

CALIPER

BENCHMARK REPORT

NOVEMBER 2008

Performance of Incandescent A-Type and Decorative Lamps and LED Replacements

Prepared for the U.S. Department of Energy by
Pacific Northwest National Laboratory



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CALiPER Benchmark Report

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Pacific Northwest National Laboratory
Richland, Washington 99352

Abstract

The U.S. Department of Energy (DOE) Commercially Available LED Product Evaluation and Reporting (CALiPER) Program was established in 2006 to investigate the performance of luminaires and replacement lamps based on light-emitting diode (LEDs). To help users better compare LED products with conventional lighting technologies, CALiPER also has performed benchmark research and testing of traditional (i.e., non-LED) lamps and fixtures. This benchmark report addresses common omnidirectional incandescent lamps—A-type and small decorative, candelabra-type lamps—and their commercially available LED replacements. The construction and operation of incandescent lamps are discussed, as well as incandescent lamp performance, based on manufacturer data and CALiPER benchmark testing. In addition, the report describes LED replacements for incandescent A-lamps and small decorative lamps and compares their performance with incandescent benchmarks on a range of standard lighting measures, including power usage, light output and distribution, luminous efficacy, correlated color temperature, and the color rendering index. Potential performance and application issues indicated by CALiPER testing results also are examined.

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Introduction

Solid-state lighting (SSL) products using light-emitting diodes (LEDs) are proliferating in the lighting marketplace. Their low energy consumption, potential long life, and compact form make LEDs an attractive alternative to traditional light sources in some applications. It can be argued, however, that the marketing of SSL technology has outpaced the development and practice of using standard test procedures by which to characterize the performance of a product. Consequently, the consumer faces a rapidly increasing variety of LED luminaires and replacement lamps, along with a bewildering range of product claims—and a relative lack of information with which to accurately evaluate LED lighting products as well as to compare them to traditional technologies.

To fill the LED lighting “data gap,” the U.S. Department of Energy (DOE) initiated the Commercially Available LED Product Evaluation and Reporting (CALiPER) Program in 2006. Industry standard test procedures now exist to measure the efficacy, photometric performance, and color characteristics of LED luminaires and replacement lamps. Related standard test procedures for determining LED product lifetime are nearing completion. Through independent testing laboratories, CALiPER has used these procedures to evaluate a variety of LED luminaires and replacement lamps available through common retail channels and has made the test results available for public review.¹ For benchmarking purposes, CALiPER also includes testing of conventional (i.e., non-LED) lamp types and luminaires that use conventional light sources. Consumers and manufacturers now have a resource for evaluating and comparing LED and conventional lighting products; with more product types that will be tested and benchmarked as CALiPER testing continues.

This benchmark report presents a comparison of common line-voltage (120-V) incandescent omnidirectional lamps—specifically A-type (e.g., A15 and A19) and decorative lamps—with commercially available LED replacement lamps. CALiPER compared incandescent lamps with LED replacements on a range of standard lighting measures, including power usage, light output and distribution, efficacy, correlated color temperature (CCT), and color rendering index (CRI). Photometric data published by manufacturers for SSL products were collected and analyzed to compare manufacturer performance claims with measured performance results.² In addition, CALiPER evaluated LED replacement lamp size and format to gauge compatibility with common light fixtures.

The emphasis in this report is on lower-wattage/lower-output lamps because high-performance omnidirectional LED replacement lamps capable of replacing higher-wattage A-type incandescent lamps are not yet available. As LED technology progresses and the CALiPER Program identifies commercially available products that are performing at the levels of traditional higher-wattage products, this report may be updated accordingly.

¹ Summary reports for DOE CALiPER testing are available online at http://www.netl.doe.gov/ssl/comm_testing.htm.

² Detailed test reports for products tested under the DOE SSL testing program can be requested online: http://www.netl.doe.gov/ssl/comm_testing_request.htm.

Incandescent Omnidirectional Lamps

Incandescent lamps used for general or decorative lighting are typically *omnidirectional* sources; that is, they emit light in all directions. Common examples include the traditional A-type lamp (A-lamp) with its instantly recognizable “light bulb” shape (Figure 1), as well as decorative candelabra-style lamps. Their characteristic warm light color evokes impressions of “hearth and home,” but these lamps also are used widely in commercial applications ranging from retail to dining to hospitality.



Figure 1.
Typical A-Type
Incandescent
Lamp

Lamp Construction, Attributes, and Operation

Incandescent lamps often are described as a “wire in bottle” and share a number of basic components:

- a tungsten filament
- a glass envelope (bulb)
- a lamp base.

For general-purpose lamps, filaments are typically of a “coiled coil” design—literally, a coil inside a coil. Light output is in part a function of filament length and thickness, which determines its resistance to current flow and thermal characteristics. The coiled coil design allows a considerable length of filament to be mounted within a bulb. For example, the uncoiled length of a filament for a typical 120-V 60-W incandescent lamp is almost 23 inches, with a filament diameter of 0.0018 inch.

Under normal use, the tungsten filament evaporates when heated, depositing on the inner surface of the bulb wall, which results in blackening and a reduction of lamp light output over time. Given its compacted form, the coiled coil filament has a thicker effective diameter that slows evaporation. In addition, incandescent lamps more than about 25 W contain argon, nitrogen, or krypton fill gas (versus vacuum fill only for lower-wattage lamps), which further suppresses filament evaporation (and improves the lamp efficacy slightly). However, the filament eventually thins to the point at which it breaks, and the lamp fails. Vibration and shock can hasten this effect, depending on the application, filament thickness, and structure of the filament supports. Ultimately, filament evaporation limits the operating life of general-purpose incandescent lamps to less than 2,000 hours on average. Manufacturers commonly offer “long-life” versions of their standard incandescent lamps, with double or more of the standard operating life. At equivalent wattages, long-life incandescent lamps operate at a lower filament temperature, which slows filament evaporation and extends lamp life. The lower filament temperature also reduces light output and luminous efficacy.³

In normal operation, approximately 90% of the power consumed by an incandescent lamp is emitted as heat radiating from the lamp, as evidenced by bulb wall temperatures in excess of 400°F (200°C) for a common A19 lamp. In fact, incandescent lamps are used as a radiant heat source in applications as

³ For example, a typical long-life version of a 60-W A19 lamp is rated at 2,000 hours life (vs. 1,000 hours for the standard version) at about 9% lower light output and efficacy than the standard version.

diverse as poultry incubators and bathroom vent fixtures—even children’s toys like the iconic Easy-Bake oven. It follows that incandescent lamps are very inefficient light sources. Luminous efficacy is the light output of a source (in lumens, lm) divided by its power usage (in watts, W), expressed in lumens per watt (lm/W). Efficacies for incandescent lamps generally do not exceed 18 lm/W and can be less than 8 lm/W for smaller low-wattage versions. It should be noted that the luminous efficacy of a tungsten filament increases with its operating temperature but decreases over the life of the lamp.

Standard incandescent lamps produce a characteristic warm, yellowish appearance with a CCT in the 2700–3000 K range. These lamps can be dimmed with conventional (i.e., inductive load) dimmers, which shifts their color to an even warmer appearance (i.e., lower CCT). By reducing the lamp power draw, dimming also slows filament evaporation and extends lamp life. Many general-purpose incandescent lamps are available in versions designed to operate at 130 V that, when operated at 120 V, provide about twice the rated life, with an approximate 20% reduction in light output.

Manufacturers rarely publish CRI values for incandescent lamps. Two benchmarks exist for CRI tests:

1. For light sources with CCTs below 5000 K, the reference light source is a Planckian (blackbody) radiator of the same color temperature.
2. For CCTs above 5000 K, the reference light source is an agreed-upon spectra that mimics daylight.

Incandescent light sources behave virtually the same as Planckian radiators and are, therefore, generally assumed to have a CRI of 100.

CALiPER benchmark testing and data-gathering focused on two common categories of incandescent lamps: A-lamps and decorative candelabra-type lamps. These lamp types—particularly low-wattage versions with low lumen output—were selected because their performance most closely matches the LED products currently marketed as their replacements. A-lamps and candelabra-type lamps are distinguished primarily by their bulb shapes and are described in the following sections.

Incandescent A-Lamps

With a mushroom-shaped bulb similar to that originally commercialized by Thomas Edison, the A-lamp—in particular, the A19 lamp—is the most common general lighting source in use today. The letter A is an arbitrary designation, and, in the case of the A19 lamp, the number 19 represents the maximum bulb diameter of 19/8-inch (i.e., 2.375 inches). A-lamps are available in diameters from A15 to A23, with maximum overall lengths (MOLs) ranging from approximately 3.5 inches to over 6 inches. As a rule, these lamps have an Edison screw base with a 26-millimeter diameter, designated as an E26 or “medium” base (Figure 2). A-lamps operate on line voltage (e.g., 120 V), and their wattages generally increase with lamp size, ranging from 15 W (A15 shape) to over 200 W (A21 and A23 shapes).



Figure 2.
Edison (E26)
Medium Screw
Base

Decorative Incandescent Lamps

For this report, decorative incandescent lamps represent a variety of candelabra-style, low-wattage incandescent lamps used primarily for decorative purposes. Technically, *candelabra* refers to the

diminutive screw-base for these lamps; however, because the lamp shapes are designed to resemble candle flames, the entire category often is referred to as *candelabra lamps*. The lamps are intended for use in decorative fixtures, including chandeliers, pendants, wall sconces and lanterns, and nightlights. Figure 3 illustrates several popular examples with their lamp designations.



Figure 3. Common Decorative Candelabra-Type Incandescent Lamps

Decorative incandescent lamps often use a candelabra base (E12), although a medium base (E26) is used with some larger lamps (Figure 4).



Figure 4. Typical Bases for Candelabra-Type Incandescent Lamps

Given their intended decorative function, candelabra-type lamps generally are not characterized by light output, which can be negligible for lower-wattage lamps (e.g., <20 lm for a 4-W C7 lamp). These lamps are designed to operate on line voltage only, with wattages ranging from 3 W to 60 W for most candelabra-type bulb shapes.

Performance of Incandescent A-Lamps and Decorative Lamps

Lamp ratings from three major lamp manufacturers were surveyed for CALiPER benchmarking purposes, covering approximately 250 A-lamps (A15 and A19) in 25-W, 40-W and 60-W versions. A-lamps rated higher than 60 W were not included because LED replacement lamps currently lack the light output to compete with higher-wattage incandescent products.

Manufacturer data were surveyed also for approximately 200 smaller decorative incandescent lamps in a variety of formats (e.g., C7, BA9, BA9.5, B10.5, B13, CA8, F10, and F15), in wattages ranging from 4 W to 25 W. Higher-wattage versions were not included because LED replacements currently compete only with products at lower light output levels.

Light Output

Predictably, light output (i.e., luminous flux) generally increases with rated wattage for incandescent lamps. Table 1 presents the ranges and averages of manufacturer-provided values for lamp light output

for decorative lamps and A-lamps, along with corresponding CALiPER benchmark data. In general, CALiPER testing has corroborated manufacturer-rated light output for these lamp types.

Table 1. Manufacturer and CALiPER Benchmarks for Incandescent Lamp Light Output

	Light Output (lm)			CALiPER Benchmark (absolute testing)	
	Minimum	Maximum	Average		
Decorative lamps	4-W	14	16	16	(In process)
	7-W	33	43	39	(In process)
	15-W	85	110	98	(In process)
	25-W	105	220	147	(In process)
25-W A lamps	130	390	221	181 (rated @ 210)	
40-W A lamps	240	505	405	387 (rated @ 390)	
60-W A lamps	340	1010	698	739 (rated @ 780)	

Efficacy

Luminous efficacy of incandescent replacement lamps typically is not reported by manufacturers but can be calculated by dividing lumen output ratings by power ratings. Manufacturer data for light output were not available for all surveyed incandescent lamps, particularly for lower-wattage decorative products. However, as shown in Table 2, CALiPER test results support the efficacy values calculated from available manufacturer data.

Table 2. Manufacturer and CALiPER Benchmarks for Incandescent Lamp Efficacy

	Luminous Efficacy (lm/W)			CALiPER Benchmark (absolute testing)
	Minimum	Maximum	Average	
Decorative lamps (4-W–25-W)	4.0	8.8	5.5	(In process)
25-W A lamps	5.2	15.6	8.8	7.5 (rated @ 8.4)
40-W A lamps	6.5	12.6	10.2	9.9 (rated @ 9.8)
60-W A lamps	6.4	16.8	11.8	12.1 (rated @ 13.0)

Manufacturer and CALiPER data show that the efficacy of smaller, lower-wattage lamps is notably less than for higher-wattage lamps. Given that efficacy of a tungsten filament increases with its temperature, it follows that efficacy should increase with lamp input power. This relationship between efficacy and lamp wattage is illustrated in Figure 5, based on manufacturer data for candelabra-type lamps.

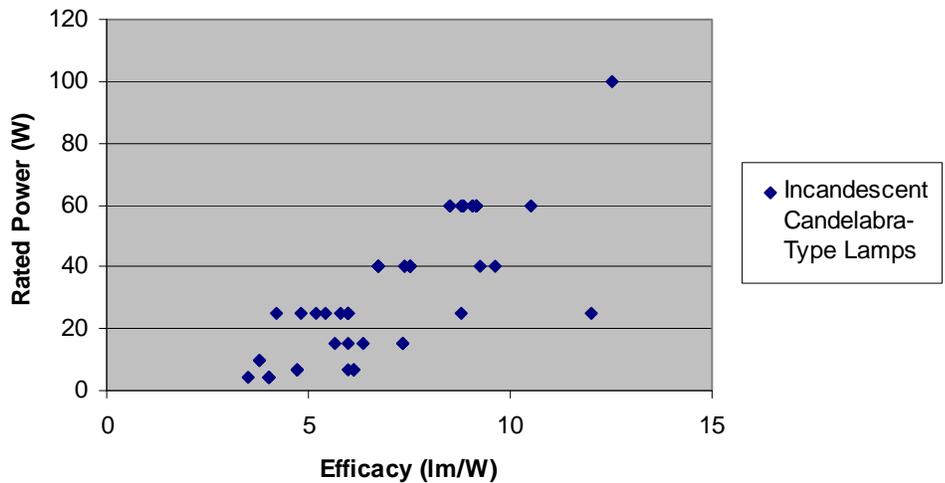


Figure 5. Efficacy vs. Rated Lamp Power for Candelabra-Type Lamps (Manufacturer Data)

Analysis of manufacturer data also indicates a relationship between incandescent lamp efficacy and rated life. As discussed above, lamp efficacy increases with wattage and, by extension, filament temperature. Filament evaporation also increases with operating temperature, contributing to shorter lamp life. Using manufacturer data for 60-W A lamps as an example, Figure 6 illustrates the inverse relationship between lamp efficacy and rated life.

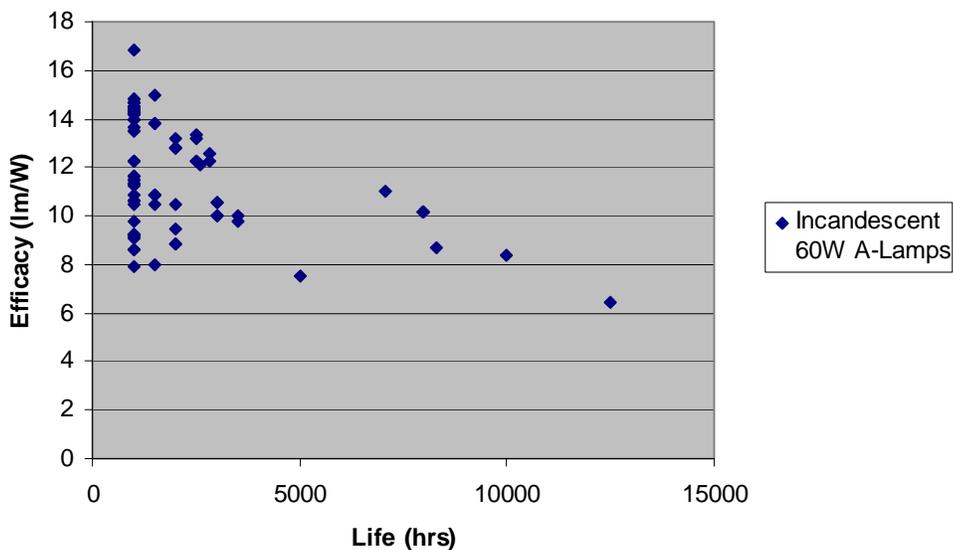


Figure 6. Tested Efficacy of 60-W Incandescent Lamps Compared to Rated Lifetimes

Although based on a relatively small set of tested products (e.g., three A lamps) and limited sampling (i.e., three samples per product), CALiPER benchmark results correlate well with published manufacturer data for incandescent lamps. This affirms that manufacturer ratings for these products are a useful tool for comparing incandescent and LED replacement lamps. Figure 7 shows the general agreement between

averaged manufacturer-based efficacy values and CALiPER test results, using incandescent A15 and A19 lamp data. Further CALiPER benchmark testing is scheduled for smaller decorative replacement lamps.

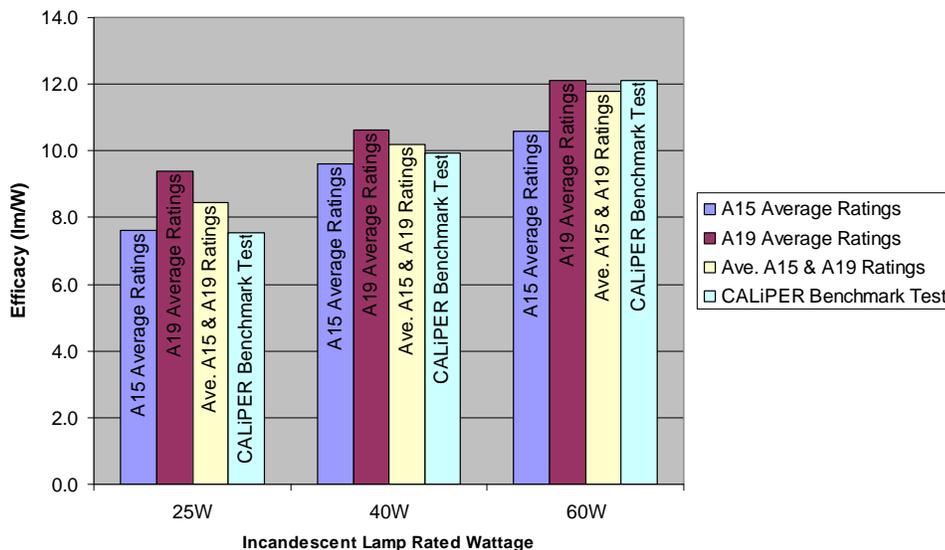


Figure 7. Comparison of Average Efficacies for A15 and A19 Lamps Based on Manufacturer Ratings and CALiPER Test Results

A Note about Compact Fluorescent Lamps (CFLs)

Screw-based CFLs are a common replacement for incandescent A lamps, producing comparable light output with significantly higher efficacy. For small format and low-wattage replacement lamp categories, fewer CFL products are available, and their efficacy diminishes with decreasing wattage and light output. In most cases today, however, CFL performance clearly exceeds that of current LED replacement lamps in terms of light output and efficacy. For this reason, CALiPER benchmark testing has focused on incandescent lamps for comparison with LED replacements.

Figure 8 illustrates how, based on manufacturer ratings, CFLs are approximately four to six times more efficacious than incandescent lamps of similar light output.⁴ Note, however, that LED replacement lamp efficacy overlaps with CFLs in lower light output ranges. LEDs appear to fill a niche as replacements for very low-wattage decorative incandescent lamps—an application that favors the LED compact form factor over the larger CFLs. In addition, LED replacement lamps may address several CFL shortcomings, including dimming, cold temperature operation, durability, and lamp disposal issues.

⁴ To date, CALiPER has performed bare lamp testing of one CFL, a 13- self-ballasted spiral lamp (two samples) that performed slightly above manufacturer ratings for light output and efficacy.

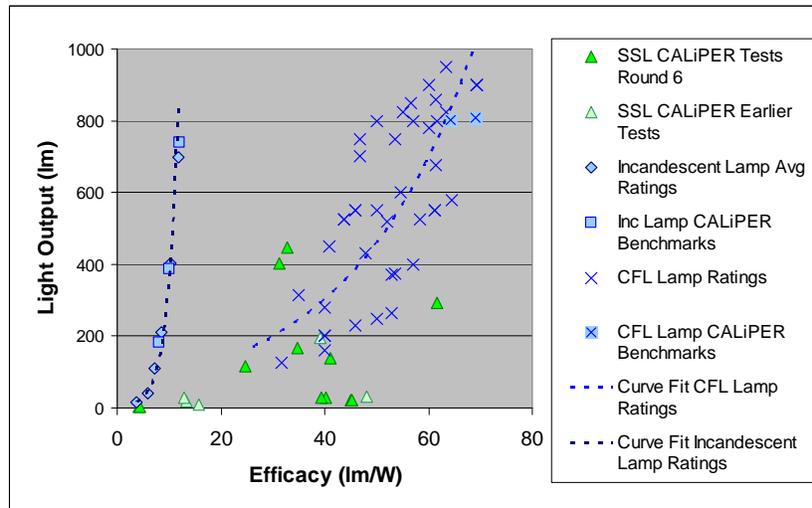


Figure 8. Comparison of Efficacies for Incandescent, CFL, and LED Lamps Based on Manufacturer Ratings and CALiPER Test Results

LED Replacements for Incandescent Omnidirectional Lamps

CALiPER tested a variety of omnidirectional LED products intended as replacements for A19 incandescent lamps. As shown in Figure 9, LED lamps came in a number of formats, including an acrylic A-type bulb (smaller than an A19), small globes, and cylindrical shapes. A number of LED products had clear bulbs with the diodes and circuit boards visible inside. All A lamp replacements were line-voltage products with standard medium (E26) screw bases.



Figure 9. Examples of Bulb Shapes for LED Lamps Replacing Incandescent A Lamps

CALiPER also tested LED replacements for decorative candelabra-type incandescent lamps (Figure 10). These products had both candelabra (E12) and medium (E26) bases, with clear and frosted bulbs.



Figure 10. Examples of Bulb Shapes for LED Lamps Replacing Decorative Incandescent Lamps

Although intended as replacements for incandescent lamps (CCT 2700 K–3000 K), the tested LED products are generally available with both warm (CCT < 3500 K) and cool (CCT > 5000 K) color appearance. To approximate an omnidirectional light distribution, LED replacement lamps must use multiple LEDs with individual optics and/or aiming. For applications in which the lamp is visible, frosted bulbs help integrate the light output of LED clusters and arrays but also decrease overall light output and efficacy. On the other hand, LED lamps with clear bulbs may be more efficacious but produce uneven light distribution and projected patterns. This effect may be mitigated in applications in which the lamp is concealed, as in lampshades and sconces.

Consequently, the user must carefully evaluate LED replacement lamps against the light output, color quality, and maintenance and aesthetic requirements of the application. Given their wide range of lamp shapes and dimensions, LED replacements should also be “fit-checked” for their intended fixture. In some applications, users may find these products to be an acceptable substitute for incandescent sources, with the added potential benefits of higher efficacy and longer lamp life.

Performance of Omnidirectional LED Replacement Lamps

To date, CALiPER has tested 10 LED A lamp replacements and 5 decorative LED replacement lamps. Table 3 presents a summary of CALiPER test results, with LED product performance discussed below. Values for CCT, CRI, D_{uv} , and power factor that are clearly outside industry norms are in red italics.

Table 3. Summary of CALiPER Testing for LED A Lamp and Decorative Replacement Lamps

	DOE CALiPER Test ID	Total Power (W)	Output (initial lm)	Efficacy (lm/W)	CCT (K)	CRI	Max D_{uv}	Power Factor
Replacement A lamps								
A lamp	07-06	0.7	10	16	3161	70	0.003	<i>0.35</i>
A lamp	07-12	1.5	20	13	<i>25263</i>	79	<i>0.014</i>	<i>0.29</i>
A lamp	07-23	0.7	33	48	3099	70	0.002	<i>0.34</i>
A lamp	08-03	3	81	31	3127	92	0.001	<i>0.55</i>
A lamp	08-25	5	194	39	3418	86	<i>0.007</i>	<i>0.33</i>
A lamp	08-55	5	116	25	5061	<i>66</i>	<i>0.017</i>	<i>0.44</i>
A lamp	08-80	5	292	62	<i>7272</i>	79	0.001	<i>0.48</i>
A lamp	08-81	14	445	33	3388	<i>52</i>	0.003	<i>0.62</i>
A lamp	08-82	5	167	35	3023	<i>66</i>	0.004	<i>0.55</i>
A lamp	08-92	13	403	31	3143	<i>49</i>	0.003	<i>0.57</i>
Replacement Candelabras								
Candelabra	07-57	2.2	28	13	2855	71	0.004	<i>0.55</i>
Candelabra	08-56	0.7	29	40	3193	<i>66</i>	<i>0.013</i>	<i>0.51</i>
Candelabra	08-78	0.5	22	45	2888	<i>64</i>	<i>0.011</i>	<i>0.41</i>
Candelabra	08-99	1.5	88	61	6378	79	0.002	<i>0.40</i>
Replacement – Other								
C7 (night light)	08-91	0.4	2	4	<i>21106</i>	73	<i>0.008</i>	1.0

Light Output and Efficacy

For LED replacement lamps, we must consider the efficacy of the replacement lamp as a whole (as opposed to the efficacy of individual LED chips used in the lamp). For A lamp replacements, the highest-performing LED products had light output comparable to 40-W incandescent products, with about three to five times the efficacy. In comparison, self-ballasted compact fluorescent lamps (CFLs) of similar light output are about 4.5 times more efficacious than 40-W incandescent A lamps, based on manufacturer data. Average light output for tested LED A lamp replacements was comparable to 25-W incandescent A lamps (incandescent data in Table 1).

Light output for decorative candelabra-type LED replacement lamps was generally comparable to low-wattage incandescent versions (see Table 1), with significantly higher efficacy. A notable exception was a 0.4-W C7 (nightlight-type) LED replacement lamp, which produced only 2 lm with an efficacy of 4 lm/W—on par with the lowest-performing incandescent lamps in CALiPER’s survey of manufacturer data in efficacy but with only negligible light output.

Color Characteristics

The color properties of light sources are described by two commonly used measures: correlated color temperature (CCT) and color rendering index (CRI). Incandescent sources inherently produce warm white light, with CCT values in the range of 2700–3000 K. Incandescent sources also have high CRI values, approaching 100.

Figure 11 illustrates how, in general, the color appearance of LED products fell under two broad categories—warm (CCT < 3500 K) and cool (CCT > 5000 K).⁵ Two tested LED products exhibited extremely cold color appearance, with measured CCT values greater than 20000 K, significantly outside the applicable ANSI chromaticity specifications (per ANSI Standard C78.377-2008). ANSI also prescribes D_{uv} chromaticity targets and tolerances, which describe the relative whiteness of LED light output for a given nominal CCT.⁶ As shown in Figure 12, a number of CALiPER-tested LED replacement lamps with acceptable CCT values had D_{uv} values that exceeded ANSI tolerances and were off-white (e.g., greenish, bluish) in appearance. Several LED products also had measured CRI values less than 70 (per Table 3 above). However, given the known problems with applying CRI to white light LED products, users should evaluate LED replacement lamps visually to gauge their color rendering for a given application.⁷

⁵ See the fact sheet, “LED Measurement Series: Color Rendering Index and LEDs,” for more information about LED performance on CRI tests and recommendations for evaluating color characteristics of LEDs, available at http://www.netl.doe.gov/ssl/usingLeds/general_illumination_color.htm.

⁶ For the measured chromaticity coordinates (as plotted on the CIE 1976 (u' , v') diagram), the target D_{uv} is the maximum allowable distance from the Planckian (blackbody) locus. This distance is specified for each nominal CCT defined in ANSI C78.377-2008 and relates to the relative whiteness of a light source appearance.

⁷ See the fact sheet, “LED Measurement Series: Color Rendering Index and LEDs,” for more information about LED performance on CRI tests and recommendations for evaluating color characteristics of LEDs.

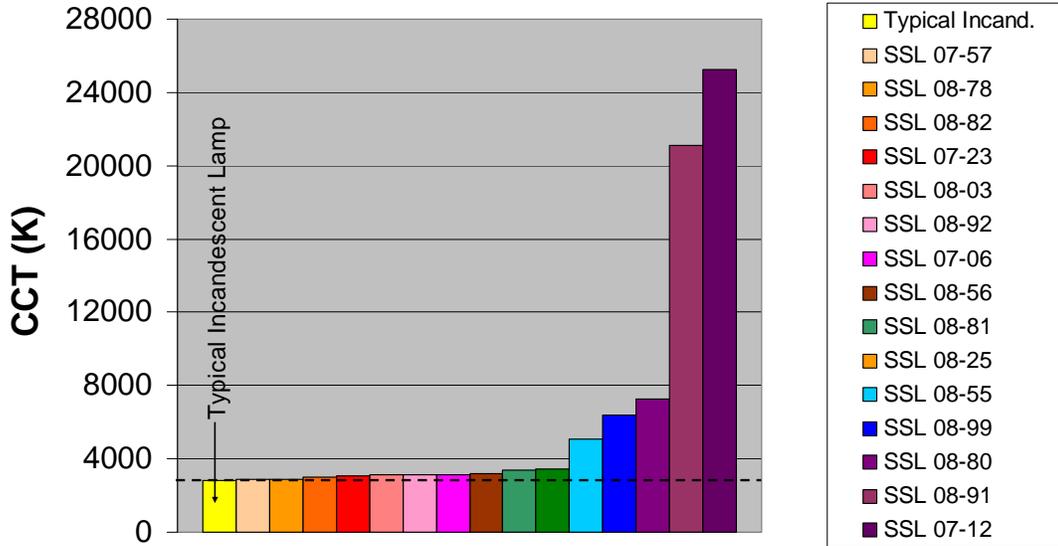


Figure 11. Comparison of CCT Values of Typical Incandescent Lamp with Those of Tested LED Replacements

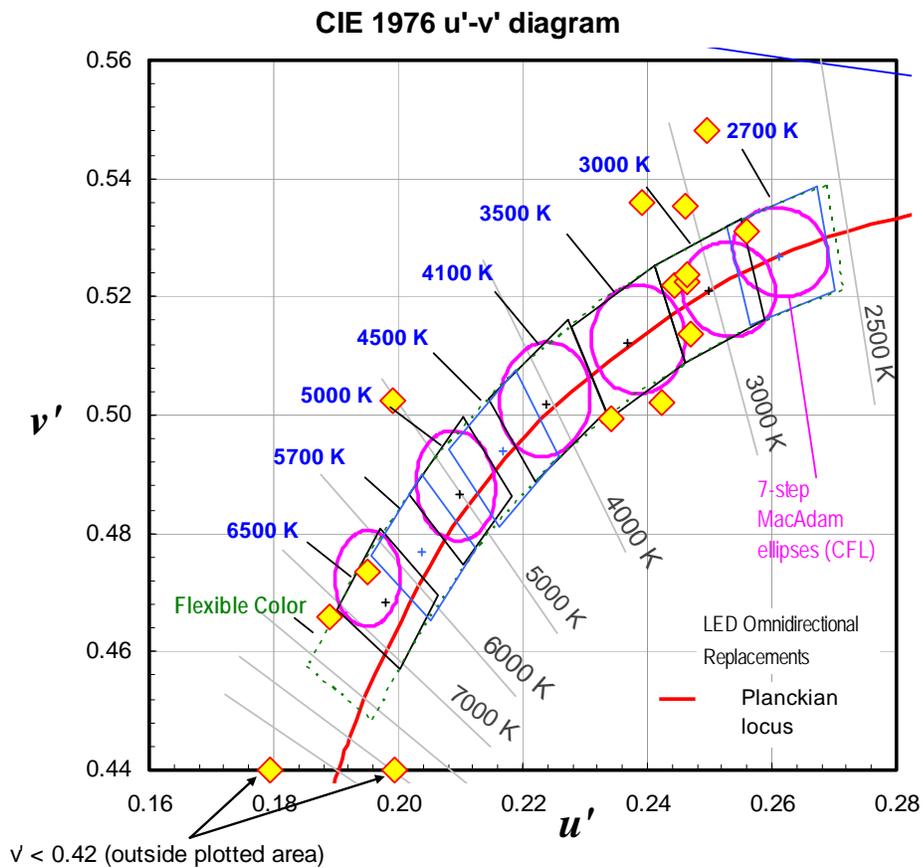


Figure 12. Chromaticity of LED Omnidirectional Replacement Lamps (shown as diamonds) Plotted Against ANSI Chromaticity Specifications (chromaticity diagram from ANSI C78.377-2008)

Power

The power factor (PF) of a light source is an indicator of how efficiently a load uses the current that it draws from an alternating current (AC) power system. For example, incandescent lamps have a PF of 1.0, which describes a state in which the lamp uses all input power in producing output (i.e., light and heat). LED systems consist of components independent of the light source (e.g., power supplies and other electronic components) that consume both reactive and harmonic power in addition to the power used to produce light, resulting in a PF less than 1.0. To encourage efficient use of power in LED products, the ENERGY STAR[®] program requires power factors greater than 0.7 and 0.9 for residential and commercial applications, respectively, for SSL products.⁸ In CALiPER testing to date (see Table 3), power factors for LED A lamp and decorative lamp replacements have been, almost without exception, less than 0.7—with several at 0.4 or lower—thereby not meeting ENERGY STAR power factor criteria.

When addressing the energy-savings potential of a replacement lamp, manufacturers often compare the power use of one LED lamp versus the power use of one incandescent lamp. As revealed in CALiPER testing, the light output of LED replacements can fall short of their incandescent counterparts—to an extent where two or more LED lamps might be needed to functionally replace one incandescent lamp. Consequently, the overall power requirements of the replacement system as a whole should be compared to the overall power use of the existing system and the desired light output. LED replacement lamps include driver electronics that also can result in a low power factor, lowering the effective energy efficiency of the technology.

Distribution and Directionality

Traditional lamps that all of these small SSL replacement lamps are intended to replace emit light in a fairly even, omnidirectional pattern. Close to half of their output is emitted upward, with half emitted downward; a maximum candela value occurs at the horizontal angle, perpendicular to the length of the lamp. Figure 13a provides an example of an intensity distribution plot for a 40-W incandescent lamp. The small, omnidirectional SSL replacement lamps tested in Round 6 exhibit a variety of distributions. One product has cosine distribution as shown in Figure 13b (typical of a directional lamp with a very wide beam angle). A number of products have spiky, downward distributions (with a base-up lamp orientation) due to the arrangement of the multiple LED sources, as illustrated by the example in Figure 13c. As illustrated by the example in Figure 13d, three products have fairly omnidirectional beams—more closely approximating their incandescent counterparts—with 60-66% of light emitted downward and 34-40% emitted upward.

Dimming

The dimmability of LED replacement lamps is largely unknown at this time. The CALiPER program has tested a number of LED luminaires and replacement lamps with 10 different dimmers. Some of the LED lamps claim to be dimmable, some provide no indication regarding dimmability, and some have product literature stating they are not dimmable. Upon testing, it was found that many LED products

⁸ ENERGY STAR power factor requirements are found in “ENERGY STAR Program Requirements for Solid State Lighting Luminaires, Eligibility Criteria – Version 1.0” (2007), available at http://www.energystar.gov/ia/partners/prod_development/new_specs/downloads/SSL_FinalCriteria.pdf.

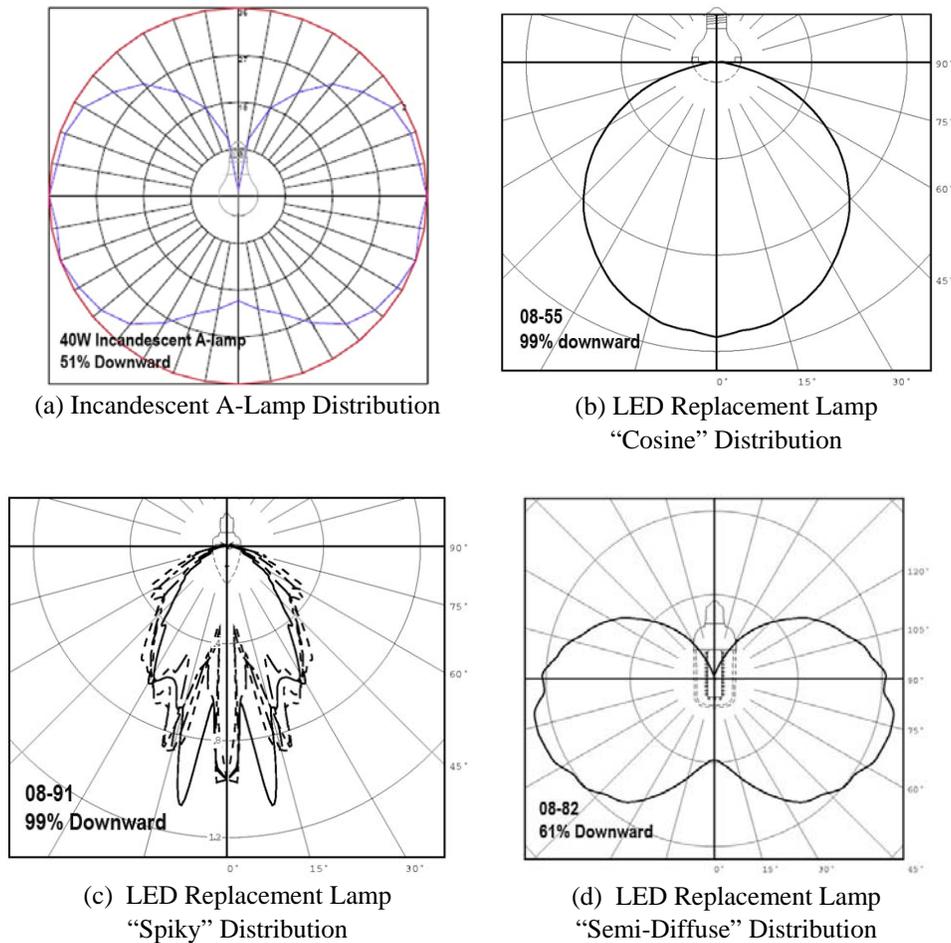


Figure 13. Lamp Intensity Distributions

were dimmable, with at least half of the sample dimmers, including magnetic low-voltage, electronic low-voltage, and electro-magnetic (standard, resistive type for incandescent lamps) dimmers. The indications on product literature regarding dimmability or non-dimmability were correct in about half of the products. Unlike incandescent lamps that shift to lower CCT values, the majority of LED white light products tested have stable color when dimmed.

Replacements That Fit

Form factor can also be an issue for the A lamp replacement products: many are purported to replace A lamps but are too long or too large in bulb diameter or too wide in the bulb neck at the base (i.e., near the socket—some replacement CFLs have the same problem). Some LED products are ambiguous in form and function; for example, they are sold as replacements similar to A lamps in shape but emit light in a directional beam. Size and form factor were problems also for CFL replacement lamps through the mid-1990s.

Manufacturer Claims

The majority of LED A-type replacement lamps and decorative lamps do not meet manufacturer performance claims. Most products carry claims such as “equivalent to a 25-W lamp” or “replaces a 40-W lamp” or “90% more efficient than a 60-W lamp.” Typically, CALiPER testing reveals that these lamps produce only 10-60% of their claimed light output, and often their directionality would not make them suitable replacements for omnidirectional lamps. In addition, in many cases the SSL products have color characteristics that are not typical of the products they claim to replace (such as much colder color temperatures, poor CRI, or light that is not truly white).

Performance claims for energy efficiency also are usually incorrect or misleading. The majority of products draw more power while producing less light output than claimed, reducing their efficacy. Because of low light output levels, typically two or more LED replacement lamps may be needed to produce the output of one incandescent A lamp, so energy savings would be diminished or lost entirely. For applications requiring very low light levels, some LED lamps could provide energy-saving alternatives. For example, some better-performing LED replacements that claim to replace 40-W incandescents would in fact be suitable to replace 25-W incandescent lamps and still achieve energy savings.

Conclusions

As CALiPER testing progresses, the light output of LED replacements for omnidirectional incandescent sources—such as A-type lamps and decorative candelabra-style lamps—has increased steadily and now rivals that of 40-W incandescent products in some cases. Unfortunately, a huge range of performance can be observed in LED replacement lamps sold today, and performance claims in product literature often are highly overstated or misleading.

Light output is a critical metric for A lamps in particular, which are relied upon as a general lighting source in fixtures ranging from floor and table lamps to recessed downlights. Color quality is also important in general lighting applications, and LED replacement lamps are available that approximate the warm appearance and good color rendering of incandescent A lamps, with significantly higher efficacy and potentially longer service life. LED replacements with a cooler appearance also are available, for better integrating with other energy-efficient sources like CFLs and linear fluorescent that often, although not always, are cooler in appearance than incandescents. Unfortunately, some LED replacement lamps on the market are sold as white light sources but actually produce yellowish, greenish, bluish, or pinkish light.

Light output is not as important for candelabra-type incandescent lamps, which typically are used to provide glow or sparkle in decorative applications. Currently, LED replacement lamps can match the light output of small, lower-wattage incandescent decorative lamps, with better efficacy and potentially longer life, but not all LED products on the market today actually reach that level of performance. Required color characteristics for decorative applications may differ from those for general lighting. However, the color quality and light distribution of LED replacement lamps vary widely and should be evaluated carefully against application requirements.

Taken as a whole, the small SSL replacement lamps tested by CALiPER also raise serious quality concerns—from poor color quality to poor power quality to failures of products during testing. Out of 15 small, omnidirectional SSL replacement lamps tested to date, only one has an acceptable power factor, and over half have power factors below 0.5. A number of replacement lamp samples that were sent for testing failed completely or partially before testing could be completed.

As evident from CALiPER testing, the performance and format of LED A lamp and decorative lamp replacements also are inconsistent. Ideally, users should evaluate samples of LED products in their intended fixtures and applications to gauge their “fit”—not only physically within the fixture but in terms of lighting quality and aesthetic requirements. Users should note that the performance and life of LED replacement lamps is highly dependent on their design and thermal management, which includes the fixture in which they are installed. Long-term reliability for this class of products is largely untested; however, well-designed LED replacement lamps should provide significantly longer service life than incandescent lamps.

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