LED Retrofit Options for Linear Fluorescent Lighting

A review of the energy, luminous and cost performance of the three options for replacing fluorescent tubes with LEDs

BY KONSTANTINOS PAPAMICHAEL, NICOLE GRAEBER AND MICHAEL SIMINOVITCH

Tubular fluorescent lamps (TFLs) comprise 80 percent of the lamp inventory in the commercial sector, or about 1.7 billion lamps, according to a U.S. Department of Energy report. This represents a very large retrofit market opportunity, as the lighting industry moves rapidly toward solid-state lighting.

The LED retrofit options for a TFL luminaire fall into three main strategies:

1. Replace TFL lamps only with tubular LED (TLED) lamps.
2. Replace the whole TFL system with an LED retrofit kit.
3. Replace the whole luminaire with a new LED luminaire.

This article compares these strategic options in terms of energy, luminous and economic performance.

Energy Performance. The DOE's most recent CALiPER study of LED retrofit options for TFL luminaires shows significant luminous efficacy improvement over TFLs for all three LED retrofit options (**Figure 1**). New LED luminaires have significantly higher efficacy values than the other two LED product categories.

In addition to opportunities for higher luminous efficacy, LED retrofit options for TFL luminaires also present opportunities for increased energy savings and peak demand reduction through occupancy/vacancy, daylighting and demand response controls.

Luminous Performance. The total light output ranges for the LED product categories are similar to the luminous output range of the T8 fluorescent products tested, with the exception of the LED retrofit kits that were included in the study; these retrofit kits showed lower levels of total luminous flux (**Figure 1**).

Our experience indicates that the total lumen output of all LED replacement products sufficiently matches that of traditional TFLs and the efficacy of LED systems continues to improve through more efficacious LEDs and improved thermal management.

While the total luminous output of luminaires is adequate for computation of luminous efficacy, evaluating luminous performance requires consideration of spectral power distribution (SPD) and candlepower distribution (CPD) as well.

SPD shapes the correlated color temperature (CCT) and the color rendering index (CRI) of light sources. Options in all three LED retrofit categories are available in a wide range of CCT and CRI combinations with high CRI options available, at levels above 90. Light sources with CRI values below 90 significantly deprive us of realizing our full visual perception potential. LED retrofit options thus present an excellent opportunity to significantly improve the lighting experience in non-residential spaces.

CPD shapes illuminance and luminance distributions, which are most critical for luminous comfort. CPD performance is not as straightforward as SPD. The CPD of TFLs is very different from the CPD of LEDs—TFLs are omnidirectional area sources, while LEDs are unidirectional, point sources.

When replacing TFLs with TLEDs and replacing whole TFL systems with LED retrofit kits, the CPD will greatly depend on the optics of the existing luminaire and the CPD of the TLED option (**Figure 2**). TLEDs and LED retrofit kits often include optics, such as mirrors and diffusers, designed to improve both luminaire efficacy and CPD. New LED luminaires offer the highest opportunity for CPD control and the available options are designed to produce specific CPD patterns.

LED retrofits offer a unique opportunity to improve our understanding of how to manage light for appropriate illuminance and luminance distribution. In terms of illuminance, light on work surfaces is indeed important, but light on other interior surfaces is also important, as it shapes the luminance distributions arriving at the eye. In terms of luminance, direct light from LED sources can result in intense glare, as LEDs produce significantly more light per unit area than TFLs. TLEDs and LED retrofit kits may need to be combined with effective diffusing optics to reduce or eliminate glare from LED sources. New LED luminaires usually have well-designed optics that spread the light from individual LEDs over the whole output area of the luminaire.

Economic Performance. Parametric economic analyses were performed to better understand performance ranges for TFL luminaires and the three main LED retrofit options. The analyses focused on payback and life-cycle cost comparisons, considering minimum and maximum values to establish ranges for key parameters that affect economic performance (**Table 1**).

The simple payback analysis focused on retrofit options for a two-lamp TFL luminaire, considering low, medium and high electricity rates, ranging from $0.085/kWh to $0.196/kWh (**Figure 3**). Energy price tiers were defined based on California rates for 2013, as reported by CLTC's demonstration partners or the Energy Information Association.

Simple payback periods are very high for all three LED options, considering current practice. Equations used to determine "worst-case" and "best-case" scenarios for incremental simple payback are provided below, using conditions cus-

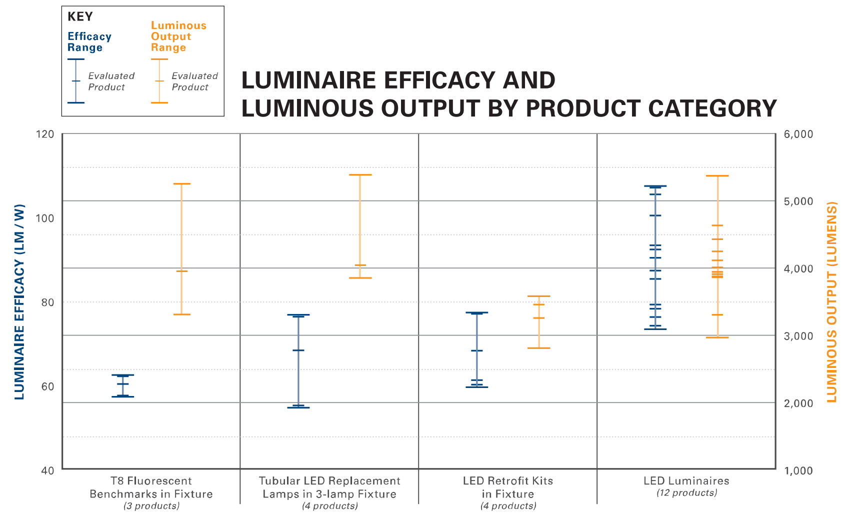

Figure 1.

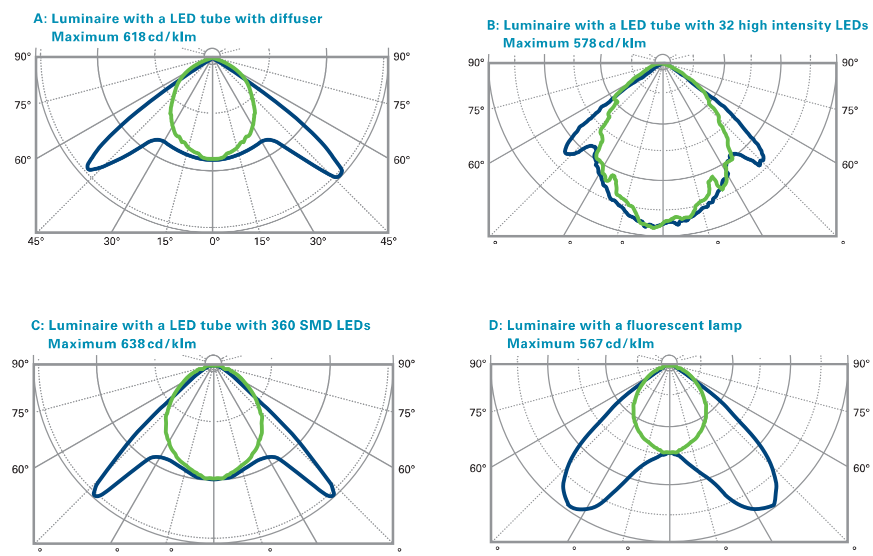

Figure 2.

ECONOMIC & PERFORMANCE VARIABLES FOR LED RETROFIT OPTIONS

2-TFL Equivalent	TFLs		TLED Lamps		LED Retrofit Kits		LED Luminaires	
	MIN.	MAX.	MIN.	MAX.	MIN.	MAX.	MIN.	MAX.
Product Cost ($/luminaire)	$4	$16	$92	$120	$140	$265	$150	$400
Installation Cost ($/luminaire)	$6	$19	$13	$38	$50	$88	$31	$56
Installation Time (hours)	0.08	0.25	0.17	0.50	0.67	1.17	0.42	0.75
Luminaire Power (W)	54	63	48	52	35	51	26	52
Luminaire Luminous Output (lm)	3,395	3,516	3,402	3,667	2,138	3,088	2,352	4,089

Table 1.

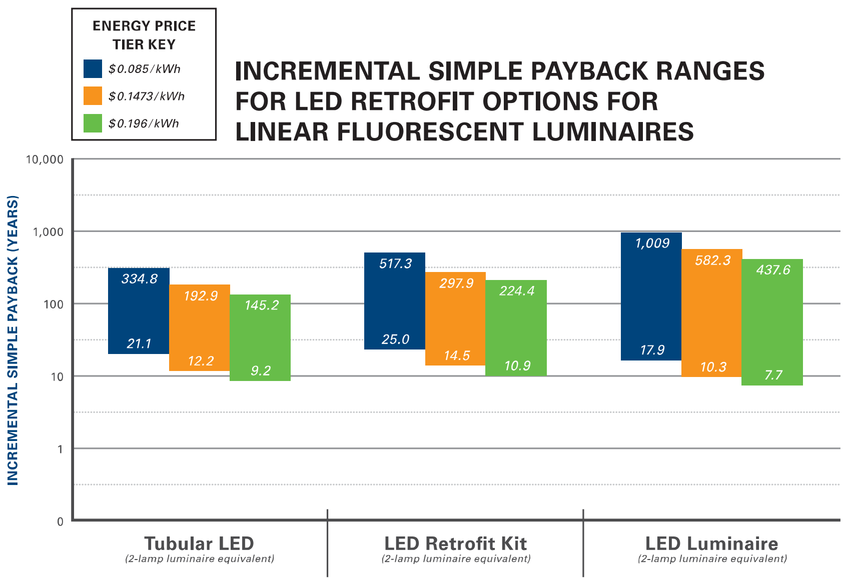

Figure 3. LED replacements for linear fluorescent lighting currently fall into three main product categories: tubular LED replacement lamps, retrofit kits and dedicated LED luminaires.

PAYBACK SCENARIOS

$$\text{Incremental Simple Payback}_{\text{Worst Case Scenario}} = \frac{\text{First Cost}_{\text{LED Max}} - \text{First Cost}_{\text{TFL Min}}}{\text{Energy Cost}_{\text{TFL Min}} - \text{Energy Cost}_{\text{LED Max}}}$$

$$\text{Incremental Simple Payback}_{\text{Best Case Scenario}} = \frac{\text{First Cost}_{\text{LED Min}} - \text{First Cost}_{\text{TFL Max}}}{\text{Energy Cost}_{\text{TFL Max}} - \text{Energy Cost}_{\text{LED Min}}}$$

EQ 1.

tomers could potentially encounter when retrofitting with these products (**see Equation, bottom left**).

Life-cycle cost comparisons were made for one-lamp and three-lamp luminaires for TFLs and TLEDs, and two-lamp luminaires for TFLs and all three LED retrofit options. This cost comparison reflects initial product costs, installation costs, and energy costs over the life of the products (25,000 operating hours for TFLs and 50,000 operating hours for the LED retrofit options).

The analyses focused on extreme "best-case" and "worst-case" cost scenarios, considering minima and maxima value combinations for key variables affecting economic performance (**Table 1**). These extreme values are unlikely to occur in real-world retrofit scenarios; most cases will fall between these low and high ends of the cost ranges in **Figure 4**.

The results for three-lamp luminaires show lower life-cycle cost for TLEDs than for TFLs. The same is true for the one-lamp luminaires, but with life-cycle costs being much closer for TFLs and TLEDs.

OTHER PERFORMANCE ISSUES

Thermal Management. As the light output and life of LEDs depends strongly on operating temperatures, thermal management is critical. Reduced light output and life can greatly reduce economic performance.

New LED luminaires provide the most opportunity for control of the thermal environment. Control opportunities decrease for LED retrofit kits and are even more limited for TLEDs, as the form factor of TLEDs and their dependence on the existing luminaire structure pose significant limitations on the system's ability to regulate resulting operating temperatures.

More information on the effects of thermal management is expected in the forthcoming *IES LM-84 (Method for Measuring Lumen Maintenance of LED Lamps, Light Engines,* and *Luminaires)* and *IES TM-28 (Prediction of Lumen Maintenance of LED Lamps and Luminaires)*.

Safety. Safety is a relevant issue in the replacement of TFLs with TLEDs. After a fluorescent luminaire is retrofit for TLEDs, safety becomes an issue should maintenance personnel try to replace the TLEDs with TFLs. Various resolutions are available depending on whether or not the fluorescent ballast is bypassed and whether or not AC current is brought to the TFL sockets. Safety standards and labels are also addressing this issue and it should eventually be resolved.

Controls. A major advantage of LED retrofits for TFL lighting is the potential for increased comfort and energy efficiency through smoother and wider-range dimming. This allows end users more personal control, and it allows for greater use of adaptive controls, based on occupancy, daylighting and demand response. The energy and economic performance of the LED options can be significantly increased through adaptive controls.

CONCLUSIONS

While payback periods are very long for short-term economic goals, life-cycle cost comparisons that consider long-term economic goals provide a significantly different perspective. The average incremental life-cycle cost of new LED luminaires is about $150 more than the life-cycle cost of staying with TFLs. Over 50,000 hours of operation, this translates to $0.003 per operating hour, or about $.03 per day (given a 10-hour day) for all of the benefits of a new LED luminaire, i.e., appropriate CPD and SPD, high CRI, and increased chances of meeting light output and life expectations through proper thermal management. ■

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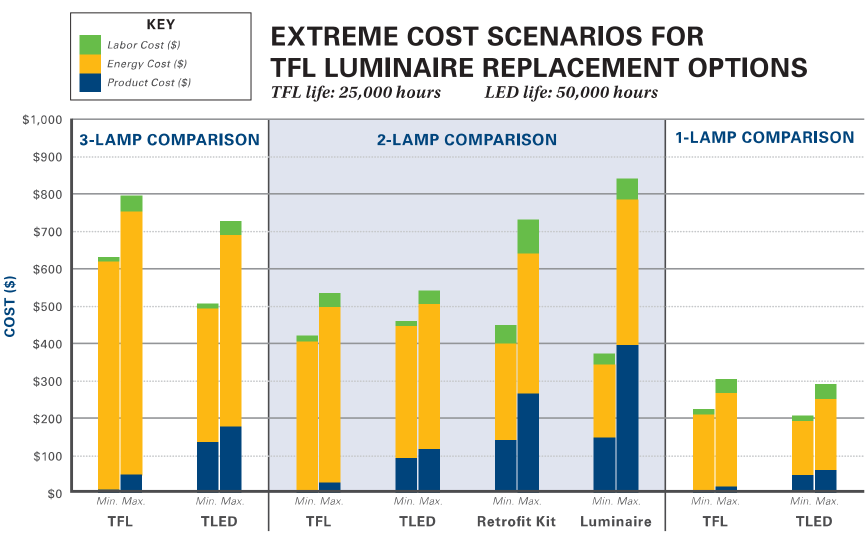

Figure 4.

Linear fluorescent lamps constitute 80 percent of the lamps installed in interior commercial building stock, according to the DOE's most recent U.S. Lighting Market Characterization report.