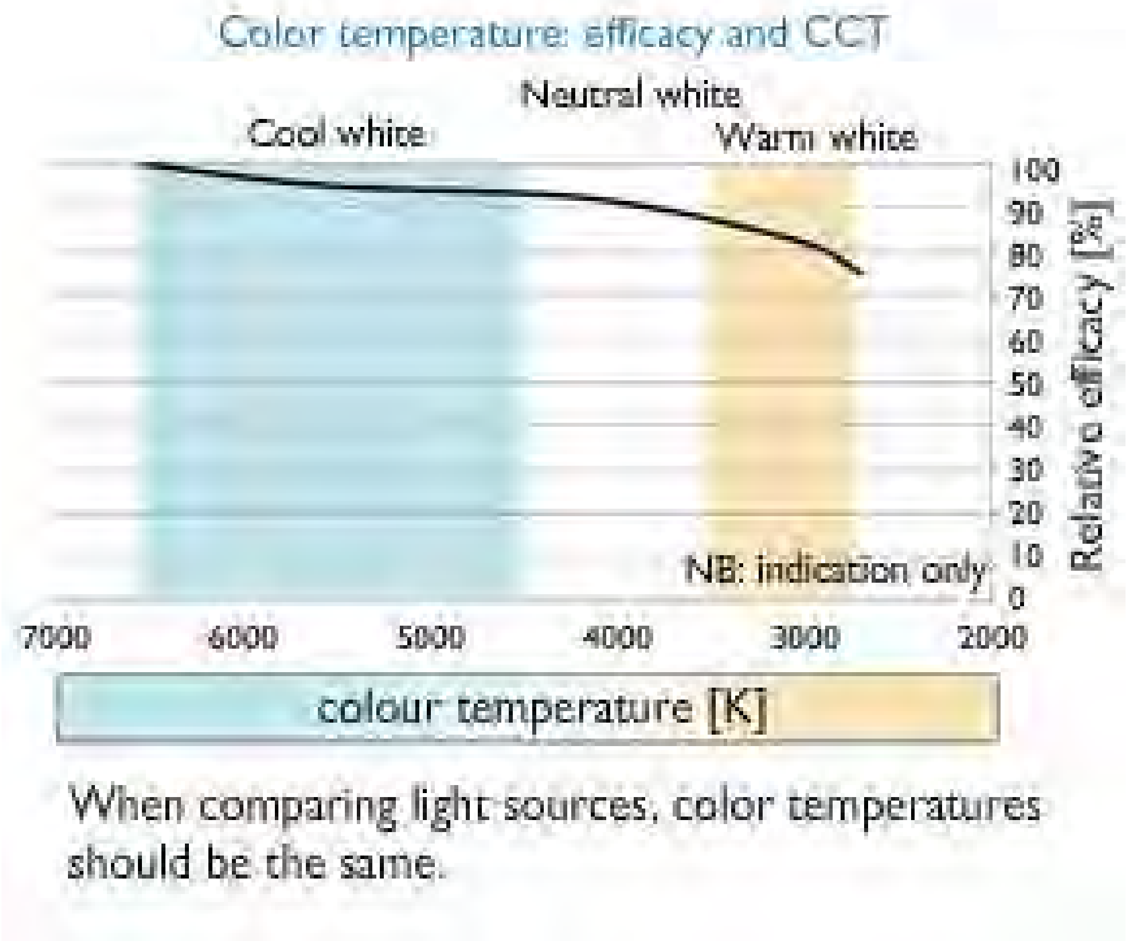
- 186 lm/W has been achieved under laboratory conditions
- Measured for milliseconds
- At cold temperature
- Not for mass production nor maintained levels - Yet
- Research indicates maximum efficacy of 254 lm/W

Efficacy

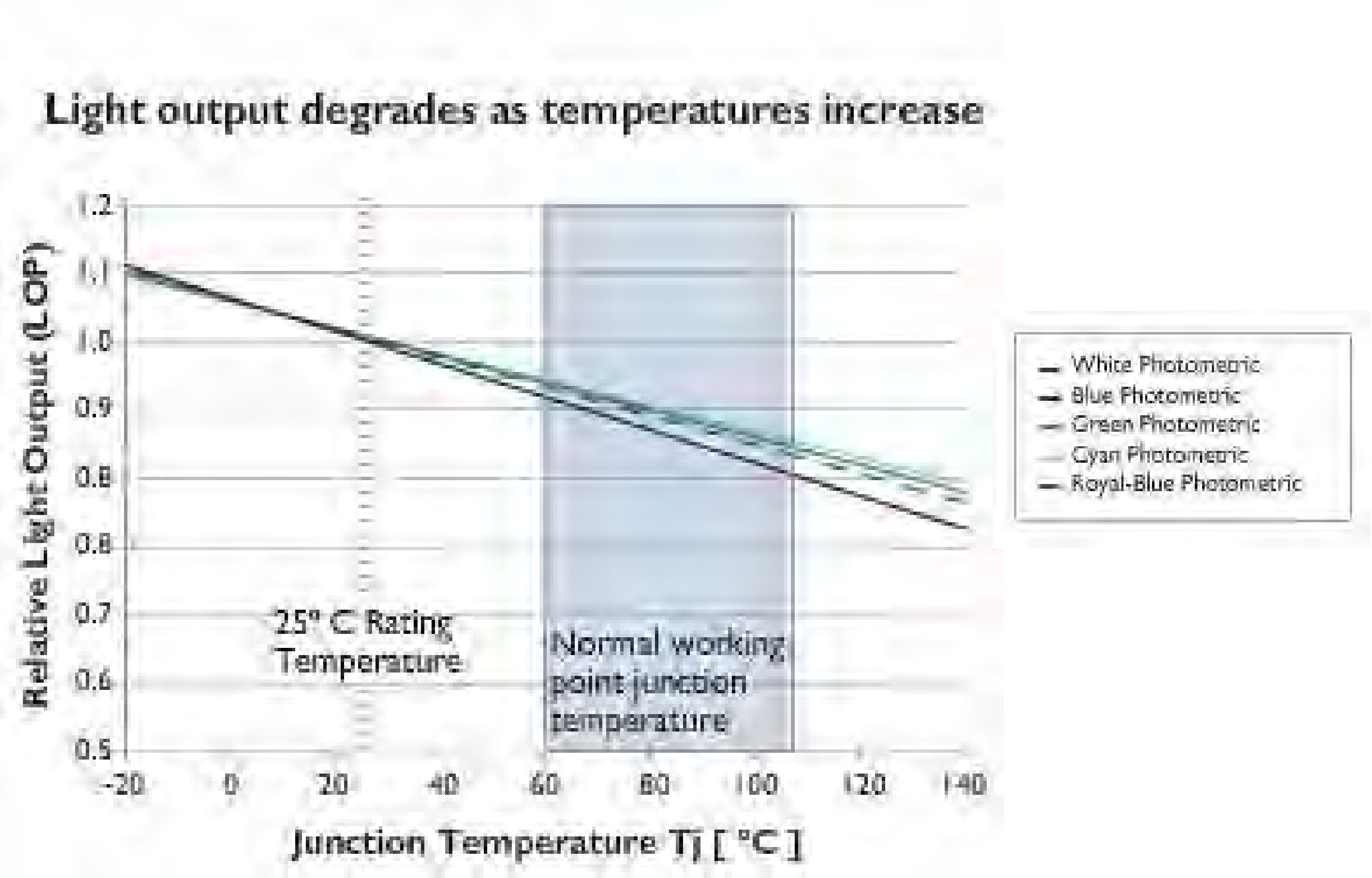


- Emerging ~ 130 lm/W white light LED sources
- Expect ~ 150 lm/W LED source performance within the next few years

Efficacy


Color temperature: efficacy and CCT
Neutral white
Cool white
Warm white
100
90
80
70
60
50
40
30
20
10
0
Relative efficacy [%]
NB: indication only
7000
6000
5000
4000
3000
2000
colour temperature [K]
When comparing light sources, color temperatures should be the same.

Efficacy


Light output degrades as temperatures increase
Relative Light Output (LOP)
1.2
1.1
1.0
0.9
0.8
0.8
0.7
0.6
0.5
-20
0
20
40
60
80
100
120
140
Junction Temperature Tj [°C]
25° C Rating Temperature
Normal working point junction temperature
White Photometric
Blue Photometric
Green Photometric
Cyan Photometric
Royal-Blue Photometric

Efficacy

Manufacturer	Lamp Type	Lumens (Initial)	Efficacy (LPW)	Instant Start		Programmed Start		Hg Content (mg)
				Rated Average Life				
				3hrs/start	12hrs/start	3hs/starrt	12hrs/start	
800 Series								
A	F32T8/SPX	2,925	91	21,000	30,000	30,000	36,000	3.0
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Energy Saving 28W								
A	F28T8/XL/SPX	2,675	96	24,000	34,000	45,000	50,000	3.0
B	FO28/XP/SS	2,725	97	24,000	40,000	40,000	42,000	3.2
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LED – 9

Fluorescent – 8

Round 8

Energy Efficiency

Efficacy

Score Card

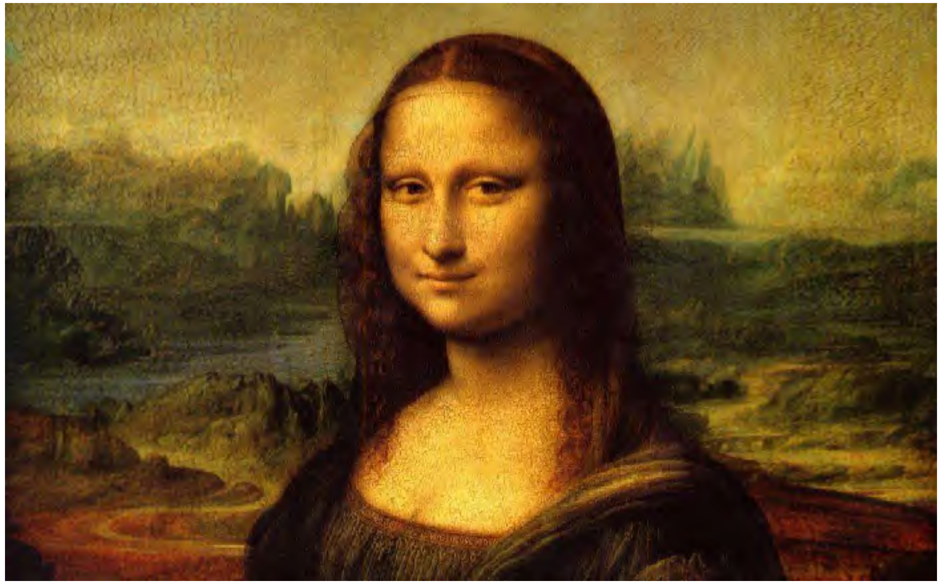
LED	Round	Fluorescent
10	1 – Light Generation	9
10	2 – CCT Options	9
7	3 – Colour Consistency	9
8	4 - CRI	8
9	5 - Life	9
7	6 - Temperature	8
7	7 - Environment	7
9	8 - Efficacy	8
67		67

It's a Draw!!!

To Discount Fluorescent for LED

I don't have to sing well.
I have auto-tune

We disagree.



The key is to recognize their respective strengths and use them

Illuminating Engineering Society

ANSI/IES RP-1-FR-12-PDF

Pratiques recommandées pour l’éclairage de bureaux

ANSI

Thank you