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CALiPER

Application Summary Report 19:

LED Linear Pendants

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Prepared by:

Pacific Northwest National Laboratory

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1 Preface

The U.S. Department of Energy (DOE) CALiPER program has been purchasing and testing general illumination solid-state lighting (SSL) products since 2006. CALiPER relies on standardized photometric testing (following the Illuminating Engineering Society of North America [IES] approved method LM-79-08[1]) conducted by accredited, independent laboratories.[2] Results from CALiPER testing are available to the public via detailed reports for each product or through summary reports, which assemble data from several product tests and provide comparative analyses.[3]

It is not possible for CALiPER to test every SSL product on the market, especially given the rapidly growing variety of products and changing performance characteristics. Starting in 2012, each CALiPER summary report focuses on a single product type or application. Products are selected with the intent of capturing the current state of the market—a cross section ranging from expected low to high performing products with the bulk characterizing the average of the range. The selection does not represent a statistical sample of all available products. To provide further context, CALiPER test results may be compared to data from LED Lighting Facts,[4] ENERGY STAR® performance criteria,[5] technical requirements for the DesignLights™ Consortium (DLC) Qualified Products List (QPL),[6] or other established benchmarks. CALiPER also tries to purchase conventional (i.e., non-SSL) products for comparison, but because the primary focus is SSL, the program can only test a limited number.

This report on LED linear pendants deviates somewhat from the traditional CALiPER approach of comparing numerous products against performance criteria and/or sample benchmarks. Rather, the LED products are compared directly against versions of the same product that use a fluorescent lamp(s); this detailed approach provides a more appropriate basis for evaluation given the diversity of linear pendant luminaires. In order to complete the analysis, data from CALiPER testing was augmented with data from IES-format files available from manufacturers. The limitations of this approach are discussed in subsequent sections.

It is important for buyers and specifiers to reduce risk by learning how to compare products and by considering every potential SSL purchase carefully. CALiPER test results are a valuable resource, providing photometric data for anonymously purchased products as well as objective analysis and comparative insights. However, LM-79-08 testing alone is not enough to fully characterize a product—quality, reliability, controllability, physical attributes, warranty, compatibility, and many other facets should also be considered carefully.

For more information on the DOE SSL program, please visit http://www.ssl.energy.gov.

[1] IES LM-79-08, *Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products*, covers LED-based SSL products with control electronics and heat sinks incorporated. For more information, visit http://www.iesna.org/.

[2] CALiPER only uses independent testing laboratories with LM-79-08 accreditation that includes proficiency testing, such as that available through the National Voluntary Laboratory Accreditation Program (NVLAP).

[3] CALiPER summary reports are available at http://www.ssl.energy.gov/reports.html. Detailed test reports for individual products can be obtained from http://www.ssl.energy.gov/search.html.

[4] LED Lighting Facts is a program of the U.S. Department of Energy that showcases LED products for general illumination from manufacturers who commit to testing products and reporting performance results according to industry standards. The DOE LED Lighting Facts program is separate from the Lighting Facts label required by the Federal Trade Commission (FTC). For more information, see http://www.lightingfacts.com.

[5] ENERGY STAR is a federal program promoting energy efficiency. For more information, visit http://www.energystar.gov.

[6] The DesignLights Consortium Qualified Products List is used by member utilities and energy-efficiency programs to screen SSL products for rebate program eligibility. For more information, visit http://www.designlights.org/.

2 Report Summary

This report contains two related datasets: a collection of nine independently tested and anonymously purchased LED linear pendants (referred to as *CALiPER Series 19*) and a collection of 11 linear pendant products available in both an LED and fluorescent version (referred to as the *supplemental data*). Six products are part of both datasets, providing substantial overlap.

The CALiPER program was only able to identify, acquire, and test a limited set of LED linear pendants. In addition, it is difficult to establish a single set of performance criteria or identify an ideal benchmark. Given these conditions, and with limited input from programs such as LED Lighting Facts, ENERGY STAR, or the DLC QPL, the analysis in this report was completed primarily using the supplemental data, which allowed for a one-to-one comparison of LED and fluorescent products.

For almost all product types considered, the LED version(s) were more efficacious than the linear fluorescent version(s). Many, but not all, of the LED products also had color quality attributes similar to what is expected from linear fluorescent lamps. However, the luminous intensity distribution often differed; particularly for products using an optical system other than a diffuse lens, the LED and fluorescent versions did not match. Further, lumen output of the LED version(s) and fluorescent version(s) was usually not similar—which is just one reason why specifiers cannot assume that differently lamped versions of the same luminaire can be used interchangeably.

3 Background

Typical Applications

Linear pendants are primarily used to provide general ambient illumination in office, retail, and classroom applications, although they may be used in a wide variety of spaces. Nominally four-foot long fixtures have become the standard size, matching the approximate length of linear fluorescent lamps, with shorter and longer fixtures sometimes available. Linear pendants may be mounted individually, but are often arranged in continuous rows. The exact mounting height and spacing of rows are dependent on the luminous intensity distribution of the product and the distribution of light desired on the work plane and room surfaces.

Linear pendants are often chosen not only for their performance, but also for their physical appearance. This inspires the wide variety of housing shapes that are available from different manufacturers. Importantly, the housing shape often plays a role in performance. For example, narrow, slot-style luminaires may provide the desired aesthetic for a contemporary space, but they are often less efficient for fluorescent lamps because of their small aperture.

Types of Linear Pendants

Distribution Type

There are three basic groups of linear pendants, irrespective of their housing style, which can be divided based on luminous intensity distribution characteristics: direct (light emitted downward only), indirect (light emitted upward only), and direct-indirect (light emitted both downward and upward).[7] The choice of luminaire distribution type has important ties to performance. The direction of emitted light can affect the uniformity of light on the work plane, the perceived brightness of an architectural space or surface, direct and reflected glare, and cleaning considerations.

Lamping

The conventional linear pendant market is almost exclusively based on linear fluorescent lamps, which allow for a variety of performance characteristics and configurations. Many luminaires are available in versions using one or two T8, T5, or T5HO lamps (per four-foot increment), and sometimes more. This provides numerous lumen output levels from which to choose, although they are discrete. For T8 lamps, additional fine-tuning can be achieved by choosing a specific ballast to increase or decrease light output—this is characterized by the ballast factor, which ranges from approximately 0.7 to 1.2. The difference between product versions with different lamp types or quantities may be as minor as a different ballast, although there are different socket sizes and lengths for T8 and T5 lamps. Sometimes, changing the lamping can affect performance characteristics. For example, a switch from one lamp to two lamps will likely have some effect on the luminous intensity distribution.

Lamp selection also dictates the color quality of the emitted light. In North America, lamps with a color rendering index (CRI)[8] in the 80s and correlated color temperature (CCT) of 3500 K or 4100 K are most common in office and classroom applications, although a wide variety of lamps is available with color properties to suit almost any application. Fluorescent lamps of the same type are interchangeable, which allows for substitution but may also result in a mismatched appearance if care is not taken when lamps are replaced.

[7] The International Commission on Illumination (CIE) provides a more detailed classification system that includes six categories: direct, semi-direct, direct-indirect, general diffuse, semi-indirect, and indirect.
[8] Appendix A provides basic definitions for many of the technical terms used in this report.

Optical System
The optical systems of linear fluorescent luminaires vary widely. Besides the primary reflector (if applicable), optical systems at the aperture may include diffusers, prismatic lenses, louvers, baffles, or custom panels. These options allow customization of output, distribution, and appearance beyond what is possible based on lamping.

The size of the light source relative to the aperture affects efficiency and light output; more light is trapped by the optical system when the source size is large. Accordingly, two-lamp luminaires are usually less efficient than single-lamp versions.

LED Linear Pendants

LED linear pendants are now offered from a variety of manufacturers. Many of the products complement existing families of fluorescent products, using the same housing shapes and aperture options. As part of the regular CALiPER process, nine LED linear pendants were anonymously purchased in 2011 and 2012—they are referred to as the Series 19 products. The products underwent independent LM-79-08 testing, the results of which are shown in Appendix B. However, because linear pendants perform so differently—owing to their different functional and aesthetic qualities—it was not as informative to analyze them in the typical CALiPER fashion, which relies on selecting benchmark conventional products and analyzing data from other programs, such as LED Lighting Facts and ENERGY STAR. In fact, given the level of customization afforded to linear pendant specifiers, it is even difficult to survey the market and establish a set of performance parameters that LED products should meet.

Given the lack of clear-cut performance criteria, for this report the CALiPER Series 19 dataset has been augmented by products that were not independently tested or acquired, but identified through a survey of manufacturer literature. The resulting dataset includes 11 products that had at least one LED and one fluorescent version that could be directly compared using IES-format files.[9] This supplemental dataset includes six of the Series 19 LED products. Two of the six are similar but not direct matches to the collected data (e.g., the tested product was 4000 K, but an IES-format file was only available for 3500 K). There are several notable limitations associated with the supplementary dataset:

- The dataset relies on manufacturer data, which past CALiPER testing has sometimes shown to be inaccurate.
- For fluorescent products, the IES-format files—and the other listed data—are based on relative photometry rather than absolute photometry. Past testing has shown differences in these two methods, with relative photometry often overestimating the lumen output compared to absolute photometry.
- The manufacturer-supplied photometry for T5 and T5HO fluorescent lamps was performed with different assumptions of lamp lumen output. Established guidelines recommend testing the bare lamp and luminaire at 25°C ambient temperature, but the lamp operates more efficiently inside the hotter internal environment of the luminaire. Consequently, a thermal factor is introduced to the luminaire efficiency rating and the lumen output estimated from relative photometry may be unrealistic.
- As much as possible, the LED and fluorescent versions share the same lens or diffuser type, although it should be noted that fluorescent versions are often available with a greater variety of options than LED version(s).

[9] The availability of some IES-format files was considered a prerequisite for inclusion in the dataset because luminous intensity distribution was an important factor for evaluation. Many of the products also had additional versions for which luminous intensity distribution data was not available.

- Linear pendants are often available in a variety of styles and with several options. Many manufacturers offer a fluorescent version but not an LED version. Consequently, the choice of luminaires compared in this report does not represent a scientific sample of all available linear pendants.
- In order to provide a concise and consistent group, data for products using T8 fluorescent lamps was omitted.

Despite these limitations, the supplementary data provides unique and valuable insight into the performance of LED linear pendants compared to their fluorescent counterparts.

4 Results

The 11 product types included in the supplemental dataset are shown in Figure 1. All of the products were available with at least three lamping options, as shown in Table 1, but detailed photometric data was not always available for all versions. Table 2 provides summary data, focused on lumen output and efficacy, for the versions of the supplemental products with available photometric data—T8 versions are not included. Many other performance criteria, such as color quality, should be used when making evaluations; these are subsequently discussed but not included in Table 2. Additional notes are as follows:

- Products marked with an asterisk and labeled with a CALiPER ID number (e.g., 11-81) were recently tested by CALiPER.
- Some of the products were available in LED versions with multiple output levels; these are denoted *LED, LED2*, etc.
- Products listed as having a direct distribution emitted all of the lumens in the 0° to 90° zone.
- Two of the products had a direct-indirect distribution. The downlight for product type H was approximately 50% of the total lumens, whereas the downlight for product type I was approximately 20%. There were small variations between the different lamping options.
- No products matching the selection criteria had an indirect distribution.

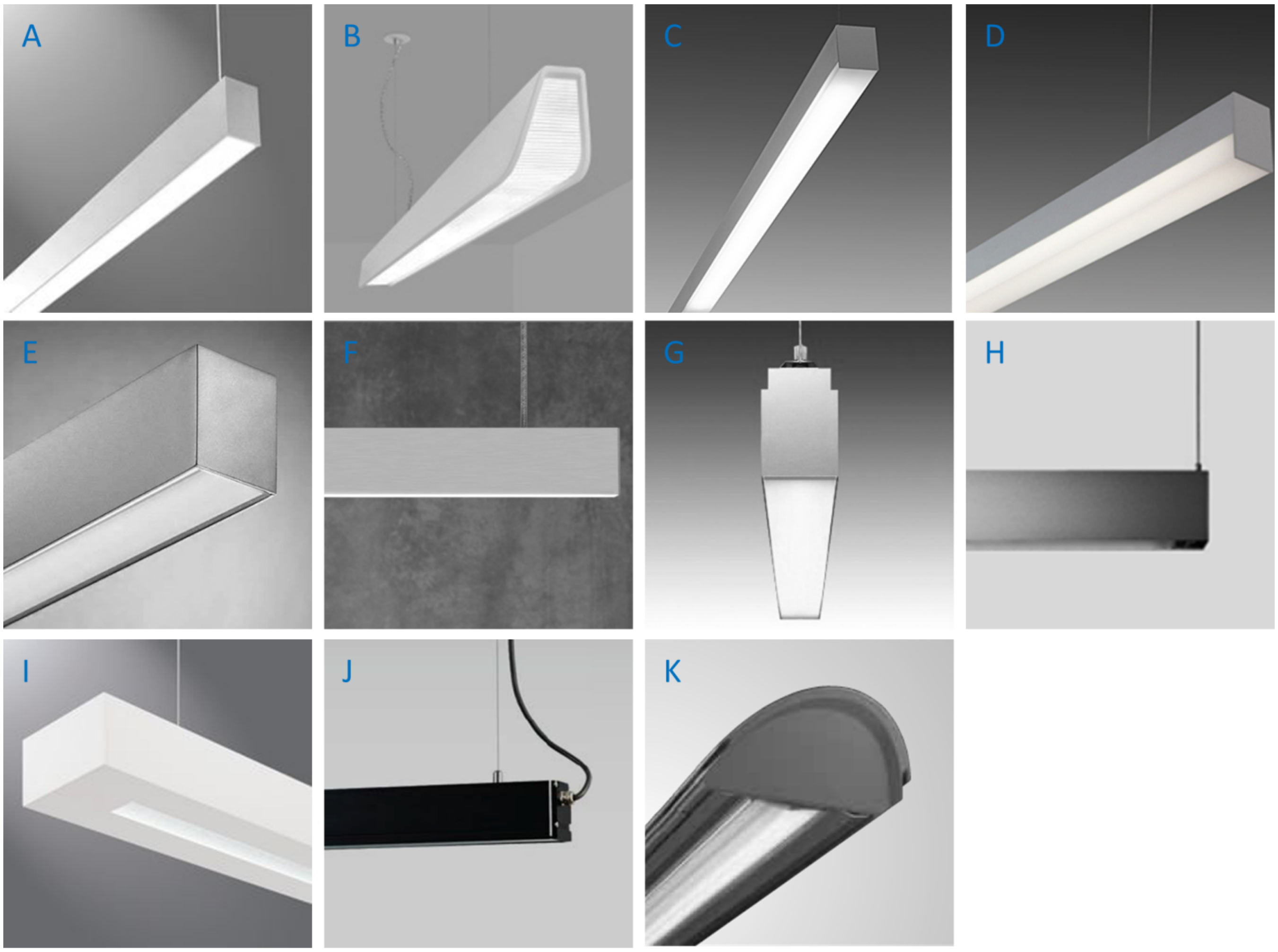

Figure 1. The eleven products included in the supplemental dataset. *Adapted from manufacturers' images.*

Table 1. Matrix of available lamping options for the surveyed products. The (+) symbol indicates that more than one output level is available.

	A	B	C	D	E	F	G	H	I	J	K
1 T5	×	×	×	×	×	×	×		×	×	×
1 T5HO	×	×	×	×	×	×	×		×	×	×
2 T5		×			×			×	×		×
2 T5HO		×						×	×		×
1 T8		×			×				×		×
2 T8		×							×		×
LED	× (+)	×	× (+)	× (+)	×	×	× (+)	×	× (+)	×	× (+)

Table 2. Performance comparison for LED and fluorescent linear pendants. All data is from manufacturer IES-format files, unless otherwise noted. Not shown are T8 fluorescent versions, which were available for some product types. All luminaires were nominally 4' long, except as noted.

Label	Lamp(s)	Location	Style	Initial Luminaire Output (lm)	Input Power (W)	Luminous Efficacy (lm/W)	Initial Lamp Output (lm)	Luminaire Efficiency (%)	Spacing Criterion (90–270°)
A, 11-81	LED*[1]	Interior	Direct	2,182	34.0	64			0.99
A	LED	Interior	Direct	2,095	33.4	63			1.04
A	LED2[2]	Interior	Direct	2,700	45.0	60			
A	1 T5	Interior	Direct	1,789	31.3	57	2,900	62	1.12
A	1 T5HO	Interior	Direct	2,973	53.0	56	5,000	59	1.12
B, 12-02	LED*	Interior	Direct	2,357	36.9	64			1.58
B	LED	Interior	Direct	2,450	37.6	65			1.64
B	1 T5	Interior	Direct	2,245	30.5	74	2,600	86	1.44
B	1 T5HO	Interior	Direct	3,500	62.0	58	4,500	78	1.44
B	2 T5	Interior	Direct	3,922	61.0	64	5,200	75	1.28
B	2 T5HO	Interior	Direct	5,264	117.0	45	9,000	58	1.28
C, 12-32	LED*	Interior	Direct	4,467	63.7	70			1.26
C	LED	Interior	Direct	4,478	64.4	70			1.28
C	1 T5	Interior	Direct	1,653	30.0	55	2,610	63	1.32
D	LED	Interior	Direct	2,483	30.4	82			1.42
D	1 T5HO	Interior	Direct	3,338	56.8	59	4,450	75	1.58
E	LED	Interior	Direct	2,705	33.0	82			1.26
E	1 T5	Interior	Direct	1,906	31.0	61	2,610	73	1.22
E	1 T5HO	Interior	Direct	3,591			5,000	72	
E	2 T5	Interior	Direct	2,705	53.0	51	5,220	52	1.16
F	LED	Interior	Direct	2,483	48.6	51			1.06
F	1 T5	Interior	Direct	1,146	30.0	38	2,600	44	1.18
F	1 T5HO	Interior	Direct	1,961	55.2	36	4,450	44	1.18
G	LED	Interior	Direct	2,435	33.4	73			1.10
G	LED2	Interior	Direct	3,433	50.1	69			1.10
G	1 T5	Interior	Direct	1,903	29.3	65	2,610	73	1.20

Continued on next page

*CALiPER Test

1. Different rated CCT than manufacturer's IES-format file for LED product (tested at 4000 K versus IES-format file at 3500 K).

2. Data from specification sheet.

Table 2, continued.

Label	Lamp(s)	Location	Style	Initial Luminaire Output (lm)	Input Power (W)	Luminous Efficacy (lm/W)	Initial Lamp Output (lm)	Luminaire Efficiency (%)	Spacing Criterion (90–270°)
H, 11-83	LED*	Interior	Direct-Indirect	2,201	50.0	44			
H	2 T5	Interior	Direct-Indirect	2,267	56.8	40	5,200	44	
H	2 T5HO	Interior	Direct-Indirect	3,897	107.4	36	8,900	44	
I, 11-84	LED2*	Interior	Direct-Indirect	7,283	92.7	79			
I	LED	Interior	Direct-Indirect	4,365	51.1	85			
I	LED2[2]	Interior	Direct-Indirect	6,914	91.0	76			
I	1 T5HO	Interior	Direct-Indirect	4,482	60.0	75	4,500	100[3]	
I	2 T5HO	Interior	Direct-Indirect	8,546	116.0	74	9,000	95	
J, 12-30	LED*[4]	Exterior[5]	Direct	969	41.0	24			0.63
J	LED	Exterior	Direct	931	60.0	16			0.26
J	LED2	Exterior	Direct	744	60.0	12			0.64
J	1 T5	Exterior	Direct	1,539	33.0	47	2,600	59	1.34
J	1 T5HO	Exterior	Direct	2,632	59.0	45	4,450	59	1.40
K	LED	Exterior	Direct	3,843	75.0	51			1.20
K	1 T5HO	Exterior	Direct	2,910	59.3	49	5,000	58	1.30
K	2 T5HO	Exterior	Direct	5,674	103.7	55	10,000	57	1.40

*CALiPER Test

2. Data from specification sheet.

3. These numbers were calculated from the manufacturer's IES-format file, but luminaire efficiency approaching 100% is not realistic for linear pendants. The cause of the discrepancy was not specifically investigated by CALiPER, but is probably due to thermal effects not addressed in the photometric test.

4. Nominal 3-foot length.

5. Products labeled as *exterior* were categorized as such based on their rating for dust and water ingress. This does not preclude them from indoor use.

5 Discussion

Lumen Output

The lumen output of fluorescent pendants can vary substantially. For the 11 fluorescent luminaire types comprising the supplemental dataset for this report, luminaire output ranged from fewer than 1,000 lumens to more than 8,500 lumens. The wide variation is due to a combination of the number of lamps (typically one or two), type of lamp(s), and efficiency of each luminaire. Standard T5 lamps emit approximately 2,600 to 3,000 lumens, whereas T5HO lamps emit between 4,450 and 5,000 lumens.[10] Additionally, fluorescent linear pendants range from approximately 40% to more than 80% efficient, resulting in the observed range in luminaire output.

In contrast with smaller form factors, linear pendants have ample surface area and volume, which creates the potential for LED products to meet or exceed the lumen output of conventional products. The CALiPER-tested Series 19 LED linear pendants ranged from 969 to 7,283 lumens, and the surveyed LED linear pendants ranged from 744 to 6,914 lumens. The lumen output for all available configurations of each product type is shown in Figure 2.

Of the 11 types of linear pendants surveyed, 9 offered an LED version with rated output between approximately 1,900 and 2,700 lumens. The two products that did not have an offering in this range were a direct-indirect pendant (above range) and an exterior pendant (below range). This range is approximately between the output from a linear pendant with one T5 lamp and a linear pendant with two T5 lamps or one T5HO lamp. Six of the surveyed LED products also offered a second, higher lumen output version, but that output value was not

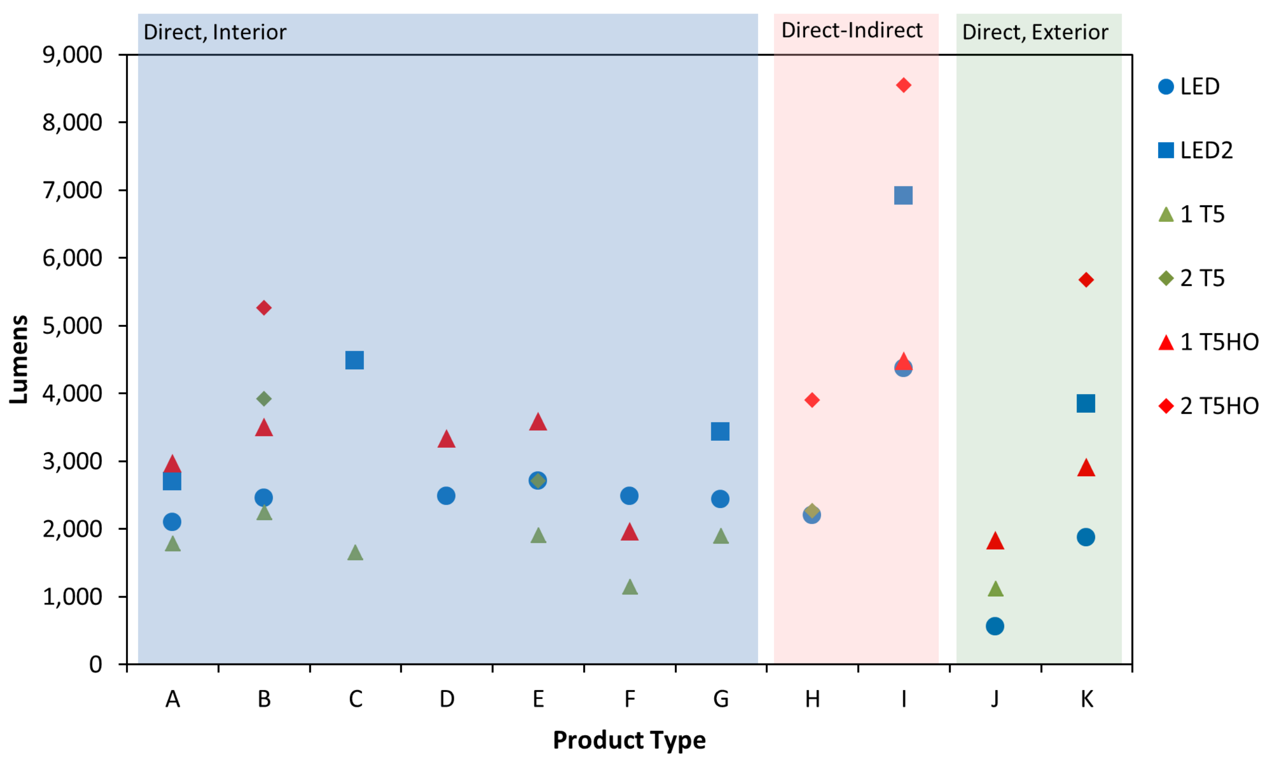

Figure 2. Lumen output of linear pendants with LED and T5 lamping.

[10] Especially for T5 lamps, lumen output is dependent on the thermal environment.

consistent among products. In only a handful of cases was the lumen output of an LED version within 10% of the lumen output of a fluorescent version; thus, it may be difficult to change the source type without changing the layout of the luminaires or changing the illuminance performance.

There are so many types of spaces where these linear products are used, that the wide range of lumen packages available in both fluorescent and LED products helps the lighting specifier. Having different options market-wide is useful, but having multiple options within a single luminaire type is even better. Some fluorescent products offered up to six different configurations (one T5, one T5HO, two T5, two T5HO, one T8, two T8), whereas LED versions were typically available in only one or two lumen packages. Moving forward, manufacturers would benefit from offering LED products with a similar variety of lumen packages while maintaining the same luminous intensity distribution.

Luminous Efficacy

Luminous efficacy is one area in which LED linear pendants often have an advantage over their fluorescent counterparts. For 8 of the 11 luminaire types surveyed, the LED version offered higher efficacy than any of the fluorescent versions, and for two other types, the efficacy was higher than at least one of the fluorescent versions. In only one case (Type J, 12-30) was the efficacy of the LED version less than all of the counterpart fluorescent versions offered by the same manufacturer.[11]

The listed efficacy for the surveyed LED luminaires reached up to 85 lm/W, with measured efficacy for the Series 19 CALiPER products as high as 79 lm/W. Only two products (Type J, 12-30; Type H, 11-83) were less than 50 lm/W. In comparison, the surveyed fluorescent products were between 35 and 75 lm/W.

Luminous Intensity Distribution

Luminous intensity distribution can be a very important factor when designing architectural lighting systems. Choosing an appropriate distribution for a given application has the potential to increase uniformity, reduce glare, decrease energy use, and decrease up-front cost by reducing the number of luminaires needed.

One of the key elements contributing to the distribution of light emitted by a luminaire is the lens or louver, which controls light as it exits the aperture. Of the 11 products in the supplemental dataset, six utilized a diffuse lens—some of the products were also available with other options. Diffuse, or frosted, lenses are commonly used with LEDs because they block direct view of the high-luminance LED point sources. This function is not as needed for fluorescent lamps; however, because it was necessary to establish a fair comparison, the fluorescent lamps in the dataset used the same lens as the LED products. The performance of fluorescent products is typically better with a prismatic lens or louver.

[11] Notably, the LED version of product J (12-30) emitted substantially less light than the fluorescent versions and CALiPER test data did not match the manufacturer data for many metrics.

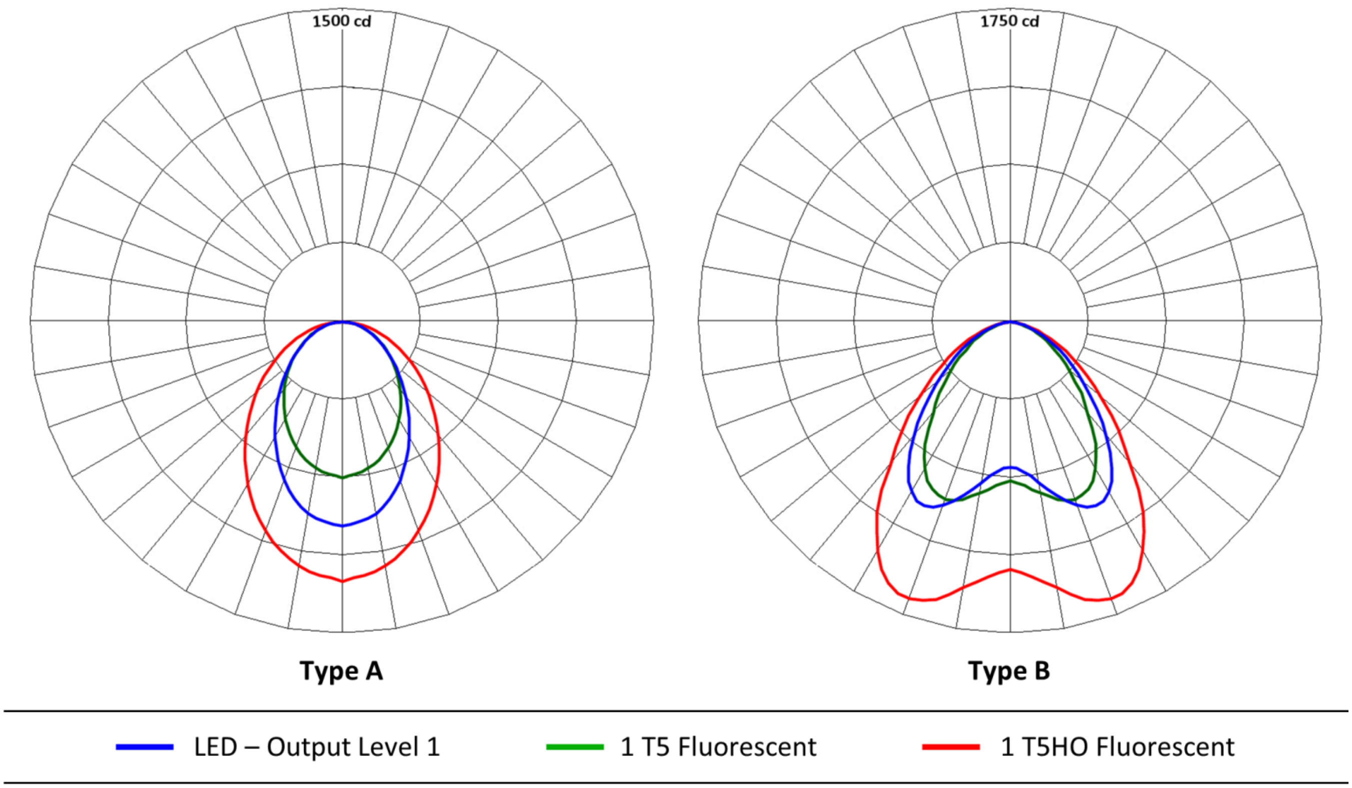

Figure 3. Polar plots of luminous intensity distribution in the plane perpendicular to the major luminaire axis for products A and B. Some of the LED linear pendants—especially those with a diffuse lens—matched the distribution of their fluorescent counterparts. Product A had a diffuse lens, whereas product B had a proprietary optic. The lumen output of the product versions is different.

Diffuse lenses usually result in the luminous intensity distributions with the highest candela value directly under the luminaire, regardless of the source behind the lens. For the six product types with a diffuse lens, the LED products were generally effective at matching the distribution of the fluorescent counterparts—irrespective of lumen output differences. Polar plots of the luminous intensity distributions for luminaire Types A and B are shown in Figure 3 as examples. One of the products (Type B) from the supplemental dataset utilized a proprietary ribbed lens with specialized optical control; for both the LED and 1 T5 fluorescent versions, the distribution of light was very similar (see Figure 3).

Four of the LED products from the supplemental dataset did not mimic the distributions of their fluorescent counterparts (see Figure 4). Three of the supplemental products utilized a prismatic lens, and these lenses generally produced a different distribution pattern, but the degree of difference varied. For product type H, the LED product's luminous intensity distribution exhibited distinct spikes[12]—this was one of the most striking differences in performance for any of the products. In contrast, the distribution for the LED versions of product types I and K looked more like products with diffuse lenses, whereas the fluorescent versions exhibited more specialized distributions such as narrow or batwing patterns. The exact cause of this difference may be due to manufacturers using diffusing lenses to mask the individual points of light from an LED array or matrix. The Type

[12] As previously noted, the IES-format file for product type H came from CALiPER testing because one was not available from the manufacturer.

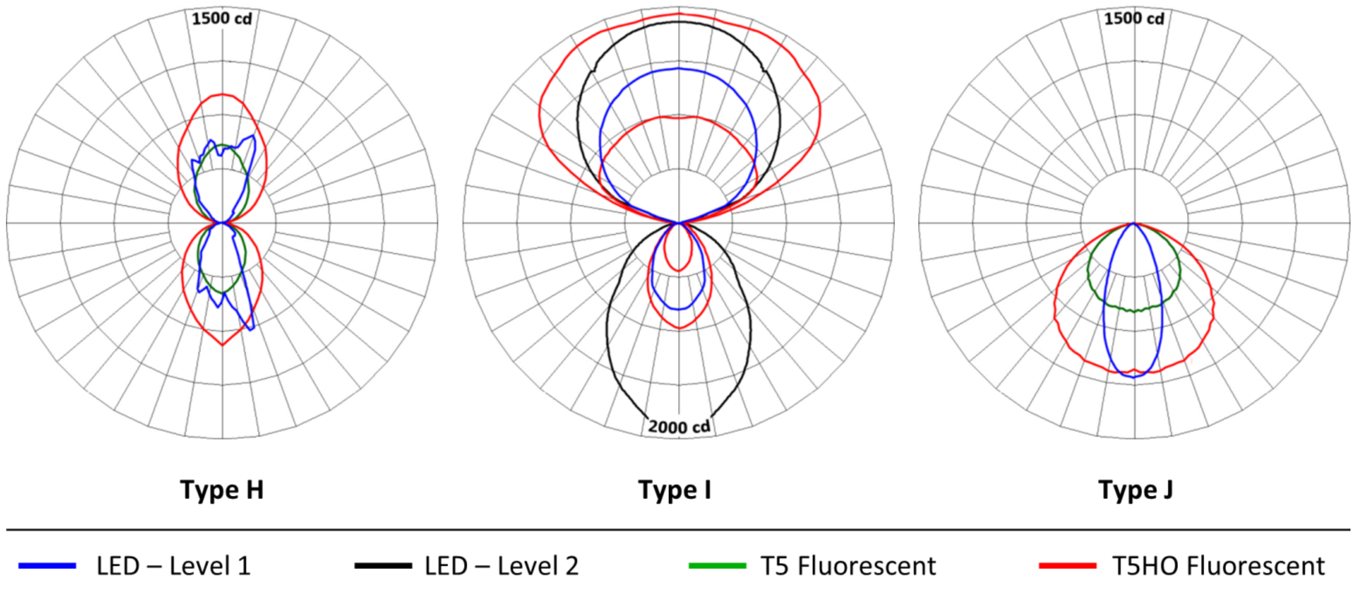

Figure 4. Polar plots of luminous intensity distribution for products H, I, and J. Some of the LED linear pendants did not match the distribution of their fluorescent counterparts—irrespective of differences in lumen output.

J product from the supplemental dataset used a clear lens and delivered a much narrower distribution than its matching fluorescent versions.

Color Characteristics

The color quality of fluorescent systems is based on the lamp, which is interchangeable and thus relatively easy to change over the lifetime of the luminaire. In contrast, LED arrays are relatively fixed for the lifetime of the luminaire and the only choices are those available from the luminaire manufacturer.

All 11 of the LED luminaires included in the supplementary dataset offered at least two CCTs, most commonly 3500 K or 4000 K, but photometric data was almost always provided for 3500 K products. A portion also offered 3000 K and/or 2700 K products, and one manufacturer offered a color-mixed red-green-blue (RGB) option. Most products for which the information was provided had a CRI in the 80s, but at least two had a CRI in the 70s. This is similar to the findings from the Series 19 LED linear pendants tested for this CALiPER report.

6 Conclusions

Two investigations—CALiPER Series 19 and a supplemental market survey—have helped to identify the state of the LED linear pendant market compared to linear fluorescent pendants. Based on the regular CALiPER process of acquiring and testing products, two key observations are possible. First, there are relatively few LED linear pendants, and those that are truly available may require extended lead times for acquisition. Second, the target—and actual—performance of LED linear pendant products is highly variable, making between-product comparisons difficult and not always meaningful.

In an effort to provide more useful information regarding LED linear pendants, a search was conducted to identify additional products offered in both LED and linear fluorescent versions. These linear products allowed CALiPER to compare performance of luminaires with similar appearance and size, but different light sources. In evaluating this supplemental dataset and comparing LED and fluorescent versions, several traits were revealed:

- For almost all product types considered, the LED version(s) were more efficacious than the linear fluorescent version(s). In large part, this is a result of the lower optical efficiency of the conventional luminaires when used with fluorescent lamps.
- LED and fluorescent products with diffuse lenses tend to have similar luminous intensity distributions. The lenses are especially important for visual masking for LED products, but they may reduce efficacy for any lamp type. Diffuse lenses tend to soften the light distribution, making the polar plot appear rounder with fewer spikes or sudden edges. This may or may not be desirable depending on the intended application.
- For products with clear or prismatic lenses, the LED versions did not match the luminous intensity distribution of the fluorescent counterparts as closely. In one case, the distribution of the LED product was dramatically different, likely resulting from the interaction of the prismatic lens and numerous LED point sources—this result was unexpected and the product could have a distracting appearance. However, matching fluorescent is not necessarily a goal; a different distribution and appearance can be the result of delivering light more effectively where it is needed, and avoiding zones where it can cause glare, for example.
- All of the LED pendants that had a direct distribution and were intended for use in interior applications offered an option for output between approximately 2,000 and 2,500 lumens (with one product at 2,700 lumens). In all cases, the rated lumen output was between the output of a matching linear pendant with a single T5 lamp or a single T5HO lamp. Several products offered a second LED version with a higher lumen output level, but the exact level varied.
- Many of the LED pendants evaluated were available in multiple color temperatures and with a CRI comparable to typical fluorescent lamps. However, some had a CRI in the 70s and CCTs above 4500 K. This is different from what specifiers have come to expect from fluorescent products, so the designer, engineer, and facility manager need to exercise care in selecting products.
- Specifiers cannot assume that LED versions of products traditionally available in linear fluorescent will deliver similar light distribution, color, and lumen output. LEDs are a new light source with unique characteristics and opportunities.

Appendix A: Definitions

Correlated Color Temperature (CCT) Kelvin (K)	The absolute temperature of a blackbody radiator having a chromaticity that most nearly resembles that of the light source. CCT is used to describe the color appearance of the emitted light.
Color Rendering Index (CRI or R_a)	A measure of color fidelity that characterizes the general similarity in color appearance of objects under a given source relative to a reference source of the same CCT. The maximum possible value is 100, with higher scores indicating less difference in chromaticity for a sample of eight color samples illuminated with the test and reference source. See also: *Special Color Rendering Index R_9*.
D_{uv}	The distance from the Planckian locus on the CIE 1960 UCS chromaticity diagram (also known as u', 2/3 v'). A positive value indicates the measured chromaticity is above the locus (appearing slightly green) and a negative value indicates the measured chromaticity is below the locus (appearing slightly pink). The American National Standards Institute provides limits for D_{uv} for nominally white light.
Luminous Efficacy Lumens per watt (lm/W)	The quotient of the total luminous flux emitted and the total input power.
Input Power Watts (W)	The power required to operate a device (e.g., a lamp or a luminaire), including any auxiliary electronic components (e.g., ballast or driver).
Luminous Intensity Distribution Candela (cd)	The directionality of radiant energy emitted by a source, which may be shown using one of several techniques. It is most often presented as a polar plot of the candelas emitted in a vertical plane through the center of the lamp or luminaire.
Output Lumens (lm)	The amount of light emitted by a lamp or luminaire. The radiant energy is weighted with the photopic luminous efficiency function, $V(\lambda)$.
Power Factor	The quotient of real power (watts) flowing to the load (e.g., lamp or fixture) and the apparent power (volt amps) in the circuit. Power factor is expressed as a number between 0 and 1, with higher values being more desirable.
Spacing Criterion (SC)	The estimated ratio between the mounting height above the work plane and luminaire spacing necessary for a regular array of a given luminaire to produce a work plane illuminance that is acceptably uniform. For example, for a luminaire recessed into a 10-foot ceiling with a work plane that is 30 inches above the floor, if the spacing criterion is 1.4, the luminaire should be spaced no more than 10.5 feet on center ($1.4 \times (10 - 2.5) = 10.5$). Spacing criterion is also referred to as the spacing-to-mounting-height ratio (S/MH).
Special Color Rendering Index R_9	A measure of color fidelity that characterizes the similarity in color appearance of deep red objects under a given source relative to a reference source of the same CCT. The maximum possible value is 100, with higher scores indicating less difference in chromaticity for the color sample illuminated with the test and reference source. R_9 and R_a (CRI) are part of the same CIE Test-Color Method, but the R_9 color sample is not included in calculation of R_a. R_9 values should not be compared to R_a (CRI) values. As a shorthand approximation, an R_9 less than zero is poor, an R_9 greater than zero is good, an R_9 greater than 50 is very good, and an R_9 greater than 75 is excellent.

Appendix B: CALiPER Series 19 Test Results

General Notes

- There was a substantial lead time associated with many of the Series 19 LED linear pendants, and some products originally intended for inclusion could not be obtained in time, resulting in the relatively small number of samples.
- One product (11-84) arrived in non-working condition, with several loose parts. The luminaire was reassembled by the CALiPER team and shipped to the laboratory for testing.

Table B1. Summary data for CALiPER testing of LED linear pendants. The first two digits of the CALiPER test ID indicate the year in which the product was purchased.

DOE CALiPER Test ID	Initial Output (lm)	Total Input Power (W)	Efficacy (lm/W)	Power Factor	CRI	R_9	CCT (K)	D_{uv} [1]	Spacing Criterion
11-81	2,182	34.0	64	0.95	86	53	4083	-0.0020	0.99
11-83	2,201	50.0	44	0.88	70	-37	4883	0.0150	
11-84	7,283	92.7	79	1.00	83	41	3452	0.0009	
12-02	2,357	36.9	64	0.97	78	9	3936	0.0016	1.58
12-11	2,719	67.6	40	0.99	83	20	3381	-0.0021	1.16
12-30	969	41.0	24	0.99	85	41	3250	-0.0022	0.63
12-32	4,467	63.7	70	0.96	82	10	3542	-0.0010	1.26
12-33	2,297	45.1	51	0.54	78	3	4763	0.0020	1.27
12-34	4,132	81.4	51	0.99	83	28	4149	-0.0048	0.98
Minimum	969	34.0	24	0.54	70	-37	3250	-	0.63
Mean	3179	56.9	54	0.92	81	19	3938	-	1.12
Maximum	7283	92.7	79	1.00	86	53	4883	-	1.58

Notes:
1. Red values are outside of ANSI-defined limits (ANSI C78.377).

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