Long-Term Performance Evaluation of LED Lighting Products

Widespread adoption of LED lighting for general illumination is one of the most significant advances in building efficiency of the 21st century. To compete in this market, the majority of LED manufacturers first focused on efficacy improvements and cost reductions. Historically, this came at the expense of product quality and feature optimization. Now, LED technology and manufacturers are positioned to incorporate consumer-optimized features into their products as a means to improve product performance, consumer satisfaction and the sustained use of LED solutions, all of which will lead to increased environmental benefits and electricity savings.

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To accelerate this process, the California Lighting Technology Center initiated a four-year research program with funding from the California Energy Commission to design and develop novel, energy-efficient LED lighting solutions with the quality and performance features desired by consumers. To achieve alignment with consumer needs, designs and other performance outcomes were based on results from two characterization studies:

1. Consumer studies that evaluated quality, performance and function through a series of laboratory-based experiments.
2. Long-term testing of commercially available LED light sources to determine if today's existing products meet stated performance when installed in worst-case thermal conditions typical of applications designed to comply with California's Building Energy Efficiency Standards (Title 24).

LD+A "Research" articles from May 2019 and August 2019 discuss outcomes from two consumer studies performed as part of this effort. This article focuses on outcomes from the long-term testing of commercially available LED light sources.

Market Assessment. In 2016, CLTC researchers conducted a market assessment to identify and characterize common LED lamp types and their energy use. Researchers inventoried commercially available LED products in the following four product categories: linear LED lamps, omni-directional LED lamps, directional LED lamps and candelabra LED lamps. This inventory included LED products from 69 manufacturers. The collection did not reflect the whole market but covered the majority of manufacturers offering products in the previously referenced categories.

Based on existing California standards and appliance regulations, three overarching performance criteria were used to narrow the product inventory and select products for evaluation:

- 90 CRI or greater
- Target CCT of falling inside the ANSI bin for manufacturer-claimed performance
- Dimmable

Given these constraints, the researchers identified and procured 23 representative LED products for evaluation under the test program. Selection prioritized lamp types that are the largest contributors to national-lighting energy use, per **Table 1**. Composition of selected products was 57% linear LED lamps, 41% medium screw-base LED lamps and 2% other. The project team selected candelabra LED lamps to fulfill the "other" category.

Product Selection. While the aforementioned criteria were prioritized at the time of purchase, only eight commercially available products met the 90-CRI-

or-greater requirement. After selection of all available 90-CRI-or-greater products, the remaining budget was used to procure lamps that had less than 90 CRI from prominent manufacturers and at competitive price points, while keeping with the overall sample set with the lamp distribution that mirrored national energy-use distribution data. Products with a variety of electrical, thermal and photometric design approaches were included to evaluate how each performs over time. The full list of products and their manufacturer claimed performance used for the long-term performance testing is shown in **Table 2**.

Six samples of each product were purchased via typical distribution channels during Q4 2016 and Q1 2017 for 138 lamps.

Test Setup. System components used in the evaluation included LED lamps, ballasts or drivers depending on product type, and housings or fixtures. Ballast selection was driven by the prevalence of ballasts installed in today's commercial building stock. Driving factors for housing selection were socket orientation, number of sockets and trim options. The medium screw-base, linear LED replacement lamps and candelabra lamps each use a different fixture configuration in the run-time test rack (**Figure 1**).

Medium screw-base lamps were installed in recessed fixtures rated as airtight and for insulation contact to understand how this specific, enclosed application affected the lifetime of the lamp. Downlight housings with airtight trim kits were used for omni-directional products, as shown in Figure 1. These components were chosen to ensure compliance with the mandatory residential lighting requirements (Section 150.0(k)1C) of California's Building Energy Efficiency Standards (Title 24). All of the downlight housings were wrapped with R-19 building insulation to simulate typical operating conditions. Directional medium screw-base products were tested in the same housing without the lens.

Four-foot, single lamp, sealed fixtures were identified as the most intensive thermal conditions that a linear LED replacement lamp would experience for indoor applications, shown in Figure 1. The instant-start ballast that ships standard with the fixture was used with the UL Type A products. The fixtures were modified to accommodate UL Type B and UL Type C replacement products with varying wire and mounting configurations.

Vanity fixtures equipped with candelabra sockets and enclosed globes were identified as being the most intensive thermal conditions that a candelabra lamp would experience for

Lamp Type	Annual National Residential Energy Use (GWh)	Annual National Commercial Energy Use (GWh)	Total (GWh)	Lighting Energy Use Contribution (%)
Medium Base Lamp (Incandescent, CFL, Halogen)	158,730	50,166	208,896	41%
Linear Fluorescent	15,658	277,585	293,243	57%
Other (LED, HID, etc.)	1,872	6,689	8,560	2%
TOTAL	**176,260**	**334,440**	**510,700**	**100%**

Table 1. National energy use by lamp type

Table 2. Replacement LED lamps selected for testing with manufacturer claimed performance

Product Description	Light Output (lm)	Power (Watt)	Power Factor	CCT (Kelvin)	CRI	Rated Life (Hrs.)
Candelabra, E12 base	350	5	N/A	2,700	90	25,000
Candelabra, E12 base	500	6	0.7	2,700	90	25,000
Directional Flood, E26 base, BR40	1,000	14	N/A	2,700	93	25,000
Directional Narrow Flood, E26 base, BR30	655	9	>0.9	2,700	80	25,000
Directional Wide Flood, E26 base, PAR20	640	11	N/A	2,700	85	35,000
Filament omnidirectional, E26 base	800	7	N/A	2,700	80	20,000
Omnidirectional, E26 base	800	9.8	N/A	2,700	90	25,000
Omnidirectional, E26 base	800	9	N/A	2,700	92	25,000
Omnidirectional, E26 base	450	7	N/A	2,700	80	25,000
Directional Flood, E26 base, BR30	800	12	N/A	2,700	93	25,000
Directional Narrow Flood, E26 base	800	10.5	N/A	2,700	90	50,000
Omnidirectional, E26 base, PAR20	445	7	0.9	3,000	94	25,000
Directional Flood, E26 base, PAR38	1,200	17	N/A	2,700	82	25,000
Filament omnidirectional, E26 base	500	5	0.9	2,700	80	25,000
Directional Flood, E26 base, PAR30	960	12	>0.9	2,700	75	50,000
Omnidirectional, E26 base	800	8	N/A	2,700	80	25,000
TLED - UL Type C	4,500	44	0.9	3,500	80	50,000
TLED - UL Type A	2,290	22	0.95	3,000	80	50,000
TLED - UL Type B	1,800	15	N/A	3,000	80	50,000
TLED - UL Type B	2,200	18	>0.9	3,500	85	50,000
TLED - UL Type A	2,000	15	N/A	3,000	82	50,000
TLED - UL Type A	1,800	14	N/A	3,000	83	50,000
TLED - UL Type A/B	1,600	15	N/A	3,000	80	50,000

indoor applications. The fixtures were mounted with lamps oriented base-up with the globe connecting to the fixture via thumbscrews.

Life testing was conducted according to Illuminating Engineering Society *LM-84-14: Measuring Luminous Flux and Color Maintenance of LED Lamps, Light Engines, and Luminaires*, which provided electrical and photometric measurements every 1,000 hours of run time for full output. Electrical and photometric measurements were made in accordance with the Illuminating

Engineering Society *LM-79-08 Approved Method: Electric and Photometric Measurements of Solid State Lighting Products* in an integrating sphere. Flicker data was also collected in an integrating sphere using custom instrumentation.

Electrical metrics measured include power, current, voltage, power factor and total harmonic distortion. Spectral power distribution data collected simultaneously with electrical data every 1,000 hours of operation was used to calculate luminous flux, chromaticity (CIE 1932 x, y), correlated color temperature (CCT), D_{UV} and CRI. Flicker data was used to calculate flicker index and percent flicker.

Study Conclusions. Evaluation results showed that LED replacement lamps met most of the performance criteria claimed by their manufacturers; however, no single commercially available product met all dimming and color quality criteria set by the project. Researchers also evaluated the products for safety issues, including appropriate markings. No safety concerns were encountered over the course of the evaluation. No issues regarding safety markings were identified for the lamps evaluated.

Figure 1. Test rack showing downlights with LED A-lamps (left) and 4-ft indoor fixtures for linear LED lamps (right)

Forty-nine individual lamps failed to turn on over 12,000 hours of testing. This is a 36% failure rate for the sample set. Failure modes and number of samples for each failure mode are shown in **Table 3.**

Projected rated life (L_{70}) calculations using IES LM-84-14 and TM-28-14 determined that 14 of the 23 products exceeded manufacturer-claimed rated life, while nine of the 23 products were

Product Category	Failure Mode	Number of Failed Samples (out of 6 total tested)
Directional MSB LED Products	LED Array	4
	Melted Optic	6
	Driver	4
Omni-Directional MSB LED Products	LED filament array	6
	N/A	1
	Driver	3
	LED filament array	6
Linear LED Lamps	Connections	6
	Driver	1
	Resistor	4
Candelabra LED Lamps	Non-functioning LED array	6

Table 3. Lamp failure modes by product category

Table 4. Projected rated life (L_{70}) for 23 tested products

	Manufacturer Claimed Rated Life (hours)	Projected Rated Life (L_{70}) Based on In-Situ Performance (hours)	Manufacturer Recommended Operating Conditions
Directional MSB LED Lamps	25,000	>60,000	None provided
	25,000	N/A (4 failures)	None provided
	35,000	N/A (6 failures)	Recessed downlights
	25,000	>60,000	Not for use in enclosed fixtures
	25,000	>60,000	Suitable for use in totally enclosed luminaires
	25,000	>60,000	UL approved for damp location and enclosed fixtures
Omni-directional MSB LED Products	20,000	N/A (6 failures)	None provided
	25,000	>60,000	None provided
	25,000	>60,000 (1 failure)	Not intended for use in totally enclosed fixtures
	25,000	N/A (3 failure)	None provided
	25,000	>60,000	Not for use in totally enclosed luminaires
	25,000	N/A (6 failures)	None provided
	25,000	>60,000	None provided
Linear LED Lamps	50,000	N/A (6 failures)	Existing dry or damp rated linear fluorescent fixtures including troffers, parabolics, strips, wraps, volumetric/baskets and industrials; not intended for use in vaportights
	50,000	>60,000	Capable of indoor usage in -5ºF to 115ºF temperature range
	50,000	>60,000	None provided
	50,000	>60,000	Suitable for enclosed fixture
	50,000	>60,000 (1 failure)	Suitable for use in fixtures where ambient temperature is between -4°F (-20°C) and 113°F (45°C)
	50,000	>60,000	Not rated for use in fully enclosed fixtures
	50,000	>N/A (4 failures)	None provided
Candelabra LED Lamps	25,000	N/A (6 failures)	None provided
	25,000	>60,000	None provided

unable to meet the manufacturer-claimed rated life when operated in conditions typical of California buildings. This is a 39% failure rate of the products tested. A summary of the findings compared to the manufacturer recommended operating conditions are provided in **Table 4.** ◎

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