CALiPER

SUMMARY REPORT

October 2011

DOE Solid-State Lighting CALiPER Program

Summary of Results: Round 13 of Product Testing

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Prepared for the U.S. Department of Energy
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DOE Solid-State Lighting CALiPER Program

Overview of CALiPER Summary Reports

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. CALiPER relies on standardized photometric testing (following the Illuminating Engineering Society, IES LM-79-08) conducted by qualified, independent testing laboratories.[1] Results from CALiPER testing are available to the public through detailed test reports for each product tested and through periodic summary reports, which assemble data from numerous product tests and provide comparative analyses.[2]

It is not possible for CALiPER to test every LED product on the market, and LED technology is constantly in flux, so it is important for buyers and specifiers to reduce risk by learning how to compare products and by examining every potential LED purchase carefully. CALiPER summary reports and detailed reports are an extensive resource, providing unbiased photometric data and explanations covering LED product performance in a wide range of lighting applications. The previous summary reports include:

- Round 12 Summary Report (June 2011)—recessed downlight luminaires, track light luminaires, cove lighting luminaires, LED replacements for A-lamps, and LED replacements for linear fluorescent lamps
- Special Summary Report: Retail Replacement Lamp Testing (April 2011)—LED replacement lamp products directly available through retail outlets, including A19, candelabra, night light, MR16/PAR16, PAR20, and PAR30 replacement lamps
- Round 11 Summary Report (October 2010)—roadway arm-mount and post-top luminaires, high-bay luminaires, linear replacement lamps, and small replacement lamps
- Round 10 Summary Report (May 2010)—parking structure luminaires, outdoor wallpack luminaires, cove lighting luminaires, and replacement lamps
- Round 9 Summary Report (October 2009)—recessed downlights, a desk lamp, LED replacement lamps for linear fluorescent lamps, and smaller diameter general replacement lamps
- Round 8 Summary Report (July 2009)—downlights and track lights, undercabinet luminaires, outdoor luminaires, and replacement lamps

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[1] IES 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/.

[2] Summary reports for Rounds 1–12 of DOE SSL testing are available online at http://www1.eere.energy.gov/buildings/ssl/reports.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.

- Round 7 Summary Report (January 2009)—outdoor area and streetlights, downlights, and replacement lamps
- Round 6 Summary Report (September 2008)—including desk lamps, a downlight, a recessed wall fixture, two different types of outdoor lighting products, and small replacement lamps (MR16, A-lamps, and candelabra lamps)
- Round 5 Summary Report (May 2008)—downlights, desk/task lamps, undercabinet lighting, outdoor lighting, and linear, A-lamp, and MR16 replacement lamps
- Round 4 Summary Report (January 2008)—downlights, desk/task lamps, undercabinet and outdoor lighting, and linear, MR16, and candelabra replacement lamps
- Round 3 Summary Report (October 2007)—directional and A-lamp replacement lamps, downlights, task lamps, and outdoor fixtures
- Round 2 Summary Report (August 2007)—downlights, desk/task lamps, outdoor wall lighting, refrigerated display lighting, and R30 and A-lamp replacement lamps
- Round 1 Summary Report (March 2007)—downlights, desk/task lamps, and undercabinet, outdoor area, and surface-mount lighting
- Pilot Round Summary Report (December 2006)—downlights, a task light, and undercabinet lighting

DOE conducts CALiPER testing on at least 75 LED products each year. A Summary Report is published following completion of each round of testing, grouping similar products and providing analysis of the test results. Products and manufacturers are not named in the CALiPER summary reports. Detailed reports, which include further photometric testing data, manufacturer ratings, and product identifying information, are posted on the CALiPER website for non-commercial, educational purposes.

Summary of Results: Round 13 of Product Testing

Round 13 of CALiPER testing was conducted from June to September 2011. In this round, 19 products (14 LED and 5 conventional products for benchmarking purposes) representing a range of product types and technologies, were tested with both spectroradiometry and goniophotometry using absolute photometry. All 14 LED products were tested following the IES LM-79-08 testing method. To enable direct comparison of results, the 5 benchmark products were also tested using absolute photometry.

Round 13 of testing included three primary focus areas:

1. LED and benchmark high-bay luminaires;
2. LED wallpack luminaires; and
3. LED and benchmark 2' × 2' troffers.

Round 13 CALiPER Testing Results

Tables 1a-c summarize results for energy performance and color metrics—including light output, luminaire efficacy, color rendering index (CRI) and correlated color temperature (CCT)—for products tested under CALiPER in Round 13. LED and benchmark CALiPER testing from earlier CALiPER rounds are given for comparison. A thumbnail photo of each product is included. These tables assemble key results as follows:

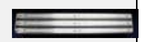
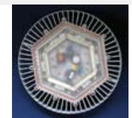
Table 1a Five pendant-mounted LED high-bay luminaires were tested along with two benchmarks: a metal halide high-bay and a fluorescent high-bay. The high-bay luminaires represent a range of formats—round, rectilinear, and square—and a range of power measurements, from 75 to 183 W.

Table 1b Three LED wallpack luminaires were tested with measured power ranging from 26 to 40 W. Results from previous CALiPER tests on six LED wallpacks and two benchmark wallpacks are listed for reference.

Table 1c Six 2' × 2' LED troffer luminaires were tested, with measured power ranging from 30 to 58 W. Three benchmark tests were conducted on 2' × 2' recessed troffers equipped with fluorescent lamps: one using two 40 W T5 biax fluorescent lamps, one using two 28 W T5 biax fluorescent lamps, and one using two U-bent 32 W fluorescent lamps. Performance values for 2' × 2' recessed troffers tested in previous CALiPER rounds are listed for reference.

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

Table 1a. CALiPER ROUND 13 SUMMARY—High-bay Luminaires

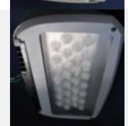
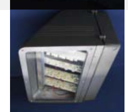
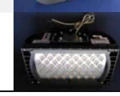
– LED testing following IES LM-79-08 – 25º C ambient temperature	DOE CALiPER TEST ID	Total Input Power (W)	Initial Output (lm)	Efficacy (lm/W)	CCT (K) [D_{uv}]	CRI	Photo
LED High-bay Luminaires							
Pendant ~20" diameter	11-50	83	5591	68	4316 *[-0.007]*	75	
Rectilinear Pendant 48" x 8.5"	11-51	157	12570	80	4144 [0.006]	69	
Pendant 16" diameter	11-52	137	11020	80	5989 [0.002]	71	
Pendant 16" diameter	11-60	75	4527	60	5354 [0.005]	70	
Square Pendant 23" x 23"	11-61	181	11930	67	4066 [0.006]	67	
Pendant 18" diameter	09-79 **Round 11**	110	5612	51	2802 *[0.007]*	57	
Pendant 20" diameter	10-25 **Round 11**	111	7822	71	5593 [0.008]	71	
Benchmark High-bay Luminaires							
Pendant 16" diameter, with 175 W ED28 metal halide lamp*	BK11-44	183	9782	53	4411 *[0.010]*	51	
Rectilinear Pendant 48 " x 16", with four 32 W T8 fluorescent lamps	BK11-54	102	8042	79	3840 [0.006]	81	

Values are rounded to the nearest integer for readability. Results shown in this table are from testing at 120 VAC.

CCT and D_{uv} values outside ANSI-defined (C78.377-2008) tolerances for white light in LED products are shown in *red italics*.

*PMH benchmark uses pulse-start quartz metal halide (not ceramic).

Table 1b. CALiPER ROUND 13 SUMMARY—Wallpack Luminaires

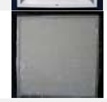
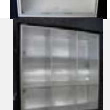
– LED testing following IES LM-79-08 – 25º C ambient temperature	DOE CALiPER TEST ID	Total Input Power (W)	Initial Output (lm)	Efficacy (lm/W)	CCT (K) [D_{uv}]	CRI	Photo
LED Wallpack Luminaires							
Wallpack	11-57	30	1760	59	5150 [0.007]	65	
Wallpack	11-58	26	1433	55	5101 [-0.001]	80	
Wallpack	11-59	40	1525	38	5157 *[0.008]*	69	
Wallpack	07-25 **Round 3**	71	3758	53	6145 [0.002]	77	
Wallpack	09-89 **Round 10**	16	420	27	5241 [0.007]	68	
Wallpack	09-90 **Round 10**	60	2459	41	6313 [0.005]	79	
Wallpack	09-91 **Round 10**	66	1829	28	4067 *[0.008]*	67	
Wallpack	09-92 **Round 10**	69	4276	62	4170 [0.000]	80	
Wallpack	09-103 **Round 10**	87	4470	52	6355 [0.003]	75	
Benchmark (BK) Luminaires: High-pressure Sodium (HPS) & Pulse-start Metal Halide (PMH)							
Wallpack with 150 W HPS lamp	BK09-105 **Round 10**	171	8103	47	*2130* [0.000]	12	
Wallpack with 150 W PMH* lamp	BK09-106 **Round 10**	188	4591	24	4504 *[0.011]*	66	

Values are rounded to the nearest integer for readability. Results shown in this table are from testing at 120 VAC.

CCT and D_{uv} values outside ANSI-defined (C78.377-2008) tolerances for white light in LED products are shown in *red italics*.

*PMH benchmark uses pulse-start quartz metal halide (not ceramic).

Table 1c. CALiPER ROUND 13 SUMMARY—2' × 2' Troffer Luminaires

– LED testing following IES LM-79-08 – 25º C ambient temperature	DOE CALiPER TEST ID	Total Input Power (W)	Initial Output (Lumens) [CBCP]	Efficacy (lm/W)	CCT (K) [D_{uv}]	CRI	Photo
LED 2' × 2' Troffer Luminaires							
2' × 2' Recessed Troffer (With 3" central pendant)	11-45	58	2058 [683 cd]	36	3428 [-0.001]	78	
2' × 2' Recessed Troffer	11-46	30	1430 [605 cd]	47	3508 [0.000]	73	
2' × 2' Recessed Troffer	11-47	44	2915 [1137 cd]	66	3588 [-0.004]	83	
2' × 2' Recessed Troffer	11-48	43	3469 [1486 cd]	80	3152 [-0.005]	94	
2' × 2' Recessed Troffer	11-55	31	2007 [1021 cd]	65	2899 [-0.001]	76	
2' × 2' Recessed Troffer	11-56	37	1992 [950 cd]	54	3440 [0.000]	86	
2' × 2' Flat Lens Troffer	08-29 **Round 5**	75	3456 [1196 cd]	46	4346 [0.002]	71	
2' × 2' Flat Lens Troffer	08-134 **Round 7**	42	2100 [847 cd]	50	5337 *[0.008]*	63	
2' × 2' Recessed Troffer	09-41 **Round 9**	41	3250 [1539 cd]	79	3339 [-0.001]	89	
2' × 2' Flat Lens Troffer	09-71 **Round 9**	65	3190 [1124 cd]	49	*3544* *[0.010]*	75	
2' × 2' Flat Lens Troffer	09-81 **Round 9**	64	2610 [896 cd]	41	3521 [-0.002]	93	
Benchmark 2' × 2' Troffer Luminaires							
2' × 2' Recessed Troffer two 40 W T5 biax fl. lamps	BK11-49i	68	4095 [1443 cd]	60	3294 [0.003]	82	
2' × 2' Recessed Troffer two 28 W T5 biax fl. lamps	BK11-49ii	63	3987 [1352 cd]	64	3435 [0.006]	83	
2' × 2' Recessed Troffer two 32 W 6" U-bent fl. lamps	BK11-62	56	3160 [1268 cd]	56	3207 [0.003]	84	
2' × 2' 9-cell Troffer two 32 W, U-bent fl. lamps	BK09-72 **Round 9**	57	2541 [1315 cd]	44	3349 [0.000]	81	
2' × 2' Recessed Troffer two 17 W F17T8 fl. lamps	BK09-73 **Round 9**	35	1706 [544 cd]	49	3318 [0.000]	86	

Values are rounded to the nearest integer for readability.
D_{uv} values outside ANSI-defined tolerances for white light in LED products are shown in *red italics*.

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

Energy Use and Light Output

All the products tested in Round 13 were luminaires rather than replacement lamps. Taken as a whole, the LED luminaires tested in Round 13 exhibited a wide range of performance, with an overall average efficacy of 61 lm/W and a range of 36 to 80 lm/W. Figure 1 summarizes the average performance of Round 13 products—considering efficacy, power factor, CCT, and CRI—as compared to benchmark luminaires and LED luminaires tested in 2009 and 2010 (excluding non-similar products such as task lamps and cove lighting luminaires). On average, the Round 13 LED luminaires show a significant improvement in efficacy over LED luminaires tested in 2009 and 2010, with a minimum efficacy close to the average observed in 2009–2010. In addition, the variation in performance across the Round 13 LED luminaires is less than in 2009–2010 products; that is, there were smaller differences between minimum and maximum efficacy, power factor, CCT, and CRI.

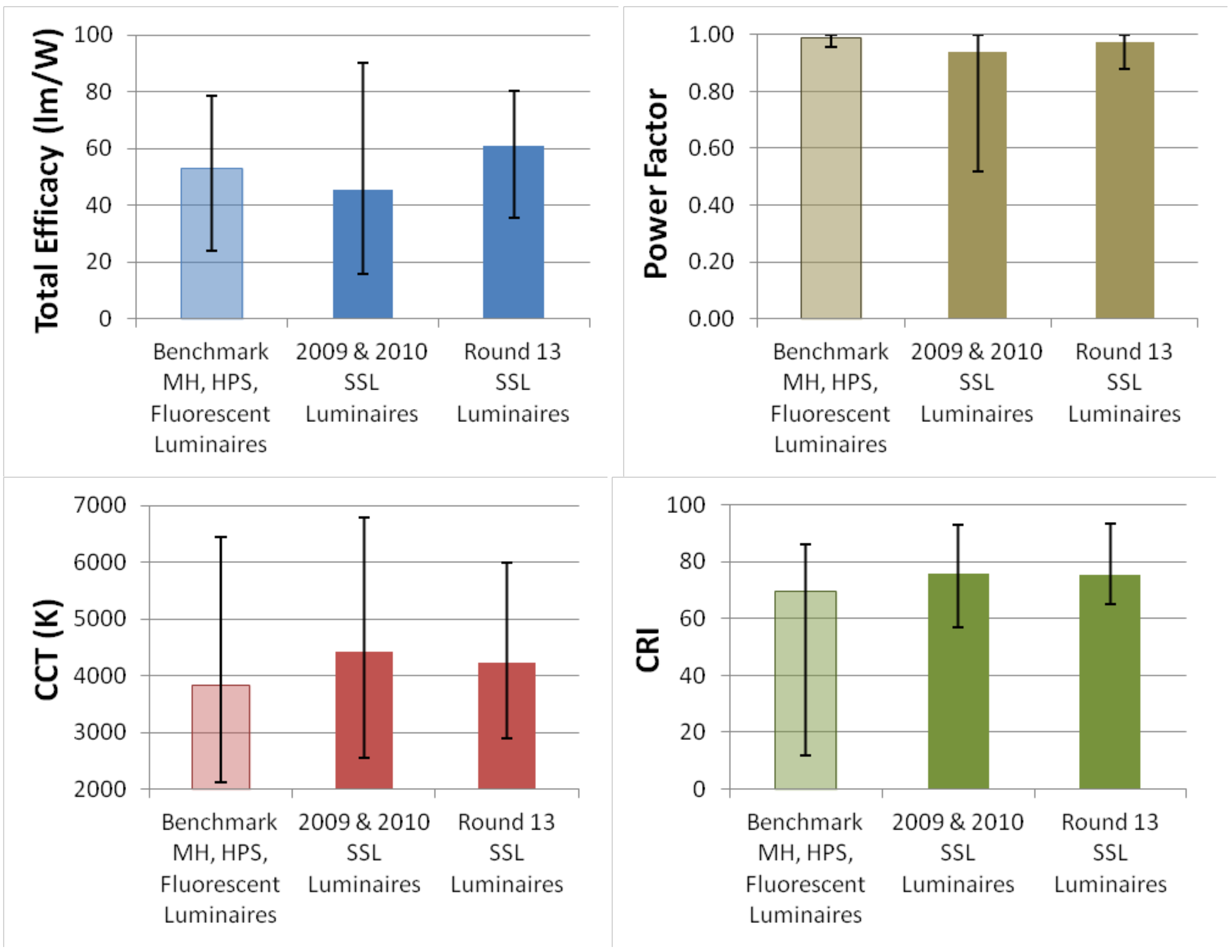


Figure 1. Average Round 13 results for LED luminaires, compared to benchmarks and earlier similar LED luminaires

Vertical bars show maximum and minimum ranges of performance.

The benchmark averages represent a very wide range of products with a variety of light sources (metal halide, high-pressure sodium, and fluorescent), so not surprisingly, there is a wide range in performance. However, the averages for luminaire efficacy, power factor, CCT, and CRI are similar between the benchmark luminaires and the Round 13 LED luminaires.

Figure 2 shows the yearly progress in LED efficacy based on CALiPER results, from the inception of testing in 2006 through Round 13. The vertical bars indicate the spread in performance. The steady increase in average and maximum efficacy is clear. The average efficacy observed during the first three quarters of 2011 was 51 lm/W, while the average for Round 13 luminaires was 61 lm/W. The minimum efficacy of LED products tested in Round 13 was 36 lm/W, which is higher than the average efficacy observed in 2008.

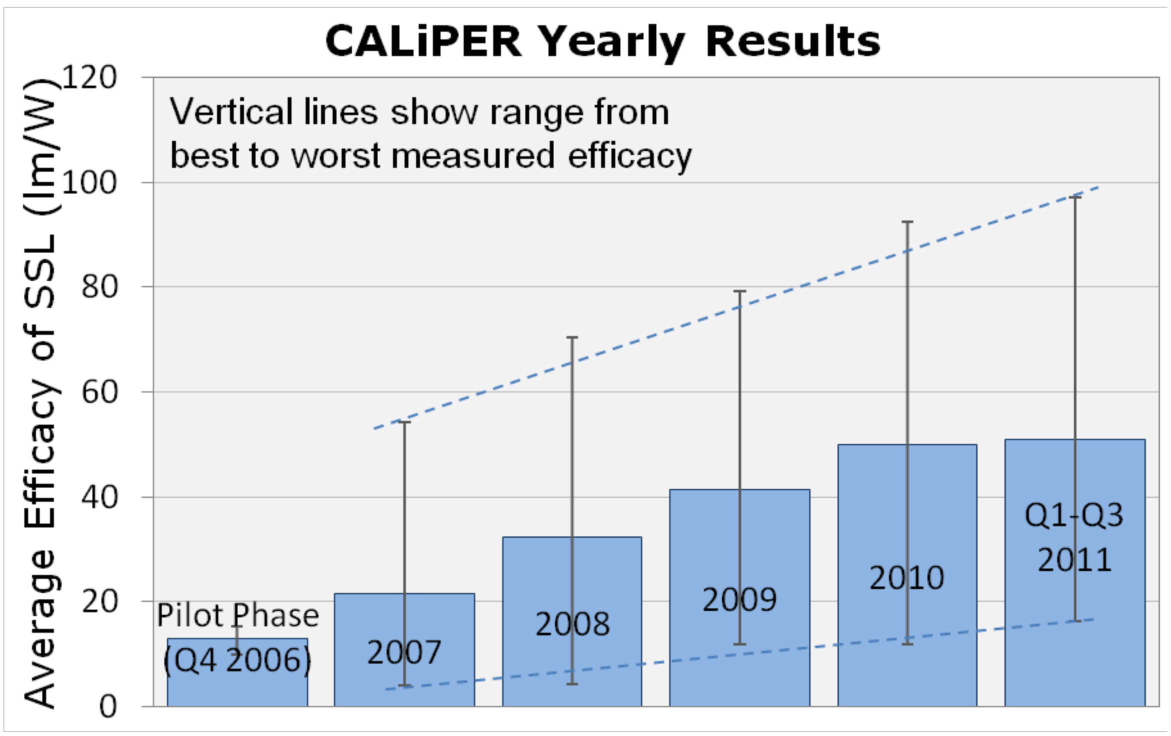


Figure 2. Average measured efficacy of CALiPER-tested SSL luminaires and replacement lamps

High-bay Luminaires

High-bay luminaires are used in both commercial and industrial applications where geometry necessitates high-lumen sources. Once dominated by high-intensity discharge (HID) lamps, the market has largely transitioned to fluorescent options—often called high-intensity fluorescent (HIF)—over the past two decades due to the better lumen maintenance of fluorescent lamps and the enhanced control options. More recently, the output of LED luminaires has become high enough for high-bay LED luminaires to be competitive with conventional sources. LED products inherently provide directional light output and may potentially bring new features and more options to the high-bay market including increased controllability, longer lamp life, increased robustness, and new form factors. However, some currently available LED products may not maximize the potential of the technology and may fail to achieve the photometric and energy performance claimed by the manufacturer.

With respect to lumen maintenance and overall product lifetime, LED luminaires behave differently than other technologies, raising unique concerns that must be understood and taken into consideration. The short record of performance and continuing rapid development of LED technology introduces uncertainty and can result in greater risk than with conventional high-bay luminaires. These factors may be of particular importance for commercial and industrial applications that require high-lumen sources. In order to reduce risk, it is advised that standardized testing, use of reputable manufacturers, learning from demonstration projects, and initial use of pilot or small-scale installations be employed.

Five high-bay LED luminaires, one high-bay pulse-start quartz arc tube metal halide pendant, and one high-bay T8 linear fluorescent pendant were tested in Round 13.[3] These new tests supplement the evaluation of two high-bay LED pendants performed in Round 11. The Round 13 LED luminaires included three round pendants, one square pendant, and one rectilinear pendant.

Light Output and Efficacy

Two points of reference are considered for the Round 13 LED high-bay luminaires: first, the two benchmark high-bay products and second, the performance criteria established in the DesignLights Consortium™ (DLC) Qualified Products List (QPL).[4] The initial light output and efficacy criteria established for the DLC QPL are 10,000 lm and 70 lm/W for high-bay and low-bay luminaires for commercial and industrial buildings, or 10,000 lm and 60 lm/W for high-bay aisle lighting. Neither benchmark product meets both the 10,000 lm and 70 lm/W criteria, though

[3] This report focuses on comparing the performance of the LED high-bay luminaires to their expected performance; performance of benchmark products is not analyzed in detail. For a discussion of the performance characteristics of metal halide lamps, see *Low-wattage Metal Halide Lighting Systems, Low-wattage MH Lamps with Electronic and Magnetic Ballasts*, Specifier Reports Vol. 10 No. 1, October 2006. http://www.lrc.rpi.edu/programs/NLPIP/PDF/VIEW/SRLWMH.pdf

[4] The DLC aims to help implement improved design practices in all areas of the commercial lighting market. Currently, there is no national standard, such as ENERGY STAR®, for high-bay and wallpack luminaires, thus the DLC criteria are provided herein as a point of reference. The DLC established the qualified lighting products criteria as a resource for the lighting industry with the intention of removing categories as they are established within the ENERGY STAR program. http://www.designlights.org/documents/Technical_Reqs_Table_v1-6_08_01_2011.pdf

BK11-44 (metal halide) comes very close in light output and BK11-54 (fluorescent) meets the efficacy criteria.

Initial lumen output versus efficacy for the CALiPER-tested high-bay luminaires is shown in Figure 3. Two of the five LED products (11-51 and 11-52) exceed both the efficacy and lumen output of the benchmarks and the DLC QPL criteria. Products 11-51 and 11-52 provide 12,570 lm and 11,020 lm, respectively, both at 80 lm/W. Product 11-61 provides a similar initial lumen output (11,930 lm), but with an efficacy of 67 lm/W, which is just short of the 70 lm/W threshold, but above the 60 lm/W DLC threshold for high-bay aisle lighting. The remaining two products tested in Round 13 (11-50 and 11-60) draw significantly less power, with a commensurate drop in lumen output. They have efficacies of 68 lm/W and 60 lm/W, respectively. Three of the LED high-bay luminaires tested demonstrate improved output and efficacy compared to previously tested LED high-bay luminaires.

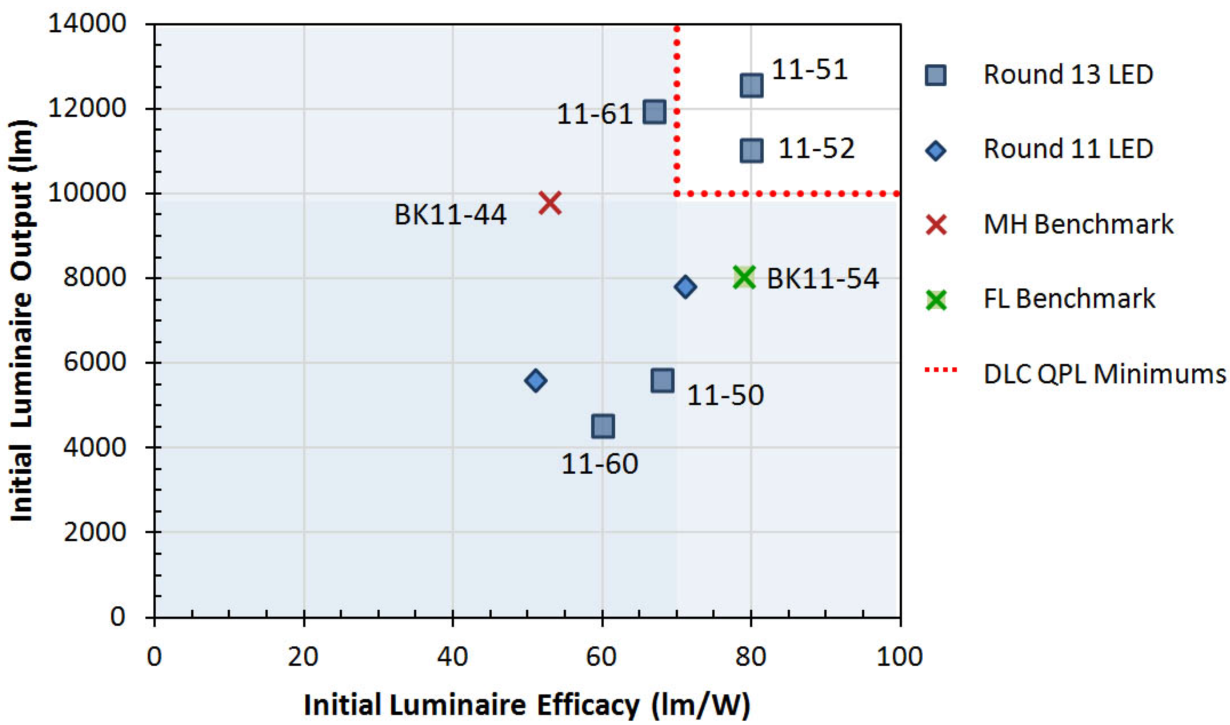


Figure 3. Initial light output and efficacy of CALiPER-tested high-bay luminaires
Two of the LED products tested in Round 13 perform very well compared to benchmark products and DLC QPL criteria.

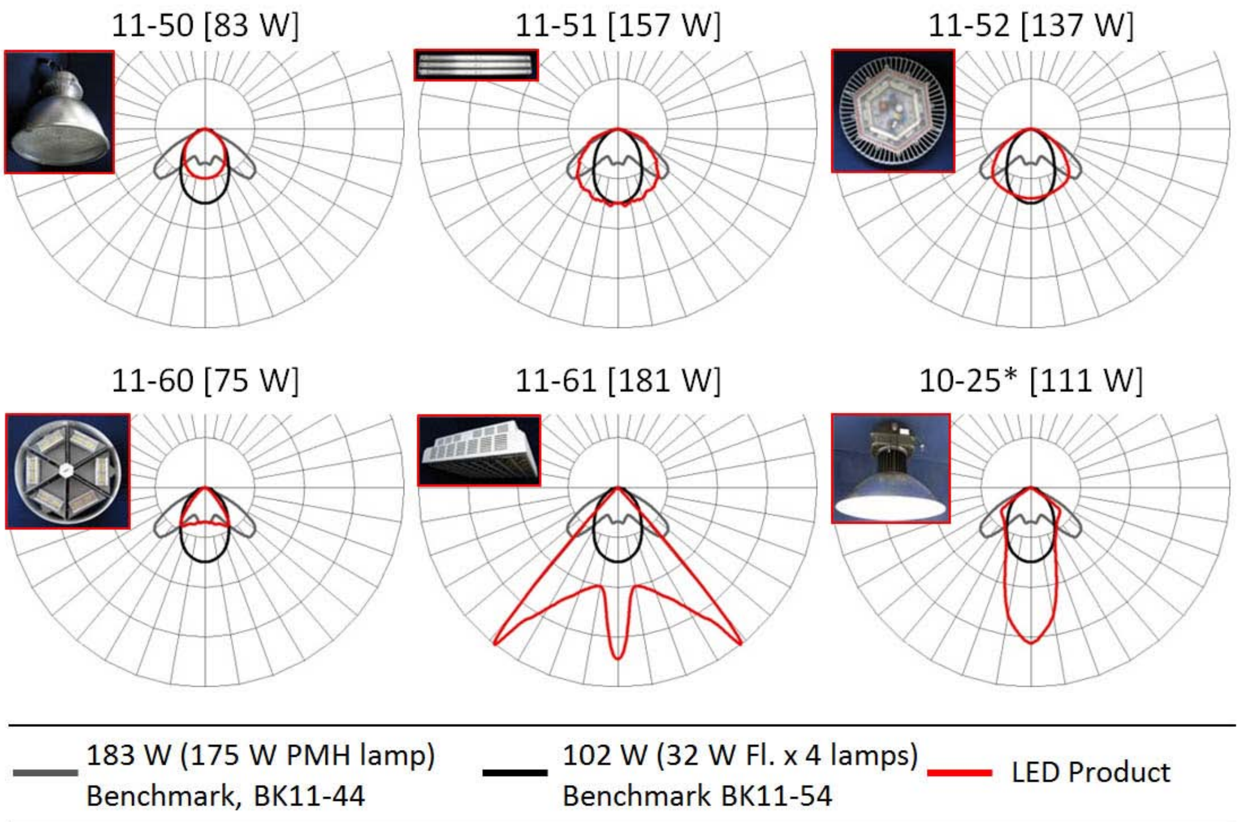
Light Distribution

The beam angles and distributions of the LED high-bay luminaires tested in Round 13 are significantly broader than those of the products tested in Round 11. Figure 4 presents the polar plots of luminous intensity distribution for each of the Round 13 high-bays and the wider beam high-bay from Round 11—all presented using the same intensity (candela) scale and with an overlay of the metal halide and fluorescent benchmark distributions. These polar plots demonstrate the wide variety in beam patterns possible in LED luminaires, from quite narrow, to cosine distributions, to fairly broad and fairly uniform distributions. None of the LED luminaires tested provides a very wide, batwing distribution similar to the metal halide benchmark.

This is also reflected in the spacing criteria summarized in Figure 5.[5] The distributions of products 11-50, 11-51, 11-52, and 11-60 are comparable to the distribution for the linear fluorescent high-bay benchmark (BK11-54), though two (11-51 and 11-52) emit a greater percentage of lumens at higher angles. The metal halide benchmark (BK11-44) exhibits a batwing distribution that increases its spacing criteria.[6] LED product 11-61 also has a distribution that is close to a batwing, but it has a very sharp decrease in luminous intensity above 50°.

Zonal lumens are illustrated in Figure 6. All the high-bay luminaires tested by CALiPER to date meet the DLC QPL requirement of greater than 30% of lumens in the 20–50° zone. However, the plot also demonstrates the failure of some LED products to produce much light above 50°—products 09-79 and 11-61 have much narrower beams and produce almost no high angle light. The relative decrease in intensity in the 50–90° range observed for the majority of the LED luminaires and for the fluorescent benchmark could lead to areas of poor uniformity on the target surface, if used in installations which have not been appropriately designed for the spacing criteria of these products. Although the reduction in high angle light can reduce glare, it can be detrimental to application efficacy[7] in some installations when luminaires must be spaced closer together or the space must be over-lighted to achieve uniformity.

[5] Note that the 0-180 axis should be taken parallel to the long axis of the fluorescent lamps per ANSI/IESNA LM-63-02. While this is not typically applicable to LED 2×2s, it can be of importance when comparing across difference specifications such as CBEA and DLC.
[6] The optical mounting system is adjustable for the metal halide benchmark (BK11-44), enabling a wide range of beam angle choices depending on the mounting leg position.
[7] Application Efficacy is defined as the lumens delivered to the target plane divided by the input watts to the luminaire.



* Round 11

Figure 4. Polar plots through the plane of maximum intensity for high-bays
The distributions of the LED products tested in Round 13 can generally be described as broad, with four products having distributions similar to the fluorescent benchmark. The batwing distribution of the metal halide benchmark offers superior performance. The maximum intensity for the plots is 10,800 cd.

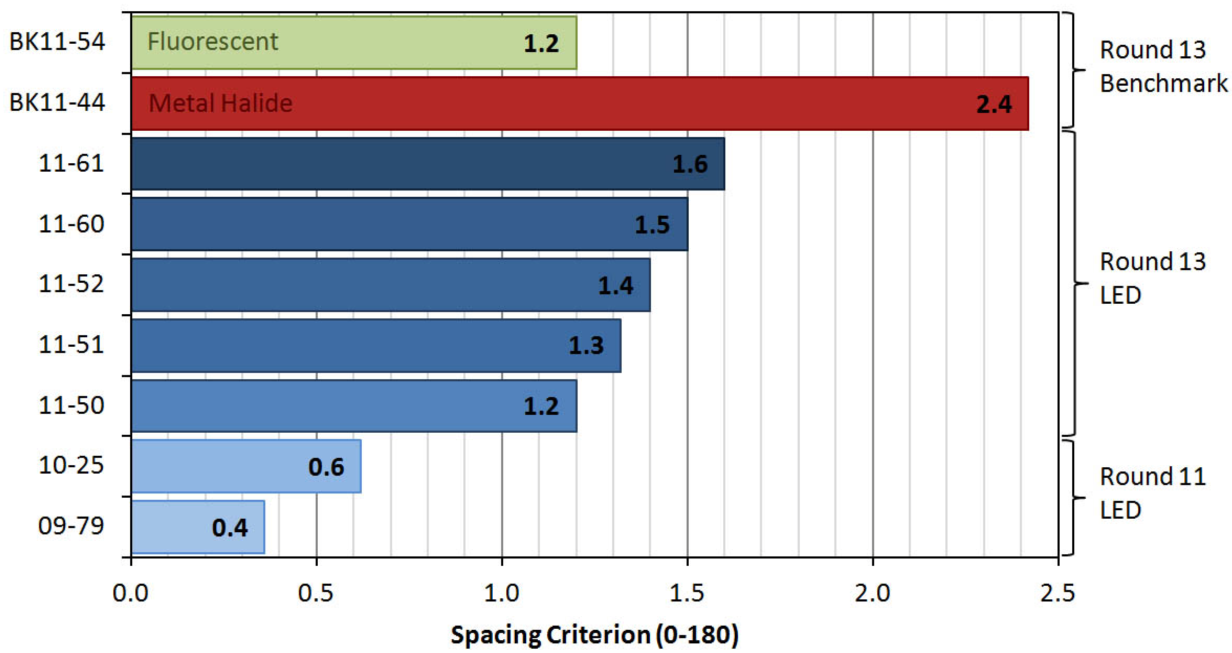


Figure 5. Spacing criteria of high-bay luminaires tested by CALiPER
The LED products in Round 13 perform similarly to the linear fluorescent benchmark. However, they have a lower spacing criterion than the metal halide benchmark.

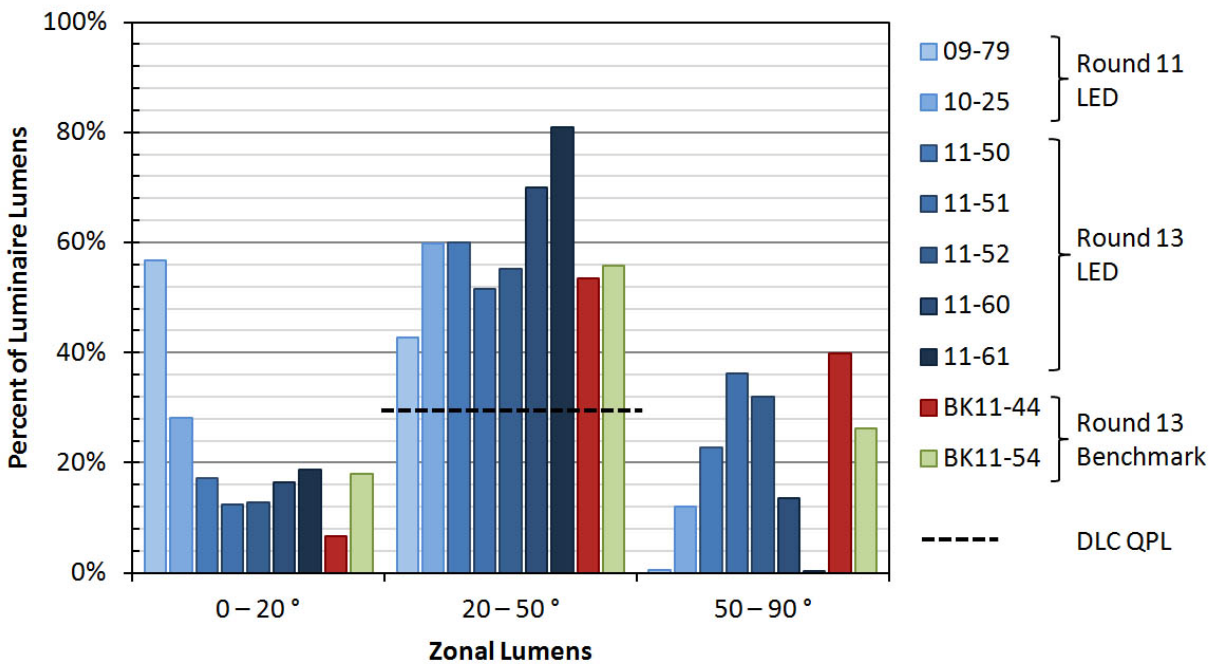


Figure 6. Zonal lumens summary for high-bay luminaires tested by CALiPER
All the high-bay products tested to date meet the DLC QPL zonal lumen criterion of 30% or more in the 20–50° range. The zonal lumen distribution in the 50–90° range demonstrates the sharp cutoff of some LED products.

Color Characteristics

The high-bay products tested in Round 13 ranged from neutral to cool white, with CCTs between 4066 K and 5989 K. Product 11-52 (5989 K) is within the range established by ANSI standards for a nominal CCT of 5700 K, thereby placing it just at the DLC limit for CCT in this product category. Depending on the application, any of the LED products tested could be appropriate, although those with a CCT of less than 5000 K are more similar to typical conventional sources.

The CRI of the products tested in Round 13 ranged from 67 to 75 with an average of 70. These products fall between pulse-start quartz arc tube metal halide and alternatives with higher color rendering, such as pulse-start ceramic arc tube metal halide and linear fluorescent. This performance level would typically be appropriate for industrial or warehouse applications, but not for most retail environments.

Claims and Lighting Facts

Manufacturer data sheets or specifications were available for all the high-bay luminaires tested in Round 13, although for one product (11-60) the data sheet did not include any photometric data. One of the products (11-61) was also listed on the Lighting Facts website,[8] although the Lighting Facts label was not found on the product packaging or in the product literature.

Three of the LED high-bays (11-51, 11-52, and 11-61) performed as claimed in product literature. The light output of product 11-61 did not match the level included in the corresponding Lighting Facts listing, although it was within 8% of the light output indicated on the product's specification sheet—possibly highlighting inconsistencies in versioning and keeping product information up-to-date where multiple resources are available. The use of the Lighting Facts label (as opposed to just having the product performance listed) may have allowed for more consistent information.

Two of the LED high-bays (11-50 and 11-60) did not perform as claimed by the manufacturers. When compared to manufacturer data, product 11-50 falls significantly short of the rated input power (83 W versus claimed 120 W), lumen output (5,591 lm versus claimed 10,000 lm), and efficacy (68 lm/W versus claimed 83 lm/W). In addition, the specification sheet for this product indicates a CCT of 3000–4000 K, where CALiPER testing shows 4316 K. A specification sheet for Product 11-50 claims that it replaces 250 W to 400 W HID fixtures, whereas, in fact, it produces approximately 57% of the lumens generated by the 175 W PMH benchmark (BK11-44). Specification sheets for product 11-50 are also inconsistent, with one claiming it has 75–90% less power draw than HID, and another claiming 50–75% less—both are false when comparing luminaire efficacies and considering HID high-bays with similar luminaire light output. For product 11-60, no photometric values are provided by the manufacturer; however, the product specification sheet claims that it is equivalent to 400 W incandescent or 85 W fluorescent high-bay luminaires. Based on the performance of the fluorescent benchmark, product 11-60 would provide equivalent light output to a hypothetical 57 W fluorescent high-bay luminaire. The webpage for product 11-60 also misleadingly suggests that a 34 W LED high-bay luminaire of this type can be used to replace a 445 W T12 fluorescent luminaire.

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

Wallpack Luminaires

Wallpack luminaires are offered in a variety of packages and can be used to meet a range of outdoor lighting needs. In addition to aesthetics, important design criteria include the illuminance level required and the mounting height of the luminaires, both of which affect the amount and distribution of light prospective wallpack products must emit. Beyond lumen output, distribution plays an important role in determining application efficacy, or the power draw necessary to meet given design criteria. Distribution also impacts appearance and potential for creating glare. For example, if the luminaire provides backlight as well as forward light the wall will be illuminated, and if the luminaire provides too much light output at high angles, it may cause glare.

Three LED wallpack luminaires were tested in Round 13. These new products supplement previous CALiPER tests of seven different LED wallpack luminaires performed in Round 3 (one product) and Round 10 (six products), in addition to HPS (BK09-105) and PMH (BK09-106) benchmarks.

Output and Efficacy

The luminaire efficacies (59 lm/W, 55 lm/W, and 38 lm/W) of the three newly-tested products fall within the range of wallpack products tested in Rounds 3 and 10, as shown in Figure 7. All three exceed the luminaire efficacy of the PMH benchmark (24 lm/W), and two exceed the HPS benchmark (47 lm/W). All three are less than the minimum efficacy listed for wall-mounted area luminaires (60 lm/W) by the DLC QPL, although product 11-57 is just shy of the minimum at 59 lm/W.

At least two products tested in Round 10 (09-92 and 09-103) produce similar initial lumen output when compared to the 150 W PMH benchmark (4,591 lm). Similar results were not seen in the most recent round, however. Round 13 products 11-57 and 11-59 claim equivalence to a wallpack with a 175 W metal halide lamp,[9] yet test results indicate they produce less than 40% of the output of the 150 W PMH benchmark. While the manufacturer-listed 4,000 lm output for product 11-59 (1,525 lm in the CALiPER test) is nearly equivalent to the benchmark, the listed output for product 11-57 is only 1,816 lm (1,760 lm in CALiPER test). Product 11-59 underperformed when compared to manufacturer data and when compared to the manufacturer equivalency claim. For product 11-57, the manufacturer’s equivalence claim did not match the manufacturer’s own data, so while the product came close to meeting the manufacturer data, it did not meet the equivalency claim.

[9] There are several types of metal halide lamps, including quartz or ceramic arc tubes and pulse or probe starting methods. The manufacturer claims made for these products do not specify the precise technology to which they claim equivalence.

In the manufacturer's literature, product 11-58 is compared to 50 W HID products. Although benchmarks in this range were not tested, these claims appear reasonable based on efficacies of other HID products tested by CALiPER.

The efficacies of products 11-57 and 11-58 are similar to the highest efficacies found in earlier rounds, including products 09-92 and 09-103. However, all three Round 13 products draw less than 58% of the power of products 09-92 and 09-103, thus the significantly lower lumen output is expected.

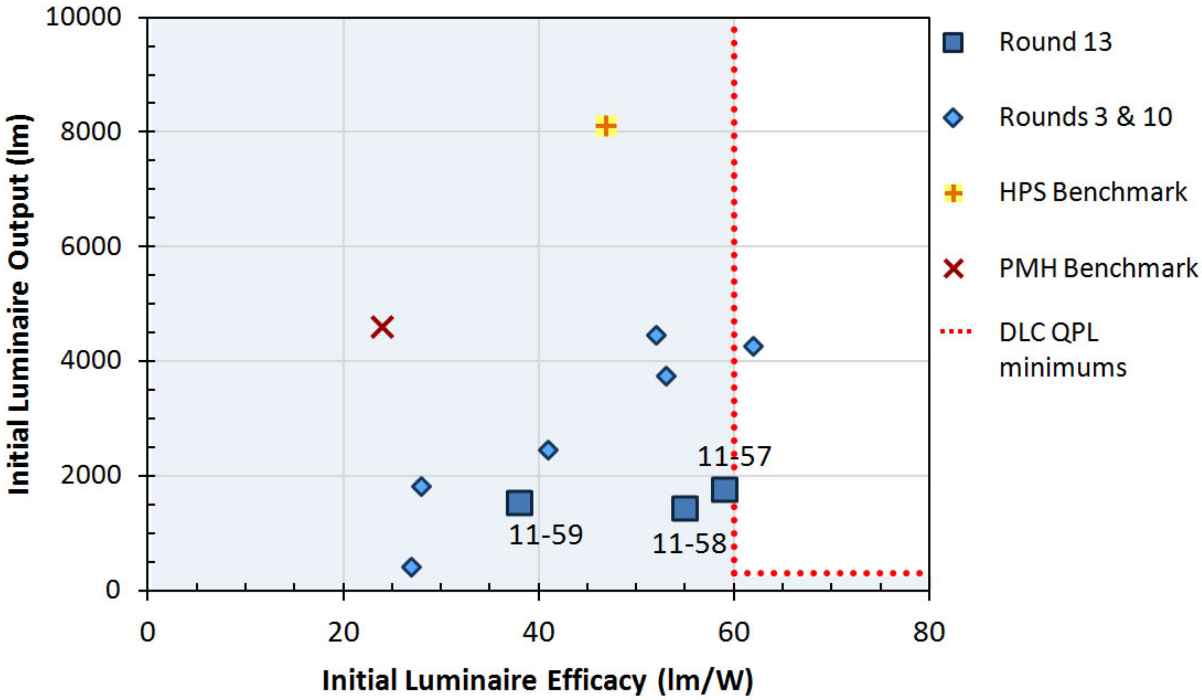


Figure 7. Initial light output and efficacy of CALiPER-tested wallpack luminaires
Efficacy for two of the LED products tested in Round 13 compares well to the benchmark products.

Light Distribution

The distributions provided by the three Round 13 LED products are very diverse and have varying levels of similarity to the benchmark HPS and PMH wallpacks, as shown in Figures 8 and 9, which provide intensity distribution plots and zonal lumen summaries. The distribution of product 11-57 is the most similar to the benchmark lamps, with a majority of lumens directed forward. Product 11-59 has a similar forward distribution, but also includes a significant amount of backlight, as defined by the IES's luminaire classification system (LCS).[10] In contrast to the other LED products, the distribution of product 11-58 is most similar to a cosine distribution,

[10] *IES Luminaire Classification System for Outdoor Luminaires*, TM-15-11. http://ies.org/store/product/luminaire-classification-system-for-outdoor-luminaires-1103.cfm.

with much of the output directed straight down. This will limit spacing and could potentially create hot spots rather than uniform illumination.

Both products 11-58 and 11-59 provide considerable backlight, whereas product 11-57 provides a small amount. The benchmark products only deliver a small percentage of lumens backwards, less than any of the LED products. All three Round 13 LED products emit significantly less uplight compared to the benchmark products, or none at all. In addition to less uplight, the LED products produce minimal output in the forward very high (FVH) region, where high intensity may contribute more to glare than to improved visibility.

In general, the LED wallpacks tested in Round 13 had broader distributions than those tested in earlier rounds, resulting in more uniform illumination of the target surface. However, because the Round 13 luminaires have lower lumen outputs than many of the previously tested products, more luminaires would be necessary to achieve the same average illuminance levels, assuming equal mounting height.

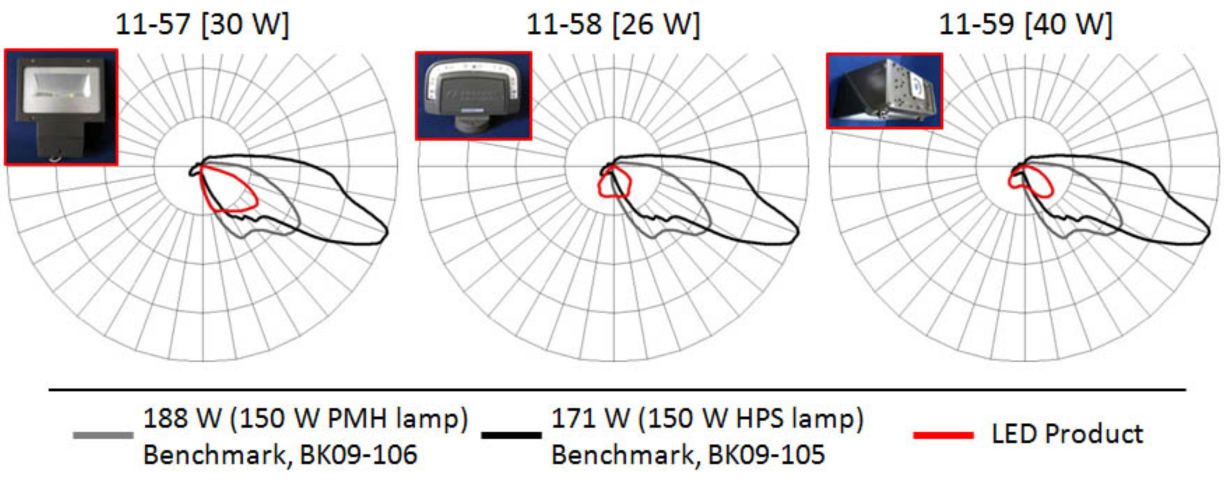


Figure 8. Polar plots through the plane of maximum intensity for wallpacks
The distributions of the LED products tested in Round 13 can generally be described as broad, with four products having similar distributions to the fluorescent benchmark. The batwing distribution of the metal halide benchmark offers superior performance, although possibly at the expense of increased glare. The maximum intensity for the plots is 10,800 cd.

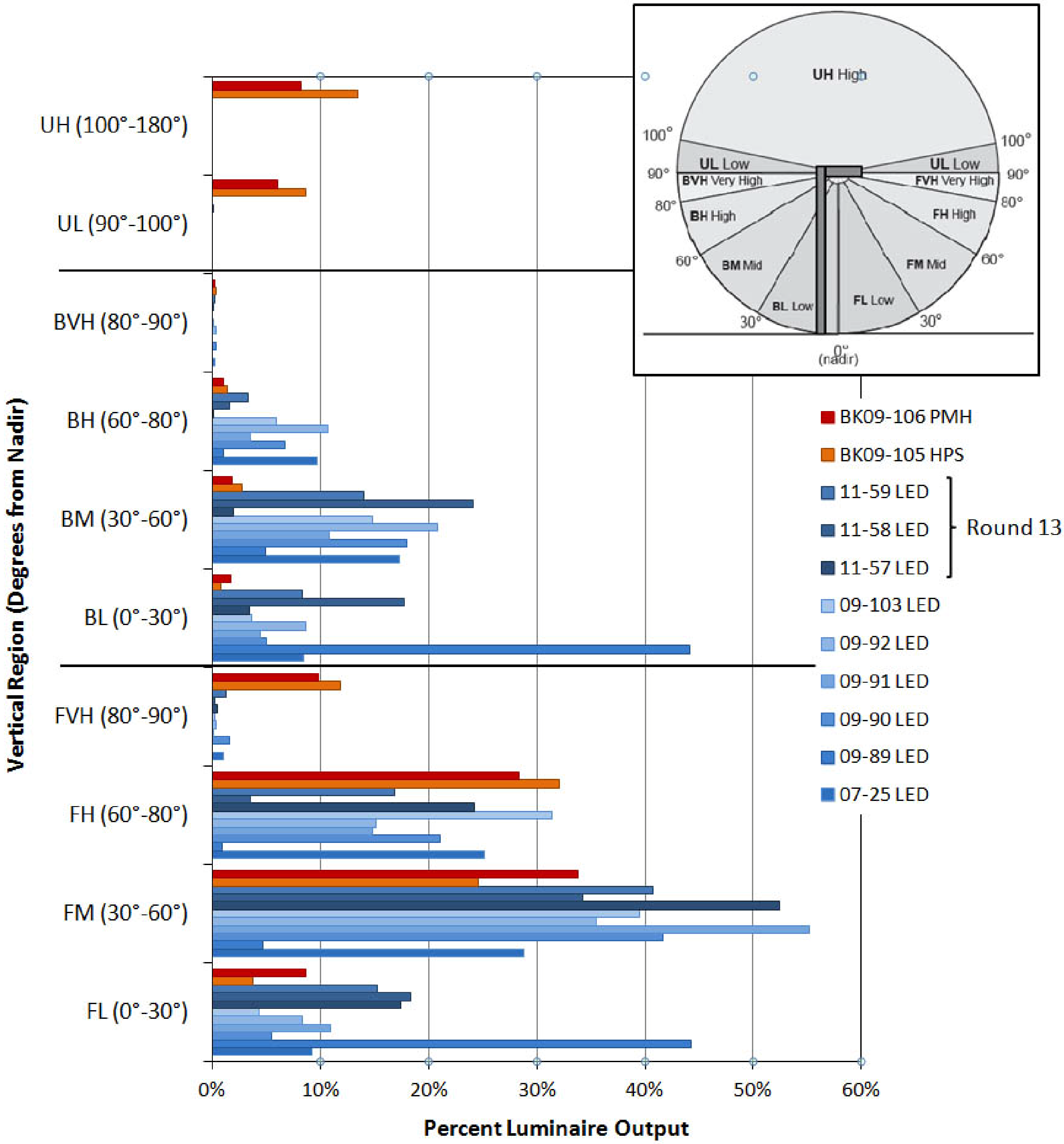


Figure 9. Luminaire Classification System values for wallpack luminaires tested by CALiPER

The LED products in Round 13 have less light in upper regions than the HPS and PMH benchmarks.

Color Characteristics

The CCT of all three LED wallpack luminaires tested in Round 13 are approximately 5100 K, near the center of the range of all LED wallpacks previously tested by CALiPER (4067–6355 K)—note that product 11-59 fell just outside the tolerances for white light established by ANSI C78.377-2008. This appearance is cooler than typical metal halide lamps[11] and significantly cooler than typical HPS lamps (approximately 2100 K). The more neutral white (approximately 3500–4500 K) possible with metal halide and LED products is often preferred, for both for safety and aesthetics.

The CRI of products 11-57 and 11-59 (65 and 69, respectively) was comparable to standard metal halide lamps, whereas the higher CRI of product 11-58 (80) was more comparable to a ceramic arc tube metal halide lamp. All exceed the very poor CRI (< 20) measured for typical HPS lamps. With respect to color characteristics, any of the wallpack LED luminaires tested by CALiPER to date could be suitable for standard outdoor applications and some offer very good color performance. Although color rendition is traditionally considered less critical in exterior applications, it can improve aesthetics and color contrast, thereby enhancing visual performance and security camera functionality.

Lighting Facts and Manufacturer Claims

Of the three LED wallpacks, product 11-58 carries fairly accurate product ratings and accurate equivalency claims, product 11-57 carries accurate performance ratings but inaccurate equivalency claims, and product 11-59 carries highly inaccurate ratings and inaccurate equivalency claims.

All three products tested in Round 13 are listed by the Lighting Facts program, but only product 11-58 included the label on its packaging.[12] Most of the attributes of product 11-58 are not significantly different from the data found on the Lighting Facts label, although the CCT is lower (5101 K measured compared to 5470 K on the Lighting Facts label). Similarly, published and measured photometric data for product 11-57 are within reasonable tolerances. However, this product is marketed as 26 W, while the measured power is 30 W, and it is falsely marketed as a replacement for a 150–200 W metal halide wallpack, whereas it produces less than one half the light output of the 150 W PMH benchmark.

Product 11-59 delivers dramatically fewer lumens than the quantity published by the manufacturer (1,525 lm at 40 W measured compared to 4,000 lm at 40 W listed). The performance is also different from that listed by Lighting Facts (2677 lm at 41 W). This occurs despite the published power draw being comparable, resulting in a significant difference between the tested and published efficacy. The product brochure incorrectly claims that this product replaces a 150–175 W metal halide wallpack.

[11] Metal halide lamps are available with a variety of CCTs, but are most commonly found between 3000 K and 5000 K. In contrast to LED and fluorescent lamps, there is no chromaticity standard for HID lamps.
[12] Product 11-59 is the full cutoff version of a product listed by Lighting Facts. Manufacturers are required to submit data for the lowest performing version/SKU of a product.

2' × 2' Troffer Luminaires

Conventional 2' × 2' troffer luminaires are offered with a variety of optics and are primarily installed recessed into the ceiling to provide direct illumination. These luminaires are selected for flexibility of output and distribution, as well as aesthetics.

Nine different 2' × 2' troffers were tested in Round 13—six LED products and three fluorescent benchmarks. The photometric performance of these products were analyzed in the context of energy efficiency program requirements and in comparison to similar products previously tested by CALiPER. Note that two of the Round 13 fluorescent benchmarks (BK11-49i and BK11-49ii) are the same product but with different lamp configurations.

Background on Conventional 2' × 2' Troffers and Earlier CALiPER Testing

Originally, conventional 2' × 2' troffers incorporated flat, lensed optical systems. The next troffers to enter the market utilized parabolic, egg crate, or mini-cell louvers. After louvered troffers, direct/indirect (basket) troffers entered the market. Although direct/indirect luminaires often have a soft appearance, they typically have lower fixture efficiencies than the other troffers and less sophisticated optical systems. The most recent conventional troffers to the enter the market utilize non-planar (i.e., curved or angled) lenses to both increase the fixture efficiency and enhance the optics of the luminaire. For this reason, these luminaires are often referred to as "high efficiency" troffers.

In previous rounds of CALiPER, five 2' × 2' LED troffers and two conventional troffers were tested. The conventional products included a nine-cell parabolic louver (09-72) troffer and a high-efficiency curved-lens (09-73) troffer, both utilizing very different types of lamps. The parabolic troffer was tested with U-shaped (also known as U-bent) T8 lamps. This lamp is nominally 32 W and works with most energy efficient linear T8 ballasts. The major advantage of the U-shaped T8 lamp is that it maximizes lumen output in the limited area of the 2' × 2' luminaire. The bend in the lamp essentially allows for the equivalent of two normally four-foot long T8 lamps to be placed into the 2' × 2' troffer. Although this configuration maximizes light output, the large form factor (overall cross-section) limits optical design. In contrast, the optical system for the high-efficiency troffer is designed to minimize optical losses so the cross-section of the lamp must be small. Consequently, high-efficiency troffers are typically designed around single-tube linear lamps, rather than U-bent T8 or long biax CFLs. Therefore, high-efficiency troffers typically utilize linear T8, T5, and T5HO lamps. CALiPER tested a high-efficiency 2' × 2' with a two-foot-long T8 lamp (F17T8), which produces approximately half the light output of a four-foot-long T8 lamp (or U-shaped T8 lamp).

The parabolic louver benchmark troffer (BK09-72) with two 32 W U-bent T8 lamps produced 2,541 lm with an efficacy of 44 lm/W, whereas the high-efficiency troffer (BK09-73) equipped with two 17 W T8 lamps produced less light output, 1,706 lm, but with a higher luminaire efficacy, 49 lm/W. Although the 17 W lamps produce only 50% of the lumens produced by 32 W lamps, the optical system in the high-efficiency troffer is designed around the linear lamp, contributing to a better fixture efficiency. This increased fixture efficiency is one reason the luminaire efficacy for the high-efficiency troffer is approximately 10% greater than for the parabolic troffer. The selection of fluorescent troffers included in Round 13 aimed to represent products with more efficacious lamps and/or higher fixture efficiencies.

The five LED troffers tested in previous rounds exhibited a range of lumen outputs (2,100 to 3,500 lm) and luminaire efficacies (41 to 79 lm/W). Although the LED troffers tested in previous rounds typically produced equal or more lumens than the fluorescent benchmarks, the luminaire efficacy for four of the five LED products was similar to the conventional troffers. The previously tested LED troffers were primarily flat-lens luminaires with a narrow cosine distribution, resulting in lower spacing criteria than for conventional troffers.

Light Output and Efficacy

Initial lumen output versus efficacy for 2' × 2' troffer luminaires is shown in Figure 10. Four of the 2' × 2' LED luminaires [three from Round 13 (65, 66, and 80 lm/W) and one from Round 9 (79 lm/W)] have greater luminaire efficacies than any of the benchmark fluorescent luminaires (maximum fluorescent efficacy of 64 lm/W). When compared to a fluorescent product with equal or similar light output, five out of six LED 2' × 2' troffers have greater luminaire efficacy than the fluorescent troffer.

The fluorescent luminaires tested produce a broad range of light output (1,700 to 4,100 lm). The Round 13 LED luminaires exhibited lumen output in the low end of the fluorescent range (1,400 to 3,000 lm), whereas the LED luminaires from earlier rounds had outputs in the middle of the fluorescent troffer range (2,100 to 3,500 lm).

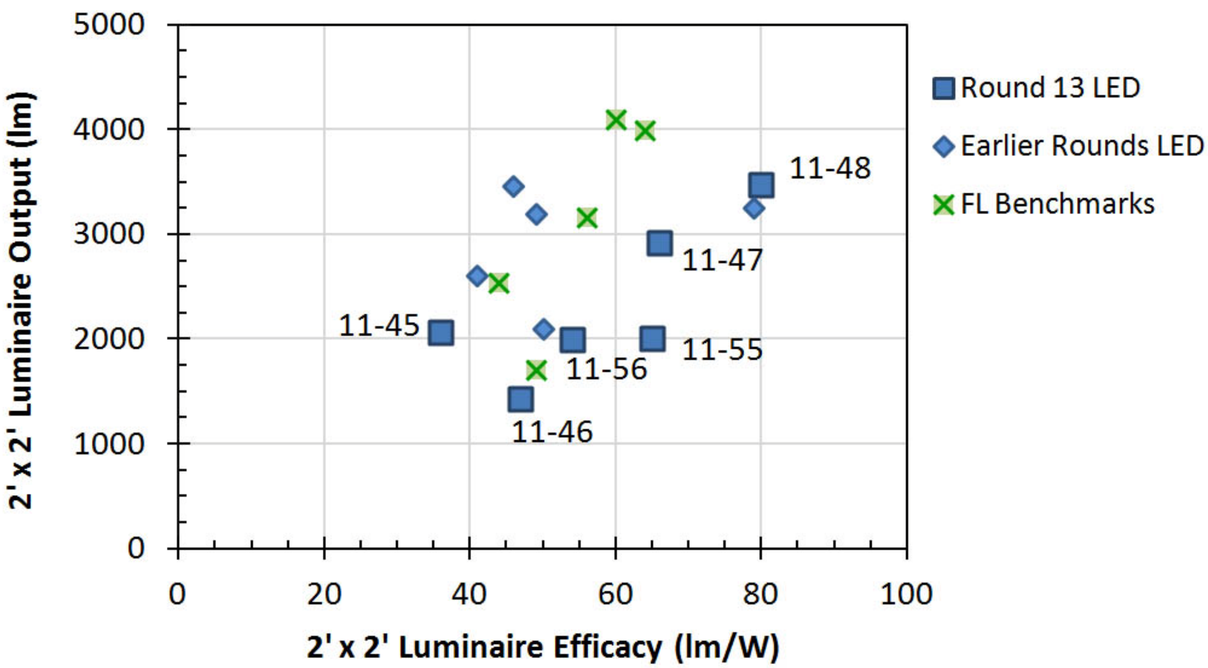


Figure 10. Luminaire efficacy for 2' × 2' troffers versus initial luminaire output

In general, as the CALiPER rounds have progressed, luminaire efficacy has increased while lumen output has either decreased or remained the same. There are many different explanations for this trend. For example, the selection process may have covered a set of products with lower lumen output, or manufacturers may be focusing on luminaire efficacy rather than luminaire output. Along those lines, manufacturers may be choosing to reduce lumen output as a method of minimizing glare.

Notably, the reported luminaire output values are initial lumens rather than maintained lumens. Lifetime lumen depreciation for linear fluorescent lamps is minimal (above 0.90), whereas the lamp lumen depreciation factor for two-foot-long biax CFLs is approximately 0.85. In contrast, LED luminaires are expected to exhibit lumen depreciation over the course of their lifetime. Thus, life-cycle cost comparisons should account for the different expected lifetimes and different lumen depreciation characteristics of each light source.

Energy Efficiency Programs

The ENERGY STAR program has not developed a specification for 2' × 2' luminaires at this time.[13] However, two other prominent programs recently developed performance requirements: DLC (see page 9) and DOE's Commercial Building Energy Alliance (CBEA). In 2010, CBEA started a project for high-efficiency 2' × 2' troffers that use either LED or fluorescent sources.[14] The CBEA specification is very similar to the DLC QPL—Table 2 compares the two specifications. Of the six LED luminaires tested in Round 13, only product 11-48 meets the minimum lumen output required by both specifications. Product 11-48 also meets the luminaire efficacy requirements of both specifications and the CBEA criterion for maximum input power. However, it fails to meet the spacing criteria requirements of the DLC QPL specification in both the 0–180° and 90–270° directions. It does meet the CBEA spacing criterion requirements.

[13] The Version 1.0 ENERGY STAR Luminaires specification was finalized on February 16, 2011 and will take effect on April 1, 2012. The Luminaires V1.0 specification will replace the Residential Light Fixtures (RLF V4.2) and Solid-State Lighting Luminaires (SSL V1.3) specifications. After September 15, 2011, the Luminaires V1.1 specification will be the primary specification available for the qualification of luminaires; certification bodies will be asked to stop certifying using the old specifications with one exception: SSL V1.3 will be available for the qualification of SSL ceiling-mounted luminaires with diffusers, SSL outdoor wall-mounted porch lights and SSL residential grade task lights. This exception will be in place until IES LM-82 is published and LM-82 testing is available at EPA-recognized laboratories. Version 1.1 will only be applicable to the following commercial grade luminaires: accent lights, downlights, under cabinet lights, and portable desk lights.

[14] http://www1.eere.energy.gov/buildings/alliances/high_efficiency_troffers.html. The CBEA is a DOE program that enables similar end user groups (e.g., retailers, hospital(s), commercial developers) to focus on using collective knowledge and potential buying power to leverage new energy efficient products and practices.

Table 2. Summary of CBEA and DLC Criteria for 2' × 2' Luminaires

	Light Source	Light Output (lm)	Spacing Criterion 0°–180°	Spacing Criterion 90°–270°	Input Power (W)	Luminaire Efficacy (lm/W)	CCT (K)	CRI
DLC	LED	≥ 3000	1.15–1.25	1.20–1.60	-	≥ 60	≤ 5000	≥ 80
CBEA	LED	≥ 3200	1.10–1.40	1.10–1.40	≤ 54	≥ 69	2700–6500[1]	≥ 80
CBEA	Fluor.	≥ 3000	1.10–1.40	1.10–1.40	≤ 54	≥ 69	2700–6500[2]	≥ 80

[1] Allowable CCTs are 2700 K, 3000 K, 3500 K, 4000 K, 4500 K, 5000 K, 5700 K, 6500 K, as specified by ANSI C78.377-2008

[2] Allowable CCTs are 2700 K, 3000 K, 3500 K, 4000 K, 5000 K, 6500 K, as specified by ANSI C78.377-2008

Figure 11 provides the same plot of luminaire light output and efficacy as in Figure 10, with the addition of the CBEA and DLC QPL 2' × 2' troffer requirements for luminaire efficacy and luminaire output. LED troffer 11-48, along with one LED troffer tested in a previous round, meet or exceed the CBEA and DLC QPL requirements for luminaire efficacy and light output. Interestingly, none of the benchmark fluorescent troffers tested to date meets the fluorescent-specific CBEA requirements for luminaire efficacy, although two of the benchmarks achieve or exceed the 60 lm/W efficacy level required by the DLC QPL for LED products. Both the CBEA and DLC QPL specifications have other requirements besides luminaire efficacy and luminaire output; prospective products should be evaluated on all applicable metrics.

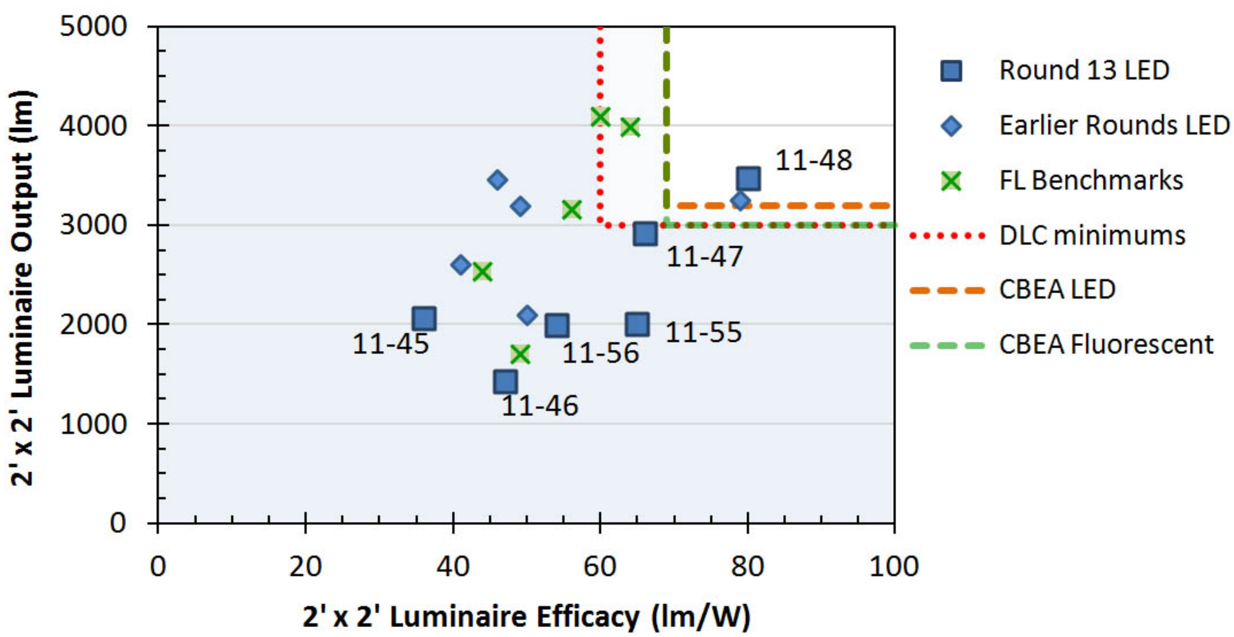


Figure 11. Initial luminaire efficacy and output for 2' × 2' troffers versus energy efficiency program requirements

Distribution and Spacing Criteria

In general, the 2' × 2' LED luminaires approximated cosine distributions and were similar to—though in most cases narrower beamed than—the fluorescent direct/indirect benchmarks (11-49 and 11-62). Figure 12 compares the LED troffers with the three Round 13 fluorescent benchmarks. The polar plots through the plane of maximum intensity are all plotted at the same scale for side-by-side comparison. For products with significant differences in luminaire efficacy and light distribution, input power cannot be used as an indicator of light output or intensity. Product 11-45 (58 W) has nearly the same intensity as product 11-46 (30 W), and product 11-48 (43 W) produces the greatest center beam intensity (even more than the fluorescent benchmarks).

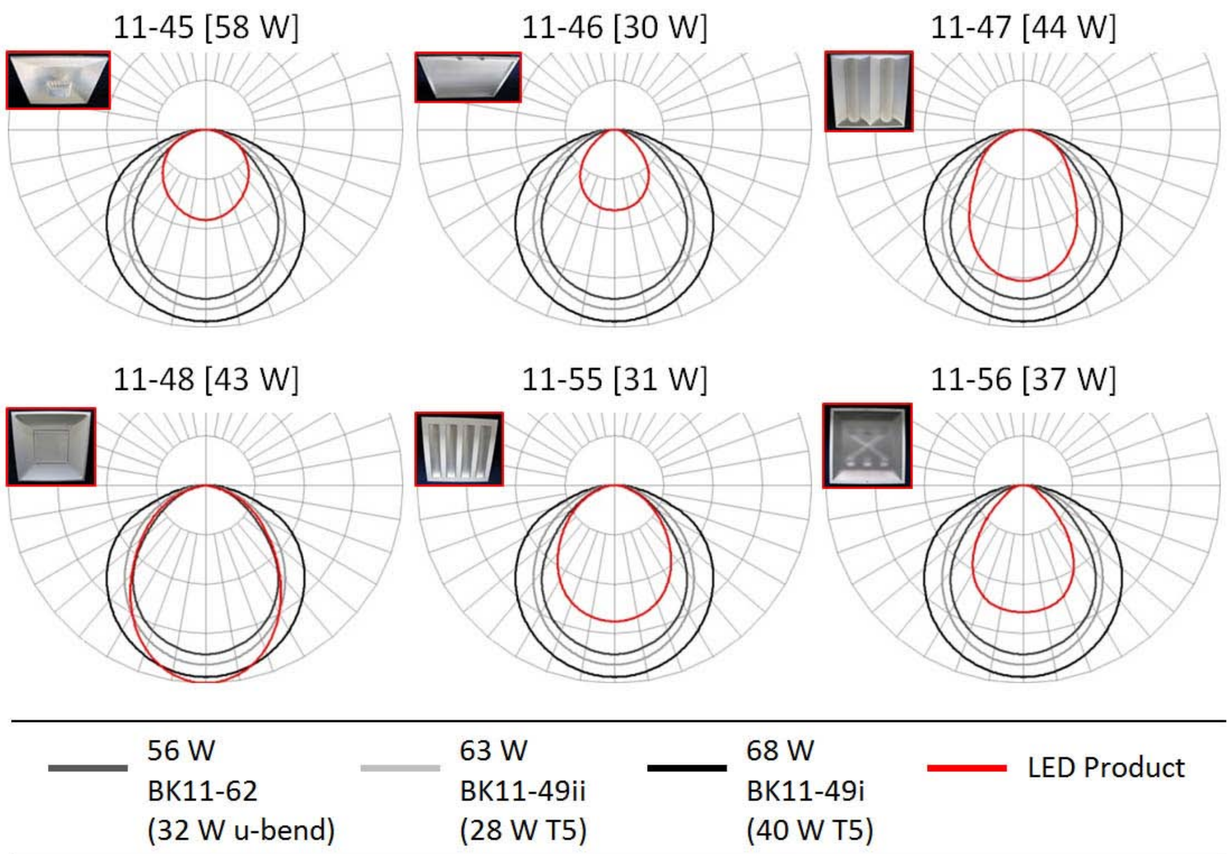


Figure 12. Polar plots for fluorescent 2' × 2' vs. LED products, through the plane of maximum intensity
The distributions of the LED products tested in Round 13 are similar to the benchmarks, but often the maximum candela is less and fewer candela are emitted at high angles. The maximum for the plots is 1,486 cd.

Both the CBEA and DLC specifications include requirements for spacing criteria (SC). Except for one LED 2' × 2' from a previous round (09-41), all the LED and fluorescent luminaires tested thus far by CALiPER meet the CBEA SC requirements (1.10 to 1.40 for both 0–90° and 90–270°). Interestingly, product 09-41 is the one that meets the CBEA requirements for luminaire efficacy and light output. The DLC specification for SC differs from the CBEA in that it requires

1.15 to 1.25 for 0–90° and 1.20 to 1.60 for 90–270°. Figure 13 compares the tested 2' × 2' troffers to the range allowed in both the CBEA and DLC specifications. Most troffers meet the CBEA requirements, but not all troffers meet the more stringent DLC requirements. It should be noted that SC is not a performance threshold—higher does not mean better. SC is a tool used by designers and engineers to lay out fixtures for uniformity. Ideally, a broad range of SC is needed to allow for design flexibility.

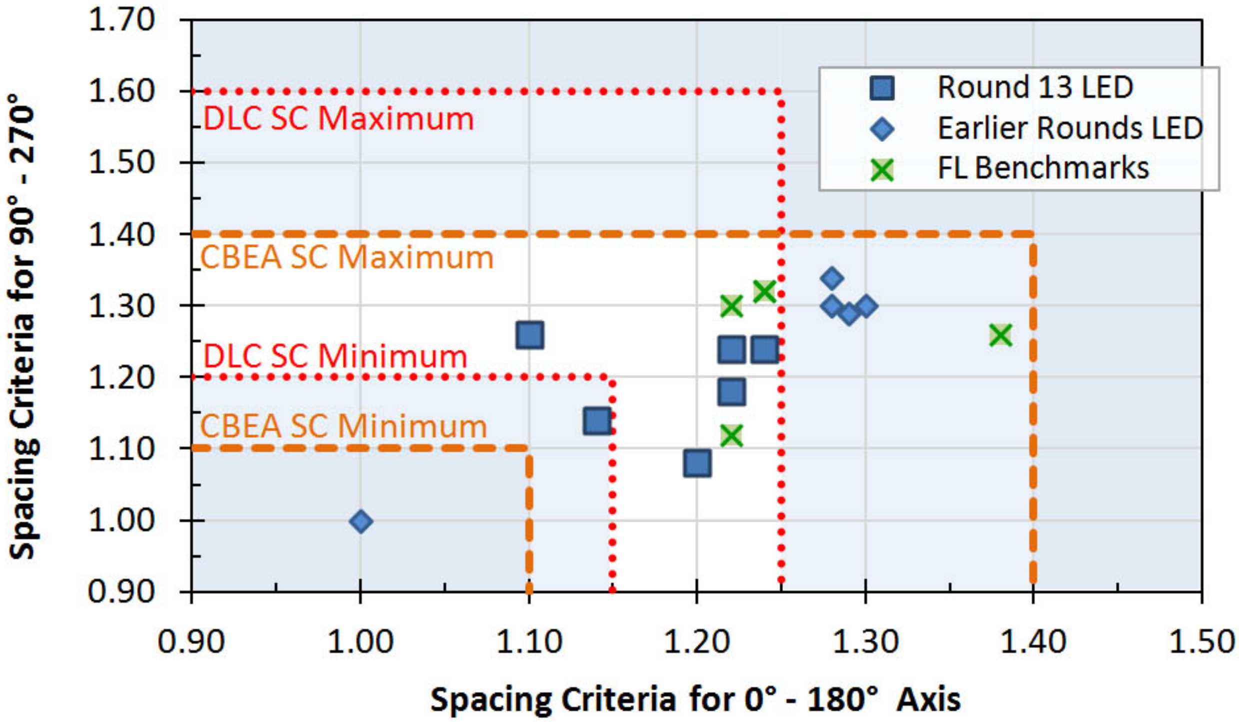


Figure 13. Comparison of spacing criteria for tested 2' × 2' troffers

Color Characteristics

The CCT of all six 2' × 2' LED troffer luminaires tested in Round 13 can be categorized as either 3000 K or 3500 K, according to ANSI C78.377-2008. The most common CCT for 2' × 2' troffers tested in both Round 13 and in previous rounds is 3500 K. The D_{uv} values for all the Round 13 LED troffer luminaires were within the tolerances established by ANSI C78.377-2008.

The CRI for all the Round 13 LED troffers was greater than 70 and half were greater than 80. All the fluorescent benchmarks had CRIs greater than 80.

Comparison to 2' × 4' troffers

The CALiPER program has yet to test 2' × 4' LED luminaires, but plans to in the future. CALiPER has tested conventional 2' × 4' luminaires using LED replacement lamps as well as conventional luminaires with linear fluorescent lamps. Of the four CALiPER-tested benchmark 2' × 4' troffers equipped with T8 lamps, the luminaire output ranged from 2,700 to 4,800 lm. The luminaire efficacy for the benchmark 2' × 4' troffers ranged from 63 to 74 lm/W. Three of the 2' × 2' LED troffers tested in Round 13 met or exceeded the luminaire efficacy of some the 2' × 4' fluorescent troffer benchmarks, and two of the 2' × 2' LED troffers exceeded the luminaire light output of the single lamp 2' × 4' fluorescent benchmark.

Glare is typically a bigger concern with 2' × 2' troffers than with 2' × 4' troffers because the luminous area of the 2' × 2' is smaller. For instance, U-shaped lamps might produce as many lumens as four-foot linear lamps, but the light is more densely concentrated, resulting in more potential for glare. 2' × 2' fluorescent troffers rarely outperform 2' × 4' troffers with respect to luminaire efficacy; however, they are usually specified because their smaller size and symmetry allow for flexibility in ceiling layout.

Manufacturer Claims

Five of the six 2' × 2' LED troffers performed fairly well with respect to manufacturer specifications for light output and efficacy (within 10–15%), and two products actually exceeded manufacturer specifications. Only one of the LED troffers was listed on Lighting Facts, and it met or exceeded all the values on its Lighting Facts label. One LED troffer performed very poorly compared to manufacturer claims, producing less than half the claimed light output. The performance of the various LED troffers compared to manufacturer claims is summarized as follows:

- ↑ The specification sheet for product 11-45 included a Lighting Facts label that listed a lumen output value identical to what CALiPER tested. However, the power measured was lower than stated on the label, which means that the luminaire efficacy was greater than actually claimed. Also, the measured CRI was 78, while the label claimed only 73. It is possible that the luminaire was improved but the specification sheet and label were not updated accordingly.

- ↑ The manufacturer of product 11-55 claimed fewer lumens than what CALiPER measured—the CALiPER measurements were 20% greater than the specification sheet. However, the measured power was the same as the specification sheet. Therefore, the luminaire efficacy tested was greater than the manufacturer's data. Again, one possible cause of this difference is that more efficacious LEDs were installed in the luminaire and the specification sheet was not updated.

- – The values in the specification sheet for product 11-46 were nearly identical to those measured by CALiPER for power and light output, but the measured CRI was 73, whereas the specifications claimed a CRI of 85. The manufacturer literature provides a variety of equivalency claims that are inconsistent and not easily understood. On the specification sheet, the manufacturer claimed that the luminaire was equivalent to one 32 W tube. It was not obvious if the manufacturer was suggesting replacing a single-lamp four-foot-long fixture with their 2' × 2' LED troffer or, if the manufacturer was suggesting that a single-tube fluorescent 2' × 2' troffer exists. CALiPER did not test (nor could it easily find) a single lamp, U-bent, 32 W troffer. However, fluorescent benchmark 09-73 uses two F17T8 lamps (a liberal approximation for a single 32 W U-tube). Product 11-46 produces 84% of the light of the fluorescent benchmark (09-73). The 16% difference in output might be attributed to optical system, ballast factor, or lamp differences (e.g., a 2'' version versus a 4' version). Thus, this particular equivalency claim might be close to accurate, however, the webpage, which implies equivalency to a 40 W fluorescent, would be misleading or inaccurate.

– The manufacturers' claims for products 11-47 and 11-48 were close to what CALiPER measured. The manufacturer's specification sheet for product 11-47 claimed the luminaire produced 3,295 lm and CALiPER measured 2,915 lm, or 88% of claimed lumens. The manufacturer's specification sheet for product 11-48 claimed the luminaire produced 3,200 lm and CALiPER measured 2,924 lm, or 91% of claimed lumens.

↓ Of the LED troffers tested in Round 13, only product 11-56 was significantly worse than the specified performance. The measured values for product 11-56 were 82% of claimed input power, 44% of claimed lumens, and thus 54% of luminaire efficacy. The manufacturer made a number of vague and misleading equivalency claims, for example, claiming that the product replaces 60–120 W conventional lamps, but failing to identify the type of light source. The specification sheet for this product did not reference IES LM-79.

The benchmark luminaires achieved light output and efficacy levels roughly 10–15% less than would be expected based on manufacturers' claims and taking into account the lamps, ballasts, and troffer configurations. The claims for product BK11-62 were roughly 90% of the measured lumens and rated input power was the same as measured. The claims for product BK11-49 were 85% of the measured lumens in CALiPER. The difference of 10–15% between conventional manufacturer claims and measured values has been seen in most other CALiPER reports for benchmark products and might, in part, be attributed to measuring the entire conventional luminaire via absolute photometry rather than relative photometry.

Conclusions from Round 13 of Product Testing

CALiPER Round 13 focused on three types of LED luminaires for commercial and industrial applications: high-bays, wallpacks, and 2' × 2' troffers. When compared to similar products using conventional light sources such as fluorescent, HPS, or metal halide, the LED luminaires provided similar or better color characteristics and comparable or better luminaire efficacies, on average. Some of the LED luminaires also provided equal or better light output and preferable distributions. There were still, however, large differences in performance across the LED luminaires, with some products not performing as rated and many not meeting manufacturer equivalency claims.

Based on Round 13 testing of five LED high-bay luminaires, a metal halide benchmark, and a fluorescent benchmark:

- Two products tested (11-51 and 11-52) significantly outperformed the benchmark products in terms of light output and efficacy, although they had somewhat different distributions. They were superior to the pulse-start quartz arc tube metal halide benchmark concerning color characteristics, but inferior to the fluorescent benchmark.

- Both products 11-51 and 11-52 met or came very close to meeting the DLC QPL criteria —product 11-51 had a CRI of 69 compared to a DLC QPL required minimum of 70.

- Three LED high-bays (11-51, 11-52, and 11-61) performed as claimed in product literature.

- Two products that made explicit equivalency claims (11-50 and 11-60) failed to adhere to those statements. The performance characteristics, such as lumen output and efficacy, of product 11-50 were significantly worse than reported by the manufacturer. No photometric performance values were provided in product literature for product 11-60.

- Although the high-bay products tested in Round 13 all offered broader distributions than those tested in Round 11, they did not match the performance of the metal halide benchmark.

Based on Round 13 testing of three LED wallpack luminaires, and compared to previous CALiPER testing of LED and benchmark wallpacks:

- The Round 13 LED wallpacks achieved luminaire efficacies comparable to previously tested LED wallpacks, but with much lower power levels; therefore, they produced proportionally lower average illuminance. All three provided higher efficacy than the PMH benchmark and two out of three exceeded the efficacy of the HPS benchmark.

- Round 13 wallpacks 11-57 and 11-59 claimed to replace 175 W metal halide wallpacks, but actually produced less than half the initial light output of the 150 W PMH benchmark.

- All three wallpacks were listed by Lighting Facts. Two of the three products met the performance values on their Lighting Facts label, but the third product (11-59) did not.[15] All three products made equivalency claims, but those claims were false for two of the products.

- All three products achieved relatively uniform light distributions, so for installations that are designed to achieve minimum (as opposed to average) illuminance levels with these particular luminaires, hot spots and wasted light can be minimized.

Based on Round 13 testing of six 2' × 2' LED troffers and three fluorescent 2' × 2' recessed troffers, and considering earlier CALiPER tests of 2' × 2' recessed troffers:

- LED troffers tested in Round 13 and previous rounds were more efficacious and produced more light than some, but not all, tested fluorescent luminaires. On average, the 2' × 2' LED troffers had higher efficacies and lower light output than the fluorescent troffers, but there was a wide range of performance for both fluorescent and 2' × 2' LED troffers.

- Luminaire efficacy generally has increased as more CALiPER rounds have been completed, but luminaire output has not shown an increasing trend for 2' × 2' troffers. This might be because of the luminaires selected, or because the products are already achieving targeted application light output levels, or because manufacturers are not focusing on increasing luminaire output. Compared to products with similar light output levels, all but one of the Round 13 LED 2' × 2' troffers exceeded the efficacy of the fluorescent 2' × 2' troffers.

- None of the fluorescent troffers tested met the CBEA fluorescent specification requirements. Two LED products tested met the CBEA LED specification for efficacy and lumen output, but did not meet all the distribution requirements.

- LED products tested in Round 13 had nominal CCTs of 3000 K or 3500 K and met the ANSI requirements. The CRIs for the LED luminaires were 70 or greater, with half over 80. The conventional luminaires tested had CRIs over 80.

- Four out of five of the performance claims made by 2' × 2' LED luminaire manufacturers approached or exceeded what CALiPER measured. The luminaire listed in Lighting Facts actually drew less power than CALiPER measured, achieving a better efficacy and CRI than indicated on the Lighting Facts label. Color measurements for CCT were as claimed for all LED troffers, although one of the products did not meet claimed CRI.

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[15] The Lighting Facts policies define measures to avoid misuse of the Lighting Facts Label. Cases of products not meeting Lighting Facts listed performance levels are investigated and inconsistencies must be rectified or products and manufacturers are at risk of being delisted. http://www.lightingfacts.com/.

Overall, Round 13 of testing continued to show improvement, demonstrating that LED luminaires can compete with conventional products even in application areas requiring high light output. The average luminaire efficacy of products continued to increase and color quality continued to improve. A wide range of performance, particularly in distribution characteristics, can be observed in LED luminaires, so buyers and specifiers must be wary, require LM-79 test results, and carefully compare photometric performance from the LM-79 test results to known benchmarks and application requirements.

Accurate reporting and product literature is still a concern, both for LED products and conventional lighting. In all cases, particularly for luminaires, care must be taken to know exactly which version of a product is represented in photometric data and not to assume that versions with other SKUs have similar performance. Most of the products found to have accurate manufacturer claims included detailed photometric performance specifications referencing the IES LM-79 standard and avoiding the use of equivalency statements. Products that omitted detailed photometric performance data and made vague equivalency claims failed to meet expectations in most cases. A majority of the equivalency claims made by Round 13 products were found to be misleading or false, thus buyers and specifiers should examine and understand photometric performance of both the LED products and conventional luminaires that they may be replacing, rather than relying on equivalency statements in product literature. To better understand equivalencies and appropriate levels of performance, criteria established by efforts such as the DOE CBEA and the DLC are available, along with GATEWAY Demonstrations and many other resources.

Next Steps for the Industry and CALiPER Efforts

Upcoming CALiPER testing will examine LED options for downlight retrofitting, flood lights, linear pendants, and a variety of options for addressing applications that currently use halogen MR16 lamps in track systems. LED luminaires designed to replace 2' × 4' and 1' × 4' troffers will also be examined in coming rounds. Further, a new series of tests on LED replacement lamps available through big-box retailers will be conducted to see what progress has been made since similar testing conducted in 2010-11.[16]

Recent and ongoing CALiPER exploratory research addresses flicker, dimming, power quality and long-term testing. CALiPER continues to provide support to testing standards communities through exploratory testing and reporting and through the annual CALiPER Standards and Testing Roundtable meetings.[17]

The CALiPER program enhances the DOE SSL commercialization support efforts in many ways, working closely with programs such as the Lightings Facts label, design competitions, GATEWAY demonstrations, the CBEA, retail sector education efforts, standards development organizations, and the development of energy codes and regulations.

[16] See the DOE CALiPER Special Summary Report: Retail Replacement Lamp Testing, April 2011. http://www1.eere.energy.gov/buildings/ssl/reports.html

[17] The 2011 CALiPER Roundtable was conducted in San Antonio, Texas, April 4-5, 2011. 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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