PROJECT REPORT

LED LAMP REPLACEMENTS FOR T8 LINEAR FLUORESCENT LAMPS

CALIFORNIA LIGHTING TECHNOLOGY CENTER

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ABOUT CLTC

California Lighting Technology Center's mission is to stimulate the development and application of energy-efficient lighting by conducting technology development and demonstrations, outreach and educational activities, in partnership with lighting manufacturers, lighting professionals, the electric utility community, and governmental agencies. CLTC was established as a collaborative effort between the California Energy Commission and UC Davis, with support by the U.S. Department of Energy and the National Electrical Manufacturers Association (NEMA).

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1.0 EXECUTIVE SUMMARY

1.1 BACKGROUND

LED replacements for T8 linear fluorescent lamps are currently coming to market and achieving wider commercial acceptance. Manufacturers of these products claim a number of advantages over standard T8 fluorescent lamps including longer life and lower energy consumption, along with comparable correlated color temperature, color rendering, and lumen output of traditional fluorescent lamps.

Because so many LED replacement lamps of varying quality are rapidly coming to market, the US Department of Energy (DOE) has enacted the Commercially Available LED Product Evaluation and Reporting (CALiPER) program to test and report on the performance of new LED lighting technology. Similarly, the Sacramento Municipal Utility District (SMUD) is interested in the performance of LED replacements for T8 fluorescent lamps and has commissioned this study. The California Lighting Technology Center (CLTC) at UC Davis was asked to evaluate the safety, thermal, and photometric performance, lamp life, and optical performance of LED replacements for T8 fluorescent lamps with the intended application of refrigeration case lighting. UL compliance and related safety issues of LED replacement lamps also were evaluated.

Seven different LED lamps of 4’ and 5’ length were evaluated for photometric performance, power and safety and the four 5’ lamps were evaluated in a refrigeration case environment.

A range of lamps were evaluated in the study. Three power supply types are represented (line voltage, external low-voltage power supply, and ballast-driven) as well as two LED chip types (through-hole and surface-mount) and a variety of lamp housing styles (various combinations of metal and plastic housing).

1.2 RESULTS

This study finds that in general, manufacturer published photometric and power data does not meet the measured performance data of LED replacement lamps intended for direct replacement of T8 linear fluorescent lamps. Measured light output was lower than published in five out of the seven lamps evaluated and efficacy was lower in all cases. Similarly, evaluation of 5’ lamps in a refrigeration case environment shows that LED replacement lamps for linear fluorescents provide less light than a standard fluorescent lamp though they also draw less power.

A survey of lamp safety certifications finds a variety of means of safety certification with three lamp systems bearing some kind of UL certification. Overall, UL seems to be just catching up with the state of LED replacement lamp technology and proper UL certification for these products should become more prevalent in the future.

Safety evaluation of the T8 fluorescent LED replacement lamps indicates some concern with regard to electrical safety. Many of the lamps require re-wiring the existing electrical fixture such that line voltage runs to the existing lamp-holders; something that should be done by a licensed electrician. Also, measurement of the current through one end of a connected lamp indicates that many of these lamps may provide a shock hazard to installers who do not turn off the power when changing the lamps. Similarly, an LED replacement lamp with a broken housing will continue to function (unlike a fluorescent) which could potentially expose end-users to live parts while the lamp is in use.

2.0 PROJECT BACKGROUND

2.1 PROJECT OVERVIEW

LED replacements for T8 linear fluorescent lamps are currently coming to market and achieving wider commercial acceptance. Manufacturers of these products claim a number of advantages over standard T8 fluorescent lamps including longer life and lower energy consumption, along with comparable correlated color temperature, color rendering, and lumen output of traditional fluorescent lamps.

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2.2 TECHNOLOGY OVERVIEW

Investigations into LED replacements for linear fluorescent lamps (henceforth referred to as LED retrofit lamps) yielded a wide array of manufacturers and lamp options. Available lamps were found to vary in the following categories: input power (ballast driven, low voltage, or line voltage), housing type (metal, plastic, or a combination), LED chip type (surface-mount [SMT] or through-hole [THT]), number of LED chips (few or many), and correlated color temperature (cool white to warm white).

2.2.1 INPUT POWER

Most of LED tube lights on the market are powered by 120V line voltage and have their LED driver circuit integrated into the lamp housing. These lamps require that the end user rewire the existing fluorescent fixture by removing the existing ballast and connecting line voltage to the existing lamp sockets.

Two lamps in the study are driven by external low-voltage power supplies designed to fit in the space intended for a traditional T8 fluorescent ballast. In these cases, the existing ballast is removed and replaced with the LED power supply whose low voltage leads are then connected to the existing lamp sockets before the LED replacement lamp can be used. The low-voltage external power supplies in this study were marked 55 Vdc and 24 Vdc.

Only one product on the market can be driven by an existing fluorescent ballast. In this case, the end user simply removes the existing T8 fluorescent lamp and replaces it directly with the new LED tube light. In this case no rewiring is required.

2.2.2 HOUSING

LED retrofit lamps come in a variety of housing options. The majority of the products consist of a plastic lens that covers the LEDs and the front half of the lamp and a metal back that comprises the back half of the lamp. The lens may be clear or frosted and with or without light-directing optics. The metal back functions as a heat sink that is generally smooth, but sometimes has radial fins to better disperse the heat. One model of LED retrofit lamp studied has a fully aluminum housing with machined openings to allow the LEDs to shine through (i.e., no lens). One model of LED retrofit lamp is encased entirely in a clear plastic tube, with no apparent metal heat sinking. None of the studied lamps appear to have any special reflective optics directing the light in any specific direction. In all cases, the LED chips are mounted directly to a printed circuit board.

2.2.3 CHIP TYPE AND NUMBER

The lamps vary greatly in the number of LEDs per foot. Some of the test lamps have as few as two LEDs/ft and some have as many as 72 LEDs/ft. Manufacturers were found to use both SMT (surface mount technology) and THT (through-hole technology) LED devices.

Five-foot lamps were preferred for this study because of their prevalence in freezer case applications, but where they were not available, 4’ lamps were used instead.

A summary of the physical properties of the LED retrofit lamps used in the study can be found in Table 1. Pictures of the lamps illustrating the LED configurations and housing styles can be found in Figure 1 and Figure 2.

Table 1: Physical Properties of Lamps in Study

Product	Power Supply	Housing Type	Chip Type	Number of LEDs	Length	LEDs/ft
A	Ballast Voltage	aluminum back with radial fins/designed acrylic lens	SMT	36	4	9
B	External Low Voltage	all aluminum/cutouts for LEDs	SMT	10	5	2
C	External Low Voltage	aluminum/plastic	THT	315	4	79
D	Line Voltage	aluminum/plastic	THT	288	4	72
E	Line Voltage	aluminum/plastic	SMT	250	5	50
F	Line Voltage	aluminum back with radial fins/designed acrylic lens	SMT	288	5	58
G	Line Voltage	aluminum/plastic	THT	360	5	72

Figure 1: LED Layout Configurations

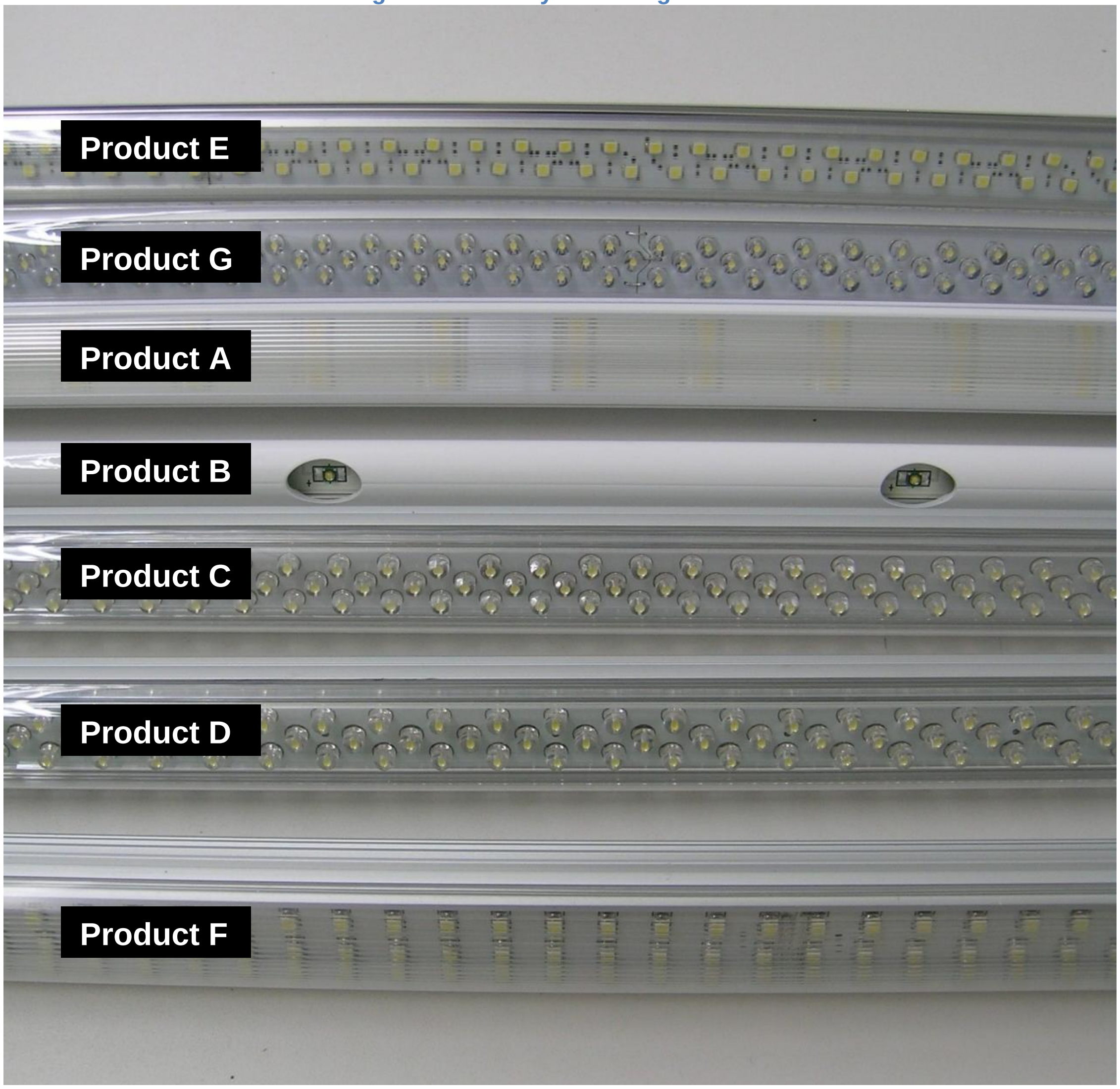
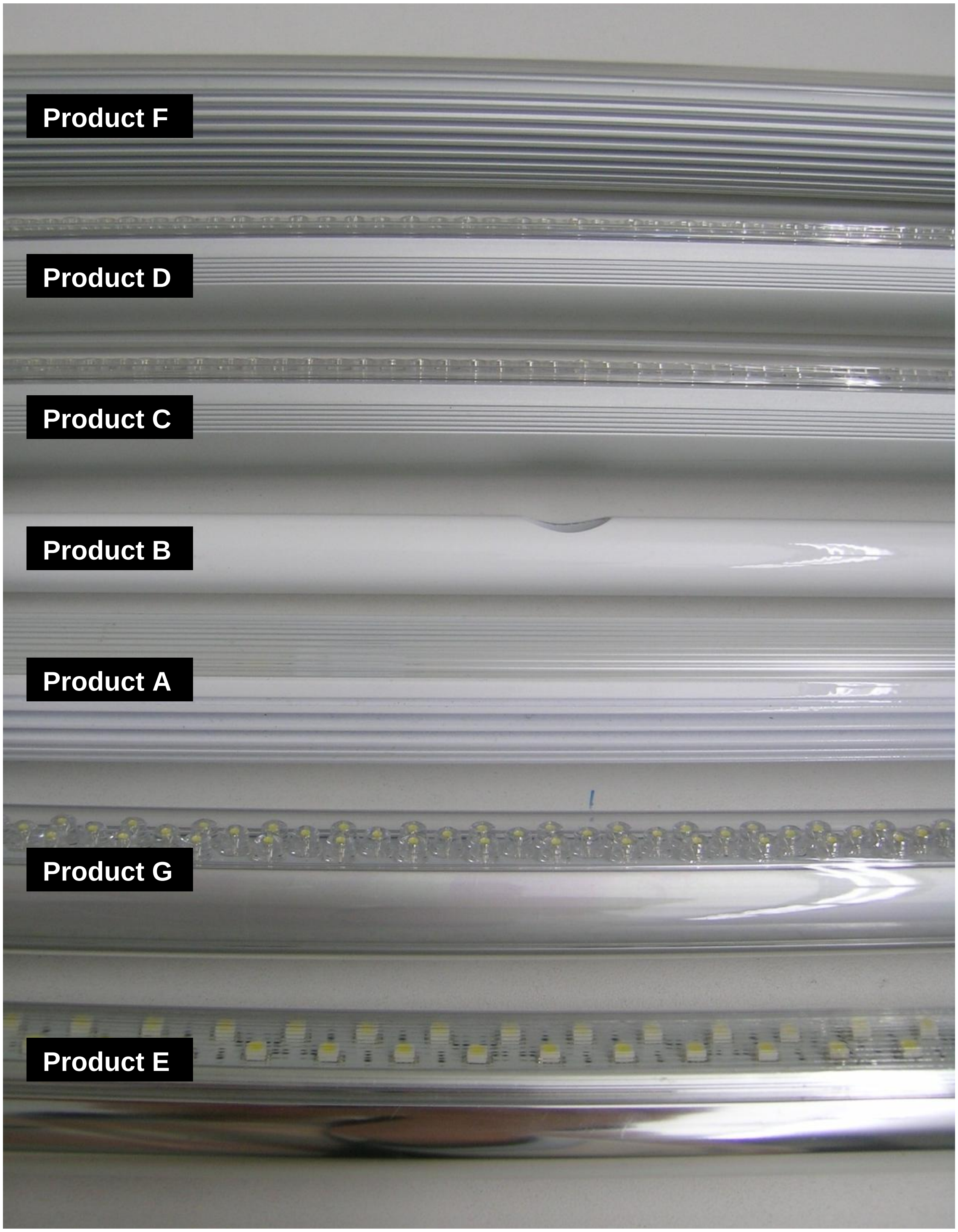


Figure 2: Lamp Housing Types



2.3 MARKET OVERVIEW

Linear fluorescent lamps of a variety of lengths are ubiquitous and used in innumerable applications, though 5' linear fluorescent lamps are most often used in refrigerated food cases. This study focused on refrigerated food case retrofit applications, though LED retrofit linear lamps could be installed in any location that currently has linear fluorescent lamps. The most logical application for LED retrofit lamps is in hard-to-reach or otherwise inconvenient locations. Generally life and the cost of an LED retrofit lamp greatly exceeds that of a standard linear fluorescent lamp, so replacements are best suited for locations where low replacement rate is preferable.

3.0 PROJECT OBJECTIVES

SMUD initiated this project to evaluate market-available LED retrofit lamps for T8 linear fluorescent lamps. CLTC was asked to evaluate the safety and UL compliance, lamp life, and thermal, photometric, and optical performance of these lamps.

4.0 METHODOLOGY

4.1 PROCUREMENT

In most cases, the lamps in this study were acquired directly from the manufacturer, though distributors were used when necessary. Reasonable precautions were taken to ensure anonymous purchasing such that manufacturers would not provide uncharacteristically high-performing samples. Four of each product was purchased. A total of 5 different products were ordered and two products were received as free demonstration units. The companies that provided the demonstration units were not aware they would be used in this study. To ensure a diversity of lamps, different power supply types were ordered, along with a variety of housing styles and LED configurations.

4.2 PHYSICAL PROPERTIES

Lamps were visually examined as they arrived and physical properties (housing type, LED packaging, etc.) were noted (see Table 1, Figure 1, and Figure 2).

4.3 POWER MEASUREMENTS

Lamp power measurements were made according to IESNA LM-79-08 (“Approved Method: Electrical and Photometric Measurements of Solid-State Lighting Products”) standards during the process of photometric testing. Lamps were allowed to stabilize according to the LM-79 procedure, and power readings were recorded. All samples were allowed at least 30 minutes of stabilization time, with some units requiring up to two hours to reach stabilization. All power measurements were taken using a Yokogawa PZ4000 Power Analyzer. Product A required a standard fluorescent ballast for operation and a Sylvania QUICKTRONIC QTP2x32T8/UNV ISN-SC (instant start, normal ballast factor) ballast running a single lamp was used for this purpose. Power, current, and power factor were recorded for each sample.

Flicker was measured using a Sylvania Flicker Checker.

4.4 PHOTOMETRIC MEASUREMENTS

Photometric measurements were made using a two-meter integrating sphere with a SphereOptics SMS-500E spectrophotomer according to the IES LM-79 standard. Two samples of each lamp model were tested. Lamp properties measured include light output (i.e., luminous flux), correlated color temperature (CCT), color rendering index (CRI), and chromaticity coordinates. Spectral power readings were taken at 1 nm increments.

4.5 REFRIGERATION CASE OPTICAL PERFORMANCE

In order to evaluate the brightness and light distribution of the different sources in a refrigeration case, a special test apparatus was assembled and HDR (high dynamic range) imaging was performed. A three bay Hussmann refrigeration case was mounted with T8 lamp holders, and the shelves were blocked out with white foam board to produce an even surface for the observation of lamp output. A picture of the test apparatus can be seen in Figure 3.

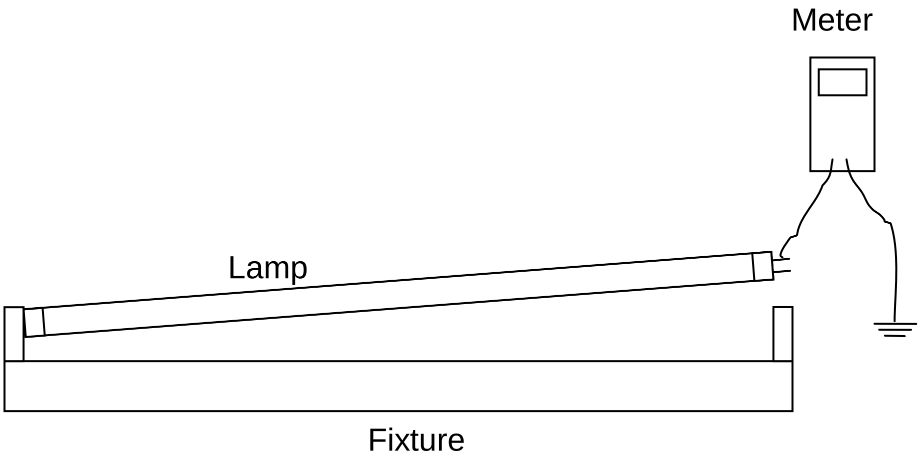
Matching sets of four lamps were installed in the refrigeration case. HDR images were created using a Nikon Coolpix 5400 camera with fisheye lens and then imported into Photolux software (a HDR imaging software). Maximum, minimum and average luminance values and standard deviation were recorded. This setup was used to provide relative data between the different lamp types. Only 5’ lamps were analyzed for refrigeration case performance as they are typically used in this application. A 5’ fluorescent lamp was used as a reference. Each GE F40T8/SPX30 fluorescent lamp (5’, 40-watt, 3000K) was powered using a single Sylvania QTP2x32T8/UNV ISN-SC ballast (the ballast was rated to operate only a single 5’ lamp).

Figure 3: Refrigeration Case Setup

4.6 SAFETY EVALUATION

Safety evaluation began by determining the UL or other certification listing of the lamps used in the study. Lamps also were tested for current and voltage to ground through exposed pins, with one end of the lamp connected. This was done to replicate what might happen in a real retrofit situation (i.e., someone touches the lamp's pins when the pins on the other side are energized). A diagram of the tested setup can be found in Figure 4. Further potential problematic wiring situations were noted and explored later in the report.

Figure 4: Setup for Testing Safety of Exposed Pins



4.7 LIFE TESTING

Though life testing evaluation was specified in the original scope of work, it was determined that not enough time was allowed for the 6,000-hour minimum specified by the IES LM-80 standard. As such, SMUD chose not to pursue life testing.

4.8 THERMAL TESTING

Thermal testing also was specified in the original scope of work but could not be completed because of the project's time restrictions. As such, SMUD chose not to pursue thermal testing.

5.0 RESULTS AND DISCUSSION

5.1 STANDARDS AND COMPLIANCE

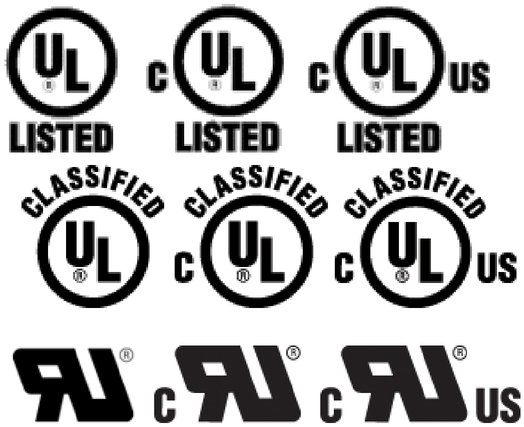
Standards testing and certification in the U.S. is performed by Nationally Recognized Testing Laboratories (NRTLs), which are private organizations recognized by the U.S. Occupational Safety and Health Organization (OSHA) as meeting certain testing standards. NRTLs are responsible for testing consumer products to certain published standards such that end users can be assured of the product's safety. Some of the more well-known NRTLs in the U.S. include Underwriters Laboratories (UL), Intertek Testing Services (formerly known as ETL), and MET Laboratories. UL is responsible for creating many of the standards to which other NRTLs test products.

5.1.1 UL MARKS

Underwriters Laboratory is a Nationally Recognized Testing Laboratory whose mark is widely accepted as a certification for a wide array of products including lighting. Most jurisdictions require some certification of building products to ensure that the products meet a basic level of safety criteria before they are installed on a job site. As such, UL has a number of standards in place for testing and certifying traditional incandescent and fluorescent light sources and fixtures.

UL issues three main types of marks in the U.S.: the UL Listing, the UL Classification, and the UL Recognized Component. UL Listed products are complete end products that have passed UL’s safety evaluation. UL Classified products have been “evaluated but only with respect to specific properties, a limited range of hazards, or suitability for use under limited or special conditions” (see www.UL.com, Marks Appearance and Significance). The UL Recognized Component mark is “specifically used on component parts that are part of a larger product or system” and intended to be factory installed into a larger UL Listed system. Illustration of the marks can be found in Figure 5.

Figure 5: UL marks - Listed, Classified, Recognized (top to bottom)



5.1.2 UL FOR LED PRODUCTS

LED retrofit lamps are a new and novel technology, and until recently, there was no clear UL standard that applied specifically to LED products. At the end of 2009, however, UL published ANSI/UL 8750 “Safety Standard for Light Emitting Diode (LED) Equipment for Use in Lighting Products.” This standard covers “LED equipment that is an integral part of a luminaire or other lighting equipment” and also “the component parts of light emitting diode (LED) equipment, including LED drivers, controllers, arrays, modules, and packages.” (UL 8750 Scope) As such, there is now a clearer standard addressing LED replacement lamps, though it had not yet been published when lamps were ordered for this study.

Because no UL standard yet existed for LED replacement lamps at the outset of this study, the tested lamps use a variety of routes to gain UL certification or certification through another NRTL. A summary of certifications can be found in Table 2: Lamp Certifications. Only two lamps in the study (B and D) had a UL certification, and these products were tested to different UL standards.

Product D is listed under the UL category “Luminaire Conversion, Retrofit,” which takes into account UL 1598 “Standard for Safety of Luminaires,” UL1598B "Supplemental Requirements for Luminaire Reflector Kits for Installation on Previously Installed Fluorescent Luminaires" and UL153 "Portable Electric Luminaires." This category covers “retrofit devices or kits consisting of parts and/or subassemblies intended for field installation in UL Listed luminaires” and specifically “retrofit kits consisting of light-emitting-diode (LED) light sources intended to replace a fluorescent lamp and where it is necessary to modify the luminaire” (www.UL.com – General Information for Luminaire Conversions, Retrofit). It is likely that in the future, an LED lamp submitted under the category “Luminaire Conversion, Retrofit” also will be subjected to the new UL 8750 standard.

The manufacturer of Product B had its lamps listed under the UL category “Lamps, Specialty – Component,” which takes into account UL 496 “Lamp holders” and UL 1993 “Self-Ballasted Lamps and Lamp Adaptors” and covers “materials or components intended for use in the manufacture of finished incandescent and discharge lamps, as well as other light-source technologies, such as light-emitting diodes or electroluminescent panels” (www.UL.com – General Information for Lamps, Specialty – Component). However, the category description also states that “the devices covered under this category are incomplete in certain constructional features or restricted in performance capabilities and are intended for use as components of complete equipment submitted for investigation rather than for direct separate installation in the field. THE FINAL ACCEPTANCE OF THE COMPONENT IS DEPENDENT UPON ITS INSTALLATION AND USE IN COMPLETE EQUIPMENT SUBMITTED TO UNDERWRITERS LABORATORIES INC.” (www.UL.com – General Information for Lamps, Specialty – Component). As such, these lamps are listed with the UL recognized component mark that indicates that they are a component and not a complete listed product. In all likelihood, this UL recognition does not cover their use in retrofits of existing lighting fixtures.

Product C comes with a UL recognized external low-voltage power supply, but this may not indicate the safety of the entire system.

While Products B and D are listed/recognized under UL categories that include mention of LED products, the standards used do not specifically cover issues particular to LED products. The new standard, UL 8750, ensures that the safety issues unique to LED light sources will be addressed in the future.

Product G uses an MET listing that is tested in compliance with UL 1993 "Lamps, Self-Ballasted." MET Laboratories is another Nationally Recognized Testing Laboratory that tests products in accordance with UL standards. Many retailers will accept an MET certification though it does not have the name recognition of UL.

Two lamps bear no UL mark but do bear the CE mark, which indicates conformity with European Union consumer safety, health, and environmental requirements. The CE mark is mandatory for products sold throughout the European Union and most other European nations. One concern about this certification is that CE conformity is "Self Declared," which may potentially lead to more non-conforming products than the UL mark.

Finally, Product E bears no certification mark of any kind.

Table 2: Lamp Certifications

Product	Listing	Listing Number
A	CE mark	-
B	UL recognized as "lamp, specialty - component"	OONB2.E316640
C	UL recognized power supply	-
D	UL listed as "luminaire conversion, retrofit"	IEUQ.E327351
E	no information	-
F	CE mark	-
G	MET certification in compliance with UL 1993 "self ballasted lamps"	-

5.1.3 CONCERNS

There are a number of concerns related to the certification of LED retrofit lamps, LED products, and electrical products in general. While the UL mark is viewed as a guarantor of safety and quality, it only applies to a specific usage of a product. If a product bears a UL mark, this does not ensure that the product will be used in accordance with the marking.

To illustrate, Product B is UL Recognized as a "Lamp, Specialty – Component" which means that it is tested for use as a component of a factory-assembled system that could then go on to be UL Listed. Field installation of this lamp/driver product in an existing fluorescent lighting fixture is not in accordance with the product's UL marking, as the "component" evaluation would not address this situation. When the lamp is marketed as a direct replacement for linear fluorescent lamps, this UL Recognized marking may mislead consumers or AHJs (Authorities Having Jurisdiction) into thinking the replacement lamp has been approved for fixture retrofit applications, when it has not.

Similarly, manufacturers have been known to apply UL markings to products that have never been evaluated by UL. Because of this concern, it is recommended that consumers search www.UL.com to find out whether a UL marking is genuine. UL markings still rely somewhat on the honesty and good intentions of the manufacturer, and a mark on a product should not be taken as a guarantee of its safety.

5.2 PHYSICAL PROPERTIES

Lamp physical properties are summarized in Table 1. In general, lamp construction varied widely, from low-quality appearance and feel to high-quality, sturdy appearance and feel. Lamp housings were constructed from plastic, aluminum or a combination of the two as seen in Figure 2. Most of the lamps consisted of a clear or frosted plastic lens on the front side of the lamp body and an aluminum back that functions as a heat sink. Two of the tested lamps had radial fins on the back half, designed to increase their heat sink surface area. Three of the lamps had a smooth or mostly smooth exposed metal back. One lamp had a smooth aluminum back that was enclosed in plastic that continued around from the front lens.

Four of the lamps had a clear plastic front lens, two of them had a lens with some sort of light-directing optics, and one lamp (B) was entirely composed of an aluminum tube with holes cut out to expose the LEDs and allow light out of the lamp (i.e., no lens). All of the lamps except for Product B were permanently fitted with medium bi-pin sockets. Product B, however, came with removable socket adaptors, allowing the lamp to be used in a T5 or a T8/T12 application (T5 lamps have smaller sockets than T8 lamps, thus the need for socket adapters).

Four of the tested lamps used SMT LEDs and three of the lamps used THT LEDs. See Figure 1 for illustration of LED chip type and layout.

One sample of Product F arrived with only half of the LEDs functioning when powered. This seems to indicate poor construction or quality control, though the product could have been damaged in shipment. The manufacturer was contacted and quickly replaced the broken lamp.

All of the lamps were capable of fitting in the space of an existing 4’ or 5’ T8 fluorescent fixture, though their physical characteristics varied somewhat.

5.3 POWER MEASUREMENTS

Manufacturer-listed and measured power data is presented in Table 3, Table 4 and Table 5. Out of the seven products studied, five products failed to meet their manufacturer's reported lumen output, and none of the tested products met the manufacturer's stated efficacy level. Similarly, the power draw of the units was largely inconsistent with the listed values, with only units D and G falling within 2% of the manufacturer listed values.

Only three of the tested products had power factor data reported by the manufacturer. Measured power factors were largely satisfactory (over 0.8) though product B had a stated power factor of >0.8 and measured a power factor of 0.31 on the Yokogawa PZ4000 Power Analyzer.

These results are consistent with recent CALiPER report findings that show that few LED retrofit lamps meet manufacturer claims.

Flicker testing showed that most of the lamps have minimal flicker, equivalent to fluorescents with electronic ballasts, but one lamp showed considerable flicker, like that of a fluorescent on a magnetic ballast.

Table 3: Lamp Life, Current, and Power Factor

Product	Power Supply	Length (ft)	Listed Life (hrs)	Measured Current (mA)	Listed Power Factor	Measured Power Factor	Measured Flicker
A-1	Ballast Voltage	4	87600	253	ballast dependent	1.00	N
A-2				251		1.00	N
C-1	Low Voltage External	4	60000	193	not listed	0.99	N
C-2				192		0.99	N
D-1	Line Voltage	4	60000	157	not listed	0.93	Y
D-2				157		0.93	Y
B-1	Low Voltage External	5	50000	310	0.8	0.31	N
B-2				310		0.31	N
E-1	Line Voltage	5	35000	270	0.95	0.81	N
E-2				200		0.97	N
F-1	Line Voltage	5	80000	141	not listed	0.87	N
F-2				148		0.90	N
G-1	Line Voltage	5	30000	180	0.95	0.99	N
G-2				180		0.99	N
table reordered to group 4' and 5' lamps							

Table 4: Lamp Luminous Flux and Lumens/ft

Product	Listed Luminous Flux (lm)	Measured Luminous Flux (lm)	Variation between Listed and Measured Luminous Flux	Listed Lumens/ft	Measured Lumens/ft	Variation between Listed and Measured Lumens/ft
A-1	1900	1398	-26.4%	475	349.5	-26.4%
A-2		1388	-26.9%		347	-26.9%
C-1	1350	1601	18.6%	337.5	400.25	18.6%
C-2		1567	16.1%		391.75	16.1%
D-1	1250	1150	-8.0%	312.5	287.5	-8.0%
D-2		1144	-8.5%		286	-8.5%
B-1	1000	588	-41.2%	200	117.6	-41.2%
B-2		620	-38.0%		124	-38.0%
E-1	1500	1596	6.4%	300	319.2	6.4%
E-2		1590	6.0%		318	6.0%
F-1	1620	1038	-35.9%	324	207.6	-35.9%
F-2		1119	-30.9%		223.8	-30.9%
G-1	1980	1414	-28.6%	396	282.8	-28.6%
G-2		1472	-25.7%		294.4	-25.7%
table reordered to group 4' and 5' lamps						

Table 5: Lamp Power and Efficacy

Product	Listed Power (W)	Measured Power (W)	Variation in Listed and Measured Power	Listed Efficacy (lm/W)	Measured Efficacy (lm/W)	Variation in Listed and Measured Efficacy
A-1	21	30.8	46.7%	90	45.4	-49.6%
A-2		30.7	46.1%		45.2	-49.8%
C-1	18	23.1	28.3%	75	69.3	-7.6%
C-2		23.1	28.6%		67.7	-9.7%
D-1	18	17.7	-1.8%	69.4	65	-6.4%
D-2		17.7	-1.7%		65	-6.4%
B-1	27	11.9	-55.9%	100	49.4	-50.6%
B-2		11.9	-55.9%		52.1	-47.9%
E-1	22	26.0	18.2%	68.2	61.4	-9.9%
E-2		23.6	7.3%		67.4	-1.1%
F-1	18	14.9	-17.2%	90	69.6	-22.7%
F-2		16.2	-10.0%		69.1	-23.2%
G-1	22	21.6	-1.8%	90	65.6	-27.1%
G-2		22.1	0.5%		66.6	-26.0%
table reordered to group 4' and 5' lamps						

5.4 PHOTOMETRIC MEASUREMENTS

Measured and listed photometric values are shown in Table 6. Section 5.3 addresses lumen output and efficacy and concludes that in most cases studied, lamp output and efficacy do not meet manufacturer claims.

Measured CCT roughly correlated to the manufacturer's listed values except for Product D, which measured approximately 6500K despite the listed CCT of 5000-5500K. It was suspected that the wrong version of the lamp had been received from the manufacturer, but 5000-5500K is the coolest color temperature version offered on their Web site. As such, it is likely that manufacturer has incorrectly reported the color temperature for this lamp.

Measured CRI values were below manufacturer claims except for Product D, which slightly exceeded the listed CRI, and Product E, which had no listed CRI value.

Table 6: Measured and Listed Photometric Values

Product	Listed Luminous Flux (lm)	Measured Luminous Flux (lm)	Listed Lumens/ft	Measured Lumens/ft	Listed CCT	Measured CCT	Listed CRI	Measured CRI
A-1	1900	1398	475.0	118.8	4100	4363	85	76
A-2		1388		0.0		4295		76
C-1	1350	1601	337.5	84.4	4000-4400	4511	75	62
C-2		1567		0.0		4526		63
D-1	1250	1150	312.5	78.1	5000-5400	6493	75	77
D-2		1144		0.0		6516		77
B-1	1000	588	200.0	40.0	4000	3973	83-85	81
B-2		620		0.0		4009		82
E-1	1500	1596	300.0	60.0	4000-4500	4326	no listing	71
E-2		1590		0.0		4322		70
F-1	1620	1038	324.0	64.8	4100	4346	84	70
F-2		1119		0.0		4304		69
G-1	1980	1414	396.0	79.2	4100	4217	75% @ 5000K*	73
G-2		1472		0.0		4202		73

* as listed on manufacturer cutsheet

5.5 OPTICAL PERFORMANCE

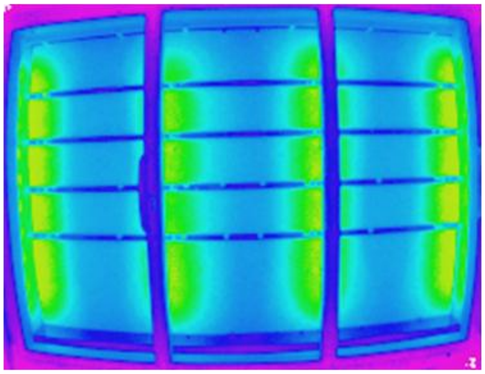
Refrigeration case HDR luminance measurements are shown in Table 7. Maximum and average luminance for all tested 5' LED retrofit lamps clearly falls below the level of illumination produced by a standard fluorescent system.

Figure 6 shows Photolux HDR images of the retrofitted freezer case using the different 5' products used in this study. All HDR images used the same luminance scale.

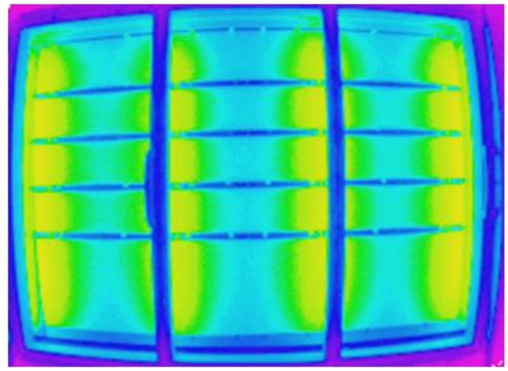
Table 7: Refrigeration Case Luminance Measurements

Product	Max. (cd/m^2)	Min. (cd/m^2)	Avg. (cd/m^2)	RMS (cd/m^2)
B	491	1.90	93.20	96.73
E	1,040	3.10	213.20	202.10
F	718	2.40	156.82	139.80
G	931	4.50	196.81	171.78
5' fluorescent reference*	5,240	5.90	357.19	325.96

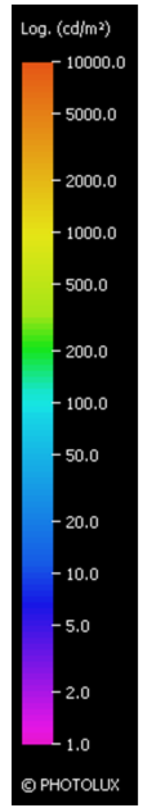
* GE F40T8/SPX30 with Sylvania QTP2x32T8/UNV ISN-SC ballast

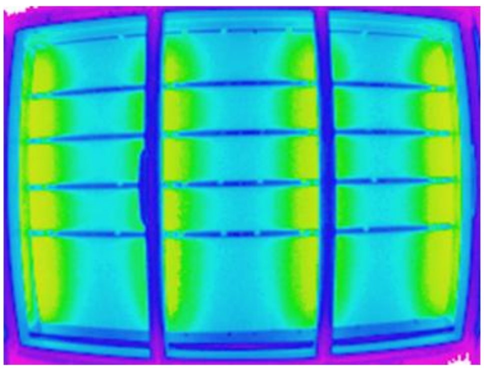


Product B Photolux Image

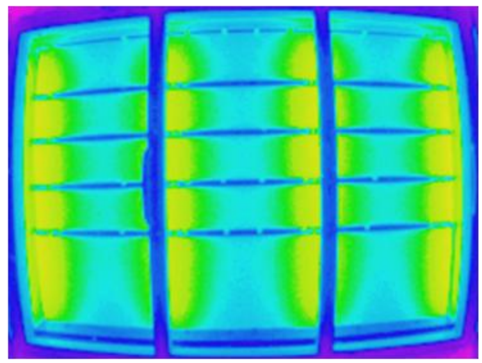


Product E Photolux Image

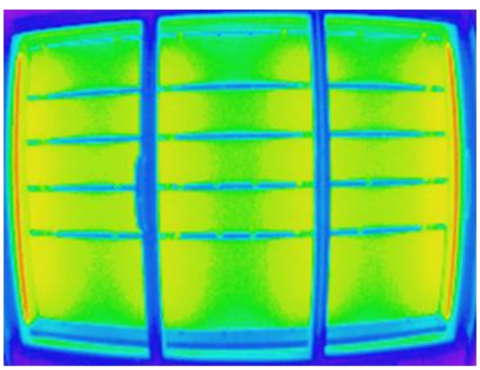




Product F Photolux Image



Product G Photolux Image



5' Fluorescent Photolux Image

Figure 6: Photolux Images of 5' Lamps in Refrigeration Case

5.6 SAFETY TESTING

LED retrofit lamps for linear fluorescent lamps present a number of safety hazards that do not seem to be addressed by any of the existing UL standards. The main safety concerns are the presentation of live current through unconnected end pins and lamps with broken housings that continue to operate, thus exposing users to unprotected live parts.

5.6.1 EXPOSED LIVE PINS

LED retrofit lamps were tested for current and voltage from unconnected end pins to ground, and the results are presented in Table 8. It is clear from the results that accidentally touching the exposed end pins of a replacement lamp after inserting the other end into a live socket could result in an electrical shock. A number of the lamps present potentially dangerous levels of current at line voltage.

Table 8: Current and Voltage of Unconnected End Pins to Ground

Product	AC open end V to ground (V)	AC open end I to ground (mA)	DC potential (V)	DC current (mA)
A	195VAC	24mA	-	-
B	-	-	29.8V	290mA
C	-	-	11V	758mA
D	64VAC	164mA	-	-
E	123VAC	158mA	-	-
F	123VAC	153mA	-	-
G	123VAC	182mA	-	-
***fluorescent reference**	84V	5.6mA	-	-

*F032/841 fluorescent lamp with Sylvania QTP2x32T8/UNV ISN-SC ballast

5.6.2 EXPOSED LIVE COMPONENTS

The construction of an LED retrofit lamp means that most lamps will not stop functioning when their housing is damaged. A fluorescent lamp, on the other hand, will not function if the glass tube has been broken. This means that a user with a broken LED tube light could put it into a fixture, energize it, and be exposed to live components.

5.6.3 FIXTURE REWIRING

The great majority of T8 LED retrofit lamps on the market require that the existing fluorescent ballast be removed and the fixture rewired such that there is 120V mains power running directly to the fluorescent sockets. Most end users aren't prepared or trained to do this kind of retrofit. This work should be done by a licensed electrician, and the extra wiring needed will contribute to the price of an LED retrofit lamp project.

6.0 CONCLUSIONS

In summary, LED replacements for T8 linear fluorescent lamps were found to use less power than traditional fluorescent lamps but also produce considerably lower light output. Similarly, light output tended to be lower than manufacturer listed values, and power draw tended to be higher than manufacturer listed values. As a result, lamp efficacy was generally lower than manufacturer claims. Measured CRI values for LED T8 linear replacement lamps in this study tended to be lower than manufacturer claims, though CCT was generally close to the manufacturer reported value. Testing in a refrigeration case environment further illustrated that the light output of LED T8 linear replacement lamps is lower than traditional T8 linear fluorescent lamps.

This study explored certification of LED retrofit lamps and found that many are not UL (or other NRTL) listed, and some are inappropriately listed. This is bound to improve, but standards are still catching up with the state of the technology on the market.

Finally, the study shows that exposure to the open pins of a connected LED T8 linear retrofit lamp presents a shock hazard to those installing the lamps.