Federal Energy Management Program

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

FEMP FIRST THURSDAY SEMIN@RS
What you need to know...online, live, and anytime.

Solid State Lighting: Highlighting Indoor Applications

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FEMP Expert: David Catarious

FEMP Federal Energy Management Program

Objectives/Competency Development

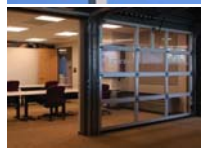
After completing this seminar, the learner will:

1. Strongly consider solid state lighting for new lighting and for lighting upgrades and replacements.
2. Make informed choices in the selection of solid state lighting using FEMP-designated and ENERGY STAR® requirements and references.
3. Evaluate SSL lighting options for troffers including: energy use, flicker, glare, visual appeal, dimming performance, color quality, and electrical safety.
4. Take full advantage of solid state lighting resources to select high efficiency indoor and outdoor lighting solutions.

Solid State Lighting

A Quick Review of SSL

- Sources of illumination rather than electrical filaments, plasma, or gas
  - inorganic semiconductor light emitting diodes (LEDs)
  - organic light emitting diodes (OLEDs)
  - polymer light emitting diodes (PLEDs)
  - both indoor and outdoor applications
- Previous First Thursday Seminar on Lighting
  http://www.wbdg.org/education/fempfts022012.php



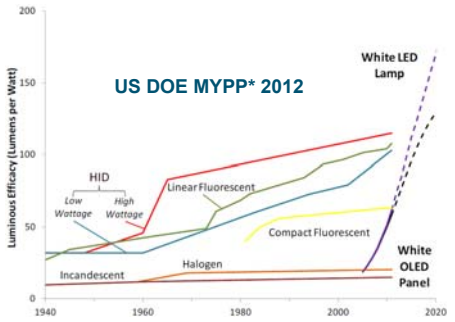
Applications Where SSL Currently Makes Sense

1. Directional applications where the combination of source efficacy and optical efficiency benefit from inherent SSL strengths, e.g. downlights, troffers, streetlights, etc.
2. Applications where the costs for energy and maintenance are high.
3. Applications that benefit from "white light" and improved uniformity, e.g. street and area lights.
4. Applications with environmental constraints, e.g. mercury restrictions, green building requirements.

Latest Press Releases

2/13/13:
"Cree Sets NEW R&D Performance Record with 276 Lumen-Per-Watt Power LED"

3/4/13:
"Philips Sets New Mid-Power LED Standard with LUXEON 3535L"
-165 lm/W Cool White
-150 lm/W Warm White



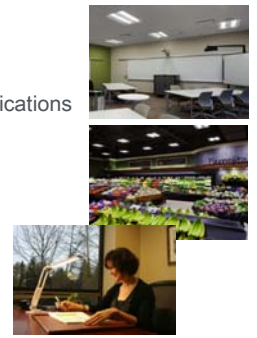
*DOE Multi-year Program Plan

Success

- City of Los Angeles LED Street Lighting Program
- 115,000 street lights installed to date
- $5.4M in annual energy savings/7-year payback
- Lessons along the way related to procurement, commissioning, monitoring, control – more to come

Now… and Ahead

- Tremendous progress to date, still much to do
- LED products now available for most lighting applications
  - Potential for greater efficacy, improved quality and performance
- OLED niche products available
  - Transition from prototypes to marketable products
- Insights from National Academy of Sciences study — current status of SSL, recommendations for future

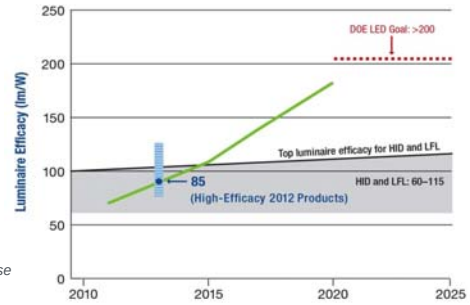


Significant Headroom Remains

R&D focus on issues that limit efficacy and performance

Maximize efficacy – not compared to what ***was***, but compared to what ***is*** and what ***can be***

The sampling of 2012 products shown achieves an average of 85 lm/W, with a range of 70–120 lm/W
Source: LED Lighting Facts® product database



What is limiting adoption of SSL?

- Color consistency: Lamp to lamp, and over time
- Reliability: LED device plus optics, thermal management, and other components
- Lumen maintenance
- Dimming performance
- Flicker
- Insufficient output
- Poor light distribution/Glare
- Thermal issues
- Cost!

Image courtesy of Lana Nathe

So Is SSL "Ready" for All Applications?... Well It Depends!

You must ask yourself the following questions:

- What are you competing against?
- What is your payback threshold?
- Are all products the same ("apples-to-apples")?
- Who actually knows how long the products last?
- Who do you believe?

When do LEDs really "pay back?"

Smithsonian American Art Museum
Scott Rosenfeld, Lighting Designer and photographer

Quality LEDs can reduce lighting power by 75% compared to halogen

- Payback will be less than 4 years if
  - Lights are on 8+ hours/day
  - Cost of relamping labor is high (>$25/hr)
  - Power cost is >13c/kWh
  - Cost of LED replacement lamp is $60 or less
- Intangibles

What products are a slam-dunk in LED (if you do your homework)

- Lower wattage incandescent replacement lamps
  - A-lamps
  - PARs and Reflector lamps
  - Candelabra-shape lamps for chandeliers

What products are a slam-dunk in LED (if you do your homework)

- New recessed commercial downlights and wallwashers
- New - Any product that used to be CFL
- New task lights and under-cabinet lights

Pamela Hope Designs

What LED products are on the cusp?

- Street and area lighting, especially where controls and dimming or color change are an option
- New recessed LED troffers

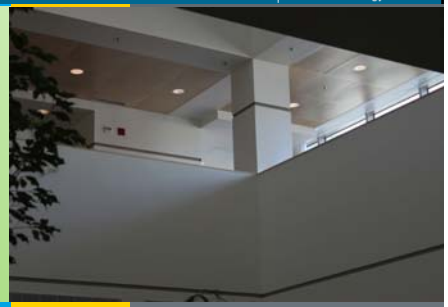
What LED products need more scrutiny?

- MR16 LED replacement lamps (system compatibility, heat, flicker)
- Applications where smooth/low/warm dimming is critical
- Replacements for halogen lamps >90W / 1300 lumens
- Retrofit for high-wattage HPS and MH lamps
- Retrofit for CFL lamps (reusing existing sockets)
- T8 fluorescent LED replacement lamps (safety issues, light dist, light output)

Considerations to Remember

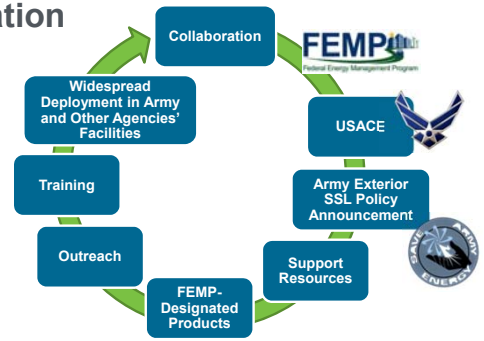
- In Summary….if considering LEDs, make sure to look for:
  - High efficacy - more lumens-per-watt
  - Sufficient light output
  - Long useful life
  - Data to support performance claims (LM-79 based data)
  - LED Lighting Facts label or similar data from listings for lumens, watts, and simple color data
  - ENERGY STAR® ratings
  - Future upgradability

How is the Federal Government Advancing the Technology?



Federal Collaboration

With support from FEMP, the USACE has developed a policy and implementation plan, including guidance materials, training, qualified product lists, and performance specifications in support of the widespread adoption of SSL in the Federal sector.



Federal Purchasers MUST Buy FEMP-Designated

Multiple laws, Executive Orders, and the Federal Acquisition Regulations have established a robust set of requirements that:

Federal purchasers MUST buy, specify, and contract for ENERGY STAR®, FEMP-designated, and low standby products

Suppliers must provide only compliant products (look for FAR clause 52.223-15 in your contract)

References:
Energy Independence and Security Act of 2007 (EISA)
Energy Policy Act (EPAct) of 1992 and 2005
Executive Orders 13221, 13423, and 13514
Federal Acquisition Regulation (FAR 23.2 and FAR 52.223-15)

FEMP Covered Product Categories for Lighting

http://www1.eere.energy.gov/femp/technologies/eep_purchasingspecs.html

FEMP-designated Efficiency Requirement for Exterior Luminaires

Established for 6 exterior lighting categories:

Category	Luminaire Efficacy Rating (LER)
Outdoor wall-mounted luminaires	60
Outdoor pole/arm-mounted area and roadway luminaires	65
Outdoor pole/arm-mounted decorative luminaires	65
Fuel pump canopy luminaires	70
Bollards	35
Parking garage luminaires	70

- These applications cover 97% of Federal exterior lighting*
- Does not overlap with ENERGY STAR® covered products
- Search "portal" being developed within DOE's Lighting Facts® Program

*Based on data from PNNL's Federal Market Assessment for Exterior lighting for FEMP

What are BBAs?

Better Buildings Alliance

The Better Building Alliances (BBAs) work with the U.S. Department of Energy and its national laboratories to help guide research and encourage industry to move toward energy-efficient design and strategies.

History of the Troffer Specification

Requested by BBA members

- Retail/Commercial Real Estate and Hospital Alliances
- Cross-cutting project

Timeline

- November 2010 a High Performance 2'x2' Troffer Committee was created
- Specification completed May 2011
- August 2011 DOE/BBA decide to expand the 2'x2' spec. to add 1'x4' and 2'x4' troffers
- Version 3.0 issued February 2012
- Version 4.0 issued April 2013

Size of Commercial Market

Configuration	Mixture	Approx. # of Installations	Hours	Input Power (W)	Estimated Energy (TWh)
2'x4'	74%	245,587,500	10.5	74	71.3
2'x2'	16%	53,100,000	10.5	59	12.0
1'x4'	8%	26,550,000	10.5	44	4.5
Total	100%	331,875,000			87.8

Notes:
- 2008 entire energy usage of Ukraine was 90 TWh
- Quantities extrapolated from 2011 DOE SSL Niche Report & NEMA LE5-2001
- Power values assume a mixture of lamps, ballast factors, and ballast efficiencies
- TWh = 1,000,000,000,000 watt-hours

BBA Specification - Light Output Characteristics

Configuration	Minimum Initial Light Output		Luminaire Efficacy Rating/Luminaire Efficacy (lumens/W)	Spacing Criteria (SC)	
	LED	Fluorescent		0 - 180°	90 - 270°
1x4, 2x2 and 2x4	2,000	1,800	80	1.0 - 2.0	1.0 - 2.0

- Chromaticity
  - CCTs: 2700, 3000, 3500, 4000/4100, 4500 (LED only) and 5000K
  - CRI: $R_a \geq 80$, $R_9 > 0$
- Luminaire Efficacy Rating (LER) used for fluorescent
- Luminaire Efficacy (LE) used for LED

Photometry Review

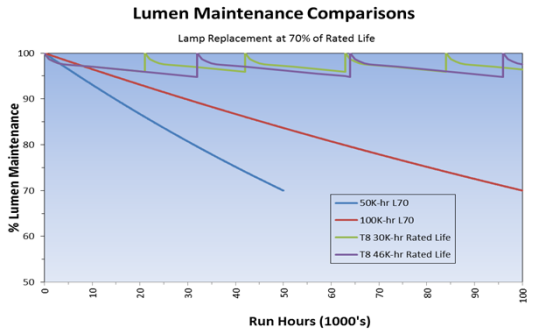
LED Troffers

- Uses Luminaire Efficacy (LE)
- IESNA LM-79
- Measured via absolute photometry
- Entire fixture measured at once

Fluorescent Troffers

- Uses Luminaire Efficacy Rating (LER)
- IESNA LM-41
- Measured via relative photometry
- Fixture measured (distribution and efficiency)
- Lamp + ballast measured separately
- Allows for different lamp + ballasts to be used in the same fixture

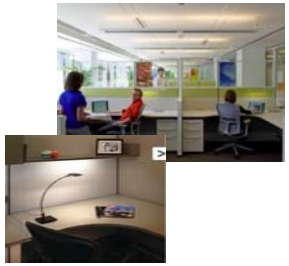
Lumen Maintenance Comparison



Troffers, Kits, and Tubes: *LEDs Challenge Fluorescents*

Principles of Task-Ambient Lighting

- Daylighting with glare control
- Ambient lighting that delivers ~300-500 lux (30-50 fc) on workplane
- Task lighting that delivers ~200-750 lux (20-75 fc) evenly across desk area. Consider spectrally-enhanced lighting here.
- Accent lighting or wallwashing to provide perception of brightness/cheerfulness
- Light finishes to bounce light and make faces attractive and save lighting energy



"Type A" Project Luminaires

Incumbent Recessed Troffers

- Prismatic lenses
- Parabolic louvers
- "Volumetric" or "High-efficiency" or "Non-planar"
- Planar or non-planar diffusers
- Perforated metal baskets

LED Kits, Tubes, and Troffers

Interest in switching to LED for:

- New projects
- Remodel projects in existing spaces
- Retrofit/refreshing of existing fixtures

LED T8 replacement lamps

Dedicated LED troffers

LED troffer kits

What's an Energy/Facility Manager to do???

LUMENS PER WATT
$$$
DIRECT GLARE
OVERHEAD GLARE
APPEARANCE
COMPUTER SCREEN GLARE
SPACING CRITERIA
COLOR QUALITY
EASE OF INSTALLATION
FLICKER
LUMEN OUTPUT
DIMMABILITY

CALiPER Troffer Study

Build a mockup office space at Intertek, Portland, Oregon

- Install 24 pairs of recessed luminaires
- 3 fluorescent benchmark troffers, 5 LED tube retrofits, 4 LED retrofit kits, and 12 dedicated LED troffers
- Install 0-10V dimming controls
- Invite 18 designers/engineers to observe, score, and comment

CALiPER Troffer Study

Criteria for 2x2 and 2x4 selection

- Designed for acoustical ceiling mounting
- Target ~4000K, CRI>80; R9>0
- ~2500-6000 fixture lumens
- 0-10V dimming drivers where available
- Range of optics, prices, and qualities
- Received in 10 weeks (from order mid-May 2012)

The study underway…



Results?

- Energy efficiency
- Light output
- Color quality
- Dimming performance
- Flicker
- Overhead glare and direct glare
- Reflected glare
- Luminance distribution
- Visual appearance
- Electrical safety of retrofitted troffers

Results: Energy Efficiency – Luminaire Efficacy

Energy efficiency – Luminaire efficacy

• Almost all LED products did as well or better than the fluorescent

	Min LPW	Max LPW	Average LPW
FL benchmark troffers (28W lamps)	57	62	59.6
Dedicated LED troffers	74	107	88.8
LED tube retrofits	55	76	68.9
LED retrofit kits	60	77	66.2

Results: Energy Use – Luminaire Watts

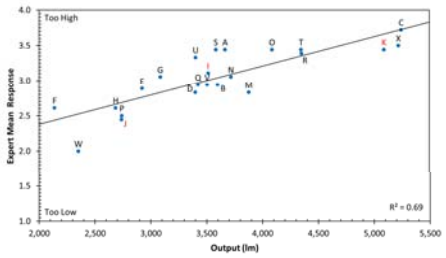
If you're not careful, LED retrofit tubes may not reduce watts

	Min Watts	Max Watts	Average Watts
FL benchmark troffers (28W lamps)	49 (2x2)	83 (2x4)	63.5
Dedicated LED troffers (2x2 and 2x4)	34 (2x2)	58 (2x2)	43.6
LED tube retrofits	48 (2x4)	79 (2x4)	16 to 26W per tube
LED retrofit kits	35 (2x2)	51 (2x2)	41.2

Results: Light Output

LED products emitting > 4800 lumens were considered too high for typical offices and classrooms (4=too high, 1=too low)

Even LED products emitting only 2400 lumens were Considered acceptable for similar office applications



Results: Color Quality

- Kits and tubes generally had poorer color characteristics than dedicated LED and fluorescent troffers
- CRI and R9 values were strongly correlated.
  (Translation: poor color rendering values also meant poor reds)

	Min CRI, R9	Max CRI, R9	Avg. CRI, R9
FL benchmark troffers	82, 14	86, 14	84, 14
Dedicated LED troffers	68, -41	91, 58	83, 20*
LED tube retrofits	68, -44	83, 36	77, -4
LED retrofit kits	82, 2	84, 39	83, 22

Results: Dimming Performance

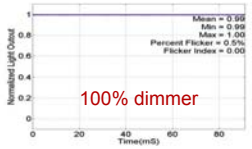
- Fluorescent and LED had similar smoothness and range down to approximately 5-15% of light output
- One dedicated LED 2x2 provided with a proprietary dimmer exhibiting “steppy” dimming that was much disliked
- 8 of 24 LED troffers/kits/tubes flickered noticeably when dimmed
- None of the 3 fluorescent troffers flickered when dimmed

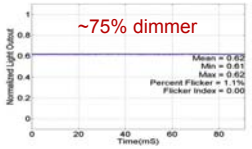
Results: Flicker

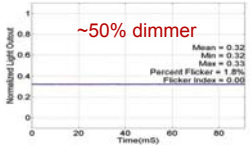
- **Fluorescent –**
  High frequency electronic dimming ballasts – no perceivable flicker
- **LED –**
  Dimming drivers at full – Little perceivable flicker
- **LED –**
  Dimming drivers at low – about 1/3 exhibited perceivable flicker, both kits and dedicated LED troffers

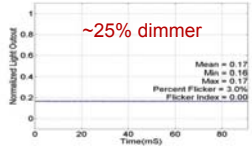
No Switch

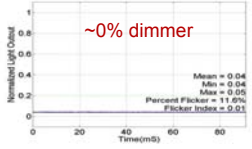
Fluor Troffer I (12-132): 2x Philips Alto II TL735, Advance IZT-2S32-SC 2-lamp ballast, 0-10V Dimming



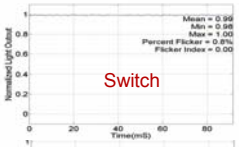


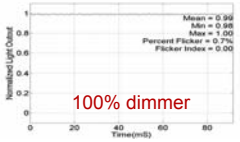


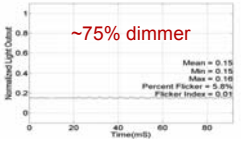


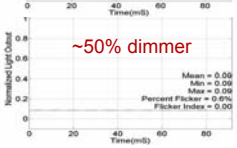


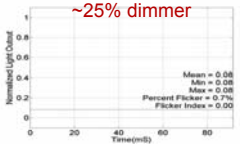
W (12-116), LED troffer

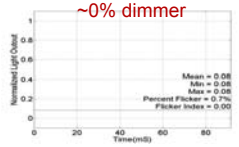




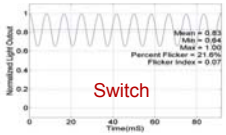


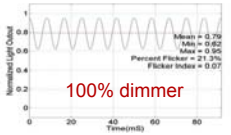


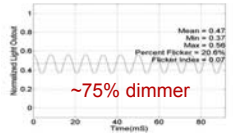


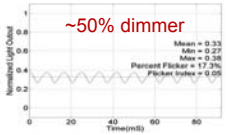


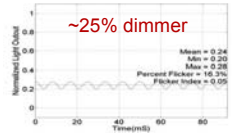
L (12-131) LED tube

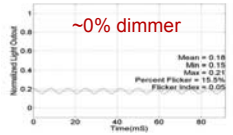


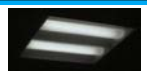




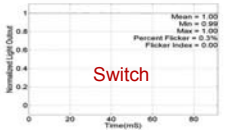


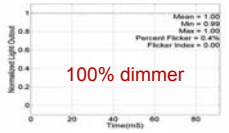


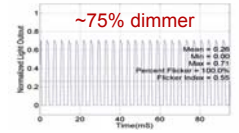


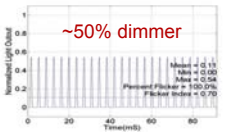


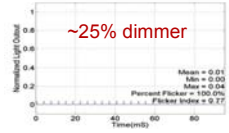
E (12-107), LED retrofit kit

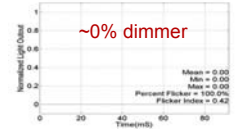




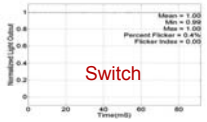


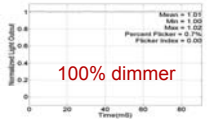




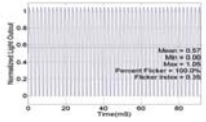


M (12-119), LED troffer

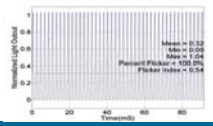




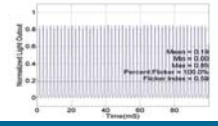
~75% dimmer



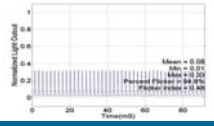
~50% dimmer



~25% dimmer



~0% dimmer

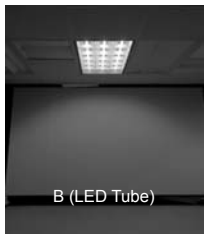


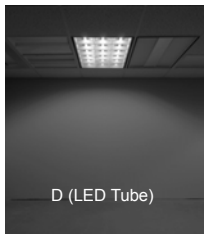
Results: Flicker

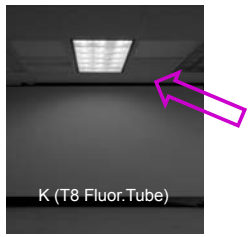
- Flicker – function of frequency, modulation depth, DC component, duty cycle
- Can be trigger for headaches and migraines, can increase autistic behaviors, can cause distraction, can reduce reading speeds
- Safe levels are being debated
- Drivers using PWM to dim will produce 100% flicker. Look for frequency >500 Hz (or higher?)
- Drivers using CCR may be more acceptable
- See an LED product before ordering it
- Use a flicker wheel or wave a pencil to test for flicker

Results: Light Patterns Produced on Adjacent Walls

- All troffers liked except … the 3 parabolic louver troffers
- Of these, observers much preferred the fluorescent light pattern

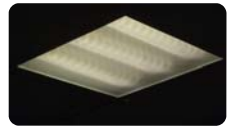


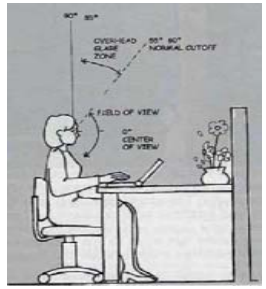




Results: Overhead Glare

- Max spot luminances measured at 10° from vertical
- Luminances > 20,000 cd/m^2 rated as uncomfortable



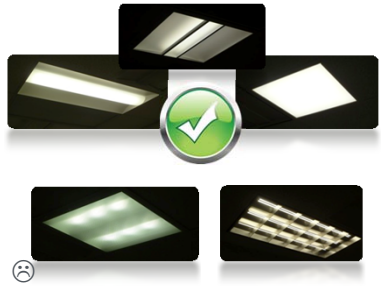


Results: Direct Glare (Discomfort Glare)

- Also related to maximum luminance ("brightness") of the lens or diffuser (>20,000 cd/m^2 rated as glaring)
- Compounded by dramatic brightness gradients

Results: Visual Appeal

- Diffuser products with linear details or mixtures of lens and reflector preferred
- Smooth white panel troffers were indifferent
- Conventional K12 lens and parabolic louver troffers not liked
- Lensed or parabolic troffers with funky patterns liked LEAST ☹



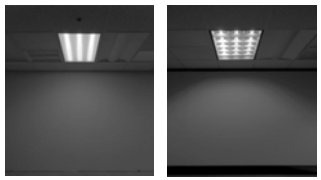
Results: Electrical Safety

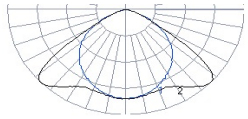
- Retrofit of troffers with tubes or kits
  - Labels!
  - Differences in wiring of LED tubes and sockets
  - Limited to no interchangeability
  - LED tubes must be NRTL approved and comply with UL1598C and UL1993 standard.
  - LED kits must be NRTL approved and comply with UL1598C.
  - Retrofit product cannot automatically use troffer chassis as heat sink, since fluorescent troffers are temperature-exempt in their testing
- Over half of tubes and kits could have been disqualified by an inspector

What Did We Learn?

Wide range of quality in LED T8 tubes

- LED tubes produce some funky luminaire appearance!
- Be careful in choosing the beam angle on these tubes
- LED tubes can change the distribution of light from the luminaire





What Did We Learn?

- LED tubes may have unexpected installation problems, especially concerning sockets
- LED tubes can be good if well-engineered, but MAY NOT save you much energy unless you drop light levels

What Did We Learn?

Wide range of quality in LED troffer kits

- LED kits, like LED tubes, can be good if well-engineered, but MAY NOT save you much energy unless you drop light levels
- LED tubes and kits often have NRTL labeling complications
- Check that the kit is NRTL approved and complies with UL1598C
- Check to see if there is any limitation on which manufacturers' troffers can be used, or depth of troffer
- Look for 70LPW or higher on kit as installed

What Did We Learn?

Wide range of quality in LED troffers

- Luminaire efficacy is very high. Holds great promise. Look for LPW of 90+
- Dramatic brightness patterns on lenses can be very distracting AND glaring for some LED products
- Color ranges all over the map, but most products are as good or better than Fluorescent light

What Did We Learn?

Wide range of quality in LED troffers

- Flicker is a problem with some LED DRIVERS when dimming and there is no complete metric at this point in time
- Dedicated LED troffers are a good option for new installations

See it, mock it up,
before you buy a bunch of them

Conclusion…..

"LEDs have not made troffers better, but they have made them more efficient"

– conclusion from the judges

CALiPER report April 2013

http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_recessed-troffer_2013.pdf

Solid State Lighting Resources

Join the LEEP Campaign to Save Energy and Money

Energy savings of over 30% compared to ASHRAE 90.1-2010, and 50% or more compared to earlier codes

Add controls to save energy during times of low occupancy or from daylighting to save even more

High efficiency lighting lasts longer than traditional lighting which leads to deferred maintenance and saves money

Join LEEP at www.leepcampaign.org

Photo Courtesy of Department or Energy

LEEP Campaign Resources

DOE BBA Lighting Specification

Incentives and Financing

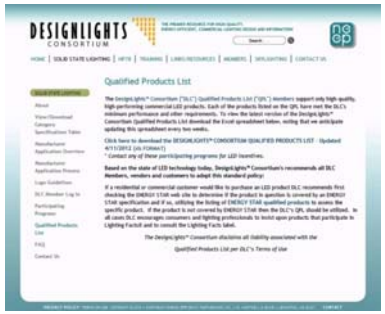
Lighting Project Evaluator Calculator –

- Over 20 Case Studies
- Technical Assistance

Department of Energy
Parking Lot Lighting Case Study

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

DesignLights™ Consortium



www.designlights.org

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Appl cat on	M n mum Light Output	Zonal Lumen Densi y	M nimum Lumina re Eff cacy	Allowab e CCTs (ANSI C78.377-2008)	M nimum CRI	L70 Lumen Ma ntenance	M nimum Luminaire Warranty
10) Stairwel and Passageway Light ng	750 lm	≥85%: 0-90° ***	70 lm/w	≤5700K	65	50,000 hrs	5 years
11) Track or Mono-point Direct onal Light ng Fixtures	250 lm	≥85%: 0–90°	40 lm/W	≤5000K	80	50,000 hrs	5 years
12) Vert cal Refr gerated Case Light ng	Center-mounted*: 100 lm/ft End-mounted**: 50 lm/ft	≥95%: 10°-90°	45 lm/W	≤5000K	70	50,000 hrs	5 years
13) Hor zontal Refr gerated Case Light ng	Standard CRI: 125 lm/ft High-CRI: 100 lm/ft	≥95%: 0°-90°	Std.CRI: 45 lm/W High CRI: 35 lm/W	≤5000K	Std.CRI: 70 High CRI: 80	50,0000 hrs	5 years
14) Display Case Light ng	End-mounted**: 50 lm/ft	≥95%: 0°-80°	35 lm/W	≤5000K	75	35,000 hrs	5 years
15) Linear Panels 2x2 Troffers)	3,000 lm	Spacing Criteria: 0°-180°: 1.15-1.30 90°-270°: 1.2-1.6	60 lm/W	≤5000K	80	35,000 hrs	5 years
16) Linear Panels 1x4 Troffers)	2,000 lm	Spacing Criteria: 0°-180°: 1.15-1.25 90°-270°: 1.25-1.7	65 lm/W	≤5000K	80	35,000 hrs	5 years
17) Linear Panels 2x4 Troffers)	4,000 lm	Spacing Criteria: 0°-180°: 1.15-1.25 90°-270°: 1.25-1.7	65 lm/W	≤5000K	80	35,000 hrs	5 years
18) High-bay and Low bay f xtures for Commerc a and Industr a bui d ngs	10,000 lm	≥30%: 20-50°	70 lm/W	≤ 5700K	70	35,000 hrs	5 years
19) High-bay-A sle Light ng	10,000 lm	≥50%: 20°-50° ≥30%: 0°-20°	60 lm/W	≤6500K	70	35,000 hrs	5 years

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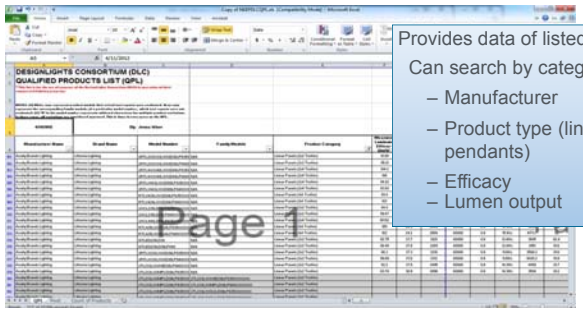
DesignLights™ Consortium



Provides data of listed products

Can search by category:

- Manufacturer
- Product type (linear pendants)
- Efficacy
- Lumen output

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LED Lighting Facts® Provides Buyer Guidance

www.lightingfacts.com

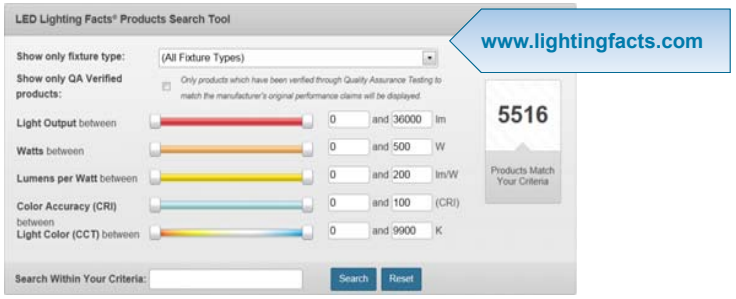
Resource for buyers and utilities to evaluate voluntarily submitted product performance data

- Standardized summary of verifiable product performance data, measured by industry standards (LM-79)
- Five key parameters: lumens, watts, efficacy, CRI, CCT
- Reported performance recently expanded to include lumen maintenance

Voluntary program; partners pledge to use or ask for LED Lighting Facts label

Resources and tools provide buyer guidance

LED Lighting Facts®



Resources Available Now

- "FEMP-designated" Covered Products
  - www1.eere.energy.gov/femp/technologies
- LED Lighting Facts®
  - www.lightingfacts.com
- DesignLights Consortium®
  - www.designlights.org
- DOE SSL Program
  - www.ssl.energy.gov
- Better Buildings Alliance (BBA)
  - www1.eere.energy.gov/buildings/alliances/

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