DOE Solid-State Lighting
CALiPER Program

Summary of Results:
Round 5 of Product Testing

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Round 5 of testing for the DOE Commercially Available LED Product Evaluation and Reporting (CALiPER) Program was conducted from January to April 2008. [1] In Round 5 of the testing program, 28 products were selected for testing representing a range of products and technologies. Products were typically tested with both spectroradiometry and goniophotometry using absolute photometry, following the recently published IESNA LM-79 testing method.[2] Testing also included measurements of surface temperatures (taken at the hottest accessible spots on the luminaire) and off-state power consumption for products with an on/off switch.

The products selected for testing in Round 5 covered a range of applications (downlights, replacement lamps, task lamps, and outdoor fixtures), with two focused series of tests conducted on recessed downlights and on 4-foot replacement fluorescent tube products. In all, Round 5 included 17 SSL products and 11 benchmark products (including spiral CFL, reflector CFL, Cold-Cathode CFL, fluorescent tubes, halogen, incandescent, and metal halide), encompassing a wide range of product shapes, sizes, and applications. Round 5 also included testing variability across product samples and on-going testing of lumen depreciation in products tested during previous CALiPER rounds.

Round 5 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 all products tested under CALiPER in Round 5. In addition to performing product testing following LM-79, photometric data published by manufacturers for SSL products (in the form of standard IES photometric data files) were collected and analyzed in order to compare manufacturer performance claims with measured performance results. Additional data on each set of testing results and related manufacturer information are assembled in a detailed report for each product tested. [3]

In Round 5, a focused series on recessed downlight products included 10 types of replacement or retrofit lamps: three SSL products, a reflector CFL (RCFL), a spiral CFL, a cold-cathode CFL (CCFL), a halogen infrared (HIR), a reflector incandescent (R30), and two A19 incandescent lamps. Two units of each lamp were tested first as bare lamps in an integrating sphere; the more efficacious unit of each pair was then mounted in a recessed downlight can in an insulated enclosure and tested with a goniophotometer.[4] Table 1a assembles the performance results for

[1] Summary reports for Rounds 1-4 of DOE SSL testing are available online at http://www.netl.doe.gov/ssl/comm_testing.htm.
[2] Please see the Appendix A for 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 requested online: http://www.netl.doe.gov/ssl/comm_testing_request.htm.
[4] See Appendix B for a complete description of the recessed can and insulated enclosure.

this series of tests. Further discussion of these results is provided in the "Recessed Downlight Series" section of this report.

Table 1a. DOE SSL CALiPER ROUND 5 SUMMARY – Downlight Series

--SSL testing following IESNA LM-79 --Integrated Sphere --25º C ambient temperature	DOE CALiPER TEST ID	Total Power (watts)	Output (initial lumens)	Efficacy (lm/W)	CCT	CRI
Replacement Lamps for Downlights – Bare Lamp Testing						
SSL Retrofit 12W	07-31	11	673	59	2753	93
SSL PAR30 18.6W	08-14*	15	627	42	5151	74
SSL PAR38 21W	08-15*	13	323	24	3127	67
RCFL 15W	08-06*	16	841	53	2740	82
CCFL Retrofit 18W	08-18*	15	513	33	2843	80
CFL Spiral 13W	08-27*	12	806	67	2703	82
HIR PAR38 50W	08-05*	46	524	11	2719	99
INC R30 65W	08-13*	65	732	11	2681	99
INC A19 60W, name brand	08-49*	61	739	12	2703	100
INC A19 60W, value brand	08-04*	55	353	7	2491	99

--Goniophotometry --25º C ambient temperature	DOE CALiPER TEST ID	Total Power (watts)	Output (initial lumens)	Efficacy (lm/W)	Fixture Efficiency** (in situ)
Replacement Lamps In Situ (Mounted in Insulated Recessed Can)					
SSL Retrofit 12W – in situ	07-31D	11	639	57	88%
SSL PAR30 18.6W – in situ	08-14A	14	556	39	87%
SSL PAR38 21W – in situ	08-15B	12	283	23	85%
RCFL 15W – in situ	08-06B	13	653	49	77%
CCFL Retrofit 18W – in situ	08-18A	15	534	35	101%
CFL Spiral 13W – in situ	08-27A	10	466	46	58%
HIR PAR38 50W – in situ	08-05B	47	529	11	93%
INC R30 65W – in situ	08-13A	65	678	11	92%
INC A19 60W – in situ, name brand	08-49B	61	446	7	59%
INC A19 60W – in situ, value brand	08-04B	54	238	4	64%

All values are rounded to the nearest integer for readability in this table.

Tests 08-06,08-18, 08-27, 08-05, 08-04, 08-13, and 08-49 were conducted on CFL, halogen, or traditional incandescent lamps for the purposes of benchmarking. All lamps have Edison socket base except the CCFL.

See "Recessed Downlight Series", for details on the geometries and configurations of the various downlight units and further discussion of results.

* For products shown with an asterisk, two units were tested; results show average between two units. The extent of variation between units is discussed under "Variability and Repeatability."

** Calculated fixture efficiency based on *(in situ* output)/(bare lamp output) for the specific sample used for in situ testing. Values over 100% possible due to expected testing variation between integrating sphere and goniophotometry tests.

Table 1b assembles the results for a focused series of testing on 4-foot replacement linear fluorescent lamps. Four SSL products and two fluorescent (baseline) products were selected for testing. Two samples of each product were tested as bare lamps in an integrating sphere and then mounted in typical housings for *in situ* testing with a goniophotometer. Further discussion of these results is provided under the "Replacement Tube Lamps Series" section of this document.

Table 1b. DOE SSL CALiPER ROUND 5 SUMMARY – Troffer Series

--SSL testing following IESNA LM-79 --Integrated Sphere --25º C ambient temperature	DOE CALiPER TEST ID	Total Power (watts)	Output (initial lumens)	Efficacy (lm/W)	CCT	CRI
Linear Replacement Lamps (4ft) – Bare Lamp Testing						
4ft Replacement lamp, SSL	07-56*	25	1058	42	3494	75
4ft Replacement lamp, SSL	08-17*	20	849	43	12583	72
4ft Replacement lamp, SSL	08-19*	18	345	19	2971	72
4ft Replacement lamp, SSL	08-37*	19	1016	52	7739	76
F32T8, 4ft linear fluorescent	08-28*	32	3081	96	3932	81
F40T12, 4ft linear fluorescent	08-30*	39	3101	80	2884	84

--Goniophotometry --25º C ambient temperature	DOE CALiPER TEST ID	Total Power (watts)	Output (initial lumens)	Efficacy (lm/W)	Fixture Efficiency*** (in situ)
4ft Linear Replacement Lamps In Situ -- Mounted in Lensed T12 Troffer Housing**					
2x4ft Replacement lamp, SSL	07-56	80	2125	27	***
2x4ft Replacement lamp, SSL	08-17	40	1451	36	85%
2x4ft Replacement lamp, SSL	08-19	36	613	17	89%
2x4ft Replacement lamp, SSL	08-37	40	1693	43	83%
2x4ft F40T12, linear fluorescent	08-30	88	4453	51	72%
4ft Linear Replacement Lamps In Situ -- Mounted in Parabolic T8 Troffer Housing**					
2x4ft Replacement lamp, SSL	07-56	47	1566	33	***
2x4ft Replacement lamp, SSL	08-17	40	1399	35	82%
2x4ft Replacement lamp, SSL	08-19	36	597	17	86%
2x4ft Replacement lamp, SSL	08-37	39	1711	43	84%
2x4ft F32T8, linear fluorescent	08-28	58	3675	63	60%

All values are rounded to the nearest integer for readability in this table.

Tests 08-28 and 08-30 were conducted on fluorescent lamps for the purposes of benchmarking.

See "Replacement Tube Lamps Series" for details on the various troffer geometries and further discussion of results.

* For products shown with an asterisk, two units were tested; results show average between two units. The extent of variation between units is discussed under "Variability and Repeatability."

**In Situ tests were conducted with two lamps of each product type installed in a troffer housing. SSL products 08-17, 08-19, and 08-37 do not use troffer ballasts—installation instructions call for bypassing the ballast. SSL product 07-56 is powered by the troffer ballasts.

** Calculated fixture efficiency based on (*in situ* output) /(bare lamp output A + bare lamp output B). Bare lamp testing on 07-56 was conducted with a reference ballast at 25W, so fixture efficiency is not calculated for use in the troffers for this product.

Table 1c. DOE SSL CALiPER ROUND 5 SUMMARY – Other Applications

Photometrics based on IESNA LM-79 for --Luminaires and replacement lamps --25º C ambient temperature	DOE CALiPER TEST ID	Total Power (watts)	Output (initial lumens)	Efficacy (lm/W)	CCT	CRI
Replacement Lamps						
Replacement - MR16	07-58*	5	90	19	2691	67
Replacement - MR16	08-07*	2	34	17	6254	75
Replacement – A-lamp (~A19)	08-03*	3	81	31	3127	92
Replacement – A-lamp (~A19)	08-25**	5	194	39	3418	86
Downlights						
Downlight (2' x 2' panel)	08-29	75	3456	46	4346	71
Task Lamps						
Desk	08-01	9	156	16 [12]	3579	73
Desk	08-02	11	301	27 [11]	6255	74
Undercabinet	08-16	9	196	21	2926	78
Undercabinet	08-26	6	144	24	3639	79
Outdoor						
Outdoor Spot (LED)	08-08†	10	90	9	6469	78
Outdoor Spot (Halogen 20W)	08-12†	22	185	8	2873	97
Outdoor Roadway, Metal Halide	08-09‡	77	4013	52	--	--

All values are rounded to the nearest integer for readability in this table. All lamps use LED sources unless otherwise noted.

Tests 08-09 and 08-12 were conducted on metal halide and halogen fixtures for the purposes of benchmarking.

Adjusted efficacy values in brackets [ ] include the effect of measured off-state power consumption assuming 3 hours on-time per day. See below for discussion of the impact of off-state power consumption on average yearly efficacy.

* For products shown with an asterisk, two units were tested; results show average between two units. The extent of variation between units is discussed under "Variability and Repeatability."

** Ten units of product 08-25 were tested; two units failed before testing could commence; results show average between eight units. The extent of variation between units is discussed under "Variability and Repeatability."

† Tests 08-08 and 08-12 are conducted on the same fixture model available in two different versions, one using an LED source and one using a halogen source.

‡ Outdoor fixture 08-09 was not tested for color qualities in an integrating sphere due to fixture size and weight.

Table 1c summarizes performance results for the remaining tests conducted in CALiPER Round 5: four replacement lamp products, one large downlight, two desk lamps, two undercabinet fixtures, and three outdoor fixtures. Two of the outdoor fixtures are alternate versions of the same product, one using an LED source and one using a halogen source. An outdoor roadway fixture using a metal halide source and innovative design was tested for benchmarking purposes.

These results are analyzed and discussed below in the broader context of test results from earlier rounds of testing and with respect to particular areas of interest — product performance in different application categories, measurements of color quality, power factors, and repeatability and variability of SSL testing.

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

Energy Use and Light Output

A key point to observe when studying CALiPER results is the wide range of performance levels across products irrespective of product geometries and application categories. Table 2 shows the minimum and maximum levels of measured power, light output, luminaire efficacy, CCT, and CRI for all products tested in Round 5. Naturally, different products target different applications and are designed with different light output or color objectives in mind. How effectively a given design implements LED chips to deliver light output at a desired level, in a desired direction, and of a desired color quality is another huge variable. The wide disparity in performance levels observed in these test results reflects not only differences in design, but also difference in effectiveness of SSL implementation.

Table 2. Range of SSL Luminaire Characteristics Tested in CALiPER Round 5

	from		*to*
Power	2 W	↔	75 W
Output	34 lm	↔	3456 lm
Efficacy	9 lm/W	↔	59 lm/W
CCT	2691	↔	12583
CRI	67	↔	93

The downlight series described in the following pages illustrates how SSL products can effectively use directionality of the LED light source to clearly compete with CFL sources in these applications. Conversely, the troffer series shows that despite benefiting from directionality, SSL technology may not yet be capable of competing in some arenas, such as those occupied by highly efficacious 4-foot fluorescent tube lighting.

The replacement MR16 style lamps that were tested did not perform significantly better than similar products tested in Round 4. However, these products fulfilled the test of full disclosure, meeting or exceeding the performance levels published in their own product literature. Conversely, the replacement A-lamps that were tested did perform better than similar products in earlier rounds of testing, but still suffered from overstated performance claims in their product literature and raised questions regarding product reliability or warranty deficiencies.

Task lamps represent a niche application where LED directionality and small form factors could be used to implement SSL effectively. Yet, the four task lamps tested in Round 5 show that these products are still not able to meet minimum levels in all areas of performance. For example, while light output for a product may be sufficient, it may have poor efficacy or poor color quality.

DOE SSL CALiPER results may not be used for commercial purposes under any circumstances;
see "No Commercial Use Policy" at http://www.netl.doe.gov/ssl/comm_testing.htm for more information.

It is essential to keep in mind the nuances of various performance parameters and the variety of products and applications that are studied in the pages that follow.

Recessed Downlight Series

Round 5 included a focused series of tests on lamps that can be used in recessed downlights. To enable direct comparison of SSL downlight products to other light sources, 10 replacement or retrofit lamps were selected: three SSL products (one retrofit, one PAR30, one PAR38), a reflector CFL (RCFL), a spiral CFL, a cold-cathode CFL (CCFL), a halogen infrared (HIR), a reflector incandescent (R30), a name-brand soft white, incandescent A19, and a value-brand, long-life, frosted incandescent A19. The selection represents an array of products that residential customers might purchase and install in a 6-inch diameter recessed can downlight, each expected to provide fairly similar light output levels (but not similar light distributions).

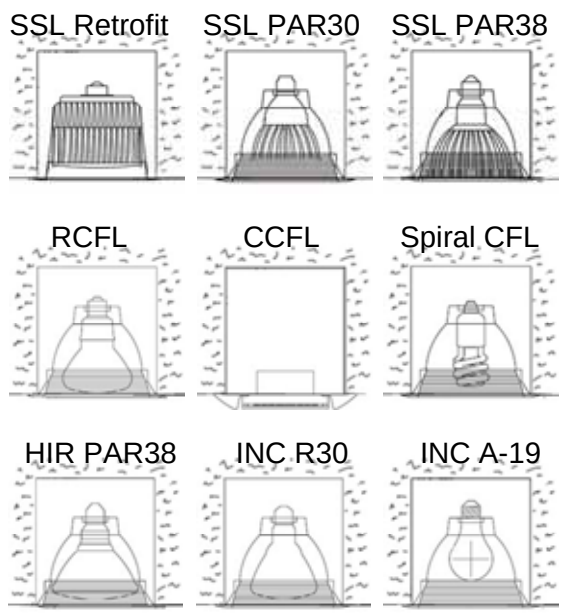


Figure 1. Schematic drawings of replacement and retrofit lamps in recessed can mounted in an insulated enclosure.

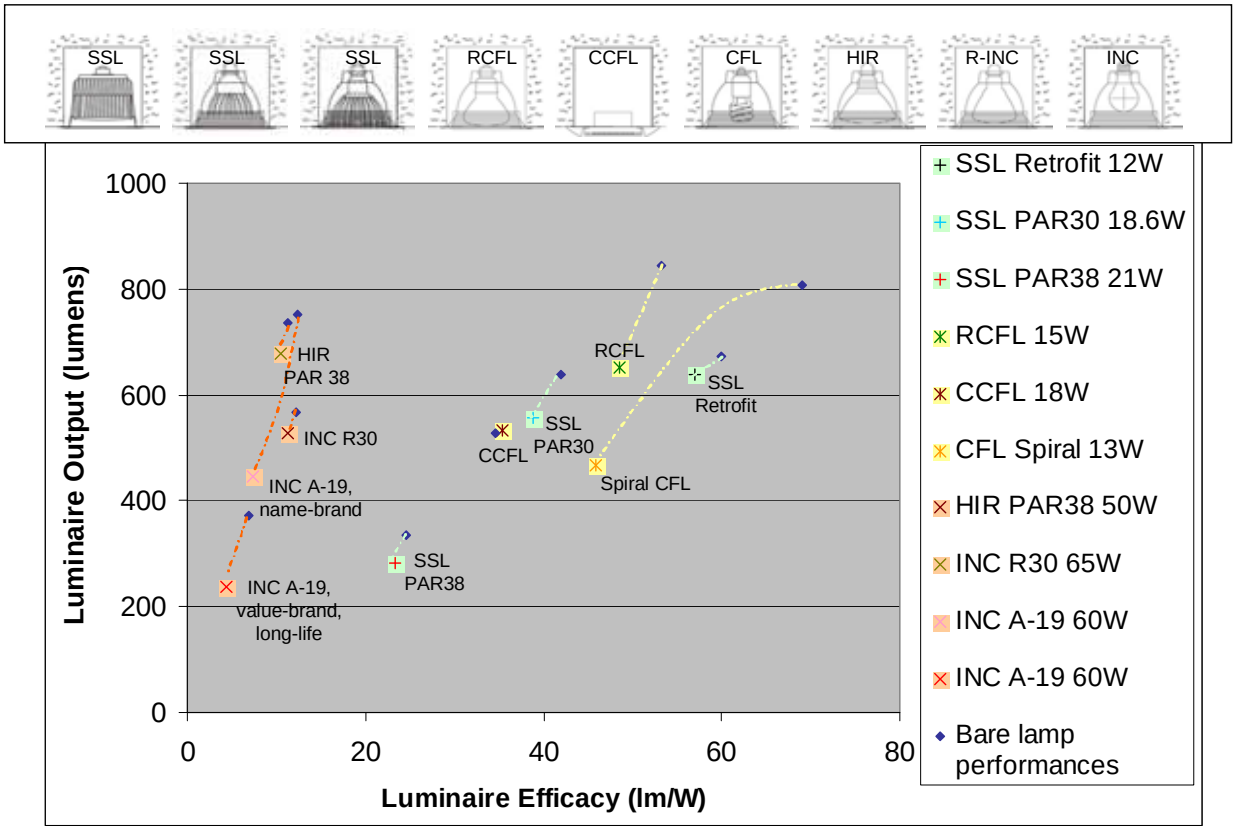
Two units of each lamp were tested first as bare lamps in an integrating sphere. The better performing unit of each pair was then mounted in a recessed downlight in an insulated UL 1598 enclosure representing an insulated-ceiling (IC) installation and tested with a goniophotometer. Figure 1 provides side-by-side sketches of each lamp mounted in the recessed IC can (the two incandescent A-19 lamps share the same geometry). The CCFL and SSL retrofit had an incorporated trim and mounting system. All other lamps had medium-base sockets and mounted in a standard trim kit. More details about the testing setup and insulated enclosure are provided in Appendix B. The goniophotometry testing in the insulated, recessed can emulates *in situ* conditions, allowing explicit understanding of fixture impacts of these products — both thermal and directional effects of operating *in situ*.

Figure 2 provides a visual summary of the light output and efficacy of these ten lamps (from data summarized in Table 1a). Both the bare lamp and *in situ* results are plotted for each lamp. The two omni-directional lamps, the A19 incandescents and the spiral CFL, and the reflector CFL show the greatest fixture loss (36 and 4% loss for the A19s, 42% for the spiral CFL, and 23% for the RCFL). The two SSL replacement lamps lost 13-15% in the fixture, probably primary due to thermal effects. All of the other products (the retrofit SSL, the CCFL retrofit, HIR PAR38, and incandescent R30) lost 8% or less of their output when mounted *in situ*.

Figure 2 also allows comparison of performance across these products. The value-brand, long-life A19 lamp provided both the lowest light output and lowest luminaire efficacy of all of the samples tested *in situ*. One of the SSL products, the PAR38, had fairly low output, only beating

the value-brand A19 for *in situ* performance, while its efficacy was higher than the incandescents and HIR products, but lower than all three fluorescent sources. The other two SSL products were comparable to the fluorescent products and HIR and incandescent R30 in output level and clearly competitive with both the RCFL and spiral CFL in efficacy under *in situ* conditions. For bare lamp testing, the highest efficacy products were the RCFL and spiral CFL; however, when these products were mounted and operated *in situ*, they had much larger losses than the SSL retrofit. Overall, the efficacy of the SSL retrofit mounted in an insulated recessed can surpassed the next-highest performing source by 15%, and it was 10 times more efficacious than the value-brand, long-life A19 incandescent lamp.

Figure 2. Downlight In Situ Losses. Performance of 6" Recessed Downlight with Different Sources



Appendix B provides further visual analysis of the results of this series of tests, showing the different illuminance levels and intensity distributions of these sources *in situ*. As expected, the two PAR38 lamps resulted in the most focused beam patterns.

The difference between manufacturers' ratings and tested performance of the bare lamps is a final point of interest for this series of tests. The manufacturer literature for the SSL PAR38 lamp significantly overstated the light output of this product. Similarly, the CCFL, the value-brand, long-life A19 incandescent, and the PAR38 HIR lamp manufacturers' literature also significantly overstated ratings. The SSL retrofit, SSL PAR30, RCFL, spiral CFL, and R30 incandescent all

met or exceeded their manufacturers' ratings. The name-brand A19 is close to meeting manufacturer ratings. For this set of 10 products, one-third of the products — whether SSL or not—had misleading or inaccurate product literature. Appendix B provides tabulated data indicating differences between manufacturer reported performance and measured output and efficacy of these products.

T8 & T12 Troffer Series

Round 5 also included a focused series of tests on 4-foot tube lamps that can be used in troffer housing to replace 4-foot fluorescent tubes. Four SSL replacement tube products were selected, along with one typical fluorescent T8 and one typical fluorescent T12 product. Two samples of each product were tested.

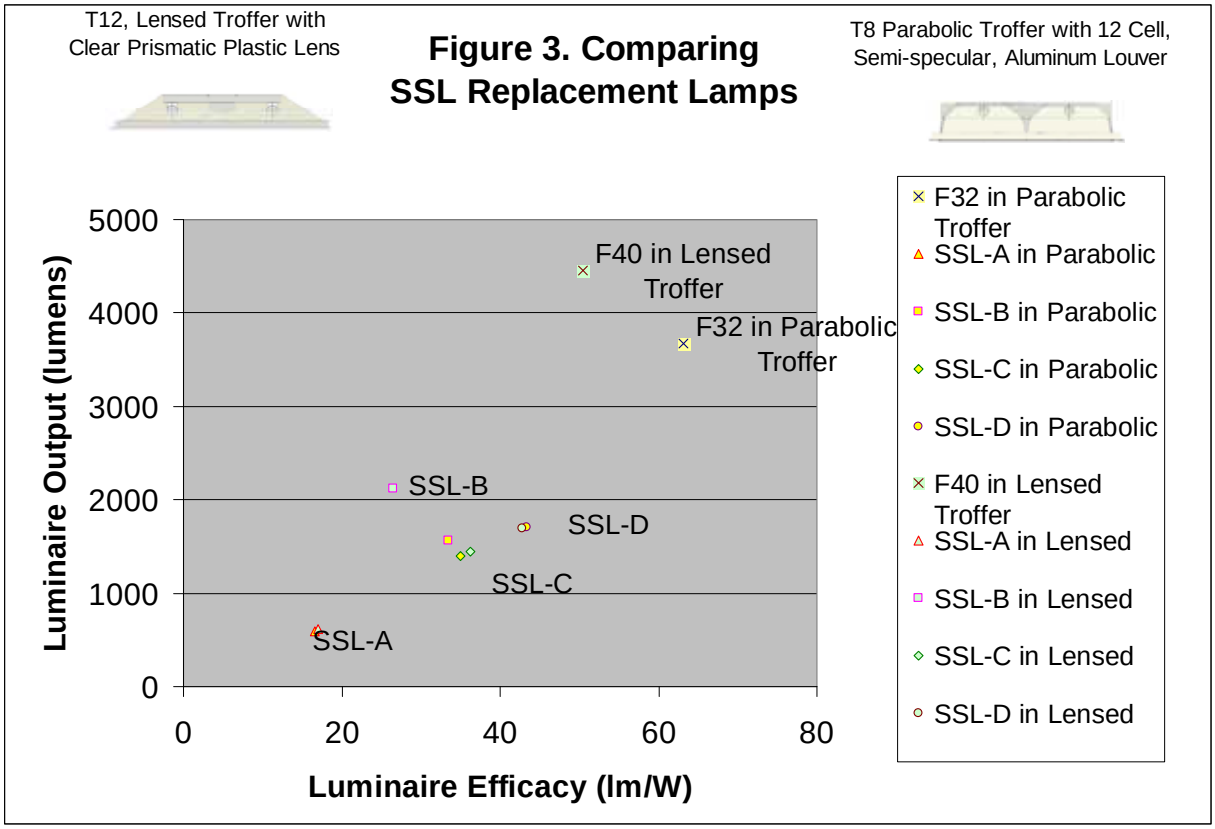
Two typical troffer housings were also selected — one prismatic, A12 pattern lensed troffer, and one parabolic, louvered troffer. The F40T12 fluorescent tubes were tested in the lensed troffer housing. The F32T8 fluorescent tubes were tested in the parabolic, 12-cell, louvered troffer. The SSL products were all tested in both troffer types. All bare lamps were also tested in an integrating sphere.

The goniophotometric testing of the lamps in the troffers allowed the study of the lamps' operation under *in situ* conditions and the direct comparison to fluorescent product performance under the same *in situ* conditions. Because of the directional nature of the SSL replacement tube products — as opposed to the omni-directional light emission of the fluorescent product —, the SSL tubes exhibited less fixture loss than the fluorescent tubes. In the lensed troffer, the fixture loss for the SSL products was, on average, 14%; the F40T12 lamps in the same lensed troffer lost 28%. In the same parabolic troffer, the fixture loss for the SSL products was 16% for the SSL products and 40% for the F32T8 lamps. [5]

Despite having lower fixture losses than the fluorescent tubes, none of the SSL products rivals the fluorescent products, whether as bare lamps or when installed in lensed or parabolic troffers. Figure 3 plots the output and efficacy of each pair of products tested in the troffer housings. A considerable range of performance was observed across the four different SSL products, with nearly a three-fold difference in output and efficacy between the lowest- and highest-performing SSL products.

For the three SSL products that bypass the fluorescent ballast, performance did not vary significantly between the lensed troffer and parabolic troffer mounting conditions. The fourth SSL product (labeled as SSL B in Figure 3) produced higher output at a lower efficacy level when operated with the F40T12 ballast than when operated with the F32T8 ballast. The SSL products do not provide even 50% of the output *in situ* of F32T8 and F40T12 fluorescent lamps. The SSL products also all achieve lower efficacy levels than the fluorescent tubes —one SSL product had only one-third the efficacy of the fluorescent tubes *in situ*.

[5] Note that one of the SSL products relies on the fluorescent ballast for its power supply, so these bare lamps were tested using a reference ballast first, then using the troffer ballasts for the goniophotometry tests. Fixture efficiencies were not calculated for this product given the different power levels of operation under these different power supplies. The other three SSL products all bypass the fluorescent ballasts.



-- 4 different SSL replacement tube products were used (2 samples each)
-- SSL-B uses troffer ballast. SSL-A, C, & D bypass troffer ballast

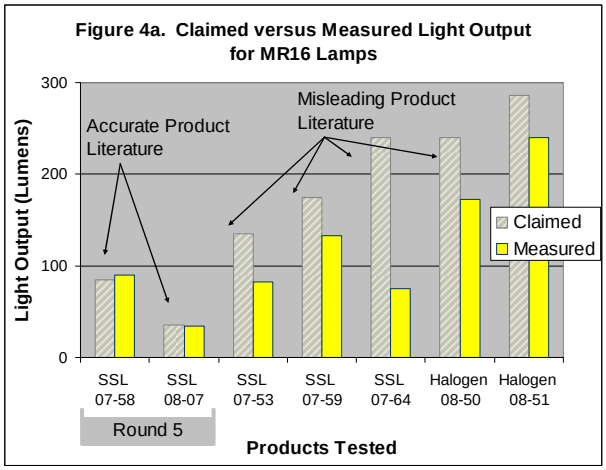
All four SSL replacement tube products mounted in the troffers result in narrower distribution of light than the fluorescent tubes mounted in the same troffers, with the SSL products emitting about 8% more out of their total light output in the 0 to 3° range.

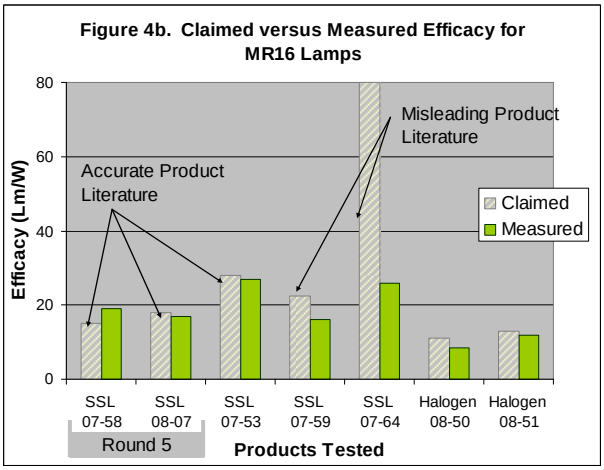
All four SSL replacement tube products had output or efficacy claims in manufacturer literature that significantly overstated their measured performance. Furthermore, the correlated color temperatures of three of the SSL products are entirely different than those stated in product literature (two products had CCTs well over 6000K). These results show that SSL is not yet competitive with fluorescent tubes in output or efficacy for this application. In general, SSL linear replacement products are not competitive in troffers as a replacement for linear fluorescent lamps at this time. However, the better-performing SSL replacement tube products might be appropriate for specific applications where fluorescent lamps are not suitable (e.g., cold or rugged environments or low output needs).

Other Replacement Lamps

In addition to the replacement lamps tested for the downlight and troffer series, Round 5 also included two MR16 products and two A-lamp style replacement lamps.

Figures 4a and 4b summarize the light output and efficacy of all MR16s tested to date, compared to the performance values for these products suggested in product specification sheets or Web pages. While the three MR16 products tested in Round 4 all had inaccurate manufacturer performance claims, the two MR16 products tested in Round 5 both provided complete and accurate performance claims. Two 20W halogen MR16 lamps were also tested for benchmarking purposes (both standard lamps from major manufacturers).[6] Figure 4a illustrates that the light output of the SSL products is not comparable to the output levels of the two SSL MR16 products, though one SSL product, 07-59, tested in Round 4, achieves about three-quarters of the output level of the lower performing halogen MR16. Figure 4b shows that the SSL products have better efficacies than the halogen products. The SSL MR16s tested to date achieve CBCP levels ranging from one-sixth to three-quarters of the CBCP of halogen MR16s with similar beam angles.





Two A-lamp style, medium-base (screw-in), omni-directional lamps were tested in Round 5. These lamps are both about equivalent in size to an A19 lamp. Table 3 summarizes the performance results for these two products as compared to a range of incandescent A-lamps.[7] One lamp, 08-03, claims to replace 20W lamps and the other, 08-25, claims to replace 40W lamps. To a certain extent, both lamps are commendable for the levels of output, efficacy, and color quality that they achieve in a small package. On the other hand, the products failed to meet the performance claims made by the manufacturers in product literature, and both products have poor power factor (one as low as 0.32). Product 08-03 would be more justified in claiming to replace a 10-15W incandescent lamp (as opposed to the 20W equivalence claimed) and product 08-25 statements would be more accurate if claiming to replace a 25W incandescent lamp (as

[6] Note that manufacturer literature for the halogen MR16 products does not indicate efficacy levels. For 08-50, the rated lamp lumens divided by a power level of 22W (rated power + 10%) was used to calculate rated efficacy. For 08-51, only CBCP is published, so a typical halogen efficacy of 13 lm/W and output of 286 lm is used in place of manufacturer values. These products were CALiPER tested for benchmarking purposes subsequent to Round 5 testing. Detailed reporting on these tests is not included in Round 5.

[7] CALiPER Tests 08-47, 08-48, 08-49 were performed subsequent to Round 5 testing for benchmarking purposes on typical incandescent A-lamps from major lamp manufacturers. Three samples of each lamp were submitted for absolute photometric testing. Detailed reporting on these tests is not included in Round 5.

opposed to the 40W equivalence claimed). Both products also drew at least 10% more power than claimed. Product 08-25 claims a correlated color temperature of 2800K, where the average measured color temperature across 8 samples was 3418K (ranging from 3261K to 3701K).

Table 3. Summary of Replacement A-Lamp Performance

Replacement Lamps	Manufacturer Reported Performance	CALiPER Measurements					
		Power (W)	Output (lm)	Efficacy (lm/W)	CCT	CRI	Power Factor
SSL (08-03)	95-105 lm (41-46 lm/W)	3	81	31	3127	92	0.55
SSL (08-25)	230 lm (57 lm/W)	5	194	39	3418	86	0.33
INC 25 W (08-47)	210 lm (8.4 lm/W)	24	181	8	2551	99	1
INC 40W (08-48)	390 lm (9.8 lm/W)	39	387	10	2610	99	1
INC 60 W (08-49)	780 lm (13 lm/W)	61	739	12	2703	100	1

Product 08-25 also raises considerable concern regarding product reliability. This product was selected for variability testing, so ten units were purchased and tested. Two of those ten units failed entirely before photometric testing commenced (during setup and stabilization). When these products were returned to the manufacturer to request replacement, the purchaser was informed that returns are only accepted within 14 days of the shipping date, despite the product packaging claim of "Lifetime 35 years."

Other Downlights

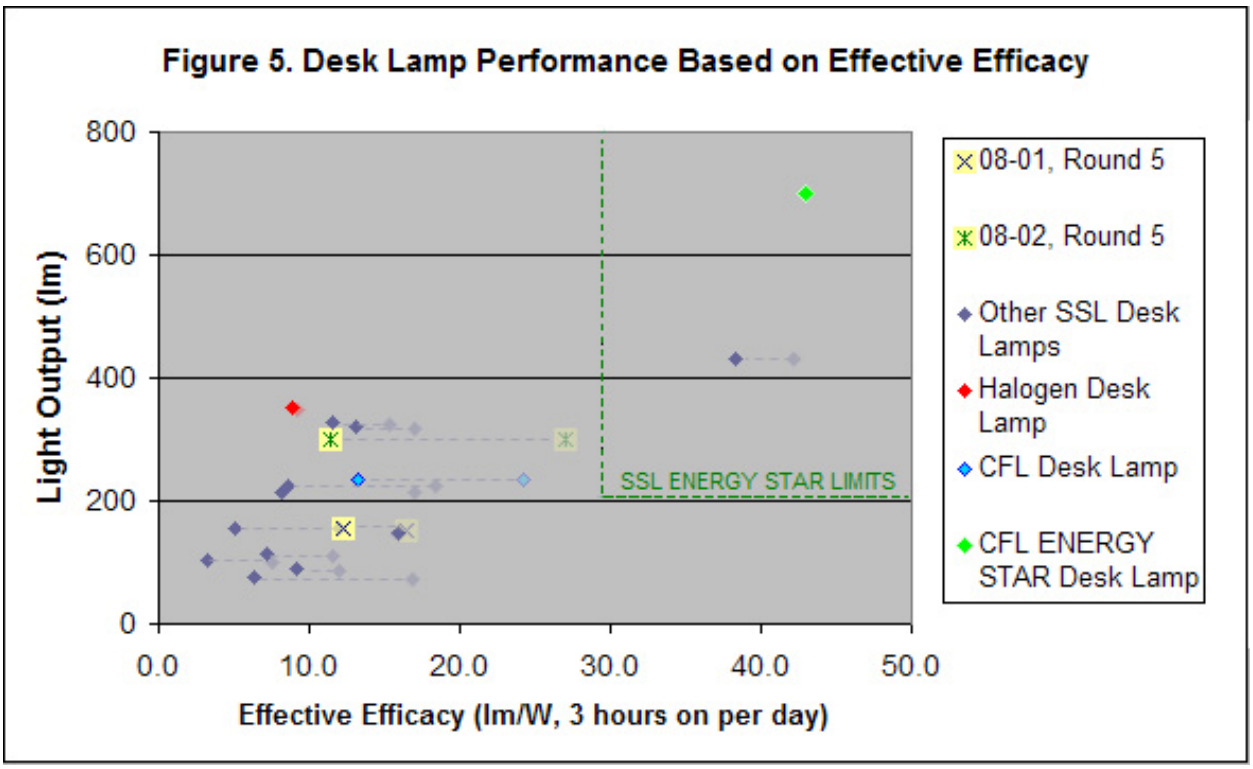
In addition to the troffer series and the series of downlight tests on replacement and retrofit lamps in a recessed can, one 2-foot by 2-foot square downlight luminaire, 08-29, was tested. This luminaire is a larger product with higher wattage level than downlights that have been tested in previous CALiPER rounds. With a CCT of 4346K and CRI of 71, this luminaire achieved an efficacy of 46 lm/W, with a total lumen output of 3456 lm. This efficacy far exceeded the efficacy of downlight products using incandescent and halogen sources, and surpassed the efficacy of all four SSL replacement tube products mounted in both lensed and parabolic louvered troffers as previously described. The efficacy of this2-foot by 2-foot ' luminaire was close to the overall luminaire efficacy of the F40T12 fluorescent tubes (08-30) mounted in a lensed troffer, and the output level was close to the output of the F32T8 lamps mounted in the parabolic louvered troffer. Unfortunately, the power factor of this product was only 0.58. This product could be a suitable choice for environments where the use of fluorescent lamps is inappropriate.

Task Lamps

Round 5 of testing included two SSL desk lamps, and two SSL undercabinet fixtures. None of these four SSL task lights met the DOE ENERGY STAR® criteria for their niche application

categories — each missed the mark on one or more criteria (such as efficacy, output, off-state power, light distribution and/or CCT requirements). [8]

The two SSL desk lights tested in this round provided outputs of 156 and 301 lm, and efficacies of 16 and 27 lm/W (if off-state power is not considered).[9] For example, 08-02 which has a measured luminaire efficacy of 27 lm/W also draws 2.2 W of power when turned off. , This resulted in effective efficacy — which takes into account off-state power consumption — that was quite poor. Figure 5 illustrates how these lamps compared to SSL lamps tested in earlier CALiPER rounds and benchmark lamps using CFL or halogen light sources. The sphere tested efficacy values for these lamps are also shown in muted points, to demonstrate how these lamps could perform if they didn't draw power when in the off state. The green lines indicate the lower limits for output and efficacy required for SSL products to meet ENERGY STAR criteria. Product 08-02 would be close to meeting the ENERGY STAR efficacy and output requirements if it did not draw power in the off state, but its color temperature (over 6000) would disqualify it. Product 08-01 only slightly exceeded the halogen benchmark example in efficacy and was far from achieving ENERGY STAR performance levels.



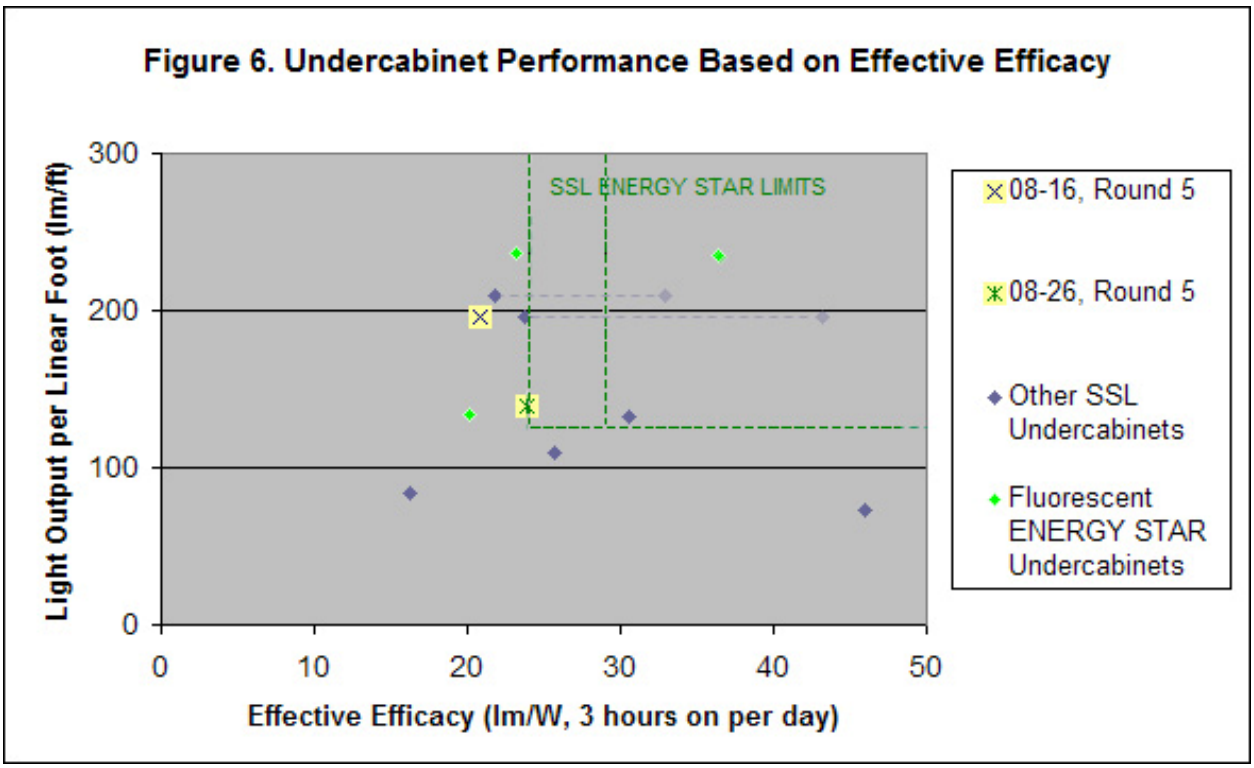
*Muted points show efficacy without including off-state power loss. Products without a corresponding muted point are those that do not draw off-state power.

[8] ENERGY STAR® Program Requirements for Solid State Lighting Luminaires Eligibility Criteria Version 1.0 (09/12/07) are available online: http://www.netl.doe.gov/ssl/energy_star.html.

[9] Off-state power consumption, also called standby power consumption or 'vampire' loading, refers to power drawn by an electronic device while it is, in essence, switched off. Some electronic devices do need to power circuitry continuously for control purposes or for other functional purposes, but many electronic devices consume power when turned off simply due to inefficient electrical design. In most cases (outside of specific applications), there is no functional reason for lamps and luminaires to draw power when they are turned off.

The two SSL undercabinet lights tested in this round provided outputs of 196 and 139 lm per linear foot, and efficacies of 21 and 24 lm/W. Both had fairly warm color temperatures, and acceptable CRIs, but as illustrated in Figure 6, their efficacy fell just below the lower limit for ENERGY STAR qualification. These two products would also not qualify for ENERGY STAR based on light distribution. More than 90% of their output falling in the 0 to 60° vertical angles, so their beams were too directional (too narrow) for this application.

While one of the four task lights tested had no marketing literature claims regarding performance, the other three had manufacturer literature that included misleading or overstated performance claims. Product 08-01 claimed to be as bright as a 40-60W incandescent and to draw only 8.8 W, yet it produced only 156 lm (less than expected from even a 40W incandescent in a desk lamp) and drew 9.5W. For product 08-02, two sets of information were found — one published by the manufacturer and one by a product distributor. The performance values declared by the distributor were fairly accurate, while the manufacturer's brochure significantly overstated the performance. The brochure claimed 08-16 produced 250 lm with only 7W of power, but tests measured 195 lm produced with 9.5W. Furthermore, this brochure claimed that the product meets ENERGY STAR requirements, but this product would fail on the basis of insufficient efficacy, too narrow a beam, and a poor power factor.



*Muted points show efficacy without including off-state power loss. Products without a corresponding dimmed point are those that do not draw off-state power.

Outdoor Fixtures

Two different types of outdoor fixtures were included in Round 5: one roadway, metal halide fixture tested for benchmarking purposes and two outdoor spot lights (the same model, using two different sources—LED and halogen).

The metal halide roadway fixture was selected as an award-winning product using a traditional source and innovative design for light distribution. The performance results for this product fall directly within the ranges that were identified by CALiPER benchmark studies of manufacturer data for similar outdoor products. This test serves to further confirm the benchmark levels that CALiPER is using in this product category; it also confirms that the higher-performing SSL outdoor products (tested in Round 3) are indeed directly competitive with products using these traditional sources based on initial luminaire efficacy.

The two outdoor spotlights (from the same product line) were chosen to provide a direct comparison between SSL and halogen luminaires. As illustrated in Table 4, the LED-based version produces only half the output of the halogen product with negligibly better efficacy. The manufacturer provides IES files for these lamps which provide information for both the LED version and the halogen version that might be misleading or difficult to interpret. The IES file for the halogen spot light indicates a fixture efficiency of over 250%, resulting in an IES photometric output of 823 lm (as opposed to 185 lm measured in CALiPER testing). The IES file for the LED spotlight indicates a lamp output of 45 lm/LED, and fixture efficiency of 100%, resulting in an IES photometric output of 135 lm (versus 90 lm measured through CALiPER). The manufacturer also claims that its LED product is comparable to its MR16 product, although the LED product achieved only one-half the light output. For lighting systems designed for lower light levels, the LED version may be an appropriate, energy-saving alternative, but it would not be suitable as a direct replacement for the halogen MR16 version.

Table 4. Comparison: Same Outdoor Spot Fixture, Two Different Sources

Source/Power	Halogen (22W)	LED (10W)
Luminaire Output (lm)	185	90
Luminaire Efficacy (lm/W)	8	9
CCT	2873	6469
CRI	97	78
Power Factor	0.98	0.74
Manufacturer lamp output (from IES)	322 lm/lamp	45 lm/LED (3 LEDs)
Manufacturer luminaire output (IES)	823 lm	135 lm
Manufacturer claim	"The LED 16 is comparable to our MR-16"	

Measurements of Color Quality

As in earlier rounds, the SSL products tested in Round 5 represent a range of white- light levels, with most available in the warm white (~2700-~3000K) and neutral white (~3500-~4000K) ranges. The average CRI of SSL products tested in Round 5 is 77 — a slight increase over earlier rounds of testing. There were five products tested in Round 5 with CCTs over 6000K. In particular, two 4-foot replacement tube products have CCTs over 7000 — well outside the nominal ranges for white light and a far colder white than would be expected for this application.

Power Factor

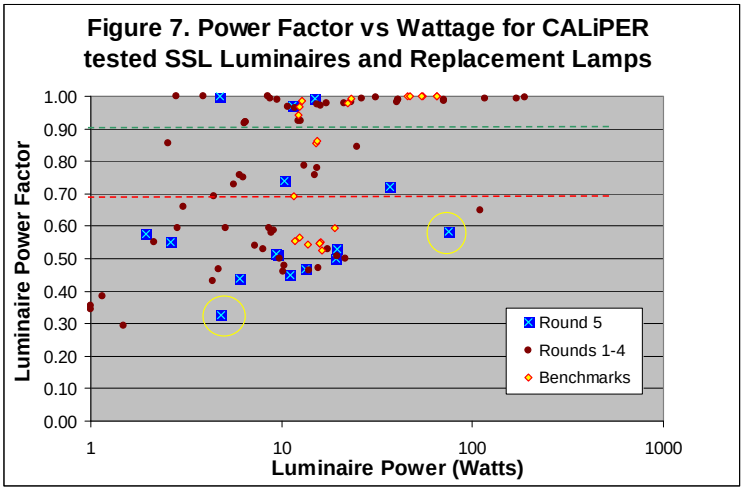


Figure 7. Power Factor vs Wattage for CALiPER tested SSL Luminaires and Replacement Lamps

The power factor of products tested to date is plotted in Figure 7, along with the luminaire power. The median power factor of all SSL products tested to date is 0.73 — exceeding the minimum power factor, 0.7, currently required for residential products in the ENERGY STAR® Program Requirements for Solid-State Lighting Luminaires.[10] The majority of products tested in Round 5 have lower-than-acceptable power factor. Of particular concern in Round 5 testing is one high-wattage product with a relatively low power factor and a smaller, highly publicized replacement lamp with a very low power factor of 0.32, both circled in yellow in Figure 7.

Performance Reports in Manufacturer Literature

In all rounds of CALiPER testing, significant discrepancies have been observed between the light outputs and efficacies published by manufacturers and their CALiPER-tested performance. The accuracy of manufacturer performance reporting for the 17 SSL products in Round 5 of CALiPER testing can be summarized as follows:

- Accurate performance reporting (4): Four SSL products tested meet or exceed the performance levels published in manufacturer literature.
- No performance reporting (1): For one product, no manufacturer-published information was found regarding output or efficacy.
- Overstated performance reporting (12): For the other twelve SSL products, information published by manufacturers regarding product output and/or efficacy overstated performance. Values were often overstated by about 25 to 100%, though in some cases either output or efficacy or both are even more exaggerated.

[10] ENERGY STAR® Program Requirements for Solid State Lighting Luminaires Eligibility Criteria Version 1.0 (09/12/07) are available online: http://www.netl.doe.gov/ssl/energy_star.html.

For the products with overstated or misleading claims, some misleadingly compared the outputs of their products to incandescent products and some published explicit values for output or efficacy of their luminaire. In many cases, the manufacturer published a somewhat overstated value for luminaire output, along with an understated value for power. If a consumer used these values to calculate the efficacy of the luminaire the results would be highly misleading.

Three products in Round 5 have measured CCT which is significantly cooler than the value announced in product literature. One undercabinet fixture claimed as well to meet the DOE ENERGY STAR requirements— a claim that was false for two reasons. First, the ENERGY STAR criteria for SSL products is not yet in effect; and second, the particular product would fail to meet the upcoming ENERGY STAR criteria on three counts.

Of the benchmark products tested in Round 5, seven out of ten products met or exceeded product performance ratings, but the other three published incorrect values or misleading statements. One of these three products is a CCFL product which did not publish explicit ratings, but highly overstated the product's performance by comparing it to a 26W CFL in a recessed can (where it fails to meet the performance of even a 13W CFL in a recessed can).

Another traditional product with incorrect ratings is a halogen HIR MR16 20W lamp. The misinformation on this lamp stems primarily from distributor-published ratings for one model of lamp that were packaged and shipped with a lamp with the same product description, but a different product code and different performance characteristics. (In many cases, two lamps have the same description in the lamp manufacturer's catalog, but different product codes and different ratings. In these cases, the buyer may receive a product which doesn't entirely correspond to what was ordered.) In this case, the tested product 08-05, when compared to the manufacturer ratings for the same product (same product code) the performance was nevertheless below the rated value for both specimens that were tested. A discrepancy of 22% for unit A and of 5.5% for unit B was observed — so even if the correct product had been received, it would not have met performance ratings. While a performance that is 5.5% below rated performance may be within normal tolerance for typical variation in large production runs, the sample that performed 22% below rated values gives more cause for concern.

One halogen spotlight also provided misleading performance information, as described previously in the outdoor lights section. In this case, the error appears to stem entirely from incorrect IES files, both for the halogen and LED versions of this product.

These examples of incorrect or misleading performance information regarding traditional products and (and examples from earlier CALiPER reports) suggest the divergence between claimed and actual tested values for SSL products may stem from a number of issues:

- Misinterpretation or lack of experience relative to SSL testing concepts (e.g., LED device performance vs. luminaire performance, lamp efficacy vs. luminaire efficacy, relative photometry vs. absolute photometry)
- Lack of industry standardization in LED device performance testing and reporting and infeasibility of determining luminaire performance based on reported LED device performance

- Confusion or lack of clear distinction in marketing literature between LED device performance and luminaire performance
- Use of inconsistent testing methods including alternatives to LM-79 (such as Japanese or Chinese standards) that may yield different results
- Manufacturers' product literature that does not clearly indicate what specific product configuration was tested to produce the performance values published (e.g., differences in LED devices, drivers, and optics may greatly influence results)
- Different basis of comparison used in manufacturer literature (such as comparing performance based only on illuminance levels for specific sources or applications, or based, for example, on Center Beam Candle Power)
- Possible inflation of performance claims (or selection of test conditions not representative of actual use; e.g., chilled or pulsed device testing)

It is hoped that the recent publication of the IESNA LM-79 testing method for SSL replacement lamps and luminaires will help improve this situation. As manufacturers make wider use of this new methodology, SSL testing and reporting practices will become more consistent and accurate. Performing appropriate SSL testing and providing accurate, understandable information regarding product performance will increase confidence in SSL technology.

In addition to questions concerning photometric performance claims for SSL, a few of the products in Round 5 raised questions regarding warranty deficiencies or purchasing irregularities. One extreme example is a product (08-25) announced to have 35-year lifetime but that has only a 14 day return policy. For another product (08-17), the invoicing and billing statements for the product did not carry the same company name and the product received did not correspond to the product ordered — and the company (whose name was on the packaging box and on the original invoice) refused to exchange the product for the one which was originally ordered. While these may be isolated cases, establishing long-term market confidence in SSL technologies is likely to be affected by concerns regarding warranty and returns policies and by purchasing and acquisition irregularities.

Variability and Repeatability

In all CALiPER testing, a certain number of tests are designed and conducted to assess facets of variation and repeatability — among samples, among testing methods or equipment, and even between two identical test runs. Over the first five rounds of CALiPER testing, these verifications have allowed us to determine, for example that on average, two samples of a given SSL product do not show any more variation in performance than two samples of incandescent or fluorescent products that have been similarly tested and compared to each other. Note that this is on average, so in some cases two samples of a product show greater divergence. Similarly, CALiPER regularly compares integrating sphere results to goniophotometry results for luminaire output and efficacy. These comparisons confirm consistently that in the great majority of cases, integrating sphere and goniophotometry tests provide similar results for total lumen output and efficacy for a given product.

In Round 5, one replacement lamp product, 08-25, was selected for broader variability testing on 10 samples of the same product. The 10 samples were purchased in three separate lots ordered at

one-month intervals. All samples were submitted to the same independent testing laboratory for integrating sphere tests. Two of the products were also tested in a goniophotometer.

Out of these 10 samples submitted for testing, all were operating when received, but two samples failed during test setup and stabilization. The remaining, functioning samples were photometrically tested. Table 5 summarizes the key performance parameters from these eight samples, showing the average, minimum, maximum, and average deviation of each of the measurements across the eight samples. The average deviation as a percentage of the average measured value for power, output, efficacy, CCT, and CRI is less than 4% across these samples, and there are no significant outliers. While this small amount of variation across eight units is reassuring, the fact that two out of 10 products failed within the first few hours of operation raises serious concerns about the reliability or robustness of the product design.

Table 5. Variation Across 8 Samples of SSL Replacement Lamp 08-25
(2 failed units not included)

Measured Quantity	Average	Minimum	Maximum	Average Deviation	Ave. Deviation/ Average Value
Power (W)	5	4.8	5.3	0.1	2.4%
Output (lm)	194	172	206	7.6	3.9%
Efficacy (lm/W)	39	36	42	1.5	3.8%
CCT	3418	3261	3701	96	2.8%
CRI	86	83	89	1.5	1.7%

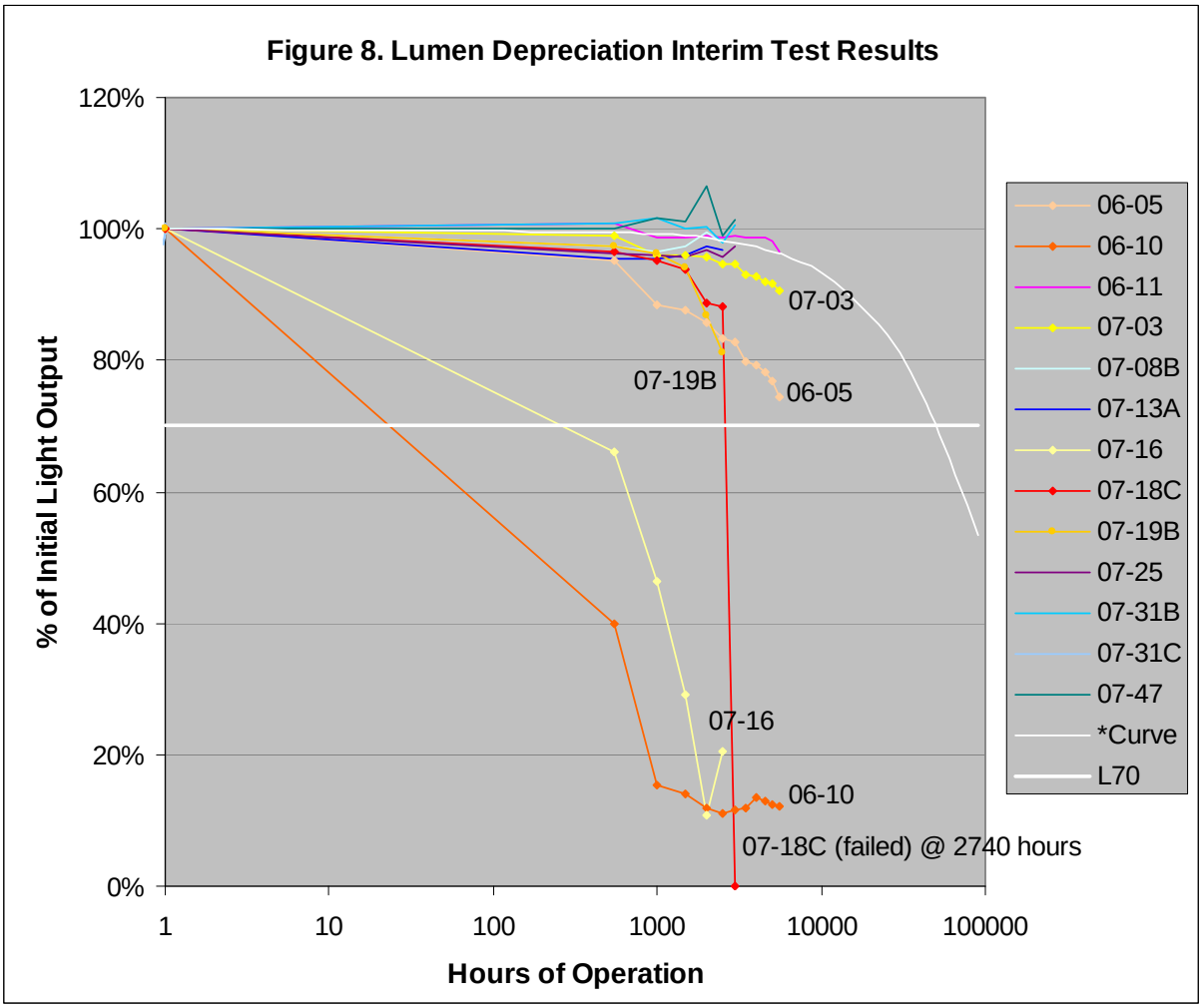
Reliability: Lumen Depreciation Testing

In addition to testing the photometric performance of products, the CALiPER program is also investigating their reliability — studying how *in situ* conditions may affect product performance and how product performance varies over time by measuring lumen depreciation. Standardized testing procedures are not yet available for performing *in situ* or lumen depreciation on SSL luminaires and replacement lamps. The CALiPER program has defined testing procedures for these situations in conjunction with qualified independent testing laboratories and has drawn on standards for similar procedures where available or under development for other product types. CALiPER *in situ* and lumen depreciation testing is ongoing, so results presented below should be considered as preliminary, introductory information only.

Lumen Depreciation Interim Examples

While LED devices — and hence SSL products — are expected to have long lives, the true rate of lumen depreciation of SSL luminaires and replacement lamps is largely unknown. Lumen depreciation characteristics for LED devices may be available from device manufacturers, but when those devices are integrated in luminaires, the LED device's long-term performance will be affected by many factors stemming from the luminaire as a whole. These factors include, most obviously, operating point characteristics (such as forward current) and thermal management (such as heat sinking and thermal bonding), but also other factors such as the use of materials during manufacturing which may effect LED device lifetime such as cyanoacrylates (super glue) and O-rings. Lumen depreciation of the LED source is not the only failure mode contributing to the reliability of SSL luminaires, but it is a primary facet of luminaire reliability that is being studied by the CALiPER program.

Figure 8 summarizes the lumen depreciation interim testing results for13 SSL products that were first included in earlier rounds of CALiPER testing. The lumen depreciation testing is not



*Note that the white curve is provided only as an example of exponential depreciation which would reach L70 (70% of initial output) at 50,000 hours. The horizontal white line indicates L70.

completed for any of these samples, but these interim results already provide insight. The two white lines in the plot are provided as reference curves: the horizontal white line indicates the level at which light output drops to 70% of the initial output (L_{70}), and the descending white curve represents a typical logarithmic decay that would reach L_{70} at 50,000 hours.

These 13 products cover a range of product configurations, including task lamps, replacement lamps, retrofit lamps, and outdoor area luminaires. At this point in this long-term testing and given the small sample size, no general observations about the speed of depreciation for any particular category of products (based on size or application) can be drawn.

Of note in these results:

- One product, a 10W medium-base socket-based directional replacement lamp, 07-18C, failed abruptly after 2740 hours of operation. This sample had depreciated to 88% of initial output prior to failing.
- Two products, 06-10 and 07-16, dropped significantly in output during the first few thousand hours of operation. 06-10 is an undercabinet product which uses only a copper core printed circuit board as a heat sink. 07-16 is a desk lamp.
- A desk lamp (07-03), a 17W PAR30 replacement lamp (07-19B) and an outdoor area luminaire (06-05) are also showing considerable depreciation during the first few thousand hours of operation, although they are still operating above the L_{70} threshold.
- Desk lamps 06-11 and 07-03 are both made by the same manufacturer, using the same design for the LED device package and driver but different thermal management. The shape, size, and sheathing of the heat sinks used are different. To determine whether lumen depreciation differences between these two fixtures stem from simple variation across samples or from differences between the two thermal management designs, testing of more units would be required.
- Seven out of these thirteen products are producing over 96% of their initial output at this point in testing.[11]

Note that these results are only interim results. These tests, and lumen depreciation testing on other products, is an on-going, long-term endeavor.

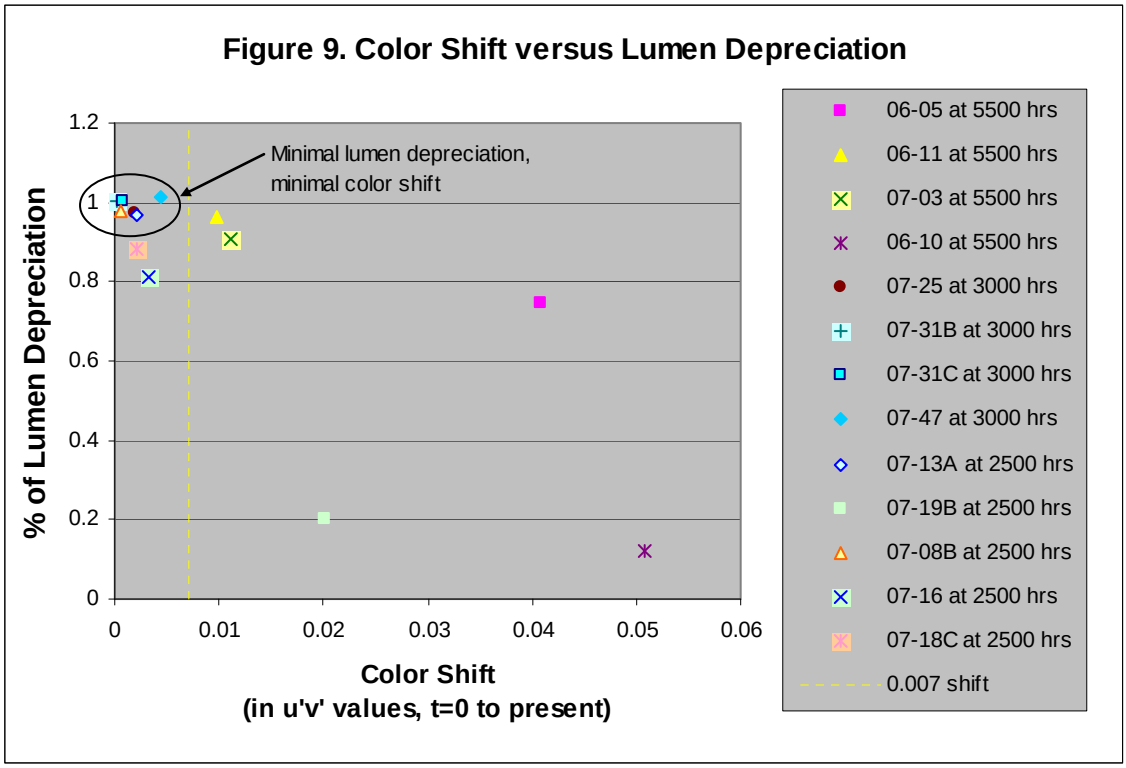
Color Shift

In addition to measuring shifts in output and efficacy due to lumen depreciation over time, this CALiPER testing is also studying shifts in color. Spot spectral measurements are taken along with spot illuminance measurements in each case. The DOE ENERGY STAR® Criteria for Solid-State Lighting requirement for color maintenance currently states, “The change of chromaticity over the lifetime of the product shall be within 0.007 on the CIE 1976 (u’, v’) diagram.”

[11] Different sets of lumen depreciation testing are at different stages of advancement. The thirteen products being tested at this time have been operated from 2500 to 5500 hours, depending on the start date of the various tests.

Figure 9 illustrates the degree of color shift of each of these products in relation to the extent of measured lumen depreciation for each. A dotted vertical line is included to mark the current ENERGY STAR cut off for lifetime change in chromaticity at 0.007. Analysis of the initial color shift results must take into consideration that the uncertainty factors for these spot color shift measurements have not yet been determined and may be relatively large. Nevertheless, Figure 9 shows clearly that products with higher lumen depreciation also exhibit greater color shift.

As noted above, all lumen depreciation and color shift test results reported here are from interim testing using relative photometry. Measurement uncertainties for this testing have not been calculated. Products will be retested in an integrating sphere after 6000 hours of operation to recheck the correlation of relative photometry to absolute photometry for these samples.



Conclusions from Round 5 of Product Testing

Key Points

As with earlier rounds of CALiPER testing, the results from Round 5 are nuanced, with some positive performance results and visible progress but also some disappointing results for specific products or certain application categories.

The series of testing on downlights in an insulated recessed can provides solid points of comparison between SSL products and a number of other light sources. For operation in an

insulated recessed can, the product with the best overall luminaire efficacy was the SSL retrofit lamp. The value-brand A19 lamp provided the lowest output and worst overall luminaire efficacy. Two out of the three SSL products included in this series met or exceeded the levels of luminaire output and efficacy of the three fluorescent products (RCFL, spiral CFL, and cold cathode fluorescent) *in situ*. These three fluorescent products and two SSL products provided output levels similar to the incandescent R30 and HIR PAR38 tested *in situ*, while using less than one-quarter the energy—the SSL retrofit use one-fifth to one-sixth of the energy of the incandescent or halogen for similar output level. While the three SSL downlight products varied in performance, they all exhibited lower fixture losses than the spiral CFL, the RCFL, and the incandescent A-19 lamp, making their performance more competitive with these other light sources *in situ*.

The series of testing on 4-foot replacement lamps in troffers also allowed the examination of the benefits of directionality of SSL products. In this application, however, LED sources have to compete with highly efficient fluorescent lamps. The results for all four SSL 4-foot replacement tube products show that SSL is not yet able to compete in this application area: even when installed in troffers, the SSL replacement tubes did not provide half the output of fluorescent tubes in the same troffers and fail to achieve the luminaire efficacy levels of the fluorescents in the troffers. The better performing SSL replacement tube products or the 2-foot x 2-foot downlight panel tested might be appropriate to consider for specific applications where fluorescent is not suitable (e.g., cold or rugged environments or low output needs); otherwise SSL is not competitive in troffers as a replacement for fluorescent tubes at this time.

For MR16 replacement lamps, both products tested in Round 5 met or exceeded their ratings. Although they do not achieve the output levels of 20W halogen MR16 lamps, they matched the high end of the range of efficacies expected for halogens and exceeded the measured efficacy of benchmark halogen MR16s that have been CALiPER tested,. These products may be suitable for applications requiring lower light levels than provided by 20W halogens.

The two A-lamp replacement products tested in this round show significant promise. The efficacy and color quality is better than for similar products tested in earlier CALiPER rounds. Unfortunately these products have poor power factor results and exaggerated rated performance. The catastrophic failure of two out of 10 samples of one of these products should serve as a serious caution regarding product reliability. These failures underscore the importance of return policies and warranties for SSL luminaires and replacement lamps.

Desk lamps and undercabinet luminaires continued to provide mixed results. None of the four task lamps tested in this round of testing would pass ENERGY STAR® Program requirements for solid-state lighting. The desk lamps continue to have off-state power consumption which diminishes their effective efficacy to the level of halogen desk lamps. The undercabinet luminaires are close to meeting ENERGY STAR requirements and match the color quality and output and efficacy levels of some of the benchmark fluorescent undercabinet products.

The direct comparison between two identical outdoor spotlights, one using a halogen source and one using SSL, once again illustrated that mounting an LED source in an existing fixture does not appear to be an effective design option for SSL. In this case, as in earlier direct comparisons,

the resulting SSL product did not achieve the performance expected from LED technology and did not provide significant advantages over the halogen option.

The intermediate results from lumen depreciation testing serve as a reminder that the reliability of SSL products is still largely theoretical, and claims of consistent color maintenance in luminaires and 50,000-hour lifetimes (or more) are largely speculative at this point. Decisions which take into account the expected life of an SSL product should consider product guarantees, knowledge about which LED devices are used in a product, the credibility of the manufacturer of the LED devices used in the luminaire, and the credibility of a luminaire's manufacturer.

Next Steps for the Industry and CALiPER efforts

With the recent publication of IESNA LM-79 testing method for SSL and with the DOE ENERGY STAR for SSL coming into effect in the fall of 2008, CALiPER testing will continue at a fast pace. Along with basic photometric testing of SSL products, CALiPER has scheduled additional benchmarking, round-robin testing, and variability and repeatability testing in the coming months. CALiPER will continue to work closely with standards development efforts and testing laboratory experts to better understand the nuances of SSL testing.

DOE plans to create a guidance committee for the CALiPER program made up of utilities and energy efficiency program sponsor representatives to guide CALiPER program planning and growth. This committee will provide feedback on which products to test, how products are tested, and how results are analyzed and characterized. The goal is to increase the value of CALiPER to the public and to utilities and energy efficiency programs.[12] The CALiPER test reports and analysis have been well received by lighting manufacturers and have had a direct impact on industry awareness and discussion about testing and reporting practices.

DOE SSL Commercially Available LED Product Evaluation and Reporting Program

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The U.S. Department of Energy (DOE) is a federal agency working in the public interest. Published information from the DOE SSL CALiPER Program, including test reports, technical information, and summaries, is intended solely for the benefit of the public, in order to help buyers, specifiers of new SSL products, testing laboratories, energy experts, energy program managers, regulators, and others make informed choices and decisions about SSL products and related technologies.

Such information may not be used in advertising, to promote a company's product or service, or to characterize a competitor's product or service. This policy precludes any commercial use of any DOE SSL CALiPER Program published information in any form without DOE's express written permission.

[12] A DOE SSL Update e-mail was issued on May 13, 2008 introducing the DOE plans to create this guidance group. More information regarding the formation of this group will be posted on the DOE CALiPER program web pages (http://www.netl.doe.gov/ssl/comm_testing.htm) during the summer of 2008.

Appendix A

Testing Methods

The lighting testing laboratories were instructed to follow test procedures specified in the draft LM-79 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).'[13] 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.[14]

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 product tested 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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[13] The testing standard entitled "IESNA Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products," designated LM-79, 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.

[14] De-rating factors for specific fixtures or fixture and lamp combinations are not specified, recommended, nor studied by the DOE at this time.

Appendix B

Downlight Series — Additional Results

After testing the bare lamps in an integrating sphere, the better performing unit of each pair of samples was mounted in a Juno IC22 insulated ceiling recessed can. The IC can was mounted in an insulated enclosure (19.75" x 19.75" x 14" high and filled with polyurethane insulating foam sealant), representing a UL1598 environment. The two retrofit products (one SSL and one CCFL) included their own white trim. The replacement lamps were mounted using a standard white baffle/trim kit, 28W-WH Airlock kit.

Figure B-1 below assembles iso-footcandle plots for nine of the downlight lamps mounted and tested in the recessed can in an insulated enclosure. Each plot is established based on a 5-foot mounting height and also indicates the footcandle value at the nadir. The beam patterns can be compared visually. The two PAR38 lamps (one SSL and one HIR) show a very tight beam with high intensity at the center. The long-life, value-brand A19 and R30 and SSL PAR30 lamps share somewhat tight beam patterns, while the SSL retrofit, the CCFL and the RCFL have the widest beam spreads. The two non-directional sources (the spiral CFL and the incandescent, long-life A19) show relatively low levels of illuminance, with only 3-4 fc at nadir.

Table B-1 summarizes the bare lamp measured performance and manufacturer published values for these lamps. The right-hand columns indicate the differences between manufacturer ratings and measured values for light output and efficacy of the replacement lamps. Two of the SSL products and the RCFL have manufacturer values that understate their performance. One SSL product, the CCFL product, the value-brand A19, and the HIR lamps all have manufacturers' claims that overstate the product's performance.

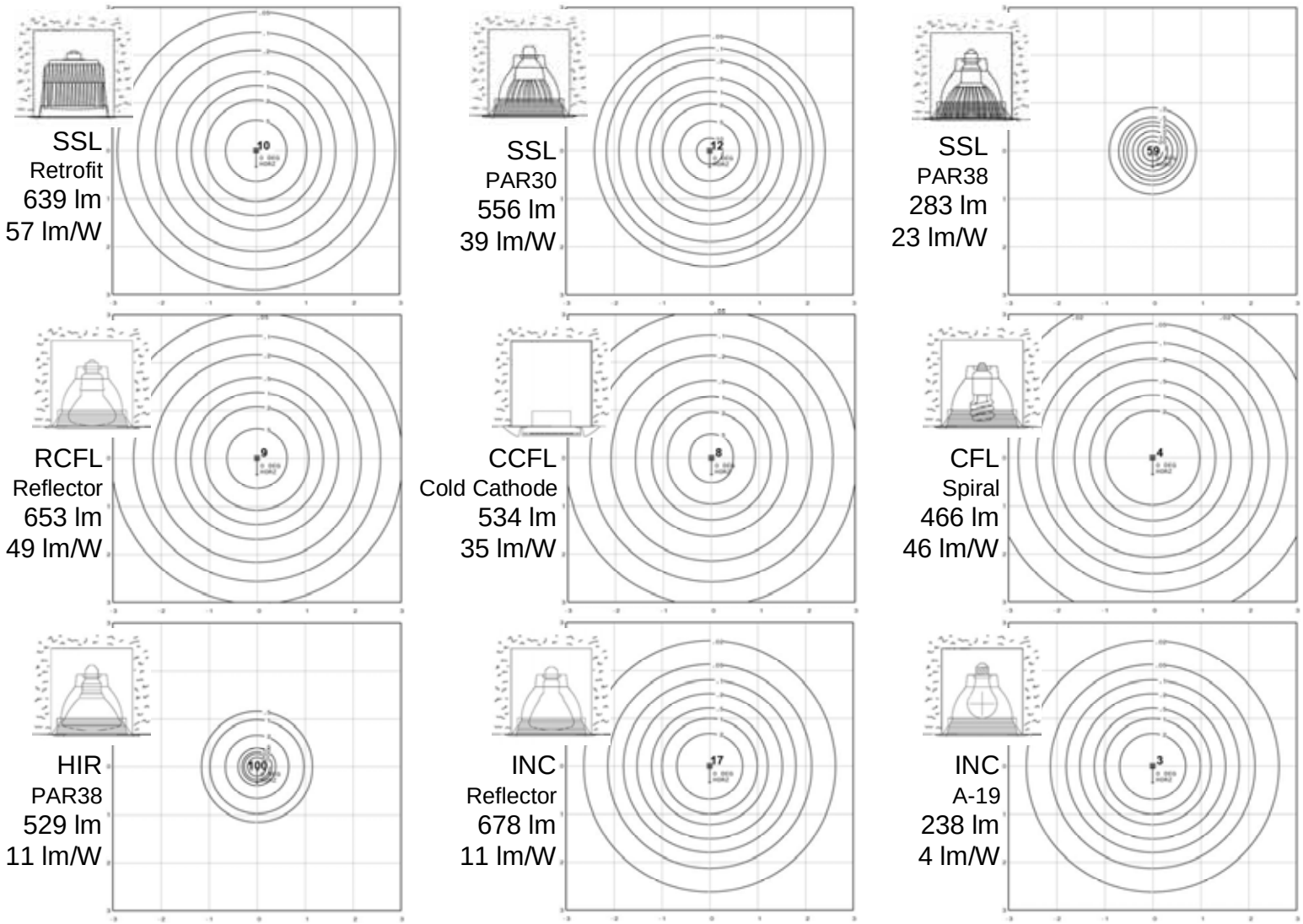

Figure B-1. Iso-footcandle Plots at 5' Mounting Height
(same scale, same insulated recessed can, different sources)

DOE SSL CALiPER results may not be used for commercial purposes under any circumstances;
see "No Commercial Use Policy" at http://www.netl.doe.gov/ssl/comm_testing.htm for more information.

Table B-1. Performance of Bare Lamps for Downlight Series

Sample description	Sphere Measurements			Manufacturer Published Values				Difference of Measured Output or Efficacy vs. Manufacturer Rating	
	Power (W)	Output (lumens)	Efficacy (lm/W)	Rated Power (W)	Rated Lumens	Calculated Efficacy (lm/W)	Life (hours)	output	efficacy
SSL									
SSL downlight retrofit 12W, warm white	12	673	59	12	650	54	--	-4%	-10%
SSL Par30 18.6W, Cool white	15	627	42	18.6	500-675	27-36	50000	-7%	-33%
SSL Par38 21W, Warm white	13	323	24	21	560	27	--	42%	10%
Incandescent, Halogen, CFL									
R30 CFL 15W, name brand reflector CFL	16	841	53	15	750	50	8000	-12%	-6%
CCFL 18W, cold cathode retrofit	15	513	33	18	750	42	25000	32%	20%
Spiral CFL 13W, name brand spiral A-lamp	12	806	67	13	825	63	8000	2%	-6%
Par38 Halogen 50W, name brand HIR*	46	524	11	46/50	600/850	13/17	3000	13%--38%	13%--33%
R30 incandescent 65W, name brand EPACT R-lamp	65	732	11	65	755	12	2000	3%	3%
A19 incandescent 60W, soft white, major brand	61	739	12	60	780	13	2000	5%	7%
A-19 inc. 60W, long-life, frosted, value-brand lamp**	55	353	7	53	466	9	14100	24%	26%

Where numerical rated values are not published by manufacturers, rated values are estimated based on manufacturer performance claims.
Where ranges of rated values are available, the average of the range is used to calculate differences.
*The HIR PAR 38 lamp was ordered based on advertised ratings corresponding to a particular PC code, the product received had same description, but different PC. Manufacturer ratings for these two versions of the same product differ.
**The value-brand incandescent is a long-life lamp (rated at 5000 hours for 130VAC operation, 14100 hours for 120VAC operation). Testing is conducted at 120VAC, so table indicates ratings for 120VAC operation.

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