

# Solid State Lighting: A New Tool in Your Toolbox

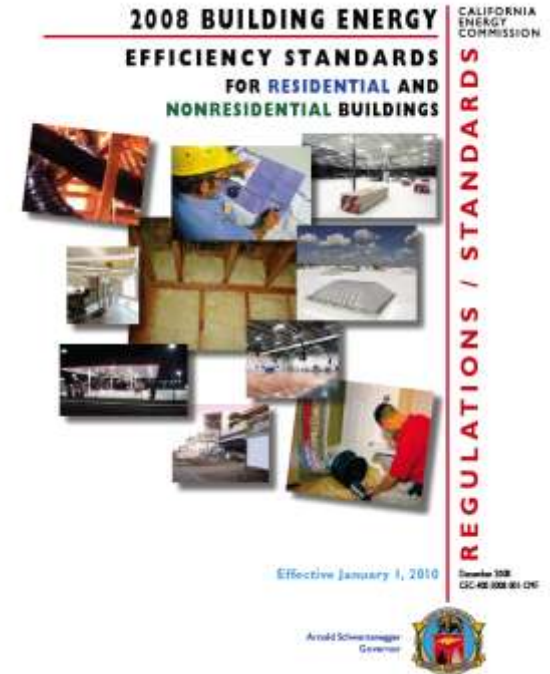
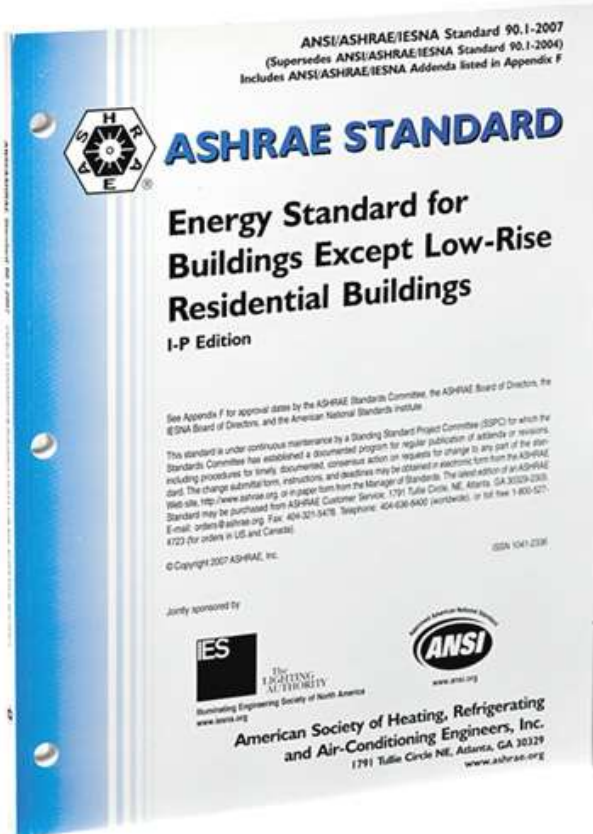
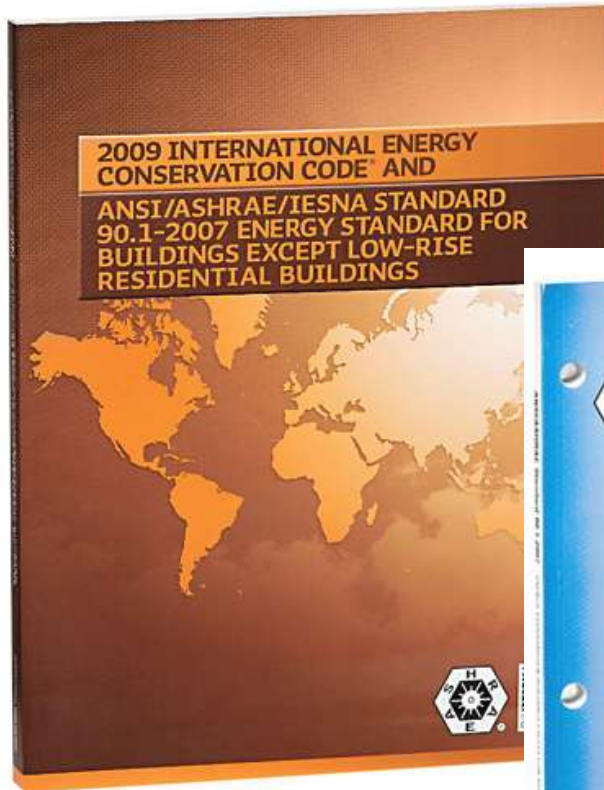
Avraham Mor, IALD, LEED AP, IESNA  
Partner, Lightswitch Architectural



# Learning Objectives

- What is Solid State Lighting (SSL)?
- What does a SSL luminaire need to produce light?
- Definitions
- SSL Design Issues
- Specification Suggestions

# It's all about ENERGY



# It's all about CREATIVITY



# Semiconductor Revolution

## INDUSTRY TRANSFORMATIONS

Word Processing



Photography



Displays



# Lighting Tools

■ Incandescent



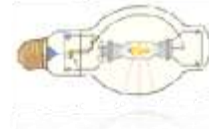
■ Halogen



■ Fluorescent



■ Arc Source



■ Gas - discharge



■ LED & OLED

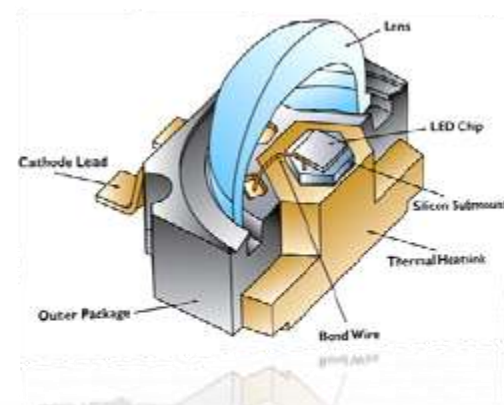
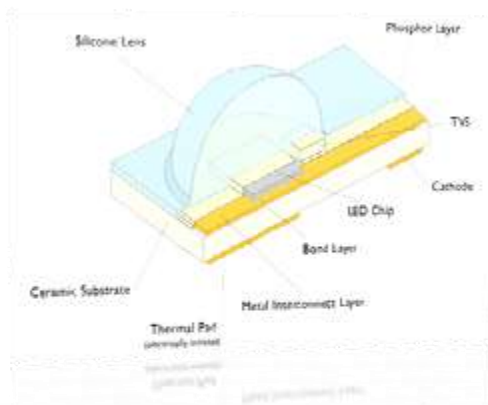


- Dimming
- Color
- Mood



# LED Background

- A semiconductor device that converts electrical energy directly into a discrete color of light
- Made from compound materials
- Made in chip fabrication factories
- Not brass, glass and gas
- White LEDs are blue LEDs + phosphor



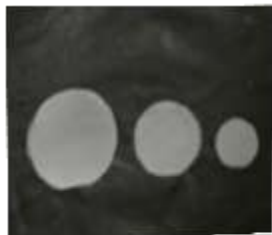
# From Silicon to Luminaire



Precursor Gases



Reactors/Epitaxy



Substrates

Materials



Wafers



Die



Package



Array



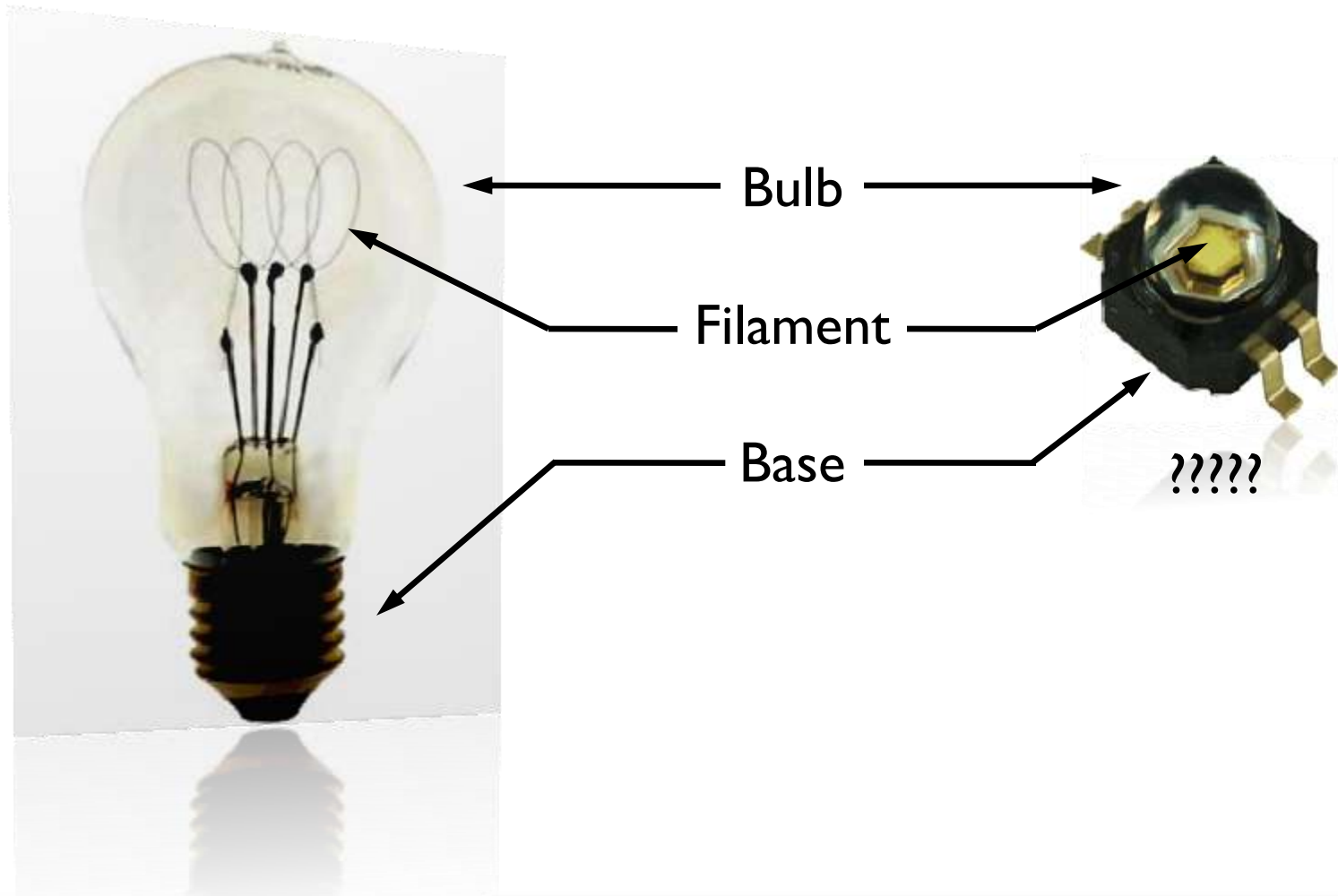
Luminaire



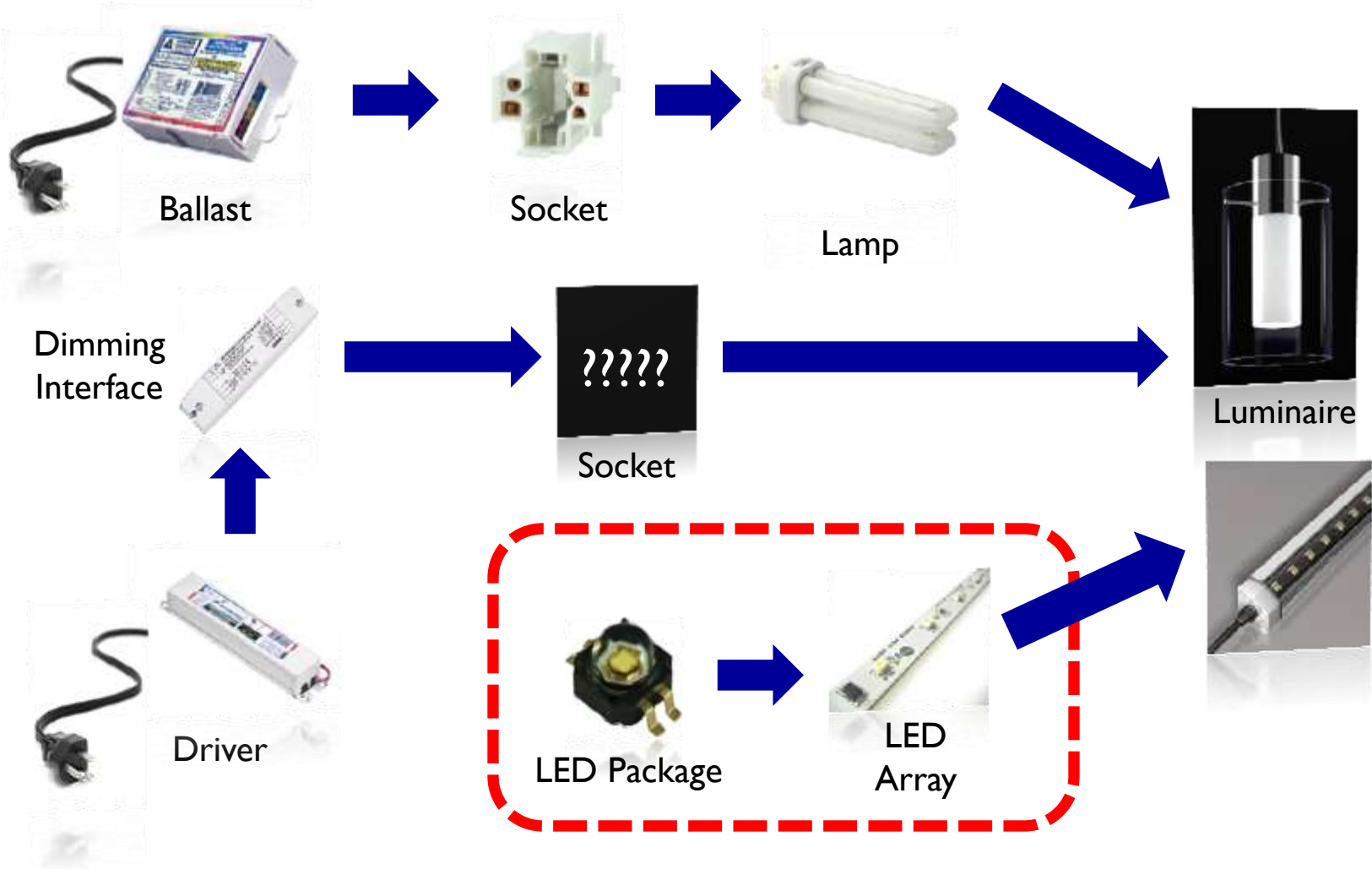
Energy



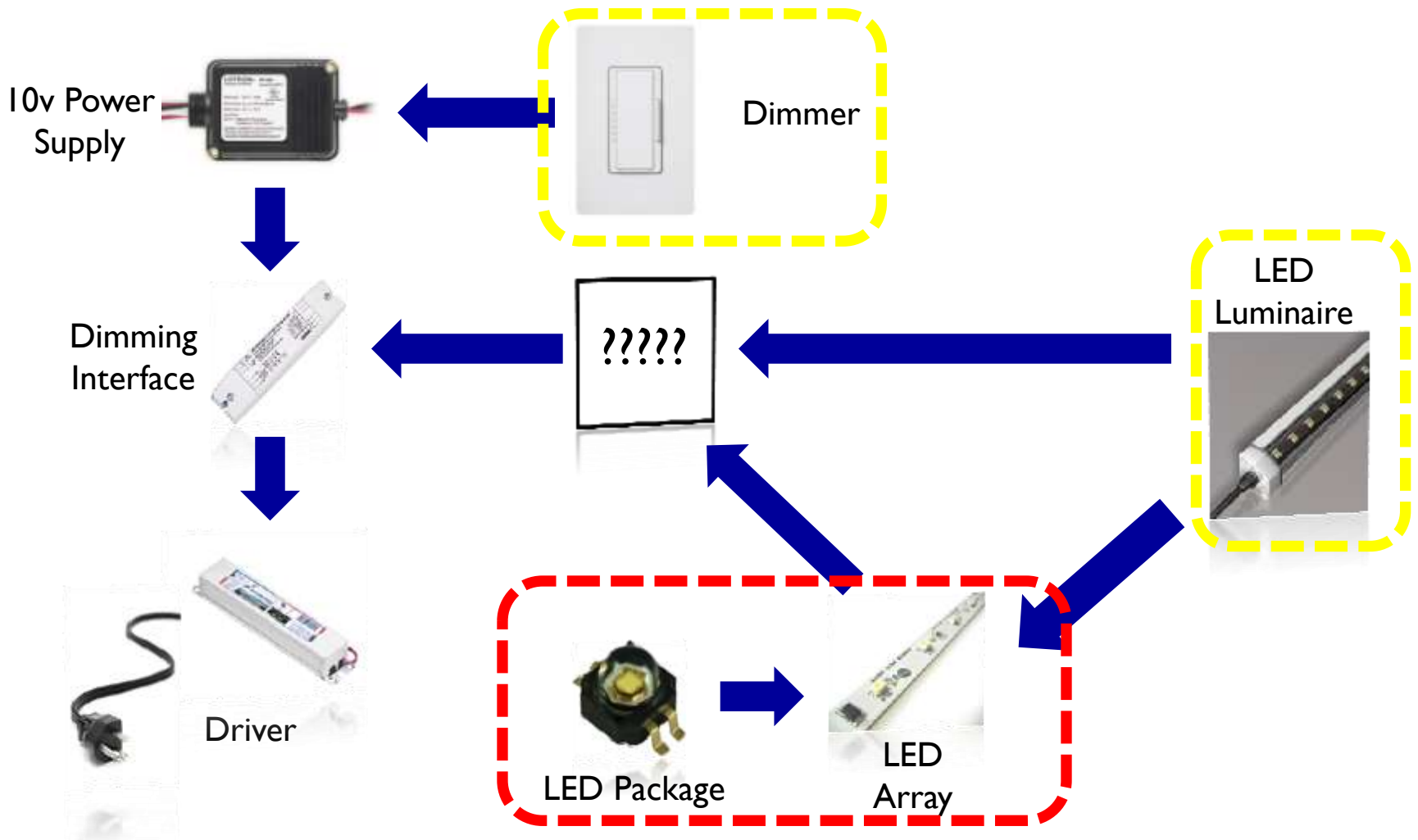
# Anatomy of a Lamp



# System Parts

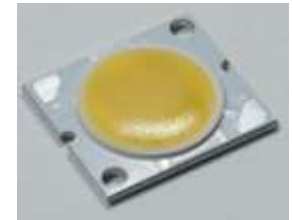


# System Parts



# Definitions

- **LED** – a semiconductor device that emits light be it ultraviolet, visible, or infrared
- **LED Die** – small block of light-emitting semiconducting material on which a functional LED circuit is fabricated
- **LED Package** – an assembly of one or more LED dies that includes wire bond
- **LED Array or Module** – an assembly of LED packages and electrical interfaces that are intended to connected to the load side of a driver



From ANSI/IES RP-16-10

# Definitions

- **LED Lamp** – an assembly comprised of an LED array or LED packages and an ANSI standard base (non-integrated and integrated)
- **LED Light Engine** – an integrated assembly comprised of LED packages or arrays, LED driver, and other optical thermal, mechanical and electrical components. Device is intended to connect through custom connector.
- **LED Driver** – a device comprising of a power source and LED control circuitry designed to operate a LED package, array, or lamp



From ANSI/IES RP-16-10

# Definitions

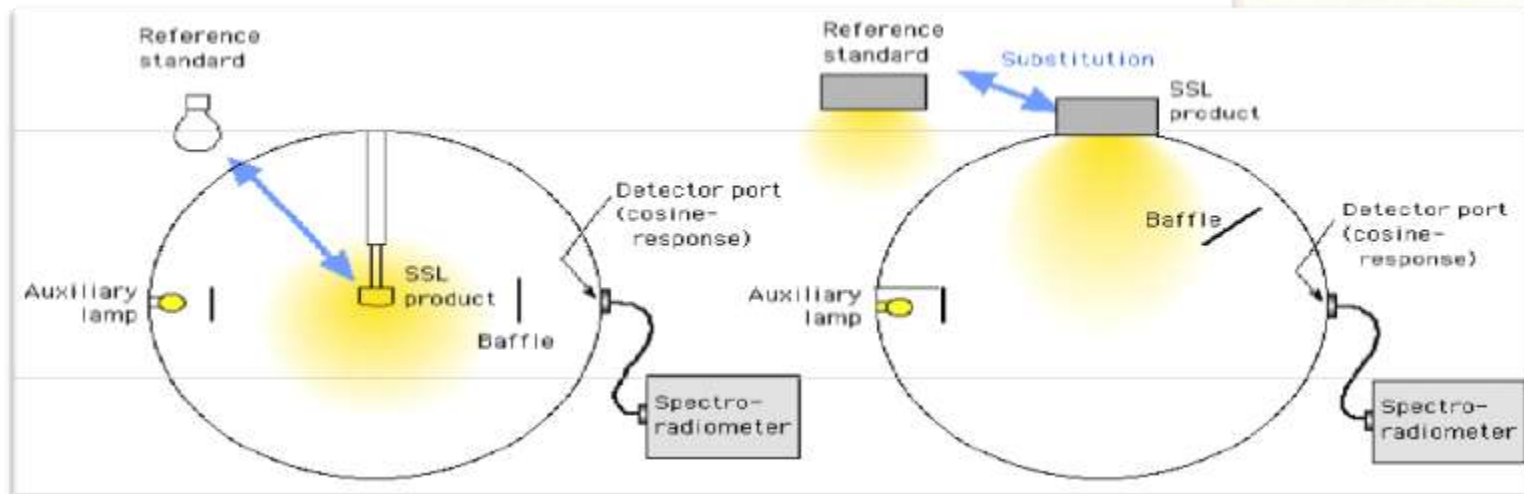
- **Bin** – a restricted range of LED performance characteristics used to delimit a subset of LEDs near a normal LED performance
- **LED Luminaire** – a complete lighting unit consisting of LED-based light emitting elements and a matched driver together with parts to distribute light, to position and protect the lighting elements, and to connect the unit to branch circuit.

From ANSI/IES RP-16-10

# Luminous Flux (LM-79)

## MEASURES LIGHT OUTPUT

- Thermally Stabilized
- Absolute Photometry
- Specifies equipment types
- Specifies environmental conditions



# Luminous Flux (LM-79)

## EXAMPLE OF AN ACTUAL TEST

- Luminaire data sheet indicates 13.3 W
- Inspection of IES file indicates 17W
- Luminaire data sheet indicates 520 lm, 39 lm/W
- Actual luminaire performance 389 lm, 22.9 lm/W
- Difference: 34% less light, 28% more power consumed, 70% less efficient

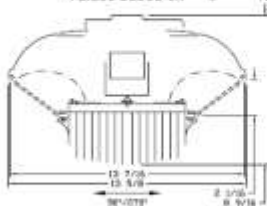
# LM-79 Reports



INDEPENDENT TESTING LABORATORIES, INC.  
 3386 LONGHORN ROAD, BOULDER, CO 80302 USA  
 PHONE (303)442-1255 • FAX (303)449-5274 • E-MAIL: [itl@boulder.com](mailto:itl@boulder.com) • WEBSITE: [www.itlboulder.com](http://www.itlboulder.com)

## ISOFOOTCANDLE LINES OF HORIZONTAL ILLUMINATION

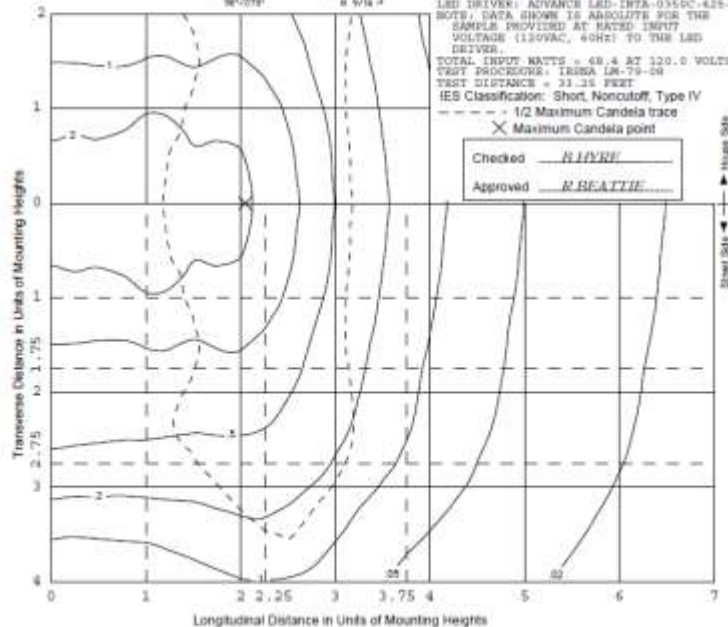
Values based on 5 foot mounting height.



REPORT NUMBER: ITL3499  
 DATE: 11/28/09  
 CATALOG NUMBER: 5\*V204-60-B-OV-RE-ASR  
 LUMINAIRE: CAST METAL UPPER HOUSING ASSEMBLY, MOLDED GRAY PLASTIC UPPER REFLECTOR SUBHOOD, FABRICATED SEMI-SPHERICAL MULTI-FACETED TITANIUM METAL REFLECTOR, 516 WHITE CIRCUIT BOARD BACK WITH 15 LEDs, EXTENDED DIFFUSE FINISHED METAL GRAY 21IN, CLEAR PLASTIC PRESUMED DROP LENS.  
 LAMP: SIXTY WHITE LIGHT EMITTING DIODES (LED) BACK WITH CLEAR HEMISPHERICAL INTEGRAL LENS, VERTICAL BASE-DOWN POSITION.  
 LED DRIVER: ADVANCE LED-DRIVER-0356C-425-PO  
 NOTE: DATA SHOWN IS ABSOLUTE FOR THE SAMPLE PROVIDED AT EXACT INPUT VOLTAGE (120VAC, 60Hz) TO THE LED DRIVER.

TOTAL INPUT WATTS = 48.4 AT 120.0 VOLTS  
 TEST PROCEDURE: IESNA LM-79-08  
 TEST DISTANCE = 31.38 FEET  
 IES Classification: Short, Noncutoff, Type IV

--- 1/2 Maximum Candela trace  
 X Maximum Candela point  
 Checked: NINNE  
 Approved: R BEATTIE



THIS REPORT IS BASED ON PUBLISHED INDUSTRY PROCEDURES. FIELD PERFORMANCE MAY DIFFER FROM LABORATORY PERFORMANCE.



LUMINAIRE TESTING LABORATORY, INC.

ISO9001  
 REGISTERED  
 TO  
 ISO9001

901 Harrison Street, Allentown, PA 18103 610-770-1044 Fax 610-770-8012 [www.luminairetesting.com](http://www.luminairetesting.com)

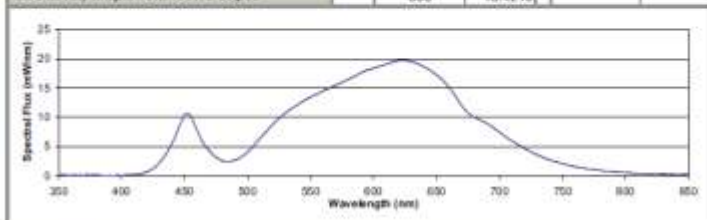
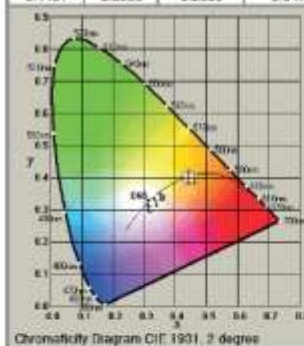
LTL Number: 16768

Date: 09-30-2009

Catalog Number: Lumar-25-LED-E-W1-120-WF-3000

Luminaire: Cast white enamel aluminum housing, no enclosure.  
 Lamp: 5 White LEDs with clear prismatic plastic optics below each.  
 LED Power Supply: One High Precision Tech LP1040-36-C0700  
 Luminaire Efficacy: 42.6 Lumens/Watt

Luminaire Input Voltage	Input Current	Luminaire Watts	Power Factor	Wavelength in nm	Spectral Flux in mW/nm	Wavelength in nm	Spectral Flux in mW/nm
120.0VAC	0.1982A	23.22W	0.977	350	0.0904	610	19.0840
Radiant Flux mW	Luminous Flux lumens	Corr. Color Temperature K	Color Rend. Index Ra	360	0.0926	620	19.6960
3478.765	988.328	2861	85.5	370	0.1049	630	19.5260
Chrome	Chrome	Chrome	Chrome	380	0.1315	640	18.6090
0.4431	0.3995	0.2565	0.347	390	0.0977	650	17.2390
				400	0.1258	660	15.1020
				410	0.2315	670	12.0010
				420	0.6937	680	10.0360
				430	2.2313	690	8.9549
				440	5.5355	700	7.4347
				450	10.3420	710	5.9332
				460	7.7029	720	4.6705
				470	4.1712	730	3.5753
				480	2.5959	740	2.7207
				490	2.6814	750	2.0704
				500	4.0668	760	1.5822
				510	6.4306	770	1.1996
				520	8.7904	780	0.8983
				530	10.7200	790	0.7369
				540	12.1820	800	0.5786
				550	13.4350	810	0.4088
				560	14.5160	820	0.3243
				570	15.4750	830	0.3020
				580	16.4330	840	0.2755
				590	17.5060	850	0.2050
				600	18.4210		



TESTING WAS PERFORMED IN ACCORDANCE WITH IES LM-79-08. Approved By: RS

# Lumen Maintenance (LM-80)

- Published and available from the IESNA
- LM-80 is not a predictive standard!
- Prescribes testing methodology only of **LED Package**
- Measurements to 6000 hours or more
- Three temperatures
- Conditions and equipment specified
- If a manufacturer provides an  $L_{70}$  value they say is LM-80 compliant it means they must have measured the full time to the  $L_{70}$  value
- IESNA TM-21 is in process to provide a simple extrapolative model, **not complete**



# LM-80 Reports



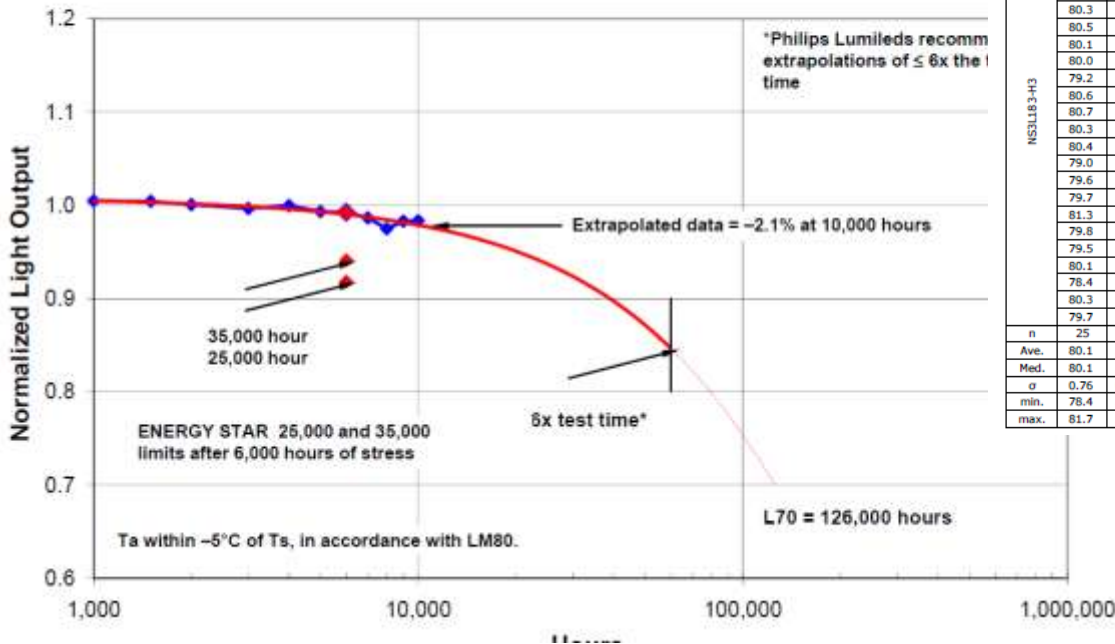
SQETC100202A  
Issue Date: February 26, 2010

LM-80 Test Report

## I. 55°C - LM-80 Required Temperature

Part Number: NS3L183-H3  
 Actual Temperature:  $T_S = 54.5^\circ\text{C}$ ,  $T_A = 51.8^\circ\text{C}$   
 Drive Current:  $I_F = 350\text{ mA}$   
 Measurement Current:  $I_F = 350\text{ mA}$   
 Air flow: Minimal air flow  
 Comments: No failure observed

**Lumen Maintenance Projection for  
 White LXM3-PWx1 LUXEON Rebel under these conditions  
 55°C, 0.35A ( $T_{\text{junction}} \cong 68^\circ\text{C}$ ) Normalized to 1 at 24 hours**



	$\Phi_v$ [lm]	$V_f$ [V]	Lumen Maintenance [%]						Chromaticity Shift $\Delta u'v'$					
			0 h (Initial)	980 h	1984 h	3016 h	4000 h	5000 h	6000 h	980 h	1984 h	3016 h	4000 h	5000 h
NS3L183-H3	81.0	3.38	101.1	100.9	99.7	98.8	98.2	97.7	0.0011	0.0007	0.0009	0.0004	0.0008	0.0009
	81.7	3.38	101.5	101.2	99.9	98.9	98.1	97.3	0.0012	0.0007	0.0006	0.0005	0.0005	0.0006
	80.0	3.38	102.2	102.0	100.8	99.7	99.1	98.3	0.0011	0.0008	0.0007	0.0004	0.0008	0.0007
	79.2	3.39	102.6	102.3	101.0	100.0	99.1	98.4	0.0013	0.0010	0.0009	0.0006	0.0008	0.0009
	81.4	3.38	101.3	101.0	99.5	98.5	97.7	97.1	0.0011	0.0006	0.0008	0.0005	0.0008	0.0009
	79.9	3.38	102.5	102.3	101.0	100.0	99.3	98.0	0.0011	0.0009	0.0008	0.0006	0.0007	0.0010
	80.3	3.39	101.2	100.9	99.7	98.9	98.4	98.2	0.0016	0.0011	0.0011	0.0010	0.0012	0.0013
	80.5	3.38	102.2	101.8	100.4	99.6	99.0	98.5	0.0013	0.0009	0.0010	0.0007	0.0011	0.0009
	80.1	3.38	101.6	101.2	99.9	99.0	98.3	97.6	0.0010	0.0006	0.0007	0.0004	0.0007	0.0006
	80.0	3.38	102.1	101.9	100.6	99.8	99.1	98.4	0.0015	0.0009	0.0011	0.0008	0.0010	0.0011
	79.2	3.38	102.4	102.2	100.8	99.7	99.0	98.1	0.0015	0.0008	0.0008	0.0005	0.0007	0.0008
	80.6	3.38	101.6	101.2	100.0	98.7	97.7	96.7	0.0013	0.0009	0.0009	0.0004	0.0008	0.0007
	80.7	3.38	101.5	101.1	99.8	98.9	98.1	97.3	0.0012	0.0009	0.0009	0.0005	0.0006	0.0007
	80.3	3.38	102.2	101.8	100.2	99.0	98.2	97.2	0.0011	0.0007	0.0009	0.0003	0.0007	0.0007
	80.4	3.38	102.4	102.3	101.3	100.3	99.7	98.9	0.0014	0.0010	0.0010	0.0007	0.0008	0.0009
	79.0	3.38	102.7	102.5	101.1	99.9	99.3	98.7	0.0014	0.0009	0.0009	0.0005	0.0007	0.0009
	79.6	3.38	102.7	102.5	100.9	100.0	99.1	98.5	0.0014	0.0008	0.0008	0.0007	0.0006	0.0008
	79.7	3.39	102.3	102.2	100.8	99.7	99.0	98.1	0.0011	0.0006	0.0008	0.0005	0.0005	0.0009
	81.3	3.36	101.0	101.0	99.7	98.9	98.3	97.8	0.0010	0.0007	0.0007	0.0006	0.0006	0.0008
	79.8	3.38	101.9	101.7	100.4	99.4	98.7	98.2	0.0012	0.0010	0.0009	0.0005	0.0007	0.0007
	79.5	3.38	102.1	101.4	100.0	99.0	98.7	98.0	0.0012	0.0011	0.0011	0.0007	0.0006	0.0009
	80.1	3.38	101.6	101.5	100.0	98.9	97.9	97.0	0.0012	0.0008	0.0007	0.0005	0.0006	0.0007
	78.4	3.38	103.1	103.4	101.9	101.1	99.9	99.3	0.0017	0.0012	0.0012	0.0008	0.0011	0.0013
	80.3	3.39	101.7	101.7	100.5	99.5	98.9	98.3	0.0011	0.0008	0.0007	0.0005	0.0006	0.0009
	79.7	3.38	101.9	102.0	100.8	99.7	99.0	98.3	0.0017	0.0011	0.0012	0.0007	0.0010	0.0010
n	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Ave.	80.1	3.379	102.0	101.8	100.4	99.4	98.7	98.0	0.0013	0.0009	0.0009	0.0006	0.0008	0.0009
Med.	80.1	3.379	102.1	101.8	100.4	99.5	98.9	98.1	0.0012	0.0009	0.0009	0.0005	0.0007	0.0009
$\sigma$	0.76	0.006	0.549	0.628	0.612	0.629	0.598	0.631	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
min.	78.4	3.358	101.0	100.9	99.5	98.5	97.7	96.7	0.0010	0.0006	0.0006	0.0003	0.0005	0.0006
max.	81.7	3.390	103.1	103.4	101.9	101.1	99.9	99.3	0.0017	0.0012	0.0012	0.0010	0.0012	0.0013

# LED Package/Luminaire Source Life

Lifetime Definitions:

- INC, FL, HID = Average time to failure
- LED = Approximate time to 70% lumen depreciation
  - FL loss typically 25% over life
  - INC loss typically 15-20% over life
- DOE Recommendation...  
“Longer than any other source  
but it will need to be replaced”



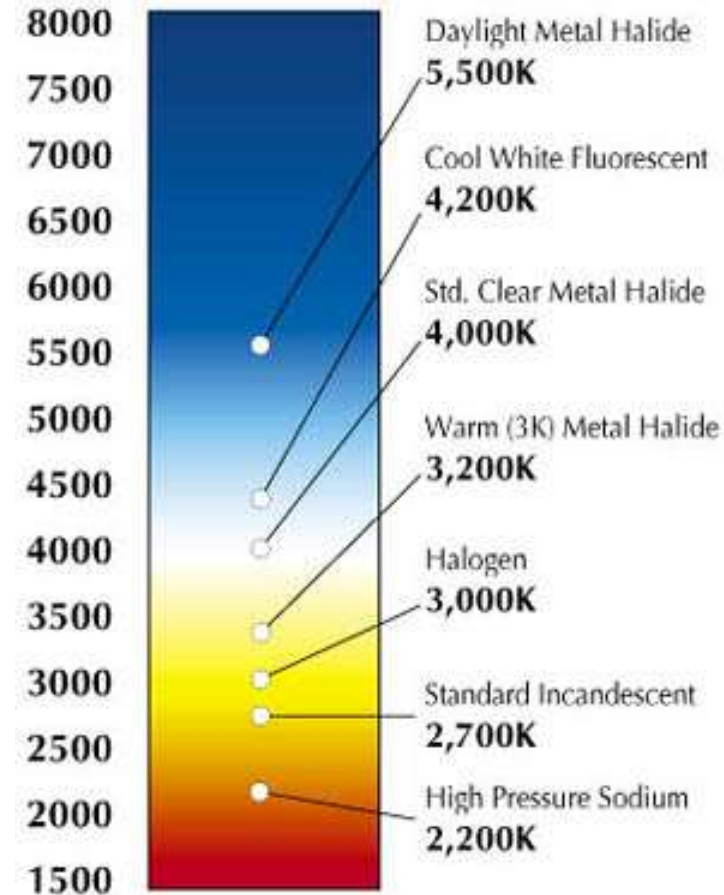
# LED Luminaire Heat

- LED Packages generate heat, but very little is radiant energy in the visible spectrum.
  - SSL systems are NOT 100% efficient
  - Power Supply + LED + Optics
- Often LED Packages are likely not the limiting device



# Typical CCT or CT's

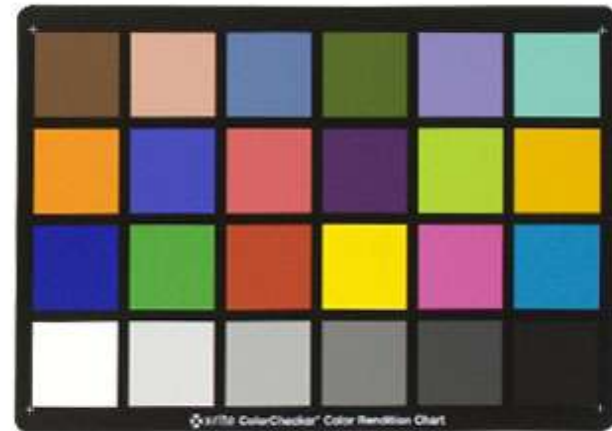
Clear blue sky	8500K
Daylight Fluorescent	6300 CCT
Clear Mercury Vapor	6000 CCT
Clear Metal Halide	4500 CCT
“Cool” fluorescent	4100 CCT
Tungsten-halogen	3200K
“Warm” fluorescent	3000 CCT
Incandescent	2700K
High pressure sodium	2200 CCT



# Color Rendering Index

- **CRI - 8 standardized reference “colors” to represent colored objects being illuminated by the lamp in question**

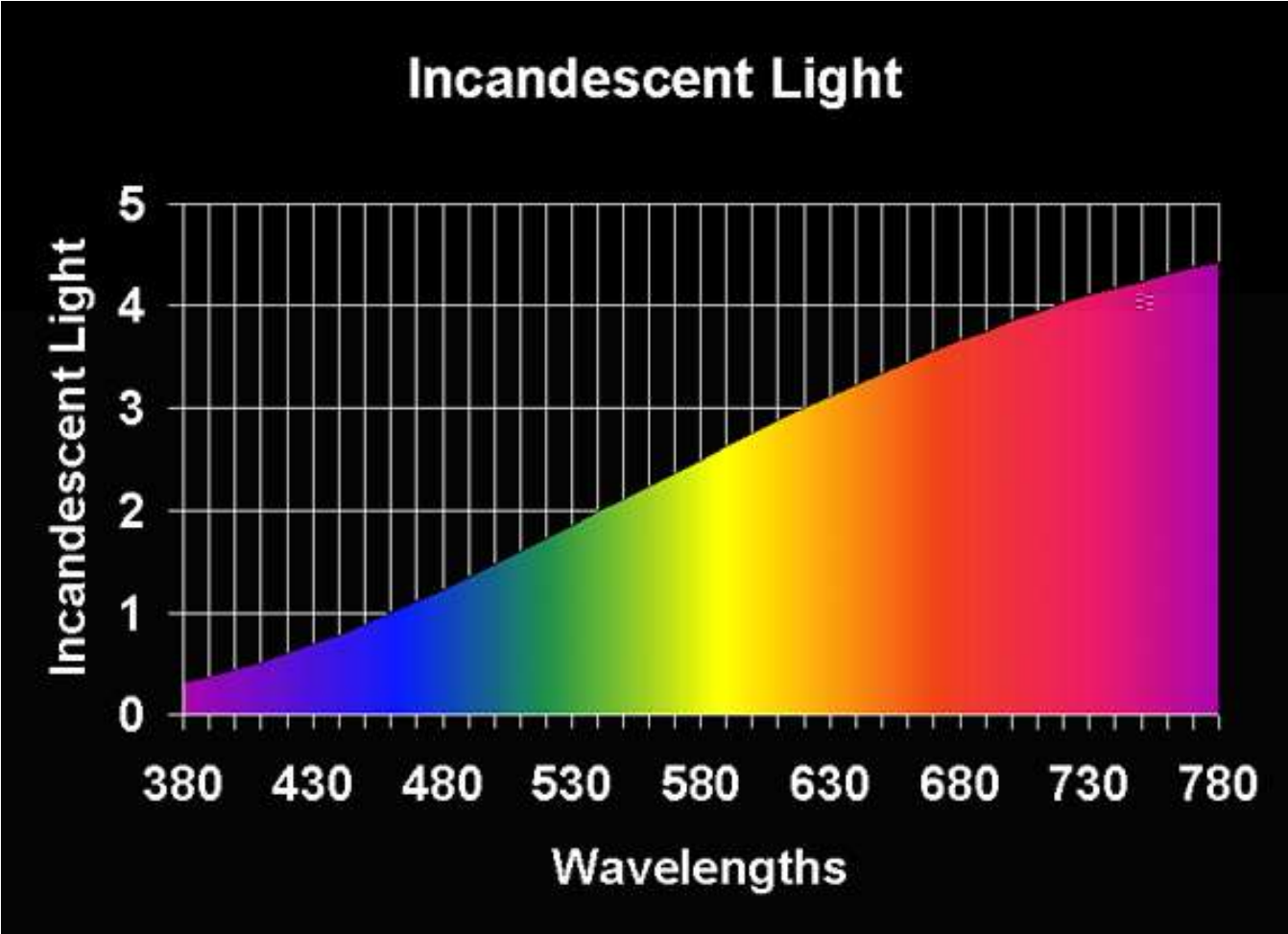
Images from NIST website



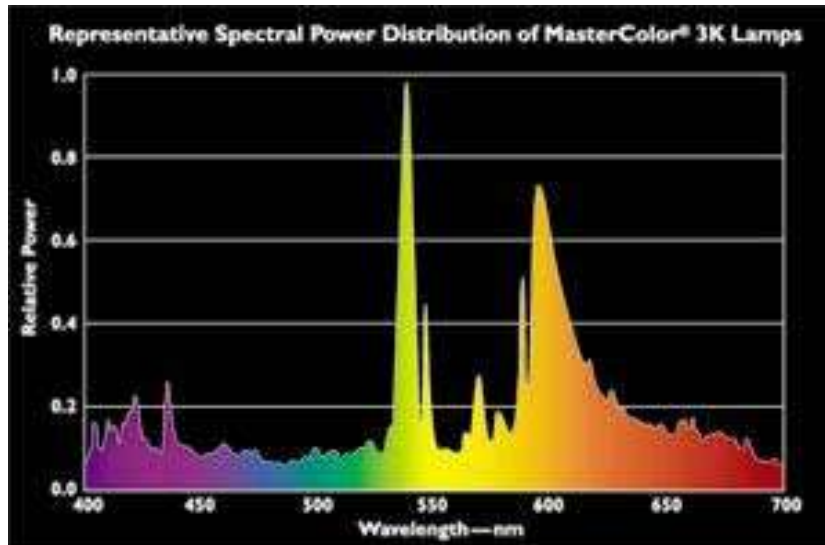
- **CQS - 15 Munsell samples to represent colored objects being illuminated by the lamp in question**



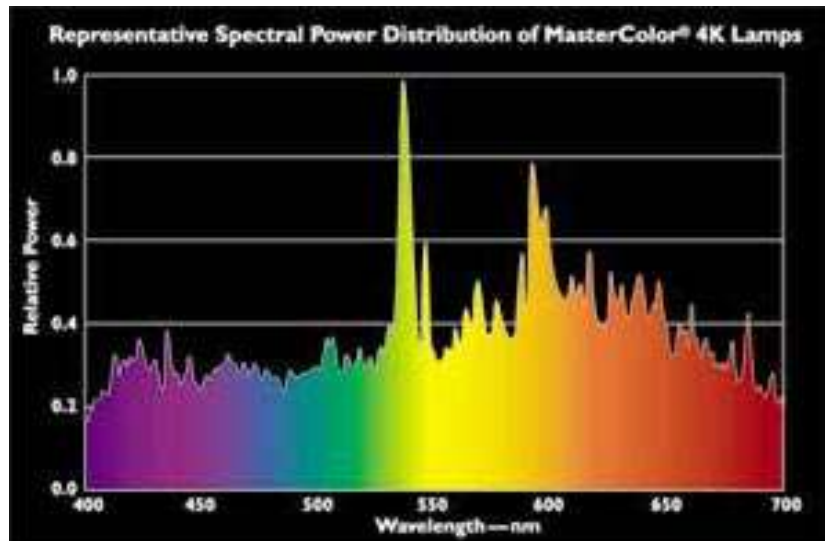
# Incandescent



# Ceramic Metal Halide

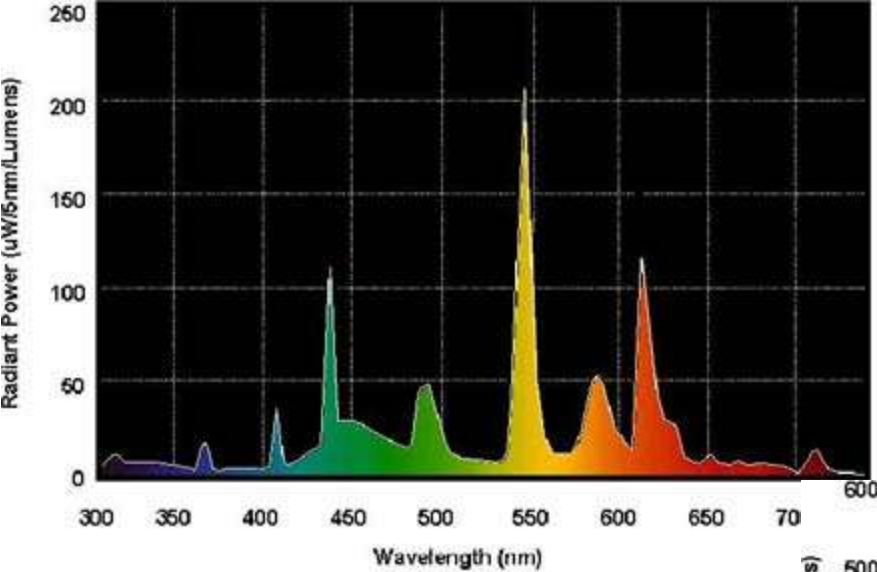


3000 K  
MasterColor® 82 CRI



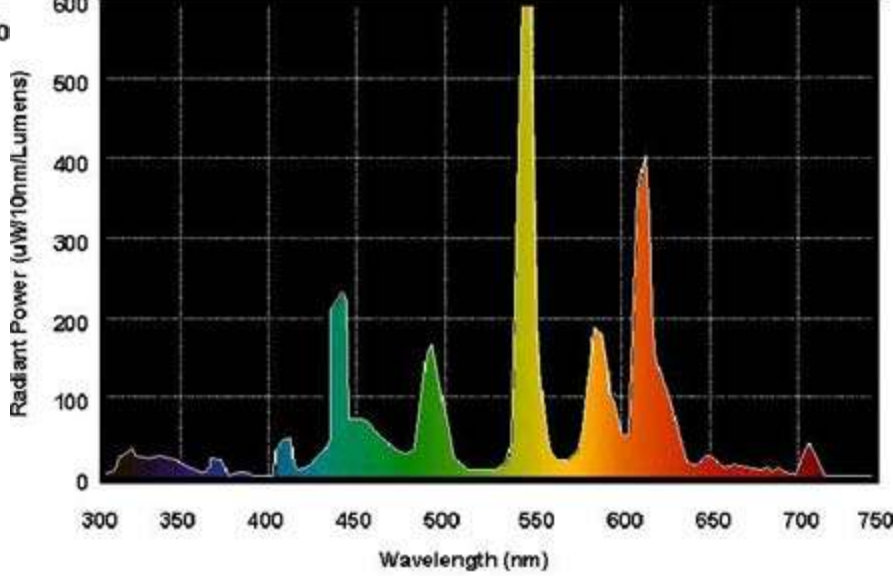
4000 K  
MasterColor® 90 CRI

# Fluorescent

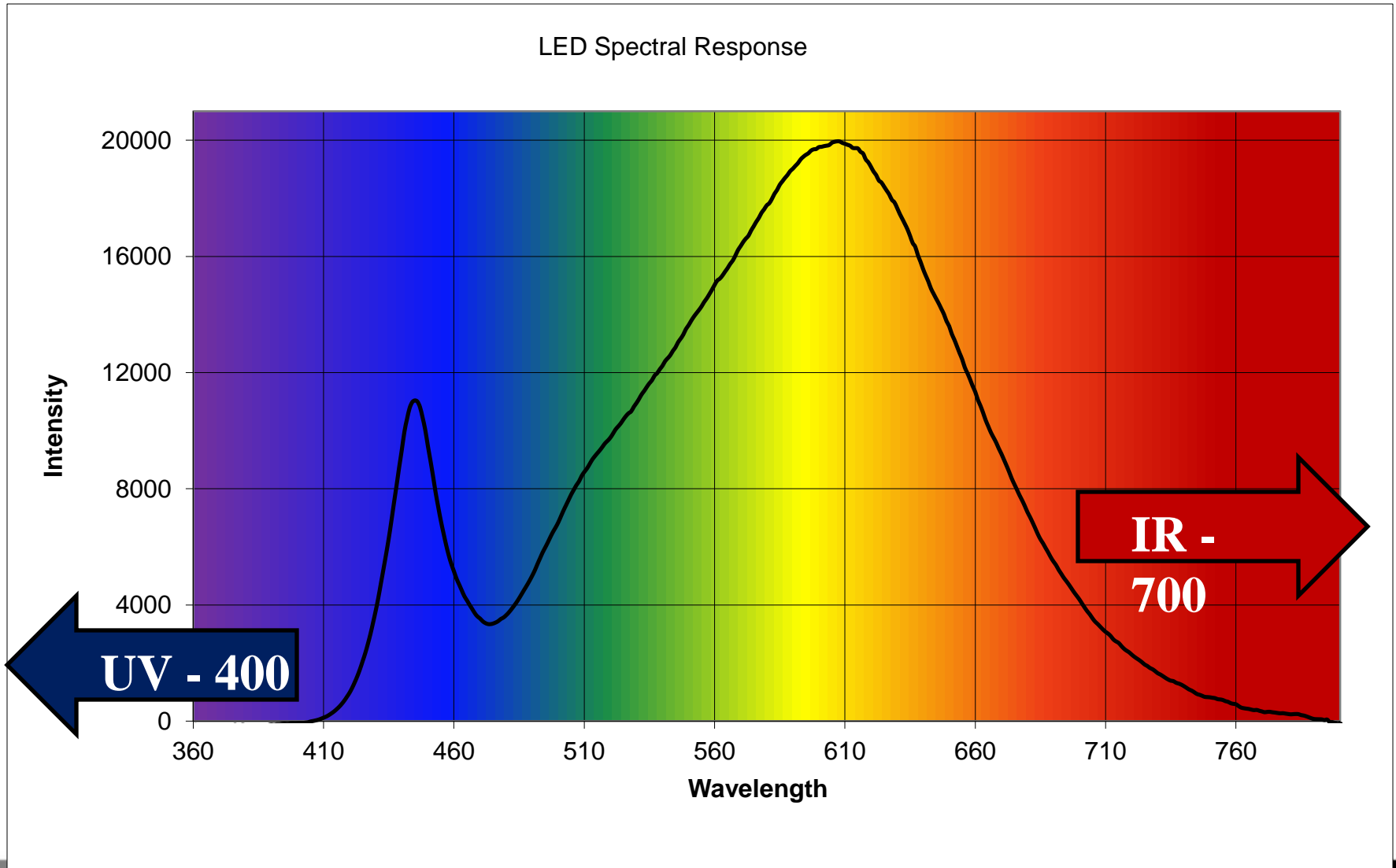


70 CRI

80 CRI



# LED Package



# Color



WARM



COOL

Warm Happy Shot According to Vivian's LA Agent's Taste

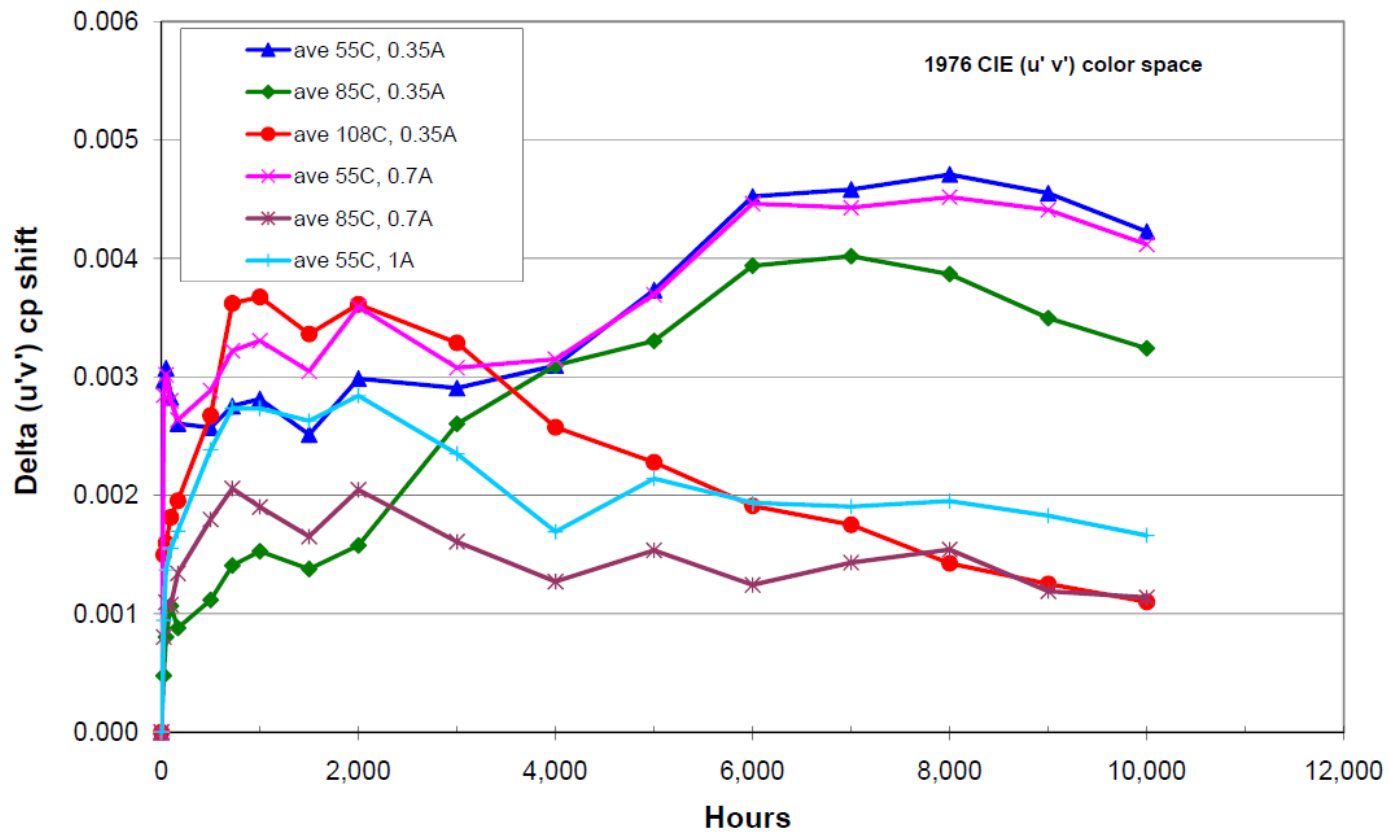


FINAL IMAGE SELECTION



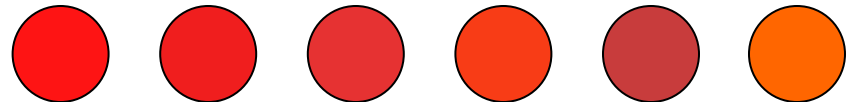
# Color Shift Over Time

Average Color Point Shift for White LXM3-PWx1  
LUXEON Rebel under these conditions  
all six LM-80 Test Report conditions, 0 to 10,000 hours



# Color Consistency

- LED packages are sorted into bins by a process called “binning”
- Binning is based on
  - Wavelength
  - Light Output
- Not all 3000K LED packages are the same 3000K
  - As with ALL lamps



# National Recognized Testing Labs

- Underwriters Laboratories – UL
- Intertek – ETL
- Canadian Standards Association – CSA

NRTL listing is **REQUIRED** for commercial use of **ANY** electrical product





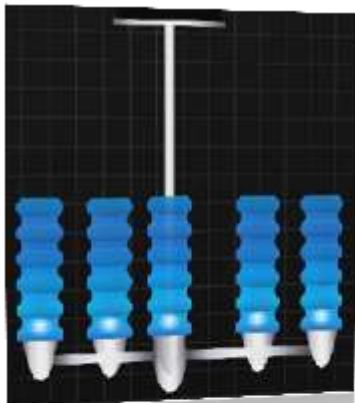
# Drivers & Dimming



Manufacturer	Model	Description	Dimming range
Lutron	Hi-lume LED driver	Driver	100% - 1%
Advance	Xitanium	Current Driver	Not Specified
Advance	Xitanium	PWM Driver	100% - off
Color Kinetics/Philips	eW PowerCore	Strip Light	100% - 15%
Color Kinetics/Philips	eW Profile : 11"	Under Cabinet Strip Light	100% - 15%
Color Kinetics/Philips	eW Profile : 41"	Under Cabinet Strip Light	100% - 15%
Color Kinetics/Philips	eW Downlight	Downlight	100% - 15%
Cooper/Halo	Downlight	6" round downlight	
Cree/LLF	LR4	4" Downlight	100% -20%
Cree/LLF	LR6	6" Downlight	100% - 20%
Cree/LLF	LR6 - 230V	6" Downlight	100% - 20%
Cree/LLF	LR24	24" x 24"	100% - 5%
GE Lumination	LED Cove light	Cove Light	100% - 3%
Juno	Track	Cove Light	Not Specified
Osram/Sylvania	OT Dim	Driver	100% - Off

# Serviceability

How is the “Lamp” going to be changed?



# DOE Energy Star Criteria

- 8 nominal CCTs
- 4-step Color Spatial Uniformity
- 7-step Color Maintenance
- CRI  $\geq 75$  for indoor
- Off-state Power prohibited

Exception for integral controls, limited to 0.5W

- 3 Year Warranty
- Thermal Management



# Energy Star

- [www.energystar.gov](http://www.energystar.gov)

## Certification Mark



Use the Certification Mark as a label on products, homes, and buildings that meet or exceed ENERGY STAR performance guidelines.

See special applications:

- Insulation (pages 9.2-9.3);
- HVAC (pages 6.6-6.7).

## Partnership Marks



Use the Partnership Mark to promote an organization's commitment to and partnership in the ENERGY STAR Program.



# Lighting Facts

■ [www.lightingfacts.com](http://www.lightingfacts.com)

**Light Output/Lumens**  
Measures light output. The higher the number, the more light is emitted.  
Reported as "Total Integrated Flux (Lumens)" on LM-79 test report.

**Watts**  
Measures energy required to light the product. The lower the wattage, the less energy used.  
Reported as "Input Power (Watts)" on LM-79 report.

**Lumens per Watt/Efficacy**  
Measures efficiency. The higher the number, the more efficient the product.  
Reported as "Efficacy" on LM-79 test report.

**IESNA LM-79-2008**  
Industry standardized test procedure that measures performance qualities of LED luminaires and integral lamps. It allows for a true comparison of luminaires regardless of the light source.

**Registration Number**  
**Model Number**  
**Type**

Brand X

**lighting facts**<sup>CM</sup>  
A Program of the U.S. DOE

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**Light Output (Lumens)** 840

**Watts** 9

**Lumens per Watt (Efficacy)** 93

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**Color Accuracy** 87  
Color Rendering Index (CRI)

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**Light Color** 2900 (Warm White)  
Correlated Color Temperature (CCT)

Warm White    Bright White    Daylight

2700K    3000K    4500K    6500K

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All results are according to IESNA LM-79-2008: Approved Method for the Electrical and Photometric Testing of Solid State Lighting. The U.S. Department of Energy (DOE) verifies product test data and results. Products qualified under the DOE ENERGY STAR program have the ENERGY STAR mark on the label.

Visit [www.lightingfacts.com](http://www.lightingfacts.com) for the Label Reference Guide.

Registration Number: NRC238714170023  
Model Number: 18758CH15642854FQ1123493  
Type: 18758CH15642854FQ1123493

**Brand**

**Color Rendering Index (CRI)**  
Measures color accuracy.  
Color rendition is the effect of the lamp's light spectrum on the color appearance of objects.

**Correlated Color Temperature (CCT)**  
Measures light color.  
"Cool" colors have higher Kelvin temperatures (3600-5500 K).  
"warm" colors have lower color temperatures (2700-3500 K).  
Color temperatures higher than 6500 are outside of the defined region for white light, but may be appropriate for outdoor applications.

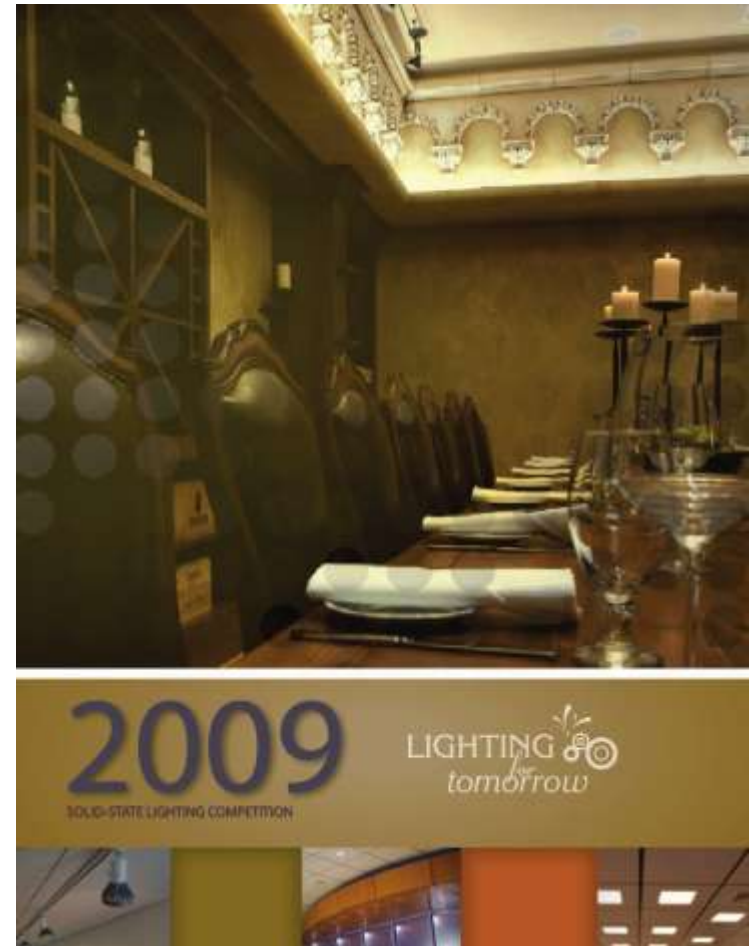
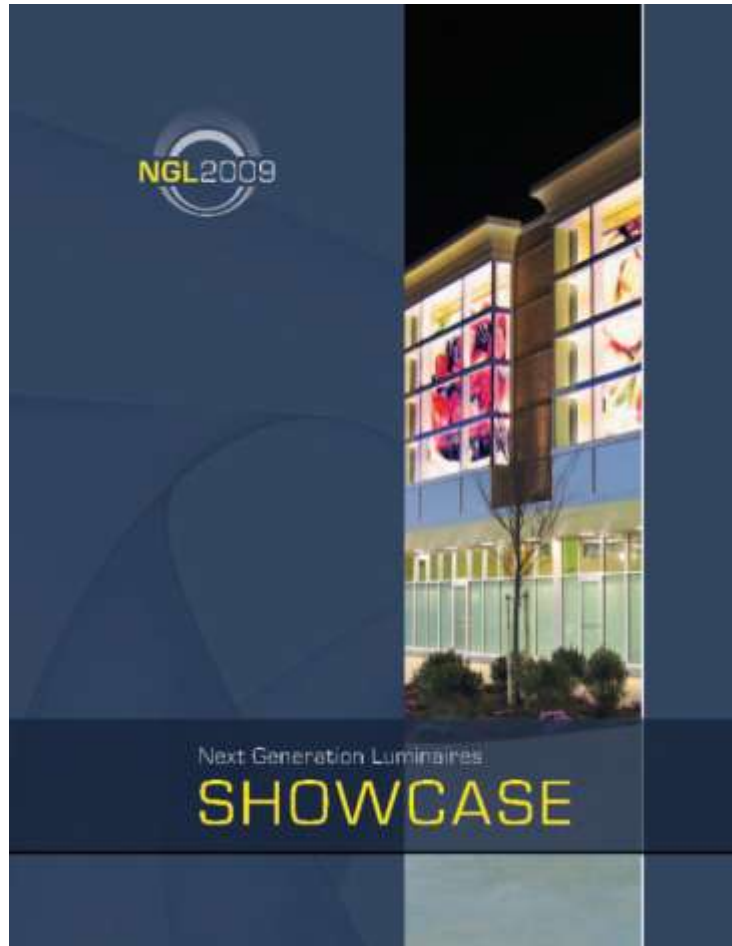
US Department of Energy Lighting Facts Label

BEWARE!

# DOE Competitions

[www.ngldc.org](http://www.ngldc.org)

[www.lightingfortomorrow.org](http://www.lightingfortomorrow.org)

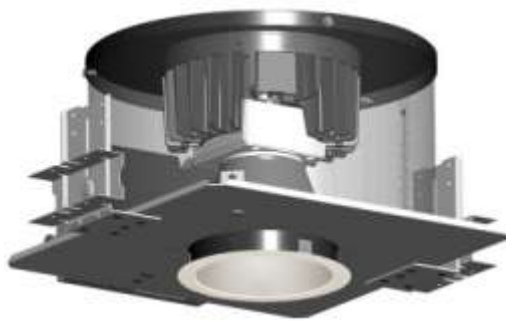


# “L” Prize

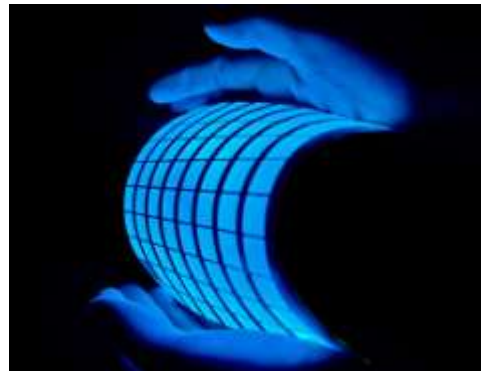
- [www.lightingprize.com](http://www.lightingprize.com)
- **60W Incandescent Replacement Lamp**
  - More than 90 lm/W
  - Less than 10 watts
  - More than 900 lumens
  - More than 25,000 hour life
  - More than 90 CRI
  - Between 2700–3000 K CCT
- **PAR 38 Halogen Replacement Lamp**
- **21<sup>st</sup> Century Lamp**



# New Products



Squares



# Exterior Products



# Questions to Ask

Is there an LM-79 testing report for the luminaire?

Has the specific luminaire been thoroughly heat tested? Can you provide a test report? What ambient temperatures did you assume?

Does the information from above exceed the LM-80 data for the LED package you use? Can you provide proof?

Who's LED package do you use in this product?

What is the process to replace defective LED packages or arrays in the luminaire?

Do you have a written color constancy policy for the luminaire? How do you match color and light output from luminaire to luminaire?

Is there a written end of life policy for the luminaire?

# Questions to Ask

Are all parts of the luminaire (LED packages, LED array, driver, driver enclosure, dimming interface, and any other parts) provided by and covered by the luminaire manufacturers warranty? How detailed and complete is the warranty?

Does the warranty include material and labor when replacing defective product?

Does the warranty include a policy for replacing luminaires where colors do not match? Who makes the call on colors not matching?

What products are required for the luminaire to dim? Has it been tested with the specific dimmer you are using?

# Our SSL Requirements

- NRTL Label
- LM-79 Photometry & Test Report
- At least two samples of the same CCT
- Written Luminaire Color Constancy Policy
- Written Luminaire End of Life policy
- Energy Star & Lighting Facts Label
- NGL or LFT Reviewed
- Digital controls DALI, ACN, or 120v control
- All system components from SSL manufacture with warranty and labor to fix/replace
- Commissioning and Dealer/Distributor Supplied



Avraham M. Mor, IALD, LEED AP,  
IESNA

Partner , Lightswitch Architectural

[amor@lightswitch.net](mailto:amor@lightswitch.net)  
312.288.8777 x101

[architecture.lightswitch.net](http://architecture.lightswitch.net)  
[avisblog.architecture.lightswitch.net](http://avisblog.architecture.lightswitch.net)

### Lighting Your Vision with Responsible Design™

Lightswitch Architectural is a premier architectural lighting design firm whose cutting edge lighting designs make it a leader in the industry. Known for innovation, attention to detail, professionalism and client service, we have a proven track record of delivering designs that are exciting, dynamic and visionary – on time and on budget.

Principals and staff members are highly trained industry professionals who understand the importance of communication. We work with property owners, developers, architects and property managers on projects such as corporate offices and exteriors, residential properties, museums, schools, outdoor events and hotels.

