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

Troffers, Kits, and Tubes: LEDs challenge fluorescent in the Office Lighting Olympics

Efficiency Vermont

Better Buildings By Design

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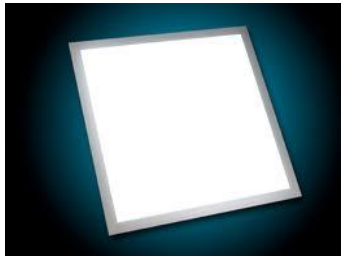
“Type A” Project Luminaires

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

Dedicated LED troffers

LED T8 replacement lamps

LED troffer kits

What's an energy manager to do???

How do you choose??

The evaluation criteria Decathlon:

CALiPER TROFFER STUDY

Build a mockup office space at Intertek Portland OR

- Install 24 pairs of recessed luminaires
- Install 0-10V dimming controls
- Invite 18 designers/engineers to observe, score, and comment

CALiPER TROFFER STUDY

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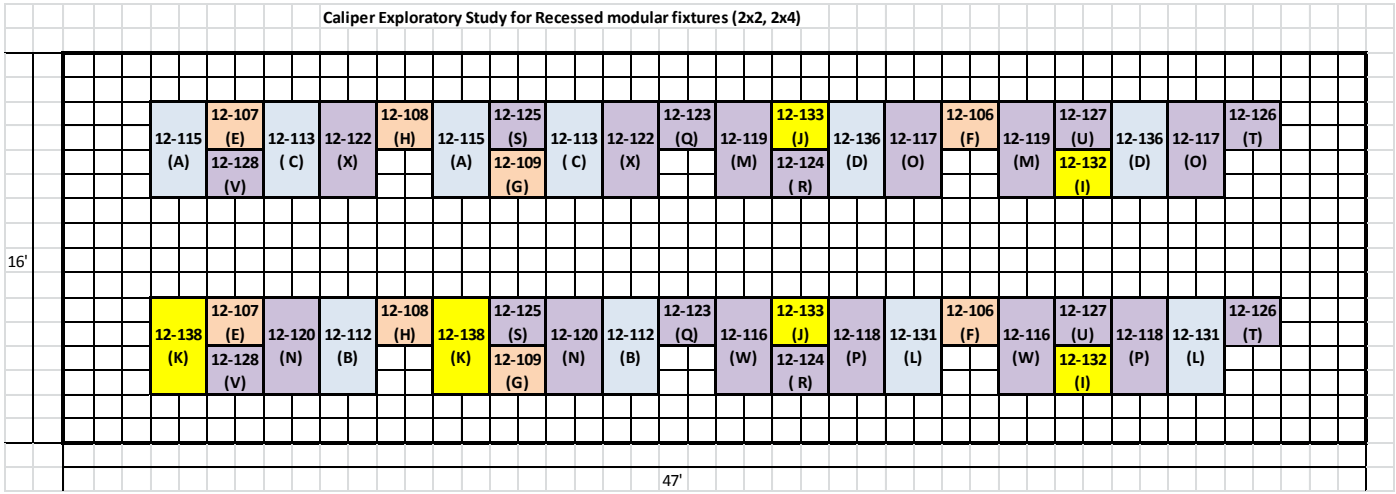
Tag	Size	Type
A	2x4	T8 LED tubes
B	2x4	T8 LED tubes
C	2x4	T8 LED tubes
D	2x4	T8 LED tubes
E	2x2	LED retrofit kit
F	2x2	LED retrofit kit
G	2x2	LED retrofit kit
H	2x2	LED retrofit kit
I	2x2	Fluor benchmark
J	2x2	Fluor benchmark
K	2x4	Fluor benchmark
L	2x4	T8 LED tubes
M	2x4	New LED troffer
N	2x4	New LED troffer
O	2x4	New LED troffer
P	2x4	New LED troffer
Q	2x2	New LED troffer
R	2x2	New LED troffer
S	2x2	New LED troffer
T	2x2	New LED troffer
U	2x2	New LED troffer
V	2x2	New LED troffer
W	2x4	New LED troffer
X	2x4	New LED troffer



Qualifying heats: 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)

Action shots of the athletes….

Judges hard at work….

CALiPER TROFFER STUDY

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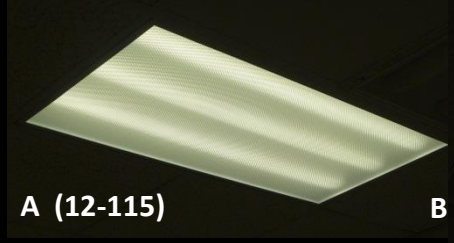
	Questionnaire for CALiPER Office/Classroom exploratory study																							
		Luminaire Tag																						
	Luminaires at full output	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**	**R**	**S**	**T**	**U**	**V**	**W**	**X**
1	How appropriate is the light output from the luminaire for this application? 1= too low 2=mod low 3=mod high 4=too high																							
2	Is the light distribution on the workplane between luminaires appropriately uniform for this application? 1 = too uneven 2 = mod uneven 3= somewhat too uniform 4=too uniform																							
3	Imagine the luminaire installed 2' or 3' from the walls. Is the light distribution on the adjacent wall appropriate for the application? 1=No 2=Somewhat inappropriate 3=Somewhat appropriate 4=Yes (Please explain your answer, e.g. "funny pattern" or "odd striations" or "hits wall too high" or "light hits wall too low")																							
4	Is the luminaire comfortable (not glaring) to sit under in a heads-down-type visual task (office)? 1 = Not comfortable 2=mod uncomfortable 3=mod comfortable 4=Very comfortable																							
5	Is the luminaire comfortable (not glaring) to sit under in a heads-up-type visual task (classroom)? 1 = Not comfortable 2=mod uncomfortable 3=mod comfortable 4=Very comfortable																							
6	Is the direct view of the luminaire comfortable (not glaring) for normal office tasks? 1=Very uncomfortable 2=mod uncomfortable 3=mod comfortable 4=very comfortable																							
7	Would you consider the luminaire's reflection in the computer screen to be a concern? 1=Reflection too bright 2=reflection mod bright 3=mod noticeable but not problematic 4=reflection not at all bright or not noticeable (Please comment if the luminaire reflection is dramatically different for the different laptop screens.)																							

Name:

The Olympic Athletes

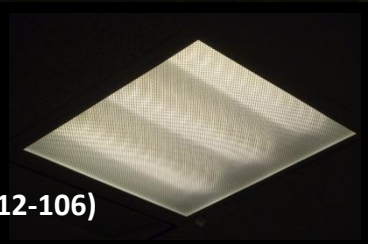

A (12-115)

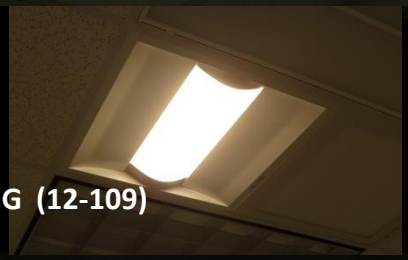

B (12-112)

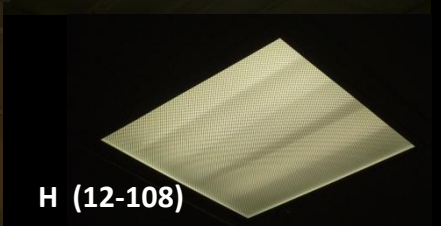

C (12-113)


D (12-136)


E (12-107)


F (12-106)

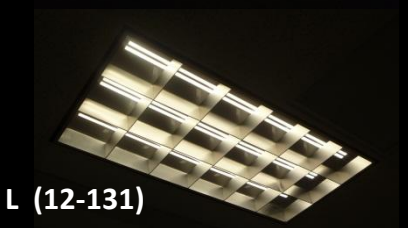

G (12-109)


H (12-108)


I (BK-12-132)

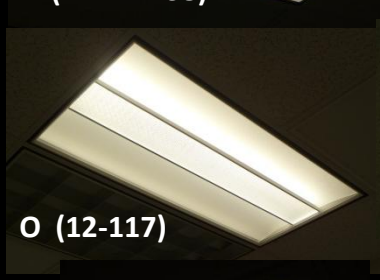

J (BK-12-133)


K (BK-12-138)


L (12-131)

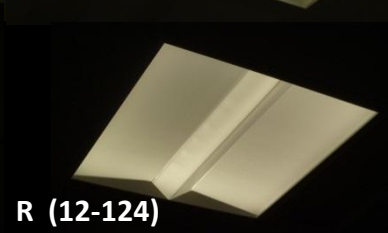

M (12-119)

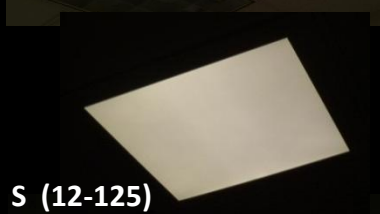

N (12-120)


O (12-117)


P (12-118)

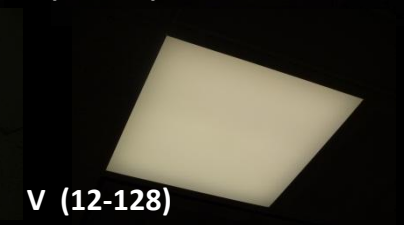

Q (12-123)

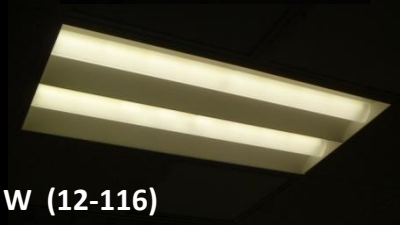

R (12-124)


S (12-125)


T (12-126)


U (12-127)


V (12-128)


W (12-116)


X (12-122)

CALiPER Athletic Events

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

- 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

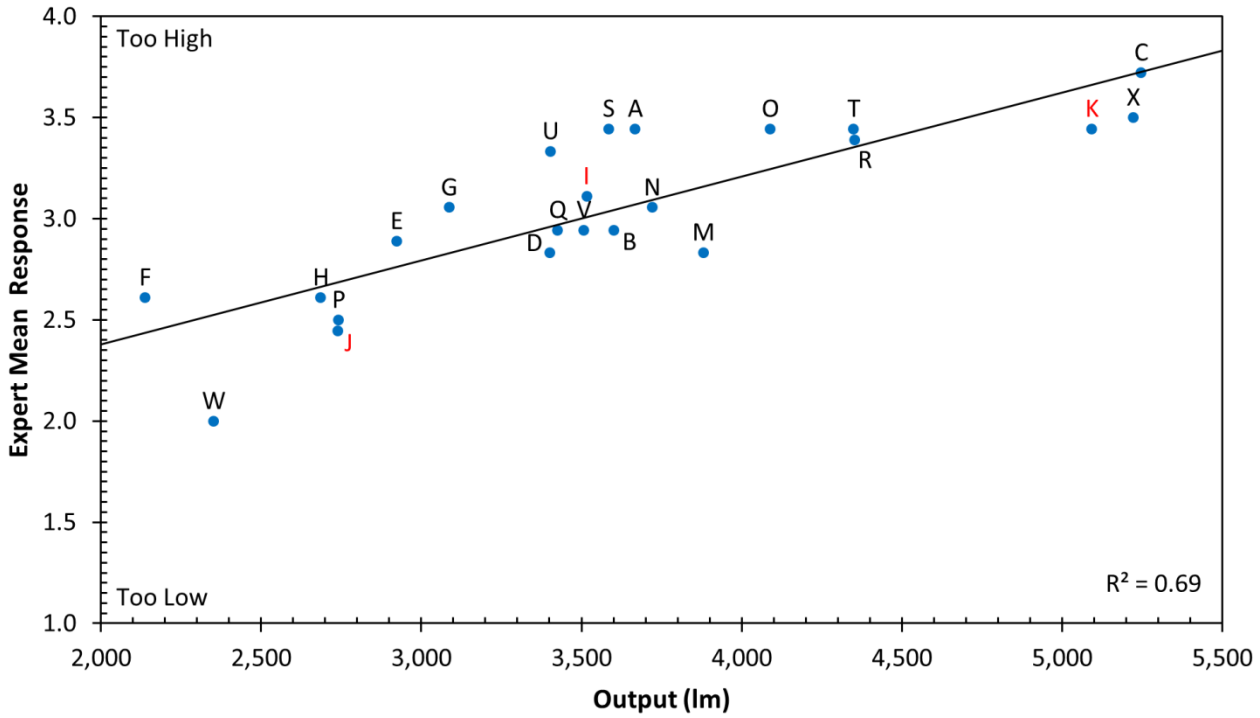
Energy use – Luminaire watts

- If you're not careful, LED retrofit tubes may not alter 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

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

** One especially poor LED troffer brought the averages down!*

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

Dimmable Luminaire Tag	% light output at minimum dimming level
E	4.2%
G	10.9%
H	10.2%
I	5.5%
J	9.2%
K	4.1%
L	18.5%
M	3.6%
N	10.8%
P	6.6%
Q	0.4%
R	11.5%
S	13.2%
T	11.5%
U	0.0%
V	4.9%
W	9.1%
X	4.0%

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M	3.6%
N	10.8%
P	6.6%
Q	0.4%
R	11.5%
S	13.2%
T	11.5%
U	0.0%
V	4.9%
W	9.1%
X	4.0%

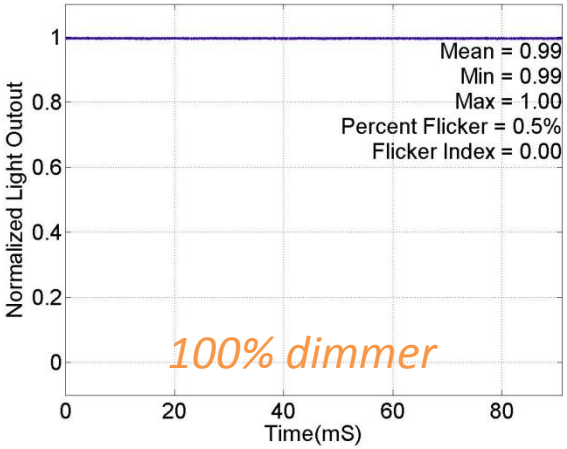
Results

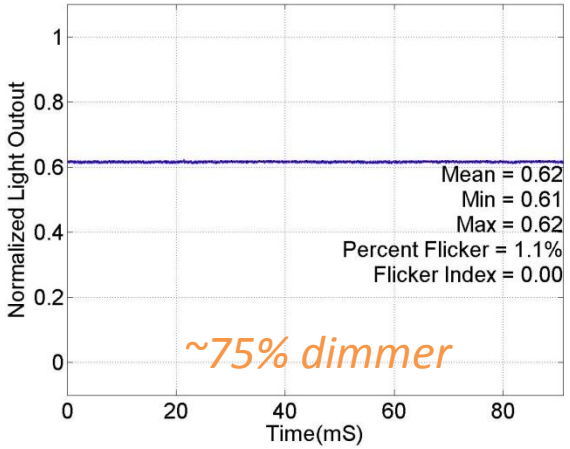
Flicker

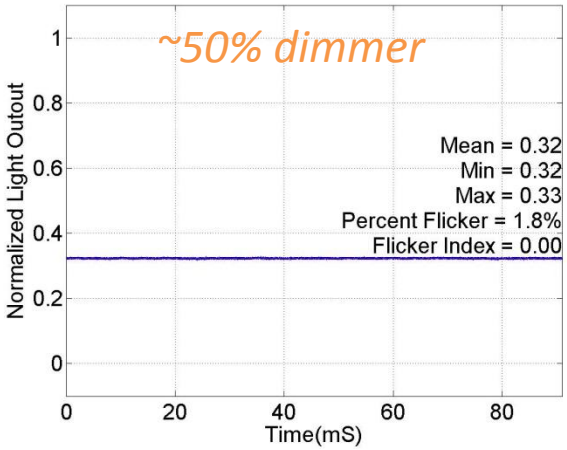
- Fluorescent – High frequency electronic dimming ballasts – no perceivable flicker
- LED – Dimming drivers at full – Little perceivable flicker
- LED – Dimming drivers at low – about 1/3 exhibited perceivable flicker, both kits and dedicated LED troffers

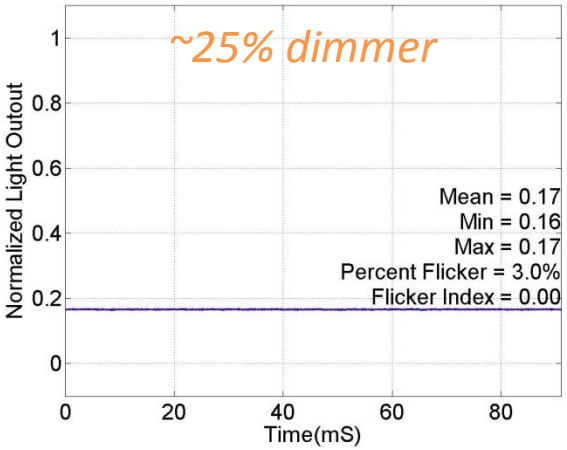
Fluorescent Troffer using Advance IZT-2S32-SC 2-lamp electronic ballast, 0-10V Dimming

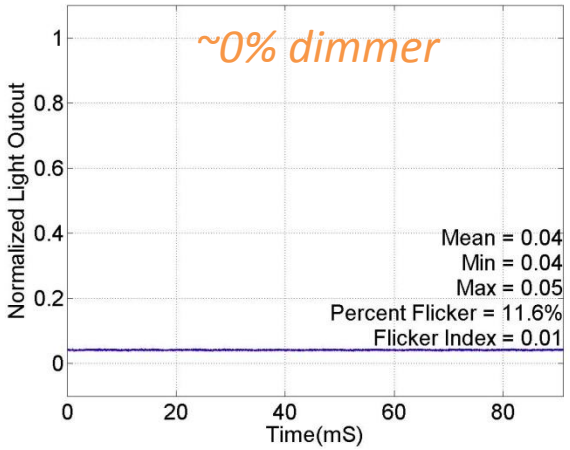
No Switch

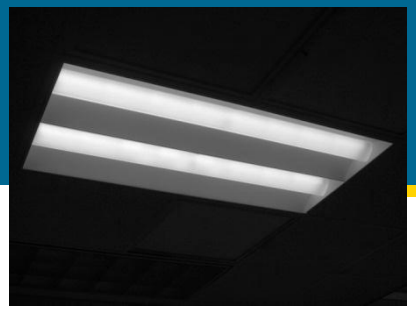




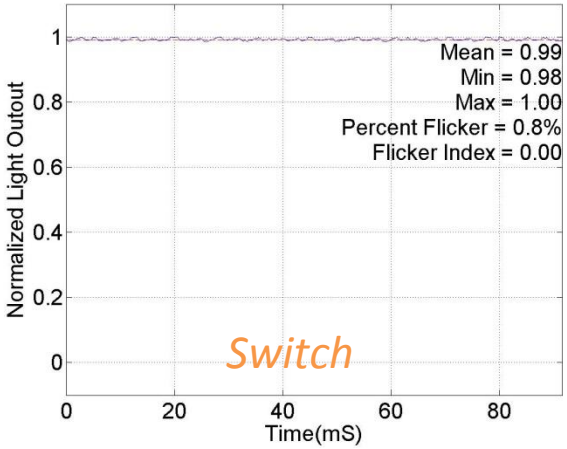


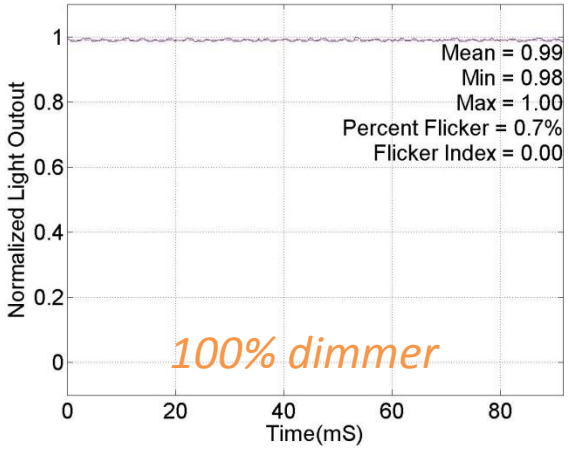


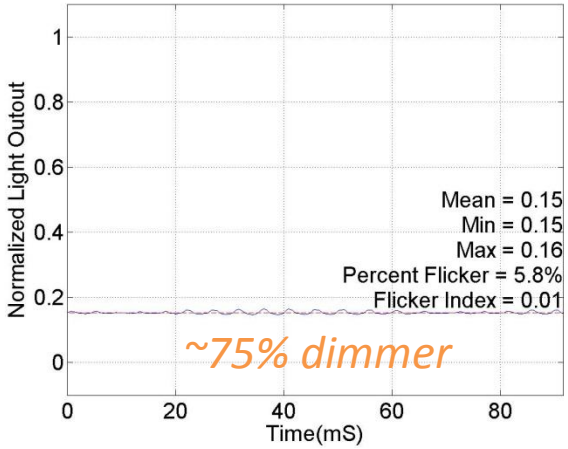


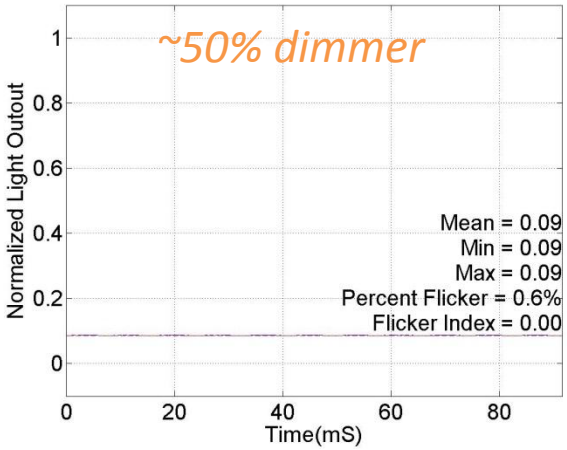


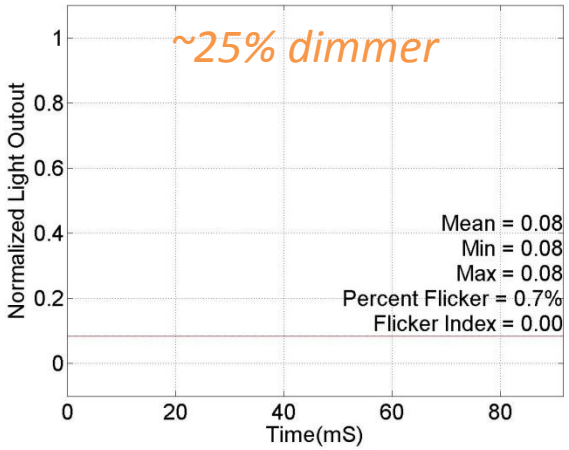
W (12-116), LED troffer

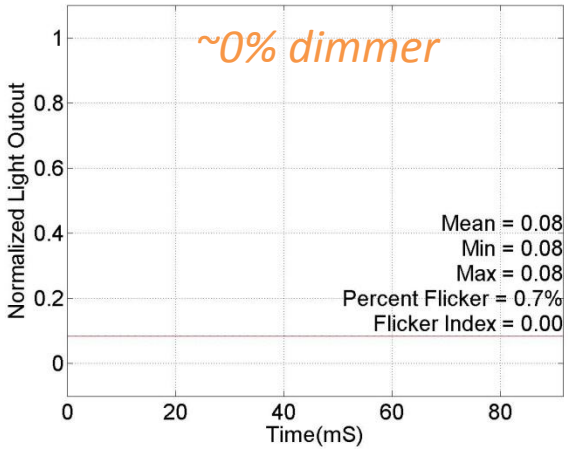




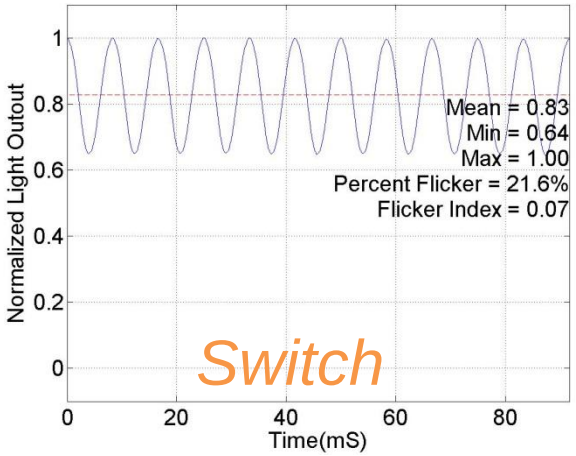


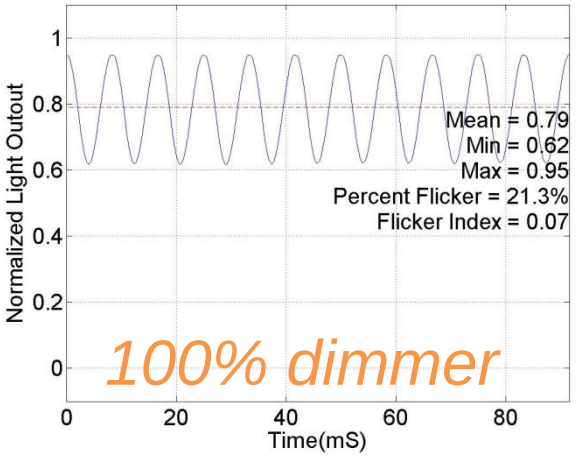


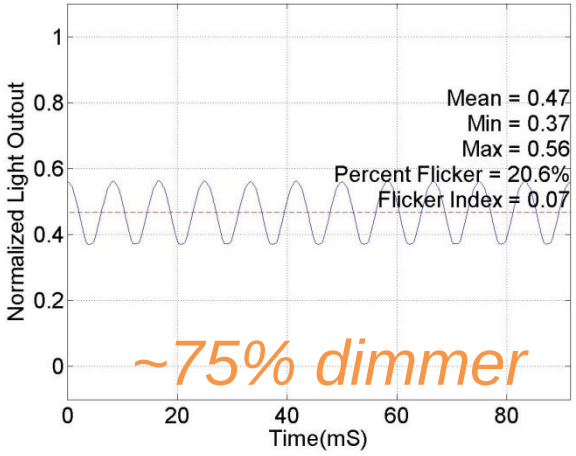


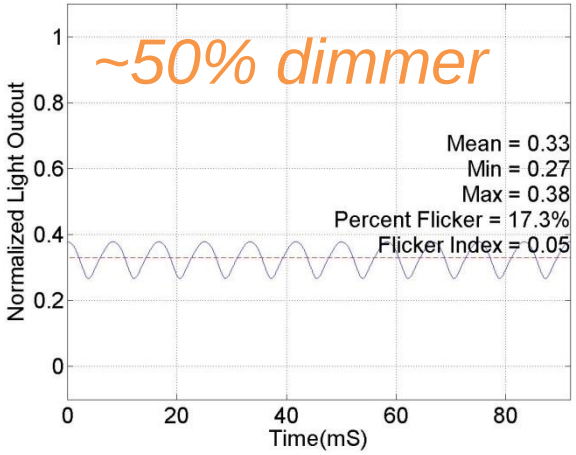


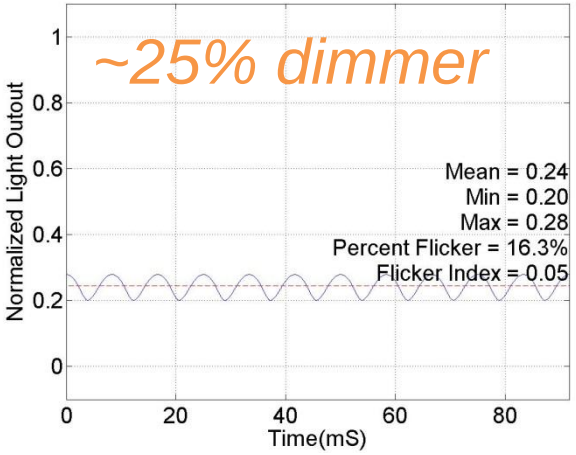
L (12-131) LED tube

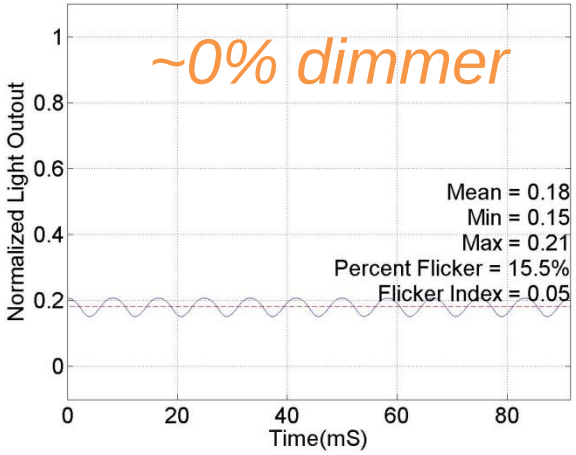




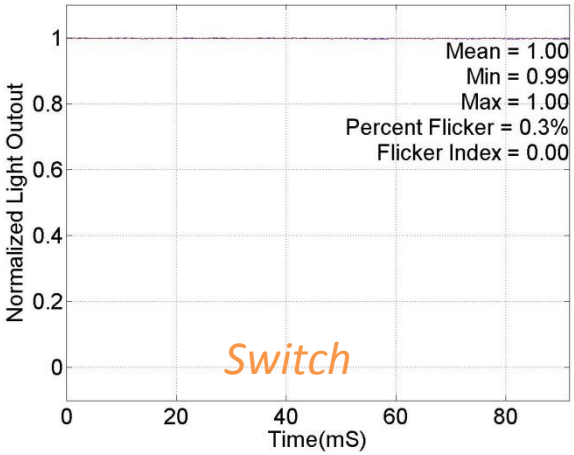


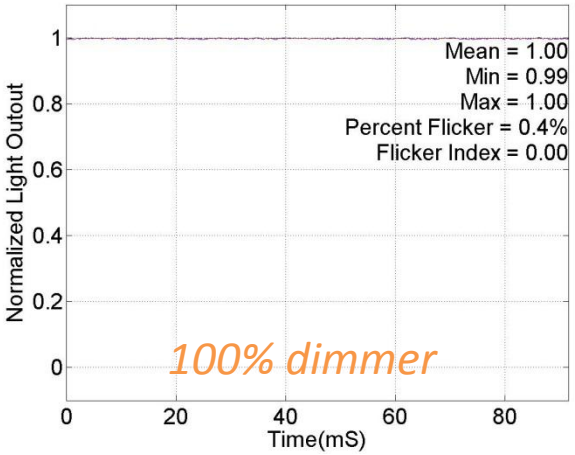


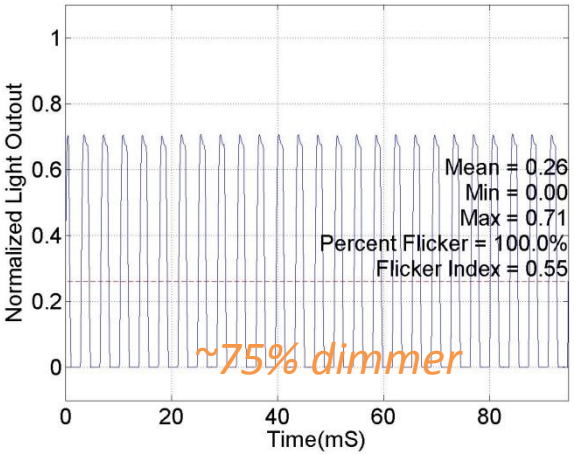


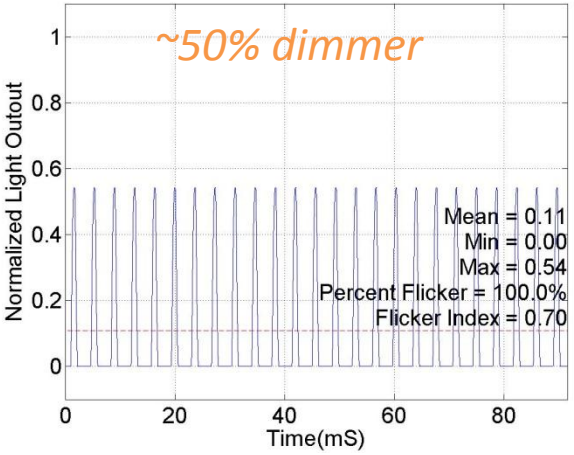


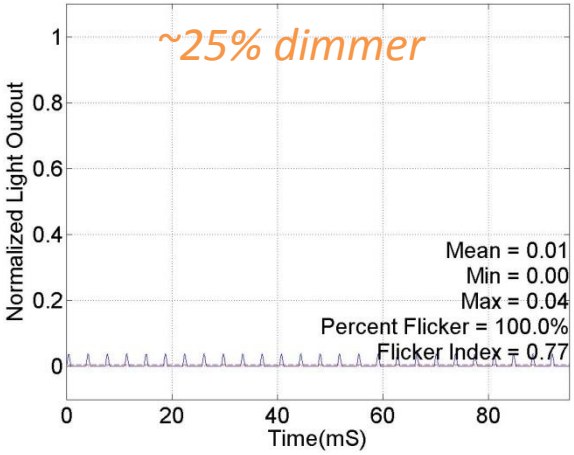
E (12-107), LED retrofit kit

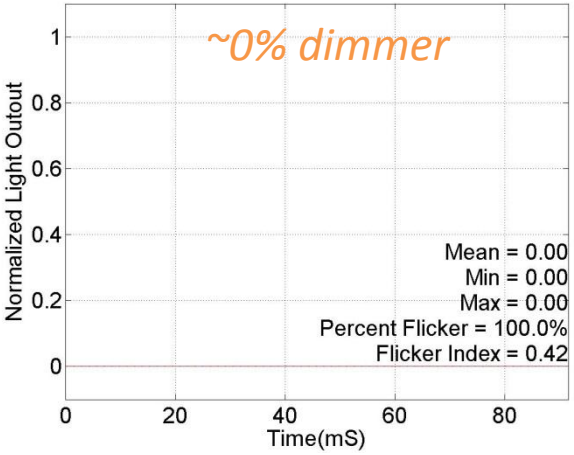




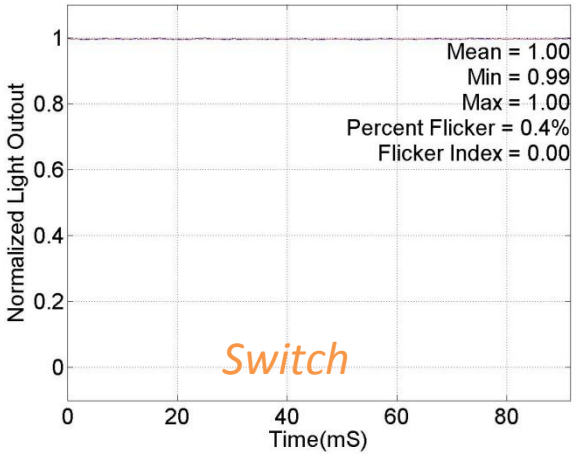


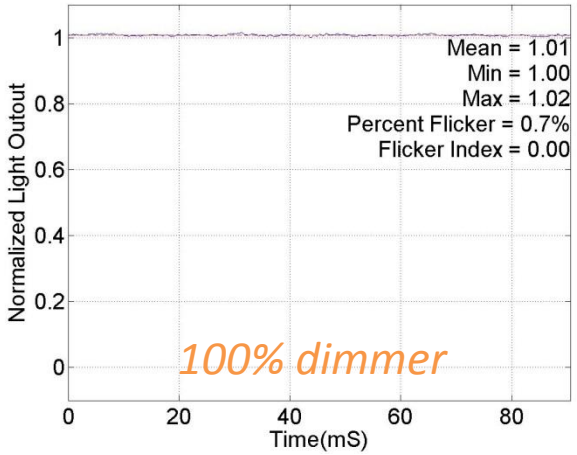


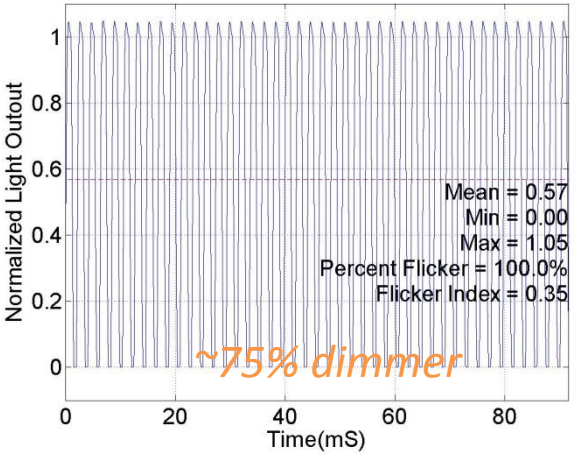


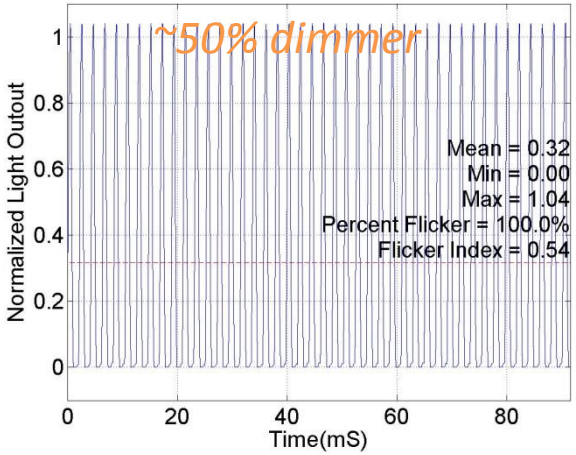


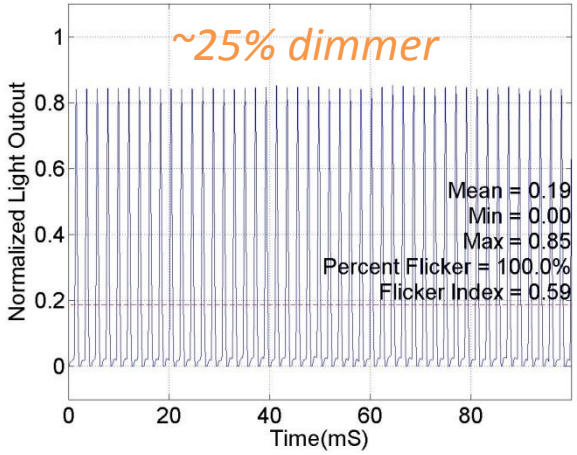
M (12-119), LED troffer

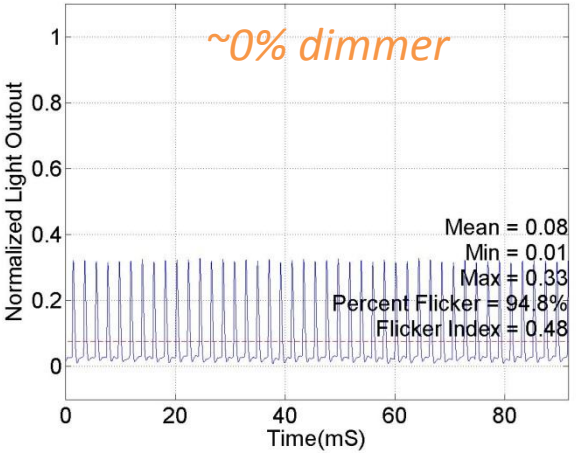












Results

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

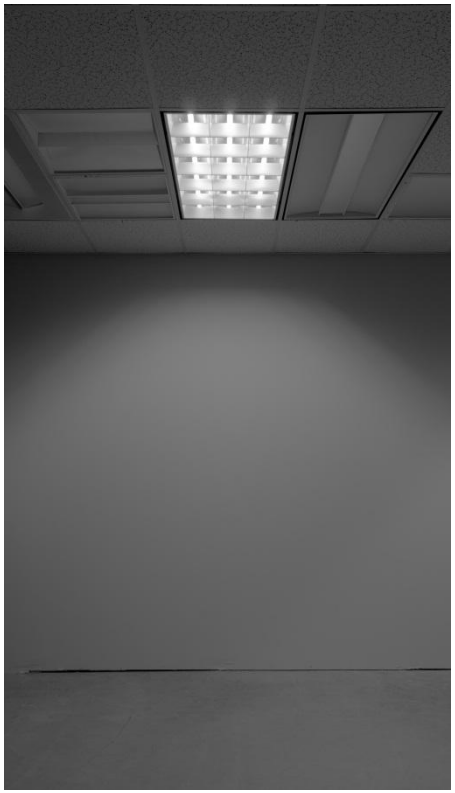
- See an LED product before ordering it
- Use a flicker wheel or wave a pencil to test for flicker

Results

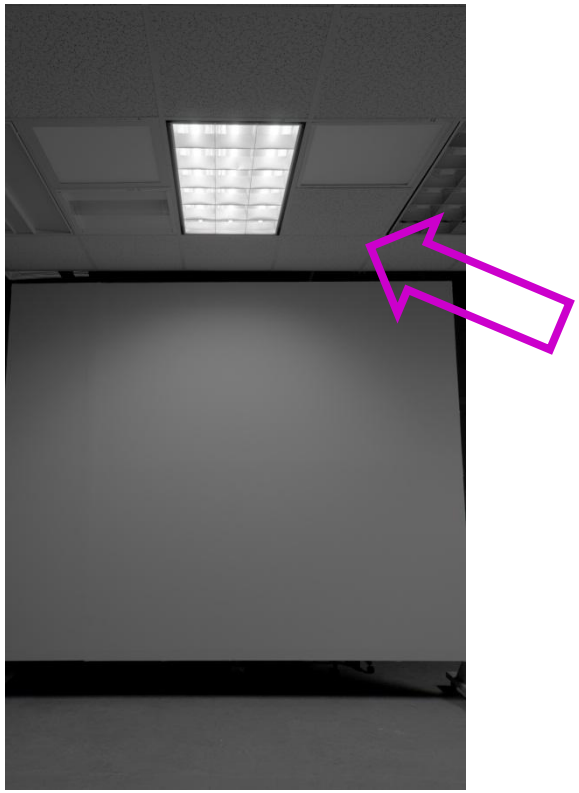
Light patterns produced on adjacent walls

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

B (LED Tube)



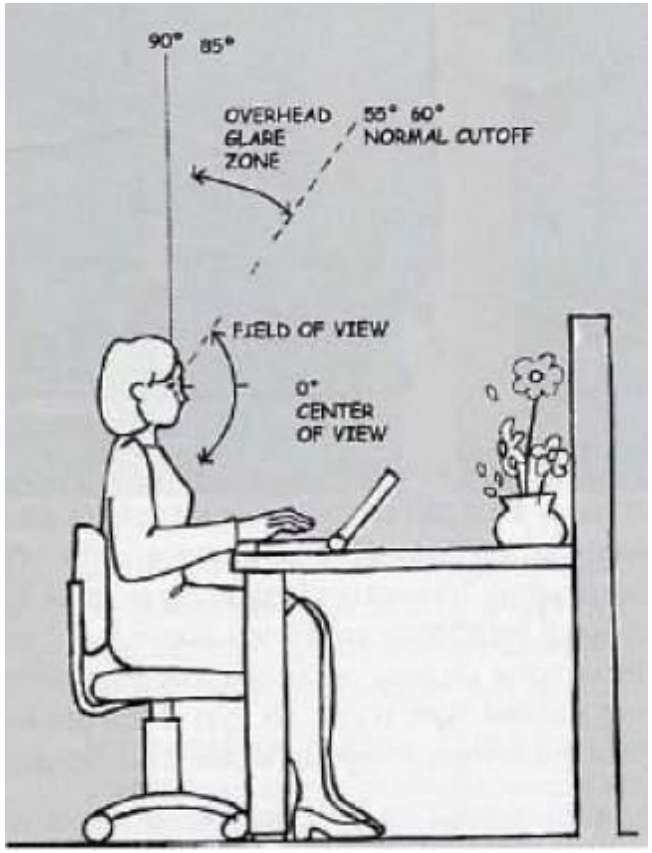
D (LED Tube)

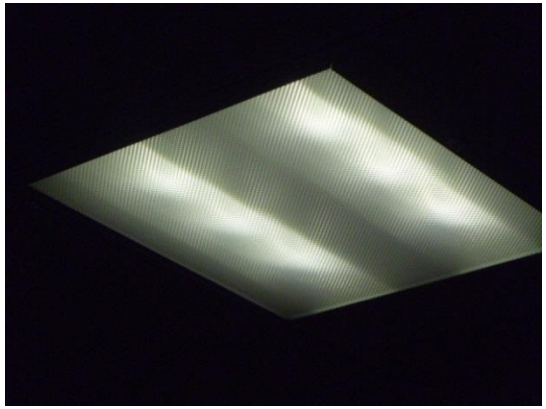


K (T8 Fluor.Tube)

Overhead glare

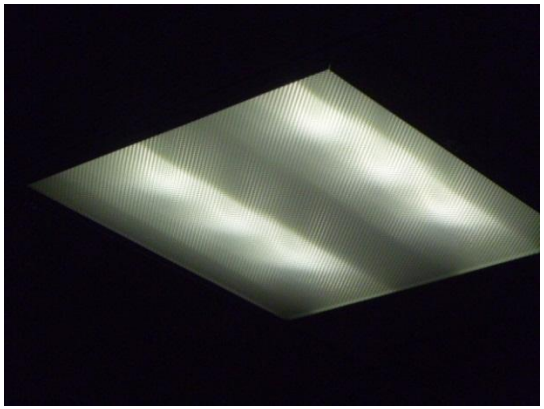
- Max spot luminances measured at 10˚ from vertical
- Luminances > 20,000 cd/m^2 rated as uncomfortable





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

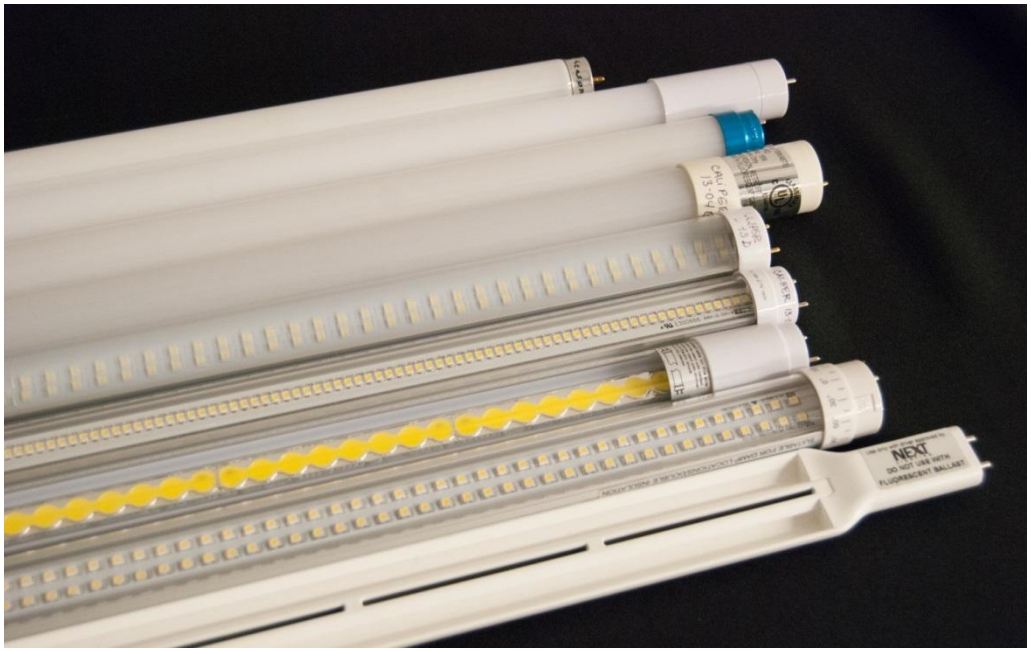
Electrical safety

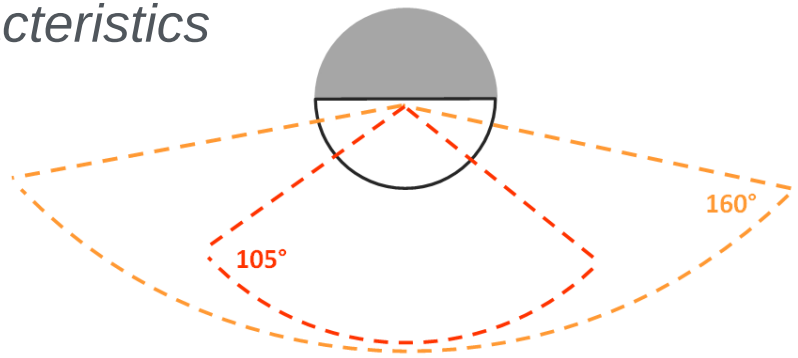
- Retrofit of troffers with tubes or kits
  - Labels!
  - Differences in wiring of LED tubes and sockets
  - Limited to no interchangeability
  - LED tubes must be NRTL approved and comply with UL1598C and UL1993 standard.
  - LED kits must be NRTL approved and comply with UL1598C.
  - Retrofit product 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

T8 LEDs: Easy Retrofit Solution?

Options in LED T8 lamps:

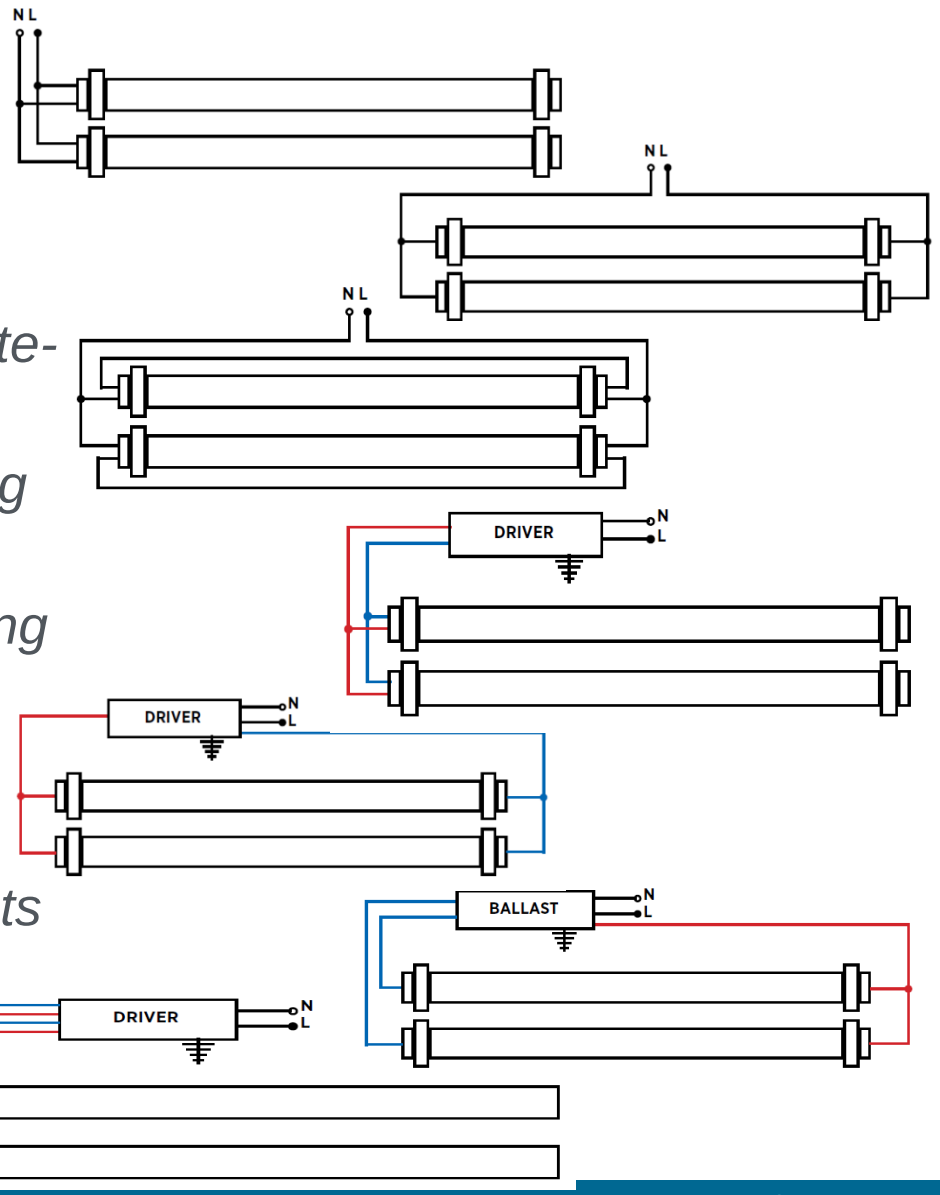
- *Beam angle*
  - *Narrow (102˚ to 115˚)*
  - *Medium (116˚ to 130˚)*
  - *Wide (131˚ to 159˚)*
- *Aperture finish (clear/striated/diffuse)*
- *Remote phosphor*
- *Color variations (CCT, CRI, R9)*
- *Dimmability (only 2 out of 35)*
- *Rotatable ends*
- *Wiring/electrical characteristics*





T8 LEDs: Easy Retrofit Solution?

1. *Line voltage single end wired (**)*
2. *Line voltage double end wired (*)*
3. *Line voltage double end wired with additional wire between two opposite-end pins (**)*
4. *Remote driver with single-end wiring (**)*
5. *Remote driver with double-end wiring (*)*
6. *Operates with existing instant-start fluorescent ballast and sockets (*)*
7. *Operates without fluorescent sockets*



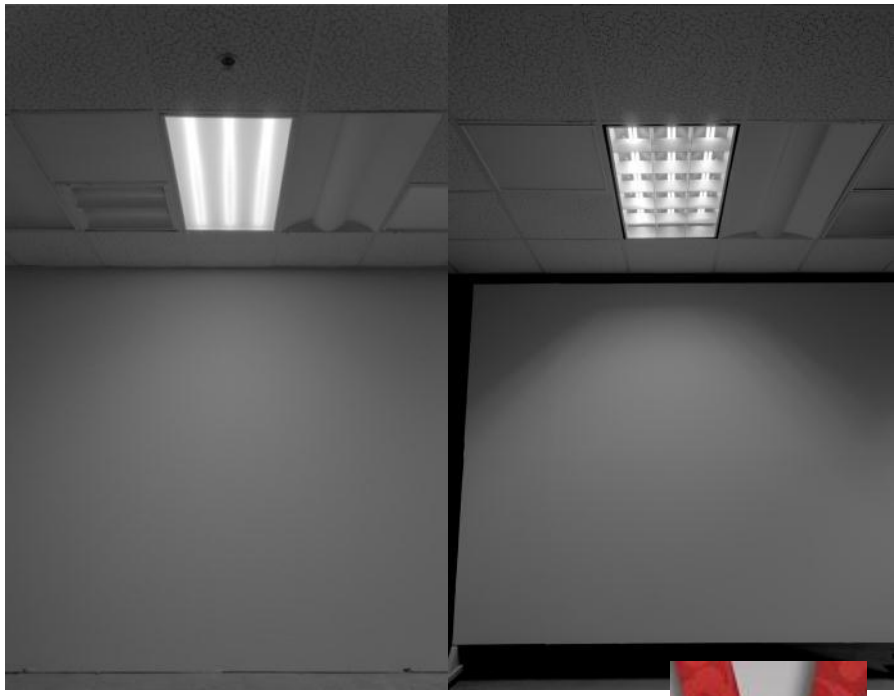
* *Instant-start or shunted sockets req'd*

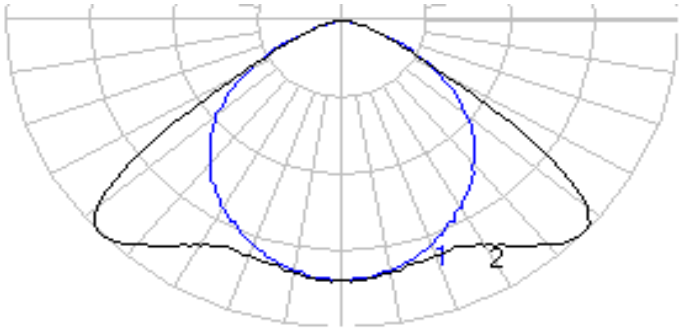
** *Rapid-start or unshunted sockets req'd*

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
- 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

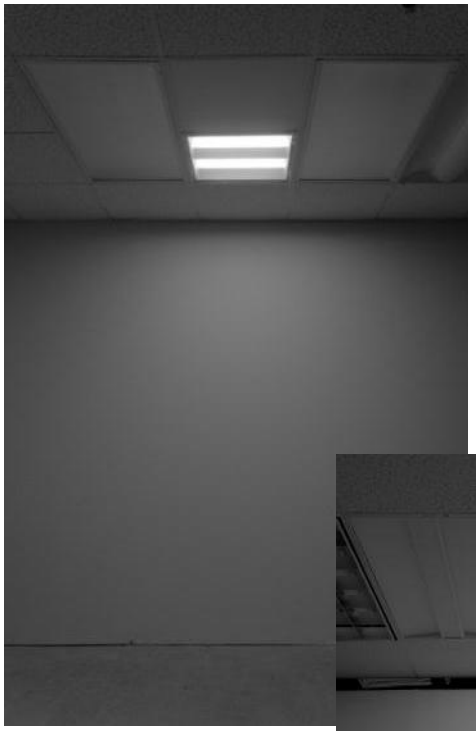


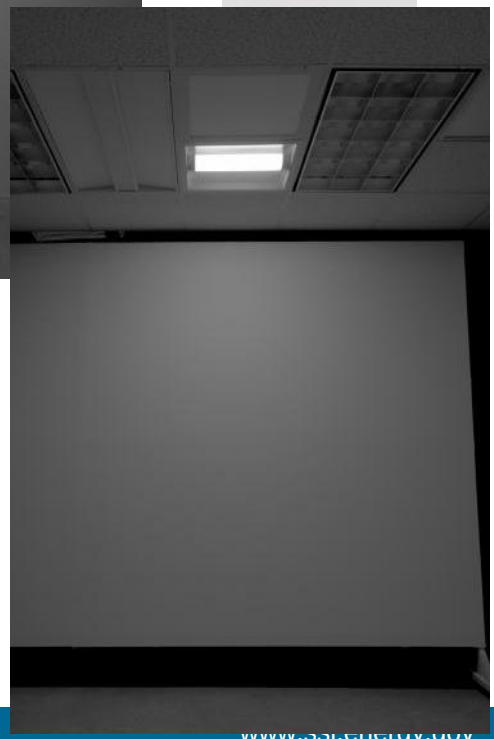


What did we learn?

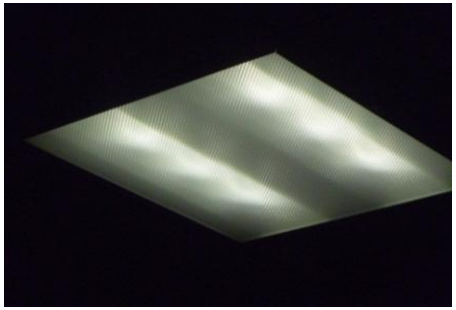
Wide range of quality in LED troffer kits

- LED kits 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 promised. Look for LPW of 90+
- Dramatic brightness patterns on lenses can be very distracting (AND glaring) from some LED products
- Color ranges all over the map, but most products are as good or better than FL
- 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

T8 LEDs: Easy Retrofit Solution?

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

Here's a handy guide:
(Google DOE…Upgrading…Troffer…

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

Building Technologies Office
SOLID-STATE LIGHTING TECHNOLOGY FACT SHEET

Upgrading Troffer Luminaires to LED

Lighting accounts for roughly 20% of the electricity use in a typical commercial building, and the workhorse in these indoor applications has been the linear fluorescent lamp. In 2010, lighting systems using linear fluorescent lamps accounted for over 75% of the lighting service in commercial buildings. Recessed troffer luminaires, commonly available in 1' × 4', 2' × 4', and 2' × 2' sizes, provide the majority of this lighting. The total installed stock of common linear fluorescent luminaires in the United States is estimated to be over 960 million luminaires.[1]

Although the installation of LED troffer-style luminaires jumped from an estimated 40,000 units in 2010 to nearly 700,000 units in 2012, LED luminaires still represent less than 0.1% of the troffer luminaires installed in commercial buildings. It may be possible to achieve over 25% energy savings on a national level if LED technology reaches its projected market penetration in troffer luminaires of over 65% by 2030. The energy savings on an individual project can be much greater than 25%. The related economic and environmental benefits are substantial.[2]

Introduction

Three primary LED options exist for upgrading lighting systems that use fluorescent troffers: replacing the fluorescent lamps with LED replacement lamps, replacing the fluorescent lamps and other luminaire components with an LED retrofit kit, and replacing the fluorescent luminaires with new luminaires designed for LED light sources. Selecting the best option for an installation depends on the current lamp and ballast types and the condition of the fluorescent troffer luminaires, the desired photometric properties of the upgraded lighting system, the accessibility of the ceiling plenum, and the initial and ongoing economic goals for the upgrade. This fact sheet provides guidance on the various factors to consider when deciding on an LED upgrade for a fluorescent system.

System Factors to Consider

An evaluation of LED upgrade options includes assessing the system costs and the impacts on the lighting system performance. Table 1 summarizes a number of the key factors, and the accompanying text explains those factors. The column heading *Lamps* refers to LED replacement lamps; the heading *Kits* refers to LED retrofit kits; and the heading *Luminaires* refers to new LED luminaires. For each of the three LED upgrade options, the table provides a color-coded identification of whether a factor is favorable for the related LED option (green circle), whether there may be reasons to exercise caution based on this factor (yellow triangle), or whether there may be significant barriers to implementing the related LED option based on this factor (red square). *Note that the performance of the products available within each of the LED options varies and each individual product must be evaluated on its own merits.*

1 "Energy Savings Potential of Solid-State Lighting in General Illumination Applications", Navigant, January 2012, http://appst.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_energy-savings-report_jan-2012.pdf.
2 "Adoption of Light-Emitting Diodes in Common Lighting Applications", Navigant, April 2013, http://appst.eere.energy.gov/buildings/publications/pdfs/ssl/led-adoption-report_2013.pdf.

Initial Costs

Equipment Purchase Costs

LED replacement lamps often provide the lowest cost option in terms of purchasing the LED components. The cost of LED retrofit kits is usually more than replacement lamps, and purchasing new LED luminaires usually is the highest cost.

Installation Labor Costs

Replacement lamps that simply snap into the existing fluorescent lamp sockets provide the lowest labor costs for installation. However, most products marketed as replacement lamps require further modifications to the luminaire, and will have labor costs similar to products marketed as retrofit kits. Labor costs for installing retrofit kits are generally higher than those for replacement lamps, and depending on the extent of the luminaire modifications required, may approach or even exceed the labor

Table 1. System factors to consider for LED upgrades.

SYSTEM FACTORS TO CONSIDER	DESCRIPTION	LAMPS	KITS	LUMINAIRES
Initial costs	Equipment purchase costs	●	▲	■
	Installation labor costs	●	▲	■
	Safety certification costs	▲	▲	●
Operating costs	Energy costs for equal light output	■	▲	●
	Replacement costs over system life	▲	▲	▲
Current light levels	Acceptable; should not be reduced at all	▲	▲	▲
	Reductions of 10% or more are okay	●	●	●
Dimming required	No, dimming is not required	●	●	●
	Yes, dimming is required	■	▲	▲

Training for the next competition

Better Buildings Alliance – LED Troffer specification

- Target minimum luminaire efficacy of 85 LPW
- 5 year warranty
- PF>.90 THD <20%
- Driver efficiency >80% for <50W
- Minimum luminaire lumens:
  - 1 × 4 - 1,500 initial lumens
  - 2 × 2 - 2,000 initial lumens
  - 2 × 4 - 3,000 initial lumens
- Minimum SC of 1.0-2.0 in both planes
- CRI >80 with R_9 >0
- Lumen maintenance >77.4% @ 36,000 hours

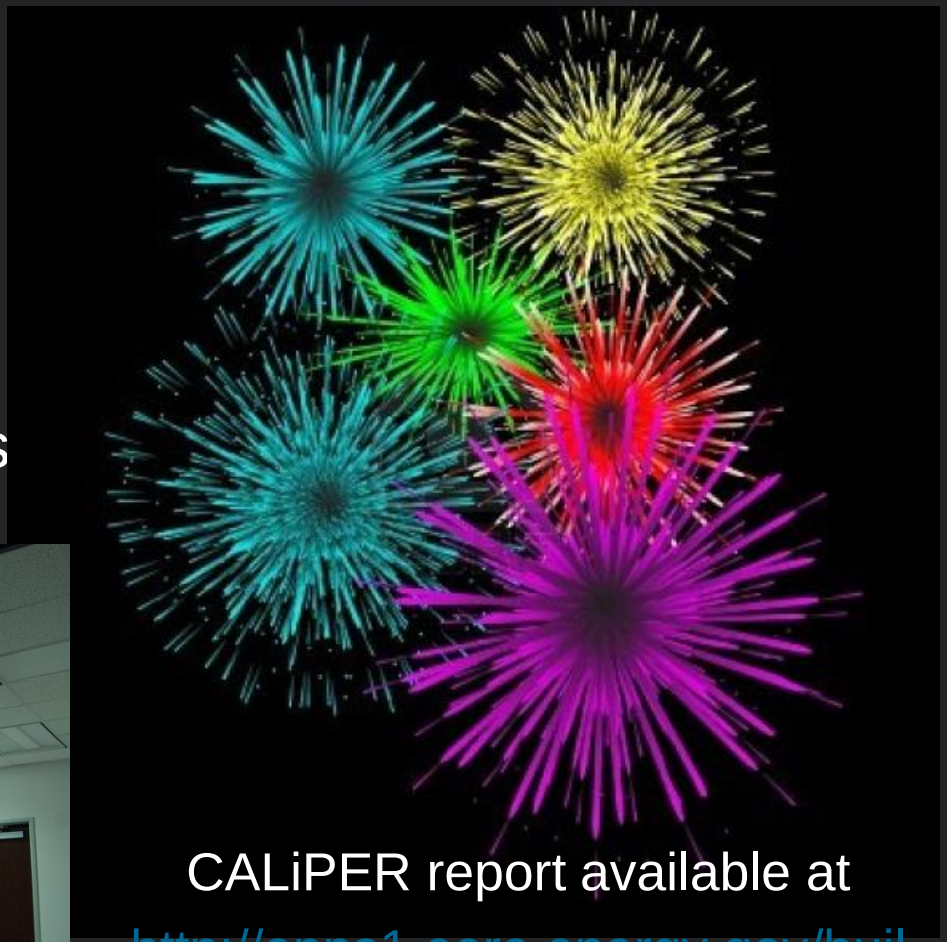
BBA spec available at:

http://apps1.eere.energy.gov/buildings/publications/pdfs/alliances/high_efficiency_troffers_spec.pdf

Closing ceremonies…..

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

– conclusion from the judges



CALiPER report available at

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

READY FOR PESKY QUESTIONS

http://www1.eere.energy.gov/buildings/ssl/m/caliper.html

Naomi . Miller @ PNNL . gov