

CALiPER

SUMMARY REPORT

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DOE Solid-State Lighting CALiPER Program

Special Summary Report: Retail Replacement Lamp Testing

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CALiPER Special Summary Report: Retail Replacement Lamp Testing

Introduction

CALiPER testing has evaluated many products for commercial lighting markets and found some excellent performers. However, many of these are not available on the retail market. This special testing was undertaken to identify and test solid-state lighting (SSL) replacement lamp products that are available to the general public through retail stores and websites.

Avoiding a repetition of the negative consumer experiences that occurred when compact fluorescent lamps were introduced¹ is important. Buyers in the retail market are typically not as discerning as lighting designers and specifiers. Many SSL stakeholders are concerned that the increasing retail availability of poorly performing SSL lamps could disappoint buyers and potentially result in widespread buyer dissatisfaction in SSL technology. This study underscores the need for buyer and specifier education along with responsible retail and manufacturer practices.

SSL replacement lamps were evaluated for light output, efficacy, power factor, chromaticity and color rendering, then operated for 1,000 hours and tested again.² Measured product performance was compared with product packaging claims to see whether manufacturer claims are substantiated. The initial and 1,000-hour test data sets were compared to provide an indication of the likelihood that products will meet their lifetime claims. In addition, products tested were compared to incandescent or halogen benchmark products that the products claimed to replace or might be expected to replace based on lamp format and labeling. Meeting performance levels of benchmark products is not always necessary (in some cases a customer may be satisfied with less light or cooler color temperatures). However, as evidenced by early CFL experiences, first impressions are very important and it is difficult to educate customers about differences in new technologies, so it is highly desirable that SSL replacement lamps perform comparably to the similar-looking traditional lamps with which they share shelf space—or else the packaging should explicitly indicate that the SSL products do not provide comparable light output, color, or distribution to traditional lamps of the same format.

Samples of 33 products were purchased anonymously from retail stores and retailers' web sites between June and August of 2010. Standardized testing was conducted on three samples of each product. A range of types of SSL lamps were purchased that mimic conventional technologies in shape/size, including five A19, four B10 (candelabra), two C7 (night light), eleven MR16/PAR16, four PAR20, and seven PAR30.³ The 33 different lamps include products from 10 different manufacturers, purchased from 8 different retail stores.⁴ It should be noted that compared to the number of products

¹ See US Department of Energy report, "Compact Fluorescent Lighting in America: Lessons Learned on the Way to Market," http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/cfl_lessons_learned_web.pdf.

² Products were tested using the IES LM-79-08 testing standard, *IESNA Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products*: <http://www.iesna.org/>.

³ Note that the B10 lamps include products with both E12 and E27 base. The MR16/PAR16 lamps include products with GU5.3, GU10, and E27 base—analyses for these lamps take into account lamp voltage and performance of benchmarks with similar formats.

⁴ Specific product names, manufacturer names, and retailer names are codified in analyses to focus on generalities and to avoid providing direct advantage or disadvantage to any given industry stakeholder.

on the market and number of retailers now carrying SSL replacement lamps, this selection of products is limited, not exhaustive. All results in this report are anonymous, to focus on general indications and lessons that can be gleaned from the results, not judgments of specific products, manufacturers or retailers.

This testing provides significant educational information for retailers, manufacturers and buyers of SSL replacement lamps. SSL technology and market-available products are evolving rapidly. In many cases, the products included in this testing may already be superseded by newer models; however, this testing reconfirms ongoing concerns observed in CALiPER testing. Key points are:

- The disparities between high performing and low performing products are striking.
- To be able to discern whether an SSL replacement lamp would meet performance expectations, consumers would have to be highly informed about lamp performance in general and would have to develop mechanisms to recognize and understand factual information from product labeling.
- There are wide differences among manufacturers. Some have SSL replacement lamps that are fairly consistently meeting expectations; others are not at all consistent.
- Likewise, there are wide differences among retailers. Some appear to screen the SSL lamps they carry such that most of the products perform well and have suitable labeling; others apparently do not.
- While there are some high performing SSL replacement lamps available through some channels today, most of the replacement lamps tested fail to meet basic performance levels of the incandescent or halogen lamps they appear to replace.

Light Output

Figure 1 shows that while the SSL products have much higher efficacy than the incandescent benchmarks, only a few products meet or come close to meeting the light output of the benchmark products.⁵ When compared with a 40-watt (W) A19, 15W B10, 7W C7, 20W MR16/35W PAR16, 35W PAR20, and a 50W PAR30, none of the SSL products meet or exceed the light output of the benchmark products. If the SSL PAR20 lamps are compared to a 30W R20 lamp (instead of 35W PAR20), they do meet the light output of the benchmark (R20). One SSL PAR30 and one SSL B10 lamp achieve within 10% of the light output level of their respective benchmark products.

- Two of the five SSL A19 lamps come close to meeting the average light output of a 40W incandescent A19 lamp. The other three SSL A19 lamps provide one-quarter to one-half of the

⁵ Only spectroradiometry testing was conducted, so center beam candlepower (CBCP) and beam angle comparisons for directional products were not possible. For simplicity, incandescent and halogen lamps representing the lowest typical wattage levels were selected as benchmarks. Comparisons with CFL benchmarks are not the focus in this report.

light output of a 40W A19 incandescent. None of the SSL A19 lamps included in these tests is comparable to the ubiquitous 60W A19 lamp.

- Three of the four B10 SSL lamps and both of the C7 SSL lamps do not produce the light output of their incandescent equivalents. The three lower-performing B10 SSL lamps provide on average about one-half the light output of a 15W incandescent. The two C7 lamps from different manufacturers emit only 1 lumen of light, whereas a typical incandescent C7 lamp produces 16 lumens.
- Four of the eleven SSL MR16/PAR16 lamps come close to meeting the average light output in lumens (light distribution and intensity were not measured) of a 20W halogen MR16, the seven other SSL MR16/PAR16 lamps provide between one-quarter to one-half the light output of a 20W halogen MR16.⁶
- None of the four PAR20 SSL lamps achieve the light output of a 35W halogen PAR20, but they do provide similar lumen output to a 30W R20 lamp. And, one SSL PAR20 claims to be equivalent to a 45W incandescent R20, which it does not achieve.
- Three of the seven SSL PAR30 lamps come close to meeting the lumen levels of a 50W halogen PAR30.

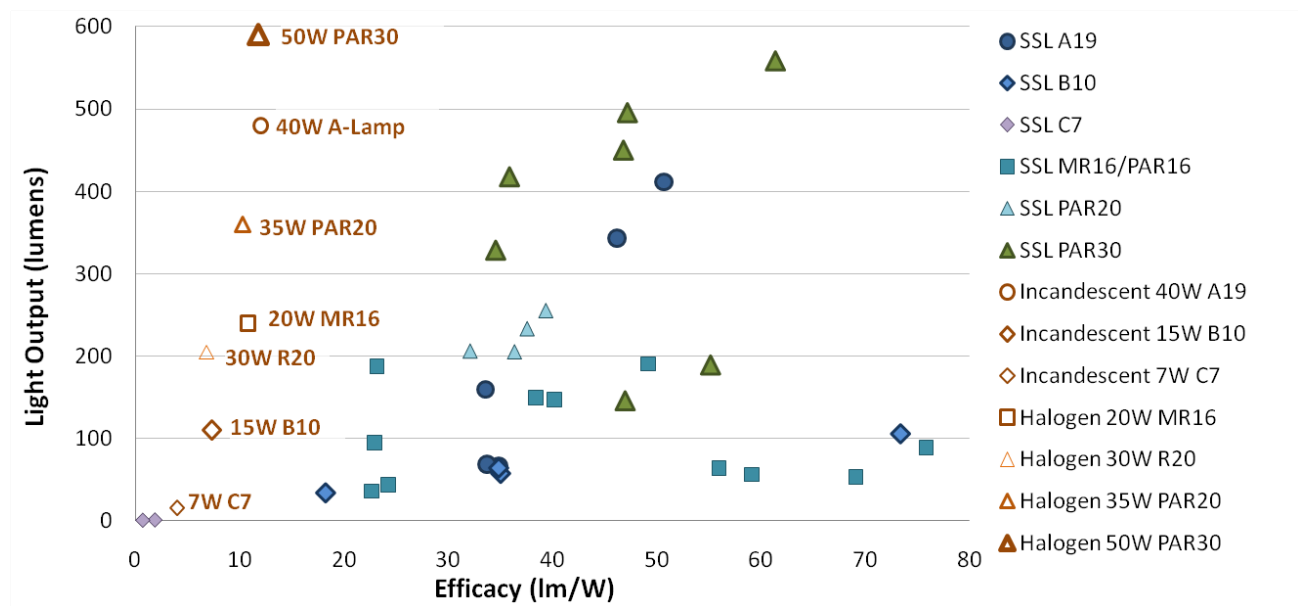


Figure 1: Light Output and Efficacy—Comparing Benchmark Incandescent/Halogen to SSL Replacement Lamps

⁶ Note: for simplicity, the MR16/PAR16 category in this report includes products with a variety of bases, some using 12VAC input, some 120VAC. Performance values are adjusted for transformer loss to enable direct comparison across lamps and for lamp type, such that the benchmarks include the lowest wattage traditional products available in each category: GU5.3 base MR16s, a benchmark for GU10 base MR16, and a benchmark for Edison-base PAR16.

Efficacy

Efficacy is a measure related to energy efficiency: how much light (lumens) is produced for a given amount of power (watts) used. All the products tested except the two C7-shaped lamps offered better efficacy than incandescent and halogen products. However, several products achieve high efficacy while Correlated Color Temperature (CCT) is much higher than the products they replace. This may prove unacceptable to consumers.

- Average efficacy observed is 40 lumens per watt (lm/W), which on average is about 4 times the efficacy of incandescent and halogen benchmarks.
- Thirteen of 33 products are 45 lm/W or better. (These efficacy levels exceed Edison-base CFL for smaller and directional lamp formats such as candelabras and R20-format CFL, but they do not meet CFL efficacy levels for larger spiral A-lamps and R30 lamps.)
 - Four of 33 products tested had efficacies in the range of 60 – 80 lm/W.
 - Ten of 33 products tested had efficacies in the range of 40 – 59 lm/W.
 - Sixteen of 33 products tested had efficacies in the range of 20 – 39 lm/W.
 - Three of 33 products tested had efficacies in the range of 1 – 19 lm/W.
 - Only two of the products tested (C7 lamps) had lower efficacy than incandescent product — they draw close to 1W and only produce 1 lumen of light output.

Color Quality

Most of the SSL products tested are being marketed explicitly or implicitly as replacements for incandescent products that typically have CCTs in the 2700 to 3000K range. However, 10 of the SSL products had CCTs measured at higher than 4000K. Only four products are within the ANSI C78.377-defined nominal CCT range for 2700K – the nominal value for incandescent lamps.⁷ Sixteen products are within the C78.377-defined 3000K range – 3000K is the nominal CCT for some halogen lamps. The remaining 13 products have CCTs that might not be preferred or acceptable to a buyer because they are a colder white (above 3000K) than typical for small replacement lamps. Figure 2 illustrates that most products with warm CCT also have relatively high Color Rendering Index (CRI). More than half of the lamps would be considered to be poor or mediocre in color quality (having one or more color characteristics outside of typical tolerance—CRI, CCT, and/or D_{uv}). Only two products are warm white and have CRI over 90.

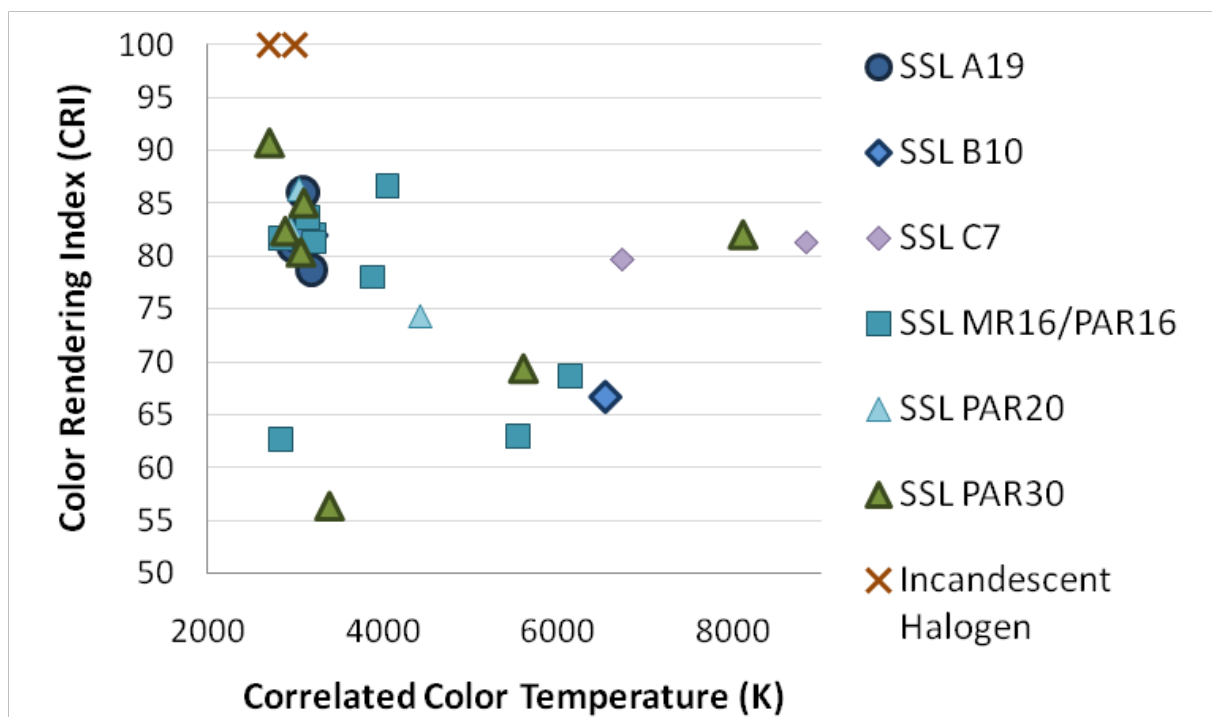


Figure 2: Color Qualities in Retail SSL Replacement Lamps

⁷ ANSI/NEMA/ANSI C78.377-2008, Specifications for the Chromaticity of Solid State Lighting Products. Downloadable from <http://www.nema.org/stds/ANSI-ANSI C78-377.cfm>, February 15, 2008, defining nominal CCT ranges for indoor SSL products and maximum and minimum D_{uv} levels (deviation from the black body locus) for each CCT.

Power

As seen in Figure 3, there was a clear delineation between products that had high power factor (greater than 0.80), and those that did not. Based on this testing, SSL products that are closer to benchmark expectations for lumen output and color qualities also tend to be those that have high power factor.

- Fourteen of 33 products have power factor over 0.80; the remainder range from 0.29–0.70.
- Twenty of 33 products tested (60%) drew 5W or less. Nevertheless, four of these 20 low power (5W) lamps had power factors greater than 0.70, including B10, C7, and MR16-shaped lamps.
- ENERGY STAR® criteria do not have requirements on power factor for lamps that draw 5W or less.
- Lamp type (size) does not appear to be associated with power factor.
- Only two products claim to be dimmable. Compatibility with dimmers was not tested.

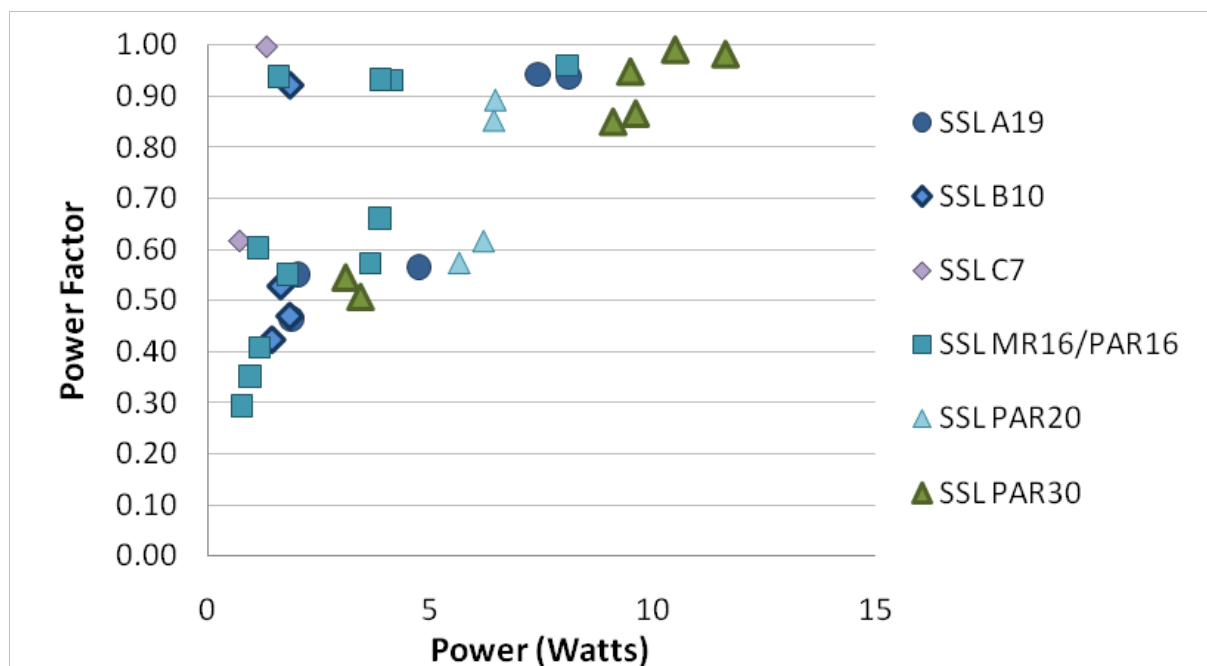


Figure 3: Power Characteristics

Product Lifetime

Manufacturer life claims for these products ranged from 12,000 to 50,000 hours. Testing the products a second time after 1,000 hours of operation allows a quick check of how the retail replacement lamps are performing, but it does not enable verification of lifetime claims, unless a product depreciates below a given threshold (e.g., 70% of initial light output (L70)). Although not enough for definite long-term predictions, 1,000-hour testing reveals immediate problems, such as exceeding color shift tolerances or lifetime lumen depreciation limits. While there are many exceptions, CALiPER long-term testing studies have shown that the general risk of SSL products failing to maintain suitable light output throughout their rated life increases for products that do not maintain or come very close to maintaining initial light output after 1,000 hours of operation.⁸ Based on this generalized evidence, over half the lamps included in this testing will most likely not achieve manufacturer-claimed lifetime.

- Three products—a PAR30, an MR16, and an A19—depreciated more than 30% after only 1,000 hours. That is, they produce less than 70% of initial light output after 1,000 hours of operation—12%, 43%, and 58% respectively.
- Twelve other products exhibit less than 97% lumen maintenance after 1,000 hours (ranging from 72 to 97% initial light output)—indicating a high risk of not being able to achieve their lifetime ratings.
- The remaining 18 products tested had only 3% or less lumen depreciation after 1,000 hours — indicating less likelihood of developing rapid lumen depreciation.
 - Four of five Lighting Facts-labeled products maintained initial light output levels after 1,000 hours, making them much more likely to meet lifetime claims.⁹
- To reduce the risk of premature failure, buyers should look for test information such as LM-80 data (not typically available for retail products), the Lighting Facts label, the ENERGY STAR label, and long-term warranties.¹⁰

⁸ Based on CALiPER long-term testing and projections on a wide range of SSL products, one-third of products that maintained 98% or more of their initial light output after 1000 hours of operation had projected L70 < 15,000 hours (after 6000 hours of testing), two-thirds of products that maintained 97% or less of their initial light output after 1000 hours of operation had projected L70 < 15,000 hours (after 6000 hours of testing). Note that this 1,000-hour check allows us to generally assess risk of lumen depreciation; it is not a definitive indicator for any specific product and should not replace longer lumen depreciation testing necessary to predict lumen lifetime. http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_round-10_summary.pdf.

⁹ <http://www.lightingfacts.com/>

¹⁰ ENERGY STAR classification for LED light bulbs (integral replacement lamps) became effective in Q4 2010, after the products in this study were purchased (http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=ILB), so none of these products were ENERGY STAR products at the time of purchase. One of the products tested has a model number which is now listed as an ENERGY STAR-rated integral replacement lamp—that product FTT CA30 carries the Lighting Facts label, and meets claimed performance levels at initial and 1,000-hour testing. An updated version of product FTT CA14 (with a similar but not identical model number) is also listed as ENERGY STAR-rated—it too carries the Lighting Facts label and meets performance claims.

Overall Retail SSL Lamp Assessments

Table 1 compares generalized assessments of the products tested, grouped by manufacturer (as marked on product packaging). This assessment is based on combined indicators that consider lamp type, product labeling, measured light output, measured color qualities, and measured changes in performance over 1000 hours of operation.¹¹ A red “N” indicates a product that is **not** likely to meet typical expectations for light output, color quality, or lifetime for a given lamp type and based on claims on product packaging. These results are illustrative and should not be considered as definitive (only a limited number of products are included and product lines are continuously evolving).

Only a sampling of products were tested from some manufacturers, so making generalizations for those manufacturers may be inappropriate, but for four of the manufacturers, several products were tested. Manufacturers 4 and 6 were the best of the group, likely to meet lifetime claims and color expectations, though still only close to meeting light output for benchmarks. Manufacturer 2 had a large number of products tested, but all ranked poor or mediocre on all three

Table 1. Indicators of Replacement Lamp Performance, Grouped by Manufacturer

Manufacturer	CALIPER RL #	Likely to Meet Light Output Expectations	Likely to Meet Color Quality Expectations	Likely to Meet Lifetime Expectations
1	1-A19	N	Y	Y
1	25-r30	—	N	Y
2	2-B10	N	N	N
2	19-r16	N	N	N
2	20-r16	—	N	—
2	24-r20	—	N	N
2	29-r30	N	N	N
3	3-A19	—	Y	—
3	4-A19 (LF)	N	N	—
3	6-B10	N	Y	—
3	7-C7	N	N	N
3	15-r16	—	N	N
3	16-r16	—	Y	—
3	17-r16	N	N	N
3	23-r20	—	N	—
4	5-A19	—	Y	Y
4	32-r30 (LF)	—	Y	Y
5	34-A19	N	Y	Y
5	33-B10	N	Y	Y
5	12-r16	N	N	N
5	13-r16	N	N	—
5	22-r20	—	Y	Y
5	31-r30	N	Y	Y
6	9-B10 (LF)	N	Y	Y
6	14-r16 (LF)	—	Y	Y
6	21-r20	—	Y	Y
6	30-r30 (LF)	—	Y	Y
7	8-C8	N	N	N
8	10-r16	N	N	N
8	26-r30	—	Y	Y
9	11-r16	N	Y	N
9	28-r30	N	N	N
10	18-r16	N	N	Y

N = not likely to meet expectations

— = neutral

Y = likely to meet expectations

LF = products with Lighting Facts label

¹¹ Assessments in Tables 1 and 2 represent combined indicators:

- For light output, consider what would be expected for the lamp type in general (based on 40W A19, 15W B10, 7W C7...) and what would be expected based on the packaging rated lumens and equivalency claims (and also consider absolute value of light output at 1,000 hours).
- For color, look at CCT, CRI, Duv, and compare to basic consumer expectations for the lamp type (e.g., 2700 or 3000K, CRI>=80, Duv within ANSI tolerance for the CCT) and also look at absolute values of the color parameters at 1,000 hours and shifts (delta uv, or CCT shifting significantly).
- For lifetime, look at manufacturer life claims, 1,000 hour lumen maintenance, and 1,000 hour color maintenance to generate an indicator of likelihood that the product will meet longer term expectations.

performance expectations. This illustrates that the manufacturer of the product can be an indicator of better or worse performance, though most manufacturers had at least one poor performing product, so a brand name is not a guarantee of performance.

Table 2 compares generalized assessments of the products tested, grouped by retailer (where each product was purchased). Again, it is important to note that these results are illustrative and should not be considered as definitive. Eight different retail stores were used, with more products purchased from some than others, depending primarily on off-the-shelf availability. None of the retailers received ‘perfect’ marks on all their tested SSL products (i.e., with light output, color quality, and lifetime likely to meet expectations for all lamps tested). However, the lamps purchased from retailers A and C show better overall performance on most counts. Of five SSL lamps purchased and tested from retailer B, none received a confident “likely to meet expectations” for any of the criteria.

These results suggest that some retailers may be working harder to screen the products they sell. Retailer A appears to do the best job, with products that are likely to meet color and lifetime expectations in most cases. Purchasing from any given retailer does not guarantee an excellent product, however.

Table 2. Indicators of Replacement Lamp Performance, Grouped by Retailer

Retailer	CALiPER RL #	Likely to Meet Light Output Expectations	Likely to Meet Color Quality Expectations	Likely to Meet Lifetime Expectations
A	1-A19	N	Y	Y
A	5-A19	—	Y	Y
A	9-B10 (LF)	N	Y	Y
A	14-r16 (LF)	—	Y	Y
A	16-r16	—	Y	—
A	21-r20	—	Y	Y
A	25-r30	—	N	Y
A	30-r30 (LF)	—	Y	Y
A	32-r30 (LF)	—	Y	Y
B	2-B10	N	N	N
B	12-r16	N	N	N
B	13-r16	N	N	—
B	19-r16	N	N	N
B	29-r30	N	N	N
C	3-A19	—	Y	—
C	4-A19 (LF)	N	N	—
C	6-B10	N	Y	—
C	23-r20	—	N	—
D	33-B10	N	Y	Y
D	34-A19	N	Y	Y
E	7-C7	N	N	N
E	10-r16	N	N	N
E	15-r16	—	N	N
E	17-r16	N	N	N
E	26-r30	—	Y	Y
F	8-C8	N	N	N
F	22-r20	—	Y	Y
F	31-r30	N	Y	Y
G	11-r16	N	Y	N
G	18-r16	N	N	Y
G	28-r30	N	N	N
H	20-r16	—	N	—
H	24-r20	—	N	N

N = not likely to meet expectations

— = neutral

Y = likely to meet expectations

LF = products with Lighting Facts label

Performance Claims

The packaging claims of all lamps were compared to measured performance. Packaging for most of the products included rated lumens, CCT, and life. One third of the products also carry equivalency claims, such as “replaces 65W uses only 12W” or “compare to 15W incandescent candle” or “5W = 40W light output”. While the rated claims for lumens and CCT were close to measured values for the majority of lamps, all the equivalency claims were inaccurate.

- Packaging on 29 products indicated rated lumens. Measured performance met or exceeded the rated lumens for 25 of these 29 products. Four products indicated no lumen rated and four other products failed to achieve the light output level indicated.
- Packaging on 30 products indicated rated CCT. Of the products indicating rated CCT, 10 products had measured CCT which did not correspond to the rated CCT (that is, was not within standard tolerances of the rated value). All six products with CCT over 5000K failed to meet rated CCT values.
- Two products were labeled as “warm white”. Buyers expecting this to indicate 2700K would be misled because these products measured 2905K and 2951K.
- One product (a C7 lamp) was labeled as “white”, but had a very cold white CCT of 8837K.
- None of the 11 products carrying equivalency claims achieves light output levels matching typical light output for their respective lamp types. One SSL A19 lamp claiming to provide light output equivalent to 40W (typically 450 lm) only produces 160 lm. One SSL B10 lamp claiming to be comparable to a 15W incandescent (for example, 110 lm) only produces 33 lm.

Conclusions: Advice for Buyers, Manufacturers, and Retailers

Purchasing retail SSL lamps through retail outlets can be a risky endeavor at this time, though products that carry a Lighting Facts label reduce likelihood of dissatisfaction. All five products that carry the Lighting Facts label meet manufacturer performance ratings during initial testing (though not necessarily the equivalency claims) and four out of five still meet their Lighting Facts label requirements after 1,000 hours of operation. Some products have both high efficacy and good color qualities. The PAR20 lamps meet incandescent R20 benchmark performance, but not minimum wattage halogen PAR20. Some PAR30 products meet the incandescent benchmark performance. Other higher performing products may be available, so buyers should carefully compare the performance of the product they are replacing with performance of the new product. Performance assessments should always be based on a Lighting Facts label or an LM-79 test report, rather than manufacturer equivalency claims.

Unfortunately, most products do not meet their equivalency claims, so buyers should choose product based on rated performance. That is, buyers of SSL replacement lamps at this stage of market development need to be very discerning about lighting products, comparing numerical values for lumen output, wattage, CCT, etc. , and not relying on packaging statements that say, for example “Equivalent to a 60W incandescent.” Buyers should not blindly expect equivalency to a typical 40W incandescent

A19, 15W B10, 20W MR16/35W PAR16, 35W PAR20, or 50W PAR30, recognizing that only a minority of products actually achieve expected equivalencies today.

Tested C7s are very poor performing products, producing little to no usable light. These lamps were tested as being less efficacious than incandescent and emitting very cold white (bluish) light.

Manufacturers need to continue to work on consistency between products, and on providing products that more closely match the buyer's expectations. Equivalency claims are not accurate and could lead to buyer dissatisfaction, which is not in the long-term interest for manufacturers.

Retailers can take active measures to be more discerning about SSL products that they stock. This study found that DOE retailer partners have a much greater chance of selecting products that perform well when they utilize Lighting Facts and other elements of DOE's SSL program.¹² That effort is paying off today as evidenced by this testing, which reveals that some retailers carry a better performing line of SSL replacement lamps than the other retailers whose products were purchased for this study.

SSL technology and market-available products are evolving quickly. Some of the products included in this report have since been superseded by more recent models, although many are still for sale. In 2011, many SSL products now carry the Lighting Facts label (providing clear performance ratings and a confirmation that standardized testing was used to obtain the ratings). Some replacement lamps which carry the ENERGY STAR label can also now be purchased, providing a recognized mechanism for identifying reliable, energy-efficient SSL light bulbs.

The test results in this study serve as a clear warning of the increasing retail availability of SSL lamps that are likely to disappoint buyers and potentially result in widespread buyer dissatisfaction in SSL technology. This underscores the need for responsible retail and manufacturer practices through participation in programs such as Lighting Facts and ENERGY STAR and proactive use of DOE SSL information resources to educate buyers and specifiers.

¹² <http://www.ssl.energy.gov/>

DOE SSL Commercially Available LED Product Evaluation and Reporting Program

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