CALiPER

SUMMARY REPORT

January 2009

DOE Solid-State Lighting CALiPER Program

Summary of Results: Round 7 of Product Testing

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

DOE Solid-State Lighting CALiPER Program

Summary of Results: Round 7 of Product Testing

Round 7 of testing for the DOE Commercially Available LED Product Evaluation and Reporting (CALiPER) Program was conducted from September 2008 to January 2009. [1] In this round, 29 products, representing a range of product types and technologies, were tested with both spectroradiometry and goniophotometry using absolute photometry, following the IESNA LM-79-08 testing method. [2] Testing also included measurements of surface temperatures (taken at the hottest accessible spots on the luminaire).

Round 7 of testing focused on three application areas: **outdoor lighting**, **downlights**, and **replacement lamps**. One series of tests included eight streetlights—five SSL luminaires, one "typical" HPS cobrahead fixture, and two fixtures using fluorescent induction lamps. For outdoor lighting, CALiPER also tested three bollards from the same product line, lamped with SSL, compact fluorescent, and metal halide sources. The series of tests on nine downlights (eight using SSL and one using CFL) included a wide range of luminaires that could potentially be used for downlighting, including: track lights, a surface-mounted luminaire, recessed downlights, volumetric-recessed lighting, and a 2 ft x 2 ft flat panel fixture. The replacement lamp category included nine different SSL products, including: MR16s, some larger directional lamps (PAR20, PAR30, and PAR38), and A-lamps. This report summarizes the performance results for each type of product and discusses the results with respect to similar products that use traditional sources, and with respect to results from earlier rounds of CALiPER testing.

Round 7 CALiPER Testing Results

Tables 1a, 1b, and 1c summarize results for energy performance and color metrics—including light output, luminaire efficacy, correlated color temperature (CCT), and color rendering index (CRI)—for products tested under CALiPER in Round 7. Table 1a assembles the key performance results for eleven outdoor luminaires that were tested. Table 1b assembles the key results for nine downlight luminaires that were tested. Table 1c assembles the results for nine replacement lamps that were tested. Additional data for each set of testing results and related manufacturer information are assembled in CALiPER detailed reports for each product tested. [3]

As shown in Table 1a, a number of outdoor products intended for streetlighting or area lighting were tested, including five SSL luminaires, one HPS, and two that use induction lamps. Also, three bollards were tested, all from the same manufacturer and same product line, but with three different light sources. An in-depth discussion of the results for these outdoor products is provided below under "Outdoor Fixtures."

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[1] Summary reports for Rounds 1-6 of DOE SSL testing are available online at http://www.ssl.energy.gov/caliper.html.
[2] Please see Appendix A for a more detailed description of CALiPER testing methods and product selection processes.
[3] Detailed test reports for products tested under the DOE's SSL testing program can be obtained online: http://www1.eere.energy.gov/buildings/ssl/search.html.

Table 1a. CALiPER ROUND 7 SUMMARY – Outdoor Area and Streetlights

--SSL testing following IESNA LM-79-08 --25ºC ambient temperature	DOE CALiPER TEST ID	Total Power (Watts)	Output (initial lumens)	Efficacy (lm/W)	CCT (K)	CRI	Power Factor
Streetlights							
SSL Streetlight	08-107	55	1028	19	14628	74	0.93
SSL Streetlight	08-108	58	3179	55	6227	75	0.99
SSL Streetlight	08-109	73	3440	47	6052	72	0.99
SSL Streetlight	08-110	37	2588	71	5210	68	0.99
SSL Streetlight	08-111	95	3105	33	3101	72	0.99
HPS Streetlight Benchmark	08-122	117	6540	56	2042	21	0.44
Fluorescent Induction Streetlight	08-152*	67-71	3695-3960	52-59	3906	75	0.96
Fluorescent Induction Streetlight	08-153*	70-71	3234-3561	46-50	4253	77	0.99
Bollards							
Outdoor Bollard SSL	08-114**	45	578	13	3977	75	0.77
Outdoor Bollard CFL Benchmark	08-112**	32	268 [371]	9 [12]	4261	76	0.99
Outdoor Bollard Metal Halide Benchmark	08-113**	87	464 [1091]	5 [12]	4319	66	0.97

Values greater than 2 are rounded to the nearest integer for readability in this table.

See "Outdoor Luminaires" below for further discussion of results.

* Products 08-152 and 08-153 use fluorescent induction lamps and are highly sensitive to thermal conditions. Test results for these products exhibit a relatively wide range of values, reducing repeatability of results between subsequent photometric tests using the same equipment or between integrating sphere and goniophotometry. Several tests were conducted on these samples, the highest and lowest values are presented here.

**Products 08-112, 08-113, and 08-114 are three versions of the same luminaire from the same manufacturer. One uses an LED source, one a CFL, and one a metal halide lamp. The LED version has an IES Type III distribution. The CFL and MH versions were tested with and without a house-side shield. The results from testing with a house-side shield should represent a similar, Type III, distribution for direct comparison with the LED version. Results from testing without house-side shield are presented in brackets.

Table 1b assembles the results for downlight luminaires that were tested in Round 7, including recessed products, surface mount products, and track lights. These products represent a wide range of dimensions, configurations, and power levels. Two of the tested fixtures represent two versions of the same product (one with SSL light source and one with a CFL), allowing for direct comparison. Further discussion of these results is provided under "Downlights" below.

Table 1b. CALiPER ROUND 7 SUMMARY – Downlights

--SSL testing following IESNA LM-79-08 --25ºC ambient temperature	DOE CALiPER TEST ID	Total Power (Watts)	Output (initial lumens)	Luminaire Efficacy (lm/W)	CCT (K)	CRI	Power Factor
Downlights							
4" ø recessed can	08-124	32	275	9	3204	70	0.98
Retrofit lamp for 5" or 6" ø recessed can, RGB SSL	08-118	13	476	36	3119	52	0.84
6" ø recessed can	08-123	13	644	48	3073	79	0.98
7.5" x 7.5" x 2" surface mounted[1]	08-120	15	417	27	2745	84	0.98
1' x 1' recessed square SSL source[2]	08-119	42	1654	39	3262	82	0.99
1' x 1' recessed square CFL source[2]	08-125	43	1503	35	3140	83	0.99
2' x 2' x 1" Panel	08-134	42	2100	50	5337	63	0.52
Spot light for track	08-126	16	261	16	3132	72	0.72
Spot light for track	08-129	10	258	26	2833	83	0.81

Values greater than 2 are rounded to the nearest integer for readability in this table. All lamps use white LED sources unless otherwise noted.

See "Downlights" below for further discussion of results.

[1] Product 08-120 has a luminous surface area of 2 ⅜" x 2 ⅜".

[2] Products 08-119 and 08-125 have a luminous surface area (diffuser lens) of 8 ½" x 4 ½". Products 08-119 and 08-125 are two versions of the same product from the same manufacturer. One uses an LED source and one uses a CFL.

Table 1c summarizes results for replacement lamps that were tested in CALiPER Round 7. These results include four MR16 replacement lamps, three PAR lamps, and two replacement A-lamps. Further details, discussion, and comparison with previous CALiPER results and with traditional lamps are provided under "Replacement Lamps" below.

Table 1c. CALiPER ROUND 7 SUMMARY – Replacement Lamps

--SSL testing following IESNA LM-79-08 --25ºC ambient temperature	DOE CALiPER TEST ID	Total Power (Watts)	Output (initial lumens)	Efficacy (lm/W)	CCT (K)	CRI	Power Factor
Replacement MR16s							
MR16 GU5.3 12 VAC[1]	08-115*	2	50	29	3414	65	0.66
MR16 GU5.3 12 VAC[1]	08-116*	3	161	50	6143	74	0.67
MR16 GU10 120 VAC[1]	08-117*	0.8	37	49	5249	66	*0.29*
MR16 GU5.3 12 VAC[1]	08-133*	5	89	17	3061	*48*	0.65
Other Directional Replacement Lamps							
PAR 20	08-130*	3	78	23	2909	93	*0.53*
PAR 30	08-128*	7	384	53	3106	79	0.90
PAR 38	08-131*	11	315	28	2953	93	0.58
Replacement A-lamps							
A-lamp	08-132*	14	466	33	3743	68	0.94
A-lamp	08-135*	7	224	31	6601	79	*0.53*

Values greater than 2 are rounded to the nearest integer for readability in this table. All samples use SSL sources.

See "MR 16 Replacement Lamps," "Small Omni-Directional Replacement Lamps," and "Other Replacement Lamps" below for further discussion of results.

* For products shown with an asterisk, two or more units were tested; results show average among units tested.

[1] Note that MR16 sample 08-117 has a GU10 base and uses 120 VAC input. All other MR16 products tested to date have a GU5.3 base and use 12 VAC input. Readers should factor in additional transformer or system losses for 12 V products before comparing efficacy with products which use 120 VAC.

Observations and Analysis of Test Results: Overall Progression in Performance of Products

Energy Use and Light Output

The SSL products tested in Round 7 exhibit a wide range of efficacy: from 9 lm/W to 71 lm/W. On average, however, market-available SSL products continue to reflect a steady increase in performance (see Figure 1).

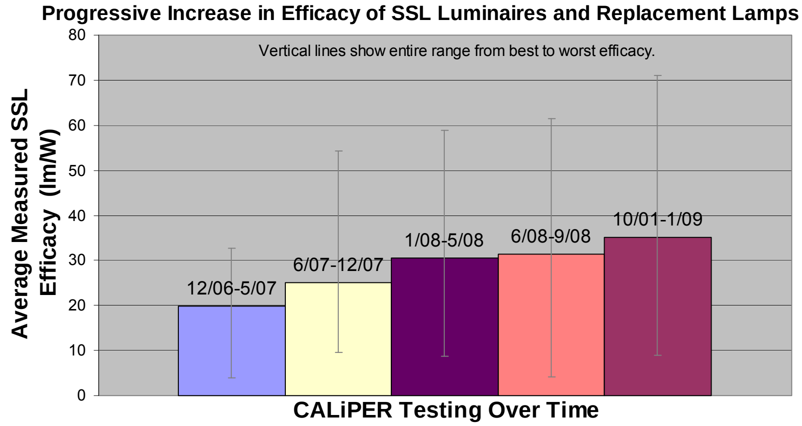

Figure 1. Average Measured Luminaire Efficacy of Market-Available SSL Products Continues to Increase.

For each application category in this round of testing, there are clearly more SSL products that are approaching—or even matching—the light output levels, distribution, and color quality of similar luminaires that use traditional sources. Also, the percentage of products for which manufacturers provide accurate performance claims is increasing. Unfortunately, approximately half of the products tested still have inaccurate or misleading product literature.

The sections below address each product category that was tested in this round, considering efficacy, light output, power characteristics, color quality, product labeling and reporting, and comparative performance to incumbent lighting technologies.

Outdoor Fixtures

Area and Streetlights

In conjunction with the DOE SSL Technology Demonstration GATEWAY Program, eight streetlights—five SSL, one HPS and two fluorescent induction—were tested in Round 7. Most of these streetlights are being tested *in situ* by various municipalities across the United States.

As summarized in Table 2, the SSL streetlights tested in Round 7 vary in wattage from 55 to 95W and in lumen output between 1028 and 3440 lm. Luminaire efficacy ranges widely from 19 to 71 lm/W. Color temperature ranged from 3101K to 14628K—well above the 6500K considered to be the "blue" (daylight) end of white. CRIs on all SSL were generally just above 70, with only one just below at 68. All of the SSL streetlights had a power factor (PF) over 0.9.

Table 2. Summary of Results for CALiPER Round 7 Streetlight Testing

--SSL testing following IESNA LM-79-08 --25ºC ambient temperature	DOE CALiPER TEST ID	Total Power (Watts)	Output (initial lumens)	Efficacy (lm/W)	CCT (K)	CRI	D_{uv}	Power Factor
SSL Streetlight	08-107	55	1028	19	*14628*	74	*-0.009*	0.93
SSL Streetlight	08-108	58	3179	55	6227	75	0.007	0.99
SSL Streetlight	08-109	73	3440	47	6052	72	0.005	0.99
SSL Streetlight	08-110	37	2588	71	5210	68	0.000	0.99
SSL Streetlight	08-111	95	3105	33	3101	72	-0.003	0.99
HPS Streetlight Benchmark	08-122	117	6540	56	*2042*	*21*	0.001	*0.44*
Fluorescent Induction Streetlight	08-152	67-71	3695-3960	52-59	3906	75	0.001	0.96
Fluorescent Induction Streetlight	08-153	70-71	3234-3561	46-50	4253	77	0.006	0.99

CCT, CRI, and D_{uv} values in red italics are outside of typical ranges for white light. Power factor values lower than 0.9 (the lower limit for commercial lighting products in ENERGY STAR® for SSL criteria) are indicated in red italics.

* Products 08-152 and 08-153 use fluorescent induction lamps and are highly sensitive to thermal conditions. Test results for these products exhibited a relatively wide difference in performance between integrating sphere and goniophotometry testing, so the range of values from the two forms of testing are presented here for power, output, and luminaire efficacy.

The HPS benchmark delivered more lumens (6540 lm) than the SSL streetlights, but also drew more power (117W), with an efficacy of 56 lm/W—somewhat higher than the average efficacy for the five SSL samples. As expected, the HPS color appearance is very warm (yellow) with a CCT of 2042K, and the CRI is very low at 21. The PF for the HPS streetlight is 0.44, far lower than is typically required for commercial lighting. With a rated lamp output of 9500 lm, this HPS streetlight has over 30% fixture loss.

On average, the fluorescent induction benchmark streetlights delivered slightly more total lumens than the SSL samples with slightly higher efficacy. Sample 08-152 performed slightly better than sample 08-153 in both light output and luminaire efficacy. While these benchmark luminaires both have similar or slightly higher CRI than the SSL samples, they do not achieve the CRI of "85+" claimed in product literature. Like the HPS benchmark, the absolute photometry on these luminaires reveals fixture losses. Manufacturer literature for 08-152 states system (lamp plus ballast) performance of 6000 lm and 70 lm/W. Considering the CALiPER results from absolute photometry, this reveals a fixture loss of about 35%. For 08-153, manufacturer literature states system performance of 6500 lm and 79 lm/W, indicating fixture losses of about 50% when compared to CALiPER testing conducted on the complete luminaire.

One SSL streetlight, 07-26, that was previously tested (in Round 3, July 2007) delivered 9808 lm with a power draw of 189W, with a efficacy of 52 lm/W. Compared to the Round 7 SSL samples and benchmarks, 07-26 had a higher wattage level and produced more light output, but with a luminaire efficacy very similar to the average of products tested in Round 7. Another earlier CALiPER from Round 4, sample 07-63 tested in January 2008, was an earlier version of 08-110 with similar color temperature. The earlier version drew much higher wattage at 170W and delivered 6294 lm, but at only 37 lm/W versus the newer version's 71 lm/W, showing clear progress in luminaire efficacy for this product. Light distribution differs for these two samples. The older, higher wattage version had a Type II, short cutoff classification, while the newer, lower wattage version has a Type III, medium cutoff classification.

To compare light distributions across the eight streetlights tested in Round 7, Figure 2 provides a side-by-side comparison of the isoilluminance diagrams for the streetlight products. To allow for direct comparison on a lumens/watt basis, the values of the isolines shown here were determined by scaling relative to luminaire wattage. The blue plus (+) shows maximum candela, the red dotted lines trace values of 50% maximum intensity. These are used to determine luminaire classification. Notice two of the luminaires (08-110, 08-111) both have Max candela on the House side rather than the Street side.

Three of the streetlight products were described in manufacturer literature with IES lateral distribution types that did not match those measured.[4] Two SSL products that were marked as Type II produced Type III distributions. The HPS streetlight was marked Type II but produced a Type I distribution. Only one of the SSL streetlights meets "full cutoff" criteria; the others are all "cutoff."[5] One of the SSL Streetlights can only be typed when considered as having a "Very Short" vertical light distribution—which is not an official IES distribution type, but is understood in the lighting industry.

The manufacturers of the SSL streetlights provided limited data about their products. All indicated total power (watts) and CCT, while only two provided initial lumens. The total power was overstated for three of the products: 80W versus actual 55W; 86W versus actual 73W; and 45W versus actual 37W. Only one of those products had initial lumens stated and, surprisingly, the measured light output was higher even though the total measured power was lower: 45W and 2100 lm claimed versus 37W and 2588 lm measured. This anomaly yielded a higher-than-expected efficacy: 44 lm/W claimed versus 71 lm/W measured. The other product that provided initial lumens slightly overstated total power while understating light output: 60W and 2500 lm versus 58W and 3179 lm measured. This also led to a higher-than-expected efficacy: 42 lm/W claimed versus 55 lm/W measured. Most of the manufacturer-claimed CCTs were in line with the measured values, except for one product that claimed 6300K and was measured at 14628K.

Clearly, the SSL products are available in a range of distribution types and light outputs. They can vary considerably in luminaire efficacy—the best is better than both the HPS and the fluorescent induction fixtures. The SSL products had vastly better CRI than the HPS and slightly lower CRI, on average, than the induction products. In terms of color appearance, the SSL products tend to be cool in appearance unlike the very warm HPS source. In one case, an SSL product had a CCT beyond what is typically available for conventional white-light products and outside of ANSI defined tolerances for white light. Implications regarding comparative long-term performance have not been CALiPER tested at this time.

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[4] Lateral distribution types are defined in LM-3-95; the types are differentiated by where the maximum and half-maximum intensity occurs.

[5] Cutoff designations have been superseded by IESNA TM-15-07; however, they are still used pending release of the revised TM-15.

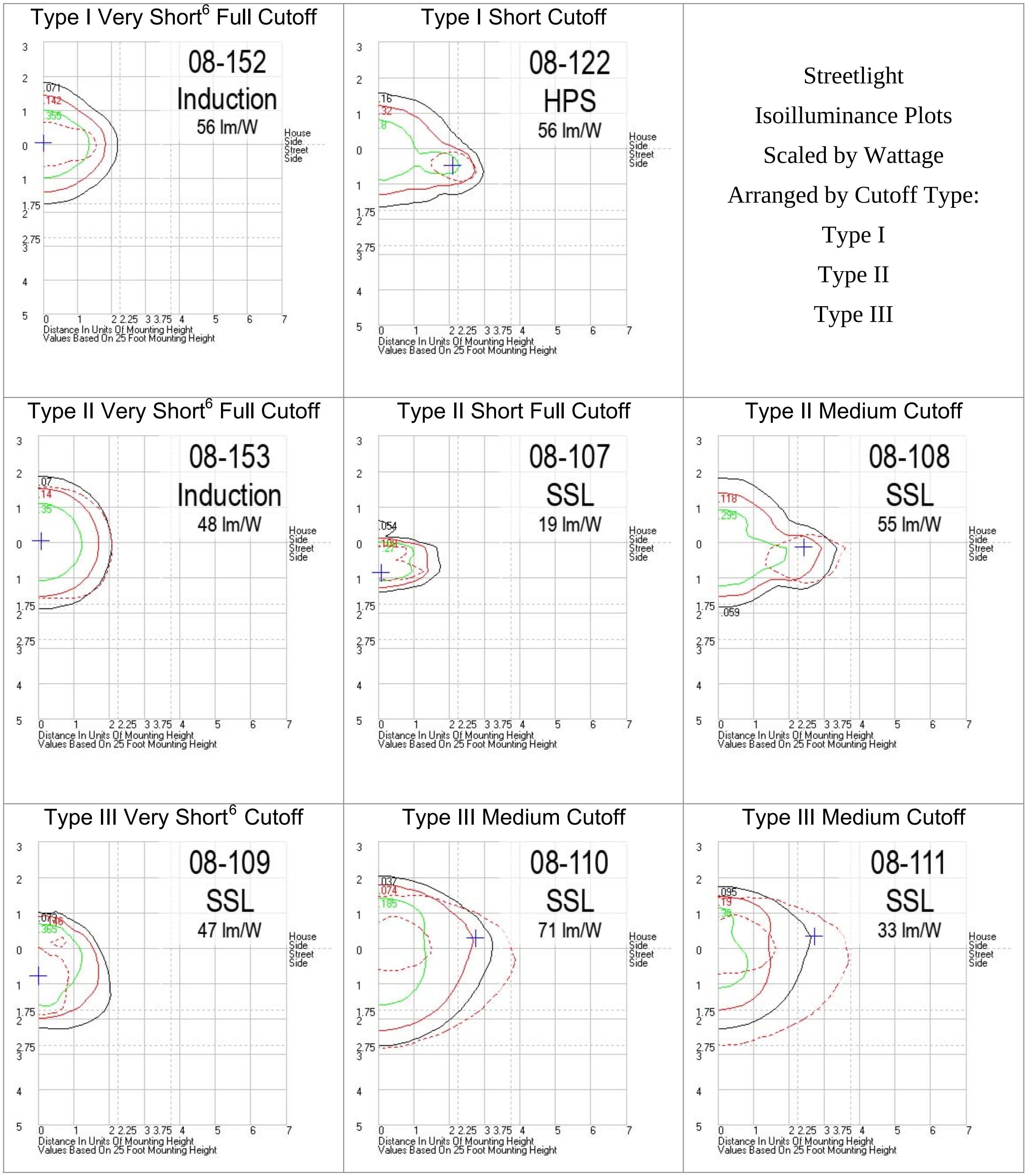


Figure 2. Side-by-Side Comparison of Isoilluminance Diagrams based on 25 ft Mounting Height for Streetlights.

[6] "Very Short" is a term often used in the lighting industry, but is not part of the IES roadway luminaire classifications.

Bollards—Direct Comparison between SSL, CFL, and MH

An outdoor bollard was tested using three different light sources: SSL, compact fluorescent lamp (CFL, 42W triple-tube, 4-pin), and metal halide lamp (MH, 70W quartz pulse-start, clear). The bollard was designed for the light source to be mounted horizontally in the top of the bollard, and the SSL version utilizes the same design with the LEDs mounted in the top of the bollard. Currently some market-available SSL products have luminaire efficacy levels of 50-60 lm/W, so the measured performance of 13 lm/W of the SSL version of this bollard is disappointing compared to the current state of SSL technology. Nevertheless, because of the very high fixture losses for the CFL and MH versions of this bollard, the SSL bollard outperforms the other two versions, as shown in Table 3.

Table 3. Summary of Performance of Outdoor Bollard with Three Different Light Sources

	DOE CALiPER TEST ID	Total Power (Watts)	Output (initial lumens)	Efficacy (lm/W)	CCT (K)	CRI	Duv	Power Factor
Outdoor Bollard SSL	08-114*	45	578	13	3977	75	-0.005	0.77
Outdoor Bollard CFL Benchmark	08-112*	32	268 [371]	9 [12]	4261	76	*+0.009*	1.00
Outdoor Bollard Metal Halide Benchmark[1]	08-113*	87	464 [1091]	5 [12]	4319	66	*+0.009*	0.97

Values over 2 are rounded to the nearest integer for readability in this table.

* Products 08-112, 08-113, and 08-114 are three versions of the same luminaire from the same manufacturer. One uses an LED source, one a CFL, and one a metal halide lamp. The LED version has an IES Type III distribution. The CFL and MH versions were tested with and without a house-side shield. The results from testing with a house-side shield should represent a similar Type III distribution for direct comparison with the LED version. Results from testing without house-side shield are presented in brackets.

[1] Note that a 70W quartz pulse-start metal halide clear lamp was used for this test. Using a similar coated lamp (as recommended by the manufacturer) would be expected to reduce the output and efficacy by about 6%, using a longer-life, ceramic pulse-start metal halide lamp would be expected to increase the output and efficacy by about 20%.

The SSL product can be purchased in different distributions (Types I, III, or V, with respective wattages of 30, 45, or 60 W). The CFL and MH versions utilize a Type V optical system, but an optional house-side shield may be installed to emulate a Type III distribution. The SSL version purchased for CALiPER testing was the 45W version (Type III distribution). The MH and CFL versions were tested both with and without a house-side shield. The key points of comparison between these three versions can be summarized as follows:

- Efficacy. The SSL version has higher efficacy than the CFL and MH versions both with and without the house-side shield installed on the CFL and MH versions. With the house-side shield installed on the MH and CFL versions to generate a similar (Type III) distribution, the SSL version has both greater output and greater efficacy—50% greater than the CFL version and over twice the efficacy of the MH version.
- Light output. The SSL version has greater light output than the CFL version (even without house-side shield). The tested SSL version (Type III) has a considerably lower light output than the MH version without a house-side shield; however, the SSL product with a Type V distribution and 60W LED array (not tested) is expected to produce 770 lm (similar to, though not quite as much as the MH version without house-side shield).
- Fixture efficiency. Based on comparison of the lamp ratings for initial lumens to CALiPER testing on the entire luminaire, fixture efficiencies for the CFL and MH versions with house-side shield in place are 8% and 10% respectively. Even without the house-side shield the fixture efficiencies are only 12% and 23%—allowing even a relatively low efficacy SSL product to outperform these two products that have source efficacies of 76 and 69 lm/W.
- Color quality. The color temperatures of the three versions are similar and CRI values for the SSL and CFL versions are nearly identical, and with the MH version somewhat lower. The CFL and MH versions have D_{uv} values that are much higher than the SSL version. SSL sources exhibiting this higher D_{uv} would be outside of ANSI-defined target tolerances for white light, and would exhibit a yellowish or greenish hue rather than being truly "white."
- Light distribution. The SSL version and the MH version with house-side shield exhibit a Type III distribution, but the CFL version with house-side shield does not achieve a Type III distribution, as illustrated by the side-by-side polar candela distribution curves in Figure 3 below.
- Cost. The SSL version was only about 20% more expensive than the MH version and about three times the purchase price of the CFL version.
- Power factor. The SSL version has a PF of only 0.77, whereas the other two versions are close to 1.

Overall, this side-by-side comparison provides an excellent example of the significance of fixture loss. While this SSL luminaire achieves efficacy levels that are not even one-quarter or one-third of the values seen in other SSL products today, it is still able to surpass the CFL and MH versions because of the high fixture losses for conventional sources in this type of product.

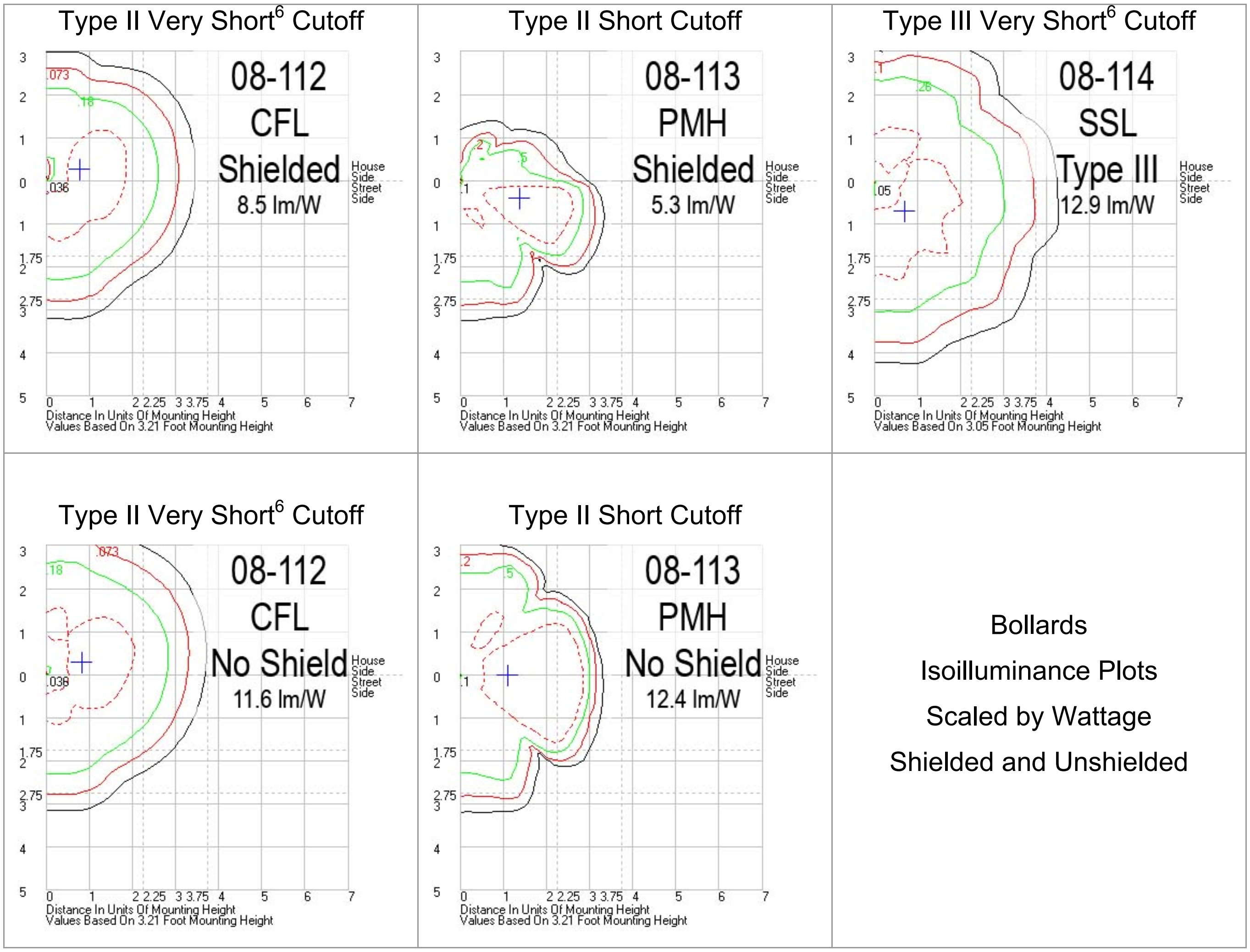


Figure 3. Comparison of Light Distribution of SSL, MH, and CFL Bollards

Downlights

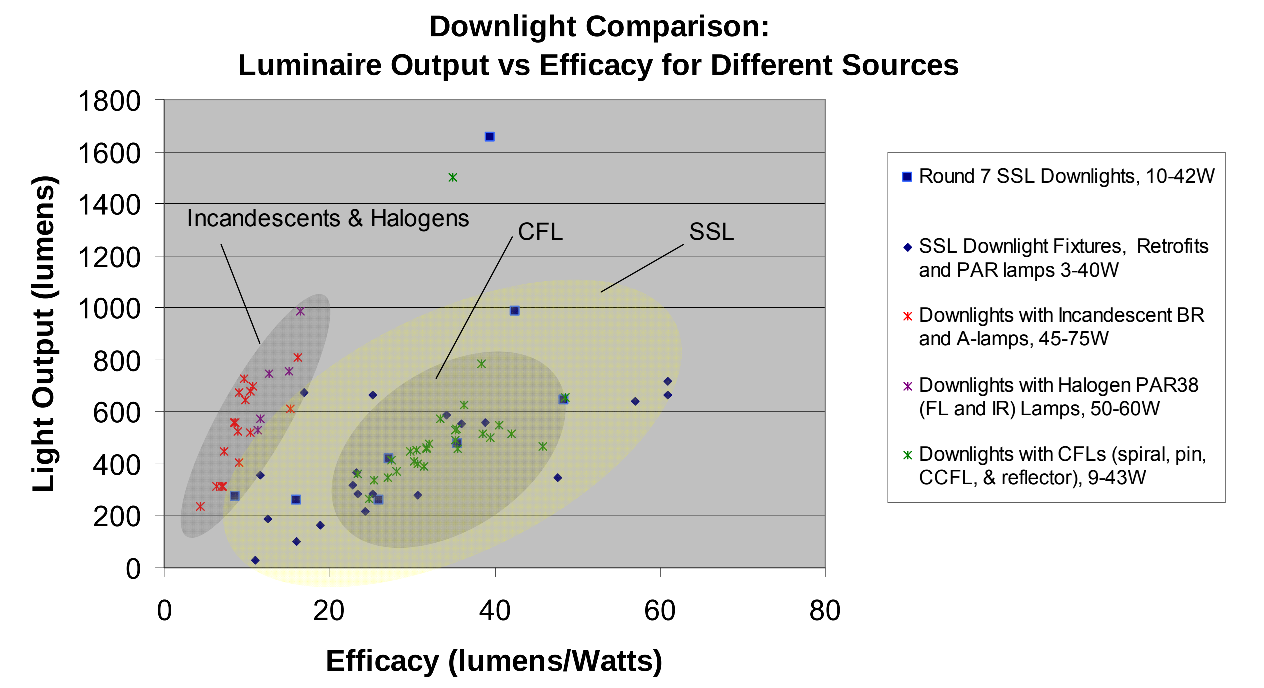
Nine products that can loosely be grouped together under the downlight luminaire category were tested in CALiPER Round 7, as summarized in Table 1b above. Table 4 below also includes a qualitative indication of how these products perform with respect to key ENERGY STAR® criteria and how accurately the products' performance is reported in manufacturer literature.[7] These products include a 4" recessed can, an Edison-based retrofit which fits in a 5" or 6" diameter recessed can, a 6" diameter recessed can, a 7 ½ inch square surface mount product, two 1 foot square recessed luminaires (identical products from the same manufacturer, one using a CFL source and one using LEDs), a thin 2 foot square panel, and two spot lights for track lighting. These nine products range in power levels from 10W to 43W, with beam angles ranging from 35° to 125°. When comparing such a variety of products with such a range of power levels and light distributions, it would not be appropriate to compare output levels or center beam candle power across the entire set of samples; however, we can examine their efficacies and color quality (see Tables 1b and 4).

Table 4. CALiPER ROUND 7 SUMMARY – Downlights

Product Type	DOE CALiPER TEST ID	Total Power (Watts)	Output (initial lumens)	Luminaire Efficacy (lm/W)	ENERGY STAR for SSL Performance on Key Parameters*	Provides Accurate Product Reporting
4" ø recessed can	08-124	32	275	9	Fails efficacy	Yes
Retrofit lamp, 5" or 6" ø recessed can (RGB SSL)	08-118	13	476	36	Fails CRI	No, 25-30% Overstated
6" ø recessed can	08-123	13	644	48	Passes	Yes
7.5" x 7.5" x 2" surface mounted (with 2 ⅜" x 2 ⅜" light source area)	08-120	15	417	27	Fails efficacy	Yes
1' x 1' recessed square SSL source (with 8 ½" x 4 ½" diffuser lens)	08-119	42	1654	39	Passes	Yes
1' x 1' recessed square CFL source (with 8 ½" x 4 ½" diffuser lens)	08-125	43	1503	35	n.a. (not SSL)	Yes
2' x 2' x 1" Panel	08-134	42	2100	50	Fails PF	Yes
Spot light for track	08-126	16	261	16	Fails efficacy	No, 25-30% Overstated
Spot light for track	08-129	10	258	26	Fails efficacy	Yes

*Note: ENERGY STAR qualification also includes other requirements which are not examined in this study (such as lumen maintenance, zonal lumen distribution, electrical safety characteristics, and size requirements).

[7] See U.S. Department of Energy. 2007. *ENERGY STAR® Program Requirements for Solid State Lighting Luminaires, Eligibility Criteria – Version 1.0.* Available at http://www.energystar.gov/ia/partners/prod_development/new_specs/downloads/SSL_FinalCriteria.pdf.



Results compiled from CALiPER and other DOE testing, NLPIP reports, and manufacturer catalogs. A-lamps, R-lamps, and PAR lamps are tested in situ, or a fixture loss factor is applied to bare lamp performance based on CALiPER in situ versus bare lamp testing.

Figure 4. Charting Round 7 Downlight Output and Luminaire Efficacy Versus Earlier CALiPER Testing and Benchmarks

Figure 4 below illustrates the relative performance of these Round 7 downlight products versus earlier CALiPER testing and benchmark results (note that 2 ft x 2 ft light panels are not included in this figure). For any given light output level, the SSL downlights meet or exceed the efficacy levels of incandescent and halogen products, and most SSL downlights tested in Round 7 meet or exceed luminaire efficacy levels of CFL downlight benchmarks. Furthermore, Figure 4 reveals that while there is a considerable range in light output across the Round 7 downlight luminaires, they all meet or exceed minimum levels that have been observed in incandescent and CFL benchmark results.

Excluding one product, all of the downlights that were tested use warm-white sources, with color temperatures ranging from 2745 to 3262K. Product 08-134 was only available in one color temperature (5000K). All nine products have CRI values between 70 and 84, except 08-118 which uses an RGB light source, for which CRI is not a suitable indicator of color quality. All nine products produce light that is within ANSI defined target levels for white light, for both color temperature and D_{uv} tolerances.

Two of these products, 08-123 and 08-119, could potentially meet ENERGY STAR for SSL criteria for downlight luminaires based on light output, efficacy, light distribution, color characteristics, and power factor.[8] Each of the other products has one or more characteristics that

[8] ENERGY STAR qualification also includes other requirements which are not examined in this study (such as lumen maintenance, electrical safety characteristics, and size requirements). Product 08-119 is a 1 foot square

would not qualify for ENERGY STAR: either light output, luminaire efficacy, CRI, or power factor.

Seven out of nine products (of which one has a CFL source) have spec sheets and manufacturer published photometric data which correspond very well with the CALiPER testing results, stating light output, luminaire efficacy, CCT, and distribution characteristics within 10% of CALiPER values. Five out of these seven accurately reported products go so far as to include references indicating the test numbers and names of the independent testing lab that conducted the testing. For the two products that do not make accurate performance claims, the light output and efficacy values are overstated in manufacturer literature by approximately 25-30%. In both of these cases, the manufacturer literature does not provide references indicating the name of an independent testing lab which performed the testing, or the test reference number.

The direct comparison between two versions of the same 1 ft x 1 ft product (labeled as "volumetric recessed lighting"), 08-119 and 08-125, reveals that the SSL product provides slightly more output, slightly better efficacy, and slightly lower spacing criteria than the CFL version, with fundamentally equivalent color characteristics and power factor. The purchase price of the SSL version is a little more than twice that of the CFL version.

This grouping covers a diverse set of products with a range of power levels, range of output levels, and range of luminaire efficacy performance results. Nevertheless, the results are on average encouraging, with output levels within benchmark ranges, most efficacy levels meeting benchmark expectations, and accurate manufacturer reporting being provided for 7 out of 9 downlight products (of which one uses a CFL source). Furthermore, the side-by-side comparison demonstrates that SSL is capable of achieving and surpassing CFL performance for all measured parameters.

Replacement Lamps

Four MR16 replacement lamps, three PAR replacement lamps, and two replacement A-lamps were tested. Table 1c (above) summarizes key performance characteristics of these lamps and Table 5 provides additional data regarding light distribution (center beam candlepower [CBCP] and beam angle), white light fidelity (D_{uv}), and manufacturer claims about product performance. As shown in the right-hand column, manufacturer literature provides accurate performance values for three of the MR16 lamps, but published values are inaccurate or misleading for all of the other replacements. For the lamps with incorrect claims, in each case the published value for output lumens was 2 to 3 times the measured value. Efficacy values calculated from manufacturer published lumen output and power ratings are also 2 to 3 times overstated as compared to measured values.

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recessed product, with a diffuser that measures 8 3/8" x 4 ½", so it may or may not qualify under the downlight category of the ENERGY STAR for SSL Criteria.

Table 5. Summary of Replacement Lamp Results

	DOE CALiPER TEST ID	Total Power (Watts)	Output (initial lumens)	Efficacy (lm/W)	CBCP (cd) & Beam Angle	CCT (K)	Max Duv	Provides Accurate Product Reporting
Replacement MR16 Lamps								
MR16	08-115	2	50	29	83/38°	3414	*0.014*	Yes
MR16	08-116	3	161	50	665/21°	6143	0.003	Yes
MR16	08-117*	0.8	37	49	133/34°	5249	0.007	Yes
MR16	08-133	5	89	17	154/50°	3061	*-0.007*	*No*
Other Directional Replacement Lamps								
PAR 20	08-130	3	78	23	428/17°	2909	-0.002	*No*
PAR 30	08-128	7	384	53	632/47°	3106	0.002	*No*
PAR 38	08-131	11	315	28	459/38°	2953	-0.005	*No*
Replacement A-lamps								
A-lamp	08-132	14	466	33	--	3743	0.005	*No*
A-lamp	08-135	7	224	31	--	6601	0.002	*No*

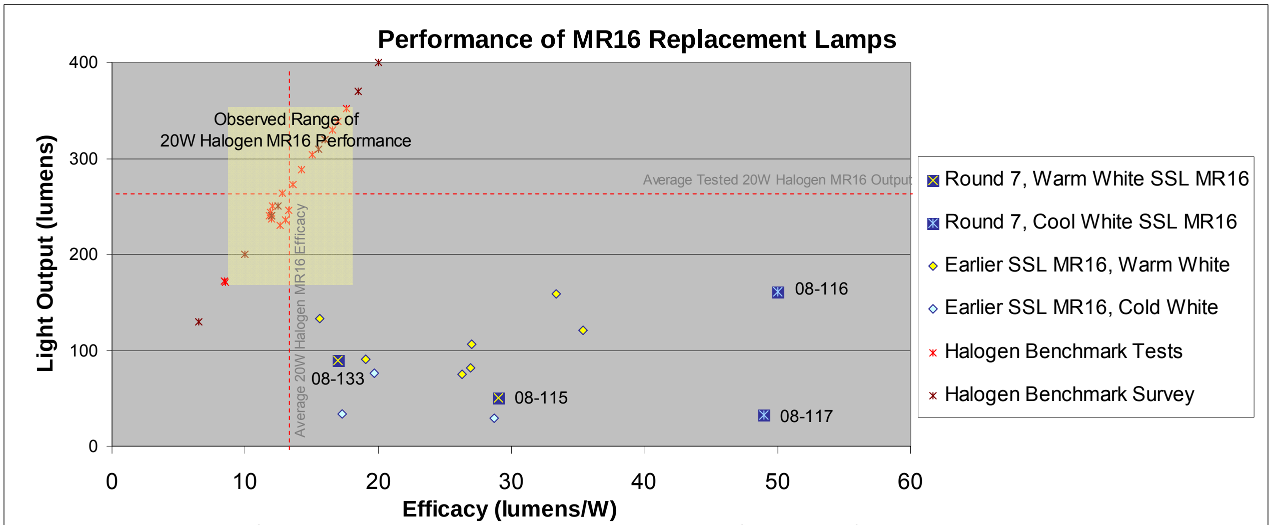
D_{UV} is the closest distance between the chromaticity coordinates and the Planckian locus. Max D_{UV} presents the absolute value of the higher D_{UV} out of the two samples tested for each product. For D_{UV}, values in red italics are outside of ANSI defined tolerances at a given CCT as defined in ANSI Standard C78.377. [9]

*Note that product 08-117 is a 120VAC lamp, while all other MR16 replacement lamps tested to date use 12VAC input. A transformer loss factor should be applied to the efficacy of all 12V lamps to directly compare with 120V products.

MR16 Replacement Lamps

Figure 5 plots the light output and efficacy of these four MR16 SSL replacement lamps against those tested previously by CALiPER, and benchmark values for 20W halogen MR16 lamps. Neither of the two warm-white products produces even one-half the light output of the lowest wattage available halogen MR16 lamps. The two cool-white samples, 08-116 and 08-117, have higher efficacy than all previously tested MR16 lamps, but they are still not achieving the light output levels or CBCP typically seen in halogen MR16 lamps with similar light distribution. The sample with the highest output and efficacy, 08-116, is approaching performance levels comparable to traditional light sources. It produces more light output than the lowest manufacturer reported ratings for 20W MR16 halogens, although it is still far below the average reported ratings and below the lowest CALiPER-tested halogen MR16. It provides a CBCP of 665 cd, which is below average, but nevertheless within the range of reported values for narrow flood MR16 halogens.

[9] ANSI/NEMA/ANSLG C78.377-2008, Specifications for the Chromaticity of Solid State Lighting Products. Downloadable from http://www.nema.org/stds/ANSI-ANSLG-C78-377.cfm, February 15, 2008.



Benchmark values are based on CALiPER benchmark tests, surveyed ratings, and averaged manufacturer ratings for 20W MR16 halogen lamps. Values are based on initial output, not average life-time output. 08-117 was tested at 120V input, all others with 12V input.

Figure 5. Comparison of Light Output Versus Efficacy for MR16 Replacement Lamps

Note that one product tested, 08-117, uses 120V input whereas all other MR16 lamps tested thus far use 12V. Transformer losses such as those that would be incurred in a luminaire or other lighting system converting 120V line voltage to 12V should be considered when comparing between products that use different input voltage levels. It should also be noted that the 120V MR16 lamp had a very low power factor of only 0.3. The three 12V products had power factors of approximately 0.7. The dominant type of MR16 is low voltage (12 VAC or 24 VAC), not line voltage (120 VAC).

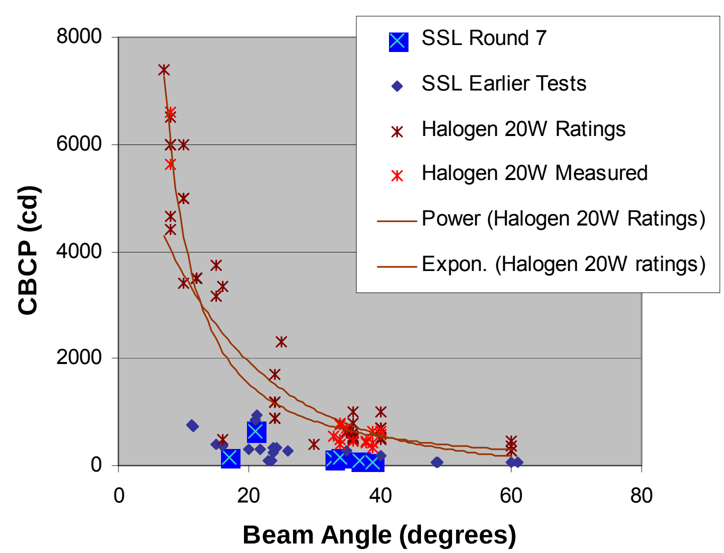


Figure 6. CBCP Versus Beam Angle for SSL and Halogen MR16 Lamps

Considering light distribution, Figure 6 plots CBCP versus beam angle for the samples that were tested, as well as for previously tested SSL and halogen MR16 lamps, and manufacturer ratings for halogen MR16 lamps. As in previous rounds of CALiPER testing, at any given beam angle, the CBCP provided by the SSL MR16 lamps falls below typical values for halogen lamps.

The two warm-white products, 08-115 and 08-132 have CCT values close to what is typical for halogen MR16 lamps, but their color quality is poor. Their CRI values are 65 and 48 (the lowest CRI performances observed thus far among non-RGB MR16 replacements). Their D_{uv} values are 0.014 and -0.007, both outside of ANSI defined target tolerance values for white light in SSL products, indicating that these lamps are likely to have a greenish or pinkish hue. The two cool color temperature MR16 lamps tested have acceptable D_{uv}, but mediocre CRI.

As with earlier tests, there were concerns regarding product form factors (shape and length of lamp base, overall lamp length) and lamp weight. The GX5.3 base on most of these lamps is a friction fit, 2 prong base, not a screw-in or clip-in socket, so the excess weight of some SSL products could cause mounting concerns in some applications. For replacement lamps, SSL manufacturers must balance the need to match the form and weight of traditional products with the need for sufficient thermal management in an SSL product. One MR16 lamp tested in this round succeeded in providing a product with the same shape and size as a halogen lamp, thermal management using numerous very thin fins, and a resulting weight that is less than a typical halogen MR16 used for comparison. While low product weight is not a fundamental parameter of photometric performance, it may also impact energy use indirectly through the amount of material (natural resources) used in producing a product and the transportation costs associated with the product.

As mentioned in earlier CALiPER reports, these replacement lamps have not yet been subjected to lumen depreciation testing, so their reliability over time is unknown. Because of the very low power levels on some of these products, their general behavior with typical power supplies for MR16 luminaires is unknown and may vary greatly depending on the replacement lamps and on the power supplies.

PAR Lamps

Three SSL replacement lamps labeled as replacements for PAR lamps were tested: one PAR 20 replacement, one PAR 30 replacement, and one PAR 38 replacement. With respect to light output, all three lamps carry performance claims that are overstated and they do not meet average rated output levels for similar sized incandescent R-lamps, reflector CFLs, or halogen PAR lamps.

Despite having highly overstated performance claims and not achieving average light output of similar traditional products, these lamps are achieving performance levels which may be appropriate for some applications. All three SSL PAR lamps have efficacies which are 2 to 5 times the efficacy of incandescents and halogens. Their light output levels and CBCP are approaching the lowest observed levels in manufacturer ratings for directional incandescent, halogen, or CFL. In addition, they all are warm-white products with acceptable D_{uv} and CRI levels (two out of three have CRI of 93).

For example, the 3W SSL PAR20, 08-130, has a measured light output of 78 lm, which is more than half the 140 lm rated output of one 30W incandescent R20. The CBCP of this SSL R20 is 428 cd, which is as high as the rated CBCP on a number of small incandescent and halogen flood lamps and twice the intensity of one CALiPER measured reflector CFL. Note, though, that with respect to the 17° beam angle of this lamp, the CBCP should be many times higher to meet halogen equivalencies. The rated efficacies of incandescent R20 lamps and halogen PAR20 lamps range from about 5-11 lm/W, while this SSL lamp's efficacy is measured at 23 lm/W. This is not quite as high an efficacy as the 33 lm/W typically seen for R20 CFL lamps, but the CFL lamps are not capable of achieving the narrow beam and high CBCP levels of the SSL PAR20.

The PAR30 and PAR38 SSL samples, 08-128 and 08-131, are both flood lamps, with beam angles of 47° and 38°, respectively. These two SSL products both provide CBCP levels comparable to 40-50W incandescent R-lamps with similar beam angles, but only about half the CBCP of 45W, 40° halogen PAR lamps. Rated light output levels for 40-50W incandescent R30 lamps were found to range from 340-630 lm, with similar or slightly higher output levels noted for wide flood halogens. Both of the SSL products achieve outputs at the low end of this range. The 08-128 PAR30 sample is particularly noteworthy at 384 lm and an efficacy of 53 lm/W, while using only 7W. The lowest wattage reflector CFL products seen in catalogs of major manufacturers were at 9-15W, and their rated efficacies were only 33-50 lm/W, so this SSL PAR30 surpasses small RCFL lamps in efficacy and CBCP.

With respect to form factor and weight, all three of these directional lamps appear to have dimensions which correspond fairly well with the type of lamp they claim to replace. The neck of each lamp appears to be the appropriate diameter and length. The PAR38 replacement may be slightly shorter in overall length than the standard minimum defined length for PAR38 lamps, and the PAR30 replacement lamp may fall between a short-neck and a long-neck PAR30 in standard overall length. Of greater concern for 08-131 may be its weight. At 579g, it is the heaviest replacement PAR lamp weighed by CALiPER to date. Product 08-128 weighed 167g and product 08-130 weighed 123g—which compares to 124g for an R30 CFL. [10]

A-Lamps

Two products tested in Round 7 are marketed as replacements for A-lamps. Both fall far short of meeting their manufacturer performance claims, as summarized in Tables 1c and 5, but when compared to SSL replacements for A-lamps tested in earlier rounds, these two products are less disappointing. Figure 7 below compares the light output and efficacy of these two products with previously tested A-lamp products and with benchmark data for similar incandescent and CFL lamps. [11] Compared to lamps with equal light output levels, both replacement A-lamps achieve efficacies of about three times that of incandescent, but are not yet reaching the efficacy levels of CFL lamps with similar output levels.

These two A-lamps both distribute light almost entirely in the downward direction (when lamp base is at the top), as illustrated in Figure 8. While they are achieving quite wide beams, they are not distributing light omnidirectionally as does the typical incandescent A-lamp shown in Figure 8a. Depending on the application or luminaire for which these lamps are used, the downward distribution may or may not provide desirable results.

[10] Based on lamp dimensions as defined in ANSI C78.21-2003, American National Standard for Electric Lamps – PAR and R Shapes.
[11] Reference to CALiPER Benchmark Report on Small Omni-Directional Replacement Lamps.

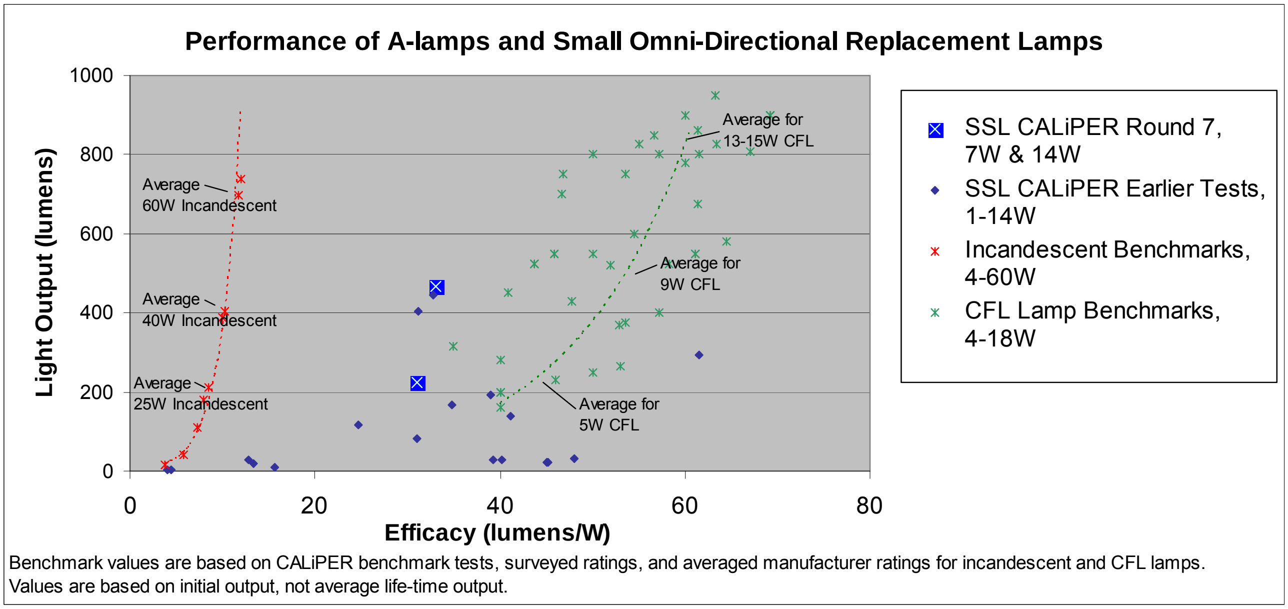


Figure 7. Comparison of A-lamp SSL Products Versus Benchmarked Traditional Lamps

Product 08-132 compares in output with 40W incandescents or approximately 9W CFLs, though the manufacturer claims that it is the equivalent of a 75W incandescent. Product 08-135 compares in output with a 25W incandescent or approximately 5W CFL, though the manufacturer claims equivalency with a 40-50W incandescent. In fact, 08-132 has both the highest output and highest power factor of any SSL A-lamp replacement products tested by CALiPER to date, with a color temperature of 3743K. Product 08-135 is a very cold white, 6601K CCT, but has a better CRI than 08-132. Unfortunately, the power factor of 08-132 is only 0.53.

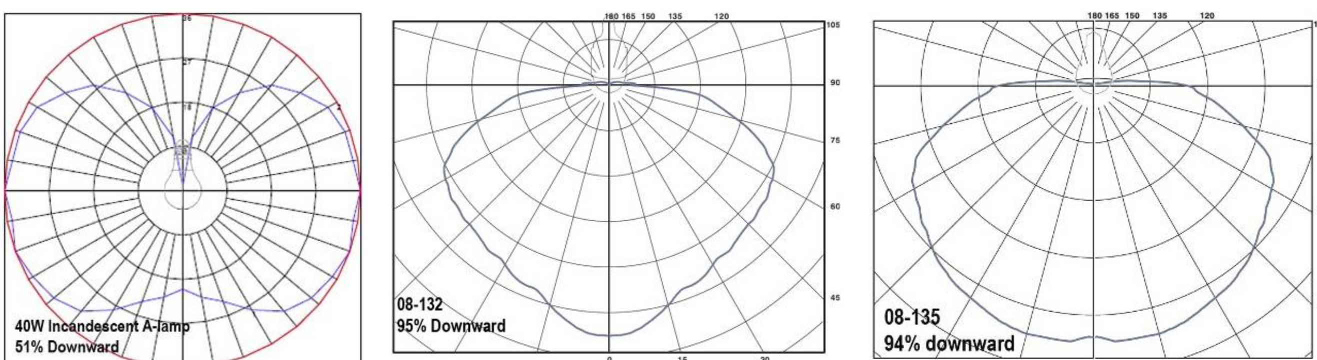


Figure 8a. Incandescent Distribution **Figure 8b. 08-132 Distribution** **Figure 8a. 08-135 Distribution**

Figure 8. Comparison of Light Distribution of SSL A-lamps with Incandescent

As learned through experience with CFL lamps, the non-standard shape, size, and weight of SSL products may also be problematic. Product 08-132 represents more than twice the volume of a typical A-lamp, with an overall length of 7 inches, maximum diameter of 3 inches, and the weight of a small melon. Product 08-135 is much more similar to an A-lamp in format, with a similar shape, length, and diameter to an A-19 lamp—though the neck near the socket is slightly larger in diameter than standard and the weight is still significantly more than an incandescent A-lamp.

Measurements of Color Quality

The majority of products selected for testing in Round 7 were warm-white products. Some of the outdoor luminaires and replacement lamps were cooler white. One had a measured CCT of over 14000K, placing it outside of ANSI defined tolerances for white light in SSL products. One downlight that was tested uses RGB LEDs to create white light, so CRI is not a suitable indicator of color quality for that product. For the other products, the average CRI was 76 (consistent with previous rounds of testing), but one product had a CRI of 48 which is notably low for a product using white LEDs (not an RGB source).

A few of the replacement lamps and outdoor products also had chromaticity coordinates which would fall outside of acceptable ranges for white light as defined by ANSI standard C78-377. [12] These products would tend to be yellowish, pinkish, greenish, or bluish, rather than clearly white. Intriguingly, if MH and CFL products were held to the same chromaticity standards as SSL, the MH and CFL bollards that were tested would not meet target tolerances for D_{uv}, while the SSL bollard would pass.

Power Factor

The power factor of Round 7 products was on average better than in previous rounds of CALiPER testing. Fifteen out of 23 SSL products tested had a power factor over 0.70, the current minimum allowed for residential products by ENERGY STAR for SSL. Eleven of those 15 products were above 0.90, the current minimum allowed for commercial products by ENERGY STAR for SSL. Only one product, a 120VAC MR16 replacement lamp, had a power factor under 0.50, circled in Figure 9. Testing laboratories should include power factor values with all testing results to help stakeholders recognize and monitor this performance parameter.

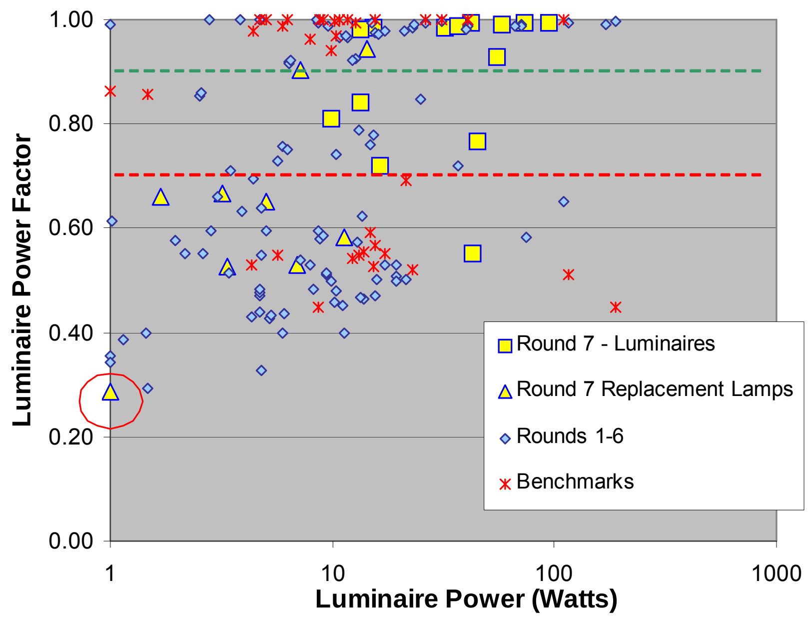


Figure 9. Power Factor Versus Wattage for CALiPER tested SSL Luminaires and Replacement Lamps

[12] ANSI/NEMA/ANSLG C78.377-2008, Specifications for the Chromaticity of Solid State Lighting Products. Downloadable from http://www.nema.org/stds/ANSI-ANSLG-C78-377.cfm, Feb. 15, 2008.

Performance Reports in Manufacturer Literature

In Round 7 of CALiPER testing, more cases of accurate and complete product performance reporting were observed than in previous rounds of testing. About half of the products tested are incorrectly or insufficiently characterized in manufacturer literature. Two of the downlight products and six of the replacement lamps had overstated or misleading performance claims—such as one lamp claiming to be equivalent to a 75W incandescent, when the tested performance shows equivalence to a 40W incandescent. The bollards and some of the outdoor streetlights provide insufficient manufacturer information for comparing performance accurately across different products.

For the products with accurate performance claims, most have spec sheets indicating clear references to independent testing lab results, and photometric data files provided by the manufacturer showing explicit LM-79 testing results conducted by independent testing laboratories. As understanding of the specificities of SSL testing and awareness of standard testing procedures become more prevalent, it is hoped that it will become standard practice for manufacturers to have their products tested by qualified laboratories following IESNA LM-79 procedures, and to reflect those testing results in product literature. Accurate performance reporting, as practiced by half of the manufacturers whose products were tested in this round, is expected to lead to increased credibility and more rapid adoption of energy saving SSL technology.

Reliability: Lumen Depreciation Testing & Variability Testing

The CALiPER program has not yet subjected any of the products tested in this round to any form of reliability testing. Long-term testing of SSL luminaires involves several months of operation and monitoring of lumen depreciation and color shift. A CALiPER report on the first batches of long-term testing of SSL luminaires and replacement lamps was recently completed, summarizing the performance results for 13 SSL products, along with testing techniques and observations from this testing. [13]

Similarly, the products tested in this round have not been subjected to CALiPER testing in large numbers. A study of variability and repeatability in SSL testing based on the first six rounds of CALiPER testing was recently issued. This study examines variability in testing across different samples, different testing configurations, and different testing laboratories. [14]

As CALiPER testing progresses, and as relevant testing procedures are addressed by standards development organizations, the CALiPER program will continue to conduct exploratory studies beyond LM-79 photometric testing to assist the industry and standards organization efforts with these new procedures and with understanding SSL product behavior.

[13] This report is available from the DOE upon request, "Long-Term Testing of Solid-State Lighting, Solid-State Lighting CALiPER Program." January 2009.
[14] This report is available from the DOE upon request, "2008 Summary Report on Testing Variability and Repeatability, U.S. Department of Energy Solid-State Lighting CALiPER Program." January 2009.

Conclusions from Round 7 of Product Testing

Key Points

Round 7 of CALiPER testing reveals a steady increase in efficacy, color quality, power factor, and accurate manufacturer reporting for SSL products. Unfortunately there is still a wide range in performance for products on the market today—as evidenced by outdoor SSL streetlight efficacy results varying from 19 to 71 lm/W, and SSL downlight efficacy results ranging from 9 to 48 lm/W. There also are still many inaccurate or misleading claims regarding SSL performance in all product categories, most frequently for replacement lamps.

Two different side-by-side comparisons of like products using different sources have shown compelling results. Direct comparison between a CFL, a MH, and an SSL version of a bollard reveal that the SSL version has better luminaire efficacy than both CFL and MH. This SSL bollard does not have high luminaire efficacy compared to what is possible in SSL products, but it surpasses the CFL and MH versions because of the very high fixture losses they incur. Direct comparison between a CFL and an SSL version of a recessed volumetric downlight reveal that the two versions achieve very similar performance levels in almost every respect.

A series of tests on outdoor streetlights reveals a variety of performance characteristics—in luminaire efficacy, light output, light distribution, and color characteristics. An HPS cobrahead and two luminaires using induction lamps were also included for comparison. These results underscore the need to require and examine complete photometric test data from luminaire testing (as opposed to relative photometry) to best compare streetlight options.

With test results from nine various downlight products added to earlier CALiPER downlight testing, it is clear that at equal output levels, SSL products surpass incandescent and halogen products in efficacy, and that most SSL products can compete directly with CFL downlights for luminaire efficacy. Warm-white SSL products are now achieving comparable luminaire output levels to downlights equipped with 60 or 75W incandescent sources, and some larger SSL downlights are also performing competitively. Two of the downlight products that were tested could potentially meet ENERGY STAR for SSL criteria for downlight luminaires based on light output, efficacy, light distribution, color characteristics, and power factor.

While many SSL replacement lamps still suffer from inaccurate performance claims or insufficient color quality, some of the replacement lamps that were tested would nevertheless be competitive when compared with low-wattage incandescent and halogen lamps. The performance of some SSL MR16 lamps is approaching the lower range of 20W halogen MR16 performance, with significantly better efficacy. Similarly, the performance of SSL PAR lamps tested approaches the performance levels of 30-45W incandescent R-lamps, with significantly higher efficacy, and one product surpasses small reflector CFLs in CBCP and efficacy. The two SSL A-lamp replacements demonstrate that SSL is capable of producing output at levels equivalent to 25 and 40W incandescent A-lamps with far higher efficacy, but they are not yet matching spiral CFL efficacy at equal light output levels. For all SSL replacement lamps, manufacturers and buyers should be wary of color quality, power factor, form factor, weight, and overstated manufacturer performance claims.

Next Steps for the Industry and CALiPER Efforts

The CALiPER program is working closely with other DOE commercialization support efforts to meet testing needs for SSL products that are gaining market recognition. In Round 7 testing, a combined effort between the CALiPER program and the DOE GATEWAY program enabled testing of a number of outdoor streetlights. Other near-term CALiPER efforts will focus on supporting ENERGY STAR for SSL, Next Generation Lighting, and the SSL Quality Advocates Program. [15]

The CALiPER program welcomes input from industry and has established a guidance committee to provide a more direct link to receive feedback and testing ideas through the eyes and ears of key stakeholders, such as energy efficiency programs, utilities, and lighting designers.

The CALiPER program also works closely with the technical side of photometric testing. It works with independent and manufacturer testing laboratories, research laboratories, and standards development efforts to identify issues and questions surrounding testing, and to contribute insight gleaned through CALiPER whenever possible. A CALiPER Roundtable meeting will be held in the Spring of 2009 to facilitate exchange between key national experts on SSL testing. Results from this meeting may serve to guide standards development, to determine directions that CALiPER testing may take, or to serve as the basis for developing technical information to help stakeholders across the industry. [16]

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[15] Visit the DOE SSL website for further information regarding DOE commercialization support programs such as GATEWAY, Lighting for Tomorrow (LFT), Next Generation Lighting (NGL), ENERGY STAR for SSL, and SSL Quality Advocates. http://www.ssl.energy.gov.

[16] Proceedings from the 2007 CALiPER Roundable are available online: http://www1.eere.energy.gov/buildings/ssl/about_caliper.html.

DOE SSL Commercially Available LED Product Evaluation and Reporting Program

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Appendix A

Testing Methods

The lighting testing laboratories were instructed to follow test procedures specified in the LM-79-08 standard (IESNA Guide for Electrical and Photometric Measurement of Solid-State Lighting Products) which covers "…SSL fixtures as well as SSL sources used in conventional light source fixtures (e.g., replacement of screw base incandescent lamps)."[17] This method tests the luminaire or replacement lamp as a whole—as opposed to traditional testing methods that separate lamp ratings and fixture efficiency or as opposed to testing LED devices or arrays without control electronics and heat sinks. There are two main reasons for this: 1) there is no industry standard test procedure for rating the luminous flux of LED devices or arrays, and 2) because LED performance is particularly temperature sensitive, luminaire design has a material impact on the performance of LEDs used in the luminaire. Similarly, for replacement lamps, the integration of LED devices, heat sinks, drive electronics, and optics within an integral replacement lamp impacts the performance of the LED components within the lamp. For these reasons, luminaire efficacy (efficacy of the whole luminaire or integral replacement lamp) is the measure of interest for assessing energy efficiency of SSL products, as specified in LM-79.

Products sold as luminaires are tested using the entire luminaire. Products sold as replacement lamps are mounted for testing in standard lampholders corresponding to the format of the replacement lamp and the geometry of the measurement instrument used for a given test. Performance results for replacement lamps are thus for the bare lamp, to which appropriate fixture losses should be applied to determine the luminaire output for the replacement lamp installed in a given fixture. [18]

Selection of Products for CALiPER Testing

The general policy of the CALiPER program is to test units of products that are commercially available and have been purchased by the CALiPER program through distributors or other market mechanisms. In some cases, sample products are accepted for testing, either because there is no market for purchasing small quantities of a product or because other DOE SSL programs request CALiPER testing of fixture samples. Detailed CALiPER test reports always indicate whether a tested product was purchased or was a sample product. Detailed CALiPER test reports are issued only for those products that are considered to be commercialized (available or soon to be available for purchase on the open market).

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[17] The testing standard entitled "IESNA Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products," designated LM-79-08, is now published. This testing procedure was developed by the Subcommittee on Solid-State Lighting of the IESNA Testing Procedures Committee (http://www.iesna.org/about/committees/) in collaboration with the ANSI Solid State Lighting Committee. This method describes the procedures to be followed and precautions to be observed in performing reproducible measurements of total luminous flux, electrical power, luminous efficacy (lumens per watt), and chromaticity of solid-state lighting (SSL) products under standard conditions. It covers LED-based SSL products with control electronics and heat sinks incorporated: that is, those devices that require only AC mains power or a DC voltage power supply to operate. It does not cover SSL products that require special external operating circuits or external heat sinks.

[18] De-rating factors for specific fixtures or fixture and lamp combinations are not specified, recommended, or studied by the DOE at this time.