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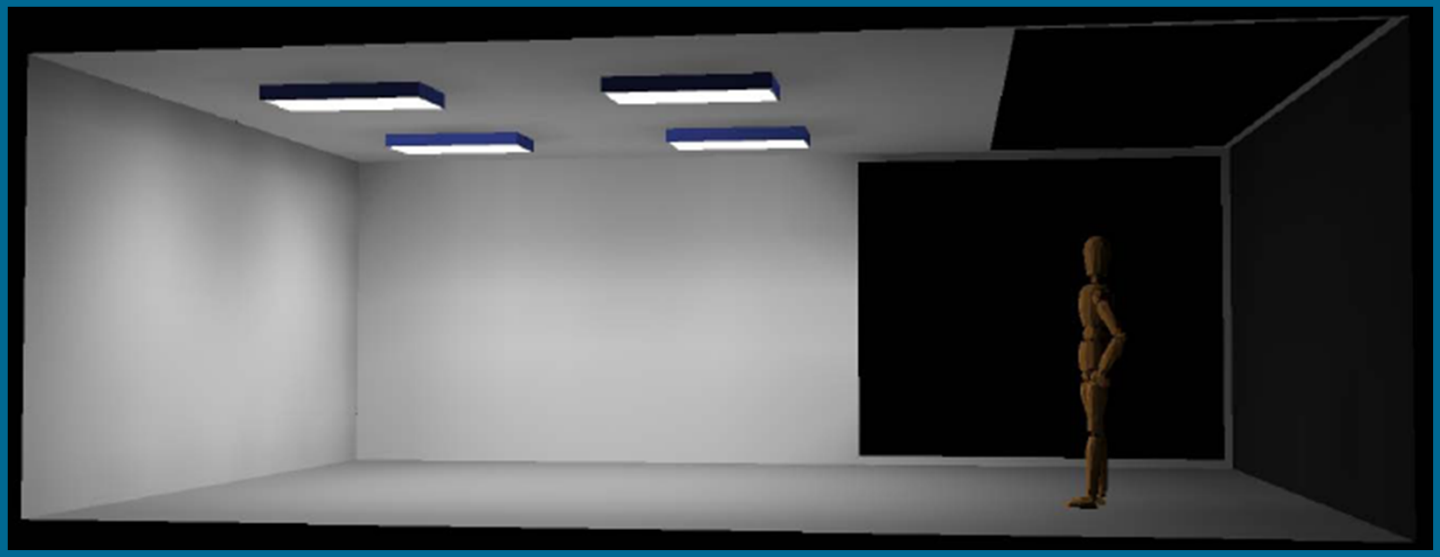
LED Replacements for Linear Fluorescent Lamps



Courtesy of Lighting Design Lab

DOE Solid-State Lighting Webcast

June 20, 2011

Jason Tuenge & Eric Richman

Pacific Northwest National Laboratory

Presentation Overview

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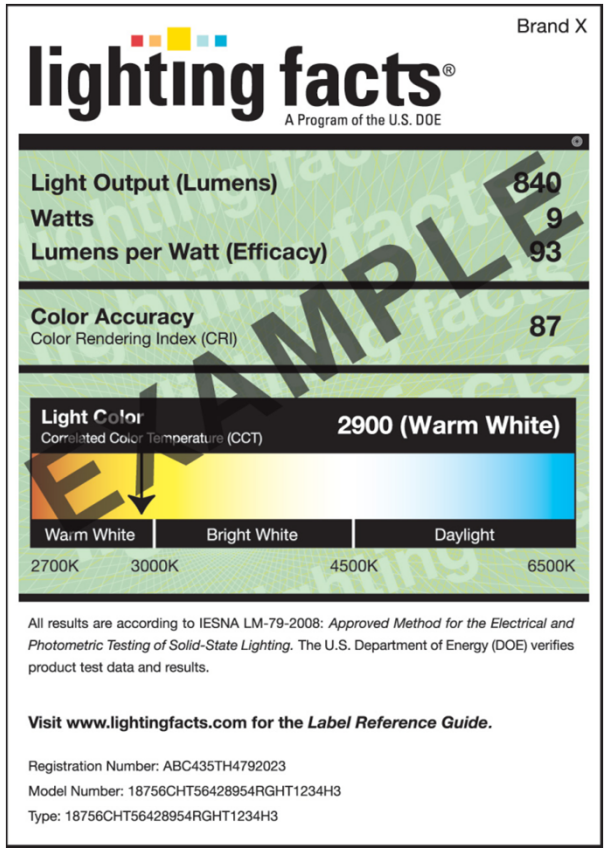
- Why this product category?
- Lighting Facts
  - May 2011 Product Snapshot
  - June website updates
- Commercially Available LED Product Evaluation and Reporting (CALiPER)
  - Round 12 report coming soon…
- GATEWAY Demonstrations
  - May 2011 report on LED T8 Replacement Products
- Suggested Specifications
- Other applications (garage)
- Other categories (luminaire rather than lamp)

Why this product category?

- Significant fluorescent installed base
- Significant interest/demand for “green” LED
- Compared to luminaires, replacement lamps are often perceived as relatively inexpensive to install
- Proliferation of LED products in the marketplace
- LED performance claims are often either unclear, or are not supported by test data

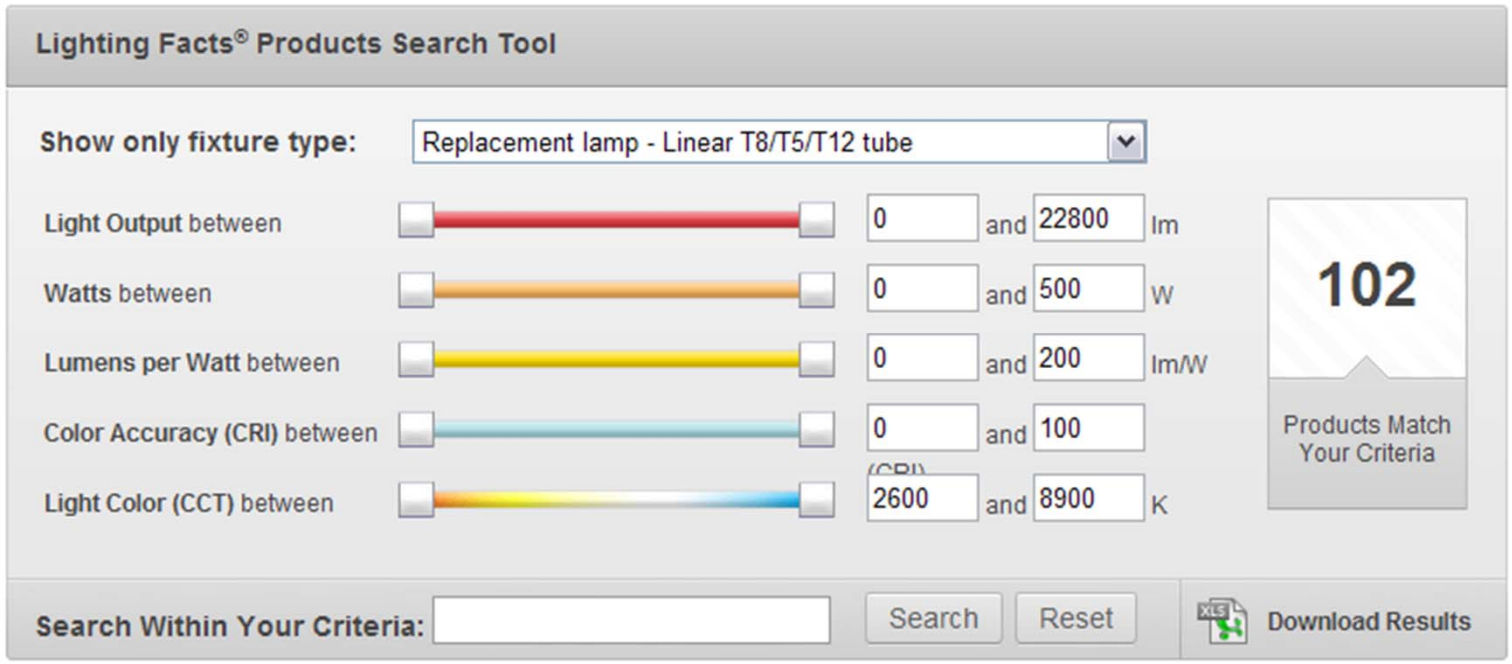
Lighting Facts

- Voluntary program for light-emitting diode (LED) products
- Developed by DOE and the Next Generation Lighting Industry Alliance (NGLIA)
- Label provides a summary of characteristics, analogous to a nutrition label
  - Light output (lumens)
  - Input power (Watts)
  - Efficacy (lumens per Watt)
  - Color Rendering Index
  - Correlated Color Temperature (K)



Lighting Facts

- Searchable product list at www.lightingfacts.com



- Product Snapshots for market characterization
- Manufacturers must test per IES LM-79
  - See website for discussion of the similar FTC label

Lighting Facts – May Snapshot

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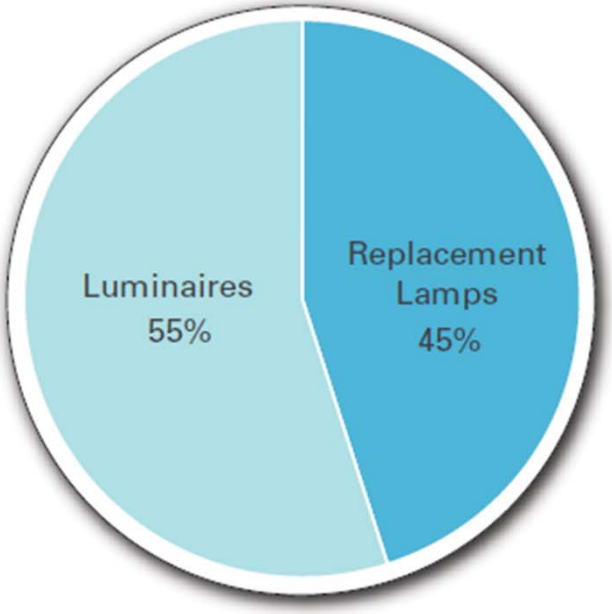
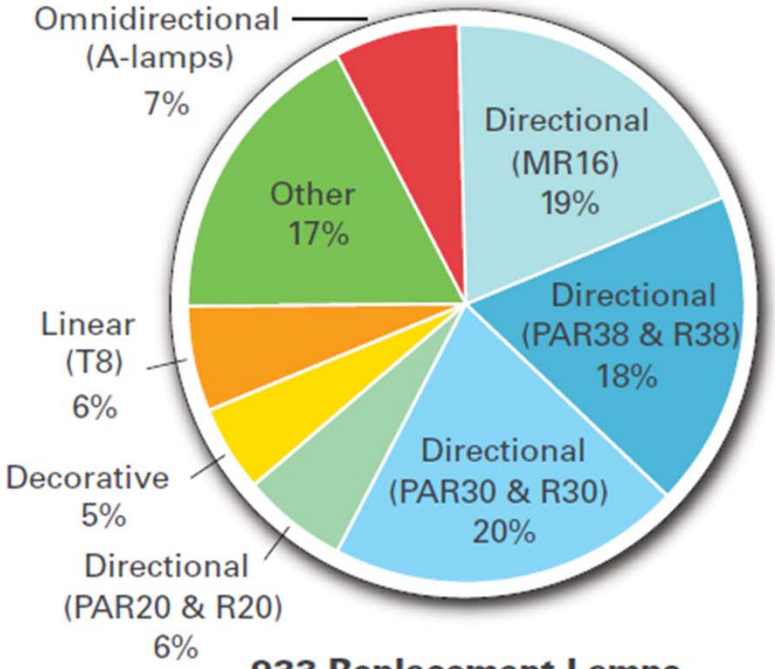
- Snapshot addresses LED replacements for
  - A-lamps
  - Reflector lamps
  - Linear fluorescent lamps



2,074 Total Products



933 Replacement Lamps

Lighting Facts – May Snapshot

- Based on February 2011 Lighting Facts list
- Previous snapshot was September 2010

	Analysis	Sample Size	
		September 2010	May 2011
Linear Lamps	LED product performance	23	55
	Non-LED product performance	3	23
Total number of LED products analyzed		218	537

Lighting Facts – May Snapshot

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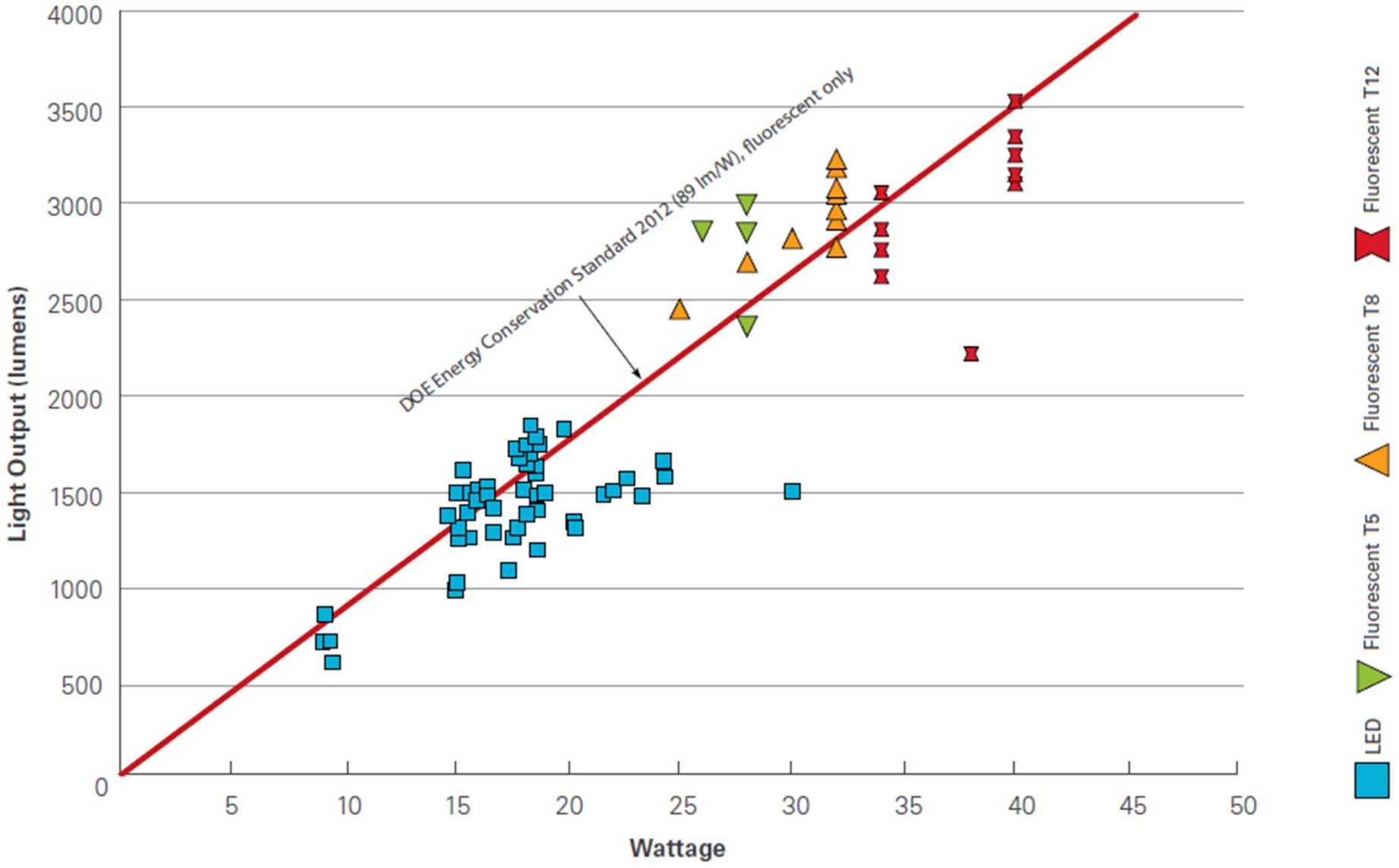


Lighting Facts – May Snapshot

- Efficacy requirements for GSFLs
  - “Mini Bi-Pin” refers to T5 or T5HO

Lamp Type	Minimum Lamp Efficacy (lm/W)	
	CCT≤4500K	4500K<CCT≤7000K
2-Foot U-Shaped	84	81
4-Foot Medium Bi-Pin Based	89	88
4-Foot Mini Bi-Pin Based Standard Output	86	81
4-Foot Mini Bi-Pin Based High Output	76	72
8-Foot Slimline	97	93
8-Foot High Output	92	88

Source: U.S. Department of Energy, Final Rule Technical Support Document: Energy Conservation Standards for General Service Fluorescent Lamps and Incandescent Reflector Lamps, July 2009.

Lighting Facts – June Update

- 102 replacement lamps as of May 31, 2011
  - 100 of fixture type “Linear T8/T5/T12 tube”
  - Two of fixture type “Other” with “T8” in description
  - Two excluded since input power > 32W
  - Average rated lifetime ≈ 50,000 hr
    - Per manufacturer websites and/or cutsheets
    - Lifetime is not evaluated by Lighting Facts
  - Some products submitted by “consultants”

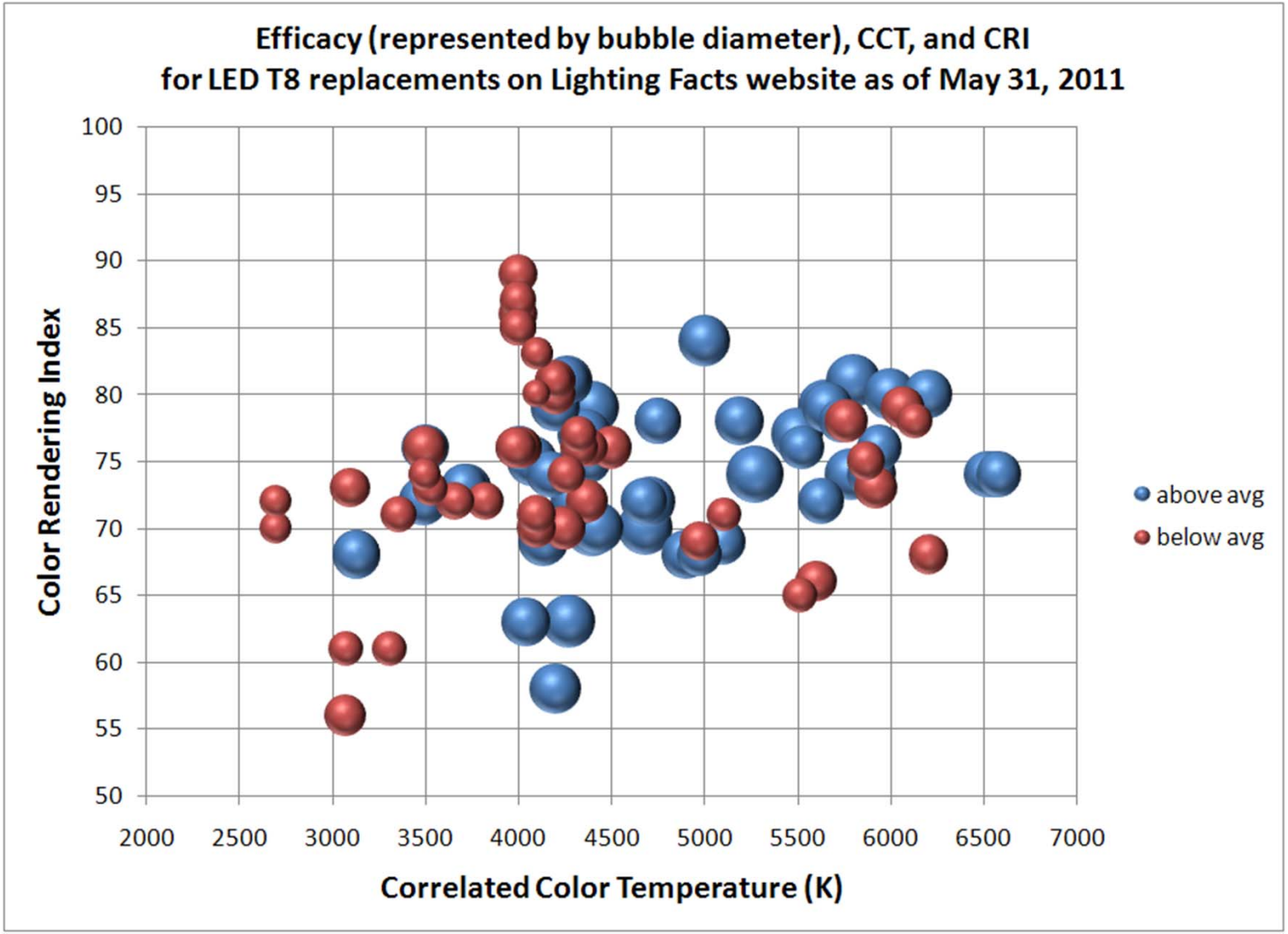
Lighting Facts – June Update

- LED linear replacement lamps under 32W listed on the DOE Lighting Facts website as of May 31, 2011

Parameter	Min.	Max.	Avg.	Std. Dev.
Initial output (lm)	581	2474	1366	421
Input power (W)	7	30	17	5
Initial efficacy (lm/W)	50	106	80	12
CRI	56	89	75	6
CCT (K)	2700	6580	4529	928

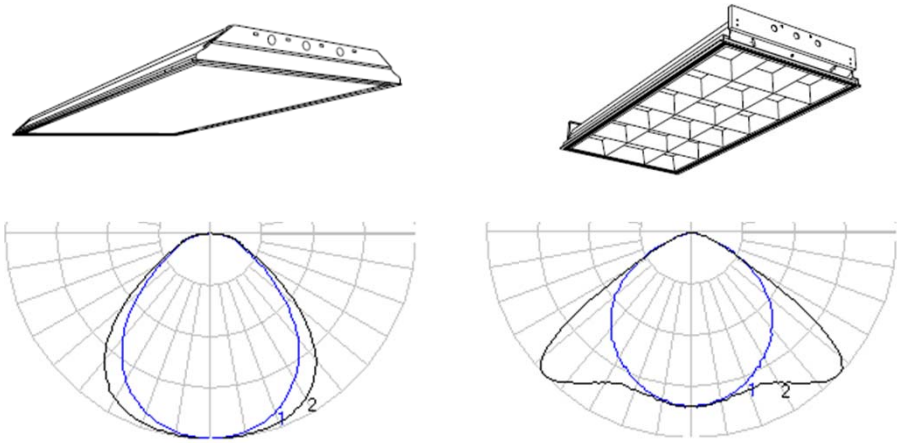
- NOTE: 32W fluorescent lamps typically operate on normal ballast factor (0.88 BF) ballasts
  - To save energy, input power for LED T8 replacements should be less than 28W (including power supply)

Lighting Facts – June Update



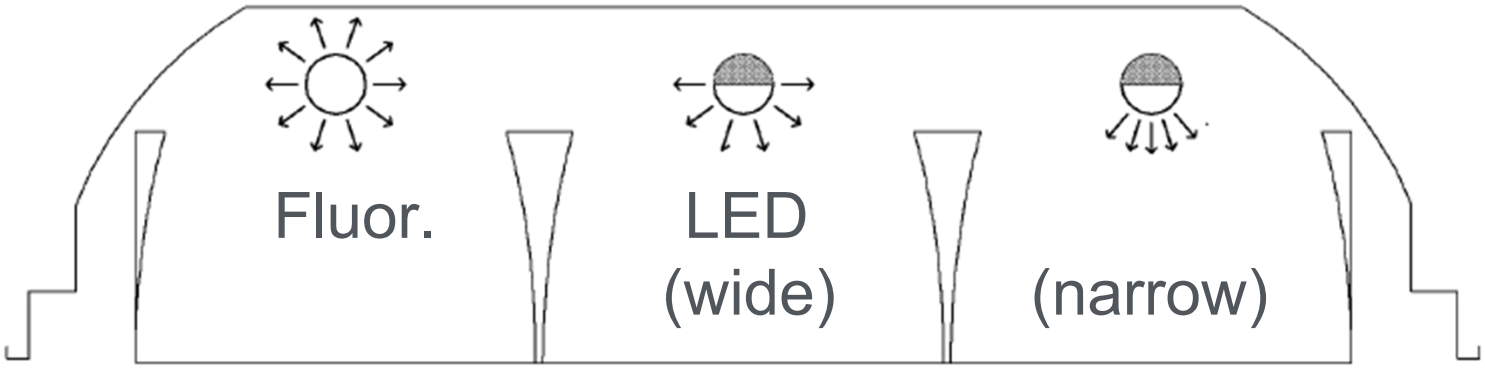
Benchmarking

- Troffers represent a significant portion of the installed base for linear fluorescent lamps
- Most troffers:
  - Measure 2x4 feet across (nominal)
  - Until recently, either prismatic lens or parabolic louver
    - Prismatic 3x more popular than parabolic in 2001



Benchmarking

- Efficiency = luminaire lumens / lamp lumens
- Efficacy = lumens / Watt
- LED directionality often offers an *efficiency* advantage
  - Approx 12% for prismatic vs. 23% for parabolic
- However, LED **doesn't** necessarily offer higher *efficacy*
  - Lower-wattage LED could mean less light



Benchmarking

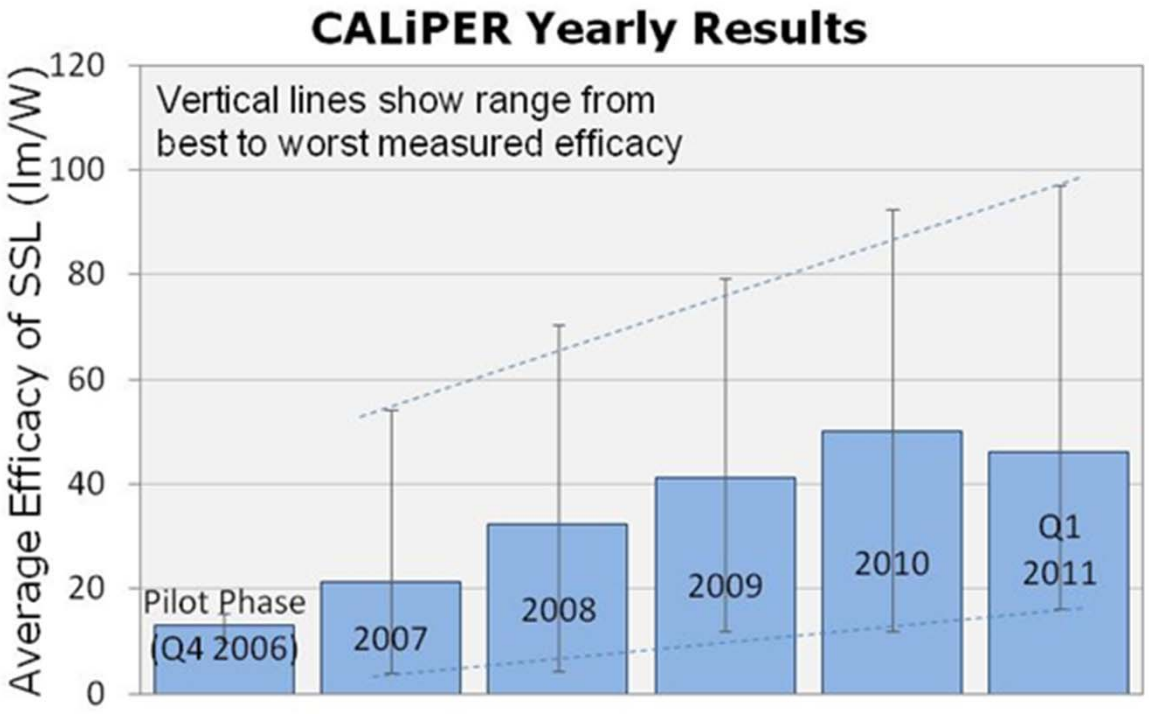
- Federal Energy Management Program (FEMP) Designated Product: Fluorescent Luminaires
  - Top 25% for luminaire *efficacy*

Performance Requirement for Federal Purchases			
Luminaire Type (NEMA Designation)	**Number of Lamps**	**Required LER (Instant-Start)**	**Required LER (Programmed-Start)**
2' x 4' Recessed			
Lensed (FL)	2	74 or higher	69 or higher
	3	71 or higher	68 or higher
	4	68 or higher	63 or higher
VDT-preferred Louvered (FP)	2	61 or higher	56 or higher
	3	60 or higher	57 or higher
	4	60 or higher	57 or higher
Wraparound			
	2	71 or higher	66 or higher

CALiPER

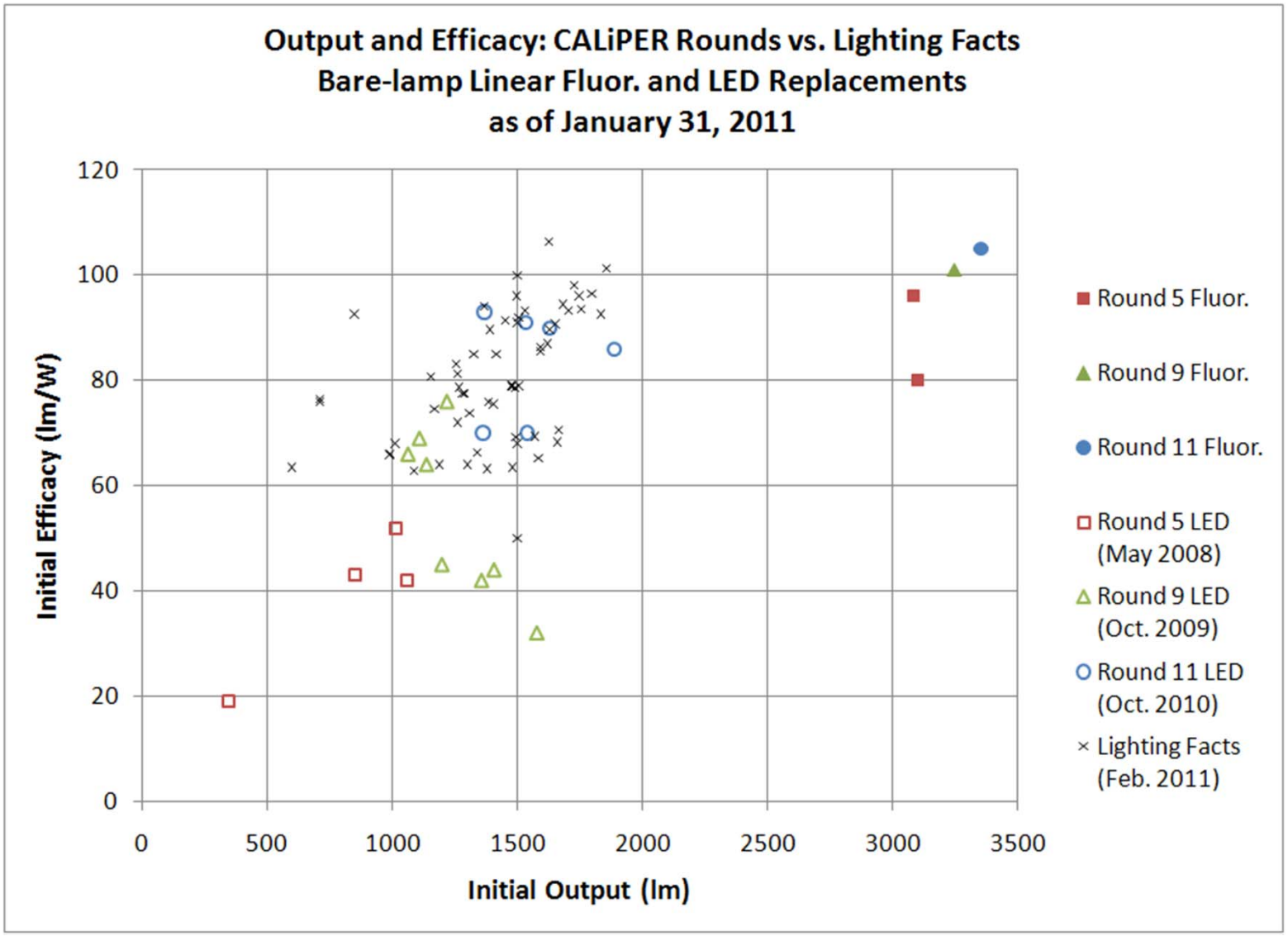
- Limited LM-79 testing of *commercially-available* LED luminaires and replacement lamps
  - Manufacturers cannot pay for testing, and are not notified of testing until after products are acquired
  - Includes some long-term testing
- Benchmark testing of other light source technologies
- Summary and Detailed Reports
  - T8 replacements tested in Rounds 5, 9, 11 and 12
- Benchmark Reports
  - Performance of T12 and T8 Fluorescent Lamps and Troffers and LED Linear Replacement Lamps

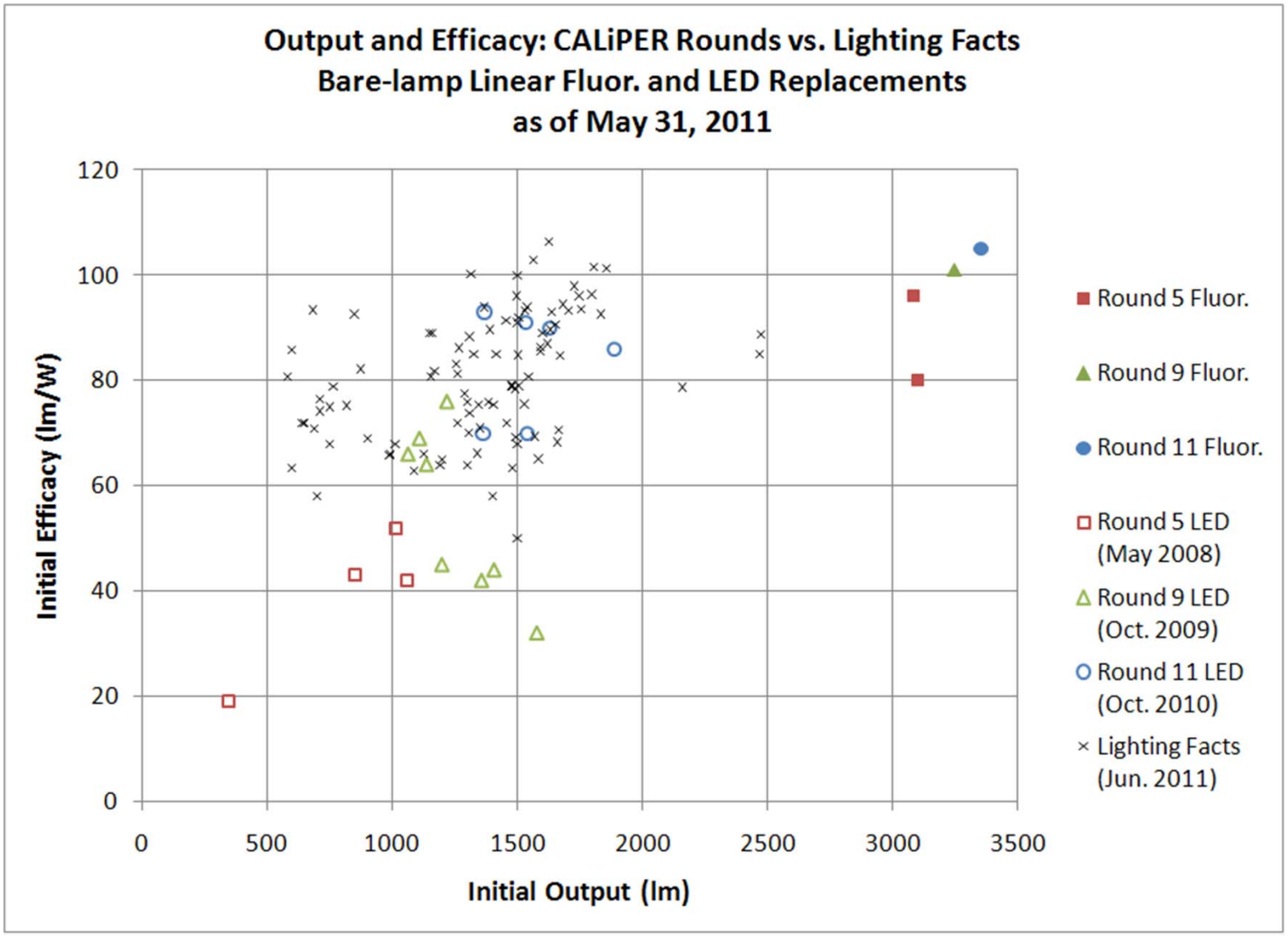
- Efficacy of Market-Available SSL Luminaires and Replacement Lamps (not just T8 replacements)
  - From the forthcoming Round 12 Summary Report



CALiPER

- **TRUE**: "CALiPER testing lags the market."
  - Due to the time required for anonymous product acquisition and testing, some lag is unavoidable
- **FALSE**: "The relevance of CALiPER data is compromised by the lag in reporting."
  - While SSL technology advances steadily, CALiPER testing provides a useful snapshot of currently available product performance and accuracy of claims
  - Bear in mind that some products are marketed as being available months before they're actually available


Output and Efficacy: CALiPER Rounds vs. Lighting Facts
Bare-lamp Linear Fluor. and LED Replacements
as of January 31, 2011
Initial Efficacy (lm/W)
120
100
80
60
40
20
0
0
500
1000
1500
2000
2500
3000
3500
Initial Output (lm)
Round 5 Fluor.
Round 9 Fluor.
Round 11 Fluor.
Round 5 LED (May 2008)
Round 9 LED (Oct. 2009)
Round 11 LED (Oct. 2010)
Lighting Facts (Feb. 2011)


Output and Efficacy: CALiPER Rounds vs. Lighting Facts
Bare-lamp Linear Fluor. and LED Replacements
as of May 31, 2011
Initial Efficacy (lm/W)
120
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0
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1000
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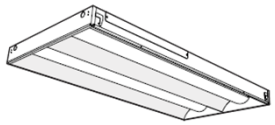
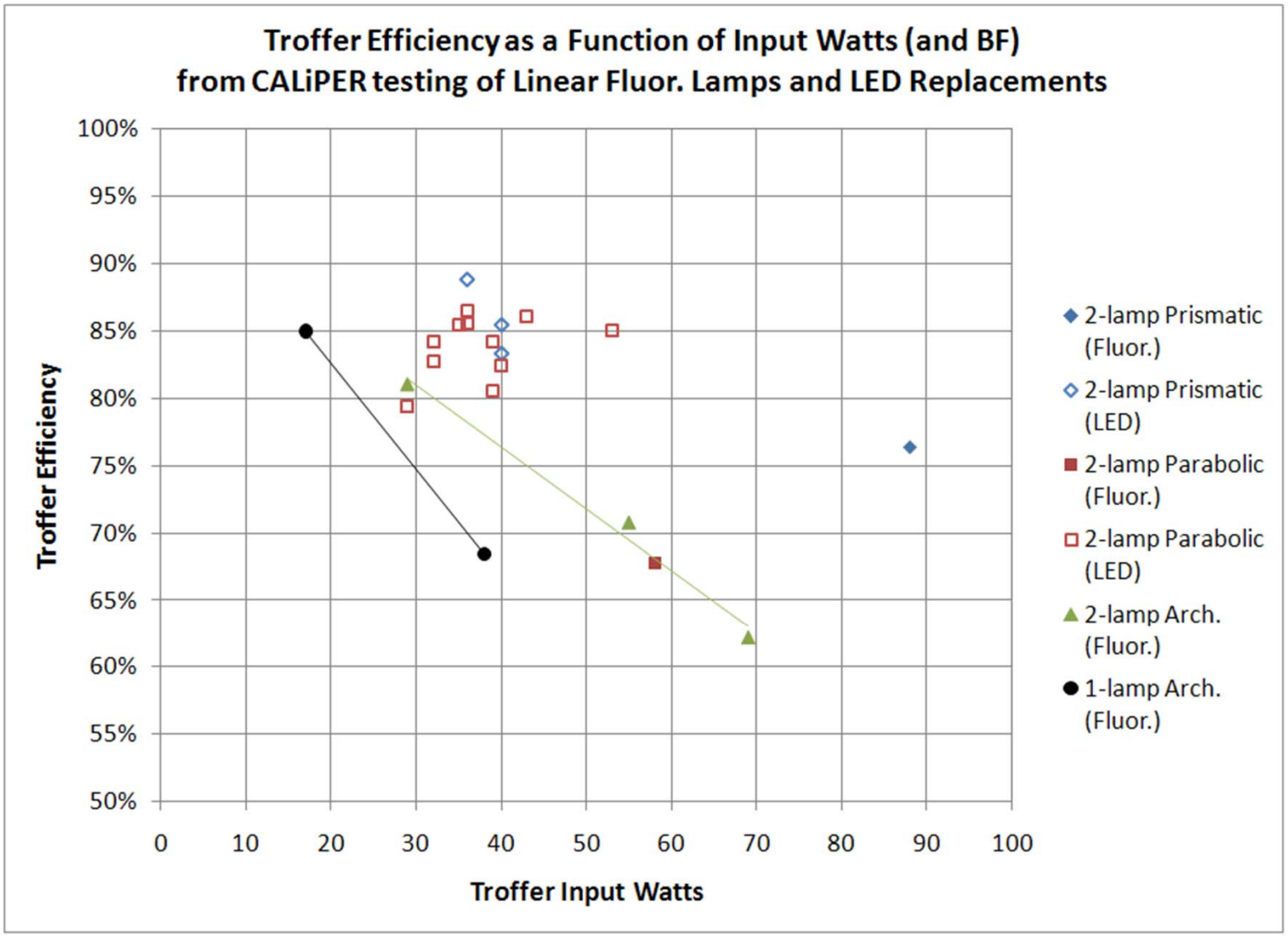
2500
3000
3500
Initial Output (lm)
Round 5 Fluor.
Round 9 Fluor.
Round 11 Fluor.
Round 5 LED (May 2008)
Round 9 LED (Oct. 2009)
Round 11 LED (Oct. 2010)
Lighting Facts (Jun. 2011)

CALiPER testing of linear fluorescent lamps and LED replacements in 2x4 troffers

Optics & Lamping	Round	Date	Efficiency (%) when lamped with		Efficacy (lm/W) when lamped with		FEMP Min. Efficacy (lm/W)
			Fluor.	LED	Fluor.	LED	
Louvered 2-T8	5	2008-05	68 (0.88 BF)	82-87	63	17-44	74 (IS) 69 (PS)
	9	2009-10		83-85		38-57	
	11	2010-10		79-86		56-77	
	12	2011-06		79		75	
Lensed Prismatic 2-T12	5	2008-05	76 (0.94 BF)	83-89	51	17-42	61 (IS) 56 (PS)
Lensed Arch. 2-T8 	9	2009-10	62 (1.18 BF)	-	69	-	n/a
	11	2010-10	71 (0.88 BF)	-	74	-	
	12	2011-06	-	81	-	76	
Lensed Arch. 1-T8	11	2010-10	68 (1.18 BF)	-	71	-	
	12	2011-06		85		77	


Troffer Efficiency as a Function of Input Watts (and BF)
from CALiPER testing of Linear Fluor. Lamps and LED Replacements
Troffer Efficiency
100%
95%
90%
85%
80%
75%
70%
65%
60%
55%
50%
0
10
20
30
40
50
60
70
80
90
100
Troffer Input Watts
2-lamp Prismatic (Fluor.)
2-lamp Prismatic (LED)
2-lamp Parabolic (Fluor.)
2-lamp Parabolic (LED)
2-lamp Arch. (Fluor.)
1-lamp Arch. (Fluor.)

GATEWAY Evaluation

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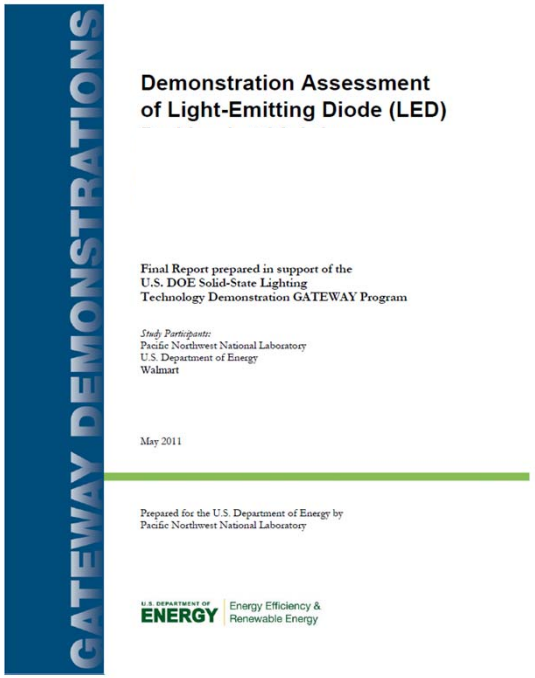
- GATEWAY Program
  - Demonstration of LED (and benchmark) installations
  - Highlight appropriate applications of LED technology
  - Present positive and negative aspects
  - Typical GATEWAY projects are existing real facility demonstrations
- GATEWAY Project focus
  - Energy savings
  - Maintained quality/quantity of light
  - Reasonable economics (payback)



GATEWAY Evaluation of LED T8 Replacement Lamps

- Goals
  - Highlight characteristics of available products
  - Evaluate important project criteria
  - Present results and relate them to useful recommendations for project considerations
- Project steps
  - Identify high performing commercially available LED products and typical baseline FL products
  - Measure and compare energy and light capabilities in consistent mock-up office setting

NOT an evaluation of ALL LED T8 replacement products!

LED T8 Replacement Lamps

- Selection criteria
  - Wide light distribution
  - High lumen output
  - High LPW
  - Timely arrival to test site

Product	Measured Wattage	Measured Power Factor	CALiPER Test No.*	Luminous Flux (lumens)*	CCT*	CRI*
LED01	18.5 W	0.78	(**)	1453**	5638K**	75.6**
LED02	17.0 W	0.86	10-16	1366	5394K	77.1
LED03	22.0 W	0.58	09-107	1539	3548K	72.9

**Shaded cells indicate results derived from separate testing of these products by the CALiPER testing program, except LED01 (**) where CALiPER had tested a preceding generation of the product. This earlier generation product corresponds to CALiPER product test 10-18. Values provided for reference only.*

Baselines for Comparison

Baselines:

- Fluorescent 32W 735 T8s with IS electronic ballast
- Fluorescent 34W CW T12s with HPF magnetic ballast

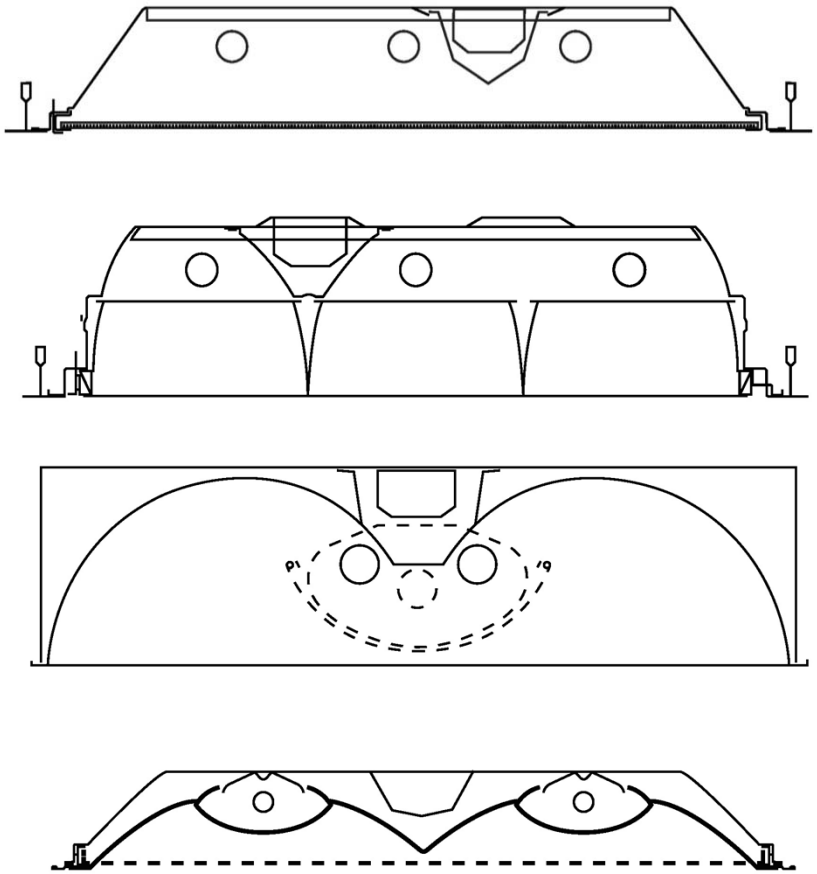
Also compared:

- (3) T8 LED products with ballast disconnected
- (1) T8 25W SS XL/XP on same IS electronic ballast
- (1) T8 32W XL/XP 835 with new LBF High Efficiency IS ballast

Luminaire Comparison Formats

Comparisons made with T8 and T12 lamps in conventional recessed fluorescent troffers:

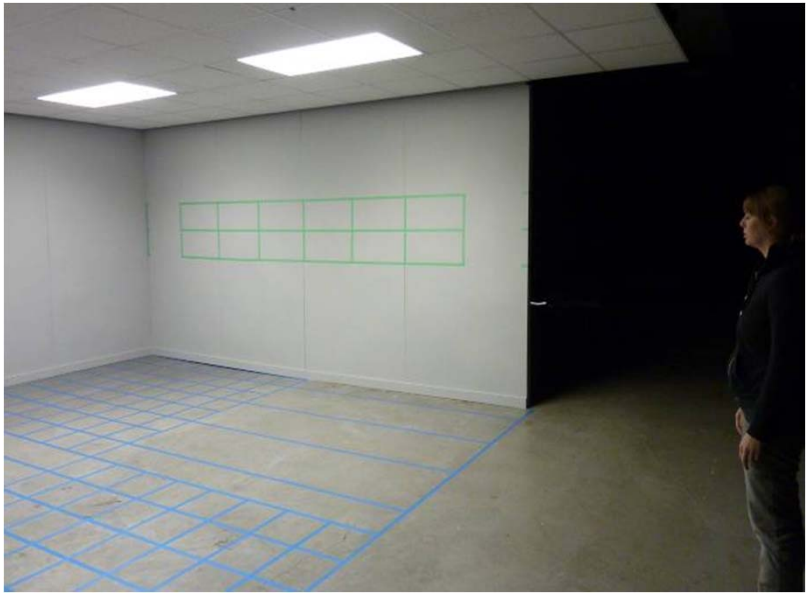
- 2 and 3 lamp prismatic lens
- 2 and 3 lamp semi-spec parabolic louver
- 2 and 3 lamp basket fixture
- 2-lamp “volumetric,” “non-planar,” “prismatic high-lumen” fixture

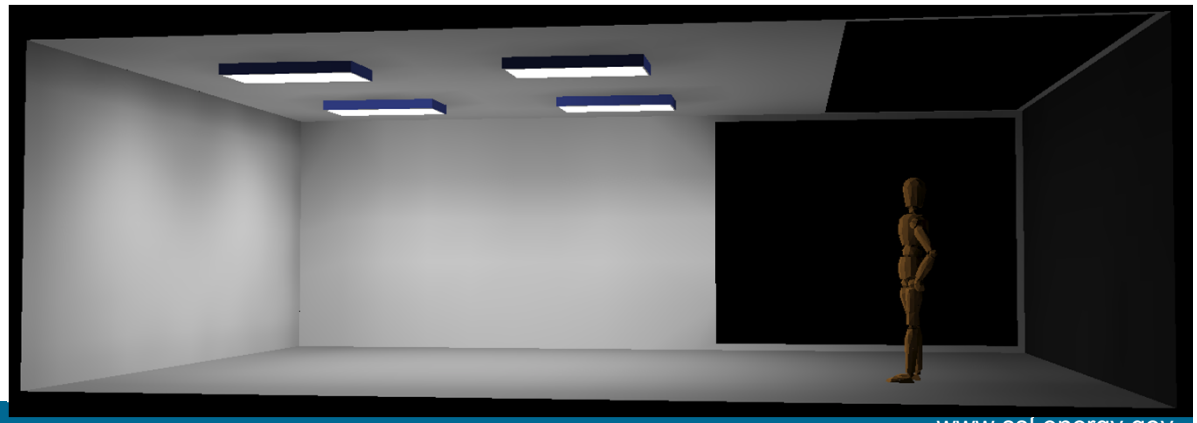


Study Space

Installed in mock-up space at Seattle Lighting Design Lab

- 16’ x 16’ x 9’ ceiling
- 75-50-20 reflectances
- 30” work plane height
- 4 troffers, spaced 8’ o.c.





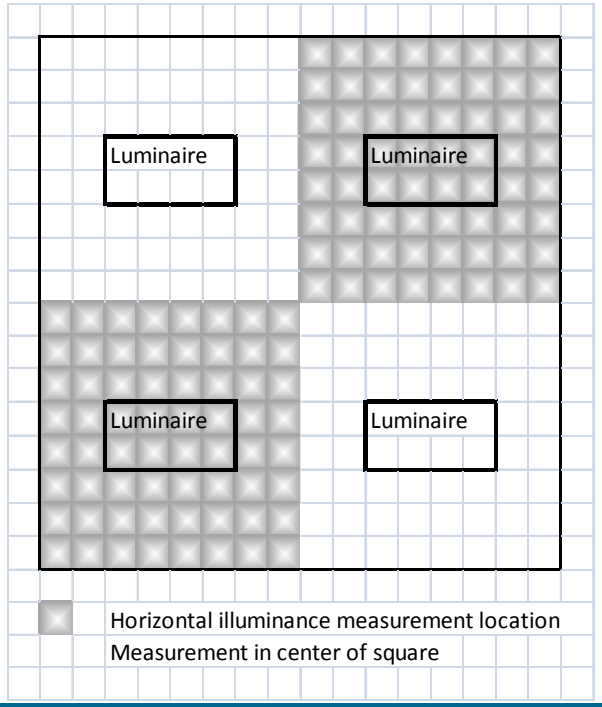
Steps in GATEWAY study

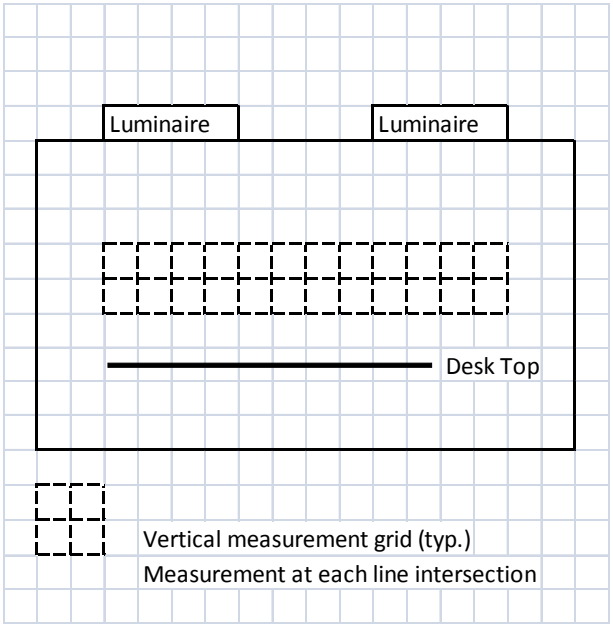
Illuminance measurements (footcandles)

- Horizontal illum on 30” workplane grids
- Vertical illum on walls 4’ to 6’ above floor

Power measurements (Watts) for each luminaire combination

Power factor





LED T8 Replacement Lamp Results

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Results

Product	Price per Lamp ($)	Measured Power (watts)	Mfr Listed Initial Lumen Output (lumens)	Mfr Listed Ballast Factor	Calculated System Efficacy* (lumens/W)	Avg Horiz** Workplane Illuminance (fc)	Avg Vert** Illuminance (fc)
Baseline T8 (735) FL	**2.00**	**28.5**	**2800**	**0.88**	**86.5**	**39.1**	**22.2**
High lumen T8 FL, low BF	**4.55**	**25.0**	**3100**	**0.78**	**96.7**	**38.3**	**23.3**
Obsolete T12	**1.85**	**38.0**	**2650**	**0.95**	**77.5**	**36.9**	**22.2**
LED 01	**89.69**	**18.5**	**1400**	**N/A**	**75.7**	**31.1**	**17.9**
LED 02	**63.75**	**17.0**	**1343**	**N/A**	**79.0**	**28.9**	**16.2**
LED 03	**120.00**	**22.0**	**1590**	**N/A**	**72.3**	**31.2**	**17.5**
Comparison 25W T8 FL* **	**5.50**	***22.5**** **	**2400**	**0.88**	**93.9**	***34.6**** **	***19.6**** **

Compare lamp cost, power, LPW, footcandles

LED T8 Replacement Lamp Results

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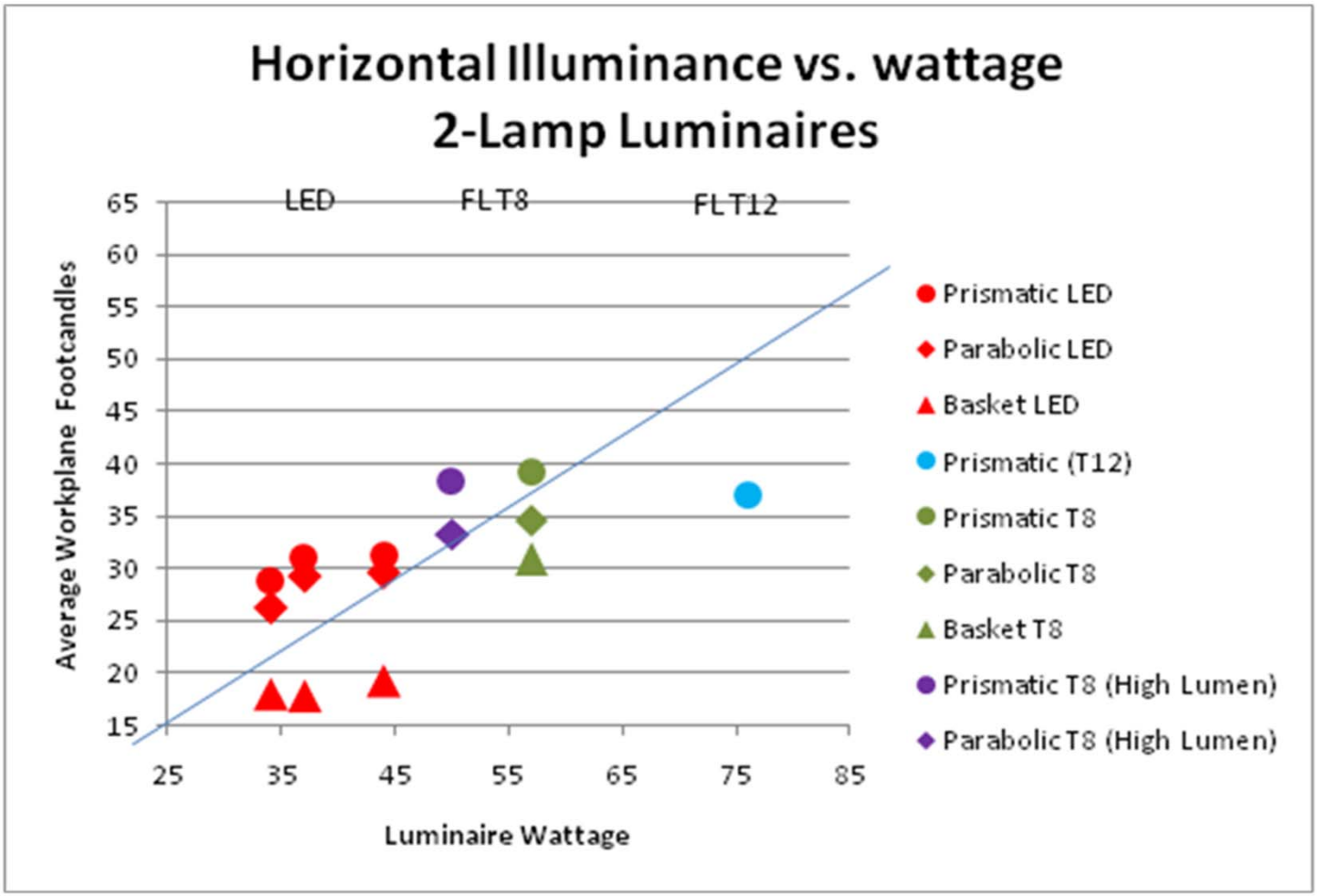
Results – Higher FC from fluorescent, lower W from LED

– LEDs don't perform well in basket fixtures



LED T8 Replacement Lamp Results

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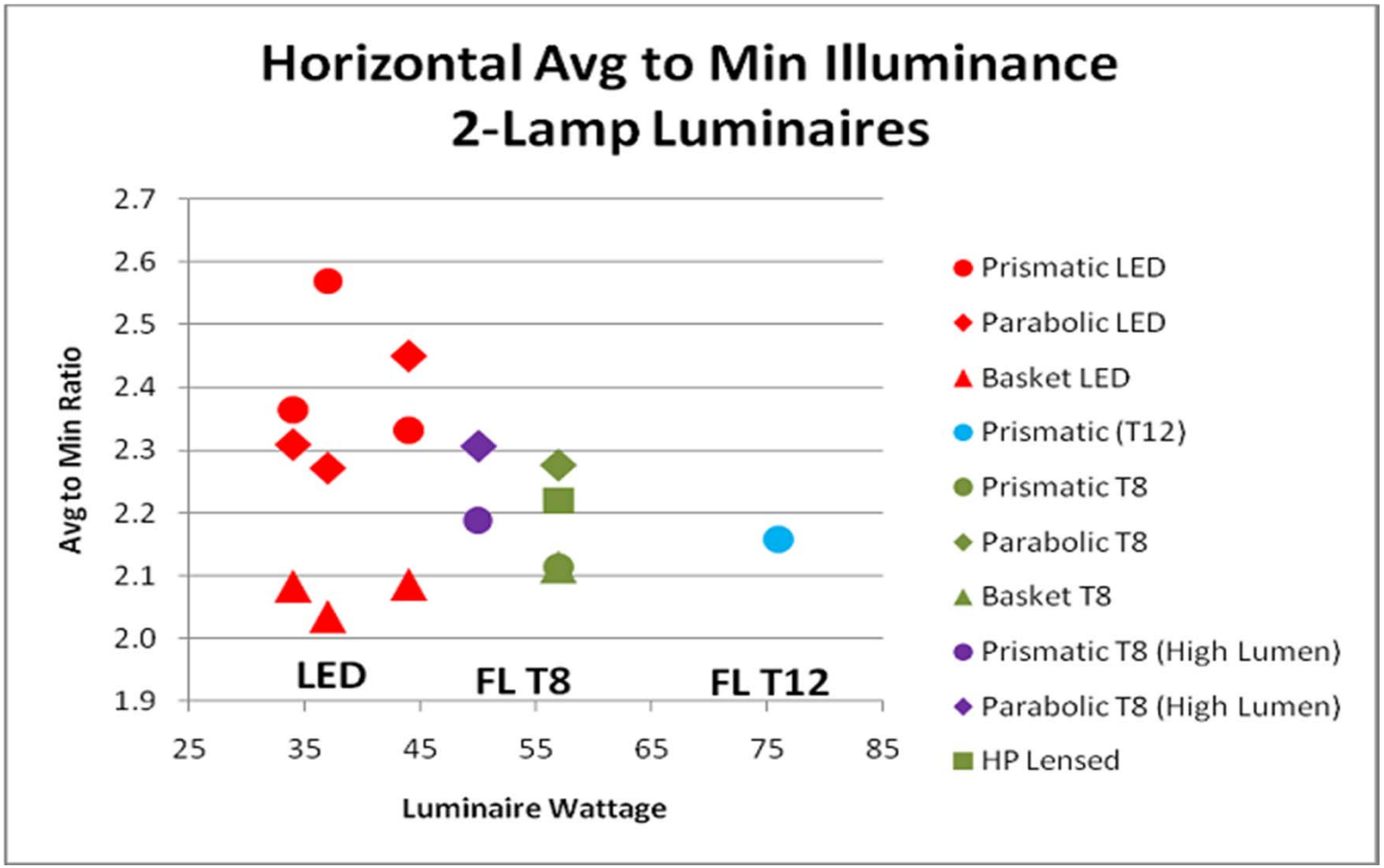
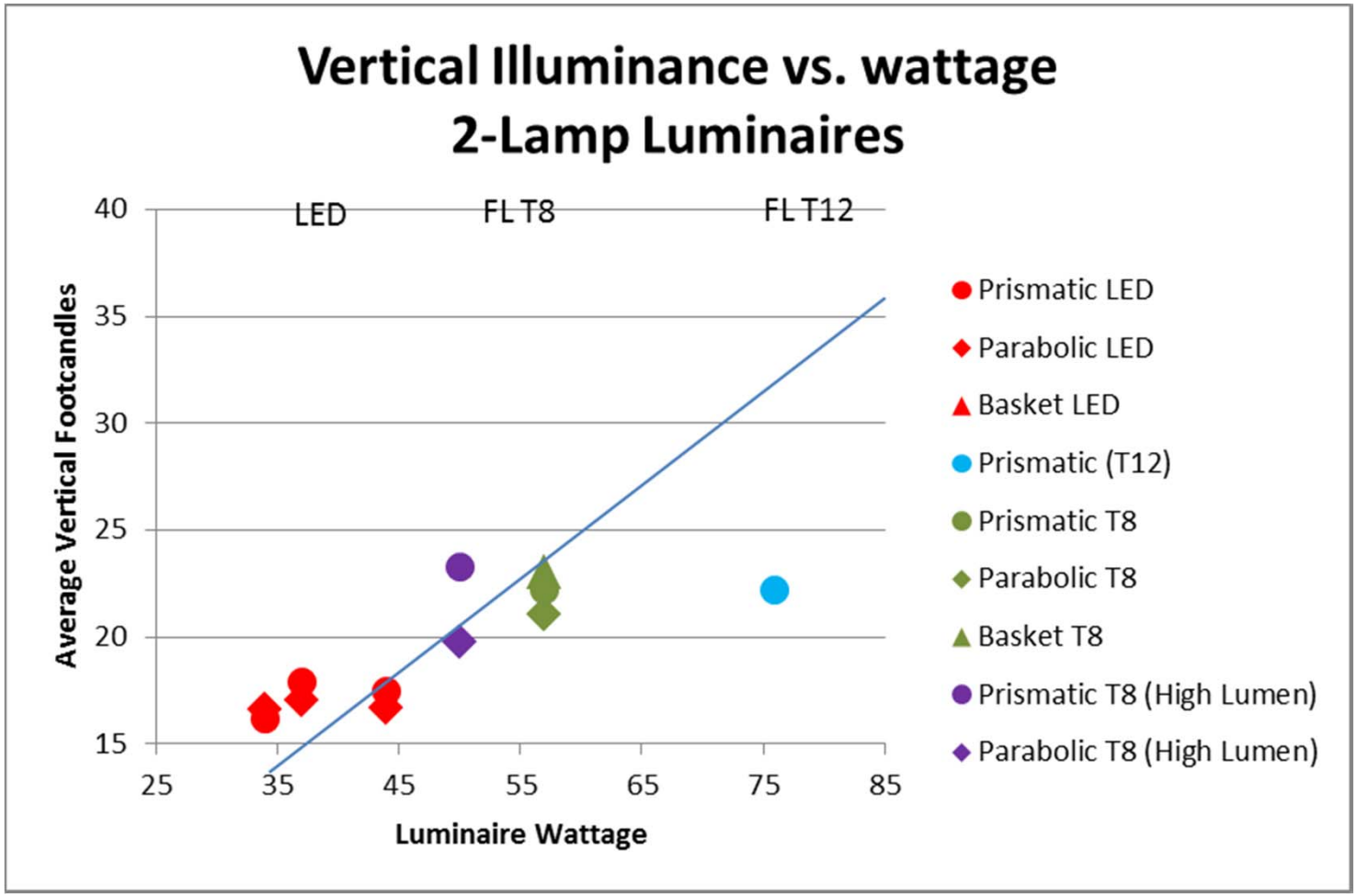
Results – Better workplane FC uniformity from fluorescent in prismatic and parabolic troffers



Results – Higher wall FC from fluorescent



LED T8 Replacement Lamp Results

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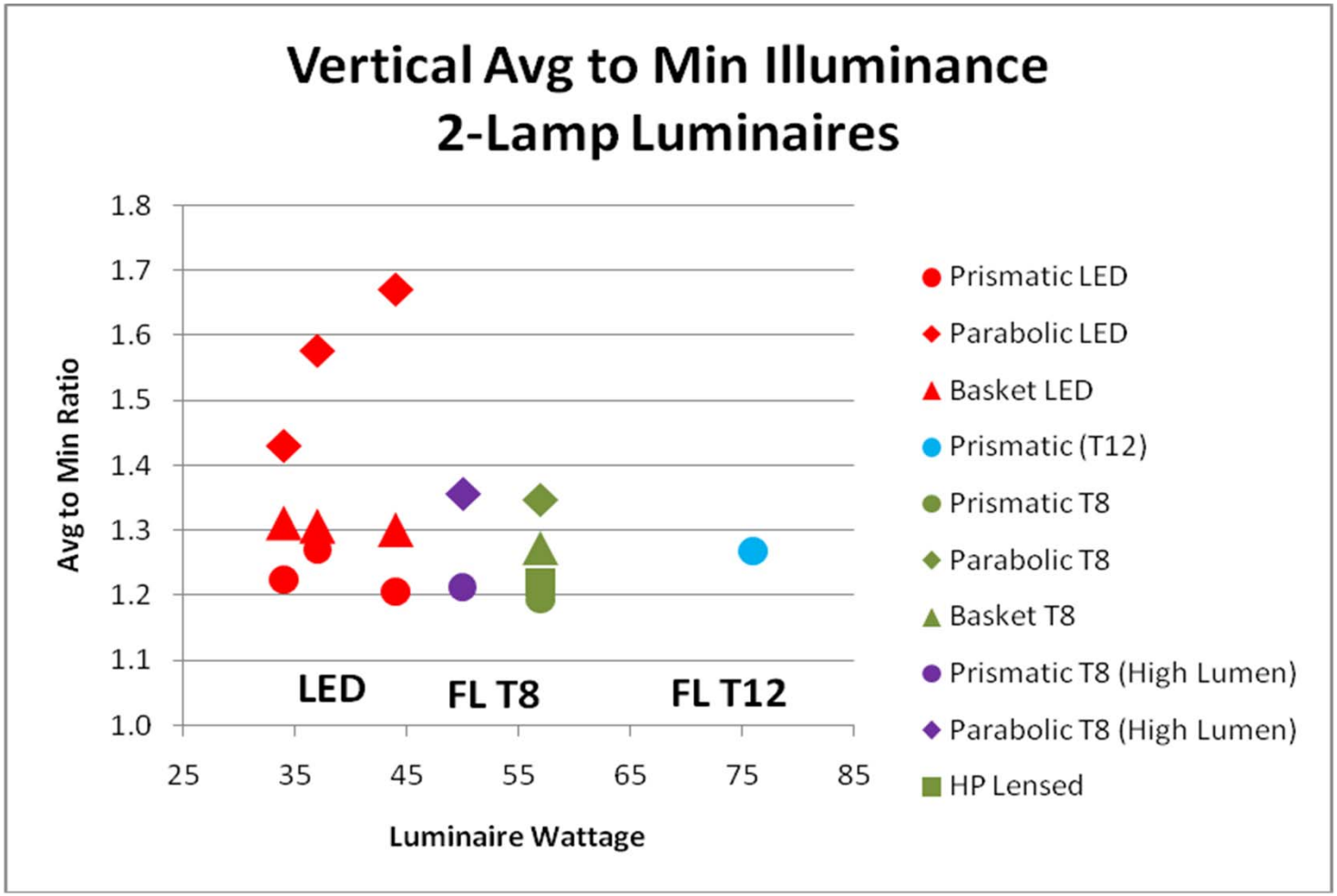
Results – Better FC uniformity on wall from fluorescent in parabolic troffers; other troffers equivalent



LED T8 Replacement Lamp Results

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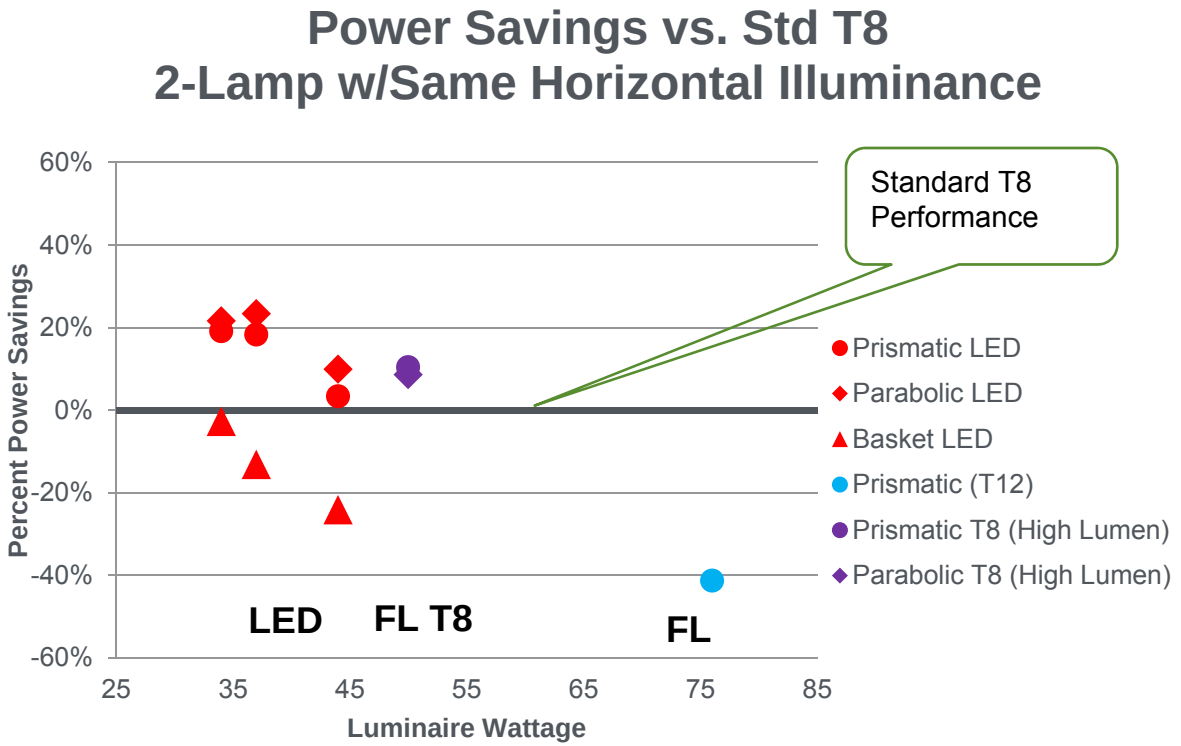
Results – Energy Efficiency

- IF LED lamp output could be increased to deliver same workplane FC, then they would be viable in terms of delivered FC-per-watt. Possible?



Economic comparison - LCC

Life Cycle Cost Input

- $0.11/kwh melded electrical rate
- RS Means derived spot and group relamping costs
- RS Means derived labor costs for disconnecting or changing ballasts
- 3% discount rate, 0% escalation rate
- 3000 hrs/yr operation
- 50,000 hour study period (16 years 8 months)
- Lamp prices as purchased by Seattle Lighting Design Lab

Economic Results

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At current prices for lamps, no LED lamps will payback over 50,000 hour study period

Alternative	Initial Cost (PV)	Life Cycle Cost (PV)	Lowest LCC
F40T12/34W/CW/RS and magnetic ballast	$31	$1458	
F32T8/735 lamp and IS ballast	$32	$1099	
F32T8/25W XL/XP/SS lamp replacement	$60	$898	******
F32T8/835/XPS lamp and LBF IS ballast	$203	$1129	
LED 02 and ballast disconnect	$629	$1243	
LED 01 and ballast disconnect	$839	$1517	
LED 03 and ballast disconnect	$1079	$1886	

LED T8 Replacement Lamp Results

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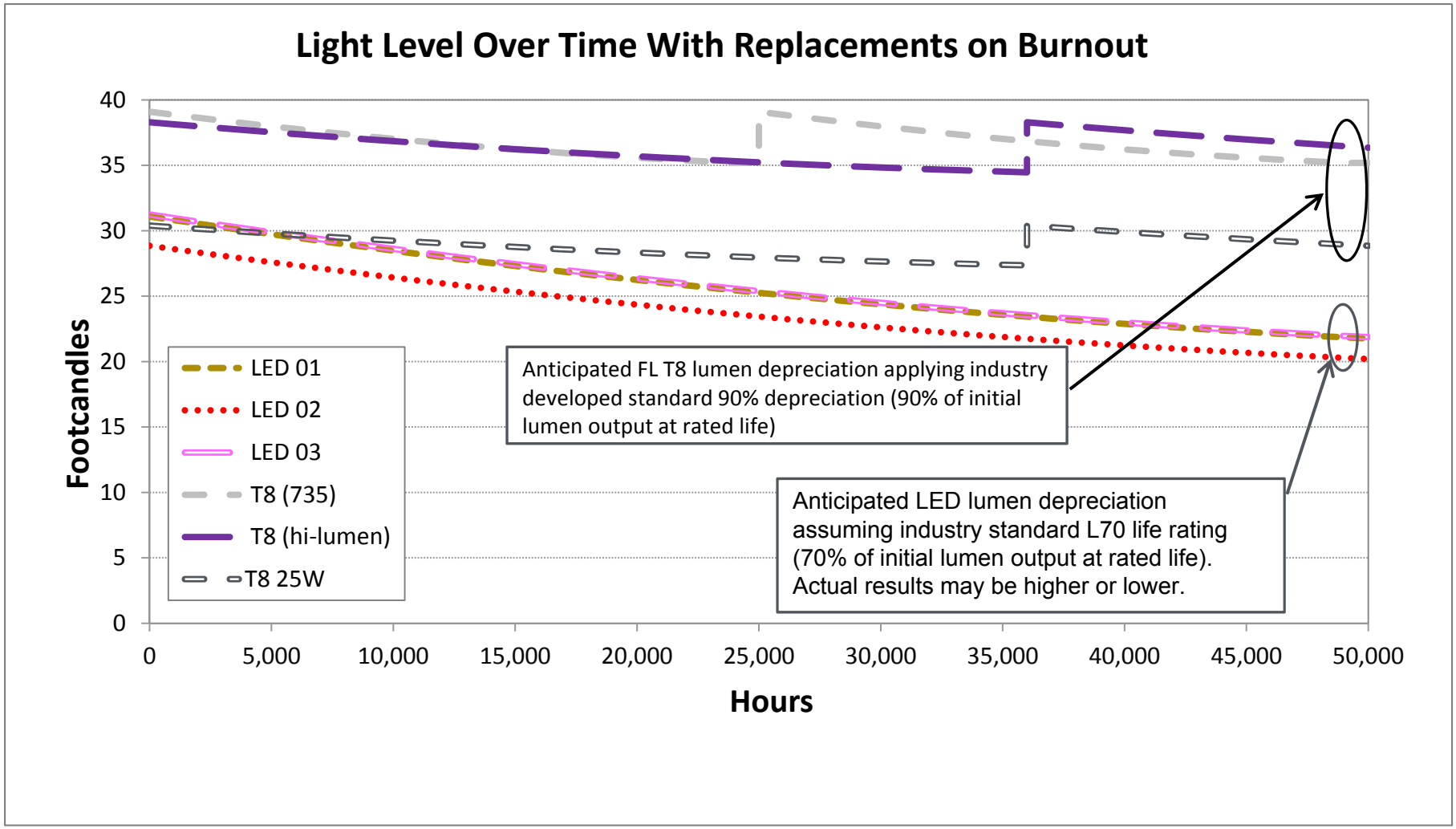
What happens when we consider lamp lumen depreciation?



Application recommendations

If your space is currently overlighted, LED options may provide effective replacement….:

- Also consider replacement with low-wattage T8 high-performance lamps (36,000 hours life)
- Perform a life-cycle cost analysis. If you can get the LED lamps at low prices, they may be economically viable.

If your space is *not* overlighted

- Ensure you use LED T8 replacement lamps with equivalent light output capability (likely around 2000 lumens) to provide equivalent delivered FC levels.

LED T8 Replacement Application

Application notes

Not all LED lamps and fixtures are wired the same.

- Shunted sockets (instant start) vs. Rapid-start sockets.
- Not all LED T8s interchangeable.

issues

- Requires disconnecting ballast and rewiring sockets - consider labeling fixture so that fluorescent lamps can't be reinstalled.
- UL Certification is still a question/issue.

T8 LED lamp replacements won't work well for all fluorescent fixtures

- Luminous area of the lamp must be oriented properly for the fixture's distribution. Test before you commit to the purchase.

LED T8 Replacement Summary

In summary

The good news:

- The efficacy of many T8 LEDs is good and rising fast
- The T8 LED doesn't need to deliver equivalent lumens to deliver equivalent FC
- Economic viability may arrive when lumen output rises and LED lamp costs drop

However:

- light output is still lower that FL for most products
- Costs are still high in relation to FL technology

Try a few before you commit to many. Consider all options. Also consider using dedicated new LED for higher efficiency, similar-cost solution.

Suggested Specifications

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

- Two related SSL Fact Sheets Available at www.ssl.energy.gov/factsheets.html
  - Application Series
    - Updated May 2011
    - Provides overview of CALiPER testing
    - 4 pages
  - Specification Series
    - Dated April 2010
    - Offers suggested performance criteria
    - 2 pages
- Following is an overview of recommendations offered in the currently-posted Specification Series Fact Sheet

Suggested Specifications

- Initial output ≥ 2700 lumens, based on:
  - 2778 lumens average T8 fluorescent output
  - 94% lumen maintenance for fluorescent at 70% of rated life
  - 0.87 BF for fluorescent
    - Ballast is typically bypassed for LED
  - 17% higher efficiency with LED, on average
  - 70% lumen maintenance for LED

Suggested Specifications

- Rated useful life ≥ 35,000 hours
  - Typical fluorescent T8 life on instant-start ballasts:
    - 24,000 hours at 3 hours per start
    - 30,000 hours at 12 hours per start
  - Fluorescent ratings can exceed 40,000 hours on programmed-start
- Lumen maintenance (L70) at end of life ≥ 70%
- Lumen maintenance at 6,000 hours operation ≥ 94.1%
  - Supported by long-term test data for complete product
- Warranty ≥ 3 years

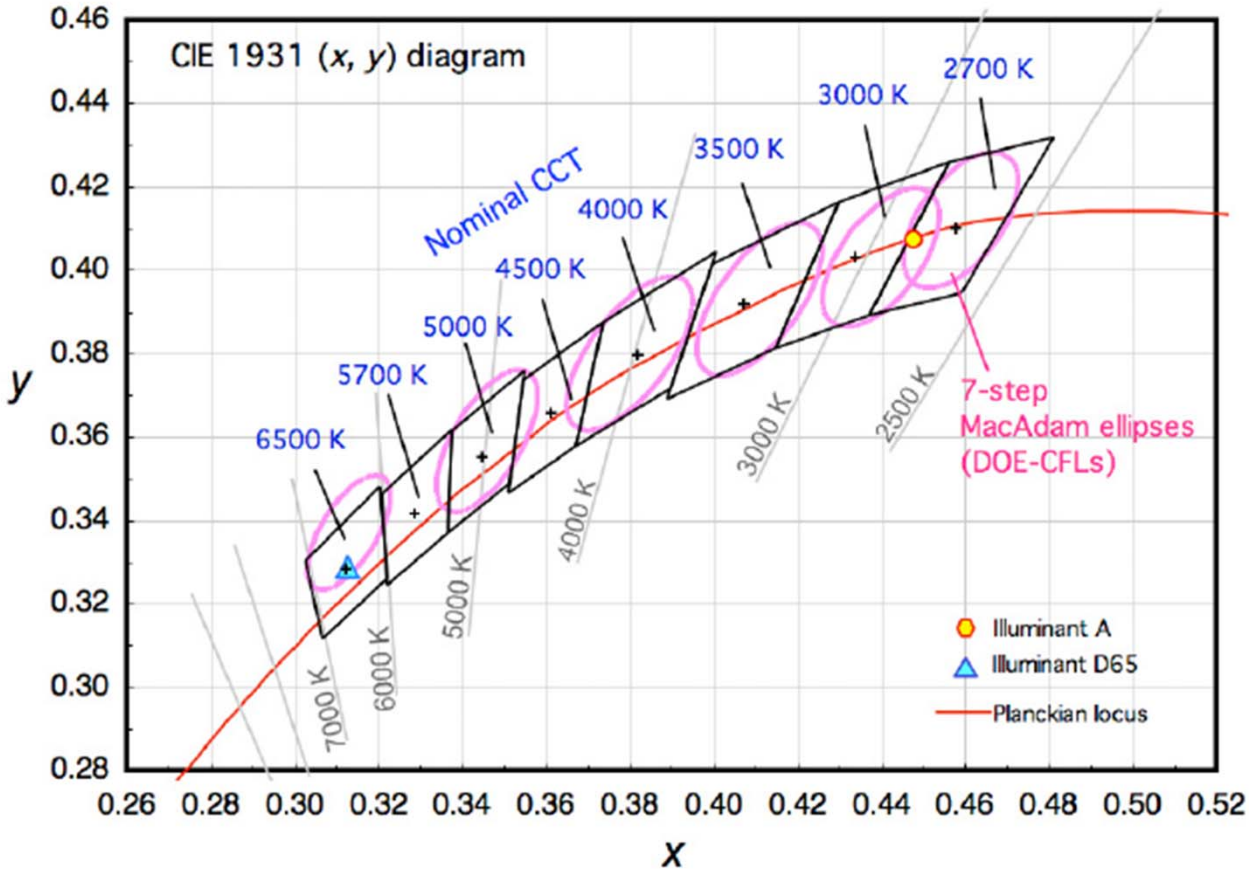
Suggested Specifications

- General Color Rendering Index (CRI or R_a) ≥ 80
  - Compare with 800-series fluorescent
- Correlated Color Temperature (CCT) as per ANSI_NEMA_ANSLG C78.377-2008
  - *Duv criteria provided here for reference*

Nominal (Rated) CCT	Target (Measured) CCT	Target (Measured) Duv
2700 K	2580 to 2870 K	-0.006 to 0.006
3000 K	2870 to 3220 K	-0.006 to 0.006
3500 K	3220 to 3710 K	-0.006 to 0.006
4000 K	3710 to 4260 K	-0.005 to 0.007
4500 K	4260 to 4746 K	-0.005 to 0.007
5000 K	4745 to 5311 K	-0.004 to 0.008
5700 K	5310 to 6020 K	-0.004 to 0.008
6500 K	6020 to 7040 K	-0.003 to 0.009

Suggested Specifications

- ANSI chromaticity quadrangles for SSL comparable to 7-step MacAdam ellipses used for fluorescent

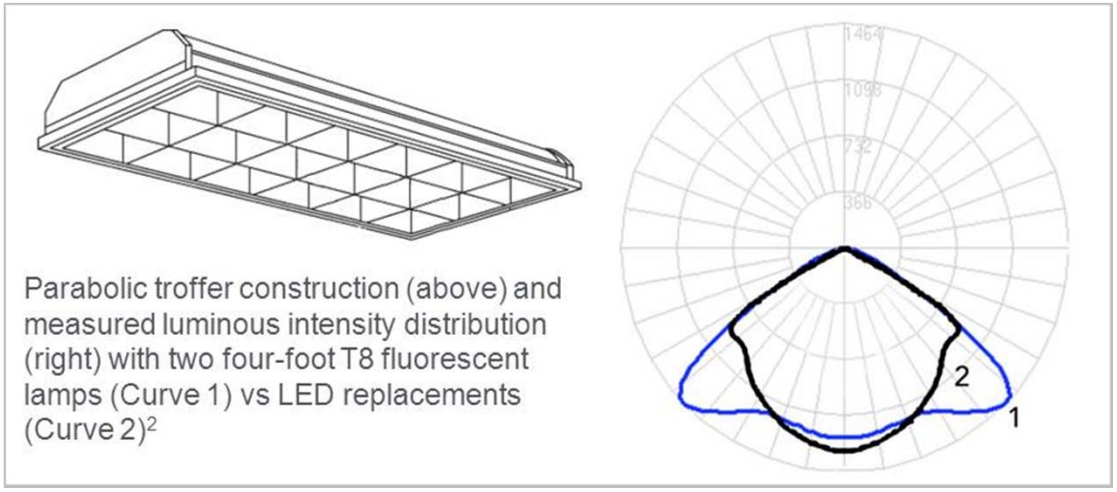


Suggested Specifications

- Electrical safety per ANSI/UL 8750
  - Requirements vary from application to application
  - Coordinate with local inspector to determine applicability of UL 1993, UL 1598C, CSA TIL B-79, etc.
  - Request safety certification and file number per the National Electric Code (NEC)
    - Testing bodies determined by the US Occupational Safety Health Administration (OSHA) as Nationally Recognized Testing Laboratories (NRTL)
  - For details, visit www.ul.com and/or www.csa.ca

Suggested Specifications

- Intensity distribution
  - No criteria given since requirements vary
    - See ANSI/IESNA RP-1-04 for guidance
  - Impact of replacing with LED can be dramatic, especially for parabolic-louvered troffers
    - Blue lines (1) below indicate fluorescent lamp
    - Black lines (2) below indicate LED replacement



Parabolic troffer construction (above) and measured luminous intensity distribution (right) with two four-foot T8 fluorescent lamps (Curve 1) vs LED replacements (Curve 2)[2]

Suggested Specifications

- Specification-series Fact Sheet was slated for update prior to this webcast
  - April 2010 version currently undergoing review
  - Update may follow release of forthcoming IES TM-21
  - May revise minimum output (lumens) criterion based on new benchmark:
    - Reduced-wattage (28W) T8 fluorescent lamp on 0.88 BF ballast
    - Note that LED would then need to be < 25W (including power supply) to save energy

Suggested Payback Analysis

- Cost to purchase and install
  - Include labor and provide bidding contractor(s) with LED manufacturer installation instructions
- Cost to operate
  - Connected load and operating schedule
  - Electricity rate(s)
  - Maintenance
  - Cleaning
  - Possible driver replacement
  - Rated life
    - Ballast type, cycling, warranty, B50 vs. L70
- Cost to replace and dispose

Other Applications

- Linear fluorescent lamps aren't restricted to use in troffers
  - Less stringent criteria may be appropriate elsewhere

Arizona State University Parking Structure
Courtesy of PNNL

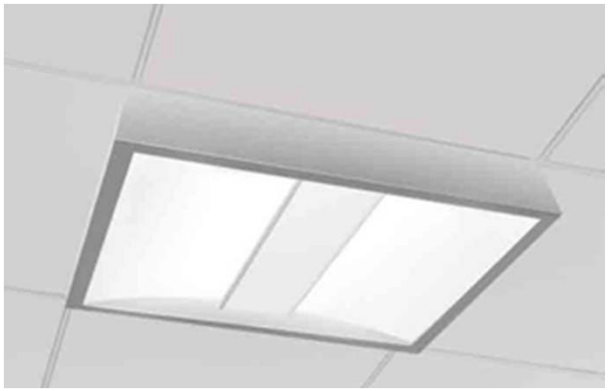
Other Applications

- Fluorescent strip lights are common in parking structures
  - In applications where no uplight is desired, less LED output (and lower efficacy) may be acceptable since no light is “wasted” upward
    - However, controlled uplight in parking structures can improve perceived brightness and safety
  - Fluorescent lamp output is also compromised in low-temperature environments

Courtesy of Acuity

Other Product Categories

- LED luminaires may offer a superior solution
  - Coordinated system of LED light source and optical/thermal/electrical components
- Visit www.ngldc.org to see winners of the annual Next Generation Luminaires design competition



Courtesy of Axis Lighting

2010 Recognized
Indoor General Illumination

Courtesy of Philips Wide-Lite

2009 Best in Class
Parking Garage

Other Product Categories

- Commercial Building Energy Alliances (CBEA)
  - Parking structure luminaire specification available
    www.eere.energy.gov/buildings/alliances/parking_structure_spec.html
  - 2x2 troffer specification under development
    www.eere.energy.gov/buildings/alliances/high_efficiency_troffers.html

In Closing

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End of Presentation

Questions?