lighting design lab

A Northwest utility funded lighting education facility promoting commercial and industrial energy conservation.

THE BASICS of LEDs

DEVELOPED BY:

Eric Strandberg, LC & Jeff Robbins, LC, MIES

PRESENTED BY:

Jeff Robbins

Fall, 2012

LIGHTING DESIGN LAB

A Northwest utility funded lighting education facility promoting commercial and industrial energy conservation.

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- Lighting Classes (local and regional)
- Demonstration Area
- LDL LED Qualified Products List
- Lighting Consultations
- Website Resources
- Outdoor Lighting Center
- Technical Information
- Product Evaluations
- Mock-Up Facility
- Lighting Library
- Tours of Facility
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Lighting Design Lab
2915 4th Avenue South
Seattle, WA 98134
Ph : 206.325.9711
Ph : 800.354.3864
Fx : 206.329.9532
info@lightingdesignlab.com
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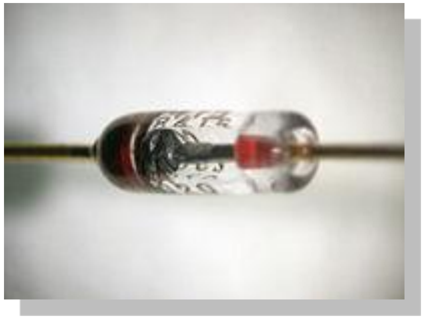
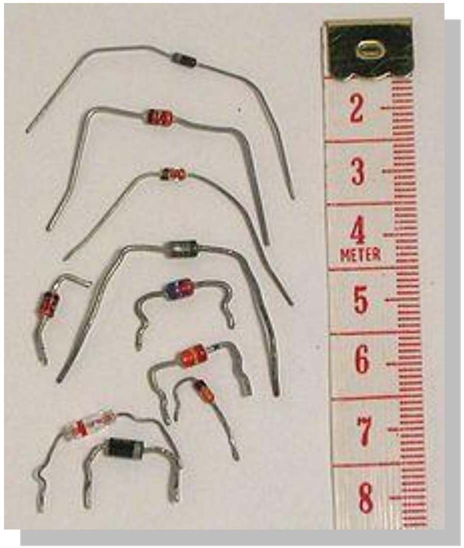
Diode Defined

- In electronics, a **diode** is a component that restricts the direction of movement of charge carriers. Essentially, it allows an electric current to flow in one direction.
- In simple terms, a switch.





LED Defined

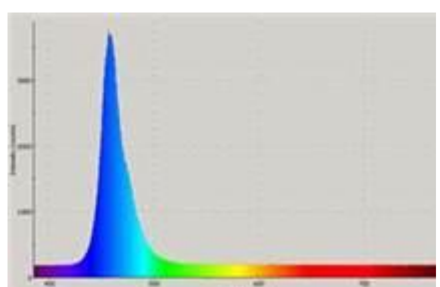
- A Light Emitting Diode is a semiconductor device that emits visible light of a certain color, and is fundamentally different from conventional light sources such as incandescent, fluorescent, and gas-discharge lamps, in that an LED:
  - uses no gas or filament, has no glass bulb,
  - and no failure-prone moving parts.

A Brief History

- In 1962 the first red LED was developed by Nick Holonyak at G.E. Throughout the 60’s red LEDs were ued as small indicator lights on electronic devices.
- Green and yellow LEDs were introduced in the early 70’s, and were used in electronics, traffic signals, exit signs, and watches, etc.

A Brief History, (cont.)

- By 1990, LEDs of one lumen output were available. In 1993, Shuji Nakamura at Nichia created the first high-brightness blue LED, making it possible to RGB mix to any color.
- This was followed in 1996 by the development of Phosphor White LEDs, which combined a blue or ultraviolet LED with a phosphor coating that produced white light.



A Brief History, (cont.)

- By 2005, output levels of 100 lumens were possible. white light LEDs became available in various shades. LEDs began competing with conventional light sources and fixtures in general illumination applications.
- The Department of Energy expects LED technology to become the preferred method of lighting in homes and offices by 2025.

Advantages

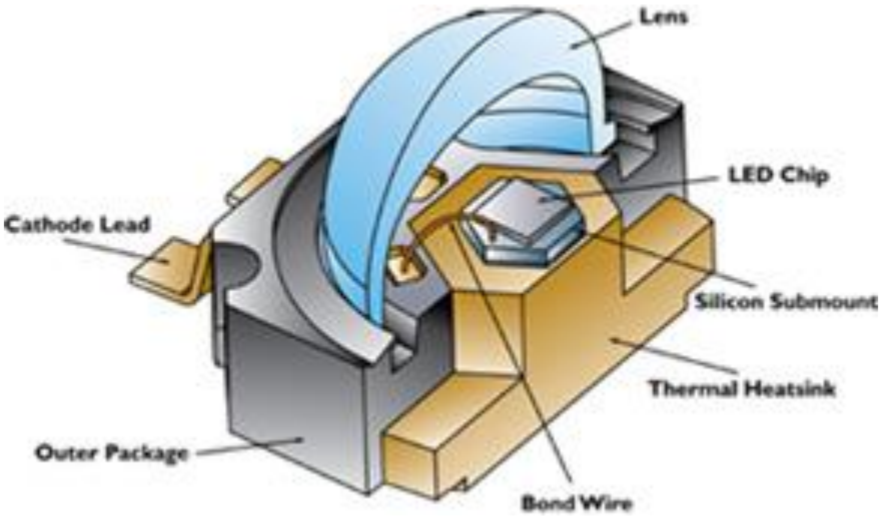
- Comparable in efficacy to CFLs, gaining on fluorescent tubes, and incandescents.
- Fixtures are directional, allowing for more efficient optics.
- Quality of White Light LEDs now comparable to CFLs, recent advances assure better consistency in color and CCT.
- Significantly longer ‘Useful’ life.

Advantages (cont.)

- Light output has improved by 35% / year, while cost has dropped by 20% / year
- No infrared, (IR) radiation
- No ultraviolet, (UV) rays
- Mercury free
- Can operate in cold environments
- Can withstand impact and vibrations
- Inherently digital for ease of control
- Instant on
- Growing trend to modularity

How They Work

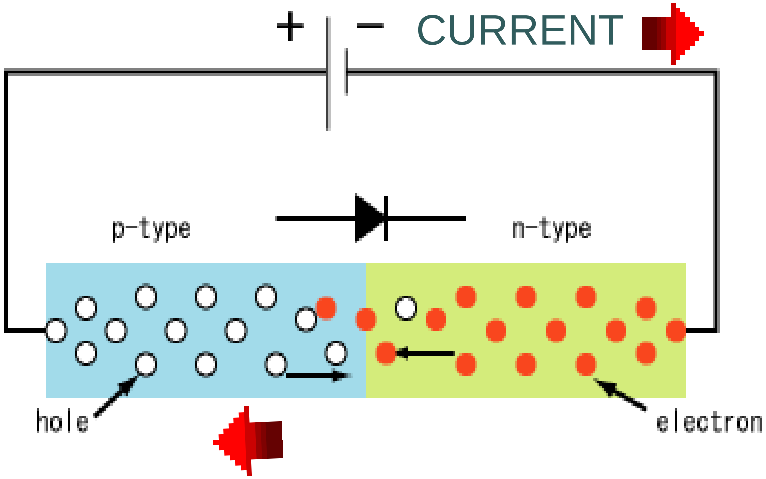
- Like a normal diode, the LED consists of a chip of semiconducting material impregnated, or doped with impurities to create a p-n, (positive / negative) junction.
- Atoms in the n-type material have extra electrons, atoms in the p-type material have electron holes.



How They Work (cont.)

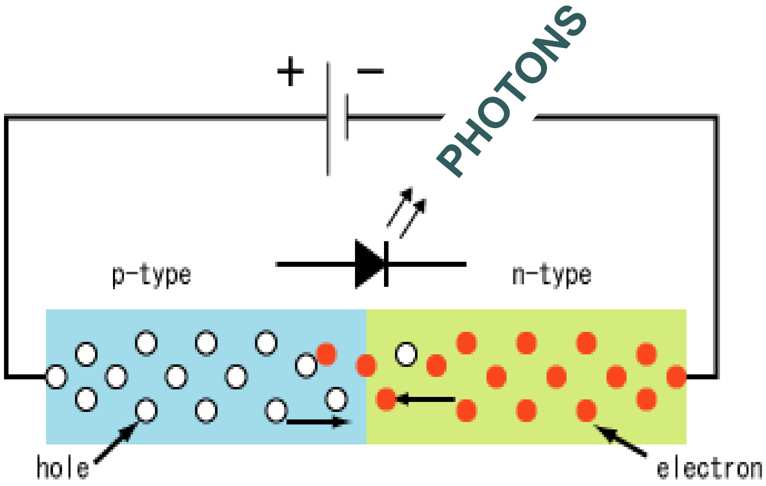
- Applying current pushes the atoms toward the junction. When they get close, the n-type atoms 'donate' their extra electrons to the p-type atoms which 'accept' them.

- A negative charge to the n-side allows current to flow from the (**-**) charged area to the (**+**) charged area. This is called 'forward bias'.



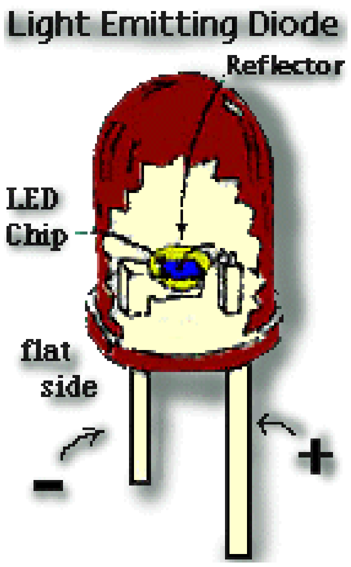
How They Work (cont.)

- When extra electrons in the n-type material fall into the holes in the p-type material, they release energy in the form of photons. The material in an LED is selected so that the wavelength of the photons falls within the visible portion of spectrum.
- Different materials produce photons at different wavelengths / color.

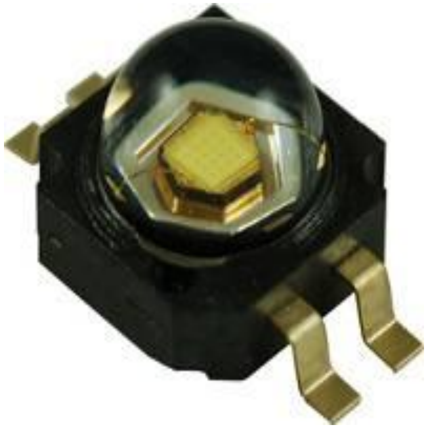


Lamp Anatomy, Indicator-Type

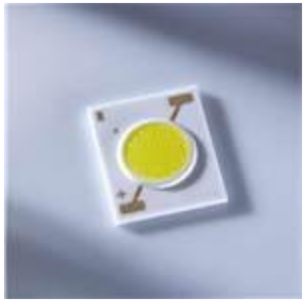
- Typically 5mm
- Usually inexpensive
- Low Power
- Generated heat dissipated internally
- Used only in:
  - Panel Displays
  - Electronic Devices
  - Instrument Illumination

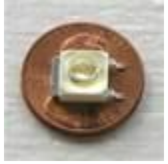


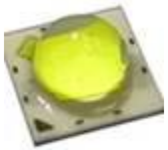
Lamp Anatomy, Illuminator-Type

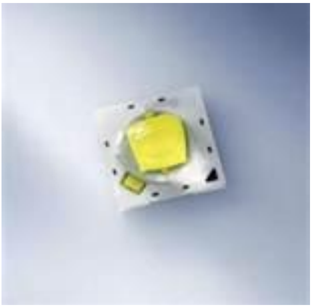


- AKA surface-mount LEDs
- High Brightness LEDs
- Durable, high-power devices
- Capable of providing:
  - Functional illumination
  - Light output equal to, or surpassing many conventional sources



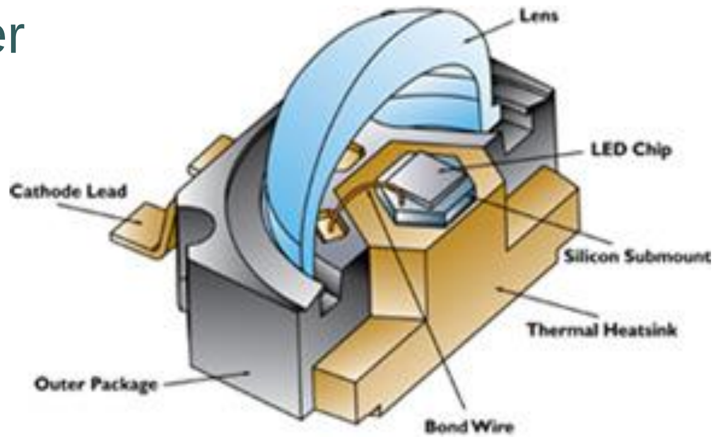






Lamp Anatomy, Illuminator-Type (cont.)

- All Illuminator-Type LEDs share the same basic architecture:
  - A semiconductor chip, (or die)
  - A substrate that supports the chip
  - Contacts to apply power
  - Bond wire to connect the contacts to the chip
  - Heat sink plus surface-mount solder connections provide a thermally conductive path
  - Lens
  - Outer casing



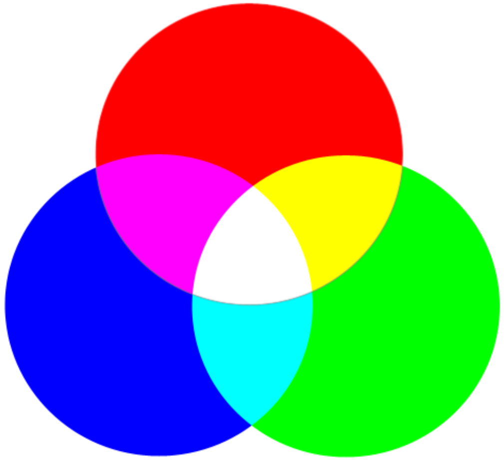
How They Produce Colors

- LEDs produce different colors by using different material systems, each system producing photons of different wavelengths.
- Illuminator-Type LEDs use systems which can handle the necessary heat, current, and humidity to produce high-brightness red and amber, (AlIn-GaP), and high-brightness blue, green and cyan, (InGaN).
- AlIn-GaP and InGan cover almost the entire spectrum.
- A gap occurs in the yellow-green portion, which can be filled by including different color LEDs in the same device.

How They Produce Colors (cont.)

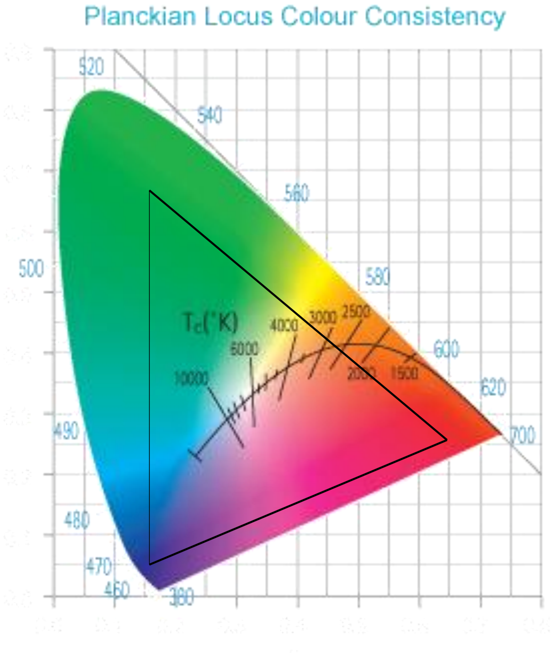
- An LED can:
  - Only emit the one color that the specific composition of its materials can produce.
  - Combine red, green and blue in a single device.
  - Create millions of colors by controlling the relative intensity of each color.
  - Use the ‘additive’ RGB color mixing process.

  (The ‘subtractive’ color mixing refers to pigments.)



How They Produce Colors (cont.)

- The Color Space chart defines the gamut of visible colors.
- The gamut of colors an LED fixture can produce depends on the specific colors of the red, green, and blue LEDs used in the fixture or chip.
- In theory a tricolor device can reproduce any color within the gamut.



How They Produce ‘White’ Light

- Method 1 – RGB mixing (previously covered)
  - Better control over exact color.
  - Is hardware intensive / expensive
  - Tends to make pastels look unnatural, hence poor CRI

How They Produce ‘White’ Light (cont.)

- Method 2 – Phosphor White (Remote Phosphor)
  - Produces white light in a single LED by combining a short wavelength LED, (blue), and a yellow phosphor coating.
  - The blue photons either pass through the phosphor layer without alteration or are converted into yellow photons in the phosphor layer.
  - The combination of blue and yellow photons produce a bluish ‘White’ light with better CRI, and is more efficient than RGB.

Fixture Anatomy

- To be used for illumination, LEDs must be integrated into systems that incorporate:
  - Optics – Reflector cups, lensing and aiming features
  - Drivers – Microprocessor-based power management, and control stages
  - Power Supplies – voltage conversion units
  - Thermal Management – vents and heat sinks
- Well designed fixtures integrate all these features into the fixture itself.
  - Effectively erases the distinction between lamp & luminaire.

Part 2: DETAILS

A. Evaluating Light Output

1. Light Output Defined
2. The Trouble with Lumen Evaluation
3. Delivered Light
4. Relative Photometry
5. Absolute Photometry
6. Sources of Light Loss

1. Light Output Defined

- How much light a fixture produces, and how the fixture emits and distributes that light.
- Data describing the quantity and distribution of the visible light produced is photometrics.
- The specification most commonly used for evaluating and comparing the performance of ‘conventional’ lighting fixtures is lumen output.

2. The Trouble with Lumen Evaluation

- The way that lumen output is traditionally measured, reported and interpreted is a problem for evaluating and comparing LED fixtures.
- Lumens are an imperfect measurement of the ‘perceived’ intensity of light.
- LED fixtures and conventional fixtures are tested differently, hence some photometric data is reported differently.
- A fixture’s total lumen output does not account for wasted light.
- LED fixtures typically waste less light than conventional fixtures.
- ‘Eye Sensitivity Curve’ adjusts lumen content by source’s Spectral Powder Distribution.

3. Delivered Light

- Instead of lumen output, it is the most relevant measurement for evaluating LED fixtures and for making accurate comparisons to conventional fixtures.
- Describes how much ‘Useful Light’ a fixture can deliver to the task area. ‘Useful Light’ is the portion of a fixture’s output that is effectively delivered to the task area, discounting any wasted light.

4. Relative Photometry

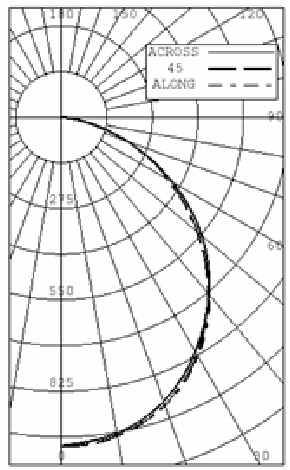
- The way in which conventional fixtures are tested
- Luminaires and their lamps are tested separately
  - Lumens and chromaticity of lamps measured with an integrating sphere.
  - Distribution and efficiency measured with a goniophotometer.
  - Lamp lumen output serves as a reference.
  - Lumen output of the fixture is measured relative to it.

Lighting Sciences
www.lightingsciences.com

Lighting Sciences Inc.
7826 E. Evans Road
Scottsdale, Arizona 85260 USA
Tel: 480-991-9260 • Fax: 480-991-0375

CERTIFIED TEST REPORT No. 25411

FINELITE - 2' X 4' FLUORESCENT RECESSED LUMINAIRE,CAT# HPR-x-2X4-1T8-DCO
WHITE REFLECTOR, FROSTED PLASTIC SIDE LENSES & FROSTED .080 CENTER LENS
ONE SYLVANIA 32 WATT T8 LAMP,CAT# FO32/835/ECO. LUMEN RATING = 2950 LMS.
ONE SYLVANIA QHE1X32T8/UNV ISN SC BALLAST OPERATING AT 120 VAC AND 30 WATTS

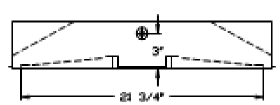


INTENSITY (CANDLEPOWER) SUMMARY

ANGLE	ALONG	22.5	45	67.5	ACROSS	OUTPUT LUMENS
0	990	990	990	990	990	
5	988	988	987	985	979	95
10	975	976	974	971	966	
15	953	953	951	948	943	267
20	922	922	917	913	908	
25	880	880	874	869	864	402
30	828	827	821	816	812	
35	765	764	758	756	754	474
40	695	693	687	692	693	
45	617	615	614	623	627	476
50	535	533	535	548	554	
55	451	449	453	467	473	408
60	367	365	370	380	386	
65	287	284	288	293	298	286
70	210	208	207	210	213	
75	139	137	134	135	135	145
80	77	75	71	70	69	
85	29	26	23	20	20	31
90	0	0	0	0	0	

ZONAL LUMENS AND PERCENTAGES

ZONE	LUMENS	% LAMP	%LUMINAIRE
0-30	764	25.90	29.58
0-40	1238	41.96	47.92
0-60	2122	71.92	82.13
0-90	2583	87.57	100.00
40-90	1345	45.60	52.08
60-90	462	15.65	17.87
90-180	0	0.00	0.00
0-180	2583	87.57	100.00



** EFFICIENCY: 87.6% **

LUMINOUS LENGTH: 46.000 INS
WIDTH: 21.750 INS

LUMINANCE SUMMARY CD./SQ.M.

S/MH: 1.2
SC: 1.2

ANGLE	ALONG	45	ACROSS
45	1352	1350	1378
55	1218	1229	1281
65	1051	1057	1097
75	829	800	809
85	514	409	360

CERTIFIED BY:

DATE:
AUG 19, 2009

PREPARED FOR:
FINELITE
UNION CITY, CA

TESTED IN ACCORDANCE WITH IES PROCEDURES.

5. Absolute Photometry

- The way in which **LED** fixtures are tested
  - The approved procedures and testing conditions are listed in IES LM-79-08, **“Electrical and Photometric Measurements of Solid-State Lighting Products”.**
- Because LEDs are inseparable from their fixtures, only fixture lumens measured, not lamp lumens.
- For a valid comparison, the measured lamp lumens of a conventional fixture must be reduced by its efficiency, as reported in a Zonal Lumen Summary chart.

ZONAL LUMEN SUMMARY

Lamp Lumens = 820

Zone	Lumen	%Lamp	%Fixt.
0-30	113	12.1	19.6
0-40	199	23.1	34.6
0-60	382	44.4	66.3
0-90	534	62.1	92.8
90-120	38	4.4	92.8
90-130	40	4.7	7.0
90-150	41	4.8	7.2
90-180	41	4.8	7.2
0-180	550	66.9	100

6. Sources of Light Loss

- Delivered light to the task surface depends on a range of factors:
  - Lumen output and lamp lumen depreciation
  - Fixture positioning
  - Lensing, filtering, shading, and accessories to redirect or alter the output

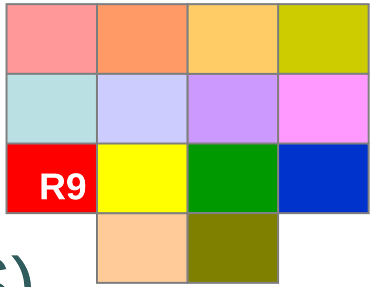
-BUT-

  - LED fixtures are inherently directional, minimizing losses
  - LEDs are natively colored, also minimizing losses

Part 2: DETAILS

B. Quality of Light

1. CRI & White Light LEDs
2. CRI vs. CQS
3. Color Consistency



1. CRI and White Light LEDs

2. CRI vs. the Color Quality Scale (CQS)

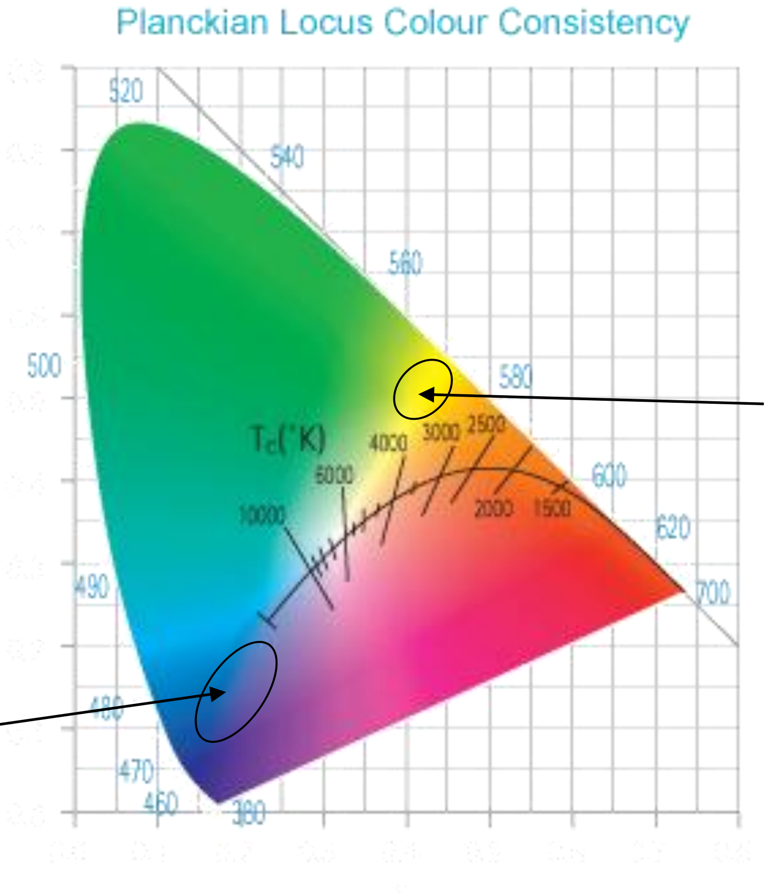
- The CIE has concluded that CRI can’t effectively predict the color quality of white light LEDs.
- The National Institute of Standards and Technology (NIST), is developing a Color Quality Scale that does a better job of measuring the color rendering abilities of white light LEDs.
- It uses 15 color samples, not the usual 8 CRI patches.
- Has not yet been widely adopted by luminaire testing labs.

3. Color Consistency

- An index of light quality for both color and white light LEDs.
- Uses CCT, which allows for a range of variation in chromaticity that can be discerned by viewers, even if the CCT value is the same.
- Manufacturers strive to keep color variations under control.

3.1 Color Consistency (cont.)

- Understanding CCT and Binning
  - Light sources with the same defined CCT can display discernible differences in hue.
  - LED makers use a method of managing manufacturing variations in chromaticity and CCT known as ‘Binning’.
- The threshold at which a color difference becomes perceptible is defined by a MacAdam Ellipse.
  - A color difference of 1 step is not visible.
  - A color difference of 2-4 steps is barely visible.
  - A color difference of 5 or more steps is readily noticeable.



As few as 3 steps

As many as 7 steps

Part 2: DETAILS

C. Fixture Efficacy

1. Off-State Power Consumption
2. Power Factor
3. Thermal Management
4. Useful Life
5. Driving & Powering
6. Controlling
7. Dimming
8. Trend toward Modularity

1. Off-State Power Consumption

- Can significantly reduce system efficacy.
- Occurs when fixture switches or dimmers are positioned between the power supply or transformer, and the fixtures.
- Transformer continues to draw power even when the fixtures are off.
- Transformer power can draw in excess of 2 watts.
- The resulting total cumulative losses can represent as much as 20% of a system's load.

2. Power Factor (PF)

- A measure of how effectively a device converts electric current into useful output power.

$$\frac{\text{Real Power (Watts)}}{\text{Apparent Power (Volt-Amps)}}$$

- EXAMPLE: An LED lamp rated at 18 watts, when measured actually draws 20 volt-amps. The PF of that lamp/driver is18W / 20VA, which is 0.9, and is considered high.
- EXAMPLE: A CFL lamp rated at 18 watts, when measured, actually draws 30 volt-amps. The PF of that lamp/ballast is 18W / 30VA, which is 0.6, and is considered low.

2. Thermal Management

- The light beam from an LED is cool, but because they are not perfectly efficient, a great deal of heat can be generated at the p-n junction. A well-designed heat sink and other thermal management features are critical for assuring:
  - Proper operation
  - Optimizing light output
  - Maximizing lifetime

2.1 Thermal Management (cont.)

- Junction Temperature
  - As it increases, output and ‘lifetime’ decrease
  - Factors are:
    - – Drive current
    - – Thermal path
    - – Ambient temperature

2.2 Thermal Management (cont.)

- Junction Temperature
  - Affect on Light Output
    - Manufacturers measure at fixed junction temp. of 25^{o}C.
    - Actual range of temperatures: 60^{o}C. to 90^{o}C.
    - Result is at least 10% less light than manufacturer rating.
  - Affect on Useful Life
    - An increase of 11^{o}C. can reduce lifetime by 50%+.

3. Useful Life

- Rated Lamp Life of Conventional Sources
  - Well established methodology: LM-49, LM-65,
  - Life rated at 50% failure point
- Lumen Maintenance and Depreciation
  - IES publication LM-80-08
  - Counterpoint to LM-49 and LM-65
  - Instead of rated life, LM-80 measures lumen depreciation
  - Factors include:
    - Drive current
    - Heat generated within the device

3.1 Useful Life (cont.)

- Lumen Maintenance and Depreciation (cont.)
  - Maintenance measurement: $\mathbf{L_p}$
  - **L** is initial output
  - **P** is the percentage maintained over a number of hours

    i.e. $\mathbf{L_{70}}$ measure how long a source will retain 70%,

    (or lose 30% of its initial output)

    Knowing an LED's Useful Life is important because they continue to deliver light after initial output has decreased by 50%., or more. Users need to know how long an LED fixture will retain a meaningful percentage of its initial light output, NOT how long will it take to fail.

3.2 Useful Life (cont.)

- Useful Life Defined
  - The length of time a light source delivers a minimum acceptable level of light in a given application.
  - Changes in light levels go undetected down to 70% of initial levels, especially if change is gradual.
  - For general lighting applications, Useful Life could therefore be defined as the length of time it takes an LED source to reach 70% of its initial output, L_{70}
  - For decorative applications, (and for Energy Star), Useful Life can be rated as low as L_{50}

3.3 Useful Life (cont.)

- Additional Testing Criteria
  - LM-80 requires testing of LED sources for 6,000 hrs.(though it recommends 10,000 hrs.)
  - Three different junction temperatures:
    - 55°C.
    - 85°C.
    - A third at the option of the manufacturer
  - TM-21 establishes criteria for projecting long term lumen maintenance of LED sources.

3.4 Useful Life (cont.)

- Useful Life of LED Sources in Fixtures
  - LM-79 calls for the testing of complete lighting fixtures.
  - Measuring lumen maintenance requires the testing of LED sources.
  - LM-80 testing for complete LED fixtures would be complex and expensive.
  - In practice, reputable fixture manufacturers ensure drive current and operating temperatures fall within the range of source manufacturer’s lumen maintenance reports, they make calculations of the Useful Life of the LED sources they are integrating into their fixtures.

3.5 Useful Life (cont.)

- Comparing Useful Life – LED to Conventional
  - 60-watt incandescent, LLD* of 15%, rated life of 1,000 hrs.
    - 10% loss at 600 hrs. Useful life is 1,800 hrs.
    - Lamp will fail before L_{70}.
    - Rated Life is its Useful Life
  - 18-watt CFL, LLD* of 10%, rated life of 15,000 hrs.
    - 10% loss at 6,000 hrs. Useful life is 18,000 hrs.
    - Lamp will fail before L_{70}.
    - Rated Life is Useful Life

*Light Lumen Depreciation

3.6 Useful Life (cont.)

- Comparing Useful Life – LED to Conventional
  - 32-watt HP T8, LLD of 5%, Rated Life of 60,000 hrs.
  - 5% loss at 24,000 hrs. Useful Life of 79,200 hrs.
  - Lamp will fail before L_{70}. Rated Life is Useful Life.

Conclusion: Comparisons of conventional fixtures to LED fixtures must be on a Rated Life-to-Useful Life basis.

4. Driving and Powering

- LED Driver
  - An electronic circuit that converts input power into a current source in which current remains constant despite fluctuations in voltage.
  - Fixtures that feature integrated LED drivers are as easy to connect to power as any conventional fixture.
  - An increasing number of integrated drivers for white light LED fixtures are dimmable.

4.1 Driving and Powering (cont.)

- Power Options for LED Fixtures
  - Low-Voltage Power Distribution
    - Requires a low-voltage power supply (brick)
    - Lighter weight and portable
    - Favored by the Entertainment industry
    - Relatively inefficient due to losses

4.2 Driving and Powering (cont.)

- Power Options for LED Fixtures
  - Onboard Power Integration

    Uses same overall control scheme as low-voltage systems but offers advantages:

    – Replaces external low-voltage power supply with standard switching power supply integrated into the fixture.

    – This allows fixtures to be connected directly to line voltage, fewer losses occur.

    – Additional components can increase fixture size and thermal load.

4.3 Driving and Powering (cont.)

- Power Options for LED Fixtures
  - Inboard Power Integration
    - Integrates a single efficient power stage into the fixture itself
    - Eliminates a significant percentage of power losses associated with low-voltage configurations with multiple stages
    - Advantages include increased system efficiency, and lower cost and complexity of installation, operation, and maintenance

5. Controlling

- Control is a general term for a wide range of methods, protocols, and devices used to operate fixtures:
  - DMX, the most commonly used and accepted control format for color changing fixtures.
  - Ethernet, a computer network not limited by addressing issues.
  - Other Options:
    - DALI

6. Dimming

- LED fixtures can be dimmed two different ways depending on the type and capabilities of the fixtures:
  - Using DMX and other Control Interfaces - color changing and tunable white fixtures can be dimmed via DMX or other control protocol
  - Using Commercially available Dimmers
    - Solid color and white fixtures can be dimmed via compatible, commercially available dimmers
    - Most drivers use Pulse Width Modulation, **ON** time dimming
    - Most are incompatible with incandescent and leading edge dimmers, (visible flicker at low levels).

6.1 Dimming (cont.)

- Using Commercially available Dimmers
  - Many LED fixtures work best with electronic low voltage, (ELV-type) dimmers, (though magnetics are quieter).
  - Fixtures that work with magnetic transformers, such as MR16 compatible LED lamps, require magnetic low voltage (MLV-type) dimmers.
  - Most ELV-type dimmers use trailing edge technology, which performs more reliably, with its 3-wire, extra neutral.
  - Trailing edge dimmers not as common, which is no problem in new construction, may require swapping existing leading edge dimmers for trailing edge types in retro-fits.
  - Manufacturers have lists of tested and approved dimmers.

6.2 Dimming (cont.)

- Dimmer Thresholds and Wattage
  - Effective dimming threshold around 10%
  - Trim-pot screw controls minimum dimming level
  - Wattage of dimmer must be sufficient for the installation
  - Number of fixtures to be controlled times wattage of each fixture equals the **minimum** dimmer wattage
  - High-resolution 12-bit or 16-bit drivers virtually eliminate visible flicker, and can be dimmed below the 10% threshold.

Trend toward Modularity

- Zhaga consortium, (and others)
  - Creates interface specifications for light engines with the goal of promoting interchangeability among manufacturers.
  - Has defined a 5-phase process to balance the need for differences with the need for uniformity.
  - www.zhagastandard.org

D. Questions to ask of any lighting system

1. How much light will they produce?
   - Lumens
   - Footcandles
2. How much energy will they save?
3. What is the light quality?
   - Color Temperature (CCT)
   - Color Rendering (CRI, or other metric)
   - Color Consistency (binning)
4. Will they save any money?

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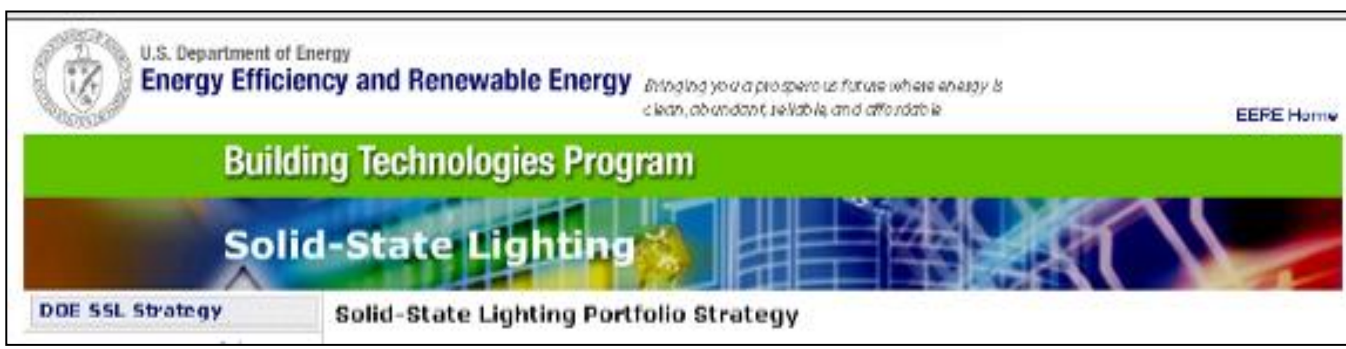

TERMS & TERMINOLOGY

Absolute Photometry

The standard method for testing light output and distribution of lighting fixtures.

Binning

Term for the production and sorting method used by LED makers to insure that what they make conforms to specifications for forward voltage, color, and luminous flux.

Controller

A device that controls the output of color changing and tunable white lighting fixtures.

Digital Addressable Lighting Interface (DALI)

A digital communications protocol for controlling and dimming lighting fixtures.

Delivered Light

The amount of light a luminaire or system delivers to the target area of task surface, measured in footcandles, (fc).

DMX

A digital communications protocol for controlling luminaires.

ELV-type dimmer

An electronic low voltage dimmer used to control LED luminaires with electronic transformers.

Ethernet

A digital communications protocol used in computer networks. Can control Ethernet compatible LED luminaires.

Forward voltage

Occurs when a negative charge is applied to the n-type side of a diode, allowing current to flow from the negatively-charged area, to the positively-charged area.

GaAsP

Gallium arsenide phosphide material used in indicator-type LED’s producing light in the red to yellow-green portion of the visible spectrum.

GaP

Gallium phosphide material used in indicator-type LED’s producing light in the green to orange portion of the visible spectrum.

Ghosting

An effect that occurs when luminaires in the **OFF** state faintly glow as a result of residual voltage in the circuit.

HB-LED’s / HP-LED’s

High-brightness or power LED’s. A synonym for indicator-type LED’s.

Heat sink

A feature or device that conducts or convects heat away from sensitive components.

Illuminator-type LED's

High performance, high power LED's capable of providing functional illumination.

Inboard power integration

An approach to power management that integrates the power supply into a luminaire's circuitry, creating an efficient power state that consolidates line voltage conversion and LED current regulation.

Indicator-type LED's

Inexpensive, low power LED's suitable for use as indicator lights in panel displays, or instrument illumination, etc.

InGaN

Indium gallium nitride material used in green, blue, and cyan LED's.

LED Driver

An electronic circuit that converts input power into a current source in which current remains constant despite fluctuations in voltage.

Lumen maintenance

Describes how long a light source will retain a certain % of its initial lumen output. L_{70} is the length of time a source retains 70% of its initial lumen output.

Luminous efficiency

Percentage of lamp lumens a conventional fixture emits, minus blocked or wasted light.

MacAdam ellipse

An ellipse, laid over a color space that defines the threshold at which color difference becomes visible.

Material system

Material, such as AlInGaP, or InGaN, used within an LED to produce light of a certain color.

Phosphor white

Method of producing white light in a single LED by combining a short-wavelength LED such as blue or UV, and a yellow phosphor coating.

Photon

The basic unit of electromagnetic radiation, including visible light

p-n junction

The location within an LED where negatively charged material donates extra electrons to positively charged material, which accepts them, releasing energy in the form of photons.

Pulse width modulation

Method used by most LED drivers to regulate the amount of power to the LEDs. PWM turns LEDs on and off at high frequency, reducing total **ON** time to achieve a desired dimming level.

Relative photometry

Method for testing the output and distribution of conventional fixtures where the fixture is measured relative to its lamps.

Remote phosphor

A technique that separates the phosph0r from the chip in a white light LED, improving and extracting efficiency of emitted light.

Trailing-edge dimmer

Type of dimmer that regulates power to lamps by delaying the end of each half cycle of AC power. Compatible with many LED fixtures.

Tunable white light

White light LED fixtures that combine channels of warm white and cool white LEDs to produce a range of colors.

Useful life

Length of time it takes an LED source to reach a certain % of its initial lumen output. Commonly known as lumen maintenance thresholds. L_{70}, 70% if initial lumen output. L_{50}, 50% of initial lumen output.

Useful light

Amount of light a fixture delivers in an application, less any wasted light.

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206.325.9711

800.354.3864

LIGHTING DESIGN LAB

2915 – 4th Avenue South

Seattle, WA 98119

www.lightingdesignlab.com

jeff@lightingdesignlab.com