



U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Adopting LED Technology: What Federal Facility Managers Need to Know

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What is planned for this webinar -

- The nature of LED technology
  - The clear advantageous
  - The cautions and caveats
- How to choose good products
  - What makes a good product
  - What makes it right for my project
- Where are LEDs a good fit
- What is important in determining project cost-effectiveness with LEDs
  - What's different about LED costing and economics
  - What might be different about my project
- What resources are available to help make good decisions

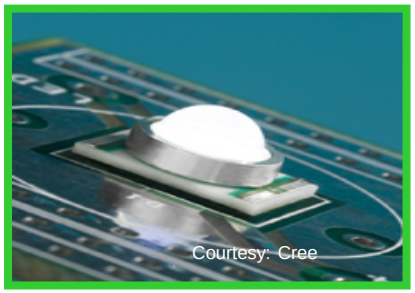
LED Basics: What makes them go….

You've heard that LEDs function differently than other lighting technology. So what's the difference?

- Incandescent/Halogen --- a glowing wire or filament

- Fluorescent --- an electric arc that excites a gas that causes phosphors to glow

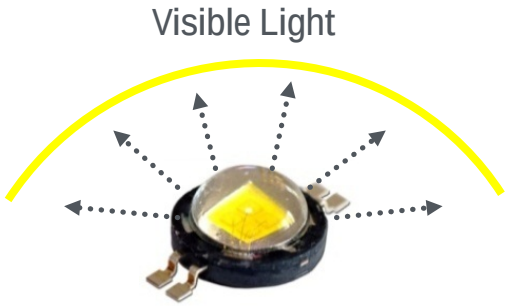
- High-Intensity Discharge (HID - metal halide, high pressure sodium) --- an electric arc that vaporizes material that emits light
- **LED --- an electronic semiconductor diode (chip) that emits photons (light) when current is applied.**



This new technology offers great advantageous….and some cautionary attributes

The good stuff about LEDs

- Small format
  - Provides for more flexibility in luminaire design
  - Great for hidden applications (e.g., showcases, equipment)
- Directional – radiate in 180 degrees
  - Can improve application effectiveness
  - Helps put light where its needed
- Robust and sturdy
  - No fragile filament to break
  - No large glass enclosure to break
- Potentially small environmental footprint
  - Relatively small material component
  - Primarily recyclable material (aluminum)



More good stuff…..with caveats!

- Do not *radiate* any significant waste heat (UV, IR)
  - Good for fragile artifacts and organics (paintings, food)

    …..but they do produce heat - more later
- Potential long life
  - Could reduce replacement and maintenance costs

    ….but this is not simple – more later
- Potential high efficacy – low energy
  - Promising efficacy that can surpass other technologies
  - Low energy a perfect “green” component

    ….but efficacy characterization is not simple – more later

Busting some popular myths….

….or at least clarifying the reality

- Three of the biggest miss-statements….
  - *"LEDs produce no heat"*
  - *"LEDs last 100,000 hours to forever!"*
  - *"LEDs are all extremely efficient"*

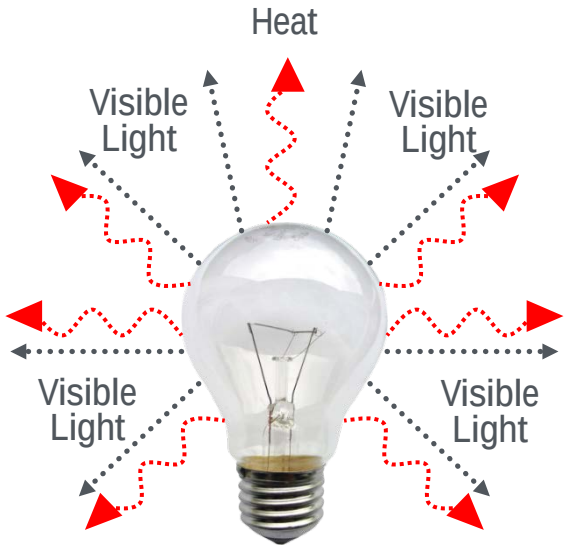
LEDs produce no heat……

….actually, they DO….but prefer to keep it to themselves

Incandescent Source

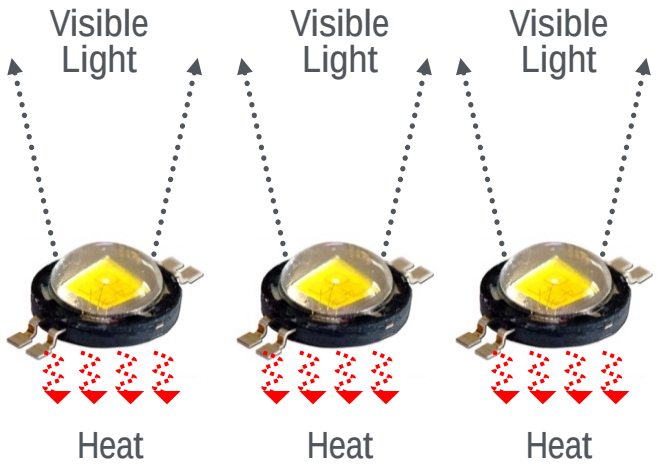
(also typical for FL, HID)

- Some generated heat is radiated away (IR)



LED source

- Generated heat does not radiate. It must be removed by conduction or convection



Comparison of Light vs. Heat

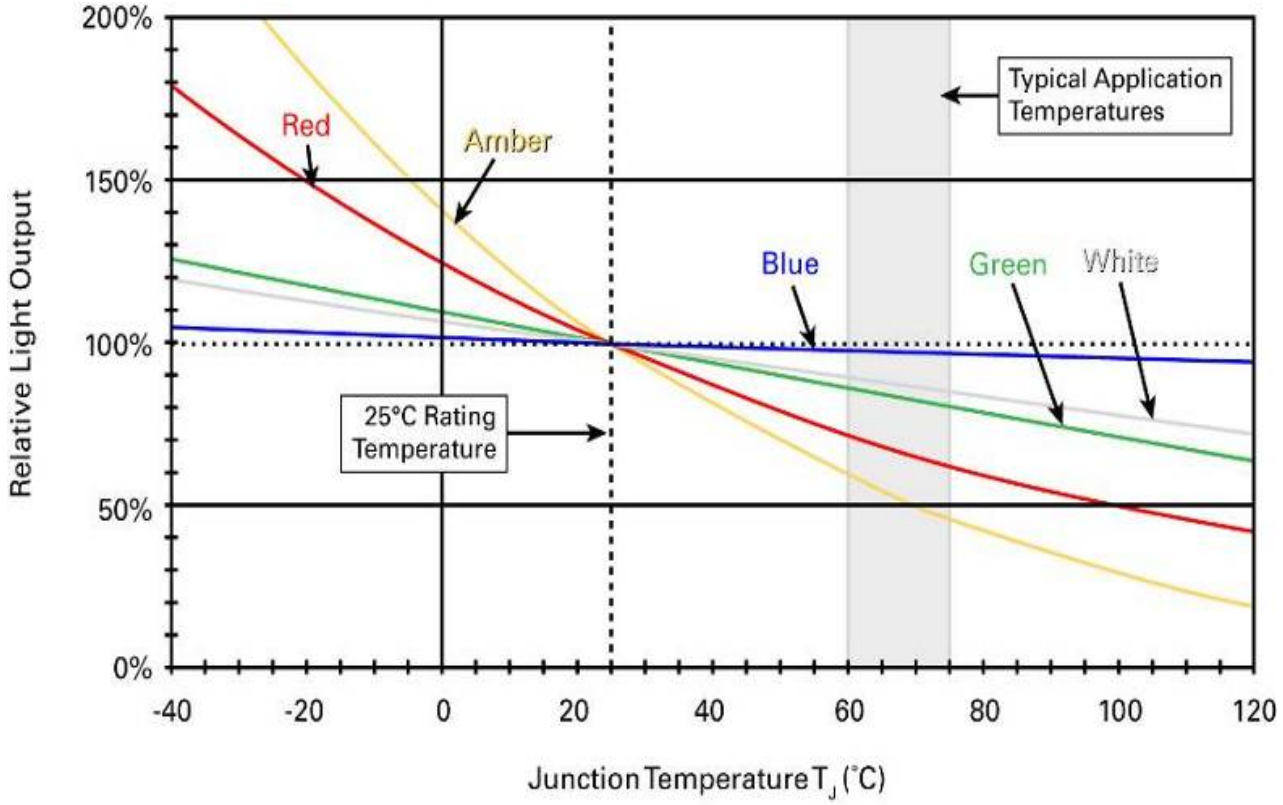
Power Conversion for "White" Light Sources

	Incandescent* (60W)	Fluorescent* (common linear lamp)	Metal Halide**	LED*** (phosphor converted LED)
Visible Radiated Light	**8%**	**21%**	**27%**	**31%**
Total energy loss (not converted to light)	**92%**	**79%**	**73%**	**69%**
radiated heat loss (IR)	73%	37%	32%	~ 0%
radiated energy loss (UV)	0%	<1%	3%	0%
non-radiated heat loss	**19%**	**41%**	**38%**	**69%**
Total Energy	100%	100%	100%	100%

* IES Handbook, 10th Edition; ** Osram Sylvania; *** DOE SSL R&D Multiyear Program Plan, 2013

Heat effects on LED performance

- Higher junction temperature (at the LED diode) degrades light output and life
- Heat can also degrade other components (lens, driver)

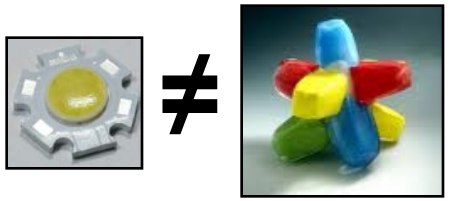


LED Heat Issue Reality

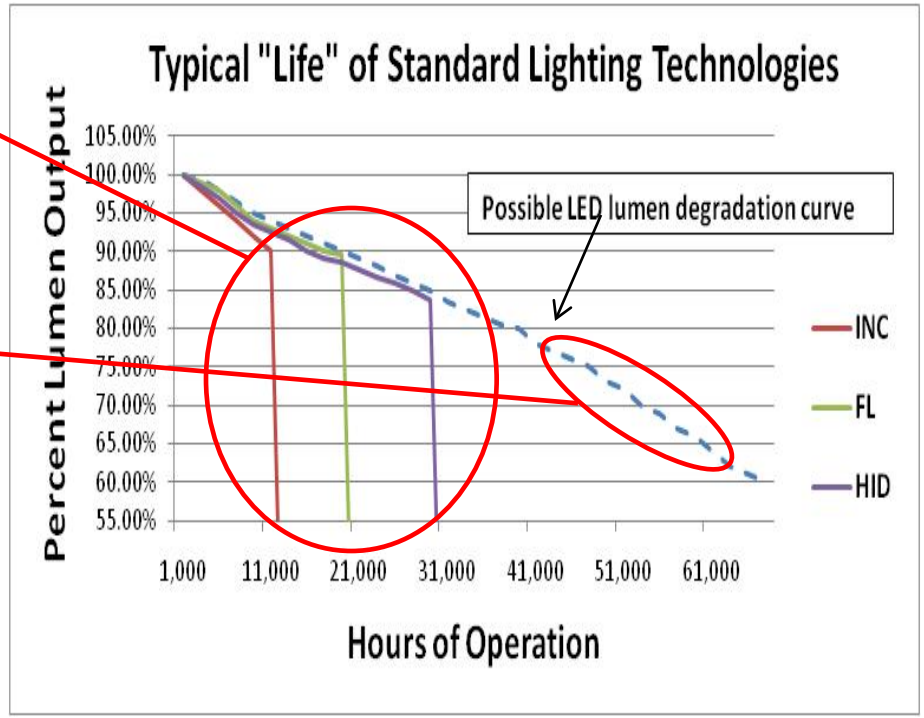
- LEDs are good options where you do not want heat (or UV) radiating on objects (art displays, fragile/melt-able foods, etc.)
- Consider product choices carefully when placing LEDs in confined environments where heat can build up
  - some lamps will be labeled not for insulated or lensed fixtures
- Look for emerging products to be progressively better at withstanding heat

LEDs last 100,000 hours to forever!

LEDs are not “Everlasting Gobstoppers”



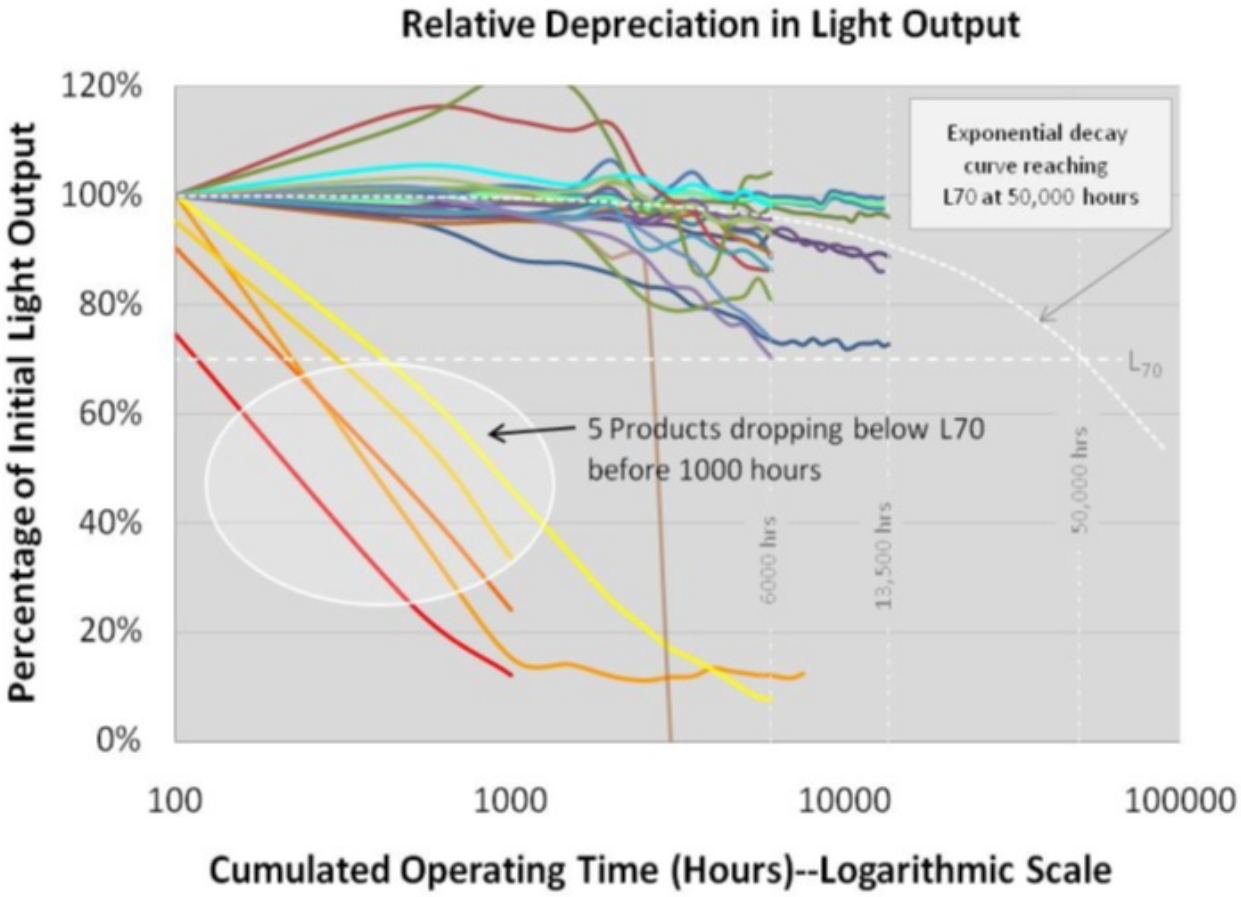
- **ALL** light sources degrade - most fail before critical light output level is reached
- LED diodes can survive but also degrade well beyond useful light level
- Industry considers lumen output as one measure of the **useful life** of an LED diode. Commonly, 70% of initial output is used.



LED life characteristics

- The "Useful Life" for an LED **system** has multiple elements:

  LED diode, encapsulant, array architecture, driver electronics



- Early LED product test data shows success and caution…

A few words about LED life and testing….

- Actual LED product life is still elusive for manufacturers and users – many variables, only one of which is lumen depreciation
- Potentially long life can drastically effect economics and project decisions….more on this later.
- The industry has developed the LM-80 + TM-21 duo of standards to put some sense to the lumen depreciation issue
  - LM-80/TM-21 provide testing and mathematical extrapolation to estimate lumen depreciation over time - but only for LED packages.
  - This LED package estimation has useful but limited application to complete LED fixture products
- The new LM-84 + TM-28 duo provide a similar method that applies directly to complete luminaire products.
  - LM-84 and TM-28 are new - so you won't see data for a while

LED “Life” Reality

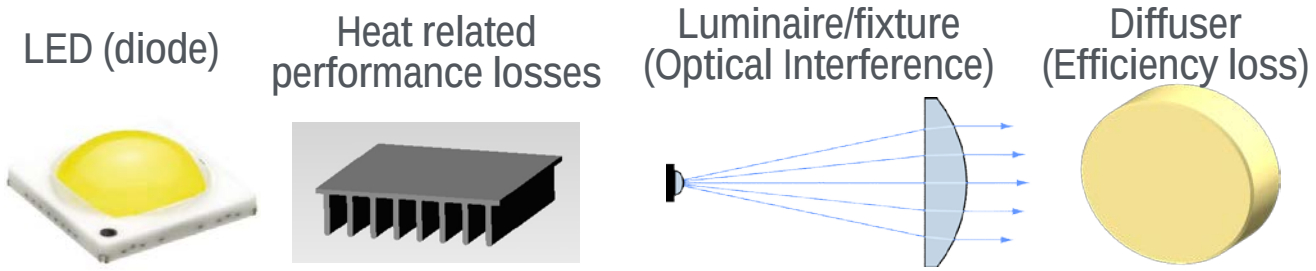
- The end of life of an LED product can involve more than just lumen depreciation. Other potential failure factors include:
  - Driver electronics
  - Material/connection fatigue
  - Lens deterioration
- However, evidence suggests that under normal operating conditions, lumen depreciation will be the primary life determinant
- At some point the light output of a long lasting LED may be too dim for its intended purpose
  - Plan accordingly for maintenance/replacement purposes
  - Consider the economics of a realistic useful life in project planning

LEDs are all extremely efficient

Well….some are and some aren't (yet)

- Reported LED **diode efficacies** (ideal lab conditions) are up to ~250 lumen/Watt – higher than other light sources

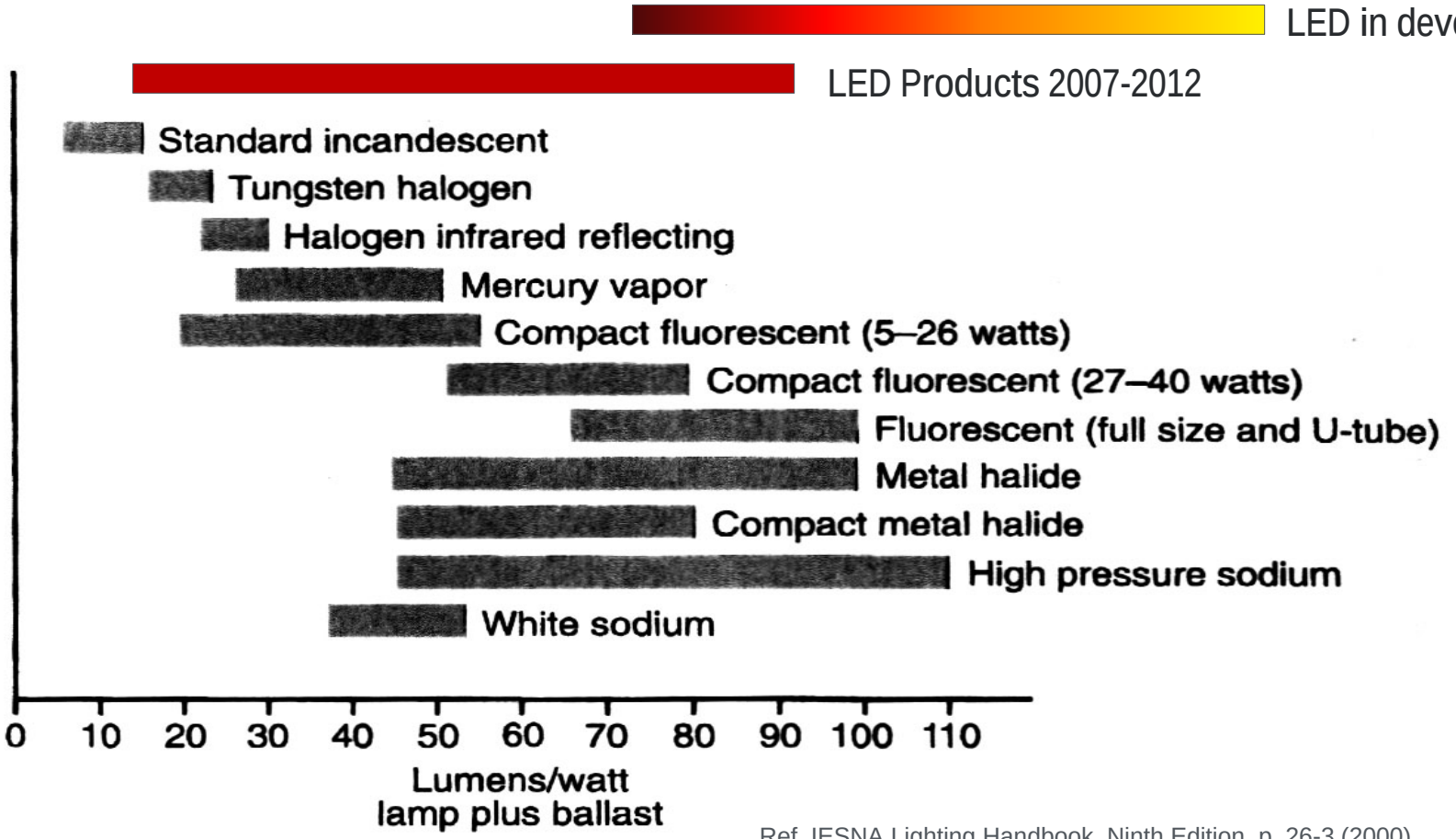
……However, an LED luminaire (fixture) is a system and all components effect the total product efficacy (lumen/watt)



- Complete LED **luminaire efficacies** are more modest.

  (~10 lm/Watt to ~120 lm/Watt)

LED diode efficacy compared to other systems



Ref. IESNA Lighting Handbook, Ninth Edition, p. 26-3 (2000).

Comparing Effectiveness of Different Lighting Types

So, how is complete product output and efficacy determined?

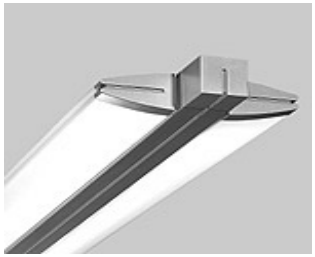
Incandescent/Fluorescent/HID:

Source (lamp+ballast) efficacy is tested

+

Fixture (housing) efficiency tested

=



Test data is combined for complete product output

LED:

Complete product is tested as a whole for output and efficacy

LED Efficacy Reality

- Look for complete LED fixture efficacy and total output based on appropriate testing (i.e. LM-79)
- Competing fluorescent fixture efficacy and output for comparison must be calculated from lamp output and fixture efficiency
- Highest efficacy may not automatically determine the best project choice - application needs are important!

A Few Other LED Characteristics/Issues…….

- Glare?
- Flicker?
- Color – availability/stability?
- Dimming capability?
- Environmental sustainability?
- Health hazards?

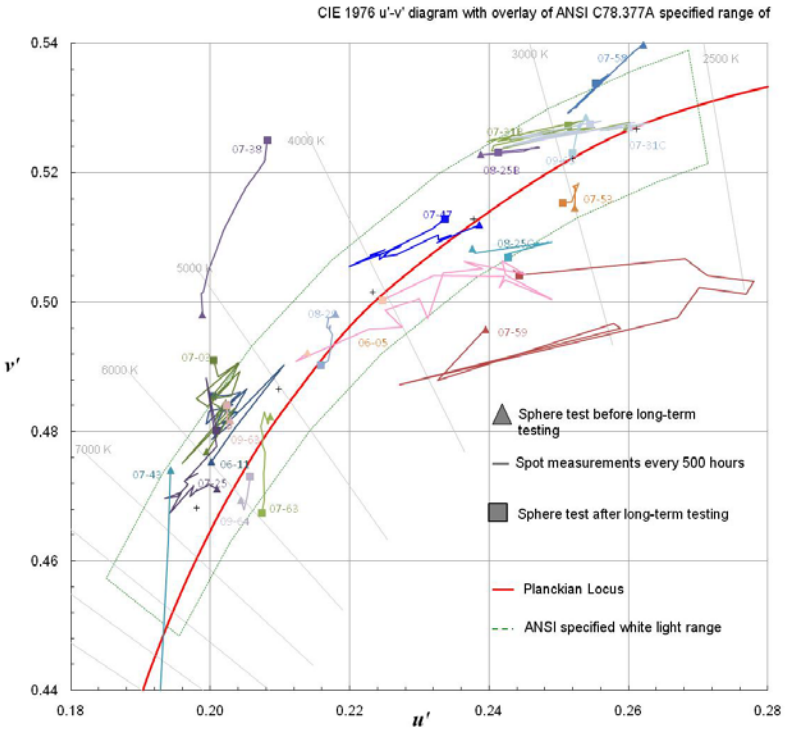
Glare and Flicker

- Glare
  - The small bright nature of individual LEDs creates the potential for glare when products are viewed directly
  - Most products cover or hide direct view of individual LEDs
  - Glare is relatively subjective to each individual
  - Try one, do a test mockup and compare before deciding
- Flicker
  - Can effect a percentage of the population at different levels
  - Flicker also occurs with discharge products (CFL. FL)
  - Most significant perceivable flicker occurs during dimming operations
  - Metrics to rate product flicker are available but with limited use and ultimately subjective for each user

Color – Availability and Stability

- LEDs can offer the same color options as Fluorescent
  - Rated in Kelvin (typically 2700k warm to 5000k cool)
  - 3500k is considered appropriate for common spaces
  - LEDs can offer the same color rendering capability as other lighting technologies

- LEDs can experience color shift over time
  - Other technologies also shift
  - Color shift perception can be very subjective
  - Shift can vary with product – a quality issue
  - Consider how important this is to the project



Dimming Capability

- LED technology (the diode itself) is inherently dimmable
- HOWEVER, the success of the dimming depends on the driver and dimmer control compatibility
- Manufacturer's are starting to label products with dimming capability
- Some guidance is available from manufacturers and DOE on identifying successful LED dimming systems

Reported Potential Health Hazards

- Optical safety (blue light) has been raised as a concern for LED products
  - The primary issue is evidence that high blue or violet light exposure can damage the retina
  - General white-light LED products do make use of Blue LED sources but only to drive mixed color phosphors
  - LED white-light products have no more blue light component than other sources at the same Color temperature
  - LED white-light products are not considered a optical safety risk per current international standards

How Do I Characterize Good LED Products?

First, look for appropriate product information

- Manufacturer/distributor product performance information should be based on appropriate test data. (LM-79 for LED lamps and luminaires)
- Understand the source of any "lifetime" claims. Look for LM-80/TM-21 or LM-84/TM-28 data when available.
- **Consider the information provided by available third party listings and rating programs:**
  - **Lighting Facts**
  - **ENERGY STAR**
  - **Design Lights Consortium (DLC)**
  - **Lighting Design Lab and similar utility lists**

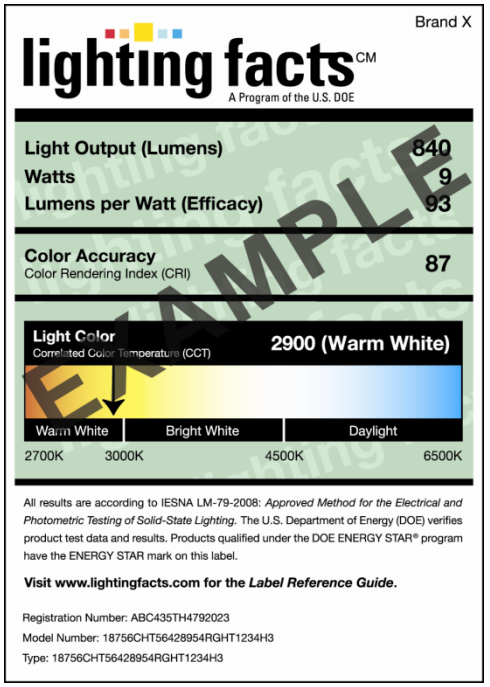
Energy Star Qualified Product List

- Federal program operated by the EPA
- Covers many consumer products aimed primarily at the residential market
- Includes CFL and LED luminaires and lamps
  - Sets a MINIMUM performance bar for efficacy, color, and rated life

- VOLUNTARY…..but often believed to be mandatory
- Required by some programs and federal agencies and widely recognized as a metric for quality

Lighting Facts Advocates Label

- A DOE program to promote accurate performance reporting for LEDs
- Manufacturers join and pledge to support quality objectives and use the Lighting Facts label on products
- Key product performance reported includes lumen output, watts, efficacy, color accuracy (CRI), light color (CCT)



- VOLUNTARY label…..but often believed to be mandatory
- Useful tool for comparison of **similar** products

DesignLights Consortium List

- A project of the Northeast Energy Efficiency Partnerships (NEEP) regional group – but **nationally available**
- Maintains listings of LED products meeting minimum performance and quality metrics in 30 specific categories
- Generally covers mostly commercial products not covered by Energy Star
- VOLUNTARY listing…..but often used and referenced
- Required by some programs and federal agencies and widely recognized as a metric for quality

DESIGNLIGHTS®
CONSORTIUM

Lighting Design Lab and Similar Product Lists

- Lighting Design Lab - a program that promotes education for lighting energy conservation
  - Supported by regional (northwest) utilities and efficiency programs
  - Maintains LED Qualified Products List
  - Major lamp and luminaire categories of products meeting minimum performance and quality metrics
  - VOLUNTARY listing…..but often referenced AND **publically available**

- Similar utility and utility group lists exist
  - Generally only available to the specific utility or a utility group
  - **Used for utility rebate programs to incentivizing efficient technology**

How Do I Choose the Right Products?

With data in hand……Does the product have the capability to provide what is needed **for the application**?

- Light delivery
  - match existing conditions or
  - meet industry recommendations to support actual needs

  Retrofits are prime opportunities to put light delivery at correct levels

- Light distribution - special needs such as spotlighting?....or just general distribution
- Useful life – how long is long enough?
- Color – match existing? or upgrade to better/different
- Economics…more on this later

What are good LED applications?

It depends on the application (you knew I was going to say that)

- Product performance is always key followed closely be functional needs
- In general, the attributes of LED technology make the following typically good applications:
  - Directional applications where the source efficacy and optical efficiency benefits are useful (e.g., downlights, troffers, streetlights)
  - Applications where the costs for energy and maintenance are high.
  - Applications that benefit from “white light” and improved uniformity (e.g., street and area lights).
  - Applications with environmental constraints (e.g., mercury restrictions, green building requirements).

What are product offerings currently like?

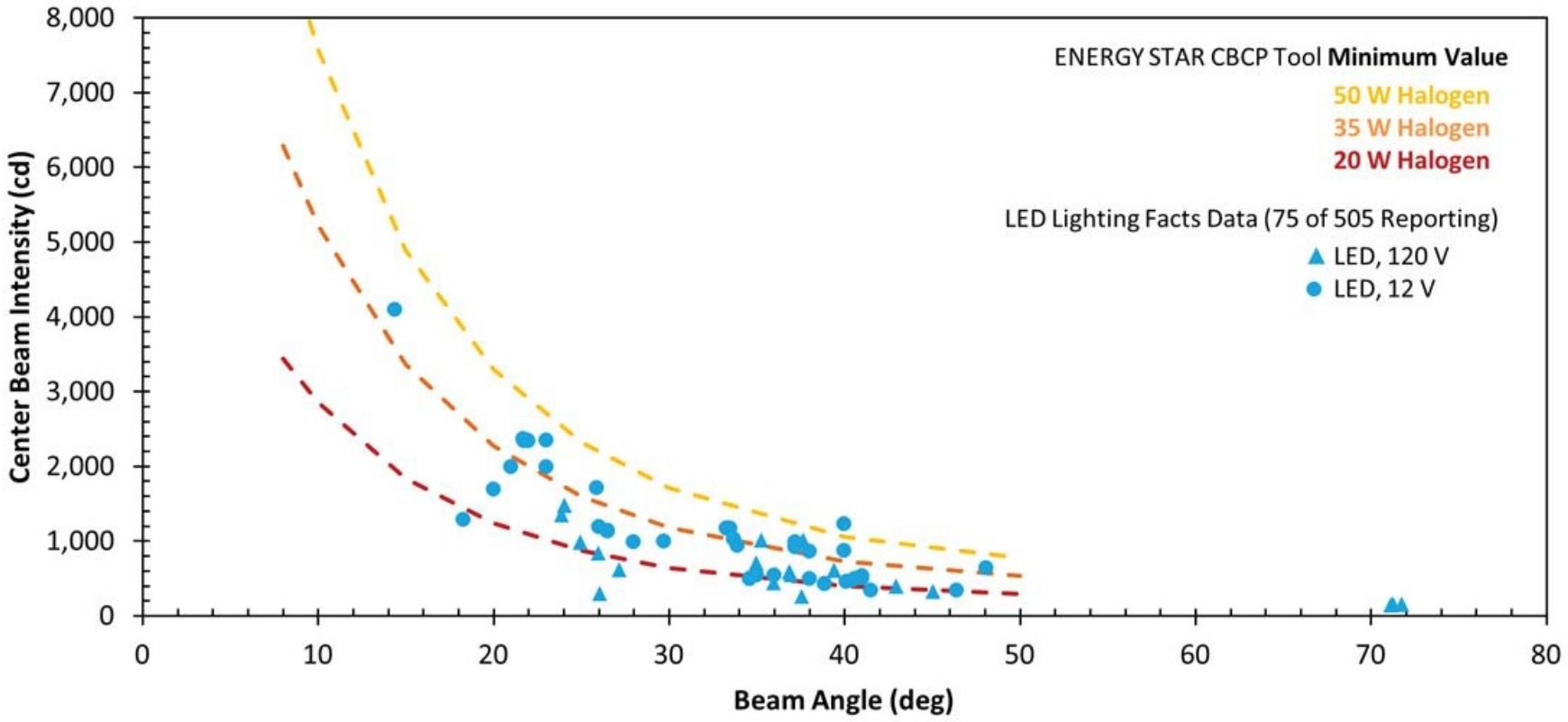
- Products and performance vary greatly due to the variety of manufacturers and relative newness of the technology
- The following charts* show current snapshots of the efficacy and output of products that
  - Have a Lighting Facts label or
  - Are on the DLC Qualified Products List
- These provide a relative idea of where products may be able to support the application
- But remember, good application also involves other criteria

*** charts from DOE CALiPER studies**

LED MR-16 Lamps

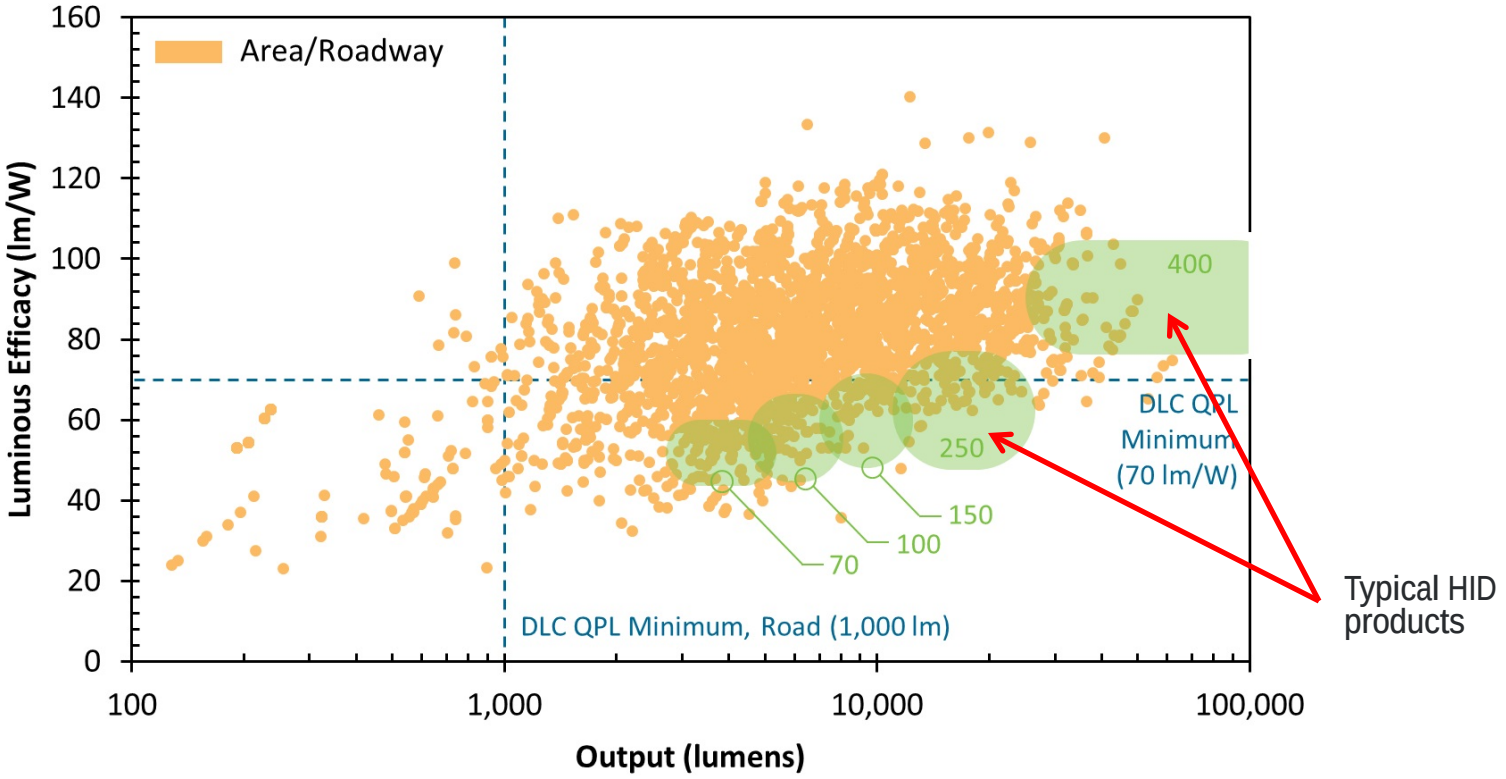
- Commonly used for retail product and display highlighting.
- Very high efficacy (compared to halogen counterparts)
- Output capability not quite matching the 50w 12v product category

LED MR-16 Lamps – beam intensity



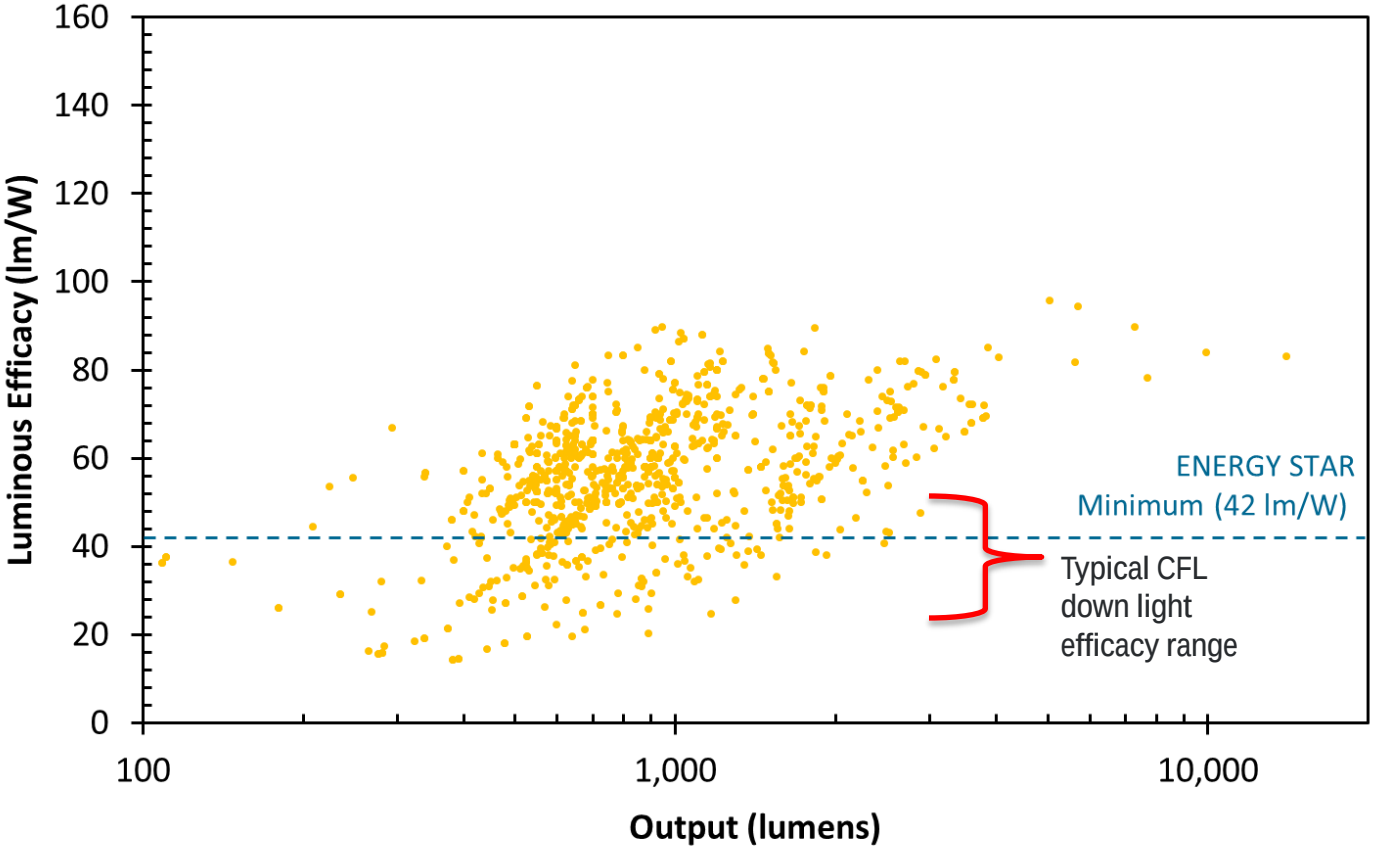
- Good options for replacing 20w and 35w halogens but weak at tighter beam angles
- More limited options for replacing 50w halogens

LED Outdoor/Parking/Area/Roadway



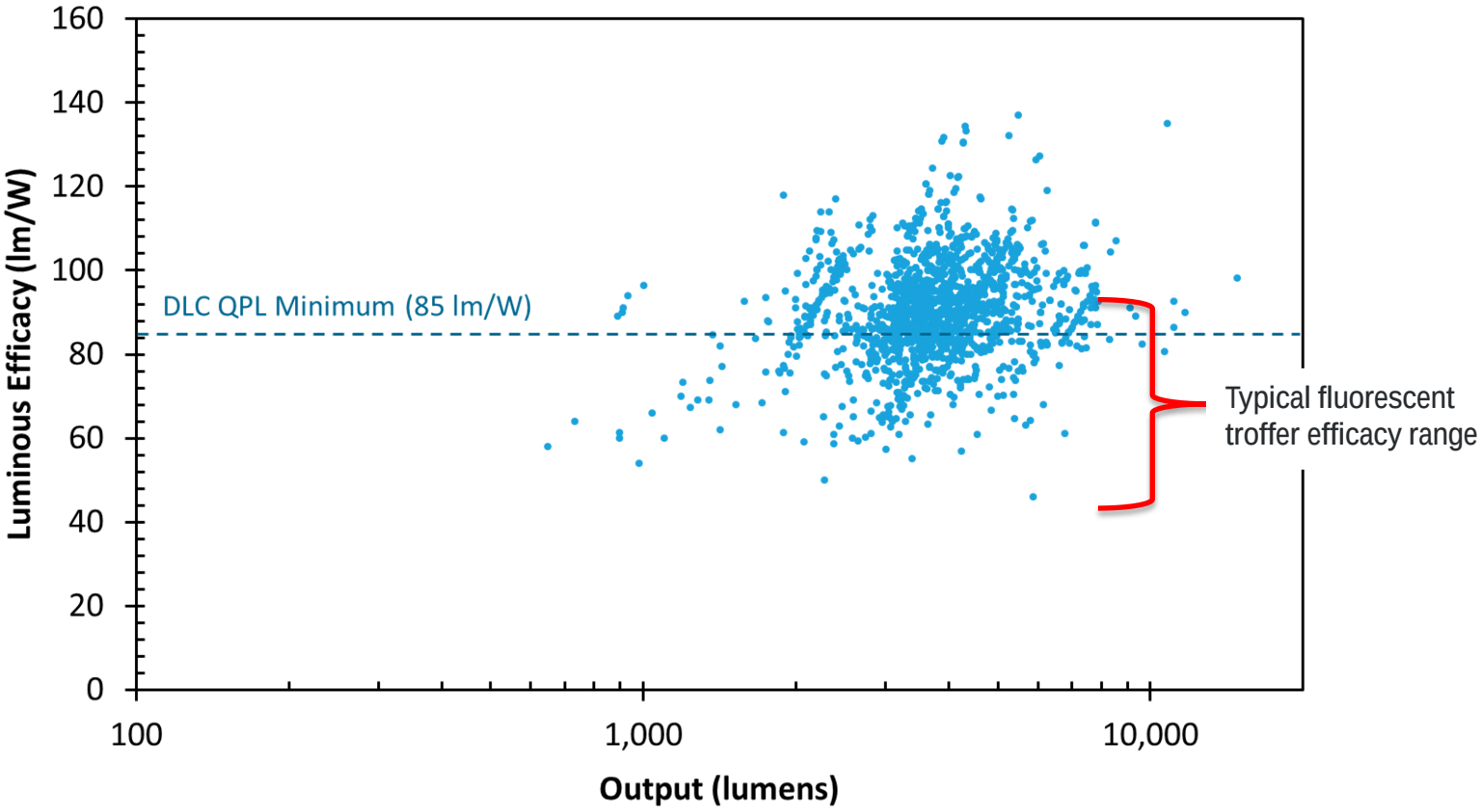
- Many options with better efficacy and comparable output to most parking or area lighting (<400w)
- Still struggling to meet output of larger (>400w) applications
- Note many products with efficacies below current technologies

LED Down lights



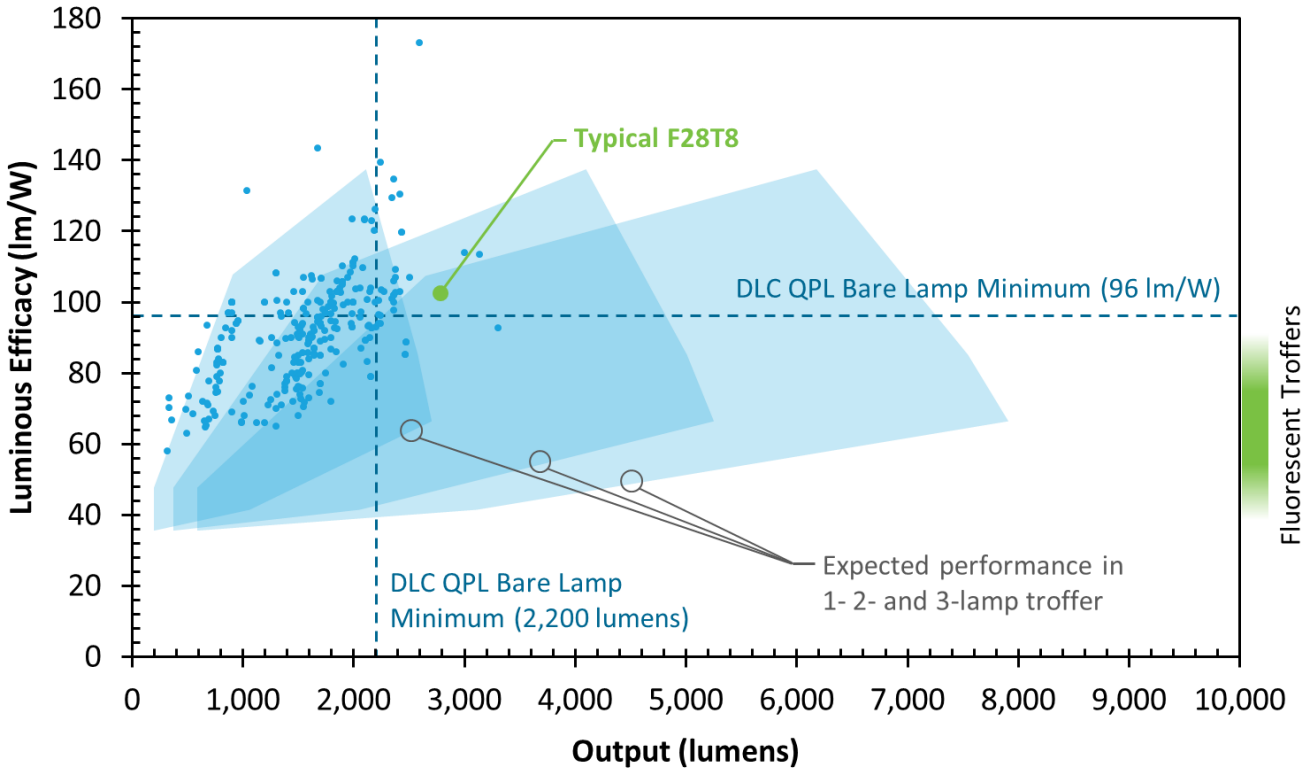
- Many efficient options in the 400 to 2000 lumen range which covers most applications
- Note that some LED products have efficacies below typical CFL!

LED Troffers



- Many products in the 2000 to 5000 lumen range similar to common 2-lamp and some 3-lamp fluorescent fixtures

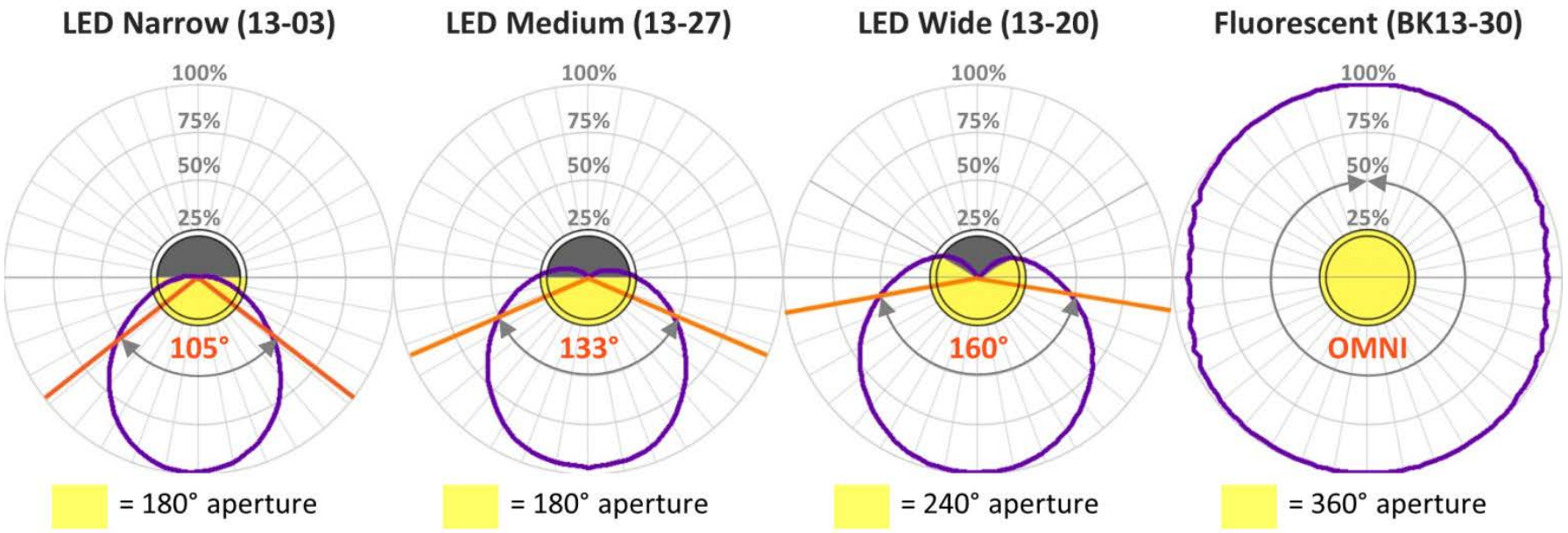
LED Linear replacement tubes



- Many products with efficacy at and far above fluorescent troffer levels.
- Common 4’ Product output in the 1000 to 2400 lumen range – generally below a typical fluorescent – but can meet most application needs

LED replacement tube varieties

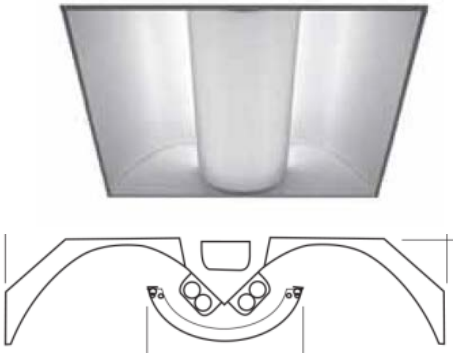
- LED replacement tubes come in a variety of distributions
- Directionality is efficacious – but can effect performance in fixtures designed for omnidirectional fluorescent tubes.



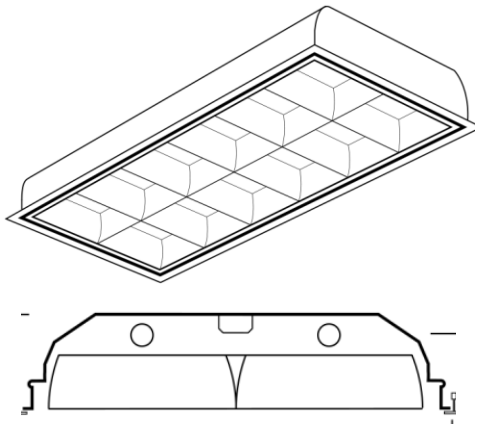
Fluorescent fixture type representations

What happens when typical LED replacement tubes are retrofitted in various fluorescent fixture types?

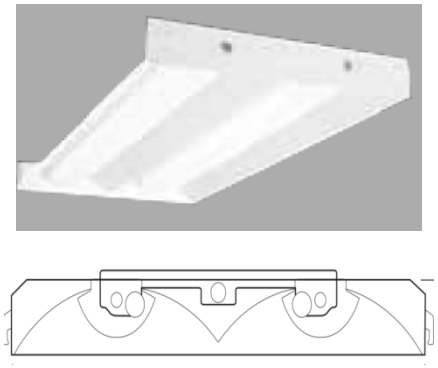
Recessed Indirect



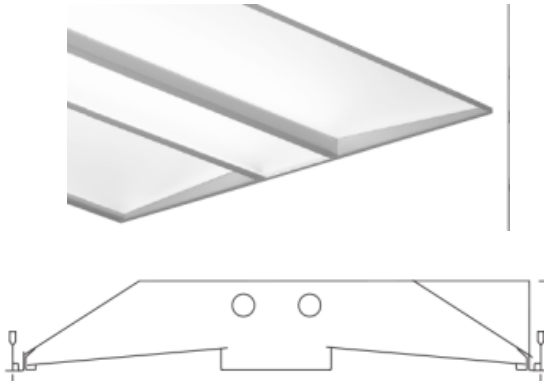
Parabolic



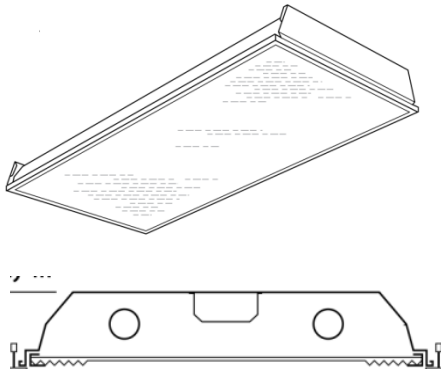
Volumetric



High Performance



K12 Lens



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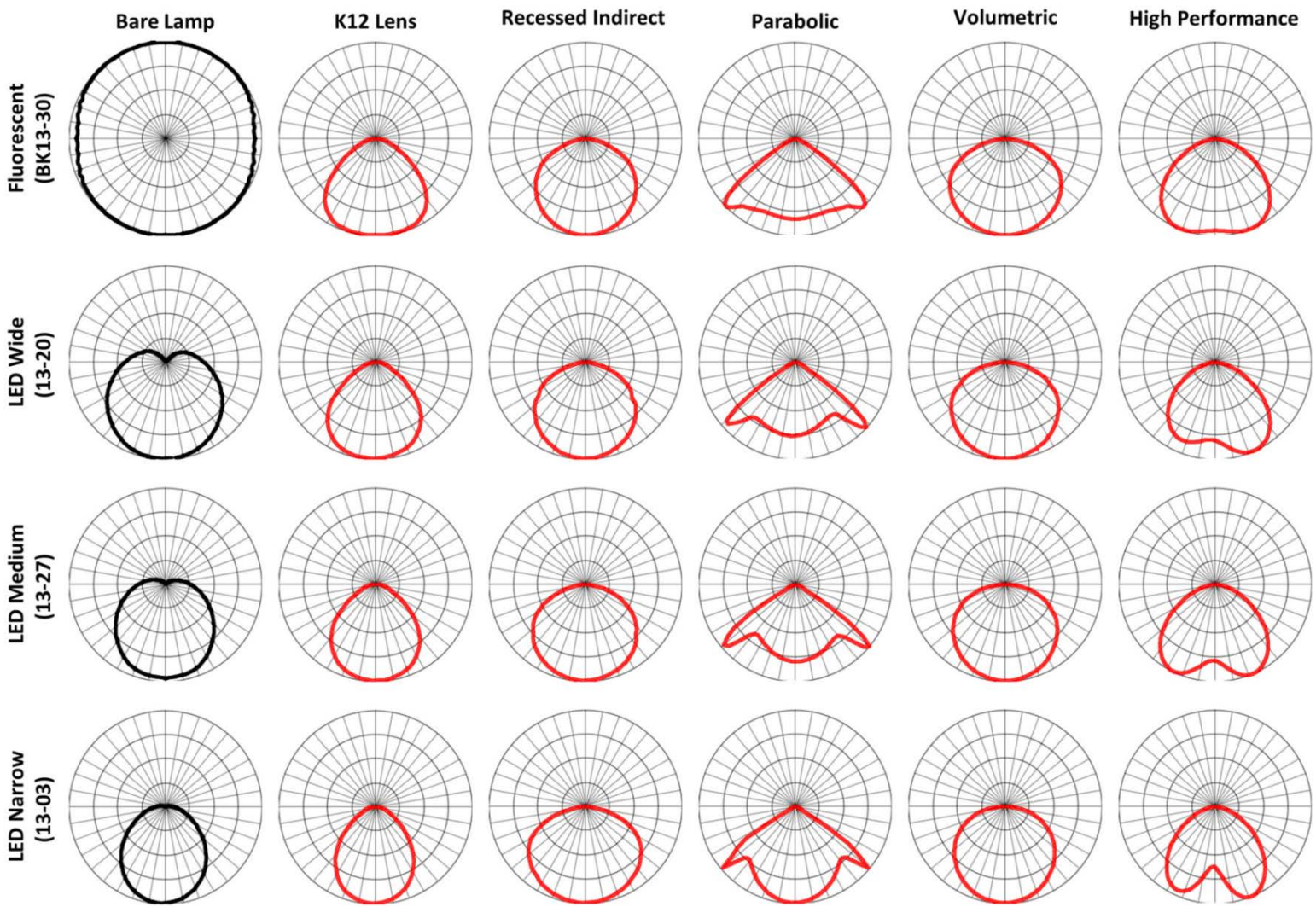
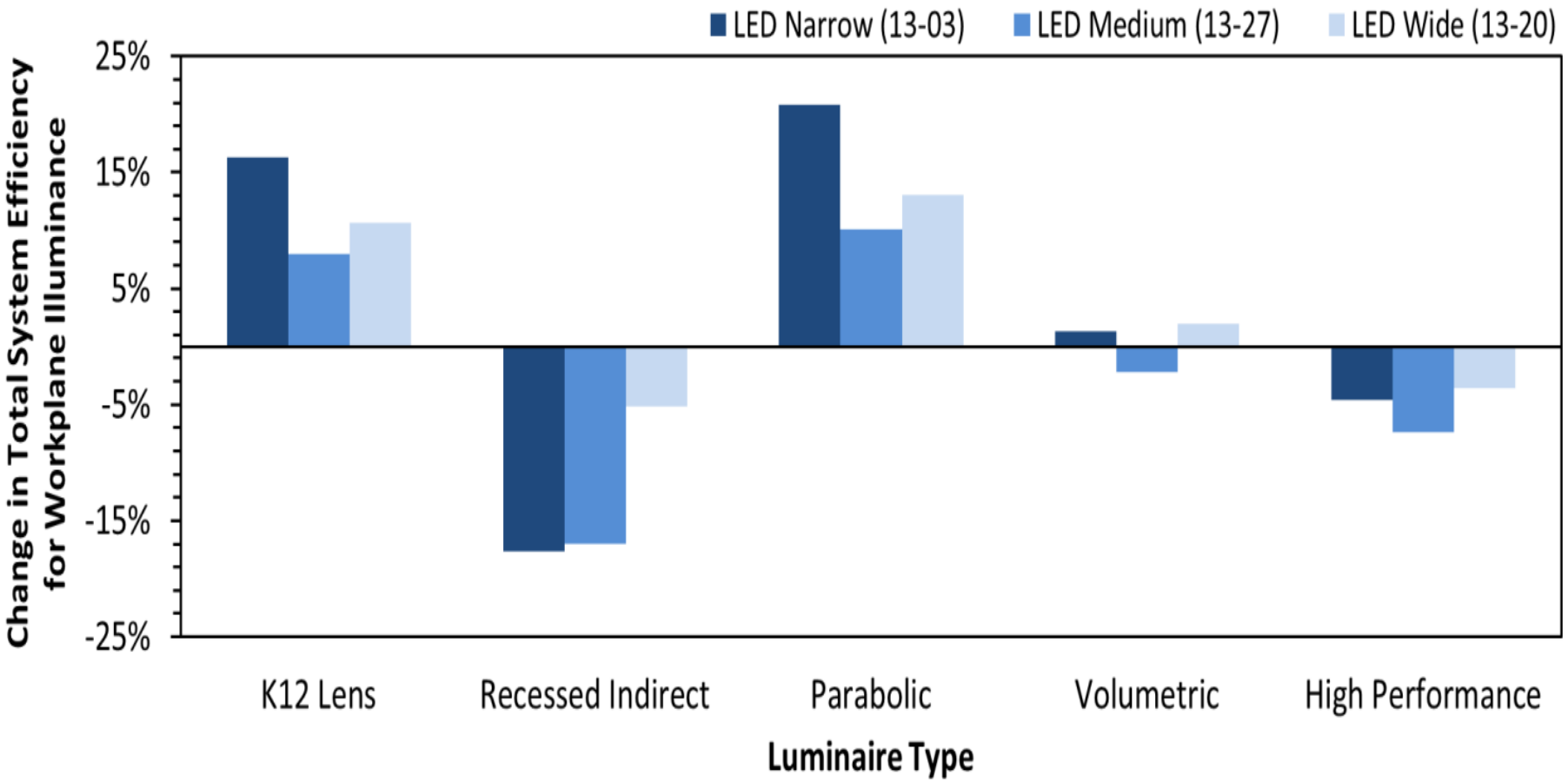
Fluorescent tube vs. LED tube – distribution patterns



Fluorescent tube vs. LED tube – workplane efficiency



- Recessed indirect fixtures present potential issues with LED replacement tubes – 15% loss in delivery efficiency

More on LED linear replacement tubes

- Can be found as lamps and kits – each with considerations:
  - Lamp w/integral driver – requires one of several re-wiring configurations. These should come as a kit with UL classification
  - Lamp w/separate driver– also requires re-wiring and should be procured as a UL classified kit
  - Lamp that runs off (many/most) existing fluorescent ballasts
    - Can be easiest and least cost option
    - Currently no UL issues
    - Potential compatibility and performance issues – try before you buy!
  - LED strips or panels w/separate driver - also requires re-wiring and should be procured as a UL classified kit
- Some kits may not fit in all fixture types
- Most options require fixture labeling of new wiring configuration which may restrict future replacement options

How Do I Correctly Consider the Economics for LEDs?

- First - Don’t assume LED is always the best option! Consider the economics of other technologies where applicable
- Economic analysis for LED lighting is no different than other technologies with perhaps one exception – **lifetime**
  - LED life is an estimate with a lot of potential variability
  - Your project may not be making use of the entire expected LED life
- Two commonly seen and used economic analysis:
  - Payback for a single proposed retrofit – often seen as part of product literature and from distributors
  - Comparison of multiple options – allows for more realistic decisions
- Multiple analysis tool options
  - Simple payback via basic spreadsheet (this is not rocket science)
  - Life-cycle cost tools – BLCC and others

Calculating Initial Costs and Energy Savings

- Initial costs
  - LED product costs can be a moving target but are acquired the same as other options
  - Since LED is new technology, contracts for labor may be variable – work with provider to familiarize them with similarities to standard work
- Energy savings
  - Are you counting reduced energy associated with reduced light levels?

  - not fair! – unless also applied to other possible options
  - Are any controls or changes in operation (reduced hours) involved?

  - also not fair unless applied to other options.
  - Are rebates or subsidies a one time deal?
  - Make sure you will be keeping them until they pay back

Calculating Practical Maintenance Savings

- Primary issue is potential long life of LEDs – savings can be substantial and drive the economics
- Consider practical life for the project
  - Driver and other component life
  - Fixture aesthetics over time – other replacement reasons
  - Acceptable light level over time
- How is maintenance costed and/or budgeted? - **will you get real credit for reduced maintenance needs?**

How to Reduce Project Risk…..

Once you have the numbers and it LOOKS OK on paper…

- See it yourself, more than one sample
- Check color rendering on your own skin, familiar fabrics
- Check dimming capability if being applied
- Check on the life of the product:
  - What is the basis for the life rating?
  - What is the life of the power supply and driver?
  - Does the luminaire stay clean over life of LED?
- Put tough performance metrics in your specification to ensure the right product and performance levels
  - Some specifications exist for parking areas and structures, and 2x2 indoor lighting

Resources and References

Listing and Rating Programs:

- DesignLights Consortium
  https://www.designlights.org/
- SSL Quality Advocates - Lighting Facts
  www.lightfacts.com
- ENERGY STAR®
  http://www1.eere.energy.gov/buildings/ssl/energy_star.html
- Lighting Design Lab – LED list
  https://www.lightingdesignlab.com/

LED characteristics and issues resources:

- Color characteristics
  http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/led-color-characteristics-factsheet.pdf
- Color stability
  - http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/color-shift_fact-sheet.pdf
- Dimming
  http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2013_gateway_dimming.pdf
- Optical safety - hazards
  http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/opticalsafety_fact-sheet.pdf
- DOE Solid-State Lighting Home Page
  http://www1.eere.energy.gov/buildings/ssl/

More Resources and References

Lighting product specifications

- DOE Commercial Building Energy Alliances Lighting Specifications
  - http://www1.eere.energy.gov/buildings/alliances/technologies.html

Lighting project economics analysis tools:

- Lighting Project Evaluator
  - https://www.lightingsolutions.energy.gov/comlighting/login.htm;jsessionid=C685A8E07AD0068D6D9BFA04B2D3315B.jvm3
- Better Bricks LCC Analysis calculator
  - http://www.betterbricks.com/graphics/assets/documents/LCCASpreadsheet(1).xls
- DOE Street Lighting Retrofit Analysis tool
  - http://www1.eere.energy.gov/buildings/ssl/financial-tool.html
- Building Life-Cycle Cost (BLCC)
  - https://www.wbdg.org/tools/blcc.php

Cost-effectiveness calculation example:

- Cost-Effectiveness of Linear LED lamps
  http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_21-3_t8.pdf

Questions?