# CALiPER

## Summary Report

May 2010

DOE Solid-State Lighting CALiPER Program

# Summary of Results: Round 10 of Product Testing

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## DOE Solid-State Lighting CALiPER Program

The Department of Energy (DOE) Commercially Available Light-Emitting Diode (LED) Product Evaluation and Reporting (CALiPER) Program has been purchasing and testing general illumination solid-state lighting (SSL) products since 2006. SSL technology and market-available products have improved dramatically since the first CALiPER testing, which was summarized in a CALiPER Round 1 Summary Report, yet there is still a wide disparity in quality among different products and manufacturers and in many cases wide disparity between manufacturer's claims and the actual performance of their SSL products.[1]

Designing and producing high-quality SSL products depends on many factors, and no single test can fully describe all facets of an SSL product's performance. Nevertheless, one cornerstone to understanding SSL performance and comparing it to traditional lighting technologies is basic photometric testing conducted using the standardized LM-79-08 testing method.[2] LM-79 is not a pass/fail test and it is not a set of criteria or specifications; it is simply a standardized method for measuring photometric performance of SSL products. Using LM-79 results from testing conducted by qualified testing laboratories allows manufacturers to more accurately define product performance ratings and allows consumers to have significantly greater confidence in SSL performance information.[3]

CALiPER summary reports provide side-by-side analysis of photometric performance of SSL products and benchmark products, along with discussion of specific factors to consider for different lighting applications. Educated consumers should be able to assess how an SSL product compares with other SSL products, with traditional products, and with manufacturer claims if they are equipped with knowledge about the general state of products on the market from CALiPER reports and an LM-79 test report on the SSL product in question. An analysis based on LM-79 results can provide insight into light output, efficacy, color qualities, power characteristics, and light distribution, but it does not provide insight into other performance characteristics such as reliability and controllability. SSL purchasing decisions should also take into consideration reliability factors (using IESNA LM-80 results, warranty information, manufacturer track record, other manufacturer-published information about product reliability, etc.), and ultimately, samples of the product should be evaluated *in situ*, to ensure that the product meets the needs of its intended application.[4]

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[1] Summary reports for Rounds 1-9 of DOE SSL testing are available online at http://www.ssl.energy.gov/caliper.html. Detailed test reports for products tested under the DOE's SSL testing program can also be obtained online: http://www1.eere.energy.gov/buildings/ssl/search.html.

[2] IESNA LM-79-08 testing standard, *IESNA Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products*, covers LED-based SSL products with control electronics and heat sinks incorporated. http://www.iesna.org/.

[3] A list of laboratories currently qualified by CALiPER to perform LM-79 testing is available on-line: http://www1.eere.energy.gov/buildings/ssl/test_labs.html.

[4] IESNA LM-80-08 testing standard, *IESNA Approved Method: Measuring Lumen Maintenance of LED Light Sources*, addresses the measurement of lumen maintenance testing for LED light sources including LED packages, arrays and modules only. http://www.iesna.org/

## Summary of Results: Round 10 of Product Testing

Round 10 of CALiPER testing was conducted from October 2009 to February 2010. In this round, 28 products, representing a range of product types and technologies, were tested with both spectroradiometry and goniophotometry using absolute photometry. All SSL products were tested following the IESNA LM-79-08 testing method. Testing also included measurements of surface temperatures (taken at the hottest accessible spots on the luminaire).

Round 10 of testing includes four primary focus areas:

1. Parking Structure Luminaires
2. Outdoor Wallpack Luminaires
3. Cove Lighting Luminaires (including two products marketed as "AC LED" products)
4. Replacement Lamps

To benchmark against tests of similar products that use conventional light sources, traditional parking structure, wallpack, and cove light products were also tested and included in this summary report (using absolute photometry performed on anonymously purchased samples). This report summarizes the basic photometric performance results for each product and discusses the results with respect to similar products that use conventional light sources, results from earlier rounds of CALiPER testing, and manufacturer ratings.[5]

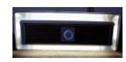
**Round 10 CALiPER Testing Results**
Tables 1a, 1b, 1c, and 1d summarize results for energy performance and color metrics—including light output, luminaire efficacy, correlated color temperature (CCT), and color rendering index (CRI) — for products tested under CALiPER in Round 10. A thumbnail photo of each product is included. These tables assemble key results as follows:

- Table 1a: Four SSL parking structure luminaires and three benchmark products (one T5HO fluorescent, one induction, one pulse-start metal halide)
- Table 1b: Five SSL wallpacks and two benchmark products (one high-pressure sodium and one pulse-start metal halide)
- Table 1c: Seven SSL cove lights and two benchmark products (one xenon and one T5HO)
- Table 1d: Five SSL replacement lamps including MR16 and PAR lamps, an A-lamp, and a 4' linear replacement lamp

[5] In addition to basic photometric testing per IESNA LM-79-08, CALiPER periodically performs additional testing—examining, for example, dimmability, reliability, flicker, or *in situ* performance. Directly applicable published standards are not available for these additional tests, so CALiPER works with standards organizations, industry trade groups, and independent testing laboratories to explore and determine appropriate testing methods. Preliminary results from these additional non-standardized forms of testing are not included in this Round 10 summary report.

Additional data for each set of testing results, and related manufacturer information, are assembled in CALiPER detailed reports for each product tested. Discussions of each set of results and further data are provided in the sections below.

**Table 1a.** CALiPER ROUND 10 SUMMARY – Parking Structure Luminaires

| -- SSL testing following IESNA LM-79-08<br>-- 25ºC ambient temperature | DOE CALiPER TEST ID | Total Power (Watts) | Output (Initial Lumens) | Efficacy (lm/W) | CCT (K) | CRI | Photo |
|---|---|---|---|---|---|---|---|
| **SSL Luminaires** | | | | | | | |
| Parking Structure | 09-87 | 110 | 6764 | 61 | 5845 | 75 |  |
| Parking Structure | 09-88 | 118 | 3885 | 33 | 6026 | 76 |  |
| Parking Structure | 09-104 | 86 | 4496 | 52 | 6414 | 74 |  |
| Parking Structure | 10-05* | 117 | 7238 | 62 | -- | -- |  |
| **Benchmark (BK) Luminaires: Linear Fluorescent (T5HO), Induction (QL), and Pulse-Start Metal Halide (PMH)** | | | | | | | |
| Parking Structure<br>T5HO Fluorescent | BK09-108 | 103 | 5787 | 56 | 4253 | 80 |  |
| Parking Structure<br>QL Induction | BK09-109 | 75 | 4143 | 56 | 3048 | 77 |  |
| Parking Structure<br>PMH** | BK09-110 | 213 | 10667 | 50 | 3847 | 57 |  |

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

* Despite repeated efforts including parts replacement by the manufacturer, the motion sensing function of 10-05 could not be deactivated using the programmable occupancy detector and the factory setting of the dimmable driver could not be reset. Due to this faulty control unit, this sample could only be tested at its highest driver setting and could not be tested in the integrating sphere. Manufacturer specifications indicate a CCT of 4125K +/- 175 and CRI of 80.

** PMH benchmark uses quartz pulse-start metal halide (not ceramic). Results shown in table are from testing at 120VAC. Testing conducted at 277VAC provided similar results (211W, 10636 lm and 50 lm/W).

**Table 1b.** CALiPER ROUND 10 SUMMARY – Wallpack Luminaires

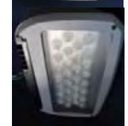
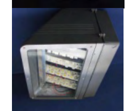
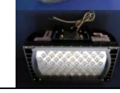
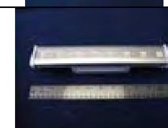
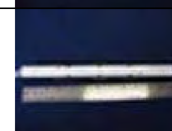
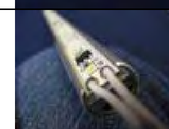
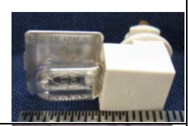
| -- SSL testing following IESNA LM-79-08<br>-- 25ºC ambient temperature | DOE CALiPER TEST ID | Total Power (Watts) | Output (Initial Lumens) | Efficacy (lm/W) | CCT (K) | CRI | Photo |
|---|---|---|---|---|---|---|---|
| **SSL Luminaires** | | | | | | | |
| Wallpack | 09-89 | 16 | 420 | 27 | 5241 | 68 |  |
| Wallpack | 09-90 | 60 | 2459 | 41 | 6313 | 79 |  |
| Wallpack | 09-91 | 66 | 1829 | 28 | 4067 | 67 |  |
| Wallpack | 09-92 | 69 | 4276 | 62 | 4170 | 80 |  |
| Wallpack | 09-103 | 87 | 4470 | 52 | 6355 | 75 |  |
| **Benchmark (BK) Luminaires: High Pressure Sodium (HPS) & Pulse-Start Metal Halide (PMH)** | | | | | | | |
| Wallpack HPS | BK09-105 | 171 | 8103 | 47 | 2130 | 12 |  |
| Wallpack PMH* | BK09-106 | 188 | 4591 | 24 | 4504 | 66 |  |
| Values are rounded to the nearest integer for readability in this table.<br>*PMH benchmark uses quartz pulse-start metal halide (not ceramic). | | | | | | | |

**Table 1c.** CALiPER ROUND 10 SUMMARY – Cove Lighting Luminaires

| -- SSL testing following IESNA LM-79-08<br>-- 25ºC ambient temperature | **DOE CALiPER TEST ID** | **Total Power (Watts)** | **Output (Initial Lumens)** | **Efficacy (lm/W)** | **CCT (K)** | **CRI** | **Photo** |
|---|---|---|---|---|---|---|---|
| **SSL Luminaires** | | | | | | | |
| Cove, 10" strip | 09-83 | 7 | 182 | 27 | 3547 | 73 |  |
| Cove, 11.25" strip | 09-84 | 7 | 243 | 37 | 2640 | 67 |  |
| Cove, 12" strip | 09-85 | 5 | 144 | 31 | 2902 | 72 |  |
| Cove, 12" strip | 09-86 | 16 | 195 | 12 | 2785 | 68 |  |
| Cove, 13" 'corner' strip | 09-102 | 6 | 236 | 40 | 3157 | 76 |  |
| Cove (track)* 4000K, 'AC LED' | 09-99 (single head) | 3 | 49 | [19] | 4226 | 71 |  |
| | 09-99 (two heads) | 4 | 97 | 27 | 4246 | 71 | |
| Cove (track)* 3000K, 3K'AC LED' | 09-100 (single head) | 2 | 18 | [9] | 2907 | 70 |  |
| | 09-100 (three heads) | 3 | 52 | 16 | 2955 | 70 | |
| **Benchmark (BK) Luminaires: Xenon and Linear Fluorescent (T5HO)** | | | | | | | |
| Cove (track)* T3-1/4 xenon-lamp 10W | BK09-101 (single head) | 9 | 64 | [7] | 2587 | 100 |  |
| | BK09-101 (two heads) | 17 | 126 | 7 | 2581 | 99 | |
| Cove, 23" T5HO Fluorescent | BK10-08 | 27 | 1317 (660 lm/ft) | 48 | 2915 | 84 |  |

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

*For products 09-99, 09-100, and BK09-101, two track heads for each were tested. 'Single head' values present averages of two samples. Efficacy values for the single head tests are shown in [brackets] to indicate that these configurations may not be providing an optimal load level to the transformer used with the track, so efficacy values for testing with two or more heads should be used. Products 09-99 and 09-100 were tested using a manufacturer-specified transformer rated at 10W. The same transformer was used for conducting the single head test on BK09-101, while a second version of the manufacturer-specified transformer, rated at 25W, was used to test BK09-101 with two heads.

**Table 1d.** CALiPER ROUND 10 SUMMARY – SSL Replacement Lamps

| -- SSL testing following IESNA LM-79-08<br>-- 25ºC ambient temperature | **DOE CALiPER TEST ID** | **Total Power (Watts)** | **Output (Initial)** | **Efficacy (lm/W)** | **CCT (K)** | **CRI** | **Photo** |
|---|---|---|---|---|---|---|---|
| **SSL** | | | | | | | |
| **Directional Replacement Lamps – MR16** | | | | | | | |
| Replacement Lamp (MR16) | 09-93 | 4 | *129 lm*<br>*618 cd*<br>21 deg | 37 | 3049 | 94 |  |
| **Directional Replacement Lamps – PAR and R Lamps** | | | | | | | |
| Replacement Lamp (PAR30L) | 09-96 | 10 | 457 lm<br>2384 cd<br>20 deg | 47 | 3060 | 85 |  |
| Replacement Lamp (PAR38) | 09-94 | 16 | 635 lm<br>3199 cd<br>20 deg | 41 | 3070 | 84 |  |
| **Omni-directional Lamps – A-lamps and Candelabras** | | | | | | | |
| Replacement Lamp (A-lamp) | 09-98 | 6 | 394 | 67 | 3029 | 87 |  |
| **SSL Replacement Lamp (4' T8 linear) – Bare Lamp and Testing in Parabolic Louvered Troffer** | | | | | | | |
| Bare Lamp (4200K)-submitted | 09-16* | 25 | 1815 | 72 | 4345 | 76 | |
| Bare Lamp A (3500K)-purchased | 09-107A* | 25 | 941 | 38 | 3767 | *72* |  |
| Bare Lamp B (3500K)-purchased | 09-107B* | 5 | 229 | 50 | 3616 | *72* | |

Values are rounded to the nearest integer for readability in this table. Two or more samples were tested for all small replacement lamps—values are average of two samples. For MR16, PAR, and R lamps, light output in lumens is provided, along with center beam candlepower (in candela), and beam angle in degrees.

For replacement lamps, lumen output requirement is based on target replacement wattage as claimed by the manufacturer. For MR16, PAR, and A-lamps, performance levels that do not meet the minimum ENERGY STAR criteria for integral SSL replacement lamps are shown in *red italics*.[6]

CRI values below 75 are in *red italics*.

*Linear replacement products 09-16 and 09-107 are in theory the same products in two different color temperature versions (4200K and 3500K), however sample 09-16 (in 4200K CCT) is a unit sent to CALiPER by a manufacturer and samples 09-107 are units of the same product (in 3500K CCT) purchased anonymously by CALiPER.

[6] *ENERGY STAR® Program Requirements for Integral LED Lamps Partner Commitments.* http://www.energystar.gov/ia/partners/manuf_res/downloads/IntegralLampsFINAL.pdf, March 22, 2010.

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

### Energy Use and Light Output

The SSL products tested in Round 10 exhibit a wide range of efficacy: from 12 to 67 lm/W, as summarized in Figure 1. The overall average efficacy for SSL products tested in Round 10 is 40 lm/W. Where previous rounds of testing all showed increases in average efficacy, Round 10 shows slightly lower average efficacy than the Round 9 average of 46 lm/W. The Round 8 average was 36 lm/W. A closer look at the groups of products tested reveals that the SSL cove light products perform on average significantly below other product categories, with only 25 lm/W on average for the SSL cove lights. Average efficacy of Round 10 SSL products excluding the cove lights gives 48 lm/W.

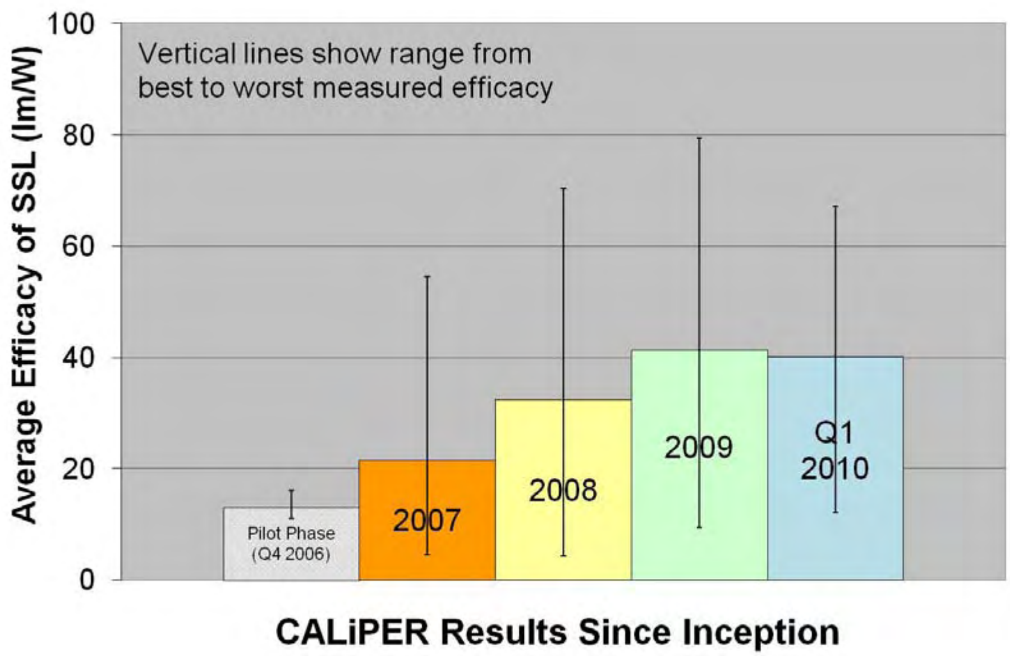



**Figure 1. Average Measured Efficacy of Market-Available SSL Luminaires and Replacement Lamps**

Earlier rounds of testing all included a significant number of smaller (size, power and output) products (such as replacement lamps and downlights), whereas half of the Round 10 products are parking garage and wallpack luminaires, drawing significantly more power and producing significantly more light output than the average product tested in earlier rounds. It is a significant achievement for commercially-available SSL products to now be able to attain the same levels of efficacy on average in both higher output luminaires and smaller integral replacement lamps.

## Parking Structure

Four SSL parking structure luminaires and three benchmark parking structure luminaires (one T5HO fluorescent, one QL induction, one pulse-start metal halide) were included in Round 10.[7] Table 1a summarizes the CALiPER-measured photometric performance of these products, including total luminaire light output, luminaire efficacy, and color characteristics. For parking structure luminaires, it is also important to consider distribution characteristics and other points of comparison, discussed below.

### Output and Efficacy

All the parking structure luminaires tested in Round 10 except 09-88 have luminaire efficacy greater than 50 lm/W. Two of the SSL products have luminaire efficacy over 60 lm/W, while the three benchmark products fall between 50 and 60 lm/W. When scaled for equal power use, light output for three of the four SSL luminaires falls within the range of light output produced by the non-LED benchmarks (product 09-88 falls well below the light output levels of all of the other samples). SSL product 09-88 and the PMH (09-110) and induction (09-109) benchmark products produce about 10-30% less overall light output and yield lower luminaire efficacy than suggested by manufacturer photometric data.

### Spatial Distribution

Figures 2a-h below illustrate the wide range of distribution characteristics of these seven parking structure luminaires, along with an additional sample, 07-43, tested in CALiPER Round 4. For each luminaire, three graphics are provided: a traditional iso-illuminance plot, a polar intensity (candela) plot, and a 3D view of the horizontal illuminance.[8] Both the 2D iso-illuminance plot and the 3D view are based on a mounting height of 9 feet and use the same color coding scheme, with black for inadequately illuminated areas below 1 footcandle (fc), blue for 1-5 fc (sufficient light), green for 5-9 fc (somewhat excessive light), and yellow for areas receiving over 9 fc (clearly excessive illuminance). The ranges used here are for illustrative purposes; criteria defining appropriate footcandle levels may vary for different applications. [9]

The multicolored 3D surface plots provide a conceptual indication of suitable light levels (which may be particularly useful for readers who are not lighting specialists). Initial illuminance, in footcandles, is shown over an area extending four mounting heights from the luminaire in each direction. Providing these three different views of the distribution data may allow readers to better picture how, for example, a batwing or cosine distribution actually translates into a broad/shallow or narrow/deep "pool" of light.

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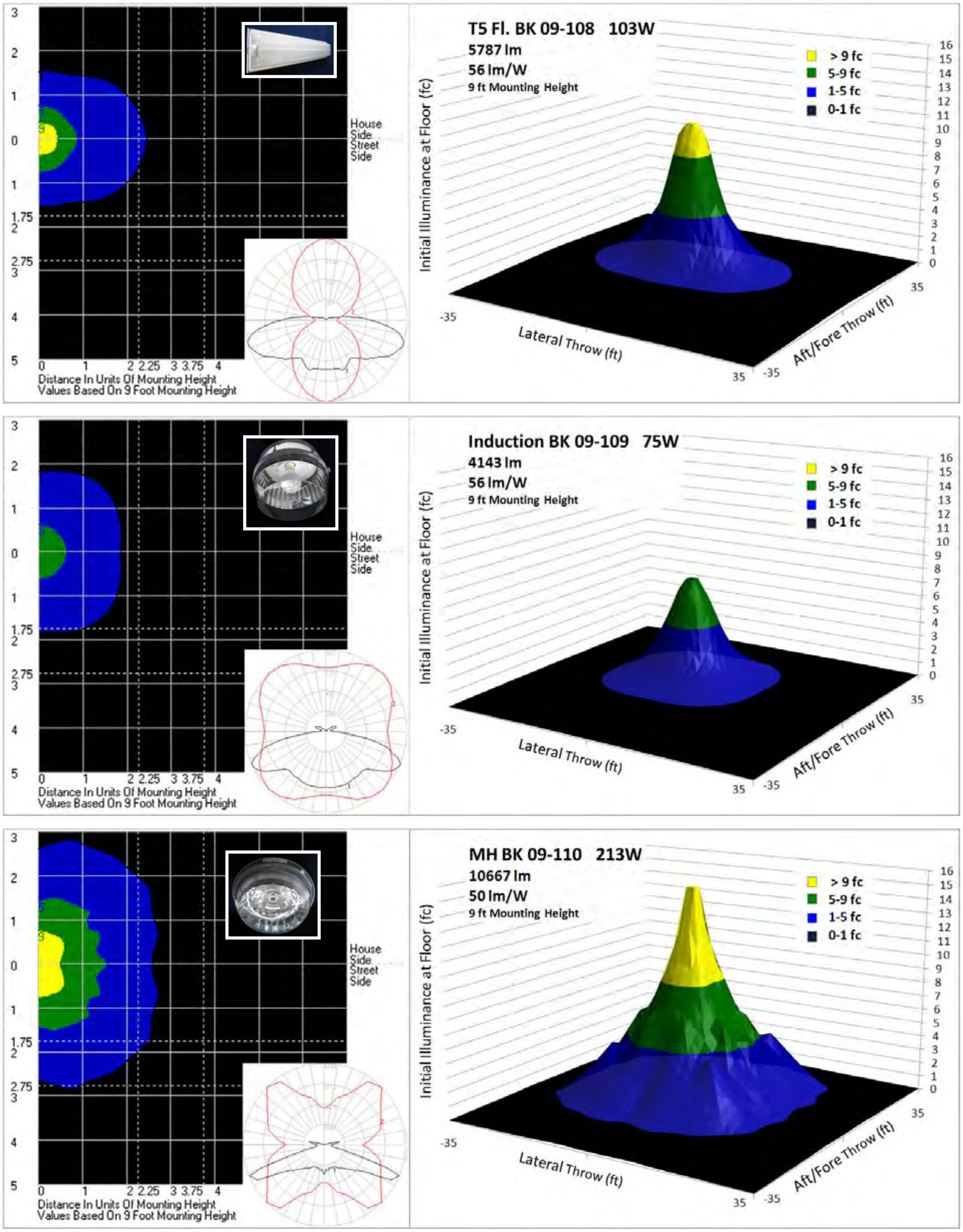
[7] Parking structures often feature supplemental daytime transitional lighting at entrances and exits. After luminaire locations are determined for adequate nighttime illumination, daytime-only luminaires may be added to boost levels near entrances and exits to facilitate visual adaptation for drivers. These luminaires, which feature greater output and/or more focused beams, were not included in samples tested by CALiPER at this time.

[8] On the polar intensity plots, two traditional candela curves are shown, representing the vertical plane through the point of maximum intensity (black) and the vertical-axis cone open downward and passing through the point of maximum intensity (red).

[9] CALiPER LM-79 testing provides initial levels. IESNA recommendations are for maintained illuminance—additional information about product lumen maintenance and additional calculations would be needed to estimate illuminance levels later in the life of each product. Additional recommendations are given in IESNA RP-20-98. Visit http://www.ies.org/ for more information.

**Figures 2a-c. Light Distribution of Benchmark Parking Structure Luminaires**



**Figures 2d-f. Light Distribution of SSL Parking Structure Luminaires (Broad Distribution)**

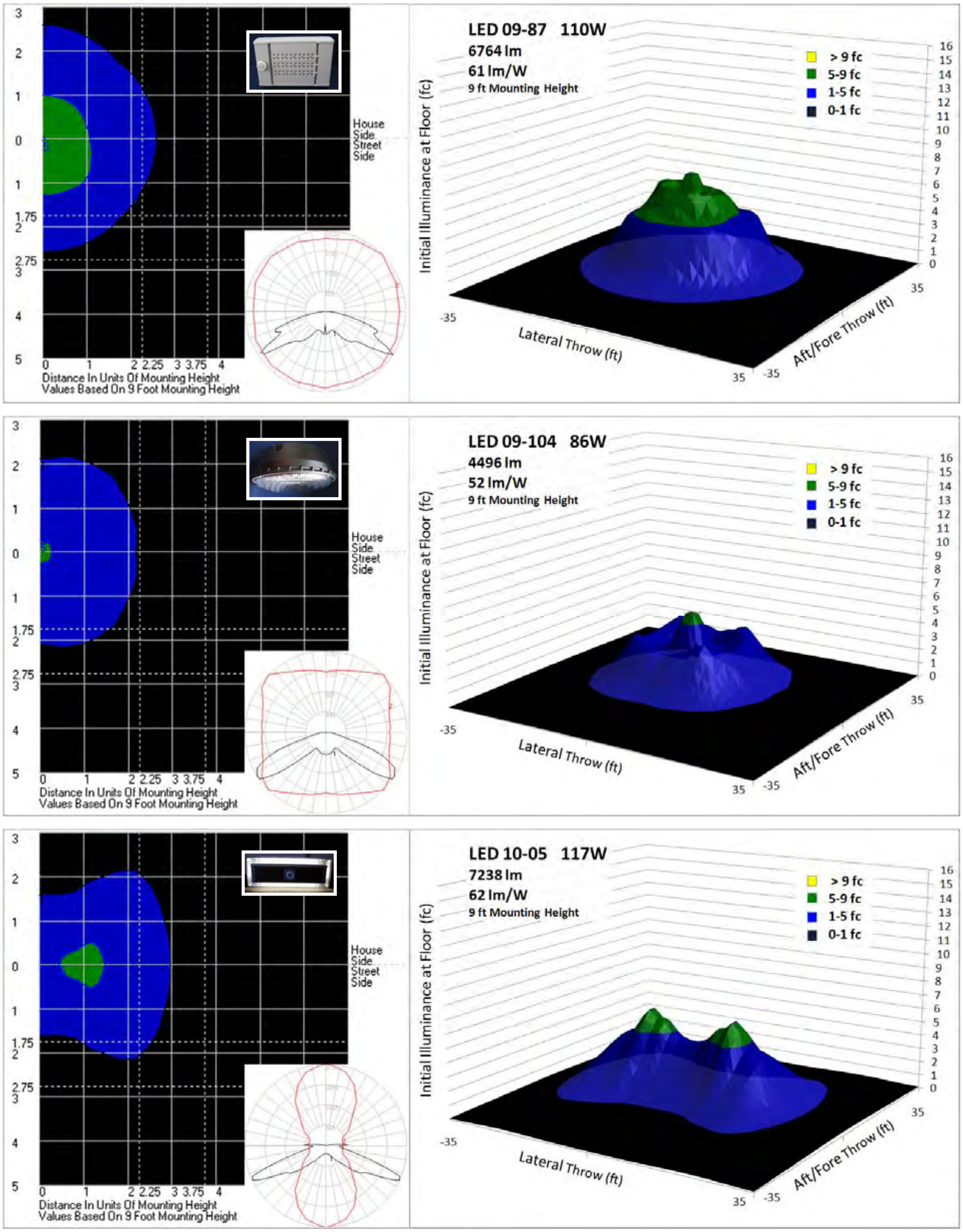
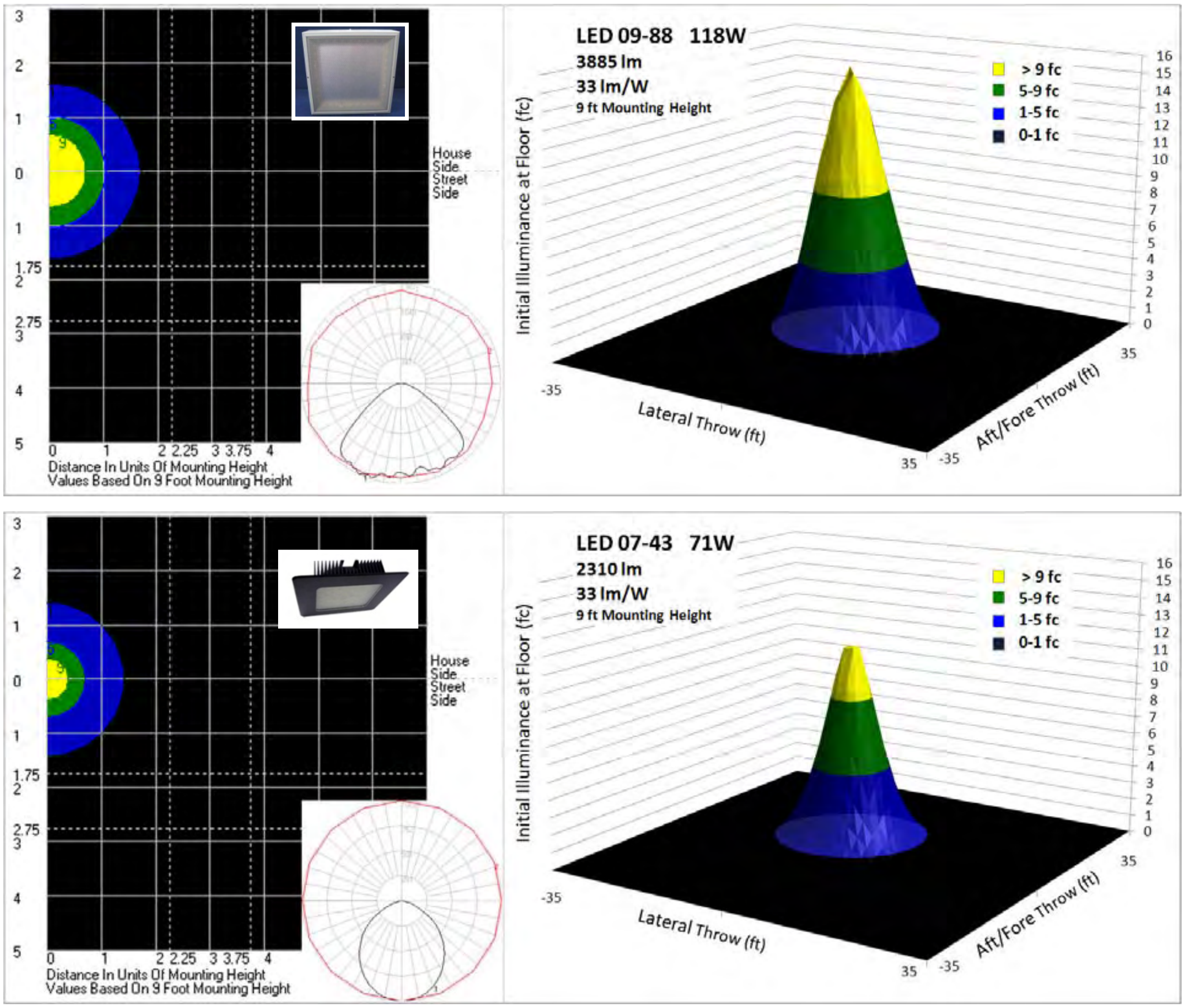


**Figure 2g-h. Light Distribution of SSL Parking Structure Luminaires (Narrow Distribution)**



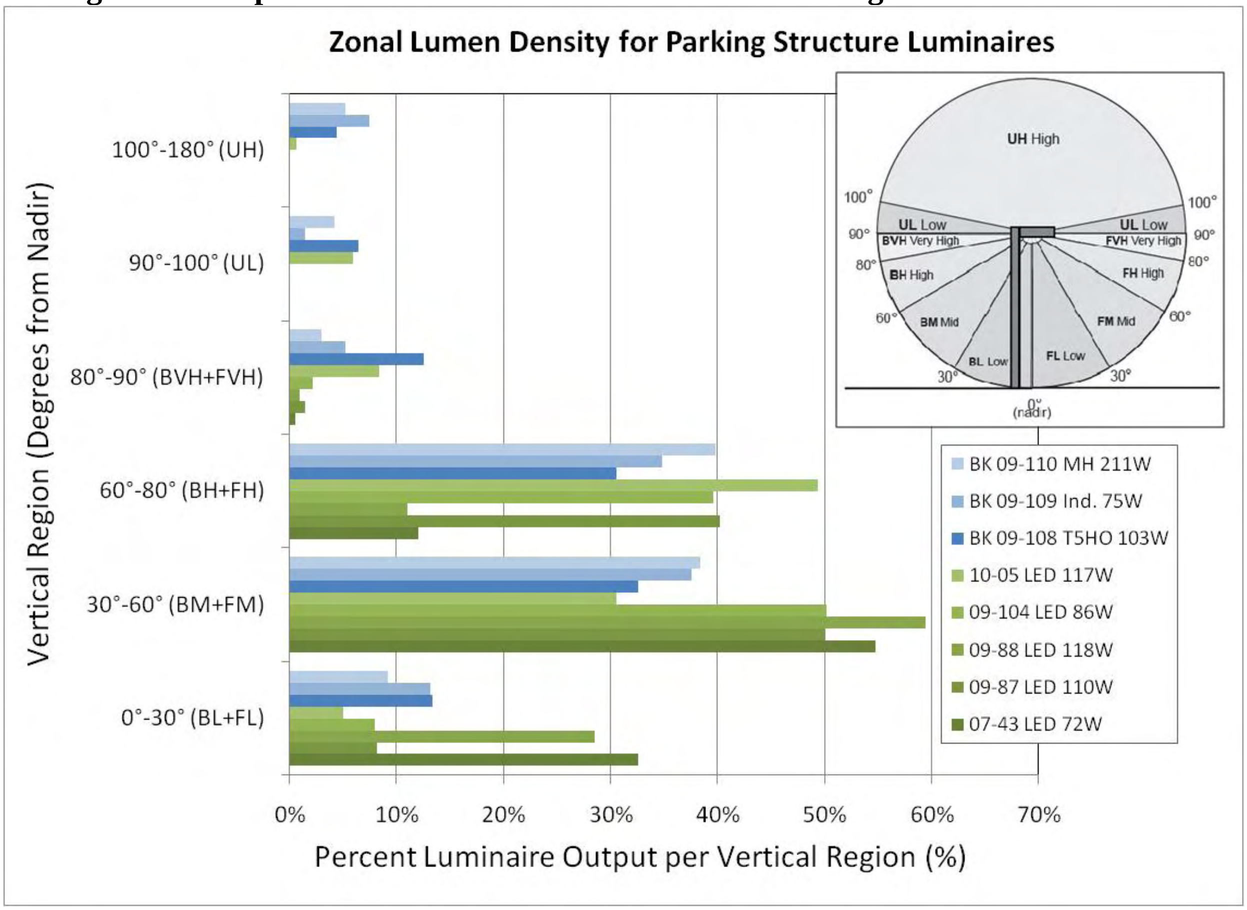

Figures 2a-c show the distribution of the three benchmark products, Figures 2d-f show the three SSL products that have fairly broad, uniform distribution, and Figures 2g-h show two SSL products that exhibit relatively focused beams.

Products 09-87, 09-104 and 10-05 appear to do the best job of efficaciously covering a sizeable area to adequate levels and uniformity. The PMH benchmark product (BK09-110) provides adequate illuminance over the largest area, but does so while using by far the most wattage and providing excessive (possibly wasted) light output by producing levels between 5-10 fc over much of that area. With appropriate spacing, products 09-87, 09-104 and 10-05 could produce the same minimum illuminance using less system wattage than the benchmark products.

The T5HO fluorescent product (BK09-108), the induction product (BK09-109), and two of the SSL products (09-88 and 07-43), all emit narrower beams of light, resulting in much higher illuminance in one spot below the luminaire (a 'hot spot' — seen as a yellow tip in the 3D plots). This distribution may be desirable for some applications, but could result in poor lighting and wasted energy in applications where typical (broad) spacing is required. The two LED products with the narrow light distributions also have significantly lower total light output and efficacy than the other SSL and benchmark products.

The various distributions of these eight products can also be evaluated by examining the zonal lumen densities, as shown in Figure 3.[10]

**Figure 3. Comparison of Zonal Lumen Densities for Parking Structure Luminaires**




When designing and selecting optical systems, a balance must always be struck between performance and obtrusive light. If high-angle light is restricted, area of coverage is correspondingly limited. To broadcast to greater distances from a luminaire, more light is required at higher angles. If too much light is directed into high-angle zones, problems can arise in the form of glare (within the garage) and light trespass (outside the garage). Only the metal-halide benchmark was offered with a variety of glare shields, which can help mitigate light trespass, particularly for perimeter luminaires. Four of five SSL luminaires shown in Figure 3 have considerably lower percentages of light output in the 80-90° zone than the benchmark

[10] The old "cutoff" classification system, which was recently deprecated by the IESNA, characterized the high-angle brightness and uplight produced by outdoor luminaires. This system was based on rated lamp lumens and relative photometry, and so cannot be applied to LED products (which utilize absolute photometry). IESNA TM-15-07 details the new Luminaire Classification System (LCS) and Backlight-Uplight-Glare (BUG) rating system.

products. Note, however, that glare is notoriously difficult to predict and quantify, and may also depend on other factors including ambient light levels, spectrum, and surface finishes.

Whereas all three benchmark luminaires emit some uplight, only one of the five LED luminaires produces any uplight. The opaque structure of parking structures will generally prevent any direct uplight from exiting skyward, so unnecessary uplight may not be of the same concern as it is for other (uncovered) outdoor lighting applications. In fact, a limited amount of uplight can be beneficial in a structure, where relatively dark surfaces can reduce perceptions of safety. Note that reflectance values are typically relatively low in parking structures, preventing the use of largely indirect illumination for efficiency reasons (however, if painted this strategy may be feasible).

**Color Characteristics**

All four LED products tested in this round have significantly different CCT than the benchmark products (yielding a "colder" or "bluer" appearance). The four SSL products and the T5HO linear fluorescent and induction products all have comparable CRI of 74-80, whereas the pulse-start metal halide product has a lower CRI of 57.

**Additional Observations**

The popularity of dimming and switching controls in parking structures, whether occupancy or photosensor based, has been growing in recent years. In fact, a recent addendum to ANSI/ASHRAE/IESNA Standard 90.1 considered requiring dimming and occupancy sensors in parking structures. Compatibility of lighting controls with HID sources like metal halide is limited due to restrike issues. In spite of reduced performance at low temperatures of the unheated structure and limited optical control, fluorescent luminaires have become increasingly popular for structure applications, thanks to their dimmability and their instant-on capability. SSL technology promises even greater flexibility, with the added benefit of high tolerance for frequent switching (which can significantly reduce lifetime for fluorescent lamps, particularly in applications using occupancy/motion sensors).[11]

One of the tested SSL products, 10-05, includes integrated motion detection and dimmer controls. The initial 10-05 sample which CALiPER received for testing was inoperable due to breakage before or during shipment from the manufacturer. A replacement sample was received in basic working condition, but suffered from control unit issues (causing an inability to control dimming level and to deactivate the motion sensor). A replacement control unit did not fix the problem. Because of these control issues, this product could only be tested in full power mode and could not be tested in the integrating sphere.

[11] The instant-on capability of LED and fluorescent can also eliminate the need for "bug-eye" emergency lights, ineffective quartz-restrike components, and inverters associated with HID.

**Key Points for Parking Structure Luminaires**

- SSL parking structure luminaires are now capable of achieving light output and efficacy comparable to MH, T5HO, and induction benchmarks, but some SSL products on the market are still not attaining these levels.
- Three of four SSL parking structure luminaires had accurate manufacturer performance claims. One of three benchmark parking structure luminaires had accurate claims.
- Only one SSL sample emitted uplight in the 90-100° zone (6%), with less than 1% of its light output above 100°. All three benchmark samples had uplight in both the 90-100° and 100-180° zones.
- Three of four SSL samples had a smaller percent of light output than benchmarks in the zone between 80 and 90°. This may indicate lower potential for glare.
- Three of four SSL samples had a larger percent of light output than benchmarks between 30 and 60°. This may indicate greater uniformity of light distribution.
- One SSL product exhibited dramatic focusing of the beam. This may indicate poor uniformity in typical applications.

## Wallpack Luminaires

Like many lighting applications, wallpack luminaires can be designed for a wide range of application needs, including for example, different lighting levels, different mounting heights, different types of forward throw, different amounts of backlight, and different degrees of cutoff. A variety of wallpack luminaires were tested in Round 10, including five wallpacks using LED sources, one using HPS, and one using PMH. The power draw of these luminaires ranges from one smaller SSL wallpack drawing only 16W, to a larger 188W PMH wallpack.

**Output and Efficacy**

The wallpacks tested in Round 10 range in luminaire efficacy from 24 lm/W to 62 lm/W. All the SSL wallpacks exceed the PMH benchmark's efficacy of 24 lm/W. Two of the SSL wallpacks also exceed the HPS luminaires efficacy of 47 lm/W. The two higher efficacy SSL wallpacks (09-92 and 09-103) produce total light output comparable to the PMH wallpack (BK09-106) while using less than half the power. The HPS wallpack generates close to twice the lumen output of the PMH and of the two higher efficacy SSL wallpacks, but it also draws about the same power level as the PMH product.

The lower power, 16W SSL wallpack (09-89) has considerably lower light output and narrower distribution than the other products (product literature for 09-89 indicates that it is designed for a 6–12 feet mounting height). Two other versions of the product are offered by the same manufacturer, one using a 70W MH lamp and the other using a 40W CFL lamp. Compared to these two other versions of the same product, based on manufacturer photometric data, the SSL version generates less than 1/3 the lumen output of the CFL product and about 1/7 the lumen output of the MH product (with significantly lower efficacy than either of these alternatives). The SSL version may be suitable for specific applications seeking lower power requirements and very narrow light distribution, but care should be taken to avoid considering this as a one-for-one replacement.

**Spatial Distribution**

Figures 4a-g below illustrate the wide range of distribution characteristics of these seven wallpacks, starting with the two benchmark luminaires (Figures 4a and 4b); followed by the SSL wallpacks exhibiting relatively broad light distribution (Figures 4c, 4d, and 4e); and then the SSL wallpacks exhibiting more narrow distribution (Figures 4f and 4g). Similar to the figures presented above for parking structure luminaires, for each wallpack luminaire, three graphics are provided: a traditional iso-illuminance plot, a polar intensity (candela) plot, and a 3D view of the horizontal illuminance.[12] In this case, the 2D iso-illuminance plot and the 3D views are based on a mounting height of 14 feet and the following color-coding scheme: black for areas with inadequate illuminance below 0.25 footcandle (fc), blue for 0.25-2.0 fc (adequate), green for 2.0-4.0 fc (somewhat excessive), and yellow for areas receiving over 4.0 fc (clearly excessive illuminance). The ranges used here are for illustrative purposes; criteria defining appropriate footcandle levels may vary for different applications.[13]

The multicolored 3D surface plots provide a conceptual indication of suitable light levels (which may be particularly useful for readers who are not lighting specialists), and the orientation is chosen to enable a visualization of the asymmetric illuminance patterns typical of many wallpacks. Initial illuminance, in footcandles, is shown over an area extending four mounting heights from the luminaire in each direction. Together, these three different views of the distribution data may allow readers to better picture how, for example, a batwing or cosine distribution actually translates into a broad/shallow or narrow/deep "pool" of light.[14]

Products 09-90, 09-103, and 09-92 appear to do the best job of efficaciously covering a sizeable area to adequate levels and uniformity. The HPS benchmark product (BK09-105) provides adequate illuminance over the largest area, but does so using significantly more power than the SSL wallpacks. With appropriate spacing, products 09-90, 09-103, and 09-92 could produce the same minimum illuminance using less system wattage than the benchmark products. Depending on the application requirements, all the wallpacks except 09-90 may be wasting light output by producing unnecessarily high footcandle levels over much of the illuminated area (depicted, for example, as green and yellow portions of the plot).

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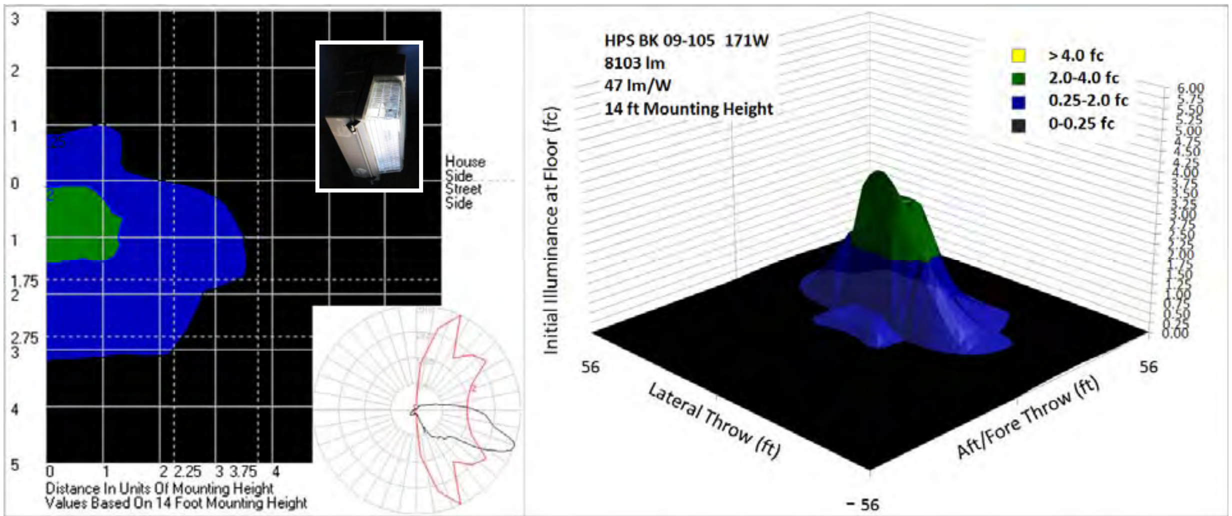
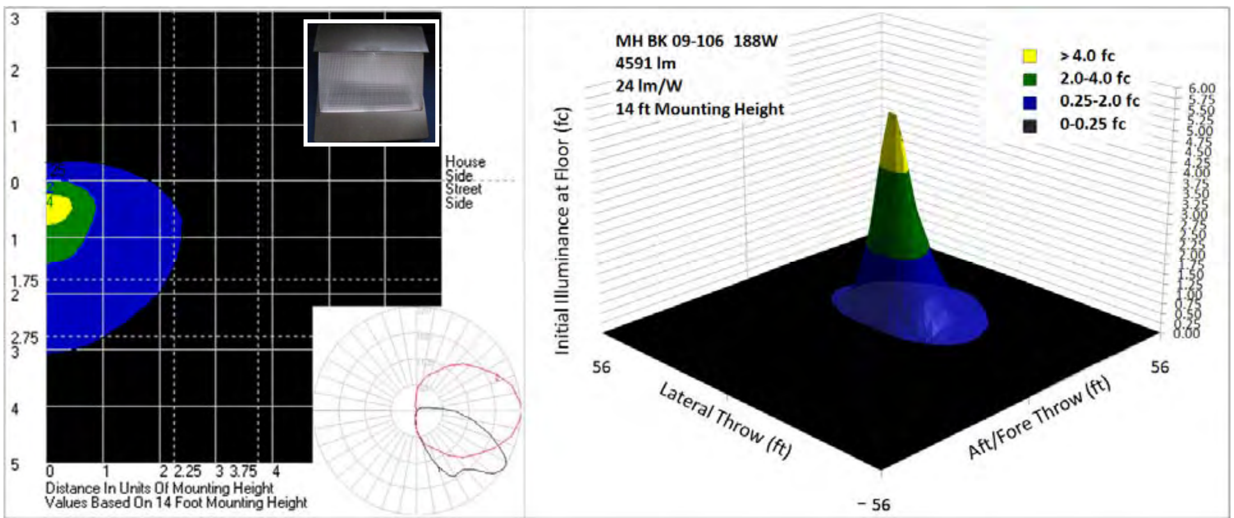
[12] On the polar intensity plots, two traditional candela curves are shown, representing the vertical plane through the point of maximum intensity (black) and the vertical-axis cone open downward and passing through the point of maximum intensity (red).

[13] CALiPER LM-79 testing provides initial levels. IES recommendations are for maintained illuminance — additional information about product lumen maintenance and additional calculations would be needed to estimate longer-term illuminance. Additional recommendations may be given in IESNA RP-20-98 or similar references. Visit http://www.ies.org/ for more information.

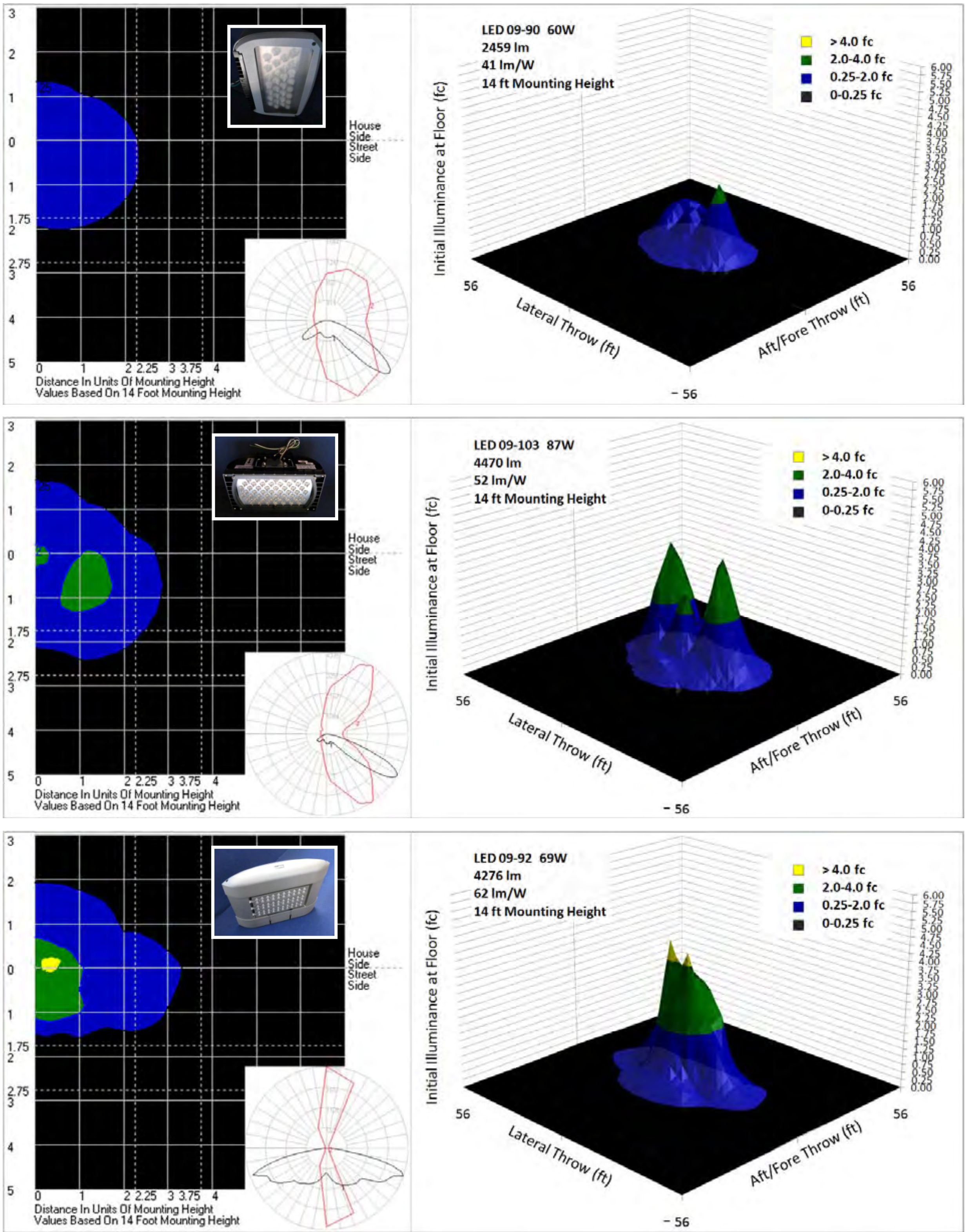
[14] CALiPER LM-79 testing provides initial levels. IES recommendations are for maintained illuminance — additional information about product lumen maintenance and additional calculations would be needed to estimate longer-term illuminance.

**Figures 4a-b. Light Distribution of Benchmark Wallpacks**

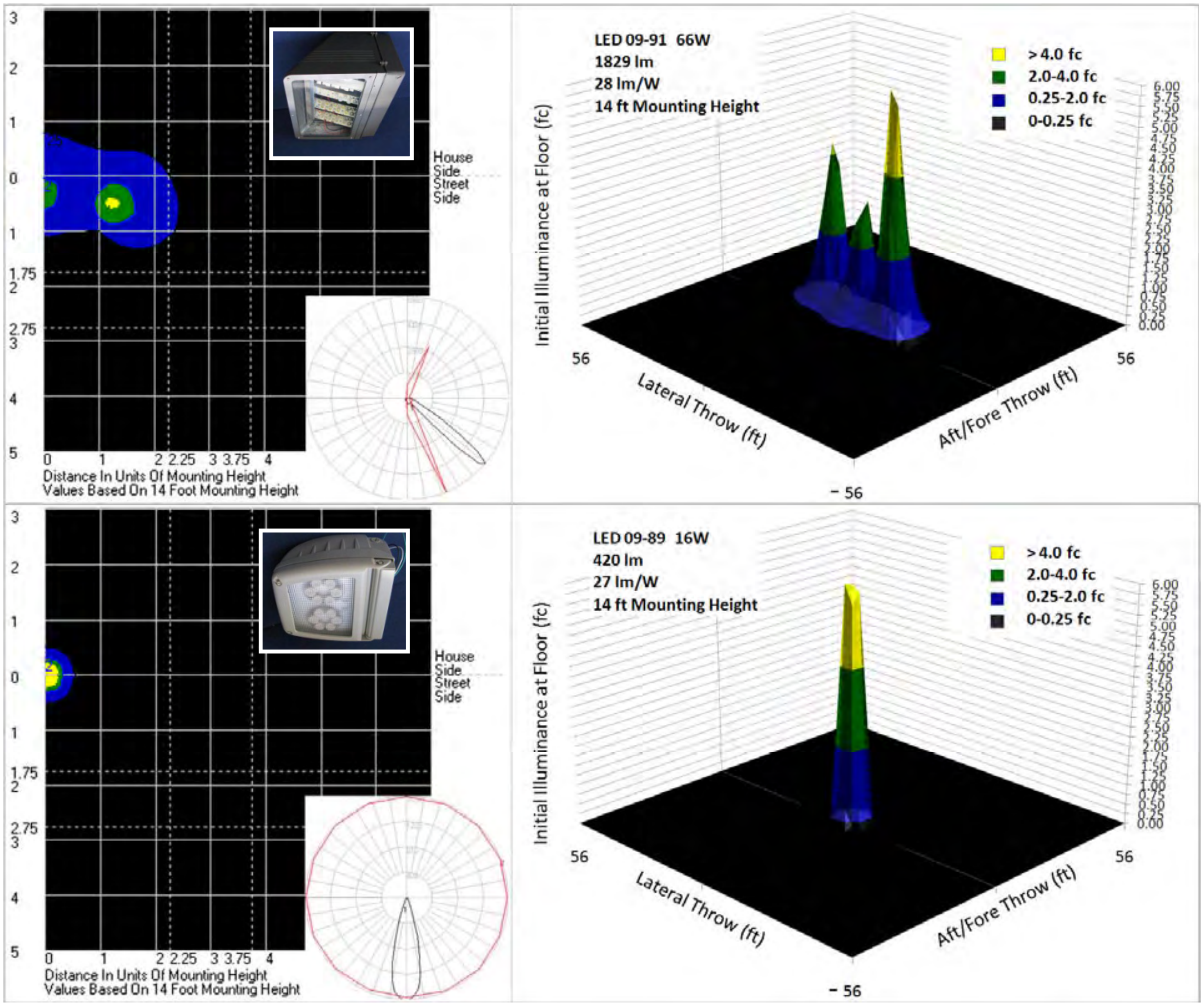


## Figures 4c-e. Light Distribution of SSL Wallpacks (Broad Distribution)



**Figures 4f-g. Light Distribution of SSL Wallpacks (Narrow Distribution)**




Products 09-91 and 09-89 both emit relatively narrower beams of light, resulting in much higher illuminance in one zone or one spot below the luminaire ('hot spots'—seen as a yellow tip in the 3D plots). Product 09-91 emits three side-by-side narrow cones of light, achieving fairly broad lateral throw as compared to its forward throw. Product 09-89 emits a single, narrow cone of light. This distribution may be desirable for some applications, but could result in poor lighting and energy waste in applications where typical (broad) spacing is required.

A variety of designs were included within these seven products, some intended for more forward throw or greater cutoff than others. The various distributions of these seven products can also be illustrated through the zonal lumen densities, as shown in Figure 5, which summarizes the total light output in each angular zone for each wallpack.[15] The SSL products that were tested all had no light output above 90° and very little from 80-90°, whereas both benchmark products have greater forward and upward throw. Among the wallpacks tested, the ratio of forward-directed flux to backward-directed flux was 3 times higher for the benchmark products indicating greater asymmetry.

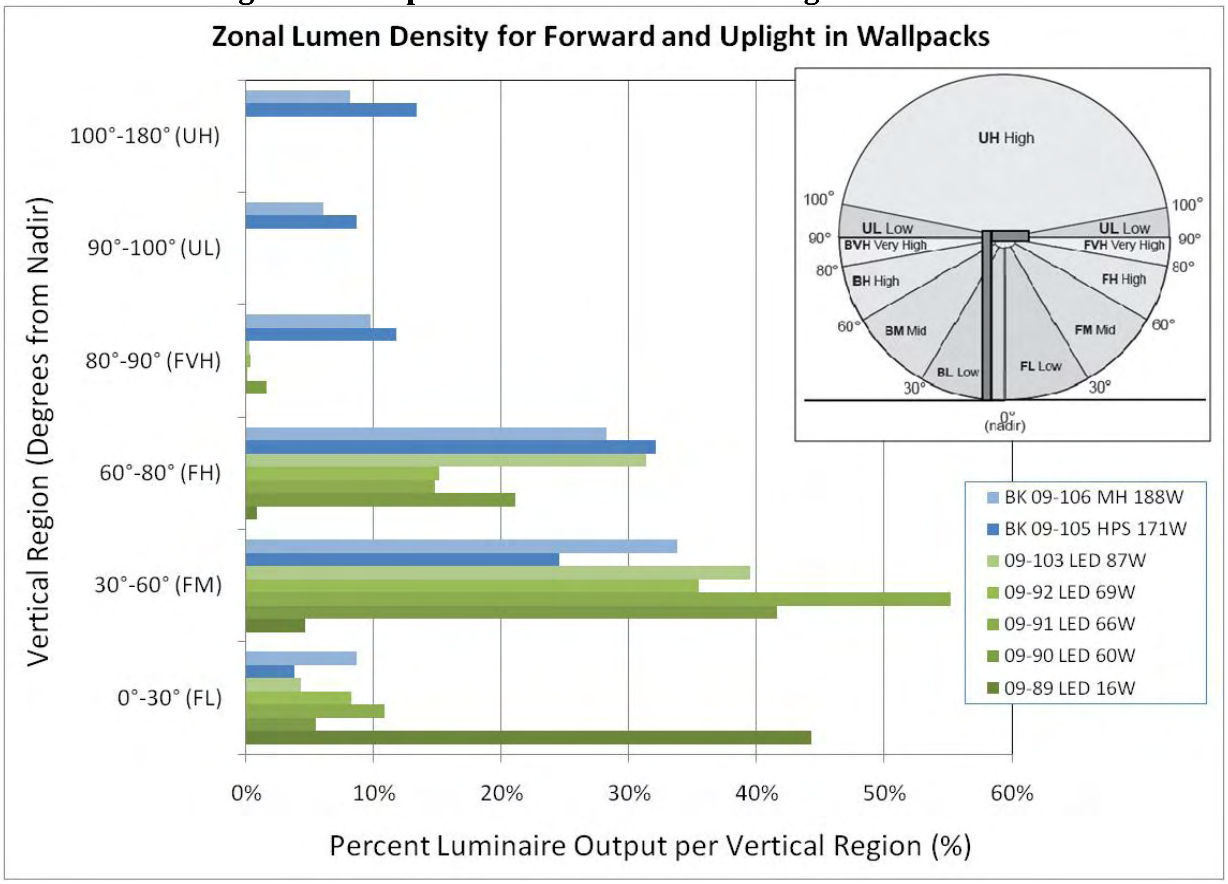
Overall , the SSL wallpacks appear to have significantly less uplight than the benchmarks. Note, however, that some of these wallpacks are available in multiple versions with varying distribution characteristics.

**Color Characteristics**

The five LED wallpacks have CCTs ranging from 4067 to 6355K. Three of these are somewhat different CCT than the MH benchmark product (yielding a "colder" or "bluer" appearance) and all are significantly higher CCT than the HPS (which emits an amber color light). All the SSL products achieve color rendering comparable to or better than the MH wallpack (which has a CRI of 66), and significantly greater than the HPS (with a CRI of only 12, objects illuminated by the HPS wallpack may not have discernable color).

[15] The old "cutoff" classification system, which was recently deprecated by the IES, characterized the high-angle brightness and uplight produced by outdoor luminaires. This system was based on rated lamp lumens and relative photometry, and so cannot be applied to LED products (which utilize absolute photometry). IESNA TM-15-07 details the new Luminaire Classification System (LCS) and Backlight-Uplight-Glare (BUG) rating system.

**Figure 5. Comparison of Distribution through Zonal Lumens**




## Additional Observations

The CALiPER testing conducted for Round 10 did not cover product controls or reliability. However, it is important to note that for outdoor applications, SSL technology has the benefit of greater and easier controllability than HID technologies. Although the National Electrical Manufacturers Association (NEMA) suggests a maximum recommended dimming level of 50% rated lamp wattage for both MH and HPS lamps to avoid reducing the product life, appropriately designed SSL products can be dimmed significantly further than 50% without an adverse impact on product life.[16] Similarly, SSL technology does not inherently suffer from restrike issues which limit the controllability of MH and HPS products. The instant-on capability of LED also eliminates the need for "bug-eye" emergency lights, restrike components, and inverters associated with HID. Compact fluorescent benchmark products, which offer instant-restrike capability but suffer from reduced optical efficiency and limited area of coverage, were not tested in this round.

## Manufacturer Claims for Wallpack Luminaires

Three out of five of the SSL wallpacks achieved performance levels claimed in product specification sheets and manufacturer published photometric data. SSL products 09-90 and 09-91 and both benchmark products (HPS BK09-105 and PMH BK09-106) did not meet manufacturer

[16] LSD 14-2002 Guidelines on the Application of Dimming to High Intensity Discharge Lamps

claims. For these products, CALiPER results show light output levels and efficacy levels about 15-40% less than claimed by manufacturers.

The manufacturer-published .ies file for one product, 09-89, illustrates some of the points of confusion and complexity when representing results from absolute photometry rather than relative photometry. In this case, the header data in the .ies file indicate a value for lamp lumen output, with another entry indicating ‘Lamp information provided by client’. Embedded in the file is an indication that total luminaire efficiency is 50%, so the total luminaire output based on the absolute photometry corresponds to CALiPER results. However, the notion of ‘lamp lumens’ for SSL products is one that is not yet standardized so representing absolute test results like relative test results (i.e., with a lamp lumen value and efficiency value other than 100%), could lead to confusion and misuse of the information. The majority of .ies files for SSL photometry are observed to indicate a value of “-1” under lamp lumens to designate absolute photometry. Standards efforts are working to provide additional guidance with respect to using .ies files with absolute photometry; in the meantime, stakeholders should be aware and informed of potential discrepancies in interpretation.

## Cove Lights

Nine cove light products were tested in Round 10, including seven SSL luminaires and two benchmark products. Of the SSL cove lights, five are linear strips (the smallest is 10" long and the longest 13"). The other two SSL cove lights are small track lights — both from the same product line designed for cove and undercabinet applications, but with two different types of LED track heads. To provide an opportunity for direct comparison, the T3-1/4 xenon-lamp 10W version of the same track system was also tested as a benchmark. A typical, linear fluorescent T5HO cove light was tested to provide a point of comparison with fluorescent cove lighting products.[17]

### Background about Cove Lighting Application

Cove light products can be used for general illumination or more decoratively (for example, for mood lighting by lighting the edge of a soffit). A large number of cove lighting products on the market today are made using linear fluorescent lamps; another segment of the cove light market uses tracks or strings of lights lamped with smaller sources such as incandescent or xenon festoon lighting. The fluorescent cove lights produce significant amounts of light output — useful for general illumination — but their long, rigid, linear geometries may be somewhat limiting in some applications (e.g., a cove along a curved ceiling in a hotel ceiling). These functional cove lights often are designed to achieve asymmetric distributions, but give varying levels of attention to reflectors for optimal asymmetric cove lighting distribution. Some compact-fluorescent (CFL) products allow for general illumination from coves having edges that curve dramatically in plan. Decorative cove lights, which use smaller light sources with flexible strips

[17] Dark areas known as “socket shadow” may occur between linear fluorescent luminaires when mounted end to end in a cove. Fluorescent strip lights are often staggered (slightly overlapped) to eliminate socket shadow; such products weren’t included in this round of testing.

or tracks, tend to be less efficacious and produce less light output — useful for mood lighting — and offer more flexible geometries.[18]

As discussed below, current SSL cove luminaires tested by CALiPER produce far less light output than typical linear fluorescent cove lights, and so may not yet for be suitable for general illumination. The SSL cove lights are often designed with symmetric distributions, and are often tiltable. They provide light output levels more typical of decorative cove products. Also, SSL cove light products are typically available in a variety of lengths, and not limited by the standard lengths of linear fluorescent tubes. Five of the SSL cove lights tested in Round 10 are linear strips close to 1 foot in length. Three of the cove lights are small track lights (two different SSL heads and one xenon), all from the same manufacturer. For the track lights, each product has been tested twice, once with a single track head and once with the number of heads described by the manufacturer as "generally providing excellent indirect lighting" in an over cabinet application (using 1 foot of track).

**Analysis of CALiPER Cove Lighting Results—Total Light Output and Efficacy**
Figure 6 plots both the light output per linear foot and the power use per foot of these cove lights. For each track system, two options are plotted, one using a 4" or 6" spacing, and one using a tighter 3" spacing.[19] The SSL products are grouped on the left, from lowest to highest output per linear foot, and the benchmark products are grouped on the right. Four of the linear SSL coves produce similar levels of light output to the xenon track light with tightly spaced (3" on center) heads, while using 1/6 to 1/3 the power drawn by the xenon product. One of the SSL coves produces about the same amount of light as the xenon cove would with a 4" spacing (3 heads per foot), while consuming about 1/4 the power. None of the SSL cove products produce even 1/2 the light output per linear foot of the T5HO fluorescent cove fixture.

[18] Cold-cathode products offer an alternative for curvy coves, intermediate to CFL and xenon in terms of output and power density, but generally require a degree of customization for each application. Neither CFL nor cold-cathode were tested in this round.
[19] Tracks were not tested with 3" spacing, so for these values light output is estimated using the test results from a single head, and power use calculated based on the efficacy measured using two or three heads.

**Figure 6. Comparison of Performance Between SSL and Benchmark Coves**

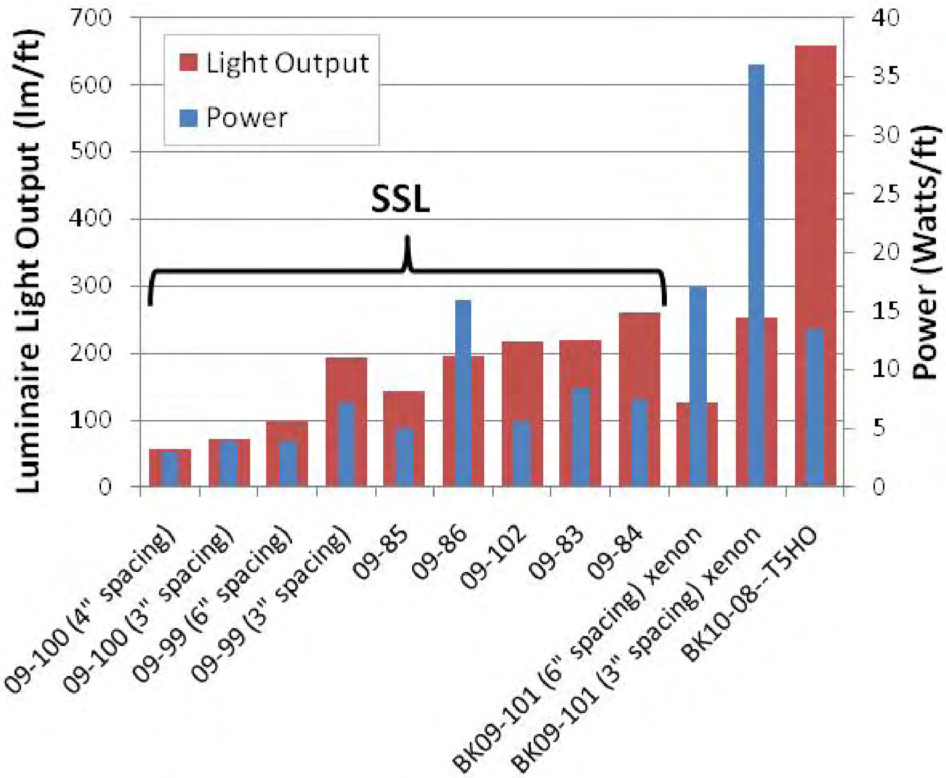



Figure 6 also allows a direct comparison between the three versions of track lighting. All three versions require use of a transformer to power the 12VAC track. A manufacturer-recommended transformer was purchased and used for testing. CALiPER measurements in this case are taken at the system level, so power and efficacy values include transformer losses, whereas the manufacturer specification sheets indicate power based on 12V input.[20] Comparing these three products, the 09-99 LED head provides about 3/4 of the light output of the xenon version while using 5 times less power. The 09-100 LED head provides only 1/3 the light output of the xenon version, while using 10 times less power. The efficacy of these track lights will depend on the overall system (including transformer and number of track heads used), nevertheless the efficacy of the SSL versions will typically exceed the xenon versions by a factor of at least two or three.

None of the SSL cove lights achieved the light output or luminaire efficacy of the benchmark T5HO cove (660 lm/ft and 48 lm/W), so SSL cove lighting does not appear to be a one-for-one, energy-efficient replacement for fluorescent cove lighting today. However, for linear fluorescent cove installations that are significantly overlit, SSL cove lighting could be an alternative that would be more energy efficient than, for example, xenon festoon lighting.

[20] Different transformers have different efficiencies and the efficiency of a given transformer may vary with load, so care should be taken in comparing with other 12V products (such as MR16 lamps or other track lighting configurations).

**Color Characteristics of Cove Lights**

All the cove lights tested were warm-white to cool-white versions (from 2600-4200K, nominal CCT). The SSL cove lights all met ANSI-defined tolerances for CCT and $D_{uv}$ for white light.[21] Regarding color rendering, the xenon and fluorescent benchmarks were at 100 and 84 CRI, respectively, while all SSL cove lights tested had CRI close to 70 (ranging from 67 to 76).

**Spatial Distribution of Cove Lights**

Some cove lights are designed to provide an asymmetric distribution, some have adjustable track heads, and some provide a symmetric, cosine distribution, but with the option of tilting the luminaire to obtain a somewhat asymmetric effect. Figure 7 provides a polar intensity plot of the fluorescent benchmark BK 10-08, illustrating its asymmetric distribution along the vertical planes perpendicular and parallel to the lamp axis.

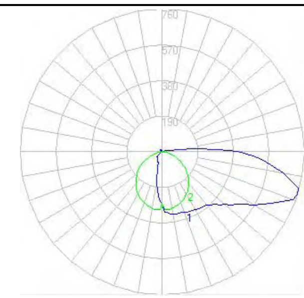


Figure 7. Intensity Distribution of Asymmetric Cove BK 10-08

Because the light output of BK 10-08 is so much greater than the other samples, and because all the other samples have symmetric distributions, manufacturer data from a symmetric fluorescent cove light and a xenon cove are used below to provide comparison with SSL coves. First, Figure 8 provides a comparison between an example fluorescent cove and an example xenon cove. Neither product was independently tested; the photometry is from the manufacturers' web sites.[22] Since the fluorescent (black line) dwarfs the xenon (red line) in terms of output, the following comparisons of the SSL cove will be against xenon.

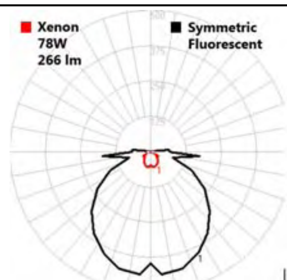


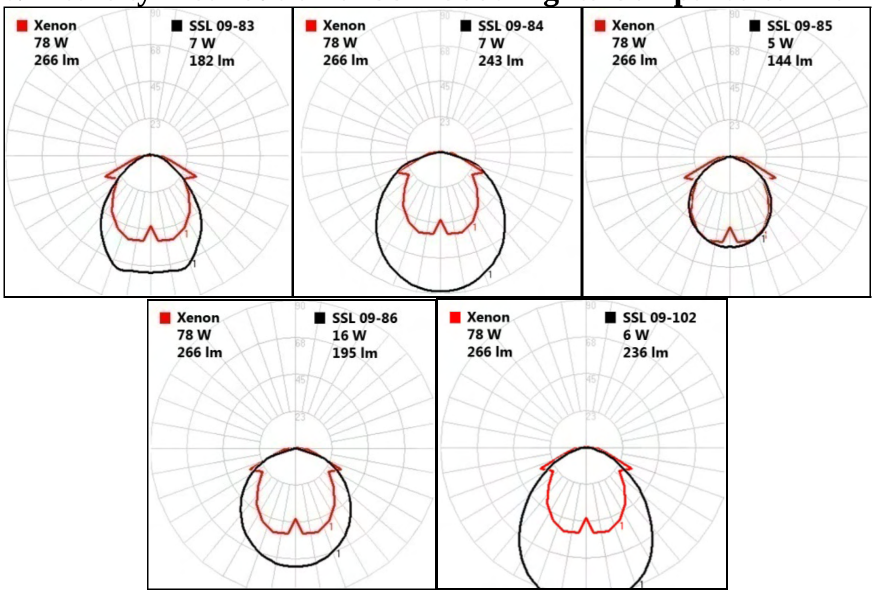

Figure 8. Intensity Distribution of Symmetric Cove and Xenon

Figures 9a-e compare the 78W example xenon benchmark distribution to the distribution of each of the five SSL cove luminaires. The five SSL coves have similarly shaped distributions, and each produce similar or more intensity than the xenon example for significantly less power. This testing does not consider near-field uniformity of intensity over the length of the strip.

[21] 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.

[22] Xenon benchmark sample 09-101 was not used in this case because it is a track system and the system with one or two track heads as tested does not provide a similar level of light output on average to the five SSL strip lights that were tested.

**Figure 9a-e. Intensity Distribution of SSL Cove Lights Compared to Example Xenon**




**Summary of SSL Cove Lighting Today**

Four of the SSL Cove products — 09-85, 09-99, 09-100, and 09-102 — and the two benchmark cove products — BK 09-101 and BK 10-08 — perform as claimed in manufacturer specifications. Three of the SSL cove products either do not meet performance claims, have misleading information, or do not provide manufacturer performance information. For product 09-83, while some information in specification sheets appears correct, some claims may be misleading, such as a statement indicating "up to 50 lm/W" (whereas CALiPER measured efficacy is 27 lm/W)—insufficient details are provided to readily interpret the performance of different versions of the product. For product 09-84, the manufacturer performance claims are about 20% higher than measured in the CALiPER sample. For product 09-86, no explicit performance data were found in specification sheets and an .ies file could not be obtained from the manufacturer.

When compared to traditional cove light products that are designed primarily for decorative purposes (such as xenon festoon lighting), SSL cove lights are able to achieve comparable levels of light output and distribution, with greater efficacy. All the strip-geometry SSL cove lights tested provided light output and distribution that was fairly similar to benchmark data from an example xenon cove light.

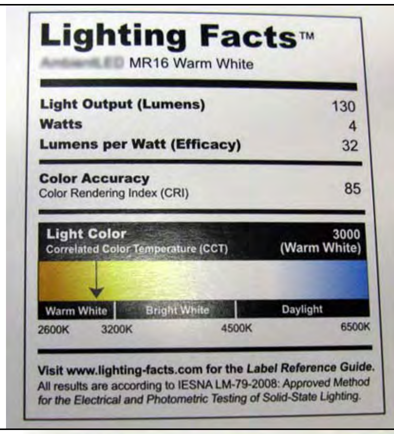
The track products tested included three variations of the same product from one manufacturer. Both SSL versions were more efficacious than the xenon version, but also provided less light output per track head than the xenon version (so more SSL track heads would be needed to provide comparable light output to the xenon track heads). The two SSL track heads are marketed as using "AC LED" sources. Neither of these two types of AC LED products achieved the average efficacy of the strip-style cove LED products (which are not marketed as "AC LED"). Some observers noted visible flicker from the AC LED products. A more thorough, quantified study of flicker in CALiPER products is under way and expected to be completed in fall 2010.

As with linear fluorescent troffers, general illumination cove lights that use linear fluorescents achieve relatively high levels of efficacy with relatively low cost products. This is an application area where SSL technology must compete with a high-performing, low-cost incumbent technology. Also, cove lighting is a niche application, representing a smaller market than troffer lighting. This relatively smaller market may represent a challenge for SSL designers — not inviting as much innovation as more common lighting applications. With steady technology progress and innovation, SSL cove lights that provide comparable light output to fluorescent coves may be developed in the coming year or two. But for now, SSL cove lights provide insufficient light output to be one-for-one replacements for general illumination fluorescent cove lights. SSL cove lighting may be a suitable, efficacious option for installations that would be overlit by linear fluorescent cove lights, or require only decorative cove lighting, or can benefit from the flexible geometries offered by SSL cove products.

## Smaller Replacement Lamps

Four replacement lamps that carry the Lighting Facts™ label were tested in Round 10. Similar to a nutrition label, the Lighting Facts label provides a quick summary of product performance data. Luminaire manufacturers can voluntarily take the SSL Quality Advocates pledge and agree to use the label to disclose performance results in five areas — lumens, efficacy, watts, CCT and CRI — as measured by the new industry standard for testing photometric performance, IES LM-79-2008.[23]

Figure 10 shows the Lighting Facts label photographed from the packaging of each product, alongside the corresponding CALiPER-measured performance. In each case, these replacement lamps meet or exceed the performance levels indicated on their Lighting Facts labels. All have CALiPER-measured light output and CCT and CRI statistically the same or better than on their Lighting Facts Label and all have CALiPER-measured efficacy at least 10% better than on their Lighting Facts label.




vs.
CALiPER
<u>09-93</u>

129 lm
4 W
37 lm/W
CRI=94
3049K


vs.
CALiPER
<u>09-94</u>

635 lm
16W
41 lm/W
CRI=84
3070K


vs.
CALiPER
<u>09-96</u>

457 lm
10 W
47 lm/W
CRI=85
3060 K


vs.
CALiPER
<u>09-98</u>

394 lm
6 W
67 lm/W
CRI=87
3029 K

**Figure 10. CALiPER-Measured Performance Meets or Exceeds Lighting Facts**

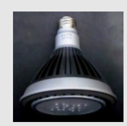
Although it is not an independent verification through anonymous purchase, the correct use of this common label may provide credibility and greater confidence in manufacturer-reported performance for SSL products. Upcoming rounds of CALiPER testing will continue to select and

[23] http://www.lightingfacts.com/

test products that carry the Lighting Facts label to ensure that manufacturers participating in the program are using the label appropriately and reflecting accurate performance.

In addition to ratings indicated on their Lighting Facts labels, the packaging of each product carries equivalency claims as summarized in Table 2. The PAR30L and PAR38 lamps exceed the average center beam candle power for halogen lamps with similar beam angles, based on the claimed equivalency wattage. The MR16, which is physically smaller, claims to replace a 20W halogen MR16 lamp, but it provides significantly less light output than an average 20W halogen MR16 lamp and only provides 618 cd at center beam, whereas a halogen lamp with a similar 21° beam angle can be expected to achieve 1154 cd.

**Table 2.** CALiPER ROUND 10 – Replacement Lamp Manufacturer Claims

| **Sample Type and CALiPER Reference** | **Manufacturer Claims** | **Actual Performance Level (e.g. Light Output, Efficacy, CBCP, Beam Angle)** | **Provides Accurate Product Reporting** | |
|---|---|---|---|---|
| Replacement Lamp (MR16) 09-93, 4W | 130 lm, 37 lm/W<br>*"Replaces 20W halogen MR16 bulb"* | 129 lm, 37 lm/W<br>618 cd, 21°<br>**Less than average 20W halogen** | YES<br>(Lighting Facts)<br>NO<br>(Equivalency) |  |
| Replacement Lamp (PAR30L) 09-96, 10W | 418 lm, 38 lm/W<br>"*Replaces a 50W halogen PAR30 bulb*" | 457 lm, 47 lm/W<br>2384 cd, 20°<br>**Meets average 50W halogen** | YES |  |
| Replacement Lamp (PAR38) 09-94, 16W | 600 lm, 35 lm/W<br>"*Replaces a 45W halogen PAR38 bulb*" | 635 lm, 41 lm/W<br>3199 cd, 20°<br>**Exceeds average 45W halogen** | YES |  |
| Replacement Lamp (A-Lamp) 09-98, 6W | 336 lm, 60 lm/W<br>*(Light Effect: 40W or 60W, see Figure 11)* | 394 lm, 67 lm/W<br>**Almost meets average 40W incandescent** | YES<br>(Lighting Facts)<br>No<br>(Equivalency) |  |

Equivalency comparisons for directional lamps (MR16, PAR & R lamps) based on CBCP, beam angle and lumens.

Misleading, erroneous or false claims are indicated in *red italics*.

Note that lamp 09-98 does not meet ANSI-defined lamp format standards for A-lamp geometry due to the lamp neck, which widens too closely to the base.

Note that lamp 09-96 does not meet ANSI-defined lamp format standards for PAR30L geometry. The length of the lamp (MOL) is too short.

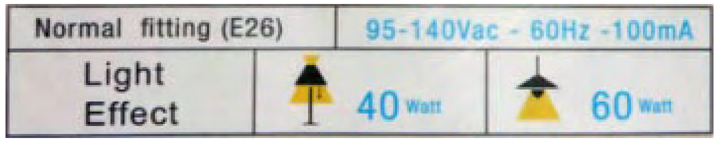



**Figure 11. Diagramatic Equivalency Description from 09-98 Product Packaging**

The A-lamp product uses a 'Light Effect' diagram (Figure 11) indicating that the lamp is equivalent to a 40W incandescent in certain (more omni-directional) applications and is equivalent to a 60W incandescent in applications where the lighting is directional. This diagram demonstrates an innovative approach toward communicating some of the nuances in comparing SSL products to more traditional lamps. As seen in earlier testing of omni-directional SSL replacement lamps, the distribution of light from product 09-98 between the upward and lower hemispheres (toward the base or toward the bulb) is not as balanced as typically seen in incandescent A-lamps, so depending on the application or luminaire for which these lamps are used, the relatively focused distribution may or may not provide desirable results.[24] The total light output of 09-98 is slightly less than an average 40W incandescent lamp.

Two of the small replacement lamps, the PAR30L (09-96) and the A-lamp (09-98), did not meet ANSI-defined lamp format standards for the geometry of the lamp styles they are meant to replace. The PAR30L lamp was shorter than the required minimal overall lamp length, which could cause the lamp to be recessed inappropriately or not fit in some fixtures. The diameter of the neck of the A-lamp was too large and widening of the neck starts too close to the Edison base, which could result in the lamp not fitting in some fixtures. Respecting form factor standards is important for market acceptance as demonstrated by lessons learned from CFLs.[25]

## 4-Foot Linear Replacement Lamps

Rounds 5 and 9 of CALiPER testing included a series of SSL products that are marketed as replacements for linear fluorescent lamps. One product of interest was not available for purchase during Round 9, but became available shortly thereafter, so this linear replacement product is included in Round 10. Testing of SSL and benchmark fluorescent products in Rounds 5 and 9 all concluded that SSL linear replacement lamps are not yet suitable as one-for-one replacement for linear fluorescent lamps. SSL linear replacement lamps tested so far do not provide the light output and efficacy levels of the linear fluorescent lamps they aim to replace and have narrower light distribution requiring closer spacing of luminaires.

The SSL linear replacement lamp (09-107) tested in Round 10 was of particular interest to CALiPER because a trade journal article published in January 2009 praised the product, indicating that it was capable of delivering 1400 lm, using 22W of power (~64 lm/W). Manufacturer literature about this product and the trade journal article about the product appeared in early 2009, but despite multiple attempts at acquiring the product, a purchased version could not be obtained until November 2009. A previous version of the product (09-13) was included in Round 9, achieving a lamp efficacy of about 40 lm/W. At that time, one sample

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[24] See CALiPER Round 8 Summary Report for illustrated comparison of light distribution from A-lamp replacement products, http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_round_8_summary_final.pdf.
[25] See "Compact Fluorescent Lighting in America: Lessons Learned on the Way to Market," June 2006, http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/cfl_lessons_learned_web.pdf.

of the newer version was submitted to CALiPER by the manufacturer (09-16). The sample was tested, but the results were not published as CALiPER results because it had not yet been acquired anonymously. However, the results for that submitted-sample were promising, so CALiPER made every effort to acquire the product anonymously to be able to report the results as CALiPER testing.

Note that fixture efficiencies for the parabolic louvered troffer with 4' SSL replacement lamps were 85% on average (excluding LED products that use the fluorescent ballast) in previous CALiPER testing. Samples 09-16 and 09-107 were not tested in a troffer, so values indicated are for bare lamp testing. Version 1 of this product (09-13) needs a ballast to operate. Version 2 includes an integrated driver, so any external ballast must be disabled when using 09-16 or 09-107.

Table 3 summarizes the results for testing on the SSL linear replacement lamps from this manufacturer in Rounds 9 and 10. Four samples of version 1 of the product were tested in Round 9 — two samples that had been submitted by the manufacturer and two that were purchased anonymously. Three samples of version 2 of the product were tested in Round 10 — one sample submitted by the manufacturer and two that were purchased anonymously.

**Table 3.** Versions 1 and 2 of a 4' SSL Linear Replacement Lamp

| -- SSL testing following IESNA LM-79-08<br>-- 25ºC ambient temperature | DOE CALiPER TEST ID | Total Power (Watts) | Output (Initial Lumens) | Efficacy (lm/W) | CCT (K) | CRI | Photo |
|---|---|---|---|---|---|---|---|
| **Round 9—Manufacturer's Version 1 of Product** | | | | | | | |
| Bare Lamp (3500K)<br>Submitted by manufacturer | 09-13AB | 32 | 1407 | 44 | 3758 | 76 |  |
| Bare Lamp (3500K)<br>Purchased anonymously | 09-13CD | 32 | 1357 | 42 | 3756 | 76 | |
| **Round 10—Manufacturer's Version 2 of Product** | | | | | | | |
| Bare Lamp (4200K)<br>Submitted by manufacturer | 09-16 | 25 | 1815 | 72 | 4345 | 76 | |
| Bare Lamp A (3500K)<br>Purchased anonymously | 09-107A | 25 | 941 | 38 | 3767 | 72 |  |
| Bare Lamp B (3500K)<br>Purchased anonymously | 09-107B | 5 | 229 | 50 | 3616 | 72 | |

As summarized in Figure 12, the purchased and submitted lamp samples tested in Round 9 achieved fairly similar performance levels, although it was noted that the submitted units showed slightly better performance than the purchased samples. In Round 10, for version 2 of this product, purchased unit 09-107B appeared to malfunction, drawing only 1/5 the expected power and producing far less light output than expected. Purchased sample 09-107A appeared to operate correctly, drawing the same amount of power (25W) as submitted sample 09-16, but only producing about 1/2 the light output and 1/2 the efficacy of the submitted unit.

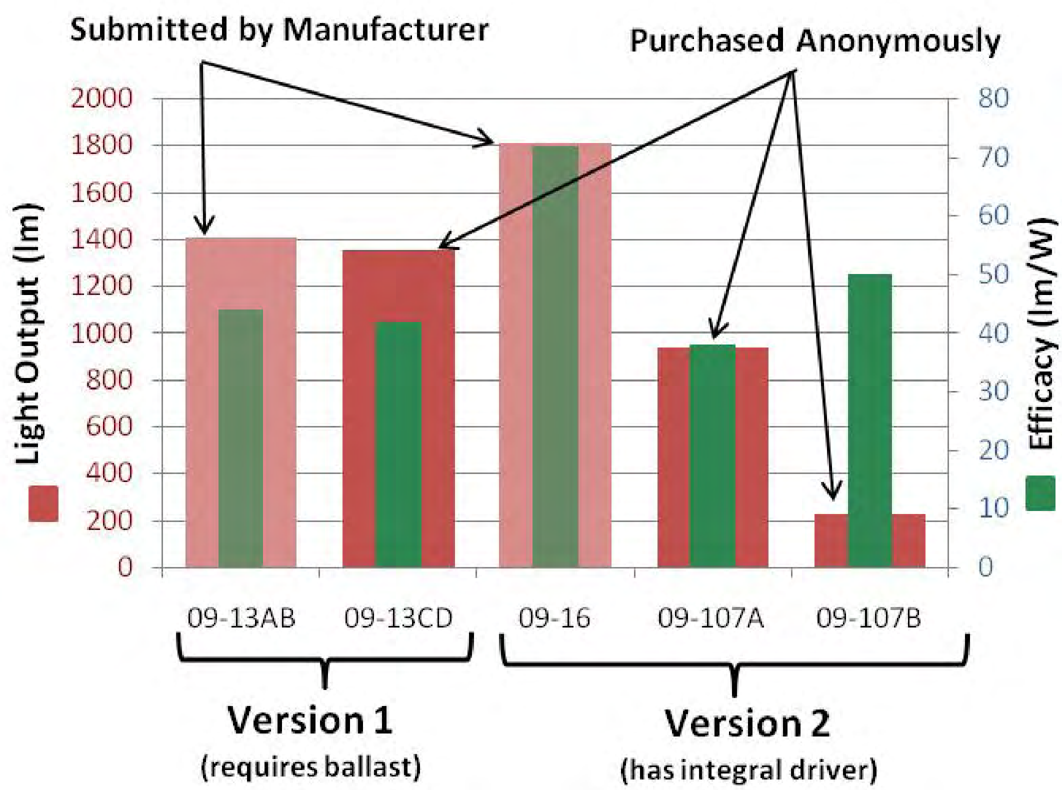


**Figure 12. Comparison of Submitted Versus Purchased Linear Replacement Samples**

Due to the large differences in performance between the submitted and purchased units, several attempts were made to purchase additional units for testing. In each case, the manufacturer indicated that the product was temporarily out of stock and would not be available for several months. The CALiPER results in this case raise a number of doubts.

- The relatively high performance of sample 09-16 submitted by the manufacturer may indicate that it was hand-picked to significantly outperform others and is not representative of the typical performance of lamps in this product line.
- The relatively poor performance of sample 09-107A as compared to the submitted sample may indicate inconsistently produced units of the product.
- The apparent malfunctioning in sample 09-107B may indicate product design flaws or quality control issues.
- The perpetual 'out of stock' status of the product may shed doubt on the general reliability of the product and on the longer-term integrity of the product warranty.

## Reliability: Lumen Depreciation Testing

A 2010 report on CALiPER long-term testing shows that a wide range of behaviors in lumen depreciation and color maintenance can be observed across SSL luminaires and replacement lamps. None of the products included in CALiPER Round 10 have been tested for reliability at this time. Figure 13 illustrates some of the different types of long-term behavior observed in other CALiPER SSL products.[26]

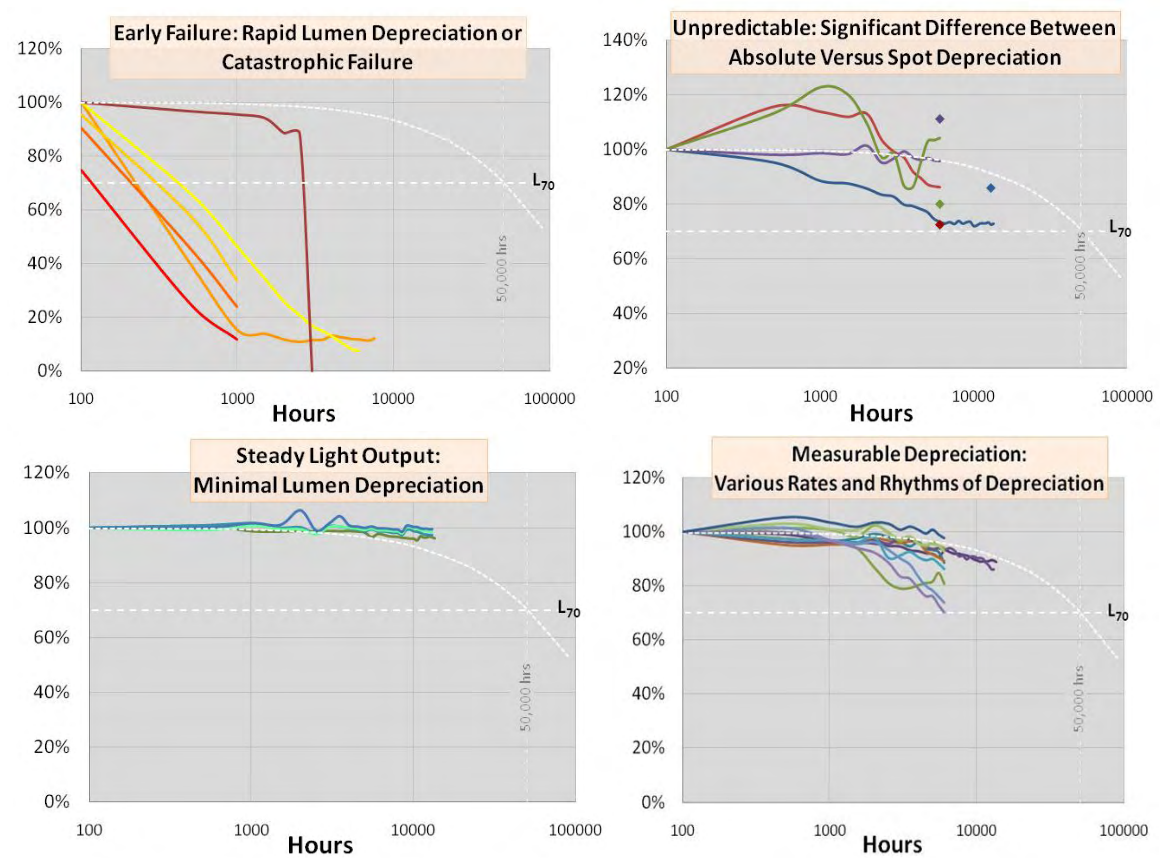


**Figure 13. Lumen Depreciation Behaviors Observed During Long-Term Continuous Operation**

Due to the range of behaviors and rapid rate of change of SSL technology, buyers and specifiers should be wary of all product life claims. More than half the SSL products subjected to CALiPER long-term testing will not provide 70% of initial light output at 50,000 hours and already exhibit significant color shift within the duration of the CALiPER long-term operation. About one quarter of the SSL products would not pass a simple 1000-hour operational test: they do not last as long as a traditional incandescent lamp. On the other extreme, a few products show negligible lumen depreciation after more than 12,000 hours of operation — demonstrating that at least in some cases, the potential for very long SSL product life appears to be achievable. Specifiers should require LM-80 data and require coverage of lumen and color maintenance in product warranty, manufacturer and product track records, and all other available reliability data.

[26] CALiPER exploratory report available upon request from DOE: Long-Term Testing of Solid-State Lighting, 2010, PNNL, January 2010.

Buyers, specifiers, and manufacturers should recognize that lumen depreciation is only one of many possible failure mechanisms in SSL luminaires and replacement lamps.[27]

## Conclusions from Round 10 of Product Testing

**Key Conclusions**
Round 10 of CALiPER testing focuses primarily on some commercial lighting applications: parking structures, wall packs, and cove lighting. Overall, this series of testing includes larger (physical) luminaires with higher wattage, on average, than earlier rounds of testing. Although the average efficacy observed has not increased in this round, the SSL products are now able to attain the same levels of efficacy on average in both significantly larger, higher light output luminaires and smaller integral replacement lamps, and are clearly competitive with benchmark products in an increasing number of lighting applications.

For both parking structure and wall pack luminaires, a wide range of performance was measured in SSL products:

- SSL parking structure and wall pack luminaires are capable of meeting or exceeding light output levels and efficacy levels of benchmark products while simultaneously achieving more uniform light distribution;
- Some SSL parking structure and wall pack luminaires do not achieve luminaire efficacy and light output comparable to benchmarks and do not provide relatively uniform light distribution;
- SSL parking structure and wall pack luminaires tested produce less uplight than benchmark products; and
- The majority of SSL parking structure and wall pack luminaires met or exceeded their manufacturer performance claims, while the majority of benchmark luminaires did not meet manufacturer performance claims.

For cove lighting, SSL products do not yet achieve the light output levels and efficacy levels of fluorescent cove lighting used for general lighting purposes. However, the SSL cove light strips do meet the light output levels of decorative cove lighting products, while providing significantly higher efficacy than xenon cove lights. A side-by-side comparison of three versions of one track system (comparing two different styles of AC LED track heads and xenon lamps), revealed that the LED versions of the product produce less light output per track head than the xenon version, but achieve two to four times the efficacy of the xenon version. Some observers noted visible flicker in the AC LED track heads. Both the benchmark cove lights and four of seven SSL cove lights provided accurate manufacturer claims.

Four small replacement lamps tested in Round 10 used the Lighting Facts label on their product packaging. All four of these lamps met or exceeded the performance levels included in their Lighting Facts labels and three of the four lamps also met equivalency claims — being suitable replacements respectively for a 50W halogen PAR30, a 45W halogen PAR38, and a 40W

[27] See "LED LUMINAIRE LIFETIME: Recommendations for Testing and Reporting," (publication pending) prepared by DOE and Next Generation Lighting Industry Alliance Solid State Lighting Product Quality Initiative.

incandescent A-lamp. The fourth small replacement lamp, an MR16, did not provide as much light output or adequate light intensity (relative to its beam angle) as an average 20W halogen MR16 lamp. Two of the small replacement lamps, the PAR30L and the A-lamp, did not meet ANSI-defined lamp format standards for the geometry of the lamp styles they are meant to replace.

One 4' linear replacement lamp was tested as a follow-up to the CALiPER Round 9 series on linear replacement lamps. Although the manufacturer-submitted samples of this product had performed admirably, the anonymously purchased CALiPER samples did not achieve similar performance levels.

In the majority of cases, when LM-79 data are provided by manufacturers for their SSL products, the products are found to meet or exceed performance claims. It is important to note that IESNA LM-79 defines a standardized testing methodology, but it is not a criterion defining “good” or ‘bad’ products. Having LM-79 test results from a qualified testing laboratory (or a Lighting Facts label based on LM-79 testing) can lend increased credibility to the test results — allowing greater confidence in the accuracy of a product’s performance claims. However, an LM-79 tested product may still be a poor performer as compared to other SSL products or benchmark products, so it is essential to review the LM-79 test results and evaluate them with respect to application requirements and to evaluate other criteria indicative of product quality and reliability.

**Next Steps for the Industry and CALiPER Efforts**

The CALiPER program continues to perform basic photometric testing of SSL and benchmark luminaires along with study of other performance characteristics such as long-term operation, reliability, dimmability, flicker, and glare. CALiPER relies on input from industry and uses the CALiPER Guidance Committee to provide a more direct channel for receiving feedback and testing ideas from key stakeholders, such as energy-efficiency programs, utilities, engineers, and lighting designers. The CALiPER program also works with lighting testing experts, standards organizations, trade groups, and manufacturers to identify and address SSL testing needs. The steady progress of SSL technology and corresponding evolving needs for testing were clearly identified during the 2010 CALiPER Standards and Testing Roundtable meeting.[28]

CALiPER detailed reports can be downloaded and searched with a powerful online tool that enables finding specific reports, listing results, and comparing products based on a number of performance parameters. Upcoming CALiPER testing includes a series on streetlight products along with a more extensive series of tests verifying products listed on the Lighting Facts label web site. Additional areas of exploratory CALiPER testing and studies are examining flicker, glare, and reliability, and are working to address key issues identified during the 2010 CALiPER Roundtable meeting.

[28] Proceedings from CALiPER Roundtable meetings 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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