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CALiPER

Application Summary Report 15:

LED Floodlights

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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 10 LED floodlights purchased between August and December 2011. The group included a wide range of products, both physically and in performance characteristics, which mirrors the nearly indefinite range of conventional luminaires designated as floodlights. Although holistic evaluations are inappropriate, the results provide several key takeaways regarding the future growth necessary for LED floodlights to compete with and overtake conventional products. Primarily, the range of lumen output and available luminous intensity distributions must expand to cover the full range of conventional products. Specifically, higher lumen output and narrow spot distributions are currently challenging for LED products. Further, many currently available LED floodlights do not offer the same level of customization as conventional floodlights, which use different combinations of lamps, reflectors, and accessories to offer a variety of products in the same form factor. Despite current limitations, LED floodlights have advantages, such as color quality and dimmability, which provide a potential avenue for widespread future adoption.

3 Background

What is a floodlight? The term can mean different things to different people; it is sometimes applied to the luminous intensity distribution of a product and sometimes to the product itself. Often, "floodlight" is used differently in the context of residential and commercial buildings—although there is some overlap—referring either to directional lamps or to luminaires used for façade, surface, or area lighting. Colloquially, "floodlight" might be used to describe the security lighting for a residence, but it is also used to describe the luminaires that illuminate the façades of skyscrapers. Clearly, the world of floodlights is diverse!

In this report, the term floodlight refers to a luminaire typically used to light exterior surfaces. The aiming angle of this luminaire type is usually adjustable; that is, the luminaire typically incorporates a lockable hinge (i.e., knuckle) or swivel point. Further, for typical conventional products the distribution is shaped by the luminaire's optical system(s), rather than by the lamp (e.g., PAR lamps). Still, the variety of floodlights is substantial because they are used in many applications. For example, floodlights can be used to highlight a small sign in front of a store, or to illuminate a monument, or for security lighting outside a building. It is also important to note that floodlights do not always have a wide distribution (e.g., flood). They can have distributions ranging from very narrow to very wide in order to suit the object being illuminated, and are often asymmetric (i.e., wider in one direction than another). Simply stated, it is difficult to categorize floodlights using a single metric.

Conventional floodlight luminaires used in commercial applications typically utilize high-intensity discharge (HID) (e.g., high-pressure sodium [HPS] or metal halide) or compact fluorescent (CFL) lamps. Incandescent or halogen lamps are used in a few select applications. Because they use the traditional modular approach, it is possible for conventional floodlight luminaires to be configured with a variety of lamps operating at different wattages in order to meet the lumen output needs of specific applications. Similarly, conventional floodlights may utilize modular optics to adjust the luminous intensity distribution of a single base unit.[7] Further, optional accessories can be used to prevent glare and light trespass, or to crop a luminaire's distribution to meet the specific boundaries of a surface.

LED Floodlights

The floodlight market has received relatively little attention from LED fixture manufacturers, likely due to a combination of several factors. One issue is that HID technology meets the needs of floodlighting applications fairly well—metal halide lamps have relatively high efficacy and can produce a lot of lumens, the distribution is easily modified with optics, and the color quality can range from acceptable to excellent. Further, tunability (i.e., fine adjustment of output and color) and controllability (i.e., compatibility with dimmers and sensors), two potential advantages of LEDs in indoor applications, are not as critical for floodlighting because the purpose is usually to light objects—particularly in exterior environments—rather than provide light for visual work. Nonetheless, these features can still be beneficial in certain applications.

As LED technology continues to develop, the lumen output and efficacy of some LED floodlights are becoming competitive with or exceeding conventional products. Further, LEDs do not suffer from some of the limitations of conventional lamps. For example, the output of CFL lamps is affected by temperature and dimming can be costly. Similarly, HID lamps have a restrike delay, cannot be easily dimmed, and the output is dependent on the lamp orientation. Although these issues may not be critical for this product category, the ability of LED floodlights to address these shortcomings is potentially valuable. Additionally, there is more opportunity to tune

[7] Modifications are usually not achievable in the field, but rather a specific configuration is specified during ordering and assembled by the manufacturer. The ballast, socket, optical system, and lamp must all be compatible.

the emitted spectrum of LED sources, which allows for greater precision in matching the light source with the material(s) being illuminated.

Specifying Floodlights

Floodlights are most often specified based on their lumen output and beam shape. In many cases, the geometry of the luminaire placement relative to the target surface will dictate the required characteristics. The further the throw distance (i.e., higher or longer), the more lumen output is needed. Similarly, narrow beams at a far distance can be used to illuminate the same area as a wide beam at a short distance. Table 1 illustrates the classification system of the National Electrical Manufacturers Association (NEMA). Using the NEMA system, a luminaire can be classified as 1×3, for example, where the first digit corresponds to the horizontal field angle and the second digit corresponds to the vertical field angle.[8]

Table 1. NEMA system for luminaire classification. This system is primarily used for floodlighting and sports lighting.

NEMA Beam Type	Field Angle (degrees)
1	10–18
2	18–29
3	29–46
4	46–70
5	70–100
6	100–130
7	130+

In addition to lumen output and beam shape, it is important for specifiers to consider secondary aspects of distribution. These include the evenness across the beam, the smoothness or abruptness at the edge of the beam, as well as the effect of light emitted outside the beam.

Testing Floodlights

Floodlights, including those tested for this report, are customarily characterized using Type B photometry. This system, which is different from what is used for most other luminaire types (Type C),[9] specifies that the origin of vertical and horizontal angles is the primary aiming axis of the luminaire. Both horizontal and vertical angles range from -90° to 90°. The practical consequences of this difference are negligible, and software used to view photometric reports is typically capable of automatically converting between the two systems. Nonetheless, for anyone viewing an LM-79-08 report for a floodlight, it is important to understand the type of information being presented.

The performance of LED floodlights is not affected by orientation; however, the lumen output of many metal halide lamps is affected by tilt. During testing, the orientation is fixed, so it may be necessary to apply additional light loss factors when calculating the performance of luminaires using metal halide lamps.

[8] Field angle, as well as other terms used in this report, is defined in Appendix B.

[9] Type A photometry is used for automotive headlights. The fundamentals of type A, B, or C photometry are the same, but the testing configurations and reporting formats are different. More information can be found in IES LM-75-01, *Goniophotometer Types and Photometric Coordinates.*

4 Results

CALiPER LED Floodlight Data

This report analyzes the independently tested performance of 10 LED floodlights—referred to as the Series 15 products—purchased between August and December 2011. The wide range in products, both physically and in performance characteristics, is indicative of the extensive range of floodlights. Rather than focusing on a single application type, this group of products demonstrates the breadth of LED floodlights. For more on the product selection parameters, both in general and as they pertain to this group of products, see Appendix A. The Series 15 products are shown in Figure 1.

All of the units were tested according to IES LM-79-08, using both an integrating sphere and goniophotometer—the difference in measured lumen output for each of the Series 15 products was less than 4%, which is typical. Except for luminous intensity distribution characteristics, all values included in this report were measured using an integrating sphere and spectroradiometer. Only one sample of each product was tested. Table 2 summarizes results for energy performance and color characteristics of the Series 15 products.

LED floodlights have not been previously tested by CALiPER. Further, they do not fall under the purview of ENERGY STAR, nor have specifications been developed by the DLC or any other energy efficiency program. The LED Lighting Facts program does not have a separate category for LED floodlights. As this product category matures, new specifications and performance criteria will be developed; however, it will likely be difficult to establish some of the criteria given the nebulous nature of the floodlight category.

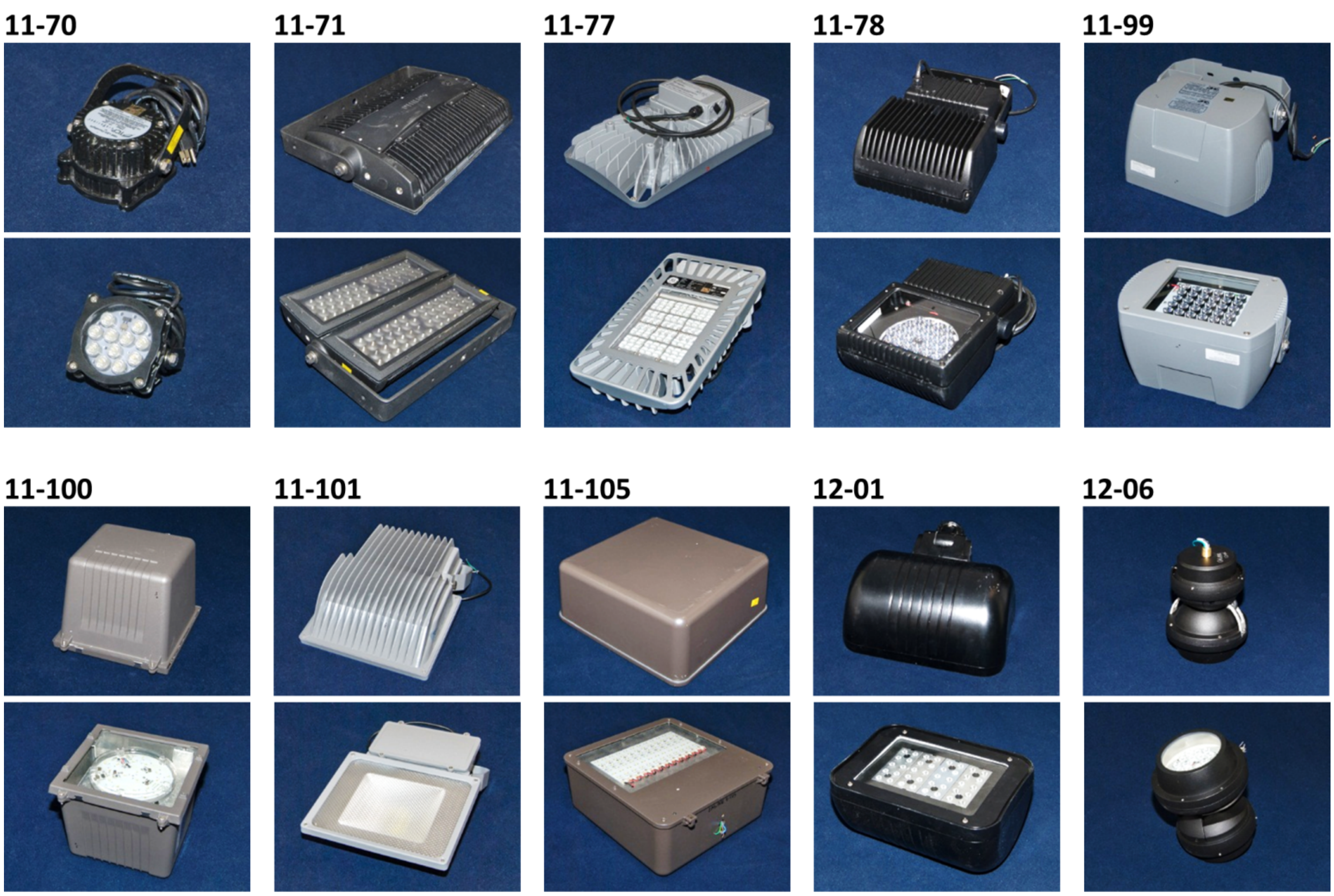

Figure 1. Photographs of products included in this series of CALiPER testing. Images are not to scale.

Table 2. **Results of CALiPER tests for the Series 15 LED floodlights.** 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}.

DOE CALiPER Test ID	Initial Output (lm)	Total Input Power (W)	Luminous Efficacy (lm/W)	Power Factor	CRI	R_9	CCT (K)	D_{uv} [1]
11-70	773	15.9	49	1.00	72	-7	6060	-0.0025
11-71	8044	251.4	32	0.99	83	27	4057	-0.0011
11-77	5685	86.0	66	0.98	72	-18	6099	0.0037
11-78	4173	79.2	53	0.97	70	-17	4043	0.0060
11-99	2692	40.4	67	0.99	68	-24	4290	0.0029
11-100	2991	56.6	53	1.00	68	-33	5288	0.0045
11-101	4170	53.7	78	1.00	66	-52	4902	0.0125
11-105	6178	76.6	81	0.98	67	-20	4341	0.0014
12-01	4417	89.2	50	0.99	66	-33	4232	0.0055
12-06	844	12.4	68	0.80	82	16	3646	0.0001
Minimum	773	12.4	32	0.80	66	-52	3646	-
Mean	3997	76.2	59	0.97	71	-15	4696	-
Maximum	8044	251.4	81	1.00	83	16	6099	-

Notes:
1. Red values are outside of ANSI-defined limits for general indoor lighting applications (ANSI C78.377).

CALiPER Testing of Conventional Product Benchmarks

One benchmark conventional floodlight was evaluated in conjunction with this series of testing. As with many floodlights, the specification sheet listed a variety of lamping options—in this case, HPS or metal halide lamps ranging from 50 to 175 W, which range in output from less than 4,000 lumens to more than 15,000 lumens. The manufacturer's data listed the luminaire as being approximately 60% to 75% efficient, depending on the configuration. The product was available in seven different distributions, ranging from spot to flood, and had numerous accessories available for further customization. In addition, the same manufacturer offered a similar product that uses CFL lamp(s), and a larger version was available to accommodate 200 to 400 W HID lamps. The manufacturer provided photometric data for well over 100 combinations of lamps and optics. One configuration was chosen for testing by CALiPER.

In order to provide a more direct comparison to the Series 15 LED floodlights, the CALiPER benchmark was tested using absolute photometry.[10] As tested, the narrow distribution product emitted 5,238 lumens and had an input power of 131.2 W (40 lm/W)—a 100 W ED-17 metal halide lamp was installed during testing. It had a

[10] Conventional products are usually tested using relative photometry. For more on the difference between absolute and relative photometry, see the DOE fact sheet, "Understanding LM-79 Reports," available at http://www1.eere.energy.gov/buildings/ssl/factsheets.html

center beam candlepower (CBCP) of 120,076 cd, with field angles of 12° and 20° (NEMA 1×2). The installed lamp had an initial rated output of 8,500 lumens; thus, the fixture was measured to be 62% efficient. The manufacturer's reported data for the 1×2 configuration used a different lamp, so direct comparison between the tested and reported data is not possible. Nonetheless, the listed efficacy for the tested luminaire configuration was 49 lm/W, which is more than 20% greater than the efficacy measured by CALiPER.[11] This difference illustrates the importance of considering both lamp and luminaire performance for conventional lighting products. More generally, all reasonable efforts should be made to ensure design calculations are based on the specific hardware intended for installation.

Characterizing Conventional Products

CALiPER is focused on testing SSL products and is only able to test a limited number of benchmark conventional products. Especially for floodlights, CALiPER cannot test enough conventional products to cover the entire scope of the market. To supplement the limited CALiPER data and informal characterizations, a profile of the conventional product market was established by reviewing manufacturer literature.[12] The review included 126 products from seven different manufacturers, all of which used metal halide lamps between 20 and 150 W. This range does not cover all possible floodlights, but is similar to the range of the Series 15 LED floodlights.

Lumen Output and Efficacy

The conventional floodlight market must be characterized by considering system performance, rather than lamp or luminaire performance. For example, lumen output is dependent on both lamp lumens and the efficiency of the luminaire optical system. Typically, conventional floodlight luminaires are 45% to 85% efficient, with some dependence on the lamp type used. Output ranges from about 1,000 lumens to more than to 20,000 lumens. Using an HID lamp, luminaire efficacy will typically be between 30 and 80 lm/W. Efficacy will tend to be slightly lower when using a CFL lamp and less than 20 lm/W for halogen lamps.

In the review of conventional metal halide floodlights conducted by CALiPER, the mean luminaire efficiency was 65% and the mean luminaire efficacy was 51 lm/W (see Table 3). The range in performance was considerable, with luminaire efficacy ranging from 25 to 83 lm/W. For the particular set of products sampled, the luminaire output ranged from 1,245 to 12,716 lumens, with a mean of 6,520 lumens.

Lamp properties can have a substantial effect on floodlight performance. For example, many HID lamps are available with either a clear or a coated bulb, which can affect both the luminaire efficacy and the spatial

Table 3. Summary performance characteristics for the CALiPER survey of 20 to 150 W metal halide floodlights. The total sample size was 126 products, representing seven different manufacturers.

	Luminaire Efficiency (%)	**Initial Luminaire Output** (lm)	**Total Input Power** (W)	**Luminaire Efficacy** (lm/W)	**Maximum Intensity** (cd)
Minimum	32.0%	1,245	37	24.6	1,024
Mean	65.0%	6,520	129	50.9	16,409
Maximum	97.0%	12,716	210	82.6	169,307
Standard Deviation	12.5%	2,741	47	14.3	29,706

[11] Some, but not all, of this difference can be attributed to absolute versus relative photometry. Other contributing factors include: (1) the magnetic ballast used in the CALiPER test fixture (BK 11-69) had a ballast efficiency of 76% and the manufacturer's IES-format file listed a ballast efficiency of 79%; and (2) the rated efficacy for the CALiPER tested lamp was 85 lm/W, whereas the lamp from the manufacturer's IES-format file had a rated efficacy of 93 lm/W.

[12] The review was not intended to be comprehensive, but simply indicative of the typical range of performance.

distribution of light emitted. All other factors being equal, coated lamps are less efficacious than clear lamps, but can improve lumen maintenance, reduce flicker, and improve color consistency. The lumen output of most metal halide lamps is also substantially affected by the orientation of the lamp. The difference in output between vertical and horizontal orientation can be as much as 20%, and the difference can manifest itself initially or over time. Additionally, metal halide lamps are available with specific orientation ratings: vertical only, horizontal only, universal, or within a small range. Although they are not affected by orientation, CFLs have their own limitations. For example, the output of non-amalgam fluorescent lamps is affected by ambient temperature—actual lumen output can be 50% less than the rated lumen output when the ambient temperature is at 0 °C (32 °F). This issue is partially remedied by amalgam lamps and enclosed luminaires that actively warm the lamp(s). Beyond temperature dependence, fluorescent lamps have a large luminous area, making precise optical control more difficult.

Distribution of Light

The luminous intensity distributions of conventional floodlights can be very different, ranging from very narrow to very wide; it is important for specifiers to have a range of options. Table 4 provides a summary of distribution characteristics for the surveyed products, whereas Table 5 provides a breakdown of the NEMA classifications for horizontal and vertical field angles. Key observations include:

- A majority of the surveyed products had wide distributions.
- On average, the horizontal angle was wider than the vertical angle. Similarly, more products had a narrow (NEMA 1–4) vertical field angle than a narrow horizontal field angle.

Table 4. Summary of distribution characteristics for the CALiPER survey of 20 to 150 W metal halide floodlights. The total sample size was 126 products, representing seven different manufacturers.

	Horizontal Beam Angle (deg)	Vertical Beam Angle (deg)	Horizontal Field Angle (deg)	Vertical Field Angle (deg)	Horizontal Angle Ratio[1]	Vertical Angle Ratio[2]
Minimum	8	6	19	13	0.11:1	0.13:1
Mean	73	46	111	89	0.63:1	0.49:1
Maximum	137	117	160	150	0.92:1	0.87:1
Standard Deviation	32	31	39	42	0.15:1	0.18:1

1. The ratio of the horizontal beam angle and horizontal field angle. A value closer to 1:1 indicates a sharper beam edge.
2. The ratio of the vertical beam angle and vertical field angle. A value closer to 1:1 indicates a sharper beam edge.

Table 5. Summary NEMA classifications for the CALiPER survey of 20 to 150 W metal halide floodlights. The total sample size was 126 products, representing seven different manufacturers.

NEMA Classification	Horizontal Count	Percent	Vertical Count	Percent
1 (10°–18°)	0	0%	5	4%
2 (18°–29°)	8	6%	10	8%
3 (29°–46°)	9	7%	8	6%
4 (46°–70°)	4	3%	16	13%
5 (70°–100°)	12	10%	27	21%
6 (100°–130°)	40	32%	34	27%
7 (130°+)	53	42%	26	21%

- The range in the ratio of beam angle to field angle, a measure characterizes the sharpness of the beam edge, was very wide.
- A majority of products (64%) had distributions where the NEMA classification was different for the horizontal and vertical angle.

Color Characteristics

The color quality of conventional floodlights is dependent solely on the installed lamp—excluding when a specific color-altering accessory is used. HPS lamps typically have a CRI of about 20 and a CCT around 2000 K;[13] because of this, they may not be suitable for some applications. Standard quartz arc-tube metal halide lamps typically have a CRI between 60 and 80, with a CCT between 3000 K and 4500 K, whereas ceramic arc-tube metal halide (CMH) lamps typically have a CRI between 80 and 95, with a CCT between 3000 K and 4500 K. CFL lamps most often have a nominal CCT between 2700 K and 4000 K, with CRIs in the 80s. Tolerances for the colorimetric performance of fluorescent lamps are defined in ANSI C78.376. There are no colorimetric standards for HID lamps.

Beyond standard color quality issues, color shift over time is a notable concern for any product type using metal halide lamps. The CCT of quartz metal halide lamps can shift by up to 500 K at 40% of rated life; CMH lamps do not shift as much (±200 K).[14] Compounding this issue, the direction of the shift in chromaticity is variable. For example, given three metal halide floodlights, one might shift pink, another blue, and the other green.

Other Factors

Other important characteristics of note include:

- Conventional floodlights with magnetic ballasts—the most commonly used type—are considered to have a high power factor when it is above 0.90. A normal or low power factor is between 0.40 and 0.60, whereas a power factor between 0.60 and 0.90 is often called power factor corrected.

- The lifetime of metal halide and CFL lamps used in floodlights is typically 6,000 to 20,000 hours. HPS lamps tend to last longer (20,000 to 30,000 hours).

[13] Some special HPS lamps with increased sodium pressure have a CRI around 85 and a CCT of approximately 2700 K. However, the expected lifetime is reduced and efficacy is lower than standard HPS lamps.
[14] *Specifier Reports: Low-wattage metal halide lighting systems.* Volume 10 Number 1, October 2006. Lighting Research Center, Rensselaer Polytechnic Institute.

5 Analysis

Lumen Output and Efficacy

The range of measured output for the Series 15 LED floodlights, 773 to 8,044 lumens, was substantial—although not unexpected given the aims for product selection. However, the maximum of that range is only comparable to a floodlight using a 100 W or 150 W HID lamp. Notably, at least one of the products tested was available in a version with a listed lumen output over 18,000 lumens (comparable to a 250 W or 320 W HID fixture). Still, LED floodlights cannot yet match the performance of many higher-wattage (400 W or more) conventional floodlights. Further, because high lumen output requires a large quantity of LEDs, the form factor for high output products may be larger and/or the LEDs must be operated at a very high drive current, which can be detrimental to lifetime.

There was also a wide range of performance with regard to efficacy, with the best product delivering 81 lm/W and the worst product delivering 32 lm/W (less than typical HID products). Notably, the product delivering 32 lm/W (11-71) emitted the most lumens—it also drew 251 W. Excluding this product, the range in efficacy was 49 to 81 lm/W, which is at the high end of the typical range for conventional HID floodlights. Efficacy versus lumen output is shown in Figure 2.

Distribution of Light

Luminous intensity distribution characteristics are paramount to the performance of floodlights. One distribution is not necessarily better than another; rather, it is critical to select a product with the correct characteristics for the application. Distribution characteristics for the Series 15 products are listed in Table 6.

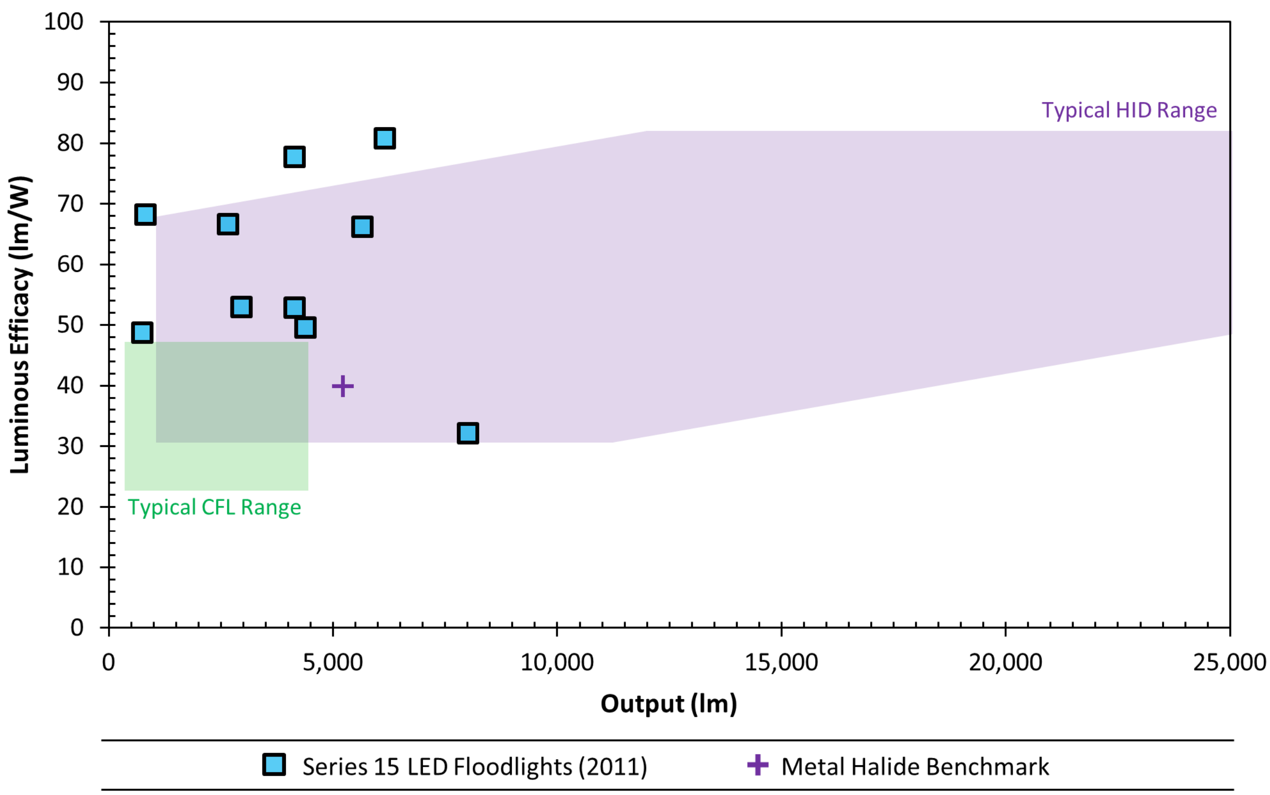

Figure 2. Efficacy versus lumen output of LED floodlights compared to conventional product performance. The Series 15 LED floodlights performed well in terms of efficacy, but did not match the lumen output of floodlights using higher wattage metal halide lamps. The approximate ranges represent luminaire performance.

Table 6. Luminous intensity distribution characteristics of the Series 15 LED floodlights and the conventional benchmark. The values listed for the benchmark product are for the specific configuration that was tested. The benchmark is not included in the summary statistics.

DOE CALiPER Test ID	**CBCP** (cd)	**Max Intensity** (cd)	**Horizontal Beam Angle** (deg)	**Vertical Beam Angle** (deg)	**Horizontal Field Angle** (deg)	**Vertical Field Angle** (deg)	**NEMA Classification (H×V)**
BK 11-69	120,076	120,076	4	10	12	20	1×2
11-70	1,269	1,270	36	36	83	84	5×5
11-71	44,464	44,464	22	22	43	42	3×3
11-77	1,909	3,912	141	65	165	116	7×6
11-78	65,241	65,241	12	12	24	23	2×2
11-99	15,703	15,772	48	10	64	20	4×2
11-100	1,082	1,083	114	113	147	148	7×7
11-101	2,381	2,483	80	74	131	131	7×7
11-105	2,148	2,153	114	114	156	155	7×7
12-01	26,577	26,577	22	21	43	41	3×3
12-06	8,580	8,580	14	14	30	31	3×3
Minimum	1,082	1,083	12	10	24	20	-
Mean	16,935	17,154	60	48	89	79	-
Maximum	65,241	65,241	141	114	165	155	-

Four of the ten products had a very wide distribution, and eight of the ten products had a symmetric distribution (i.e., they had the same NEMA classification for the horizontal and vertical angles). This is not typical of the bulk of conventional floodlights, and may indicate an area where LED floodlights need to offer added capability. Two of the Series 15 LED floodlights (11-100 and 11-105) had no optical control system; hence, they had very wide luminous intensity distributions. An uncontrolled distribution can result in stray light, which represents wasted energy and can pose problems in terms of glare and light pollution.

Not all aspects of distribution can be captured numerically. In some applications, the smoothness of the beam pattern from the center to the edge can be very important. This characteristic lacks a metric, but adjectives such as “smooth,” “spotty,” or “uneven” are sometimes used. The photographs in Figure 3 illustrate the beam patterns created by the Series 15 floodlights. The LED floodlights tended to have very smooth distributions—product 11-77 was the exception. This characteristic is somewhat different from the conventional benchmark, product 11-69.

Figure 3 also illustrates the difference between a soft and hard beam edge, a characteristic that can typically be inferred from the relationship between the beam angle and field angle of a given product—the greater the difference between beam angle and field angle, the sharper the beam will appear. For example, product 12-01 (0.5:1 ratio of beam angle to field angle) has a fairly sharp beam edge, whereas product 11-105 (0.73:1 ratio of

Horizontal Vertical

11-69 [BK]

11-70

11-71

11-77

11-78

11-99

11-100

11-101

11-105

12-01

12-06

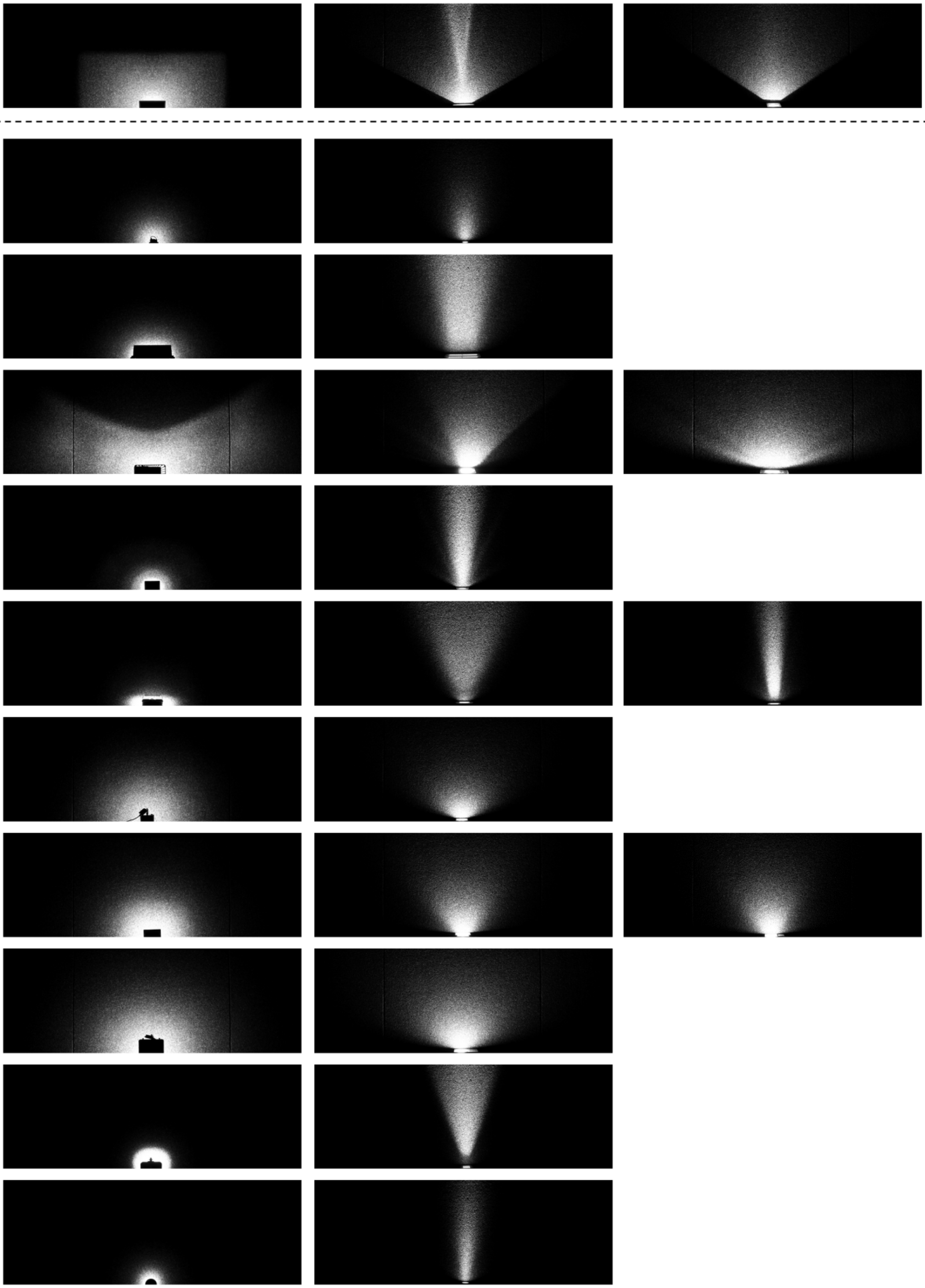

Figure 3. Photographs demonstrating the distribution of the Series 15 floodlights. The first column shows the product aimed straight at the wall (i.e., the axis of the beam was perpendicular to the wall). The second and third columns (if applicable) show the distribution of light created with the luminaire positioned at the base of the wall, aiming straight up. The horizontal and vertical columns visually represent the horizontal and vertical angle values listed in Table 6. All photographs were taken using the same exposure settings and from the same location, with the luminaire mounted at the same position.

beam angle to field angle) has a softer beam edge. Overall, the range of beam edge characteristics for the Series 15 LED floodlights and the surveyed conventional floodlights was similar.

Color Characteristics

In many applications where floodlights are used, color quality is a secondary consideration. In some applications, the color of a specific object (e.g., a red brick wall or a bronze sculpture) dictates the color quality that is necessary, but this cannot necessarily be captured with a metric. Sometimes, analyzing the spectral power distribution or visually evaluating a mockup are the best options. Given these considerations, rigid criteria for color quality are not appropriate for floodlights; nonetheless, it should not be ignored.

The CCT of the Series 15 LED floodlights ranged from 3646 K to 6099 K, and several of the products extended above the range typical of metal halide and CFL lamps. One of those products (11-101) also fell outside the ANSI-defined limits for nominally white light—which are intended only for solid-state lighting products used indoors—having a D_{uv} of 0.0125. Although higher CCTs may be appropriate in some applications, the prevalence of these products among the sample suggests that more work is necessary to ensure LED floodlights are an equivalent alternative to conventional floodlights.

Each of the products had a CRI between 66 and 83, with a mean for the group of 71. Only two products had a CRI greater than 80 (11-71 and 12-06). These CRIs are typical of standard quartz metal halide lamps, but only the two highest begin to match the performance of CFL or CMH lamps, as shown in Figure 4. Similar to other recent CALiPER testing, the R_9 values for the Series 15 LED floodlights had a strong correlation with CRI; the products

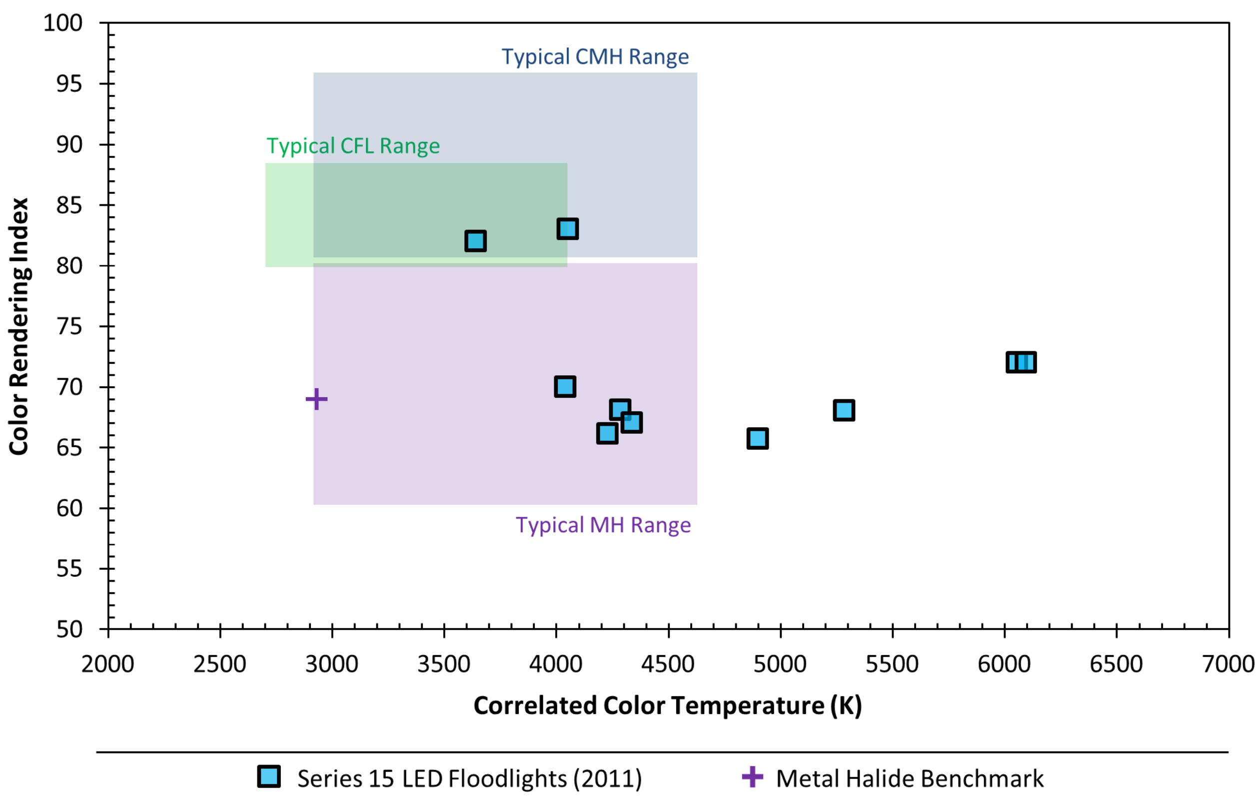

Figure 4. Color rendering index (CRI) versus correlated color temperature (CCT) for the Series 15 LED floodlights in comparison to typical ranges for conventional products. The CCT for several of the Series 15 products extends beyond the typical range for conventional floodlights. HPS lamps (not shown) typically have a CRI of about 20 and a CCT of about 2000 K.

that had a CRI below 80 all had an R_9 of less than zero. As previously noted, however, these low values are not necessarily inappropriate for floodlights.

Electrical Characteristics

Input power for the Series 15 products ranged from 12.4 to 251.4 W, corresponding to the substantial difference in lumen output. The measured power factor ranged from 0.80 to 1.00, with a mean of 0.97. Nine of the ten products had a power factor of 0.97 or greater, which is considerably better than typical conventional products.

Variability and Customization

One common attribute of many conventional floodlights is the ability to customize performance using different lamps, optical systems, and accessories (e.g., snoots, louvers, barn doors). For many installations, it is necessary to use a combination of different distributions/outputs to achieve a specific visual effect. It is also desirable to have all the fixture housings be identical, necessitating the numerous options. As shown in Table 7, some of the Series 15 LED floodlights afforded this flexibility, but others did not. It is likely that products only offering a single distribution type and single lumen package will be less suited for any given application, and may be relegated to less refined installations. In the future, it would be best if all LED floodlights offered the same customizability currently available from conventional floodlights.

Manufacturer Claims

Evaluating the accuracy of manufacturers' performance claims is an important component of the CALiPER program. Although several of the Series 15 products did not list key performance criteria on their specification sheet, six of the ten products had measured performance within ±10% of all the listed values, which is considered accurate. Those failing to meet at least one manufacturer claim include:

- Product 11-71, which produced fewer lumens and had a lower efficacy than claimed (8,044 lumens measured compared to 9,532 lumens listed [16% fewer]; 33 lm/W compared to 38 lm/W [13% lower]).
- Product 11-100, which produced fewer lumens, had a lower efficacy, and had a lower CRI than claimed

Table 7. Customizability of the Series 15 LED floodlights. The attributes were determined by reviewing the product specification sheets.

DOE CALiPER Test ID	Accessories/Shields Listed	Listed Lumen Packages	Listed Distributions
11-70	No	1	1
11-71	No	1	6
11-77	No	1	3
11-78	Yes	2	6
11-99	Yes	1	3
11-100	No	1	1
11-101	No	2	1
11-105	No	4	1
12-01	Yes	6	7
12-06	Yes	1	1

(2,991 lumens measured compared to 4,320 lumens listed [31% fewer]; 53 lm/W compared to 80 lm/W [34% lower]; CRI of 68 compared to a CRI of 80).

- Product 11-101, which had a measured CRI of 66, but claimed a CRI of 83.
- Product 12-06, which had a measured input power of 12.4 W, but a claimed input power of 18 W. This product did not list lumen output or efficacy on the product specification sheet. This could be the result of product improvements not being represented in manufacturer literature.

Ensuring that listed information reflects the performance of products being sold is important for building consumer and specifier confidence. Although CALiPER has noticed improvement in this area over the past several years, evaluation of the Series 15 products illustrates that it is still a concern. Regardless of the ability of conventional products to meet the same ±10% criterion, as a new technology it is especially important for LED products to meet expectations. Furthermore, it is desirable for products to list basic performance parameters (e.g., lumen output, input power, CCT, CRI), which was not the case for some of the Series 15 products.

6 Conclusions

Given the broad and ambiguously defined nature of the floodlight category, making absolute conclusions regarding the performance of the Series 15 products is inappropriate. Each may be effective for a given application.

This series of testing highlighted several key areas in which LED products can improve in order to be more competitive with conventional floodlights—or already offer an advantage:

- Conventional floodlights are available exceeding 20,000 lumens, but few (if any) LED floodlights can match this performance. The maximum lumen output for the Series 15 products was approximately 8,000 lumens. Currently, generating high lumen output requires a large surface area for numerous LED packages. LEDs can be driven at higher operating currents to increase light output, but among other tradeoffs, lifetime usually decreases. Improvement in LED packages will help resolve this limitation, but it is likely a long-term challenge.

- The efficacy of many of the Series 15 LED floodlights was equal to or better than the typical efficacy of conventional floodlights using metal halide or CFL lamps.

- Most of the Series 15 LED floodlights had wide, symmetric distributions. For many applications, this is not appropriate, which limits the market for LED products. Because LED floodlights require an array of LEDs, rather than the single point source of a metal halide floodlight, producing narrow spot distributions can be difficult.

- The output of conventional floodlights is highly customizable—using modular lamps, reflectors, and accessories, dozens of options are available in the same housing. This offers tremendous flexibility to enable specifiers to meet exacting performance criteria. Although some of the Series 15 LED floodlights followed a similar approach, others offered no variation. Developing more complete product lines would help LED floodlights fill the same role as conventional products.

- Although color rendition is not as important for floodlights as it is for some other product categories, it is one area where LEDs have a potential advantage. However, many of the Series 15 LED floodlights did not exploit this opportunity, and many had CCTs outside the typical range for the competing conventional floodlights. On the other hand, the color consistency and color stability of LED floodlights is likely favorable compared to conventional floodlights using metal halide lamps.

- The power factor of the Series 15 LED floodlights was considerably better than that of conventional floodlights.

- Although not specifically examined or measured by CALiPER, the rated lifetime of LED floodlights is typically as long or longer than the rated lifetime for conventional floodlights.

- As with all LED products, manufacturer claims must be accurate. Four of the ten Series 15 products failed to meet at least one manufacturer claim. To strengthen consumer confidence, this deficiency should be remedied.

7 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 manufacturer's 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 LED floodlights, the following features were evaluated and led to the final selection:

- Lumen package – Luminaires with output between 3,000 and 6,000 lumens were sought, which is roughly equivalent to the output of 70 to 150 W HID floodlights. Most LED products surveyed were within this range, but products above and below were selected as well.
- Color temperature – A CCT of 4000 to 4500 K is representative of metal halide sources, but 3000 K and 6000 K metal halide lamps are also available. Not all LED products were available within this range.
- Color rendition – A CRI of 70 or better was sought when considering luminaires for acquisition.
- Dedicated white – Color changing/tunable LED floodlights were not considered for inclusion in this series of testing.

Some 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.

8 Appendix B: Definitions

Beam Angle
Degrees (°)

The angle between the two directions for which the intensity is 50% of the maximum intensity (ANSI/IES RP-16-10) or center beam intensity (ANSI C78.379-2006), as measured in a plane through the beam axis. For example, if the maximum intensity is 1000 cd, the angle at which the intensity is 500 cd is half of the beam angle. If 500 cd occurs at 20° from center beam, then the beam angle is 40°.

Center Beam Candlepower (CBCP)
Candela (cd)

The luminous intensity at the central axis of the beam, which typically corresponds to a vertical angle of 0° (called nadir for lamps oriented downward). Although candlepower is a deprecated term, it is still widely used in this context.

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.

Field Angle
Degrees (°)

The angle between the two directions for which the intensity is 10% of the maximum intensity (ANSI/IES RP-16-10) or center beam intensity (ANSI C78.379-2006), as measured in a plane through the beam axis. For example, if the CBCP is 1000 cd, the angle at which the intensity is 100 cd is half of the field angle. If 100 cd occurs at 32° from center beam, then the field angle is 64°.

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 amps) 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.

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