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

CALiPER

Application Summary Report 18:

LED Recessed Wallwashers

October 2012

Prepared for:

Solid-State Lighting Program
Building Technologies Program
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

Prepared by:

Pacific Northwest National Laboratory

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service
5301 Shawnee Rd., Alexandria, VA 22312
ph: (800) 553-NTIS (6847)
email: orders@ntis.gov <http://www.ntis.gov/about/form.aspx>
Online ordering: http://www.ntis.gov

This document was printed on recycled paper.
(8/2010)

1 Preface

The U.S. Department of Energy (DOE) 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 of North America [IES] approved method LM-79-08[1]) conducted by accredited, independent laboratories.[2] Results from CALiPER testing are available to the public via detailed reports for each product or through summary reports, which assemble data from several product tests and provide comparative analyses.[3]

It is not possible for CALiPER to test every SSL product on the market, especially given the rapidly growing variety of products and changing performance characteristics. Starting in 2012, each CALiPER summary report focuses on a single product type or application. Products are selected with the intent of capturing the current state of the market—a cross section ranging from expected low to high performing products with the bulk characterizing the average of the range. The selection does not represent a statistical sample of all available products. To provide further context, CALiPER test results may be compared to data from LED Lighting Facts,[4] ENERGY STAR® performance criteria,[5] technical requirements for the DesignLights™ Consortium (DLC) Qualified Products List (QPL),[6] or other established benchmarks. CALiPER also tries to purchase conventional (i.e., non-SSL) products for comparison, but because the primary focus is SSL, the program can only test a limited number.

It is important for buyers and specifiers to reduce risk by learning how to compare products and by considering every potential SSL purchase carefully. CALiPER test results are a valuable resource, providing photometric data for anonymously purchased products as well as objective analysis and comparative insights. However, LM-79-08 testing alone is not enough to fully characterize a product—quality, reliability, controllability, physical attributes, warranty, compatibility, and many other facets should also be considered carefully.

For more information on the DOE SSL program, please visit http://www.ssl.energy.gov.

[1] IES LM-79-08, *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. For more information, visit http://www.iesna.org/.
[2] CALiPER only uses independent testing laboratories with LM-79-08 accreditation that includes proficiency testing, such as that available through the National Voluntary Laboratory Accreditation Program (NVLAP).
[3] CALiPER summary reports are available at http://www.ssl.energy.gov/reports.html. Detailed test reports for individual products can be obtained from http://www.ssl.energy.gov/search.html.
[4] LED Lighting Facts is a program of the U.S. Department of Energy that showcases LED products for general illumination from manufacturers who commit to testing products and reporting performance results according to industry standards. The DOE LED Lighting Facts program is separate from the Lighting Facts label required by the Federal Trade Commission (FTC). For more information, see http://www.lightingfacts.com.
[5] ENERGY STAR is a federal program promoting energy efficiency. For more information, visit http://www.energystar.gov.
[6] The DesignLights Consortium Qualified Products List is used by member utilities and energy-efficiency programs to screen SSL products for rebate program eligibility. For more information, visit http://www.designlights.org/.

2 Report Summary

This report analyzes the independently tested performance of 17 LED recessed wallwasher luminaires having a nominal aperture size of 6 inches or less. Each of the luminaires was anonymously purchased in February or March 2012. These are the first LED recessed wallwashers to be tested by the CALiPER program. The products had a wide variety of physical attributes and a similar diversity in luminous intensity distribution and lumen output. This reflects the varied applications in which recessed wallwashers are used.

The lumen output from each of the products was generally equivalent to luminaires using up to 32 W compact fluorescent (CFL) or 20 W metal halide lamps, with luminous efficacies between 23 and 64 lm/W. Several products were measured to have lumen output equivalent to 42 W CFL or 35 W metal halide lamps, although direct comparisons are difficult because the luminaire efficiency of conventional recessed wallwashers covers a wide range. Further, the luminous intensity distributions—an important element of equivalency—of recessed wallwashers can be highly variable, as was seen for both the LED and conventional products included in this report. In general, the color quality attributes were appropriate for the intended applications. Continued improvements in efficacy and lumen output will help make LED recessed wallwashers competitive across a broader range of applications.

Compared to standard downlights, the market for recessed wallwashers is small. Nonetheless, having compete families of products—that is, augmenting a collection of downlights in different lumen packages with wallwashers having a similar form factor—is a valuable asset for lighting specifiers. Thus, continued development of LED recessed wallwashers will aid the broader market adoption of LED products.

3 Background

Recessed wallwashers are distinguishable from standard downlights because they use an optical system to create an asymmetric distribution of light, which is primarily used to illuminate vertical surfaces near the luminaire. Typically, the *room side* of a given wallwasher produces the same distribution as its matching downlight, whereas the *wall side* of the luminaire delivers a greater proportion of its output at higher vertical angles. Thus, a recessed wallwasher may be used in lieu of a standard downlight to provide illumination higher on a nearby wall and more evenly across the wall. Accordingly, it is often possible to use fewer wallwashers than standard downlights to uniformly illuminate a vertical surface, and scalloping on the wall is likely to be lessened.

Typically, recessed wallwashers are offered as part of a larger family of products, sharing non-optical characteristics (e.g., trim, aperture size, housing) with standard downlights. A comparison of an example recessed wallwasher and two standard recessed downlights (medium and wide distribution) from the same product family is shown in Figure 1. These products share the same LED array and other concealed components, but use different reflectors and thus have different luminous intensity distributions. They emit 1,312 lumens (standard medium), 1,426 lumens (standard wide), and 1,407 lumens (wallwasher), and have matching color characteristics. For both of the standard downlights—only one is pictured—the reflector and resulting luminous intensity distribution are symmetric. The distribution of the wallwasher is similar to the wide distribution downlight in the 90°–270° plane, and for the room side of the 0°–180° plane; however, the *kick reflector*—visible on the left side of the wallwasher photograph—redirects light that would have otherwise been emitted at low vertical angles to higher vertical angles. This gives the wallwasher an asymmetrical distribution.

As with the more general category of recessed downlights—which were discussed in *CALiPER Application Summary Report 14: LED Downlight Retrofit Units*—the recessed wallwasher category encompasses a broad range of luminaires that share the common attribute of being installed above the ceiling and emitting light through an aperture. Importantly, the recessed wallwasher category is distinct from adjustable recessed downlights and track lighting, which are sometimes used for similar purposes. The asymmetrical distribution that characterizes recessed wallwasher luminaires may be created using a number of different optical systems,

Figure 1. A comparison of standard recessed downlights (medium and wide distributions) and a recessed wallwasher from the same product family. The wallwasher uses a kick reflector (seen in center image) to redistribute some lumens from lower to higher vertical angles; this is visible on the right hand side of the polar plot. In particular, note the difference between the blue and green plots.

including reflectors and lenses, among others. The light source itself may also be mounted so that it is tilted and not parallel with the ceiling plane. LED recessed wallwashers may even introduce new configurations, such as distributed optics at the LED package level, which may reduce optical losses.

Owing to their specialized characteristics, recessed wallwashers are predominantly used in commercial applications, rather than residential. They most often use compact fluorescent (CFL) lamps, although halogen and metal halide lamps may also be used, and their performance—efficacy, color characteristics, output, etc.—is highly dependent on the specific lamp installed. One notable concern for recessed wallwashers using CFL lamps is the lamp geometry: rather than a point source, CFL lamps are large area sources. This makes optical control far more difficult and leads to low luminaire efficiencies, often less than 50%. Additional limitations of CFL technology that are common to all luminaire types are also applicable to wallwashers. These include dimming and startup limitations, or the relationship between lumen output and lamp orientation—which can be either horizontal, angled, or vertical. These limitations provide an opportunity for emerging technologies such as LED to rapidly gain market share.

Some performance characteristics are also influenced by the luminaire design. For example, when CFL or other omnidirectional lamps are used, total luminaire efficacy can be affected by the efficiency of the optical system, and a significant portion (50% or more) of the lumens emitted by the lamp can be trapped in the luminaire. Major factors affecting downlight and wallwasher luminaire efficiency include: (1) the finish and/or color of the reflector (also known as the cone)—clear is generally more efficient than colored, and white is more efficient than black in grooved baffles and trims; (2) the optical system used to distribute the light and mitigate glare (e.g., reflectors, lenses, or baffles); (3) the orientation of the lamp, depending on the type; and (4) the size of the aperture.

Although the recessed wallwasher market is much smaller than the broader recessed downlight market, it is nonetheless an important category for SSL technology. The availability of complete families of products is frequently important to designers and specifiers because it enables consistency within installations where downlights and wallwashers may be intermingled. As with standard downlights, LED recessed wallwashers can overcome some of the limitations of CFL and metal halide products. At this time, performance varies widely; however, the variation may be justified to some extent because lumen output, luminous intensity distribution, and other factors must differ according to the wide range of applications in which recessed wallwashers are used.

4 Results

CALiPER LED Recessed Wallwasher Test Data

This report analyzes the independently tested performance of 17 LED recessed wallwasher luminaires. Each of the luminaires was anonymously purchased in February or March 2012. In this report, they are collectively referred to as the Series 18 products. These are the first LED recessed wallwashers to be tested by the CALiPER program. For more on the product selection parameters, both in general and as they pertain to this group of products, see Appendix A.

The Series 18 products are shown in Figure 2. Nominal aperture size ranged from approximately 3 to 6 inches, and the exact shape and construction of each luminaire varied substantially. The optical systems used to obtain

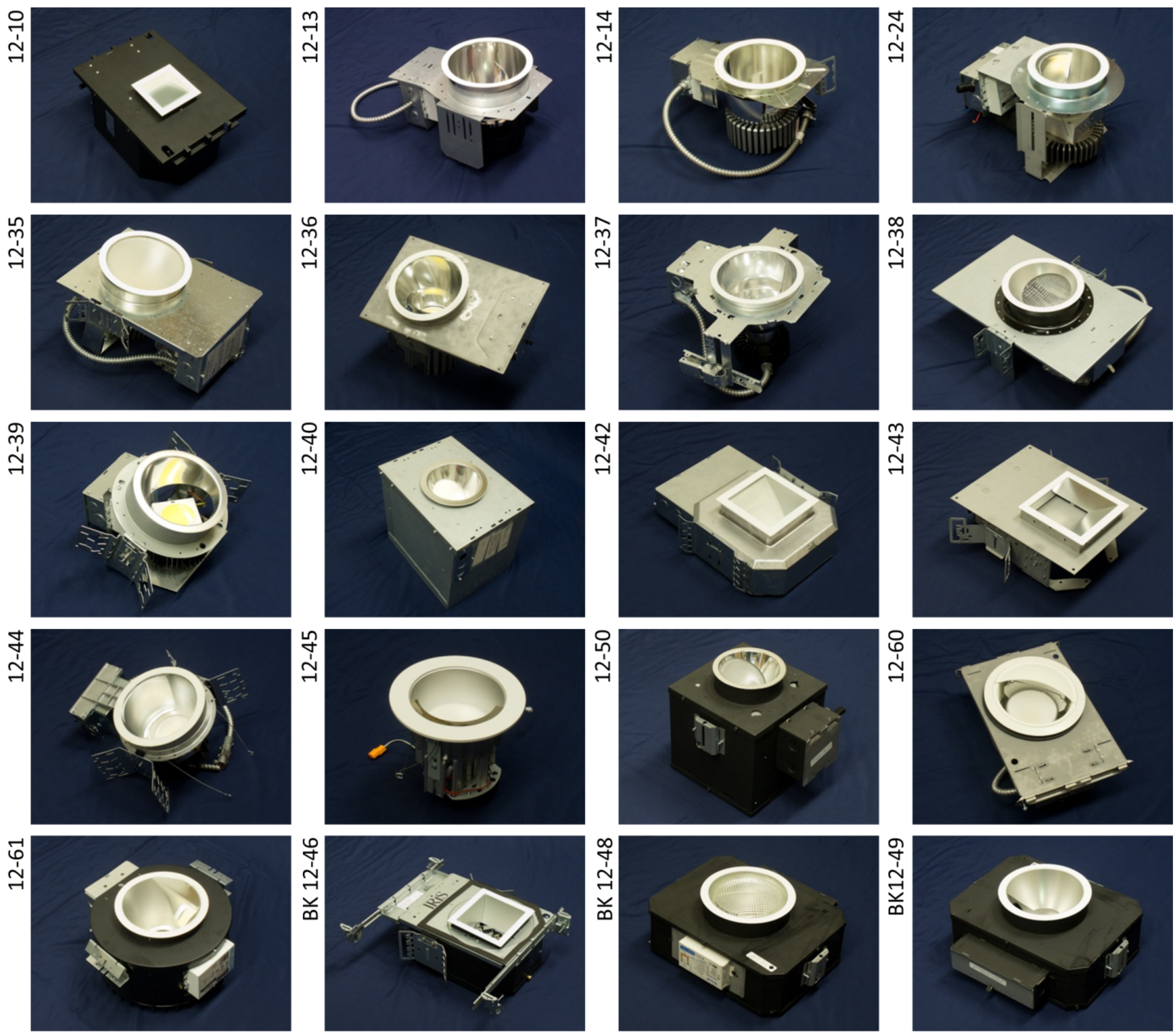

Figure 2. Photographs of the products included in this series of CALiPER testing. The products used a variety of optical systems to shape their luminous intensity distribution. Product BK 12-47, not shown, is very similar to BK 12-46 but uses a different lamp.

an asymmetric distribution were likewise different for each luminaire, as is the case with conventional recessed wallwasher luminaires.

All of the units were tested according to IES LM-79-08, using both an integrating sphere and goniophotometer. For each of the Series 18 products, the difference in measured lumen output between the two methods was less than 5%; for all but one product, the difference was less than 3%. Except for luminous intensity distribution characteristics, all values included in this report were measured using an integrating sphere. One sample of each product was tested. Table 1 summarizes key results from CALiPER testing. Definitions for many of the terms used in this report can be found in Appendix B.

Table 1. Results of CALiPER tests for the Series 18 LED recessed wallwashers. Performance criteria include initial output, total input power, luminous efficacy, power factor, color rendering index (CRI), special color rendering index R_9, correlated color temperature (CCT), and D_{uv}. The abbreviation LF indicates a product that is listed by LED Lighting Facts.

DOE CALiPER Test ID	Nominal Aperture Size[1]	Initial Output (lm)	Input Power (W)	Luminous Efficacy (lm/W)	Power Factor	CRI	R_9	CCT (K)	D_{uv}	Label
12-10	3" square	813	20.3	40	0.78	87	52	2974	-0.0007	
12-13	6" round	1,469	28.9	51	0.99	81	10	3530	0.0002	LF
12-14	6" round	1,707	26.8	64	0.99	80	9	3475	0.0004	
12-24	5" round	1,470	31.6	47	0.99	78	-4	3370	0.0016	
12-35	6" round	1,142	32.4	35	0.99	77	-5	3357	0.0010	
12-36	6" round	1,606	29.7	54	0.89	80	8	3490	0.0020	
12-37	6" round	152	4.7	32	0.89	92	64	3257	-0.0030	
12-38	6” round	1,068	27.6	39	1.00	83	24	3435	-0.0040	LF
12-39	6" round	1,790	36.4	49	1.00	79	0	3386	0.0010	LF
12-40	6" round	933	23.2	40	1.00	83	39	3376	-0.0009	LF
12-42	4" square	1,066	28.5	37	0.99	85	30	3247	-0.0039	
12-43	5" square	856	30.2	28	1.00	85	27	3380	-0.0013	
12-44	6" round	1,346	24.8	54	0.96	81	30	3463	0.0019	
12-45	6" round	611	14.3	43	0.95	86	50	3495	-0.0004	
12-50	4" round	616	27.2	23	0.99	82	19	3408	-0.0012	LF
12-60	6" round	449	11.8	38	0.98	83	38	3427	0.0003	
12-61	6" round	1,174	29.8	39	0.99	76	-9	3252	0.0023	
Minimum		152	4.7	23	0.78	76	-9	2974	-	
Mean		1,075	25.2	42	0.96	82	22	3372	-	
Maximum		1,790	36.4	64	1.00	92	64	3530	-	

1. Diameter or width, as listed by the manufacturer.

Supplemental LED Recessed Wallwasher Data

ENERGY STAR

Recessed wallwashers are not covered by ENERGY STAR—the downlight category requires axial symmetry—but standard downlights in a broader product family may qualify. In some cases, this may lead to confusion about the status of the wallwasher product. For example, two of the Series 18 LED recessed wallwasher products (12-42 and 12-45) appear to be ENERGY STAR qualified because the logo is present on the manufacturers' specification sheets. In both cases, the logo explicitly refers to the wallwasher product, not a standard downlight in the same family. A third product (12-60) appears to be ENERGY STAR qualified based on the manufacturer's webpage, although the page is for both the standard and wallwash optics. Despite the presence of the ENERGY STAR logo in relation to these products—and their relationship to qualified standard downlights—by definition they do not meet all the ENERGY STAR program requirements.

DesignLights Consortium

The DLC QPL includes a specific *wallwash luminaire* category. Among other criteria, the requirements for qualification include output of 575 lumens or higher, with more than 50% of the lumens emitted in the 20°–40° zone; efficacy of 40 lm/W or greater; a CCT less than or equal to 5000 K; and a CRI greater than 50. These requirements are illustrated in Figures 3 and 8. As of September 7, 2012, the DLC QPL did not include any products categorized as wallwashers.

LED Lighting Facts Data

As of September 7, 2012, LED Lighting Facts included a category for *wallwash fixtures* that contained two products from CALiPER Series 18; however, the products listed also included many luminaires outside the recessed wallwasher classification. Additionally, some wallwasher products—including several of the Series 18 products—were listed under the downlight category. Given the ambiguity of the classification system and the comingling of multiple product types, it is difficult to establish a dataset for recessed wallwashers listed by LED Lighting Facts.

Conventional Product Benchmarks

In conjunction with testing of the Series 18 LED recessed wallwashers, CALiPER tested four recessed wallwashers using conventional lamps. Products 12-46 and 12-47 use an asymmetrical square reflector, product 12-48 uses a lens to shape the distribution, and product 12-49 uses a kick reflector. The products included three CFL and one ceramic metal halide (CMH). All three CFL products had a horizontal lamp orientation, and used the same model of 32 W triple tube lamp. When tested alone—in the horizontal orientation—by CALiPER using the same ballast as the associated luminaire,[7] the lamps used in products 12-47, 12-48, and 12-49 emitted 1,884 lumens, 1,749 lumens, and 1,694 lumens, respectively. These values are substantially less than the typically published lumen output for a 32 W CFL (2,400 lumens). The difference may be attributable to the ballast used and lamp orientation; manufacturers test CFLs in a vertical orientation (both base up and base down) using a high-frequency reference ballast. Unlike for metal halide lamps, manufacturers typically do not provide the output when operated in a horizontal orientation. Importantly, the wallwasher manufacturers' literature and photometric reports for these products were all based on 2,400 initial lumens. The CALiPER program will continue to investigate the cause of the lower-than-expected lumen output.

For CALiPER, the benchmark products were tested using absolute photometry to provide the most accurate comparison to the results of the LED product testing. The results are provided in Table 2. In part because of the

[7] Each luminaire's ballast was used in order to precisely determine luminaire efficiency. All three ballasts had a ballast factor of 1.0.

Table 2. **Summary data for CALiPER tests of benchmark conventional recessed wallwashers.**

DOE CALiPER Test ID	Source Type	Nominal Aperture Size[1]	Initial Output (lm)	Input Power (W)	Efficacy (lm/W)	Luminaire Efficiency[2] (%)	Power Factor	CRI	CCT (K)
12-46	CMH (20 W)	4" square	1,174	22.5	52	NA[3]	1.00	83	3155
12-47	CFL (32 W)	4" square	843	36.9	23	44.7	1.00	83	3463
12-48	CFL (32 W)	6" round	625	33.4	19	35.7	1.00	85	3179
12-49	CFL (32 W)	6" round	614	34.2	18	36.2	1.00	84	3251

1. Diameter or width, as listed by the manufacturer.
2. Calculated as the ratio of luminaire lumens to lamp lumens, both as tested by CALiPER.
3. Lamp not tested alone.

reduced lamp output, the CFL-based luminaires all emitted fewer lumens and had lower efficacy than claimed. This was particularly notable for products 12-48 and 12-49, which emitted 57% and 54% of their rated luminaire lumen output, respectively. However, both products also had a much lower luminaire efficiency than claimed (36% versus 45%, 36% versus 48%), so the difference cannot be solely attributed to lamp orientation or ballast. The two products are from the same manufacturer, but use different optical systems.

Notably, the handful of tested products represents only a small fraction of the conventional recessed wallwasher market. Given the number of combinations of lamp and luminaire options, there is a vast range of product performance that is difficult to capture in a small sample. In fact, given the lower-than-expected lumen output of the CALiPER CFL benchmarks, they may not accurately capture the performance of other similar CFL recessed wallwashers. In contrast, the performance ranges used in the subsequent analysis are approximations intended to represent typical products. Nonetheless, the test results for these conventional wallwashers highlight several key concerns that specifiers should be aware of, including the potential complications associated with relative photometry.

5 Analysis

Lumen Output and Efficacy

The Series 18 LED recessed wallwasher luminaires had measured output ranging from 152 to 1,790 lumens, with a mean of 1,075 lumens (see Figure 3). Although the Series 18 products effectively span the typical range for lower wattage CFL and CMH wallwashers, they do not match some higher output products (e.g., multiple lamp CFL or 50 W CMH).[8] The CALiPER CFL benchmarks all used 32 W lamps, whereas the CALiPER CMH benchmark used a 20 W lamp. However, conventional recessed wallwashers delivering 5,000 lumens or more are available; currently available LED recessed wallwashers rarely exceed 2,000 lumens.

The 42 lm/W mean efficacy for the Series 18 products is the lowest measured for any of the product categories tested by CALiPER in 2012, which included downlight retrofit units, floodlights, BR30 lamps, AR111 lamps, and linear pendants. For example, the Series 14 LED downlight retrofit units—which were also primarily 6 inch diameter units—had a mean efficacy of 49 lm/W. Notably, care should be taken in comparing different product types because the products' intended application, optics, and size will likely affect the efficacy. For example, the optics needed to create a wallwasher's asymmetric distribution usually reduce the overall efficacy of the

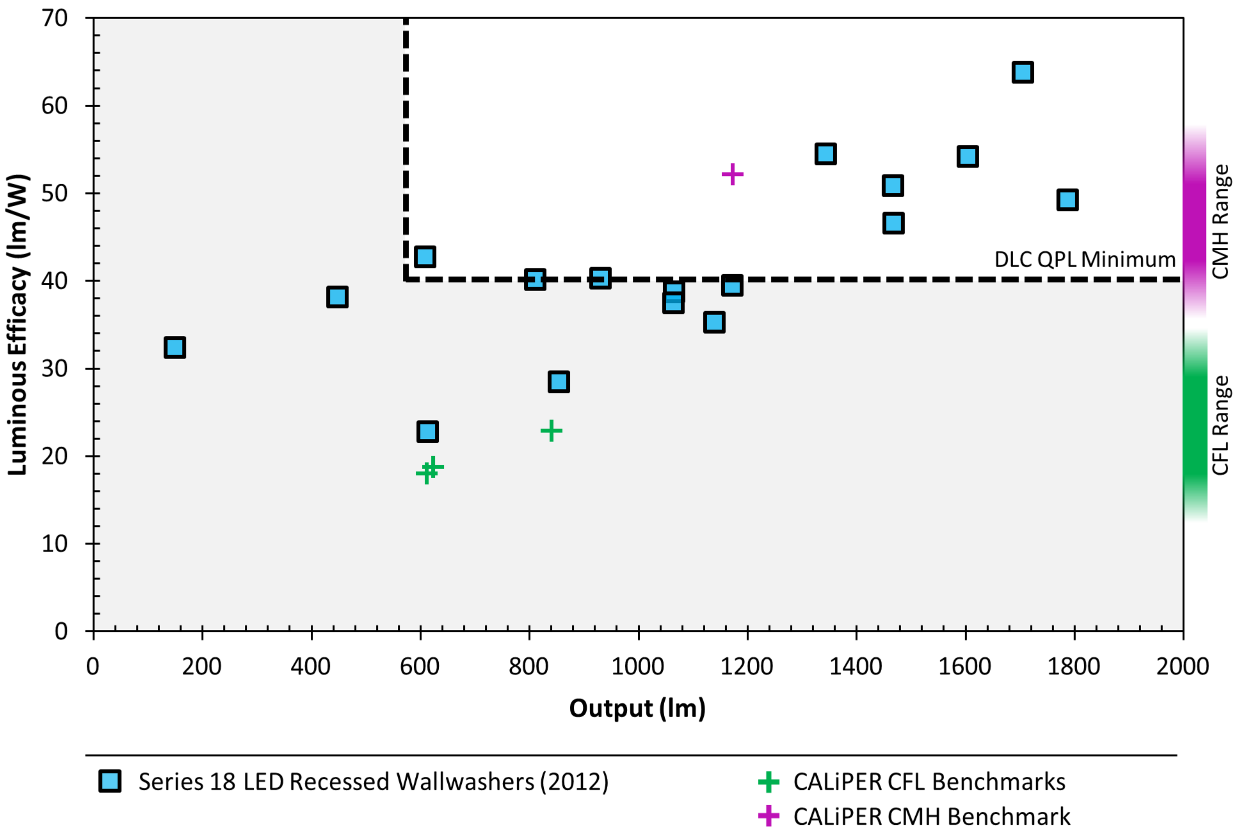

Figure 3. Luminous efficacy versus lumen output. All of the Series 18 LED recessed wallwashers had luminous efficacies that were higher than the CFL benchmarks—with some comparable to the CMH benchmark—but they were generally less efficacious that other recently tested LED products. The lumen output was equivalent to only lower wattage conventional products (higher wattage conventional benchmarks were not tested).

[8] In many cases, higher output conventional wallwashers require a larger luminaire/aperture.

luminaire—or the efficiency of the luminaire if relative photometry is used. Nonetheless, only 9 of the 17 Series 18 LED recessed wallwashers met the DLC QPL minimum efficacy requirement of 40 lm/W, and only 7 products would meet current ENERGY STAR efficacy requirement for downlights of 42 lm/W, if they applied. Among other LED products, this level of performance is below average, but compared to conventional wallwashers—which typically exhibit poor luminaire efficiency—the efficacy of many of the Series 18 products may still be an improvement.

Distribution of Light

The Series 18 LED products were found to have a wide range of different distributions, although one is not necessarily better than another given the numerous possible applications—that said, some may not be what is expected of a wallwasher. The products mainly used two different methods to generate an asymmetric distribution: a kick reflector (Figure 4) or a recessed, angled lens (Figure 5). In addition, one product used a curved reflector ("scoop") to alter the distribution and two had the LED source mounted at an angle (Figure 6), whereas another used an asymmetrical square reflector (Figure 7). Some products used a combination of different methods, but they are grouped here according to their predominant optical system. Importantly, the polar plots shown in Figures 4–7 may not capture the true performance of a product; they are a simple cross-section of luminous intensity in two perpendicular planes. The 0°–180° plane, shown in blue, is perpendicular to the wall, whereas the 90°–270° plane, shown in red, is parallel to the wall. One recurring problem with wallwashers is that they are not installed in the proper orientation; this is especially true for products with a kick reflector. In the included figures, the wall side is indicated for the 0°–180° plane.

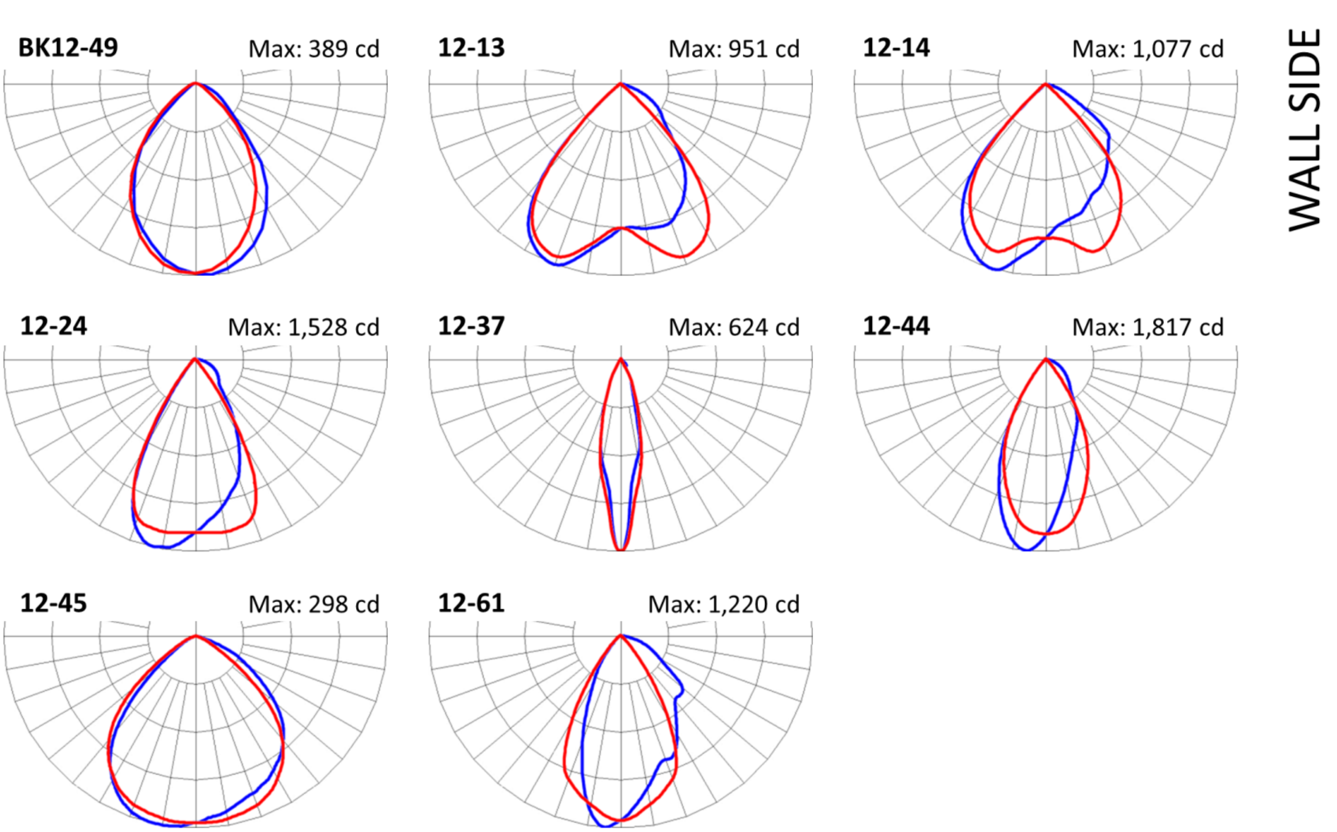

Figure 4. Polar plots of luminous intensity distribution for the Series 18 products that used a kick reflector as the primary optical system. The plots do not have the same scale.

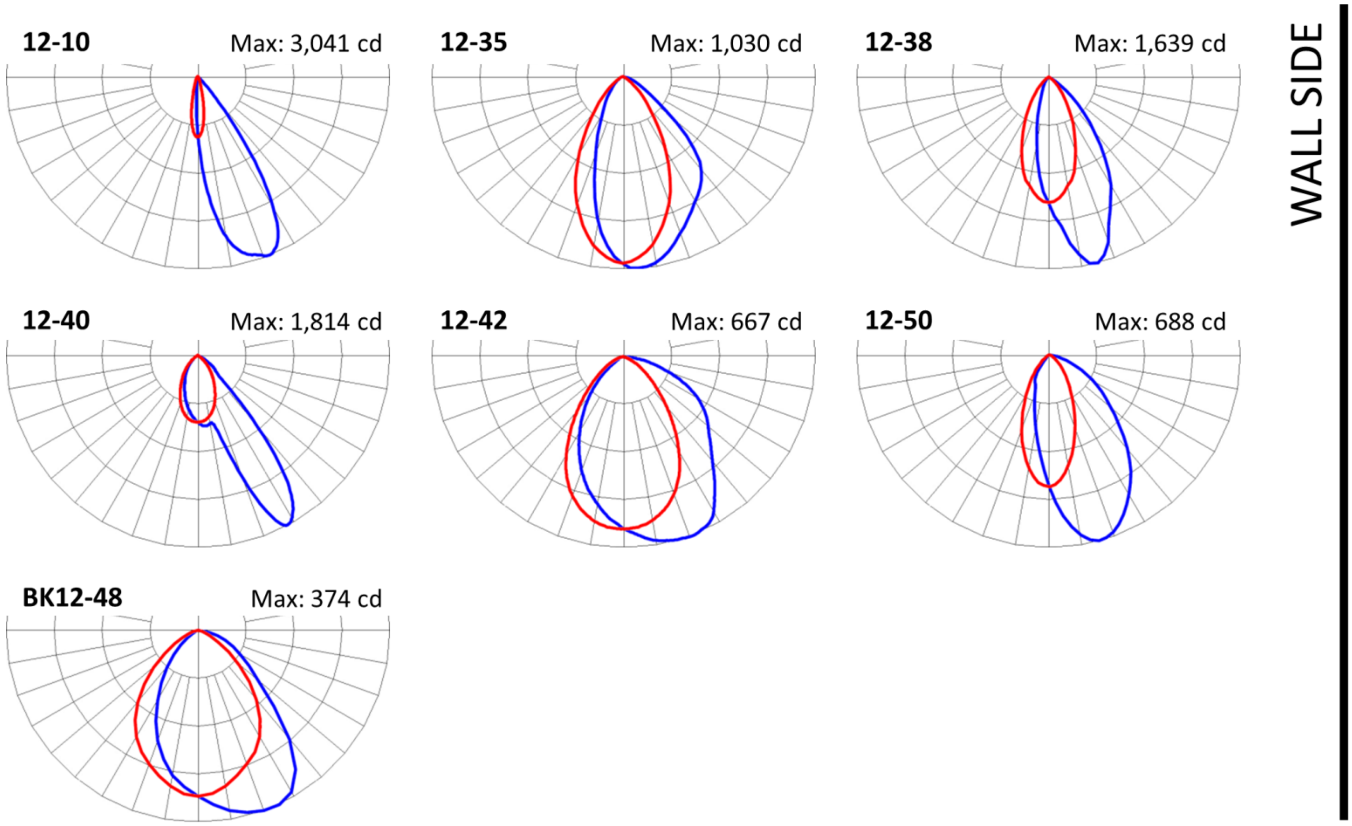

Figure 5. Polar plots of luminous intensity distribution for the Series 18 products that used a recessed, angled lens as the primary optical system. The plots do not have the same scale.

The typical distributions created by products using the aforementioned optical systems are distinct from each other. In essence, a kick reflector redistributes the lumens from lower to higher vertical angles on the wall side of the luminaire while leaving the opposite side unchanged (i.e., the same as a standard downlight in the same family). This behavior was matched by all of the Series 18 products using a kick reflector, although the degree of redistribution, or asymmetry, varied substantially. Notably, small changes in intensity at higher angles in a polar plot can be substantial when the product is installed. The CFL benchmark product that used a kick reflector had only a small degree of asymmetry, although this is not common.

The second major group of products used a recessed lens, positioned at an angle to the ceiling plane and aimed at the wall. In some cases, the source itself was also aimed at the wall, but for others it was aimed directly down. The LED products in this category all produced distributions having the majority of lumens on the wall side, sometimes with very little intensity at high angles on the room side. Thus, these products generally would be used differently than the products using a kick reflector; more emphasis is given to illuminating the wall, rather than also serving as a source of ambient illumination. Some of the Series 18 products (e.g., 12-10, 12-38, 12-40) appear to function more as accent lights than typical recessed wallwashers.

Several products fell outside the two major optical system categories. The distributions for these products are shown in Figures 6 and 7. In general, they performed similar to the lensed wallwashers, rather than the wallwashers using a kick reflector. Of particular note is the difference between benchmarks 12-46 (CMH) and 12-47 (CFL). Both are from the same product line of one manufacturer, but use a slightly different faceted inner reflector tailored to the specific light source. Despite only minor differences in the luminaire design, the

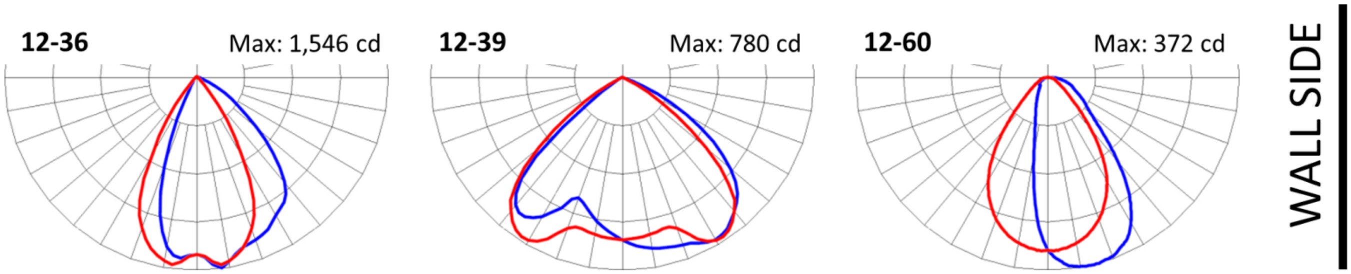

Figure 6. Polar plots of luminous intensity distribution for the Series 18 products that used an angled source (12-36, 12-39) or a scoop (12-60) as the primary optical system. The plots do not have the same scale.

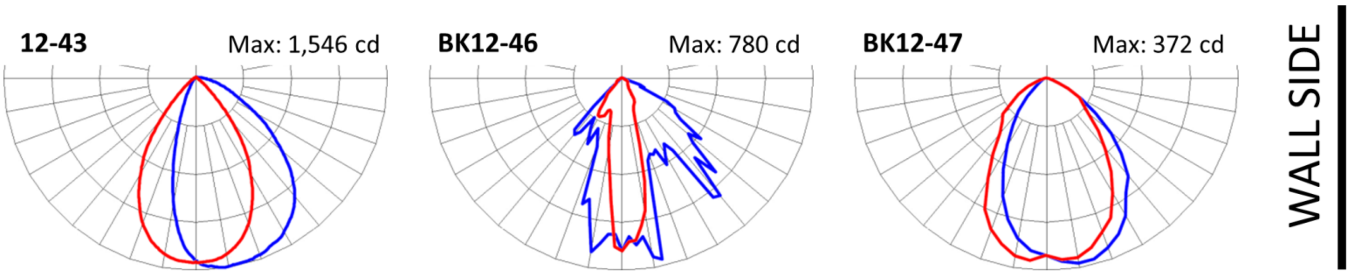

Figure 7. Polar plots of luminous intensity distribution for the Series 18 products that used a square, asymmetrical reflector as the primary optical system. The plots do not have the same scale.

distributions are noticeably different; the distribution of the CMH product has distinct spikes, whereas the distribution of the CFL product is generally smooth. This difference is primarily a function of the emitting area of the two light sources.

Regardless of optical system, some products (e.g., 12-10, 12-37, 12-44) were not very effective at creating high angle illumination and/or an asymmetric distribution—each of the three products emitted fewer than 16% of the total lumens above 40°. Additionally, at least two of the benchmarks did not have distributions that were noticeably asymmetric, potentially due to the difficulty in controlling luminous flux emitted from an area source (CFL), although they still emitted some high-angle flux. Depending on the design of the system, the emitting area for an LED product may be relatively small, offering more opportunity to fine-tune the luminous intensity distribution.

One of the listed DLC QPL requirements is that wallwashers deliver more than 50% of their total lumens in the 20°–40° zone, although there is no requirement for asymmetry of those lumens. Only four of the Series 18 products (12-10, 12-13, 12-14, 12-40) met this criterion. Given that none of the CALiPER-tested benchmarks met the requirement, it may require additional consideration by energy efficiency groups. A more effective criterion may examine the luminous intensity or zonal lumens delivered only to the wall side of the luminaire, and/or develop a way to evaluate asymmetry. Additional consideration for flux at angles above 40° is also warranted; many of the CALiPER products emitted a substantial percentage of lumens above 40°—potentially good for wallwashing—which reduces the relative percentage of lumens in the 20°–40° zone.

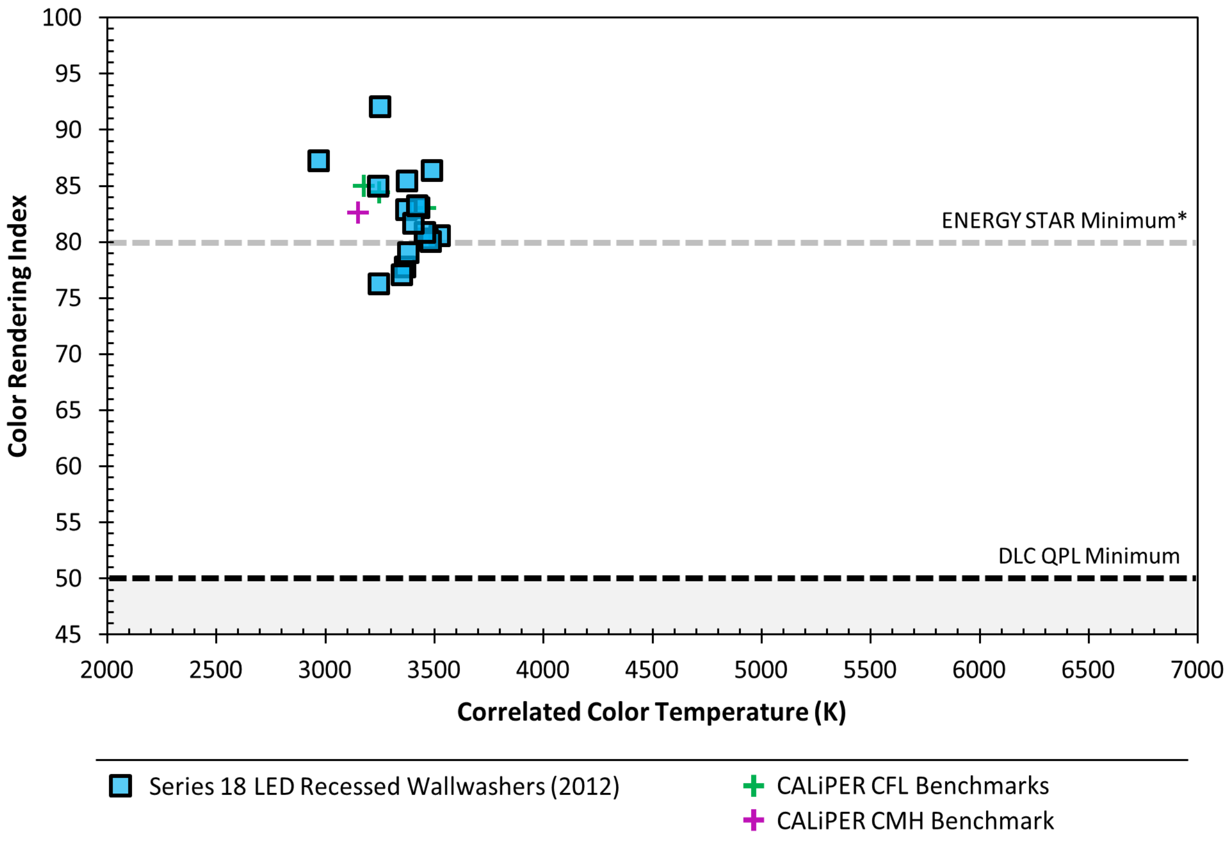

Figure 8. Color characteristics of the Series 18 LED recessed wallwashers. In general, the products had color characteristics that are appropriate for commercial interior applications. *ENERGY STAR criterion is not applicable to recessed wallwashers; it is shown for reference only.

Color Characteristics

The CCT of the Series 18 LED recessed wallwasher luminaires ranged from 2974 K to 3530 K, as shown in Figure 8. All but one product (12-10, 2974 K) had a nominal CCT of 3500 K.[9] This is primarily a result of the product selection parameters, but also indicates that a vast majority of products are available in a CCT that matches what is typical of interior commercial applications (i.e., 3000 K to 4100 K). The lamps selected for the benchmark products had similar CCTs.

Each of the Series 18 LED products had a CRI between 76 and 92, with 13 of the 17 products having a CRI above 80. Although this level of performance is generally acceptable for architectural interiors, more demanding applications may require use of products at the higher end of the range. Similar to other recent CALiPER testing, the measured R_9 values for the Series 18 LED recessed wallwashers had a strong linear correlation with CRI ($r = 0.94$). All four products that had a CRI below 80 had an R_9 of 0 or lower.

Manufacturer Claims

Evaluating the accuracy of manufacturers' performance claims is an important component of the CALiPER program. This task is often difficult because different values are reported in different literature. For example, performance values listed on specification sheets are sometimes different from values listed by LED Lighting

[9] Nominal CCT ranges are defined in ANSI C78.377-2008.

Facts or on product packaging. In some cases, these differences may be attributable to rounding to simplify visual appearance or improve legibility. In others, nominal values may be used instead of a single specific test result to better reflect the distribution of performance that can be expected from lighting products (i.e., not every product is identical). In other cases, updates to products may not be immediately reflected in literature. Nonetheless, given the status of LED lighting as an emerging technology, it is especially important for all manufacturer literature to represent the true performance of a product.

Four products (12-37, 12-39, 12-43, 12-61) were measured as delivering fewer than 90% of the lumens claimed by the manufacturer. Two of those products (12-37 and 12-61) were especially deficient, delivering 14% and 65%, respectively. For both products, the input power and luminous efficacy were also lower than claimed. One product (12-14) was measured to deliver 14% more lumens than claimed, although this is less problematic than underperforming. The other 12 products were all measured to be within 10% of the claimed lumen output. With a few minor exceptions, the product claims for other characteristics were generally deemed to be accurate.

6 Conclusions

Seventeen LED recessed wallwasher luminaires were tested and evaluated by CALiPER. The products had a wide variety of physical attributes and a similar diversity in luminous intensity distribution and lumen output. This reflects the varied applications in which recessed wallwashers are used, and creates a need for specifiers to choose products with great care. Some LED recessed wallwashers are already competitive with conventional products, but improvement in several areas is still possible. The findings from this series of testing can be summarized as follows:

- The lumen output from each of the products was generally equivalent to luminaires using up to 42 W CFL or 35 W metal halide lamps. CALiPER did not test any LED products that exceeded 1,800 lumens, although it is possible that LED products with higher output exist.
- The Series 18 products had luminous efficacies between 23 and 64 lm/W, with an average of 42 lm/W. A majority of the products were between the CALiPER CFL and CMH benchmarks, with only three products measured at more than 52 lm/W, the most efficacious benchmark tested. This level of performance is generally lower than for other product categories recently tested by CALiPER.
- The tested products used a variety of optical systems, primarily a kick reflector or an angled lens. Although the variation in performance was dramatic, most of the products produced an acceptably asymmetric distribution with a zonal lumen distribution similar to the conventional benchmarks. However, several of the products—both LED and conventional—had distributions that did not display the asymmetry that is typical, and expected, of recessed wallwashers. Specifiers should carefully evaluate photometric distributions, and manufacturers should strive for more precise optical design.
- All of the Series 18 products were selected to have a nominal CCT of 3500 K, except one that had a nominal CCT of 3000 K. The measured CRIs ranged from 76 to 92, with a majority of products having a CRI in the 80s. The CCT and CRI performance was consistent with the color that had been ordered and the claims of the manufacturer.
- The performance of the benchmark CFL lamps was different from what was anticipated. The absolute photometry measurements performed by CALiPER showed lumen output to be approximately 25% lower than the rated lamp lumen output, ostensibly due to the orientation of the lamp (horizontal versus vertical) and the ballast used for testing—although further investigation is underway. All three CFL benchmark luminaires used the *rated* lumen output—for a vertical orientation on a reference ballast—in calculating the relative photometry. Consequently, the CFL wallwashers delivered far fewer lumens than manufacturer literature would suggest. Differences in luminaire performance also contributed to the discrepancy between rated and measured values.

Compared to standard downlights, the market for recessed wallwashers is small. Nonetheless, having complete families of products—that is, augmenting a collection of downlights in different lumen packages with wallwashers having a similar appearance and lumen output—is a valuable asset for lighting specifiers. Based on the results of the Series 18 CALiPER testing, it is reasonable to conclude that LED products are generally comparable to conventional recessed wallwashers at lower lumen output levels. However, continued improvements in efficacy and lumen output would be beneficial.

Appendix A: Product Selection

Product selection is an important part of the CALiPER process. Products are selected with the intent of capturing the current state of the market—a cross section ranging from expected low to high performing products with the bulk characterizing the middle of the range. However, the selection does not represent a statistical sample of all available products.

Product selection starts with a review of the technology. Beyond relying on professional experience, the team surveys:

- Trade publications, including *Lighting Design + Application*, *LEDs Magazine*, *Mondo ARC*, and *Architectural Lighting*
- Internet websites, including Elumit, DesignLights Consortium, ENERGY STAR, LED Lighting Facts, ESource, and Lightsearch
- National retailers, including Grainger, Goodmart, The Home Depot, Lowe's, Amazon, and Sears
- Other sources, including trade shows (local and national) and manufacturers' representatives

After surveying available products, the CALiPER team characterizes the features of the products and determines what can be standardized to ease comparison. For this report focusing on recessed wallwasher luminaires, the following features were evaluated and led to the final selection:

- Diameter – A nominally 6 inch wide aperture was targeted because it is the most common size. A smaller group of products with an aperture less than 5 inches wide was also included.
- Distribution – Products having an angle of maximum intensity in the 10°–20°range were given priority.
- Lumen package – Ideally, selected LED products were rated as emitting at least 800 lumens, with preference given to those emitting 1,000 lumens or more.
- Color temperature – Products with a nominal CCT of 3500 K were targeted.
- Physical attributes – The selected products included a mixture of round and square apertures.

Other non-performance related criteria are also considered:

- Product availability – As a federally funded program, CALiPER focuses on products available in the United States.
- Energy efficiency programs – Some emphasis is given to including products listed by large energy efficiency programs (e.g., ENERGY STAR).

After establishing a list of appropriate products, attempts are made to anonymously purchase the products through standard industry resources (e.g., distributors, retailers). Sometimes, products are not available or cannot be shipped in a timely manner. Thus, the final group of products tested does not always match the intended results of the selection process.

Appendix B: Definitions

Correlated Color Temperature (CCT) Kelvin (K)	The absolute temperature of a blackbody radiator having a chromaticity that most nearly resembles that of the light source. CCT is used to describe the color appearance of the emitted light.
Color Rendering Index (CRI or R_a)	A measure of color fidelity that characterizes the general similarity in color appearance of objects under a given source relative to a reference source of the same CCT. The maximum possible value is 100, with higher scores indicating less difference in chromaticity for a sample of eight color samples illuminated with the test and reference source. See also: *Special Color Rendering Index R_9.*
D_{uv}	The distance from the Planckian locus on the CIE 1960 UCS chromaticity diagram (also known as u', 2/3 v'). A positive value indicates the measured chromaticity is above the locus (appearing slightly green) and a negative value indicates the measured chromaticity is below the locus (appearing slightly pink). The American National Standards Institute provides limits for D_{uv} for nominally white light.
Luminous Efficacy Lumens per watt (lm/W)	The quotient of the total luminous flux emitted and the total input power.
Input Power Watts (W)	The power required to operate a device (e.g., a lamp or a luminaire), including any auxiliary electronic components (e.g., ballast or driver).
Luminous Intensity Distribution Candela (cd)	The directionality of radiant energy emitted by a source, which may be shown using one of several techniques. It is most often presented as a polar plot of the candelas emitted in a vertical plane through the center of the lamp or luminaire.
Output Lumens (lm)	The amount of light emitted by a lamp or luminaire. The radiant energy is weighted with the photopic luminous efficiency function, V(λ).
Power Factor	The quotient of real power (watts) flowing to the load (e.g., lamp or fixture) and the apparent power (volt-amperes) in the circuit. Power factor is expressed as a number between 0 and 1, with higher values being more desirable.
Special Color Rendering Index R_9	A measure of color fidelity that characterizes the similarity in color appearance of deep red objects under a given source relative to a reference source of the same CCT. The maximum possible value is 100, with higher scores indicating less difference in chromaticity for the color sample illuminated with the test and reference source. R_9 and R_a (CRI) are part of the same CIE Test-Color Method, but the R_9 color sample is not included in calculation of R_a.

DOE SSL Commercially Available LED Product Evaluation and Reporting Program
NO COMMERCIAL USE POLICY

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

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

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