



# LED RETROFIT OPTIONS FOR LINEAR FLUORESCENT LUMINAIRES

*Fluorescent lamps currently dominate the commercial sector, where they account for 80 percent of installed lamps.<sup>1</sup> LED lighting products are receiving a great deal of attention for their potential to replace fluorescent lighting, reduce energy use and improve lighting quality in a variety of indoor commercial applications, including offices, classrooms and retail stores.*

*LED alternatives to fluorescent lighting products fall into three main categories: tubular lamps, retrofit kits and dedicated luminaires. This guide provides the latest available information on each of these three rapidly developing lighting product categories, including safety precautions and labor requirements.*

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<sup>1</sup> Department of Energy, *2010 U.S. Lighting Market Characterization*. Prepared by Navigant Consulting for DOE Solid-State Lighting Program, 2012, p. 44.



## LED REPLACEMENT OPTIONS

Three main categories of LED products are currently available for LED retrofit options for existing linear fluorescent fixtures. These LED replacement options require varying amounts of labor to install, entail different costs, and require different safety precautions.

### 1 Tubular LED Lamps

Replacing existing linear fluorescent lamps with similarly shaped LED lamps requires minimal new hardware, but this strategy also presents some unique challenges that should be understood thoroughly before purchase or installation.

Based on the particular LED replacement lamp product being considered, this approach also typically requires changing the electrical wiring, replacing the ballast with an external driver, or altering the existing lamp holders (or “tombstones”) to accommodate the new lamp. Electrical architecture and installation challenges are addressed in a later section of this guide.



### 2 LED Retrofit Kits

An LED retrofit kit provides the required electrical components, optical elements and light sources in a prepackaged kit. This replacement option provides a repeatable, efficient retrofit solution for the majority of troffers in today’s building stock.

When updating existing troffers, it is critical to make sure they can accommodate the retrofit kit selected, as not all retrofit kits are universally accepted by troffers. In addition, any retrofit option should preserve the safety rating of the existing luminaire.



### 3 Dedicated LED Luminaires

Dedicated LED luminaires can often easily replace existing linear fluorescent luminaires. While typically higher in cost, this option often provides the LED technology in a well-designed package with a straightforward electrical installation.



*Replacing existing fluorescent lamps with LED lamps of the same size and form factor may be a viable retrofit option. This almost always requires rewiring to make the existing luminaires compatible with the new lamps.*

## DESIGNLIGHTS CONSORTIUM QUALIFIED PRODUCT LIST

To ensure that LED retrofit options for existing linear fluorescent fixtures live up to the performance, quality and reliability claims of their manufacturers, the DesignLights Consortium (DLC) maintains a Qualified Product List (QPL) of LED lamps. Products are listed on the QPL only after rigorous testing by qualified laboratories.

QPL products must meet a number of stringent criteria, including benchmarks for light output (lumens), efficacy (lumens per watt), correlated color temperature (CCT), color rendering index (CRI), power factor, total harmonic distortion (THD), warranty, and safety certification.

To qualify for inclusion on the QPL, tubular LED lamps must have documented safety certification, system efficacy of at least 100 lm/W, lumen maintenance ( $L_{70}$ ) of 50,000 hours, and a five-year warranty.

The DLC categorizes all tube-style LED products as “linear replacement lamps,” even if safety organizations classify them as retrofit kits. This is due to the common need to perform electrical or mechanical alterations to existing luminaires for proper installation. Only fully-integrated “insert-style” kits are eligible under the DLC’s retrofit kit categories.

## LIGHTING TERMS

- **Luminaire** is the lighting industry’s term for what is commonly referred to as a “light fixture.” It is also the term you will find used in California’s Building Energy Efficiency Standards (Title 24, Part 6). A luminaire consists of the housing, power supply (ballast or driver), “lamp” or light source (linear fluorescent tube or LED array, etc.), and optical components, such as reflectors and lenses.
- **Color Rendering Index (CRI)** is the current industry standard for measuring how accurately a light source renders the colors of objects it illuminates. The maximum CRI value is 100.
- **Correlated Color Temperature (CCT)** indicates the warmth or coolness of light emitted from a particular source. Light sources with a low CCT (2700 – 3000K) emit light with a warmer appearance. Those with a higher CCT (4000 – 6500K), emit light with a cooler color appearance.
- **Efficacy** indicates how much light is produced by a lamp or lighting system per unit of electrical power it consumes, measured in lumens per watt (lm/W).

## SAFETY STANDARDS FOR LED REPLACEMENT TECHNOLOGIES



Nationally Recognized Testing Laboratories, or NRTLs, provide crucial third-party verification of the safety of lighting products. These labs apply a variety of marks, or badges, to indicate the level of examination a product has undergone and what standards it has met. Safety standards are developed and published by organizations such as the Canadian Standards Association (CSA) and Underwriters Laboratories (UL).

### UL Listed



The "UL Listed" product category indicates that a testing laboratory found a representative group of product samples met UL's safety requirements, usually based on published standards.

The typical listed product is a complete system meant to be "plug and play" or "drop in," meaning nothing else needs to be done to the product other than connecting power, either with a cord and plug or by hard-wiring.

Tubular LED lamps can fall into this category if they are designed as a linear fluorescent lamp replacement with no ballast changes or disconnections, but "UL Listed" LED replacement lamps are uncommon. Note that the term "UL Listed" is often used inaccurately in advertising, when the product is in fact "UL Classified."

### ETL Listed



The Electrical Testing Labs (ETL) Listed mark indicates that a product has been tested to the same standards as UL and met the same minimum safety requirements. Testing is performed by

an independent Nationally Recognized Testing Laboratory, recognized by OSHA. The ETL Listed mark with the "US" identifier meets U.S. product safety standards only. An ETL Listed mark with the "C" identifier complies with Canadian product safety standards only. Marks bearing both identifiers comply with both U.S. and Canadian product safety standards.

### UL Classified



A mark of "Classified" indicates that the product has been evaluated by a qualified laboratory, but only with respect to specific properties, a limited range of hazards, or suitability for use under limited or special conditions.

LED retrofit kits and LED replacement lamps that require disconnection of the original fluorescent ballast and re-wiring fall into the "UL Classified" category. LED replacement lamps, kits and other components are rated as "UL Classified" under UL-1598C, the specific standard for LED retrofit luminaire conversion kits.

### UL Recognized



The "Recognized" mark is used with components that are intended to be installed as part of a larger specific system, such as an LED driver, where the luminaire housing may provide protection from heat. The components are intended to be installed at a factory, not in the field. A luminaire can be rated for use with a variety of "Recognized" components without requiring retesting.

*More information on UL, ETL and CSA standards is available at [UL.com](http://UL.com), [Intertek.com](http://Intertek.com) and [CSAgroup.org](http://CSAgroup.org).*



*Key Questions to consider for an LED replacement lamp or retrofit kit installation:*

- Is the lamp or kit Listed, Classified or Recognized per UL/CSA standards?
- If it is a tubular LED lamp being considered, does it comply with both UL-1598C and the UL-1993 standards for self-ballasted lamps and lamp adapters? LED replacement lamps or retrofit kits that use a separate driver, not built into the lamp itself, must comply with UL-1598C only.







## CALIFORNIA TITLE 24 & LINEAR FLUORESCENT LIGHTING RETROFIT PROJECTS

Starting July 1, 2014, more lighting retrofit projects will be considered *alterations* that must comply with California's Building Energy Efficiency Standards (Title 24). Under the previous regulations, lighting system alterations that replaced, removed or reinstalled more than 50% of a building's luminaires required compliance with the standards. Going forward, altering just 10% of the luminaires in a building will make the project subject to Title 24 regulation.<sup>2</sup>

In most cases, replacing linear fluorescent lamps with tubular LED lamps requires making modifications that are considered an alteration by Title 24 standards. In some cases, no modifications are needed to the existing luminaire housing, wiring or other components; these replacements are not considered alterations under Title 24.

Most retrofits will qualify as alterations, including those that require the ballast to be disconnected and replaced with an LED driver and those that require disconnecting the fluorescent ballast and wiring the tombstones directly to line voltage. Replacing or relocating entire luminaires may also require other lighting system upgrades to bring the system into compliance with the newest standards.

Under Title 24, Part 6, tubular LED installation is not recognized as converting a luminaire from linear fluorescent to LED technology, so the luminaire type will not change for Title 24 compliance purposes. The same is true for some LED retrofit kits; the rated wattage of the luminaire does not change, and the same rated (linear fluorescent) wattage still applies for lighting power allowances. As the luminaires are still classified as linear fluorescent, they must also comply with the lighting control requirements for fluorescent lighting systems.

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<sup>2</sup> California Energy Commission, *2013 California Building Energy Efficiency Standards*, Title 24, Part 6. 2012.

## PERFORMANCE CHARACTERISTICS

Tests of tubular LED replacement lamps, retrofit kits and dedicated luminaires show that while their performance continues to improve, limitations remain.<sup>3</sup> For instance, tubular LED replacement lamps vary greatly in their ability to dim without perceivable flicker. LED products in the tubular replacement lamp category demonstrate a wide range of performance characteristics, making the replacement process more complicated than a simple exchange based on the stated manufacturer specifications.

### Luminous Output

Additional tubular LED replacement lamps may be needed to deliver luminous output equivalent to that of the existing fluorescent lamps, which would decrease the potential energy savings of retrofitting. This additional lighting may not be required for retrofits in spaces that are overlit or those that introduce task lighting to supplement general lighting.

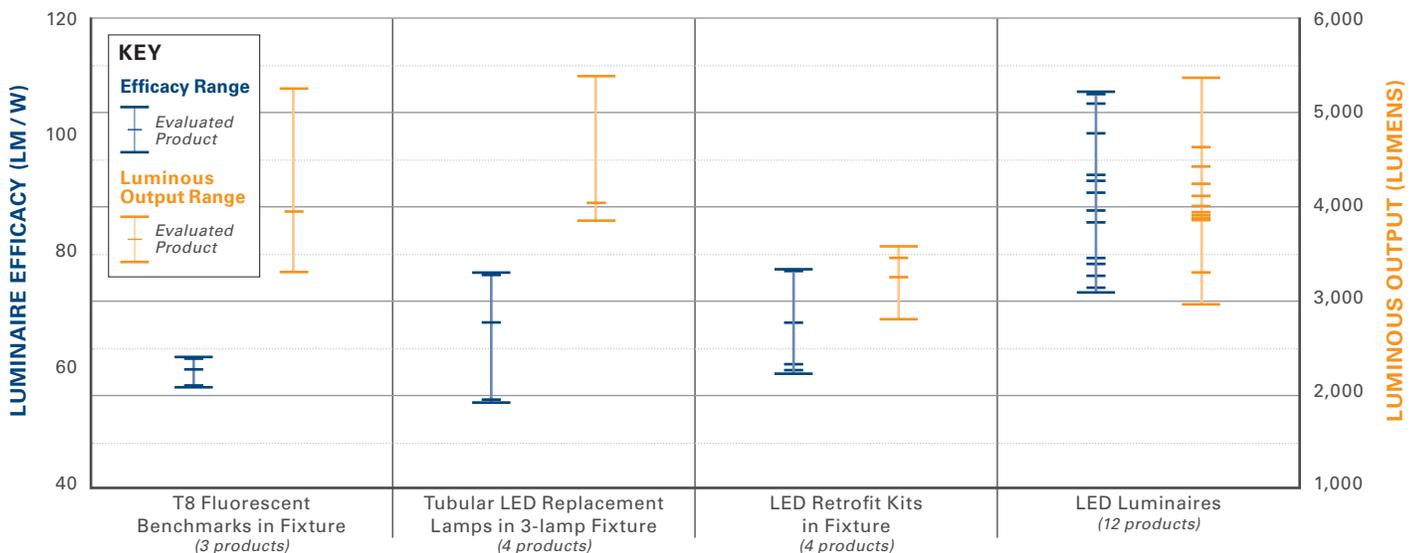
Lighting design best practices and guidelines published by the Illuminating Engineering Society (IES) should be used to determine if additional lamps or luminaires may be needed based on the tasks performed in the space.

### System Efficacy

The efficacy, or the amount of light produced per watt of power consumed, is not dramatically higher for tubular LED lamps than it is for linear fluorescent lamps. Still, recent studies<sup>3</sup> show that LED retrofit kits and dedicated luminaires are somewhat more efficacious.

The graphic below shows luminaire efficacy and luminous output for a cross section of evaluated LED and linear fluorescent products. As the table indicates, T8 LED lamps are nearly 10% more efficacious, on average, than the typical fluorescent T8 lamp. LED troffers are 44% more efficacious than fluorescent luminaires.

Luminaire efficacy and luminous output by product category<sup>3</sup>



<sup>3</sup> CALIPER Exploratory Study: Recessed Troffer Lighting, Prepared for the U.S. Department of Energy by the Pacific Northwest National Laboratory, PNNL-22348, 2013.

## Light Distribution

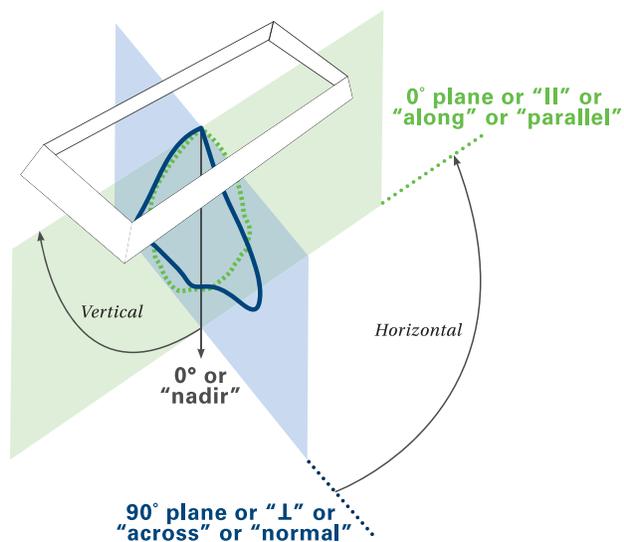
Tubular LED replacement lamps incorporate multiple, directional light sources into a linear form factor through varied optical design strategies. As a result, tubular LED and linear fluorescent lamps installed in the same troffer can produce different light distribution patterns, as illustrated by plots A–D.

Plots A, B and C depict the light distribution patterns of three different tubular LED replacement lamps while figure D shows a “batwing” distribution of a fluorescent lamp. The lamps were installed in one-lamp, ceiling-mounted luminaires for testing.

Plot A indicates the light distribution of a tubular LED lamp with a diffuser, plot B corresponds to a lamp with 32 high-intensity LEDs, and plot C to a lamp with a total of 360 surface-mount device (SMD) LEDs.

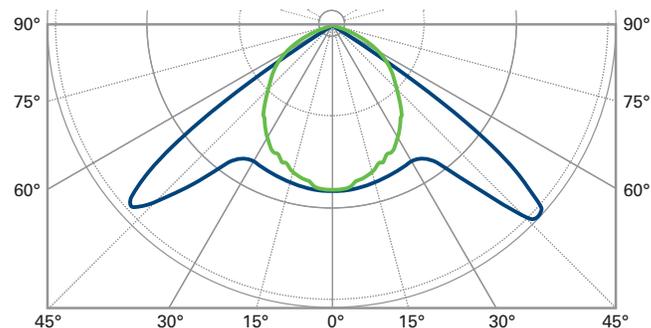
The distribution characteristics of LED lamps can increase brightness (and glare) to an uncomfortable degree as compared to linear fluorescent lamps. Installing a luminaire reflector and optical lens optimized for the LED replacement lamp’s distribution can achieve a “batwing” fluorescent distribution pattern and improve uniformity.

**The green and blue lines represent light intensity distribution patterns in the axial and transverse planes, respectively.**

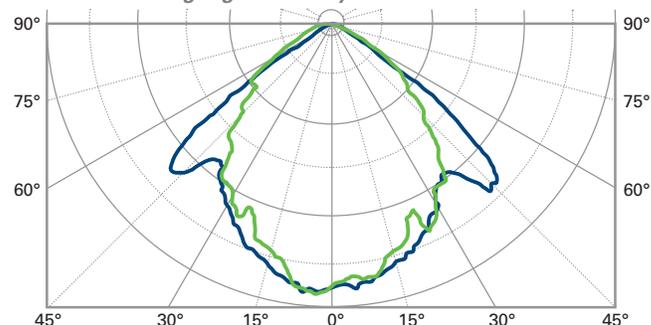


## Luminous intensity distribution of tubular LED and linear fluorescent lamps installed in identical luminaires

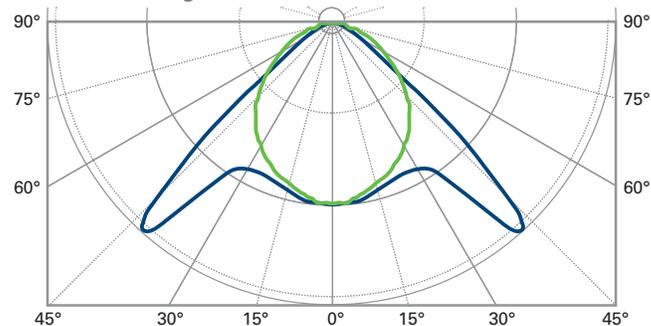
**A: LED tube with diffuser**



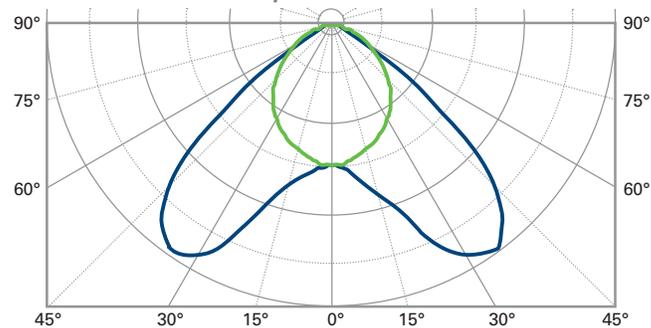
**B: LED tube using high-intensity LEDs**



**C: LED tube using surface-mount LEDs**

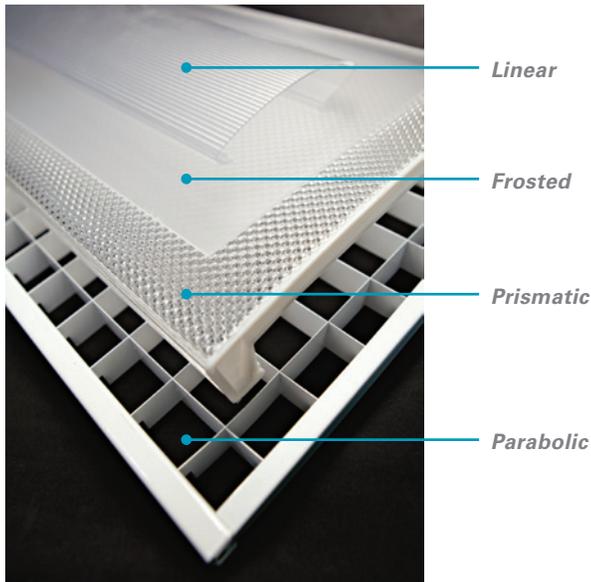


**D: Linear fluorescent lamp**



Source: W.R. Ryckaert, K.A.G. Smet, I.A.A. Roelandts, M. Van Gils, P. Hanselaer, “Linear LED tubes versus fluorescent lamps: An evaluation.” *Energy and Buildings*, 2012, 49: p. 433.

## Luminaire lens options



## Optics and Design

Retrofit kits and fixture replacements often provide better light distribution than tubular LED replacement lamps because they are able to better integrate the LED source(s) with the structure of the troffer and optical elements. The lensing for most current troffers consists of diffuser surfaces with linear details, frosted diffusers or parabolic louvers. Older, prismatic lenses may not pair well with tubular LED lamps and can produce distracting patterns.

## Lifetime and Cost Comparison

Long product lifetime is an advantage of LED-based lighting technologies. An industry metric for specifying length of dependable service for LED lamps is “lumen maintenance.” Current methods for measuring and projecting the lumen maintenance of LED light sources are outlined in *IES LM-80* and *IES TM-21*, respectively. (The forthcoming *IES LM-84* and *IES TM-28* will address useful lamp life and incorporate system factors such as thermal management.)

Traditional lamps are typically measured in hours to lamp failure, but because LEDs last longer than traditional light sources and depreciate more slowly, their useful life is measured in the hours they can maintain at least 70% of their initial lumen output. This is known as “L<sub>70</sub>.” The DLC requirement for the useful life of tubular LEDs is 50,000 hours, or a practical

lifespan of roughly 16 years.<sup>4</sup> This is about twice the life of the average fluorescent tube, although some long-life fluorescent lamps now offer comparable lifetimes.

A long lifespan is a critical factor when calculating the cost-effectiveness of LED replacement lamps. Current prices for linear LED replacement lamps vary considerably, from \$30 to over \$100 per lamp, while fluorescent tubes cost \$2 to \$10 per lamp. To offset their higher initial cost, LED replacement lamps must last longer than their fluorescent counterparts and be more energy efficient.

## Installation Challenges

Fluorescent lamps can be replaced with LED lamps, but a large majority of tubular LED replacement lamps require a different electrical system. Fluorescent lamps are supplied electricity through a ballast that regulates electrical current to the lamps and supplies sufficient starting voltage for them. LED technology uses an electronic driver to provide the proper voltage and current for LED operation. For this reason, new electrical components and rewiring are often necessary to make the existing fixture compatible with the new lamps. The electrical incompatibilities between linear fluorescent and linear LED lamps constitute the most important safety issue facing tubular LED technology.

The majority of LED replacement lamps with internal or integrated drivers require line voltage be supplied directly to the lamp holders, bypassing the fluorescent ballast. Internal driver LED lamps may be either single- or double-ended, with power running to one or both ends, respectively.

“Drop-in” tubular LED replacement lamps incorporate a driver into the lamp. This allows the tubular LED to utilize existing fluorescent ballasts with no additional rewiring required. With these products, the tubular LED bi-pins connect directly to the existing G13 lamp holders (or “tombstones”). The thermal performance of the technology must be evaluated while installed in situ to ensure lamp life will not be compromised with the driver components exposed to higher temperatures.

LED replacement lamps with external or remote drivers differ still, and require their driver be connected to either the existing tombstone, or directly to the lamp, while using the tombstone merely for stability.

<sup>4</sup> Product life based on 12 hours of operation per day, 255 days per year.

Another electrical wiring point of interest is whether the lamp holder is shunted for instant start fluorescent ballasts or un-shunted for rapid start ballasts. Generally, linear LED tube replacements that receive electricity through the lamp holder require un-shunted lamp-holders to operate as intended by the manufacturer.

All these factors concerning electrical architecture increase the complexity of the retrofit process and raise safety concerns. The fact that many LED replacement lamps connect through the bi-pin tombstone can create confusion for future maintenance workers who might attempt to replace lamps with an incorrect linear LED, or a traditional fluorescent lamp.

Installing a fluorescent lamp into a retrofitted lamp holder with unregulated line voltage modifications introduces a potential hazard for the installation team.

Proper documentation and labeling of LED replacement lamps is crucial to avoid such hazards and protect the safety of maintenance staff and end users after retrofitting. Manufacturers require this step in the installation of a retrofit system.

### Thermal Management

The ability of an LED replacement lamp to manage heat affects its performance, longevity and safety. The form factor of the linear tube lamp presents certain constraints on thermal management. Innovative lamp manufacturers employ a number of solutions for thermal management, including improved drivers, forced convection methods, improved heat sink designs, and advanced materials.

To select suitable tubular LED replacement lamps for existing troffers, facility personnel should consider the lamps' thermal performance in that specific troffer, with careful attention paid to how the lamp is built to manage heat.

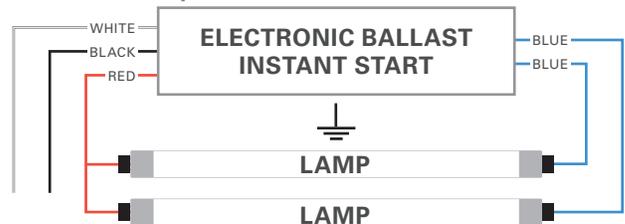
Dedicated LED luminaires utilize the fixture housing to provide thermal management for the LEDs. Similarly, LED retrofit kits utilize the optical reflector and mechanical elements as thermal conductors. Although some tubular LED replacement lamp products successfully manage the heat generated by LEDs, the inherent differences in these mechanical architectures place the dedicated luminaire and the retrofit kit at an advantage when it comes to thermal management.

**Example of a linear fluorescent lamp holder, or "tombstone," being retrofitted with a tubular LED product**



**Examples of some wiring configurations of LED retrofit products as compared to a typical electronic instant start ballasted fluorescent luminaire wiring configuration**

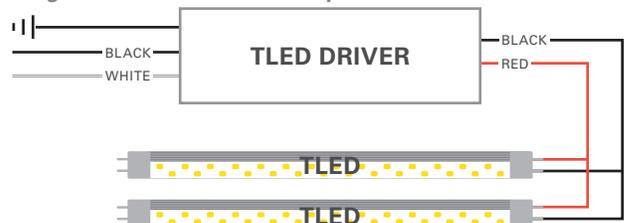
*Fluorescent lamps with instant-start electronic ballast*



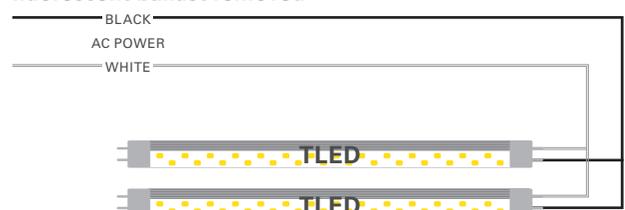
*Double-ended tubular LED lamps with external drive*



*Single-ended tubular LED lamps with external driver*



*Tubular LED lamps with internal driver and fluorescent ballast removed*



## LED RETROFIT OPTIONS FOR LINEAR FLUORESCENTS: POINTS TO CONSIDER

Those interested in updating their linear fluorescent lighting systems should carefully compare all viable lighting options, including Energy Saver linear fluorescent lamps, LED retrofit kits and dedicated LED replacement luminaires, along with tubular LED replacement lamps. When retrofitting between fluorescent lamps and tubular LED replacement lamps, it is also extremely important to observe safety precautions and consider performance variables.

- LED replacement lamps typically require wiring modifications to the existing luminaire, increasing labor costs and raising safety concerns
- Installation and maintenance teams must observe safety protocols and pay careful attention to luminaire labeling, both during and after installation
- The performance characteristics and energy savings of tubular LED replacement products vary widely from product to product, even within the same product category
- Tubular LED replacement lamps often require un-shunted lamp-holders for successful operation; facility managers should keep this in mind during project planning and preparation
- Thermal performance should be analyzed in the specific troffer considered for retrofit, with attention paid to how the LED lamp manages heat
- As a directional source, LED replacement lamps require custom optics to achieve distribution patterns like those typical of omni-directional fluorescent lights

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**ABOUT THE CALIFORNIA LIGHTING TECHNOLOGY CENTER, UC DAVIS:**  
*The California Lighting Technology Center was created in 2003 by the California Energy Commission in collaboration with the U.S. Department of Energy and the National Electrical Manufacturers Association. Part of the Department of Design at the University of California, Davis, CLTC is dedicated to accelerating the development and deployment of energy-efficient lighting and daylighting technologies.*

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