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Over time, various components of commercial and industrial lighting systems need to be maintained or replaced. As lamp technology has evolved from incandescent to fluorescent, and more recently to lighting based on light emitting diodes (LEDs), many facilities are evaluating the replacement of older lighting fixtures (luminaires) with systems based on newer lighting technologies. Upgraded lighting systems can offer significant operating savings over their lifetime, resulting from reduced energy and maintenance expenses.

Unfortunately, upgrading lighting system components is not as simple as changing a traditional light bulb. Fluorescent lamps and lighting systems are not generally compatible with LED-based lamps and luminaires. Further, even when technical challenges are addressed, there are other considerations, such as expected lighting performance, that may complicate upgrade plans. Therefore, a luminaire retrofit program must be designed and implemented so that an upgraded lighting system continues to function as intended, that lighting application performance requirements are met, and that safety is not compromised.

This UL white paper provides an overview of the issues related to the replacement of linear fluorescent lamps with LED lighting in commercial and industrial settings. Beginning with background information on the growth in the use of LEDs, the white paper identifies some of the technical challenges involved in retrofitting linear fluorescent luminaires with LED replacement lamps, and other potential impacts from such changes. The paper then offers a review of the current standards applicable to LED lamps, luminaires and retrofit kits. The white paper concludes with a list of additional issues facing builders, building owners and operators considering the retrofitting of linear fluorescent luminaires with LED replacement lamps.

The Opportunity for LED Lighting in Commercial and Industrial Settings

Linear fluorescent lamps and luminaires represent the overwhelming share of lighting products found in commercial and industrial settings, and a significant portion of all lamps currently in use in the U.S. According to the most recent data available from the U.S. Department of Energy (DOE), more than 1.7 billion linear fluorescent lamps were in use in commercial and industrial settings in the U.S. in 2010. This represents over 80% of all lamps used in these environments and nearly 22% of the more than 8 billion lamps in general use in the U.S.[1]

More significant than the number of linear fluorescent lamps is the amount of electricity that they consume. U.S. DoE data indicates that linear fluorescent lamps consumed 294 terawatts (TWh) of electricity in 2010, representing 42% of all electricity consumed by lamps in the U.S. in that year. As such, linear fluorescent technology is the single largest user of electricity for lighting applications, followed by high intensity discharge lighting at 26% and incandescent lighting at 22%.[2]

A number of factors, including federal regulations, utility incentive programs and increased interest in energy conservation, have already driven some improvement in the energy efficiency of linear fluorescent lamps. For example, the use of linear fluorescent lamps over the past decade has migrated from magnetically ballasted T12 model lamps to the more efficient T8 and T5 models with electronic ballasts.[3] Further energy savings will also result from new DoE energy conservation standards applicable to general service fluorescent lamps that became effective July 2012.[4]

However, the greatest potential energy savings is likely to result from the switchover from fluorescent lamp to solid state lighting (SSL) technologies, including LED-based lamps and luminaires. In commercial settings, a 28% penetration by LED lighting by 2020 would result in energy savings of 12% in 2020, with savings of up to 35% based on a 70% penetration rate in 2030. In industrial settings, LED lighting penetration is expected to reach 36% in 2020 and 72% in 2030, with energy savings of up to 29%.[5]

Based on these anticipated penetration rates, the cumulative savings that would result from the switch to LED lighting in commercial and industrial settings between 2010 and 2030 is significant. DoE researchers project energy savings approaching nearly 1,000 TWh of electricity, enough to power 79 million households for a year.[6] A separate DOE study predicts that the rapid adoption of LED lighting in the U.S. could result in energy savings of about $265 billion by 2027, and reduce lighting electricity demand by 33%.[7]

The prospect of greater energy efficiency, along with improved technology and reduced operating costs, has helped drive the rapid growth of the market for LED lamps and luminaires. The value of LED sales in 2011 is estimated at $12.5 billion, representing an increase of 8% over 2010 sales of $11.2 billion, and a significant 270% increase over the $4.6 billion in revenue generated in 2007, just four years earlier. Looking ahead, LED revenue is expected to grow to over $16 billion by 2016, driven largely by an anticipated 33% compound growth in LED lighting and lighting products.[8] And expanded LED production to meet this increased demand will likely place downward pressure on LED unit prices,[9] further spurring demand for LED-based lighting and other products incorporating LEDs.

Linear Fluorescent Luminaires and LED Replacement Lamps

Significant improvements in the quality and performance of LEDs have made this technology the lighting option of choice for a wide range of applications in commercial and industrial settings. LEDs today provide brightness, color quality and light output equal to or greater than many other commercially available lighting technologies. LEDs also offer the prospect of longer operating life, reducing replacement frequency and potentially lowering overall operating costs. Finally, because they do not contain mercury found in fluorescent lamps, LEDs are environmentally preferable.

When it comes to retrofitting existing fluorescent luminaires, some LED replacement lamps already on the market are equipped with a pin-type lampholder interface found in fluorescent lamps. In theory, this design can provide a straightforward upgrade path from linear fluorescent lamps, resulting in considerable energy savings with minimal effort. But achieving a compatible electrical interface is often more complicated than simply achieving a proper fit.

A fluorescent luminaire includes a ballast that produces an electrical output designed to match a specific type of fluorescent lamp. The input requirements for a fluorescent lamp include a starting voltage or pulse of up to several hundred volts, which is disconnected once the lamp's arc is established. LED drivers are designed for connection to a line voltage input of 120 – 277 V, and provide the constant current source (typically 350-750 mega amps, but can vary widely) needed to drive LED arrays. The current and nominal voltage levels vary depending on the individual electrical characteristics of the LED packages and the number of LEDs connected in series.

Retrofitting fluorescent luminaires with LED replacement lamps typically requires bypassing the ballast in the luminaire. In cases that the LED driver circuitry is integral to the lamp, the branch circuit wires that previously served as input to the ballast are connected directly to the lampholder. In cases where a separate driver is provided, the branch circuit wires are connected to the LED driver input and the driver output is connected to the lampholder. Depending on specific retrofitting instructions, the now unneeded fluorescent ballast can be discarded or left in place.

Some “universal” LED replacement lamp models are available that incorporate electronic circuitry that can handle a wide range of input signals. This design may make it possible to directly replace a linear fluorescent lamp with an equivalent LED replacement lamp without the need to rewire the luminaire. However, installers should carefully review all documentation accompanying such "direct replacement" lamps to ensure a lamp’s compatibility with the chosen luminaire and the fluorescent lamp being replaced. Using such LED lamps without regard for their markings can cause potential safety issues.

In addition to achieving a compatible electrical interface, there are other safety considerations in retrofitting a fluorescent luminaire with LED replacement lamps. For example, fluorescent luminaires can be equipped with ballasts and lampholders designed to support different types of lamps, such as switch-start, rapid start, progressive start and instant start. These important aspects of a luminaire must be taken into account in the selection of suitable LED replacement lamps.

Finally, fluorescent luminaires that have been rewired to accommodate LED replacement lamps are no longer compatible with linear fluorescent lamps, and attempting to install a linear fluorescent lamp in a retrofitted luminaire can create a safety hazard. Accordingly, retrofitted luminaires must be clearly labeled to warn users against the re-installation of fluorescent lamps. Appropriate labels are typically supplied by the manufacturer of the selected LED luminaire conversion kit.

Product Safety Standards for Lamps and Luminaires

As LED technology has become a more popular source of light in today’s lamps and luminaires, product safety standards have evolved to address LED-specific requirements. This evolution is especially evident in the standards that are currently applicable to LED replacement lamps and LED luminaire conversion kits. Here is a brief summary of the current UL Safety Standards that apply to these products:

- **UL 1598, the Standard for Safety of Luminaires** — This end-product standard, which applies to luminaires intended for use in non-hazardous locations, was first published in 2000 and replaced multiple standards for various types of fixed luminaires, including luminaires for incandescent, fluorescent and high-intensity discharge (HID) lamps. The third edition of UL 1598 was issued in September 2008.
- **UL 8750, the Standard for Safety of Light Emitting Diode (LED) Equipment for Use in Lighting Products** — This standard addresses LED equipment that is an integral part of a luminaire or other lighting equipment, and also covers LED components, including drivers, controllers, arrays and modules. The requirements in this standard are intended to supplement those in other end-product standards, such as UL 153, UL 1598 and UL 1993.
- **UL 935, the Standard for Safety of Fluorescent Lamp Ballasts** — This standard covers ballasts used in fluorescent luminaires. Fluorescent self-ballasted lamps and ballast adapters are covered under UL 1993.

- **UL 1993, the Standard for Safety of Self-Ballasted Lamps and Lamp Adaptors** — As noted above, this standard covers fluorescent self-ballasted lamps and ballast adapters, as well as self-ballasted LED lamps, used in connection with screw-pin-base and recessed single contact lampholders in luminaires for non-hazardous locations. The requirements are applicable to self-ballasted lamps used in both fixed and portable luminaires.
- **UL Subject 1598C, Outline of Investigation for LED Retrofit Luminaire Conversion Kits** — Published in 2011, this document specifies the requirements for LED retrofit luminaire conversion kits intended to replace existing light sources and systems in previously installed luminaires. Retrofit kits covered by this document include LED lamps and arrays, control modules, drivers, power supplies and other mechanical, electrical or optical devices. The requirements in UL 1598C are intended to supplement the luminaire and retrofit kit requirements found in UL 1598, the end-products standard for luminaires. UL 1598C does not apply to LED conversion lamps that are intended to replace existing lamps without any modification, rewiring, or component replacement in the luminaire other than direct replacement of the lamp using the existing lampholder. Such conversion lamps would be covered under UL 1993.
- **UL 1993 Certification Requirement Decision (CRD) dated May 23,2012 (written as draft Annex H)** — Finally, additional guidance in the investigation and testing of LED direct replacement lamps can be found in a UL Certification Requirement Decision (CRD), originally published in 2011 and revised May 23, 2012. The CRD includes construction and testing requirements for LED replacement lamps intended to operate directly from existing fluorescent ballasts. The CRD includes detailed marking requirements and instructions to minimize the risk of undesirable operation due to misuse.

The actual Standards to be applied in a product investigation will vary, depending on the specific type of product, its construction and its intended use. Therefore, the determination of the standards that should be used to fully assess the safety considerations of LED replacement lamps or LED retrofit conversion kits should be made in consultation with a qualified third-party certification organization experienced in the evaluation of such products.

Additional Considerations for Builders, Building Owners and Operators

In addition to safety issues, there are other considerations that builders, building owners and building operators should take into account when evaluating the feasibility of retrofitting existing fluorescent luminaires to accommodate LED replacement lamps.

Perhaps the most significant issue is assessing the potential impact of the total illumination and illumination distribution patterns generated by LED replacement lamps. Unlike fluorescent lamps that illuminate in all directions, LED lamps typically provide more directional illumination. Fluorescent luminaires are typically designed to maximize the spread of light from the lamp through the use of reflective surfaces and optimizing lenses, and may contribute little to enhancing illumination generated by an LED lamp. Therefore, consideration should be given to whether luminaires that have been retrofitted with LED lamps will provide illumination consistent with the needs of a facility, or if additional lamps or luminaires will need to be installed.

A separate but equally important concern involves the maintenance requirements related to the aging and failure characteristics of LED lamps. Other light sources, including incandescent and fluorescent lamps, have a lumen output vs. lifetime curve that is relatively flat until the lamp fails completely, at which point the need for replacement is obvious. LED lamps, on the other hand, emit gradually lower amounts of light as they age. This aging characteristic can make it difficult for maintenance personnel to determine whether an LED lamp is near the end of its useful life without directly measuring an LED lamp's illumination using a light meter.

Another potential issue relates to the pace of change in LED lamp technology. LED lamps have improved dramatically in just the past ten years, and future developments in technology are likely to make LED lamps ten years from now even better. While such improvements are good, future generations of LED lamps may not be backward compatible with existing products, thereby shrinking the effective lifetime of current product lines. Today's LED lamps are expected to produce quality light for many years to come. However, using conservative estimates of the potential savings in energy costs and reduced maintenance expenses in calculating the potential return on investment for a retrofit program may be appropriate.

Finally, the use of LED replacement lamps in specialty lighting applications may magnify some of the considerations noted here. For example, emergency lighting systems play a key role in the safety of building occupants, and changes to any component must be carefully evaluated to determine that the system itself is not compromised. In such circumstances, a thorough assessment of life safety codes, regulations and requirements is appropriate.

Conclusion

The quality and performance of today's LED lamps make them the foremost lighting technology choice in commercial and industrial settings. Retrofitting existing fluorescent luminaries with LED replacement lamps can result in significant energy and maintenance savings, at a cost considerably less than that required for a complete luminaire replacement program. LED replacement lamps and LED retrofit conversion kits that have been evaluated for compliance with relevant product safety standards are now available to help make the retrofit process safe and affordable.

However, the technical differences between fluorescent and LED lighting means that the process of retrofitting fluorescent luminaires with LED replacement lamps typically involves more than just changing a lamp. In evaluating the potential advantages and drawbacks of a lighting retrofit program, builders, building owners and operators should evaluate the electrical specifications of currently installed luminaires so that selected LED replacement lamps and retrofit conversion kits can be safely installed and used. Consideration should also be given to the total illumination generated by LED replacement lamps, as well as their effective lifetime and expected maintenance requirements. Completing this assessment in advance can provide assurances that a lighting retrofit program will deliver the anticipated energy savings and represent an effective investment.

For further information about the evaluation and testing of LED replacement lamps and luminaire retrofit kits, contact Juan Caamaño, principal engineer, at 631.546.2752, or at Juan.M.CaamanoJr@ul.com.

[1] "2010 U.S. Lighting Market Characterization," Table 4.1, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy. Jan. 2012. Web. 25 June 2012 . http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_energy-savings-report_jan-2012.pdf

[2] Ibid, Table 4.8

[3] Ibid, p. 23

[4] "Energy Conservation Program: Energy Conservation Standards and Test Procedures for General Service Fluorescent Lamps and Incandescent Reflector Lamps," 10 CFR 430. 14 July 2009. Web. 25 June 2012. https://federalregister.gov/a/E9-15710

[5] "Energy Savings Potential of Solid-State Lighting in General Applications," P. 47-48, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy. Jan. 2012. Web. 25 June 2012. http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_energy-savings-report_jan-2012.pdf

[6] Ibid

[7] "Learn About LEDs," Energy Star, U.S. Environmental Protection Agency. Web. 12 Apr. 2012. http://www.energystar.gov/index.cfm?c=lighting.pr_what_are#all_equal

[8] "High-Brightness LED Market Review and Forecast—2011," Strategies Unlimited. Sep. 2011. Web. 12 Apr. 2012. summary available at http://www.strategies-u.com/articles/reports/high-brightness-leds/high-brightness-led-market-review-and-forecast---2011.html

[9] For example, see "LED Streetlight's Price Cut in Half," Wall Street Journal. 10 Apr. 2012.