LEDs and Lighting Controls

What are they? How do they work?

Bob Viehweger, President
LED Light Energy
Decatur, GA
(312) 451-4341
bob@ledlightenergy.com

What we will cover

Brief History – the two most important guys in LED lighting
LED technology – what they are, how they are made
Key issues – CRI, binning, heat management
Testing
Standards and regulations
Controls
LED lighting/controls advantages
Applications
Retrofit solutions
Cost of Ownership
What’s next?

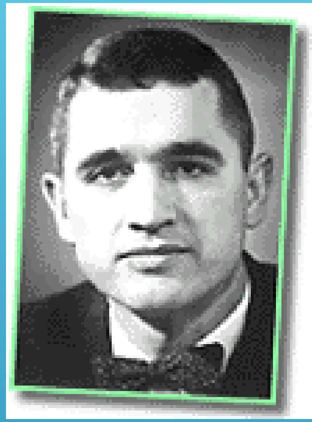
When is a technology ready for commercialization?

History and Manufacturing

LEDs are semi-conductors – *"it ain't easy"*

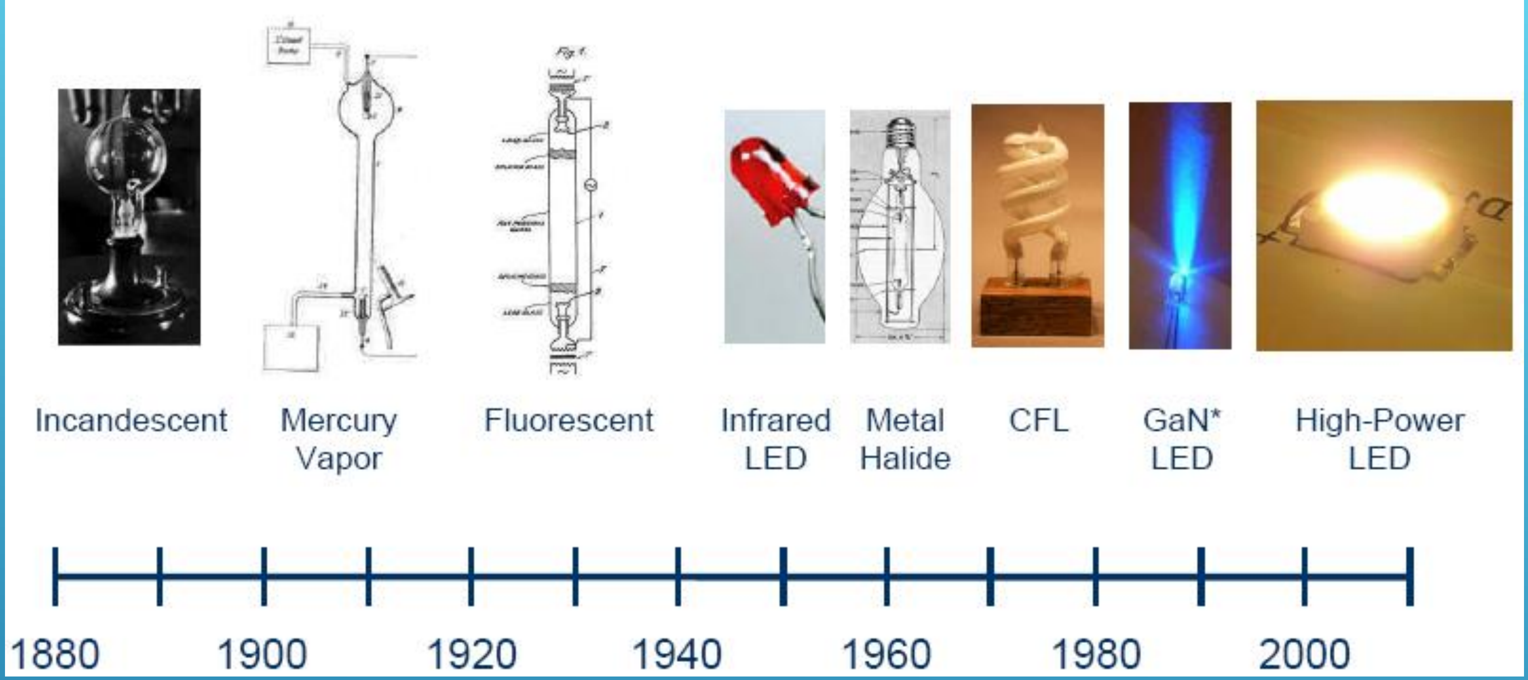
LED Basics

A Brief LED History



- 1962 First visible LED (Holonyak@GE) **red LEDs**
  - 0.001 lumens
- 1960’s Red LEDs (H.P. and Monsanto)
  - 0.01 lumens
- 1970’s–1980’s Green LEDs, Watches, Calculators
  - 0.1 lumens
- 1990’s **Blue LEDs** (Nakamura@Nichia)
  - 1 lumen
- 2000+
  - 10-100 lumens
- 2015
  - 100 lumens/watt
- 2015
  - >300 l/W – Cree R&D

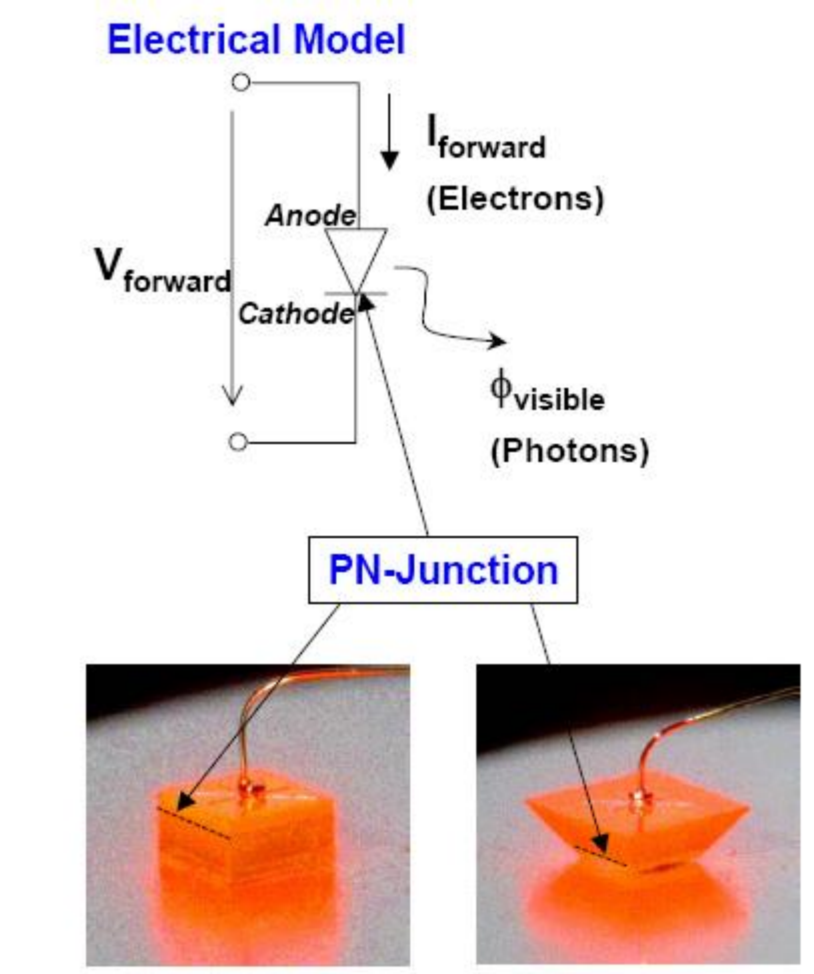
Progression of lighting



Advantages:

Significant improvement in energy efficiency (40% - 90%)
Reduction in heat radiation
Longevity – low maintenance
No hazardous materials – 100% recyclable
Improved illumination – CFLs in cans?
No short-term lumen loss
Lighting where you want it (lensing), when you want it (controls)
No “on/off” issues
No UV

What is an LED?



Courtesy of Lumileds

An LED is an electrical device (diode) that emits light when there is an electrical signal across it.

It is a DC device (preferably constant current)

How is an LED made?

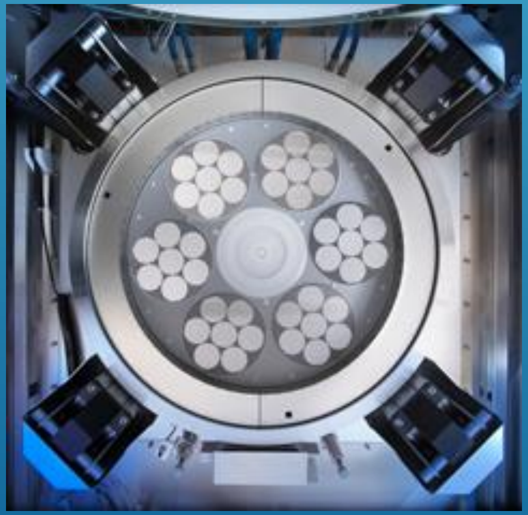
- Growth machines
- Controlled environment
- Complex process

Growth machine

Controlled environment

Complex process

LED “wafers”



From LED to a Fixture

Red LED

GaP window layer
AlInP (Zn)
AlGaInP active
AlInP (Si)
InGaP buffer
GaAs substrate

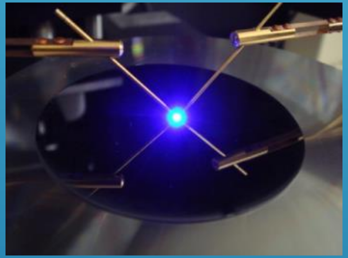
Blue LED

GaN (Mg)
InGaN active
GaN (Si)
GaN buffer
Saphire substrate

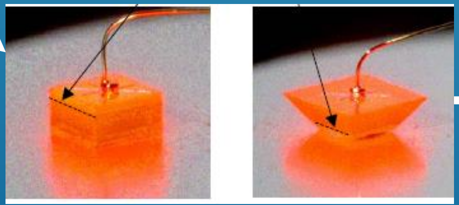
Growth machine

Bare substrate

Processing



Cutting/dicing



Separate the die

Package the die

+ heat sink

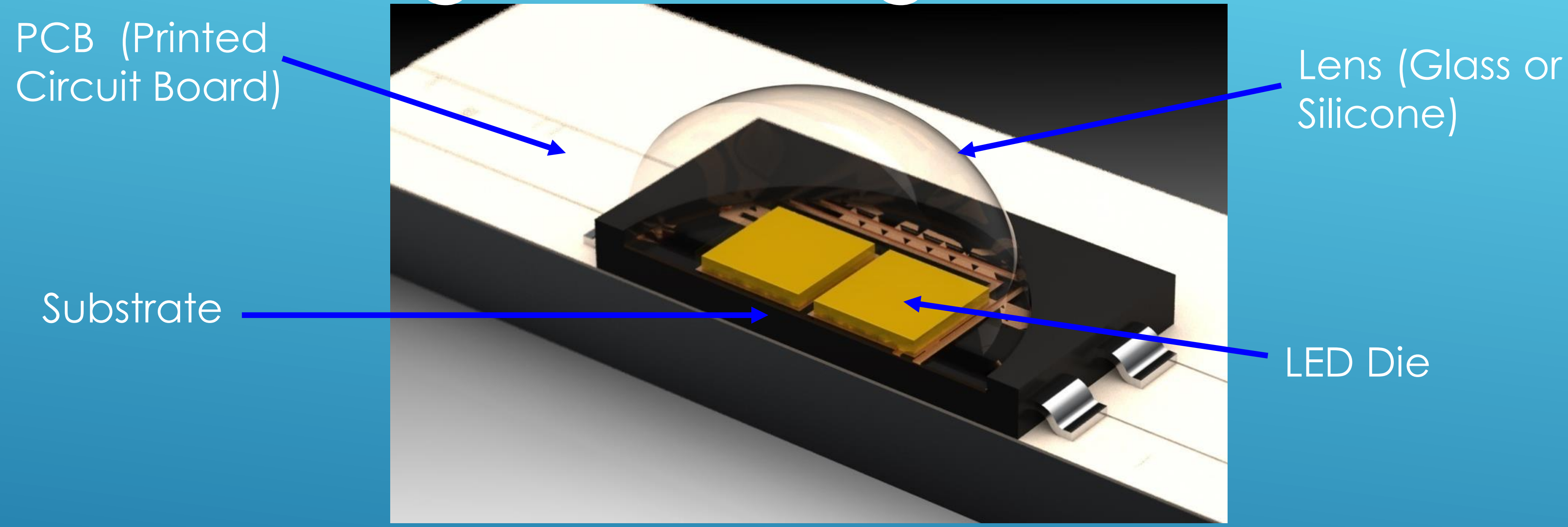
+ enclosure

+ lenses/diffusers

VOILA!

The Basic Package

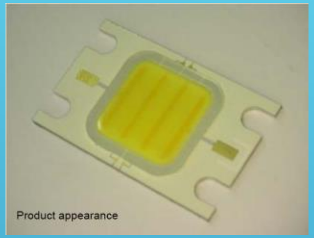
Light Emitting Diode

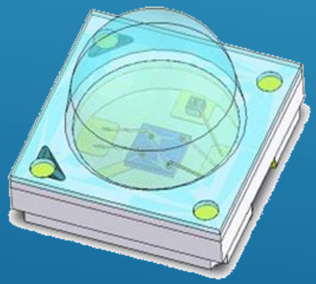


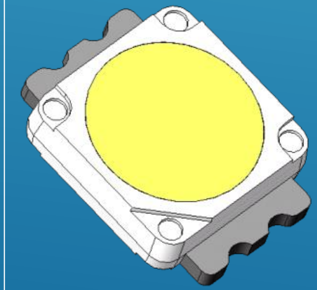
The LED Package provides:

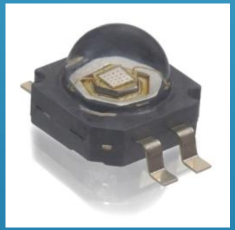
- Protection for the LED die from the outside environment
- Conductive path to carry heat away from the LED die
- Refractive index matching from the LED die to air

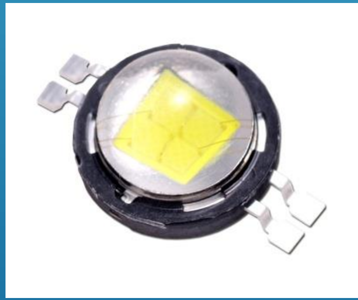
Current LED Packages









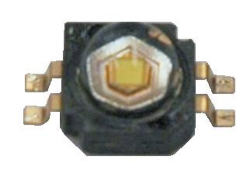


White Light?

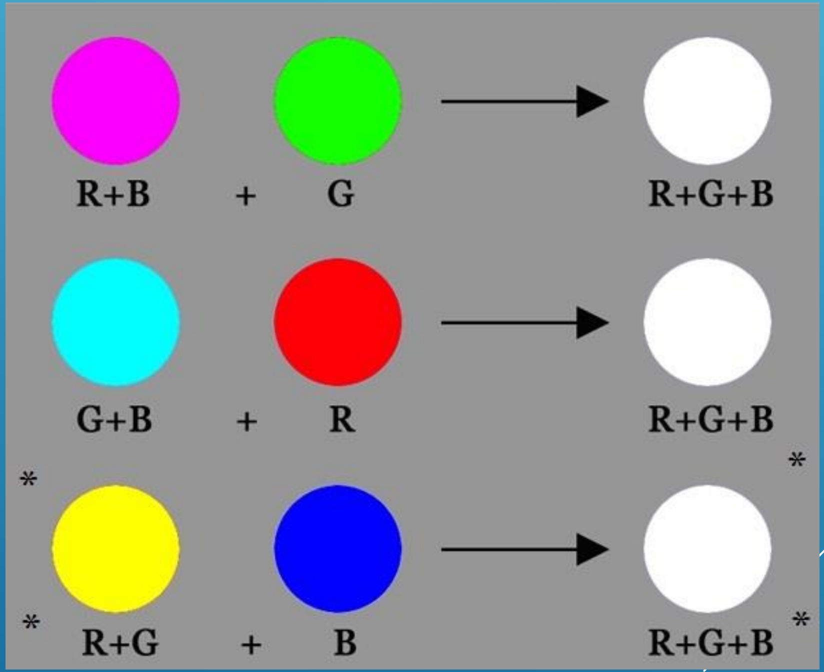
The LEDs I have seen are mostly blue-ish

How do we get white light?

White light is obtained by 2 different methods with LEDs

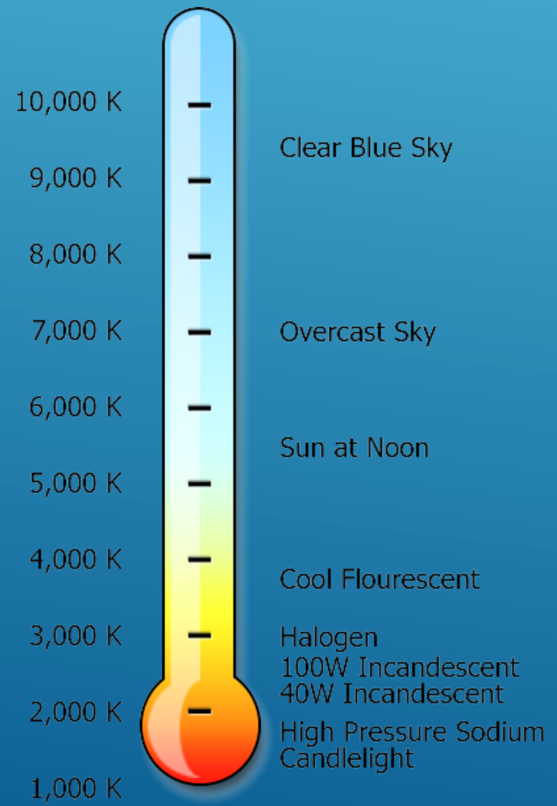


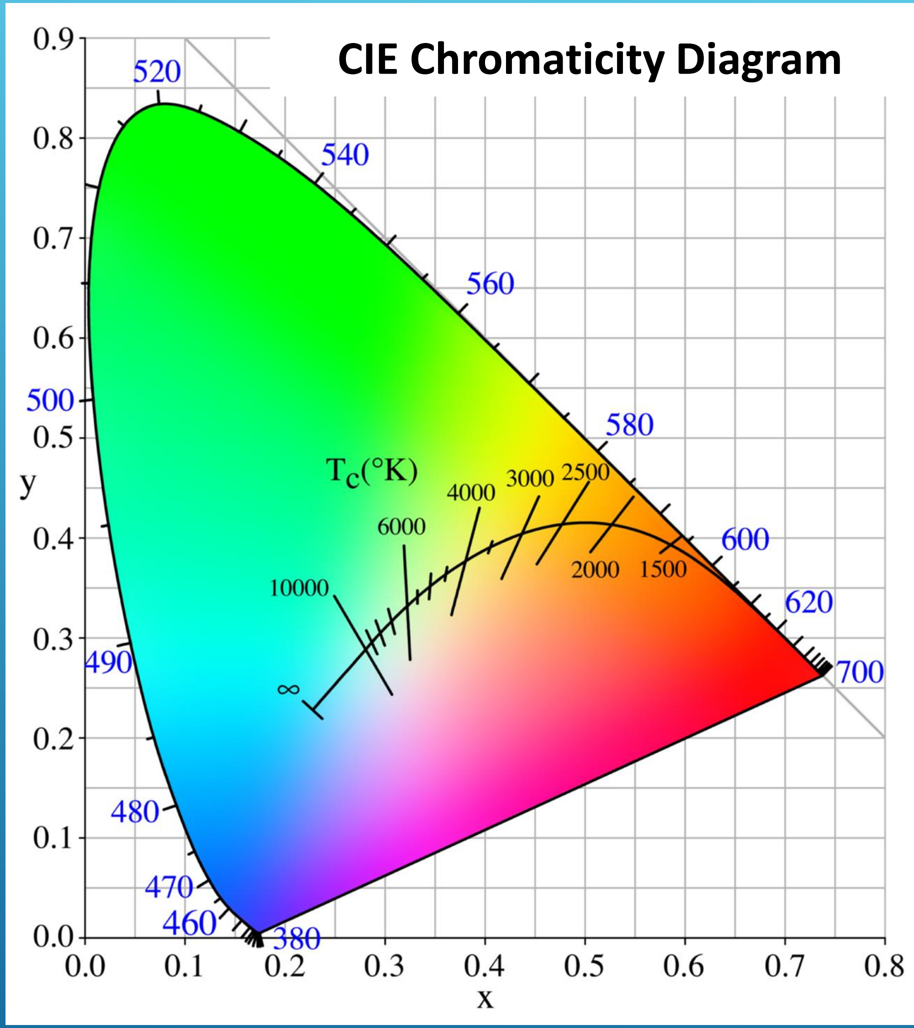
PHOSPHOR CONVERSION

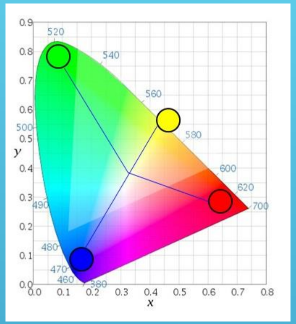


Color Temperature

Heating a "black-body"



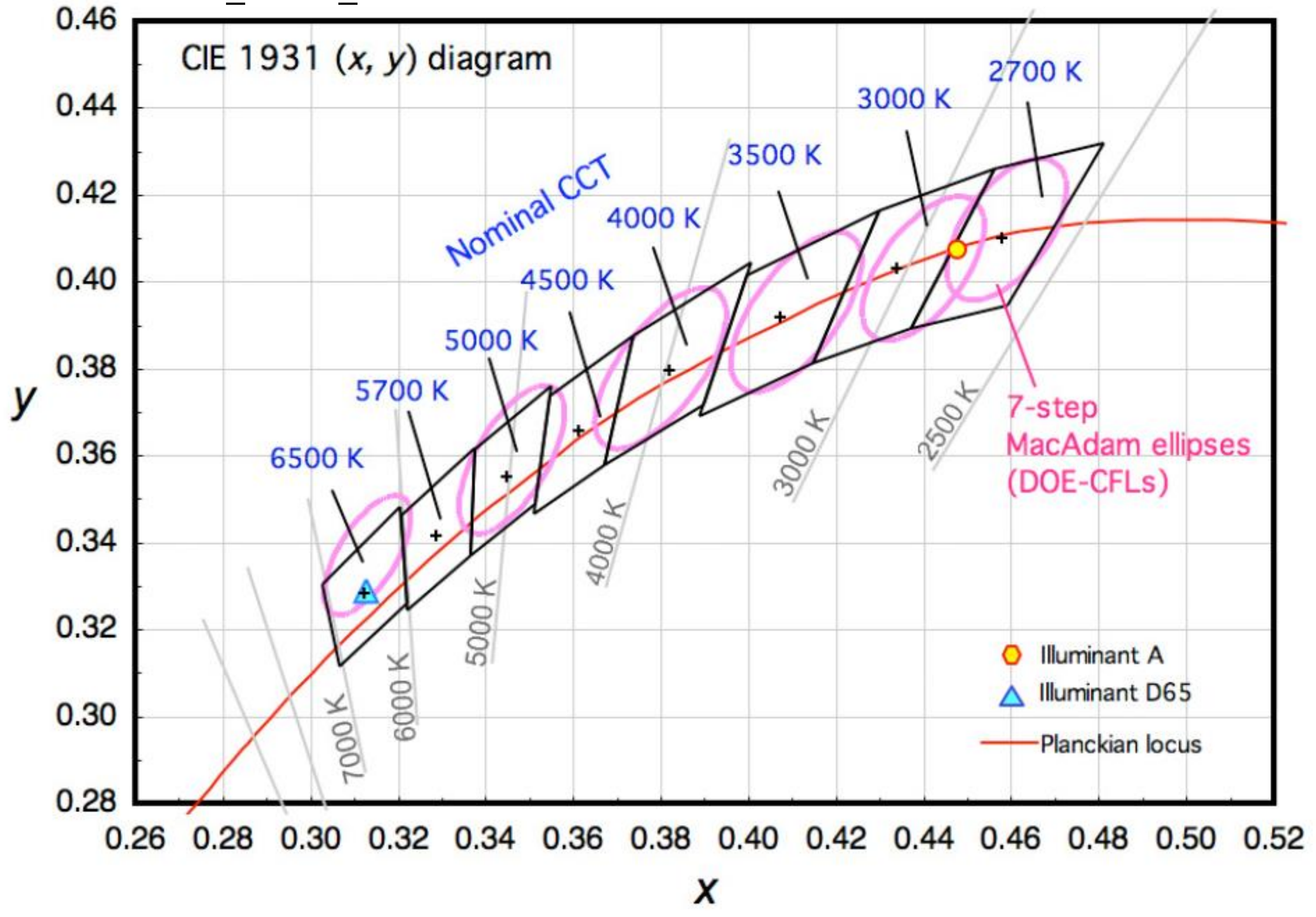




Hue

Color Binning

ANSI_NEMA_ANSLG C78.377-2008



ANSI / NEMA have defined color ranges for SSL product.

Color Binning

ANSI 1/4th quadrant bin structure for LXM7-PW40 emitter

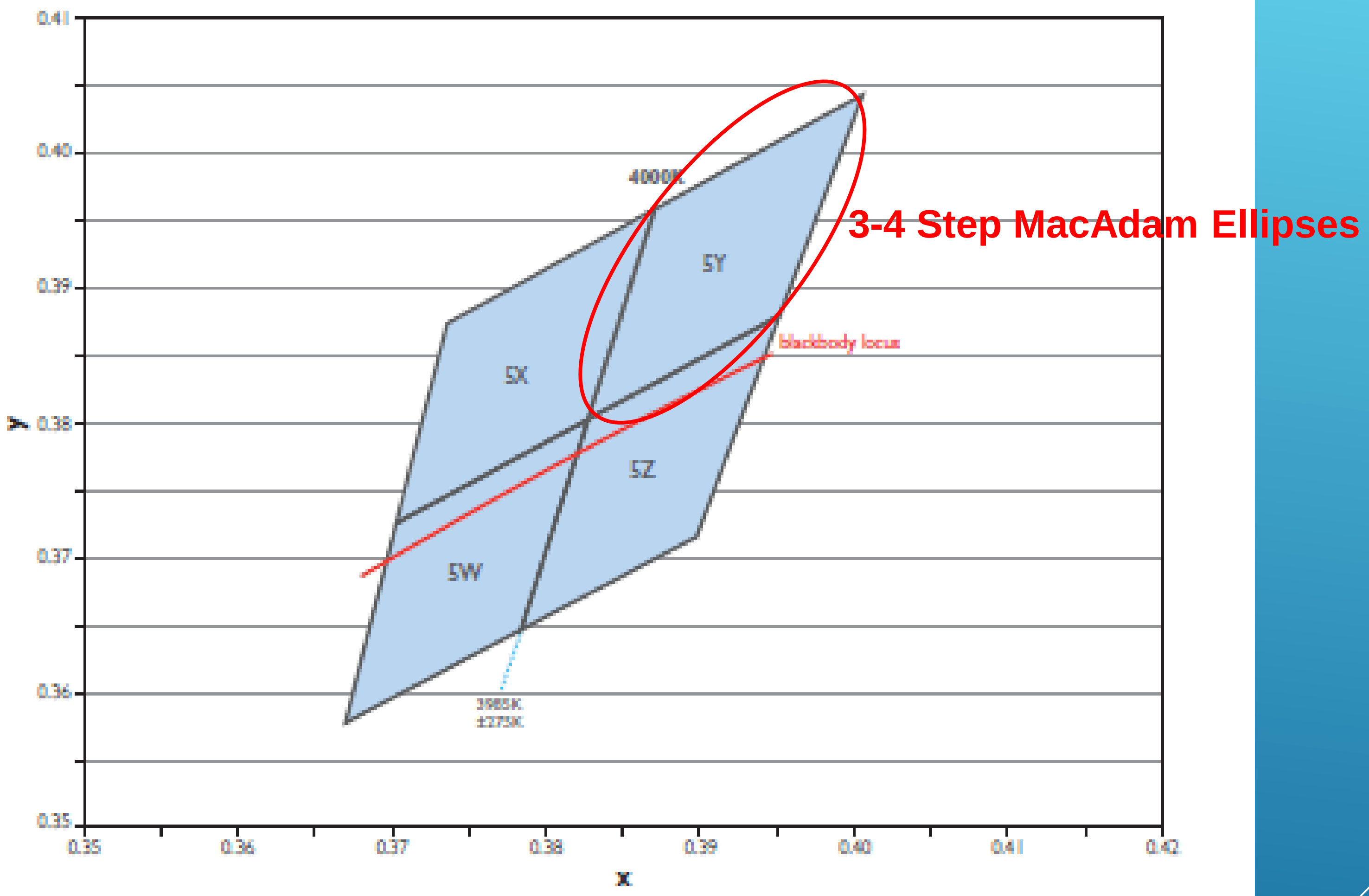
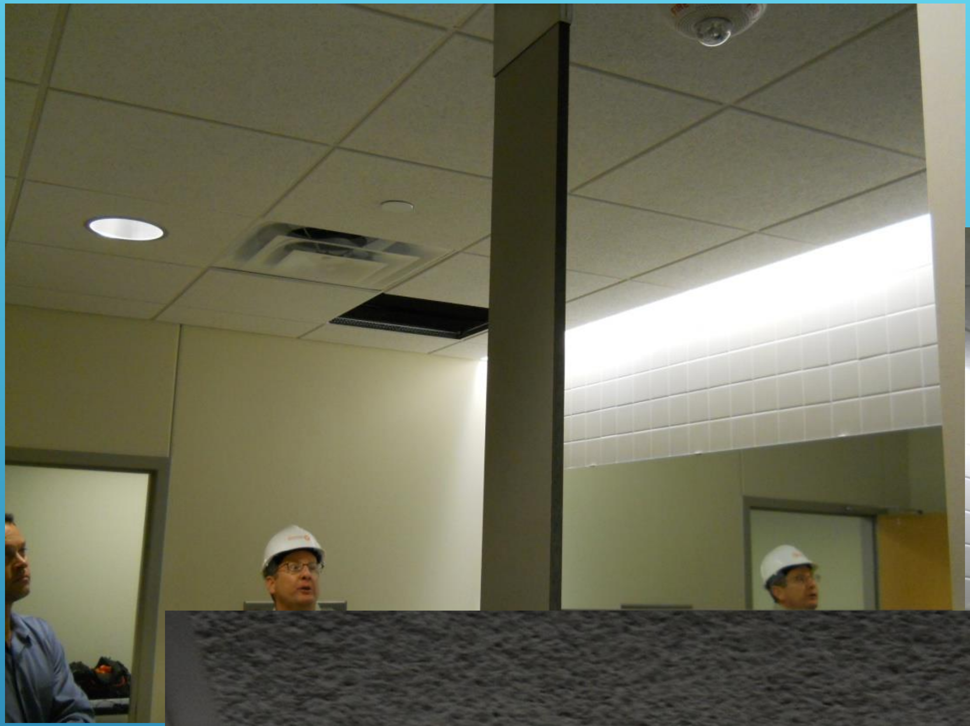


Figure 28. LUXEON Rebel ANSI 1/4th quadrant bin structure (LXM7-PW40 emitter only).

Color Binning

Color Consistency



What about how things look?

WHAT IS CRI???

"The color rendering index (CRI), is a measure of the ability of a light source to reproduce the colors of various objects being lit by the source (100 is the best CRI)."

Light source	*CRI*
Sunlight	100
W filament incandescent light	100
Fluorescent light	60 - 85
Existing Phosphor-based white LEDs	75-98
Na vapor light	40

Courtesy F. Schubert (RPI) and G. Jabbour (ASU)

Color Rendering Index (CRI)

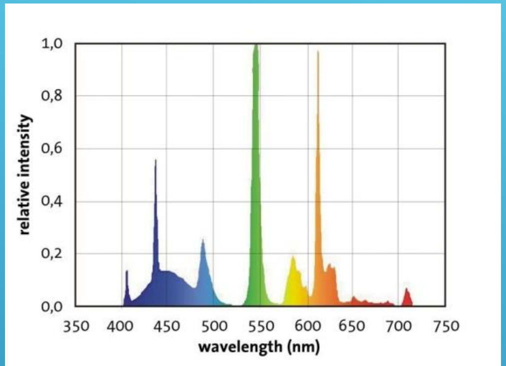
Name	Appr. Munsell	Appearance under daylight	Swatch
TCS01	7,5 R 6/4	Light greyish red	
TCS02	5 Y 6/4	Dark greyish yellow	
TCS03	5 GY 6/8	Strong yellow green	
TCS04	2,5 G 6/6	Moderate yellowish green	
TCS05	10 BG 6/4	Light bluish green	
TCS06	5 PB 6/8	Light blue	
TCS07	2,5 P 6/8	Light violet	
TCS08	10 P 6/8	Light reddish purple	
TCS09	4,5 R 4/13	Strong red	
TCS10	5 Y 8/10	Strong yellow	
TCS11	4,5 G 5/8	Strong green	
TCS12	3 PB 3/11	Strong blue	
TCS13	5 YR 8/4	Light yellowish pink (skin)	
TCS14	5 GY 4/4	Moderate olive green (leaf)	
TCS15	1 YR 6/4	Asian skin	

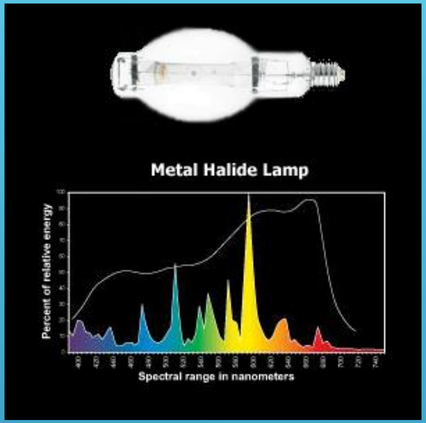
The lack of saturated colors in the current CRI definition has driven artificially low values for SSL. NIST is in the process of creating a new Color Rendering Standard which will be called a Color Quality Scale (CQS).

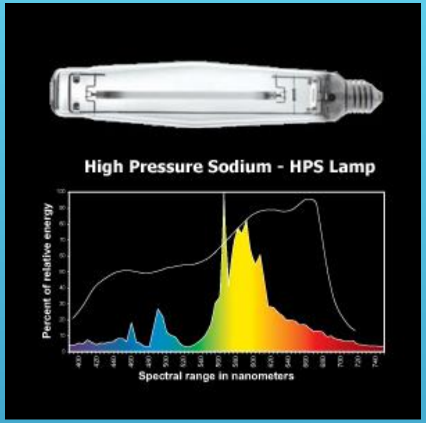
http://physics.nist.gov/Divisions/Div844/facilities/vision/color.html

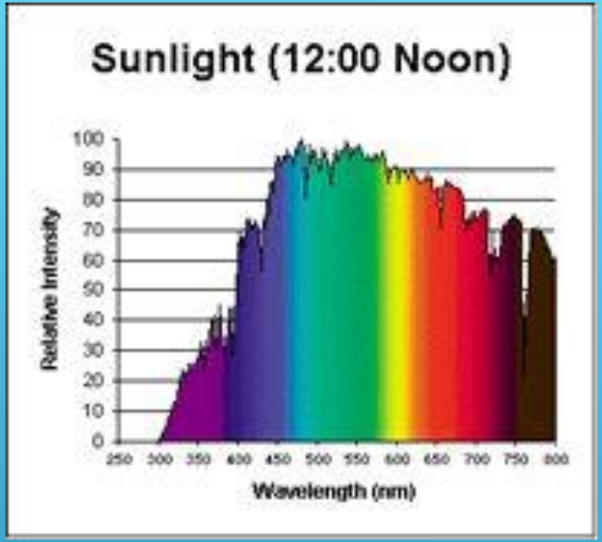
Spectral Power Distribution SPD

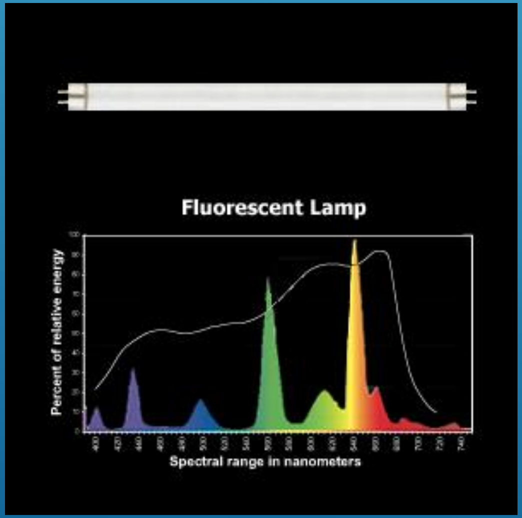
RGB LED

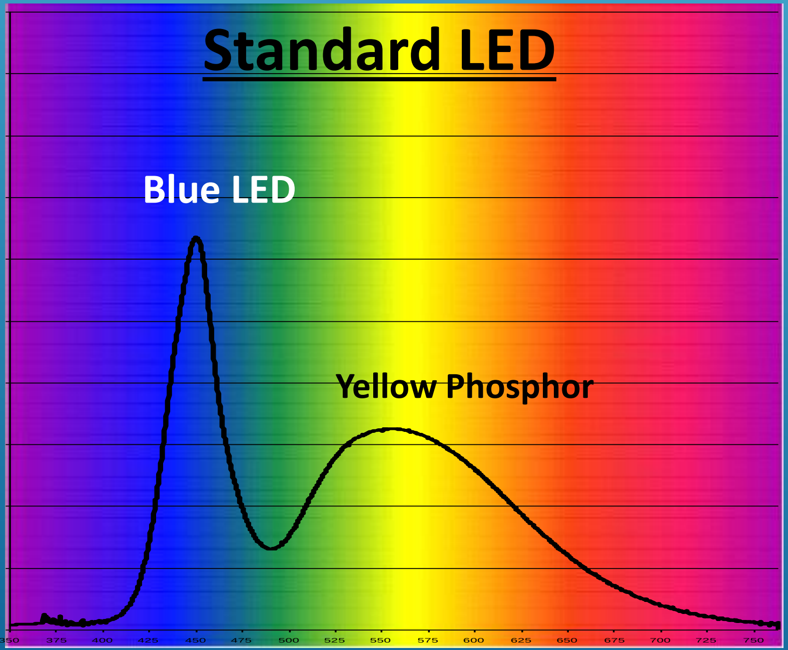


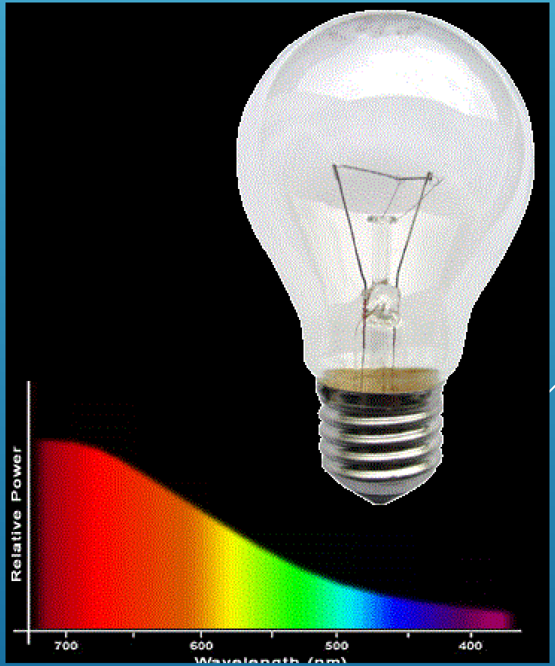








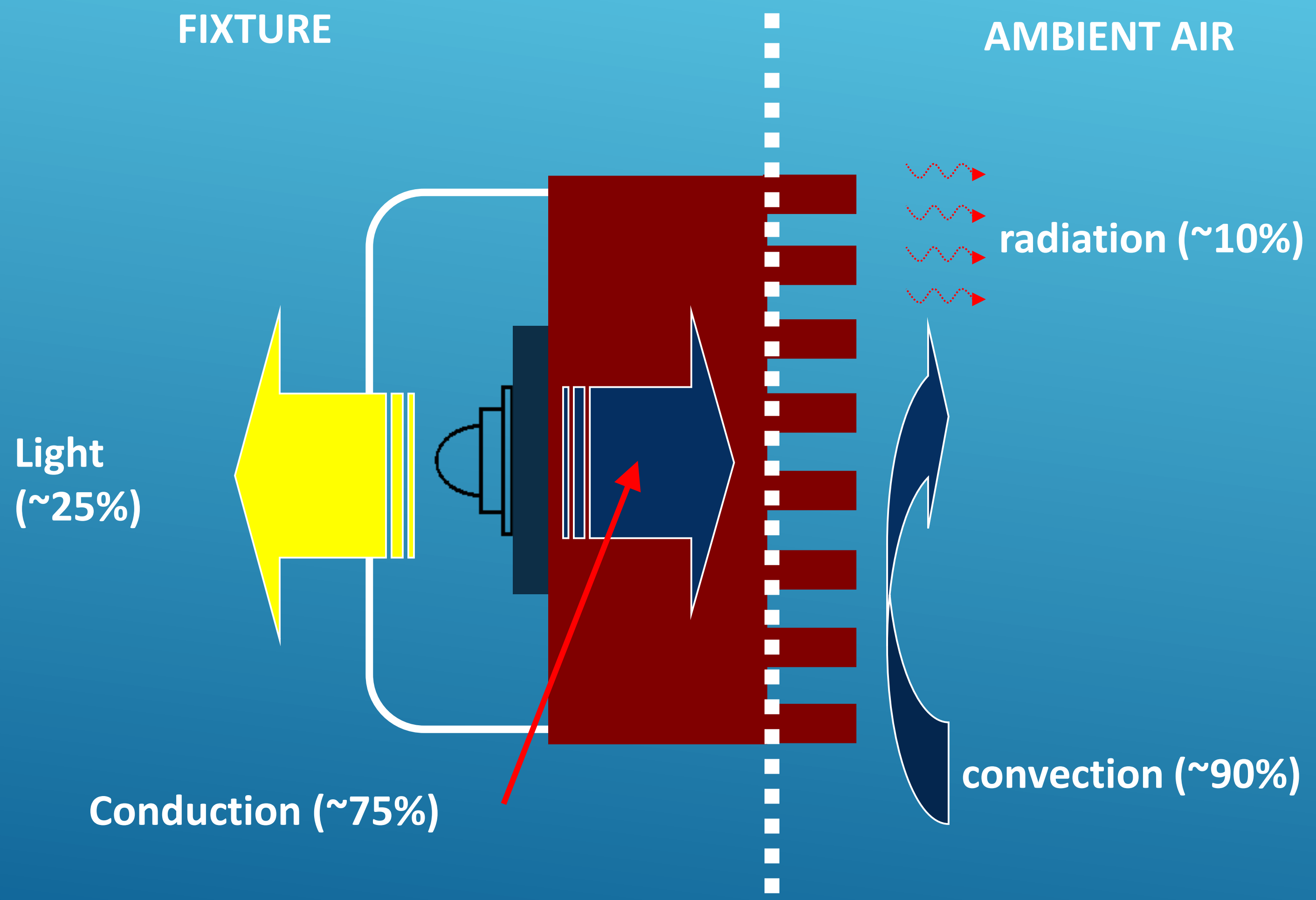




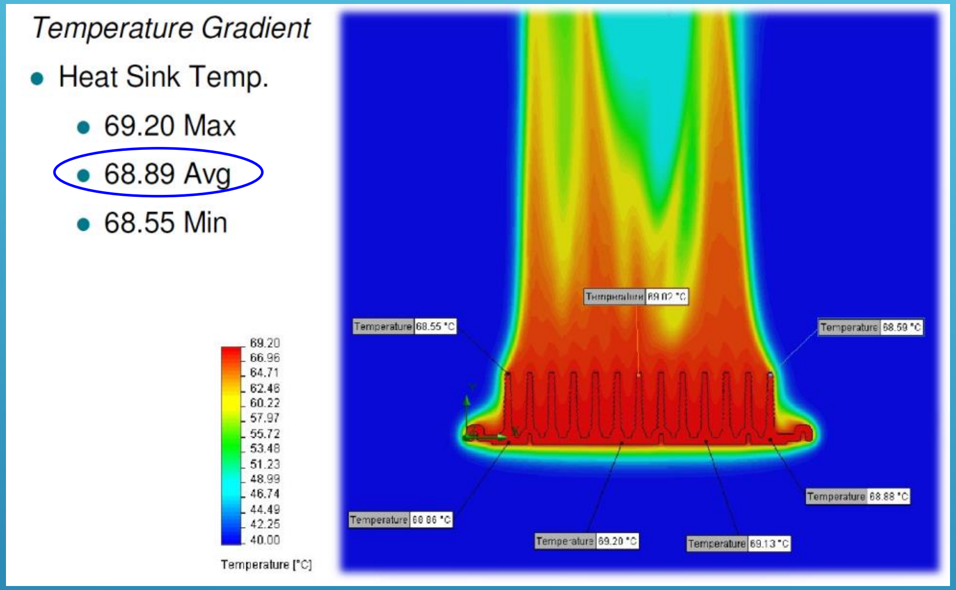
Heat Management

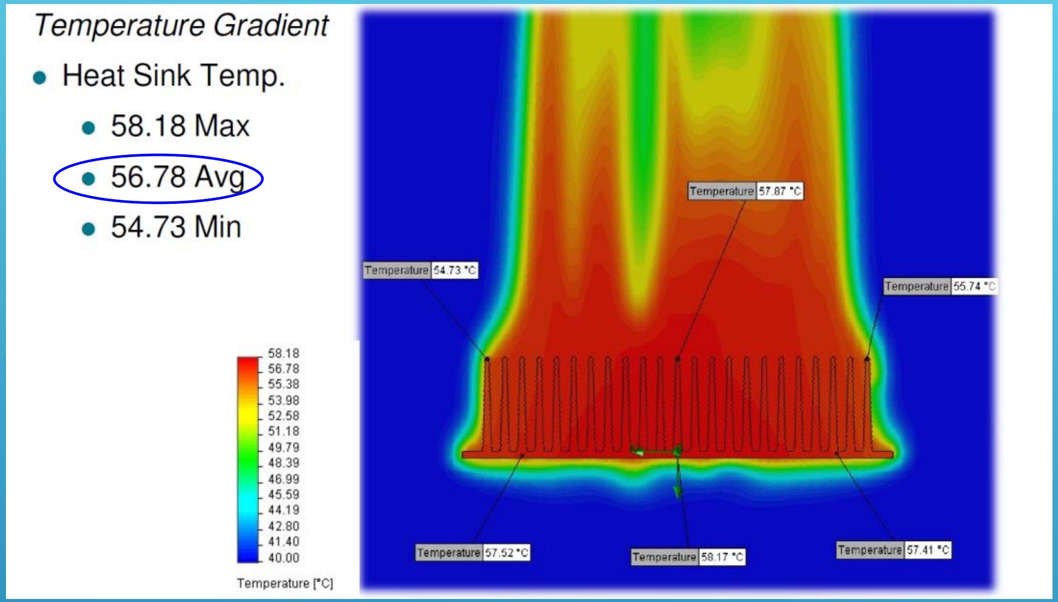
They get hot, but its different

Thermal Design



Thermal Design





Considerations

- Theoretical vs. Reality
- Optimization and Iteration
- Experience

Thermal Design

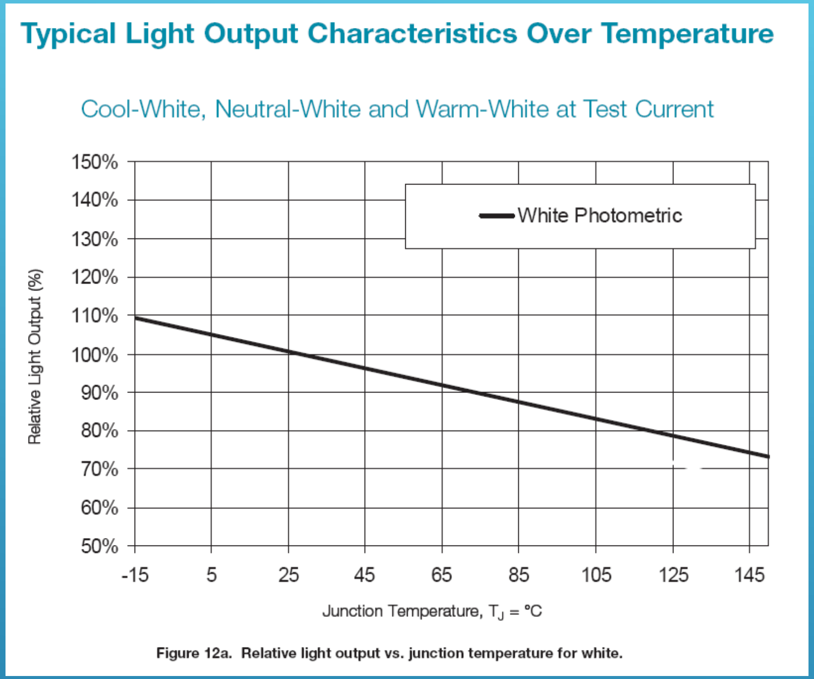
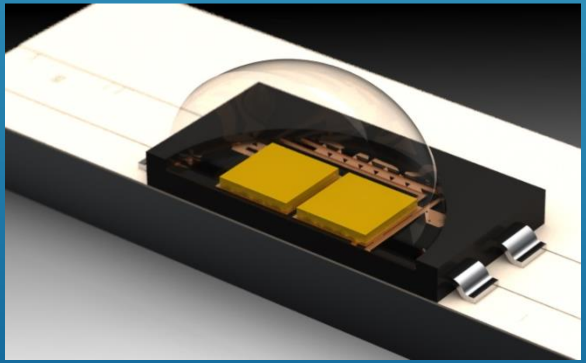
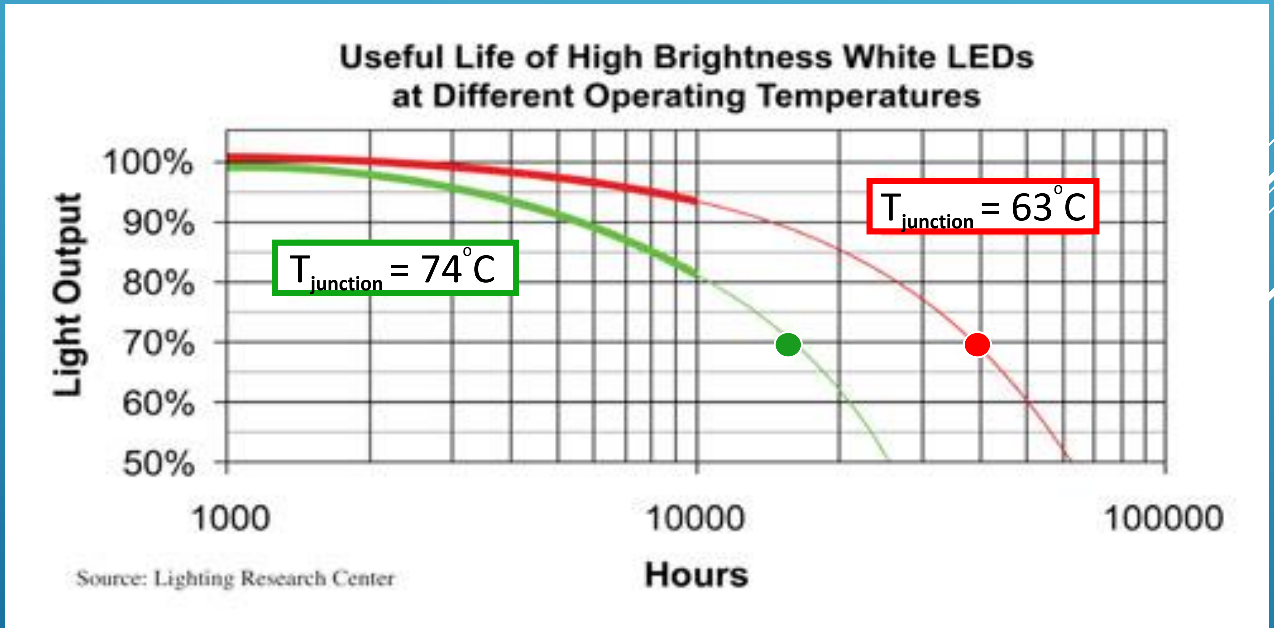


Figure 12a. Relative light output vs. junction temperature for white.



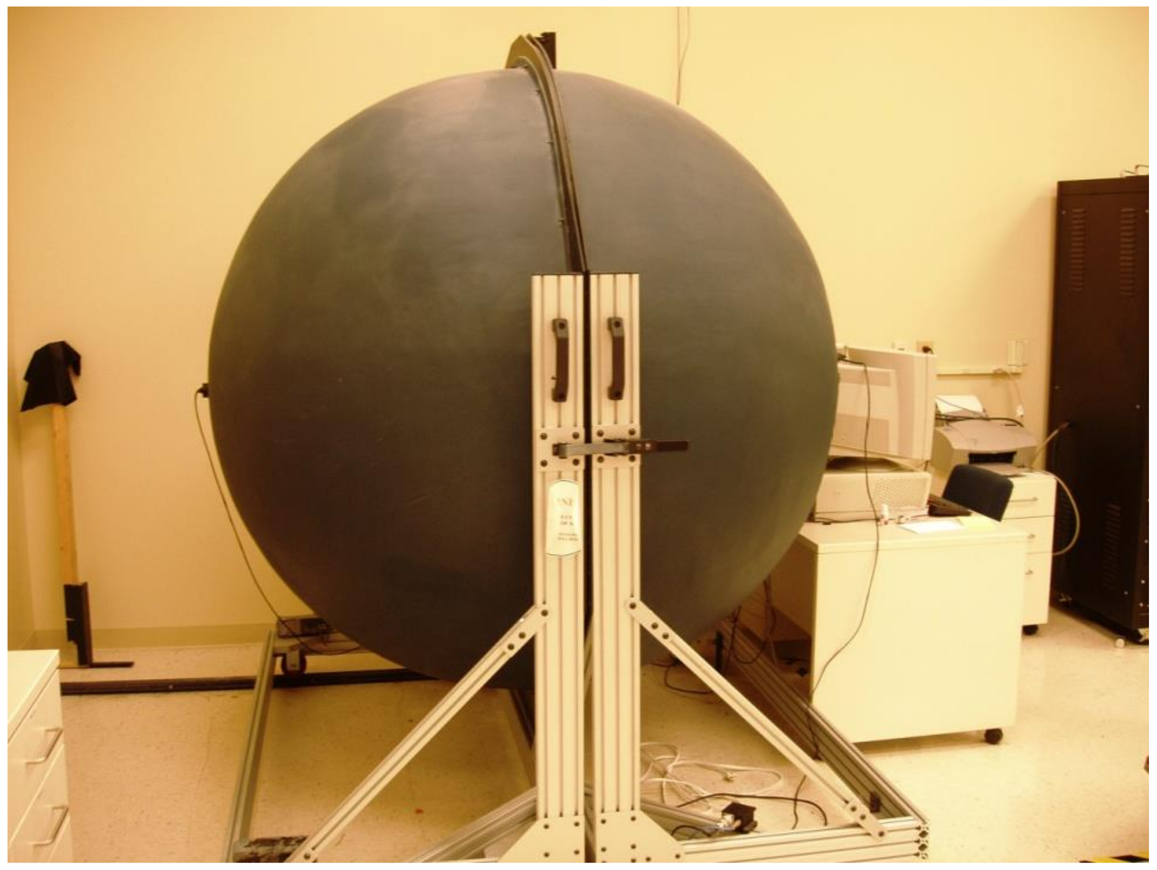
Considerations
- Performance Ambient
- Rated Ambient
- Extreme Ambient



TESTING

How do you get the seal of approval?

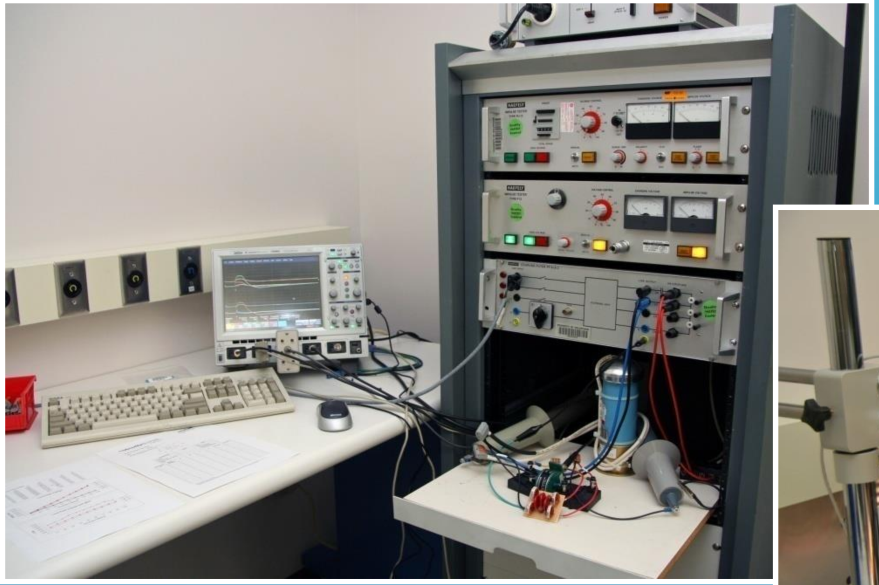
Photometric Testing



INTEGRATING SPHERE

Testing

Electronic Capabilities



Surge Testing

Failure Mode Analysis

Testing

IP Rating

Dust Chamber

Rain Testing

Vibration Testing

Thermal Chambers

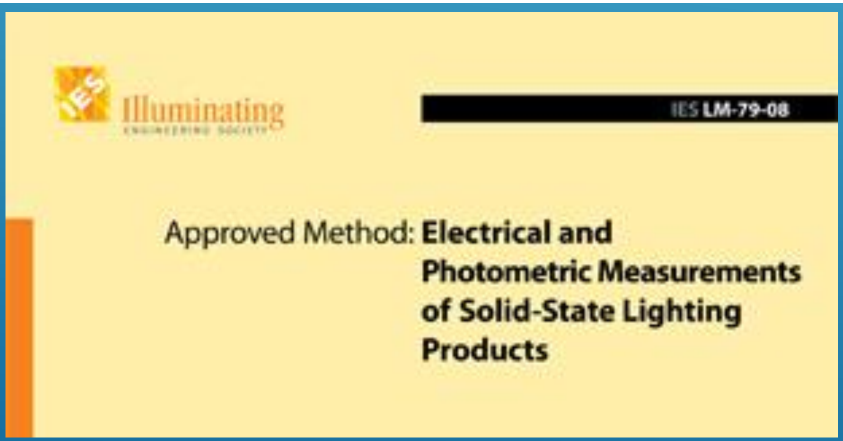
STANDARDS and REGULATIONS

How do you know what you're getting is good?

Standards

COMPLETED STANDARDS

- Completed standards, test methods, and CIE/IEC counterparts
  - ANSI C78-377 (chromaticity)
  - IES LM-79 (luminaire photometric testing)
  - IES LM-80 (LED module lumen depreciation testing)
  - IES RP-16 Addendum "a" (LED definitions)
  - CIE TC2-45 CIE 127-2007 Measurement of LEDs
  - CIE TC1-62 177-2007 Colour Rendering of White LED Light Sources
  - IEC SC 34A - TS 62504 Terms and Definitions for LEDs and LED Modules in General Lighting



IESNA LM-79-08

IESNA LM-80-08

LM-80

IES LM-80-08

Approved Method: **Measuring Lumen Maintenance of LED Light Sources**

IESNA LM-80-08

- LM80 provides
  - First 6000 hrs of LED life
  - Measured each 1000hr
    - Lumens, CCT
  - Three temperatures
    - 55C, 85C, Select
  - Single drive current

- Does not provide
  - Data past 6000hrs
  - Projections of life
    - USE **TM21** standardized methods

IES TM-21-11

Projecting Long Term Lumen Maintenance of LED Light Sources

LM-79

IESNA LM-79-08

- *Provides Luminaire info*
  - *Lumens*
  - *Distribution*
  - *CCT/CRI*
  - *Watts*

Market Adoption

DOE PROGRAMS

CALiPER

GATEWAY Demonstrations

L-PRIZE℠

NGL2009

Retailer Energy Alliance

LIGHTING for tomorrow

Technical Information Network

QUALITY

lighting facts
A Program of the U.S. DOE

ENERGY STAR

DESIGNLIGHTS CONSORTIUM®

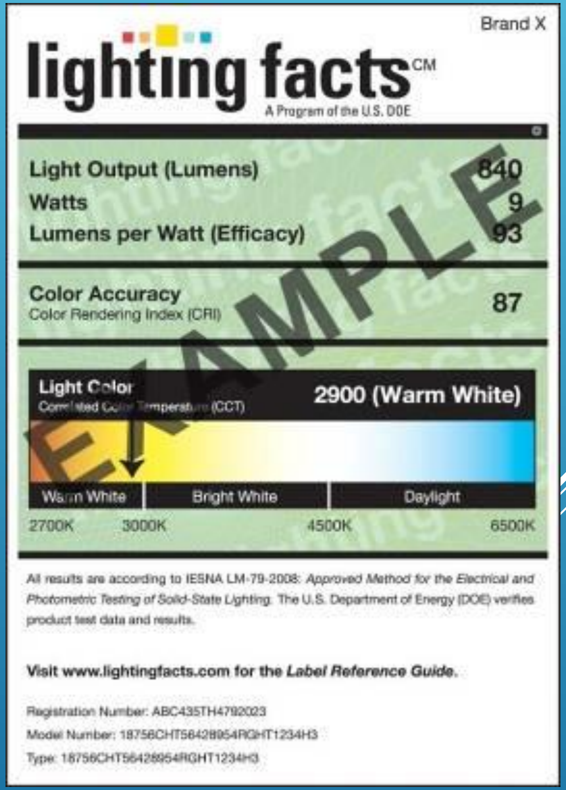
lighting design lab

CALiPER

Lighting Facts^{CM}

- "Nutrition Label" for SSL
- Labeling system that aims to address the problems in manufacturer product performance reporting as noted by DOE's CALiPER program
- Help to avoid some of the pitfalls experienced with the early introduction of CFLs

www.lightingfacts.com



Design Lights Consortium

- DLC Formed by Northeast Energy Partnership
- “Qualifies” LED products for Utilities
- Rebates are available for products on QPL (Qualified Product List)
- Does not duplicate Energy Star

Lighting Design Lab

lighting design lab

- DLC Formed by Northwest Energy Partnership
- “Qualifies” LED products for Utilities
- Rebates are available for products on QPL (Qualified Product List)
- Does not duplicate Energy Star

LIGHTING CONTROLS

Manual, Scheduling, Sensing

Why lighting controls?

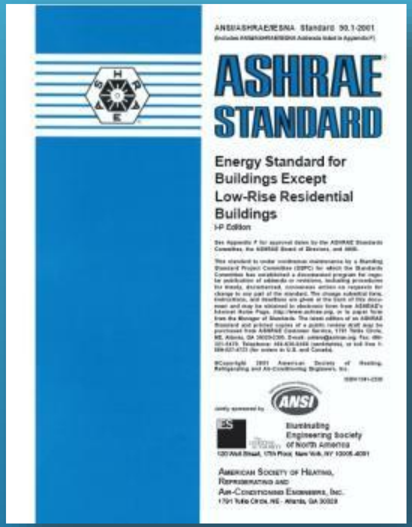
- Lighting energy is the major electricity usage in buildings today (30%)
- Buildings waste lighting energy
- Buildings do not consider daylight

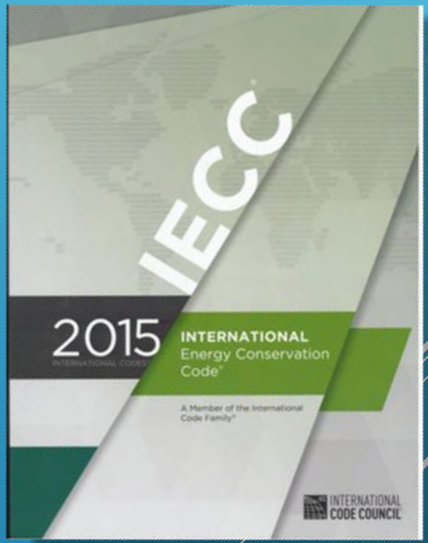
Why lighting controls?

Energy Management & Sustainability

- Major trends driving the greater adoption of lighting controls…
- Several new and existing codes mandate the use of controls

TITLE24





IECC 2015

Lighting control strategies - MANUAL

Manual Light Reduction Options

(Ideal for spaces occupied by critical tasks)

Switching

- Economical and effective way to save energy
- Minimal equipment required

Dimming

- Flexible and effective way to save energy
- Greater choice of light levels

Energy Savings

- 22% in private office
- 16% in open office
- 15% in retail environment
- 8% in classroom

Lighting Controls Effectiveness Assessment, ADM Associates, May 2002

Lighting control strategies - SCHEDULING

Overview

- Manages light status based on time of day
- Complies with commercial building energy codes requiring automatic shutoff
- Where lights cannot be turned OFF during normal operating hours without hurting safety or security

Strategies

- Time-based control provided through astronomic timeclocks or intelligent relays (distributed or centralized)
- Local wall controls and override switches provide enhanced control options and in many areas are required by code

Lighting control strategies - SENSING

Occupancy Sensing

- Turn off lights in an empty room
- Vacancy sensors, manual on, make light use purposeful
- Complies with commercial building energy codes requiring automatic shutoff
- Ideal applications
  - smaller, enclosed spaces
  - spaces that operate on an unpredictable schedule
  - spaces that are intermittently occupied

Lighting control savings

Occupancy Sensing Energy Savings

Space Type	Lighting Energy Savings Demonstrated in Research or Estimated as Potential	Study Reference
Private Office	38%	*An Analysis of the Energy and Cost Savings Potential of Occupancy Sensors for Commercial Lighting Systems*, Lighting Research Center/EPA, August 2000.
Classroom	55%	
Restroom	42%	
Conference room	23%	
Break room	15%	
Open Office	15%	*Lighting Controls: Patterns for Design, R. A. Rundquist Associates*, Electric Power Research Institute, 1996.
Open Office (individual fixture control)	35%	Canada National Research Council study on integrated lighting controls in open office, 2007.

Lighting control strategies

Occupancy Sensing Options

- Sensor technology
  - Passive infrared (PIR)
  - Ultrasonic
  - Microwave
  - Acoustic
  - Dual Technology
- Mounting/enclosure
  - wall
  - ceiling
  - high bay
  - Indoor/outdoor
- Power wiring
  - line voltage
  - low voltage

Lighting control strategies

Daylight Harvesting Overview… benefits of daylight

- Numerous studies link daylight and views to higher levels of satisfaction and productivity
- Maximum 40% increase in sales in retail study
- Students with highest levels of daylight progressed 20-26% faster on math and reading tests in school study
- Office workers performed 10-25% better on tests and recall when they had the best possible view in office study

Above data supported by Heschong Mahone studies, 1999, 2003

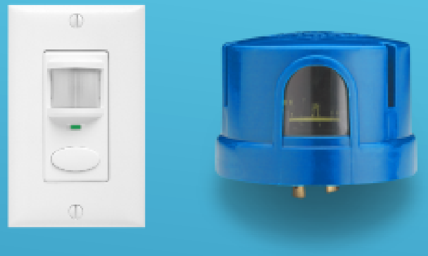
Lighting control strategies

Outdoor Lighting Control Schemes

- Dusk to Dawn -
  Lights on at Dusk, Off at Dawn
- Trimming -
  Lights on at a preset time after dusk, Lights off a preset time before dawn
- Part Night -
  Lights on at dusk, Off/dimmed at approx. midnight
- Group Scheduling -
  Ability to turn groups of fixtures on/off/dim at a desired time
- Individual Scheduling -
  Ability to turn individual fixtures on/off/dim at a desired time

Lighting control strategies

The Right Design for the Project



- Standalone

- Networked – Centralized (relay panels)

- Networked – Distributed (wired CAT5 or wireless)

Applications/Solutions

The sharp end of the stick

But first, ….

Performance advantages

Significant improvement in energy efficiency (40% - 90%)
Reduction in heat radiation (lower AC demand)
Longevity – low maintenance
No hazardous materials – 100% recyclable
Improved illumination – CFLs in cans?
No short-term lumen loss
Lighting where you want it (lensing), when you want it (controls)
No “on/off” issues
No UV

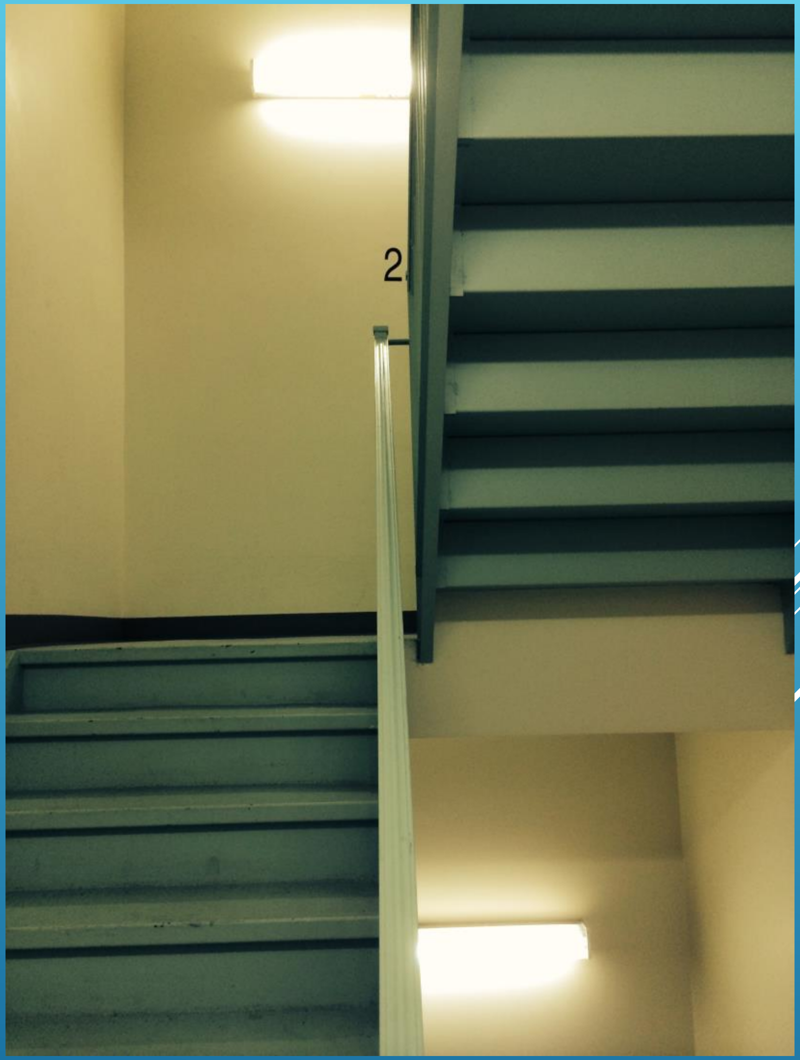
Applications

Low hanging fruit:

- All 24/7 applications
- All existing incandescent lighting
- All existing halogen lighting

Specific areas:

- Stairwells (lighting plus EXIT signs)
- Corridors
- Lobbies
- Meeting rooms
- Parking areas and garages
- Accent/cove lighting



Solutions

CANs – PARs, BRs => halogen? CFL? => LED lamps or retrofit kits

TROFFERS – 2X2, 2X4 => fluorescent tubes => LED tubes, retrofit kits or new fixture

STRIPS – 1X4 => fluorescent tubes => LED tubes, retrofit kits or new fixtures

TRACKS – MR16 (5.3 or GU10) => halogen lamps => LED lamps or integrated head

CEILING MOUNTED FIXTURES => incandescent/CFL lamps => LED lamps (E26 and G24) or retrofit kit or new fixtures

SCONCES => incandescent/CFL lamps => LED lamps (E26 and G24) or retrofit kit or new fixtures

CANDELABRAs => incandescent lamps => LED lamps (test the look!!)

Solutions

PENDANTS - 1X4 => fluorescent tubes => LED tubes, retrofit kits or new fixtures

COVES/UNDER COUNTER – fluorescent tubes, halogen fixtures => LED tubes, LED tape, LED lightbars or LED fixtures

GARAGE FIXTURES – metal halide, HP sodium => LED lamps or new fixtures

WALL PACKS - metal halide, HP sodium => LED lamps or new fixtures

BOLLARDS – metal halide, HP sodium => LED lamps or new fixtures

POLES – Georgia Power!

HIGH BAY- metal halide => LED lamps or new fixtures

Cost of Ownership

Show me the money

Key Performance Tools

RETURN ON INVESTMENT (ROI) – measures the amount of RETURN on an investment relative to the investment's cost. To calculate ROI, the benefit (RETURN) is divided by the COST of the investment and the result is result is expressed as a percentage (allows for comparison).

PAYBACK PERIOD – the length of time required to recover the cost of an investment. To calulate payback, you take the cost of the project and divide that by the estimated annual cash flows (savings).

Calculating Savings

INPUT
Existing lamp or fixture
Description: Incandescent BR30

Total wattage per lamp:	65
Price per lamp:	5
Number of lamps:	10
Labor cost to change lamps:	0
Days per year operation:	365
Hours per day operation:	17.95
KWHr rate:	0.10
Rated lifetime of lamps (hrs):	2000
Expected years of operation:	0.31
Scheduled change-out period:	0.31

INPUT
Existing lamp or fixture
Description: CorePro LED BR30

Total wattage per lamp:	10
Price per lamp:	16.58
Number of lamps:	10
Labor cost to change lamps:	0
Days per year operation:	365
Hours per day operation:	17.95
KWHr rate:	0.10
Rated lifetime of lamps (hrs):	40000
Expected years of operation:	6.11
Scheduled change-out period:	0.00

OUTPUT	Existing	Retrofit	Savings
Energy consumption (KWHrs):	4258.64	655.17	3603.47 (84%)
Energy cost ($$):	$4,25.86	$65.17	$360.35

Annual energy savings:	Yr1	Yr2	Yr3	Yr4	Yr5
Energy savings:	$360.35	$360.35	$360.35	$360.35	$360.35
Change out savings:	$163.79	$163.79	$163.79	$163.79	$163.79
Cost of LEDs:	($165.80)				
Labor:	0				
Rebates:	0				
Cash flow:	$358.34	$524.14	$524.14	$524.14	$524.14

NPV:	$2,111.35
ROI:	1273.43%
PAYBACK:	.316 years = 3.8 months

Calculating ROI and payback

What are the parameters:

- kWh cost at your facility = E_{COST}
- Wattage of LED= W_{LED}
- Wattage of existing light= W_E
- Hours of operation= H_{OP} (24/day? 12h/day?)
- Number of lights = N_L
- Number of existing bulb changes/year = N_{EB}
- Cost of existing bulb = EB_{COST}
- Cost of LED fixture = LED_{COST}

⇒You can now do a simple calculation of yearly savings:

•Money saved/year = $(((W_E - W_{LED}) \times H_{OP} \times 365 \times E_{COST} \times N_L)/1000) + (N_L \times N_{EB} \times EB_{COST})$

•Payback period (in years) = $(N_L \times LED_{COST})$ / (Money saved/year)

Additional parameters you can take into account;

- Maintenance: how much does it cost you to change bulbs? Ballasts?
- AC saving: lights contribute 20% to your AC load. Can you estimate the savings?

For halogen and incandescent payback ~1 year or less for 24hr operation

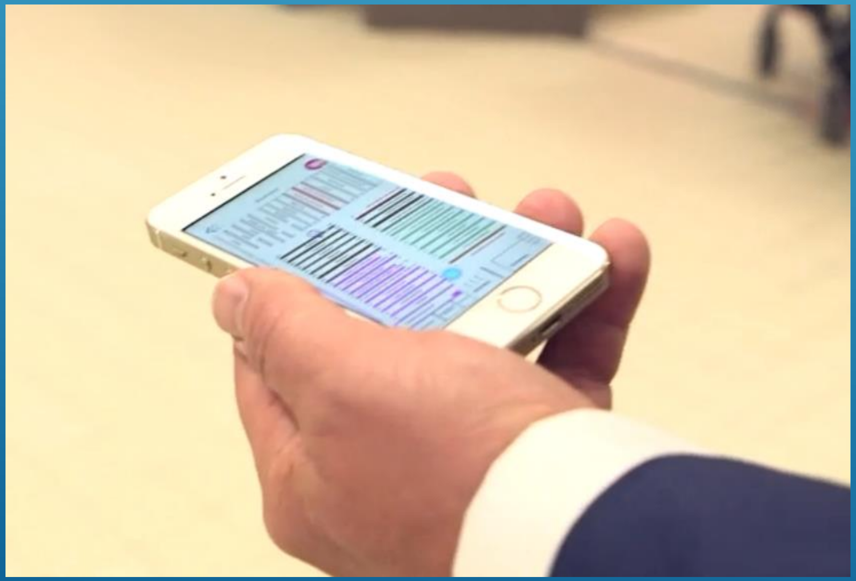
Simple ROI – savings/investment X 100. Over time use NPV/investment X 100.

What is next?

Beam me up Scotty – The Internet of things

Visible Light Communication

- LED lights are the "satellite" or GPS system
- Using LED lights (or satellites) you essentially have an indoor positioning system.
- How? The lights oscillate at a very high frequency (on/off) that your eye cannot detect but a camera's phone can. That allows an app to identify your exact location because it knows where the lights are.
- Carrefour and Target are the largest first movers.



Carrefour Lille – 80,000 sq ft. 1.5 miles of LED lighting

LIFI

The use of the visible light spectrum, instead of radio frequencies, to enable wireless data communication. Already being tested (Paris Metro)

Why?
1. Very safe
2. Very fast

QUESTIONS

??????????????????

Bob Viehweger, President
LED Light Energy
Decatur, GA
(312) 451-4341
bob@ledlightenergy.com

IFMA objectives and quiz questions

Learning objectives:
To understand the technical performance of LEDs and why they are superior to existing lighting technologies;
To be familiar with current/future "high value" applications for LED lighting and controls;
To understand the commercial viability of LED lighting relative to existing light sources, and to be able to to calculate a simple energy savings analysis including payback and ROI.

Questions:
1. Is ROI an acronym for payback period? Y/N?
2. Which one of the following does not influence total cost of ownership?
A. electricity rate ($/KWHr)
B. correlated color temperature (CCT)
C. maintenance
D. cost of LED lamps or fixtures
E. operating hours
3. Name the two quality assurance accreditations that are generally required to receive utility rebates?
4. Who invented the first visible LED?
5. Which one of the following is not a wireless control technology?
A. ZigBee
B. WiFi
C. CAT 5
D. Microwave
E. Ultrasound