LED Replacements for Four-Foot Linear Fluorescent Lamps

Linear fluorescent lamps are widely used in commercial spaces such as offices, schools, hospitals, and stores. Vendors of LED linear replacement lamps claim energy savings and long lifetimes, but testing of currently available products to date does not support these claims. This factsheet compares LED linear replacement lamps to fluorescent lamps in terms of light output, distribution, color quality, energy efficiency, and cost-effectiveness.

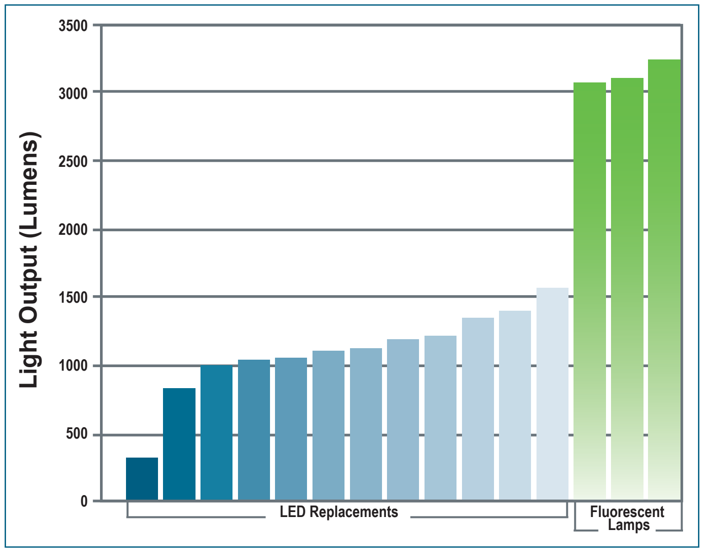

Figure 1: Measured light output (lumens) for four-foot LED and fluorescent lamps[2]

The most common linear fluorescent lamps are four-foot long, bi-pin tubular T12 and T8 lamps. Since their introduction in the 1980s, T8 lamps have largely supplanted less-efficient T12 lamps in new commercial and institutional applications. DOE's Commercially Available LED Product Evaluation and Reporting (CALiPER) program has benchmark-tested linear fluorescent products and linear LED replacement lamps. Tests were performed on bare lamps and complete two-lamp lensed and parabolic louver troffers. These tests showed the linear LED lamps did not match fluorescent lamps' light output, light distribution when used in a fixture, or luminaire efficacy.

In addition, the fluorescent and LED products were measured for color attributes: correlated color temperature (CCT) indicates the color appearance of a light source, and color rendering index (CRI) is a measure of how colors look under the light source compared to a reference source (maximum score is 100). For general lighting applications, U.S. buyers of linear fluorescent tubes tend to prefer neutral-colored light, which ranges from "warm" light of about 3000 Kelvin (K) to "cool" light of about 4100 K. Several of the LED replacement lamps tested exhibited very cool (>5000 K) CCTs, but most had CCTs below 4000 K. Most of the LED lamps had CRIs approximating those of lower-quality fluorescent lamps, with CRIs in the 70s.[1]

Light Output of Four-Foot LED Replacements vs. Linear Fluorescent Lamps

To establish performance benchmarks, CALiPER tested representative four-foot T8 and T12 fluorescent lamps and tested a variety of LED linear replacement lamps. Average initial bare lamp light output of the LED replacement lamps was about one-third the average for the fluorescent lamps. As shown in Figure 1, the disparity between the LED and fluorescent lamps' measured light output is one of the biggest challenges with LED replacement lamps. Currently-available LED linear replacement lamps do not come close to matching the measured light output of benchmarked fluorescent lamps. In these samples, the best-performing LED bare lamp produces only one-half the light output of a typical four-foot fluorescent lamp.

Linear Fluorescent Lamps and Troffer Fixtures

The second challenge to using LED replacements has to do with the optical design of linear fluorescent fixtures that are designed for fluorescent lamps' omnidirectional light output. Linear fluorescent lamps are omnidirectional sources and emit 360° of light. When these lamps are mounted in troffer fixtures, a portion of their total light output is directed back into the fixture.

[1] See CALiPER Round 5 and Round 9 summary reports for additional details: www.ssl.energy.gov.
[2] Source: CALiPER Performance of T12 and T8 Fluorescent Lamps and Troffers and LED Linear Replacement Lamps Benchmark Report (Jan 2009)

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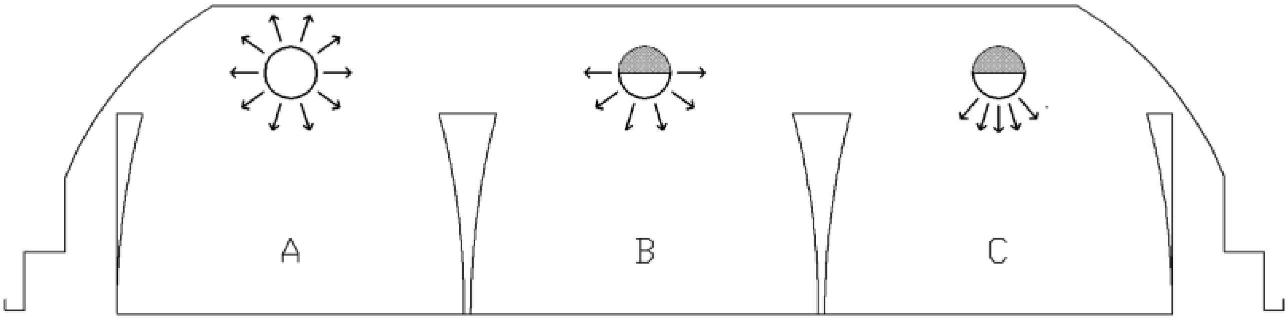


Figure 2: Cross section of three-lamp troffer fixture showing light distribution of a linear fluorescent (A) vs. LED replacement lamps (B and C)[3]

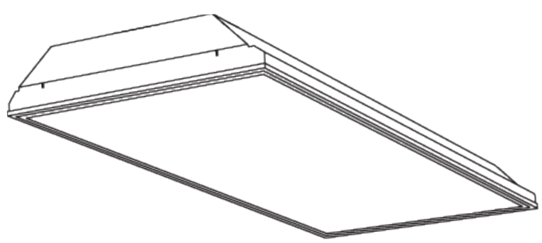
Many fluorescent troffer fixtures use reflectors to direct this back-light out of the troffer and then use parabolic louvers or lenses to shape and/or diffuse the light. Louvers and lenses also shield the lamps from direct view and reduce glare. All these fixture design factors affect the *percentage* of light that actually makes it out of a fixture, or *fixture efficiency*. Fixture efficiency directly affects *luminaire efficacy*, which is the total delivered lumens per watt of input power (expressed in lm/W).

Figure 2 illustrates how the directionality of a light source may affect a fixture's efficiency. Lamp A represents a typical linear fluorescent lamp, such as a T8 or T12; lamps B and C illustrate LED replacement lamps' more directional output. Little to none of the LED replacement lamps' light is directed back into the fixture which means that LED lamps do not take advantage of the troffer's optical elements that reflect, shape, spread and diffuse light across a large area. Both lensed and parabolic louver troffers are designed to spread their light output in varying ways to enhance illumination uniformity. Fixtures using LED lamps will have higher fixture efficiencies than fluorescent lamps, as a higher percentage of the LED lamps' lumens are directed out of the fixture than are absorbed in fixture, but higher fixture efficiencies do not automatically translate to better light distribution or illumination.

Fixture Light Distribution and Resulting Illumination

Lensed troffers generally shape light in a *cosine* distribution (Figure 3), similar to the shape of a teardrop. CALiPER measured the different intensity distributions and calculated zonal lumen densities for lensed troffers lamped with fluorescent lamps versus lensed troffers lamped with LED linear replacements. The LED replacement lamps produce a similar shaped (but narrower) distribution than T12 fluorescent lamps in the lensed troffer—with significantly lower luminous intensity.

Parabolic louver troffers are designed to gather light from an omnidirectional source and redirect it to form a *batwing* distribution (Figure 4). When LED lamps were tested in a parabolic louver troffer, they failed to produce the luminous intensity or desired batwing distribution provided by the benchmark T8 fluorescent lamps. A batwing distribution allows for a wider spacing of luminaires because the center intensity is lower than at the higher angles, creating more uniform lighting beneath the fixture. In contrast, a cosine distribution focuses the intensity below the fixture requiring more fixtures and closer spacing to achieve uniform illuminance.



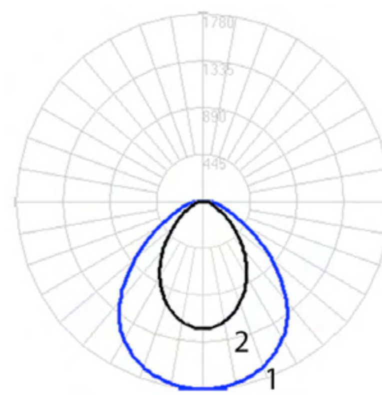
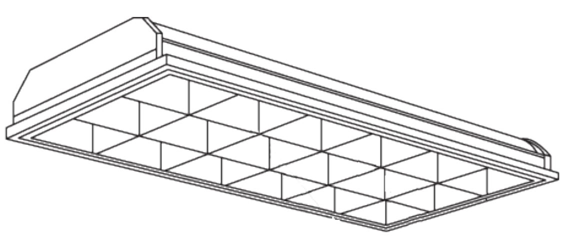


Figure 3: Lensed troffer construction (above) and measured luminous intensity distributions (right) with two four-foot T12 fluorescent lamps (Curve 1); LED replacements (Curve 2)[3]



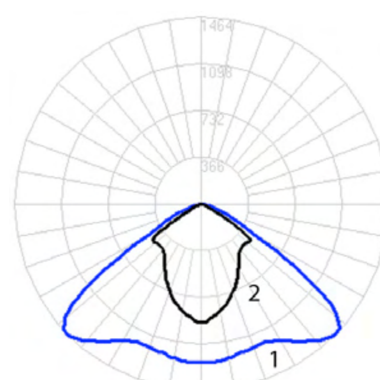


Figure 4: Parabolic troffer construction (above) and measured luminous intensity distribution (right) with two four-foot T8 fluorescent lamps (Curve 1); LED replacements (Curve 2)[3]

[3] Source: CALiPER Performance of T12 and T8 Fluorescent Lamps and Troffers and LED Linear Replacement Lamps Benchmark Report (Jan 2009)

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The narrower distribution evident in CALiPER test results for LED linear replacement lamps in retrofitted troffers will not provide the same light intensity or light distribution that fluorescent lamps create across a space. The illuminance directly below the fixture might be the same or even higher than under the fluorescent fixtures, but with the existing fixture spacing, the illuminance in the room will be much different, characterized by bright spots and dark areas between fixtures. To match the illuminance levels and uniformity of fluorescent lamps with LED replacement lamps in either lensed or parabolic louver troffers would require installing more fixtures, with closer spacing. Additional fixtures would result in increased cost and reduced or negated energy savings (see Table 2 for cost examples).

Table 1: Four-Foot Linear Fluorescent Lamps and LED Replacements in Lensed and Parabolic Louver Troffers

	Lensed Troffer		Parabolic Troffer	
	2 Fluorescent lamps (T12s)	2 LED lamps	2 Fluorescent lamps (T8s)	2 LED lamps
Total Power (watts)	88	36–80	58	36–47
Output (initial fixture lumens)	4453	613–2125	3675	597–2038
Fixture Efficiency	76%	83–89%	68%	74–86%
Luminaire Efficacy (lumens/watt)	51	17–43	63	17–43

Source: CALiPER Performance of T12 and T8 Fluorescent Lamps and Troffers and LED Linear Replacement Lamps Benchmark Report (Jan 2009)

As shown in Table 1, the CALiPER-tested fluorescent T12 lensed troffer had a fixture efficiency of 76% and a luminaire efficacy of 51 lumens per watt (lm/W). The CALiPER-tested fluorescent T8 parabolic louver troffer had a lower fixture efficiency of 68%. However, the T8 parabolic fixture uses higher-efficiency lamps and ballast, so it delivers a luminaire efficacy of 63 lm/W. Although fixture efficiency is higher with LEDs, fluorescent fixtures have higher light output and higher overall efficacy.

Color Characteristics (CCT and CRI)

The CCT values for some of the CALiPER-tested LED linear replacement lamps were considerably higher than the fluorescent benchmarks, exhibiting very-cool color appearance. Two of the LED products exceed industry norms for CCT (greater than 7000K). Further, many of the LED lamps have atypical chromaticities which give a non-white hue to the light, making it appear greenish or purplish. Fluorescent lamps have CRIs that range from 60 to more than 90; the measured CRI for linear LED replacement lamps ranged from 63 to 76. However, given the known problems with applying CRI to “white-light” LED products, users should visually evaluate LED replacement lamps to gauge their color quality for a given application.[6]

Electrical Modifications

Another important consideration with linear LED replacement lamps is how they interact with existing fluorescent ballasts. Some LED products are intended to operate with the existing ballast, but performance in these cases is unpredictable depending on the specific ballast. Ballast losses can be much higher than with fluorescent lamps. Other LED products bypass the existing ballast. Of four LED products initially tested by CALiPER, three required bypassing the existing fluorescent ballast to connect directly to a line-voltage circuit. This requires the ballast be disconnected by a licensed electrician, which adds additional labor costs to a retrofit installation. A fixture that is modified so it can no longer accept its original lamp has to have a label affixed (provided by the retrofit kit manufacturer) indicating the fixture has been modified and can no longer operate as originally intended.[7] Linear LED replacements may be certified under multiple product safety standards, addressing both the replacement lamp and the modified fixture. Purchasers should ask manufacturers and lamp vendors about their lamps’ compliance with safety standards or the UL status of their products.

Lifetime of Four-Foot LED Linear Replacements

LED lamp lifetime projections are generally based on the estimated hours for light output to reach 70% of initial output (i.e., L_{70}). Manufacturers commonly claim L_{70} lifetime values of 35,000 hours or more. They claim that this lifetime translates into fewer relamping cycles, which offsets the higher initial cost of LED products. Currently, no known field data is available to substantiate long-term performance claims of LED replacement lamps. Further, many LED linear replacement lamps use 5-mm “through hole” LEDs. With very few exceptions, 5-mm LEDs are not designed for general illumination applications or for long life. Fluorescent lamps on the market are rated and tested to have lifetimes that range from 24,000 to 42,000 hours, depending on switching frequency and the type of ballast used. In addition, fluorescent T8s have very high lumen maintenance—approximately 92% at end of life. CALiPER testing indicates that even the initial performance of linear LED replacements does not meet fluorescent benchmark performance—and the L_{70} life definition means output will decline by 30% over the LED lamp life.

[6] See the fact sheet “LED Measurement Series: Color Rendering Index and LEDs” for more information about tested LED lamps’ CRI performance results and recommendations for evaluating color characteristics of LEDs.

[7] See UL 1598, the Standard for Safety of Luminaires, Category IEUQ, Retrofit Luminaire Conversions. www.ul.com.

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Cost Effectiveness of LED Replacements

LED replacement lamp prices vary significantly. Recent prices have ranged from $50 to $150 per lamp. A fair cost analysis should compare linear LED replacements to linear fluorescent lamps on the basis of equivalent lighting performance. Table 2 below compares costs and performance of linear fluorescent and LED lamps under two scenarios. Both examples assume a 30’x30’ room lit by two-lamp parabolic troffer fixtures. Three different possible prices for the LED lamps are provided: $50, $100, and $150 per lamp.

Section A shows costs in lamps and fixtures alone (not including labor costs) to light the space to an average maintained illuminance of 35 footcandles (fc). Approximately 13 fluorescent fixtures would meet that illuminance requirement; using LED replacement lamps would require 2.5 times more fixtures to be added to the space. Lighting power density (LPD) would increase by more than 1.5 times and cost per square foot would be 4 to 8 times higher than with fluorescent. Payback period is infinite because there are no energy savings.

Section B shows the costs of retrofitting LED T8 lamps into an existing layout of 13 fixtures. Illuminance levels in the space drop to less than half of the fluorescent level. Energy use is lower, but not proportional to the loss of illuminance: LPD is 34% lower than with fluorescent, but illuminance levels drop by 59%. Cost per square foot is 17 to 50 times higher than with fluorescent lamps. Even if the drastic reduction in illuminance were accepted (which would run counter to IES recommended practice), the simple payback period for the LED T8 lamps would be 15 to 46 years.

Table 2: Fluorescent T8 Compared to LED T8 Replacement Lamps at 3 Example Unit Prices

Source	Fluor T8 $3 per lamp	LED $50 per lamp	LED $100 per lamp	LED $150 per lamp
Total Price (lamps+fixture)†	$131	$225	$325	$425
Input Power per Fixture (W)	58	39	39	39
Output per Fixture (lumens)	3675	1754	1754	1754
A. New Construction – Target maintained illuminance 35 fc, 900 square foot space				
Number of Fixtures	13	32	32	32
Cost per Sq Ft (lamps+fixtures)	$1.89	$8.00	$11.56	$15.11
Lighting power density (W/sf)	0.84	1.37	1.37	1.37
Simple payback period (years)	Infinite (no energy savings)			
B. Retrofit – 13 fixtures, 900 square foot space				
Avg Maintained Illuminance (fc)	34	14	14	14
Cost per Sq Ft (lamps only)	$0.09	$1.44	$2.89	$4.33
Lighting power density (W/sf)	0.84	0.56	0.56	0.56
Simple payback period (years)*		15	31	46

NOTE: Figures are rounded for legibility. LED output and wattage figures are averages of two LED T8 replacement lamps tested in Jun 2009. Luminaire outputs and efficacies for these products when measured in a 2’x4’ parabolic troffer were 1674 at 37 lm/W, and 1834 at 57 lm/W. Actual prices were $140 and $51 per lamp, respectively.

† Assumed fixture price $125; two-lamps per fixture. * Based on 3120 hours per year operation and $0.104 per kWh.

For recommended minimum performance specifications, see DOE fact sheet, “LED Performance Specification Series: LED T8 Replacements.”

Summary

LED linear replacement lamps available today do not compete with linear fluorescent lamps on the basis of light output, color quality, distribution, lumen maintenance, or cost-effectiveness. DOE does not recommend replacing linear fluorescent lamps with LED linear replacements.

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For Program Information:

Kelly Gordon
Pacific Northwest National Laboratory
Phone: (503) 417-7558
E-mail: kelly.gordon@pnl.gov

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