NATIONAL LIGHTING PRODUCT INFORMATION PROGRAM

Specifier Reports

Reflector Lamps

Energy-efficient replacements for 75-watt, 100-watt, and 150-watt incandescent reflector lamps

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Contents

Introduction

Late in 1992, the United States enacted the Energy Policy Act (EPACT), which addresses energy issues ranging from nuclear power plant development to automobile fuel efficiency. Part of EPACT sets new efficacy requirements for some fluorescent lamps and incandescent reflector lamps. Lamps that do not meet these requirements are prohibited from being imported or manufactured for sale in the United States after October 31, 1995. Noncomplying lamps manufactured before then still may be sold after that date.

The new requirements will affect lighting manufacturers, consumers, and specifiers by eliminating in the United States widely used lighting products such as some reflector (R) and parabolic aluminized reflector (PAR) lamps. The many specifiers and consumers who are familiar with these lamps may become confused when they have to choose from the array of unfamiliar, alternative products that meet the EPACT requirements.

Incandescent R and PAR lamps are used extensively for applications such as accent and retail lighting and in spaces such as lobbies, corridors, and outdoors. When EPACT takes effect, what alternatives will specifiers and consumers have for replacing these lamps? Will the alternatives provide similar distributions, intensities, and beam patterns?

In this issue of *Specifier Reports*, the National Lighting Product Information Program (NLPIP) addresses these and other questions involved in selecting replacements for the incandescent R and PAR lamps that are prohibited by EPACT. Manufacturers' data are supplied for 75-, 100-, and 150-watt R and PAR flood and spot lamps and for their recommended replacements. The report compares the measured performance characteristics of four categories of lamps often used in architectural lighting (150-watt PAR38 and 75-watt R30 flood and spot lamps) with their manufacturer-recommended replacements.

The production of this report involved important contributions from many people. Donna Abbott Vlahos shot all of the photographs. Contributing Lighting Research Center (LRC) staff members include Q. Wang, who constructed the testing apparatus and conducted the testing with S. Mangum and A. Bierman, and E. Gillmeister, who compiled the data for the report. LRC members J. Barry, N. Bayer, A. Buddenberg, J. Ceterski, K. Conway, Y. Ji, M. Rea, and P. Schemenaur also contributed.

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Nomenclature

Throughout this report, NLPIP uses the following nomenclature:

- A *reflector lamp* is any lamp or product that has a reflective coating, such as incandescent reflector lamps and compact fluorescent lamp (CFL) reflector products.
- An *incandescent reflector lamp* is any reflector lamp whose light is produced by an incandescing filament. This term refers to common R and PAR, energy-saving R and PAR, krypton-filled R, ER, BR, and halogen PAR lamps.

  NLPIP uses the term *common reflector lamp* to refer collectively to standard incandescent R and PAR lamps, most of which do not meet EPACT efficacy requirements.
- A *CFL reflector product* is a type of reflector lamp that has three components: a fluorescent lamp, a ballast, and a reflector.

Lamp Technologies

Common R and PAR Lamps

Common R and PAR lamps are incandescent lamps that produce light in the same way as the common incandescent A-lamps used in homes and residences. Electric current passes through a tungsten filament, increasing the temperature of the filament until it incandesces (gives off light).

Under normal operating conditions, the temperature of the filament determines the efficacy of an incandescent lamp: as the filament gets hotter, lamp efficacy increases. Lamp efficacy, expressed in lumens per watt (LPW), is the lamp's initial light output divided by its active power (see p. 7 for information about light output and active power). If the filament becomes too hot, the tungsten rapidly evaporates, decreasing lamp life. Most common incandescent lamps are filled with a gas mixture composed primarily of the inert gas argon to help retard the evaporation of the tungsten. A small amount of nitrogen also is added to prevent electric arcs between the filament and the glass.

Table 1 shows the minimum efficacy requirements established by EPACT for incandescent R and PAR lamps. Of the common R and PAR lamps presently available, the only ones that meet the EPACT efficacy requirements are the 50-watt R30 and 65-watt R30 lamps.

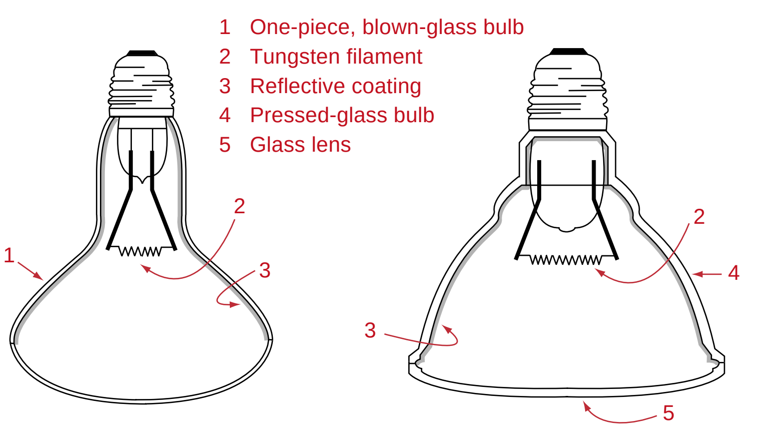
Energy-Saving R and PAR Lamps

Energy-saving R and PAR lamps are incandescent lamps that are rated for approximately 20% fewer watts than the common reflector lamps that they are designed to replace. For example, a 120-watt energy-saving R40 lamp sometimes is used as a replacement for a 150-watt common R40 lamp. Energy-saving reflector lamps have slightly higher efficacies than common reflector lamps because the energy-saving lamps are shaped to reflect some of the heat produced by the filament back onto the filament. These lamps do not produce as much light as the lamps that they are intended to replace, and they distribute light differently. They do not meet the EPACT efficacy requirements.

R and PAR Lamps

The descriptors "R" and "PAR" designate two different shapes of reflector lamps. An R lamp is made of a one-piece glass bulb that has a reflective coating applied to the inside of the glass. A PAR lamp is made of a heat-resistant, pressed-glass bulb that has a reflective coating on the inside and is sealed to a separate glass lens. R lamps are used for accent lighting in areas such as retail displays and museums and for general area downlighting where a smooth distribution of light with a soft-edged beam is desired. PAR lamps are used in accent lighting and for lighting outdoor areas such as driveways, signs, and building facades where a sharply defined, hard-edged beam is desired.

In reflector lamp nomenclature, the number preceding "R" or "PAR" is the lamp wattage, the number following "R" or "PAR" is the diameter of the widest part of the lamp in eighths of an inch, and the letters following a slash represent the beam spread. For example, 150PAR38/FL is the designation for a 150-watt PAR lamp, $^{38}/_{8}$ or 4.75 inches in diameter, with a flood (FL) distribution. For more information about beam spread, see pp. 8–9.



Cross Section of an R Lamp

Cross Section of a PAR Lamp

Krypton-Filled R Lamps

The efficacy of a common incandescent lamp can be increased by including krypton gas in the argon gas fill. Krypton does not conduct heat as well as argon, so less heat is conducted away from the filament. Thus, the filament stays hotter, and the efficacy of the lamp increases by 7 to 20%, depending on how much krypton is used. Furthermore, krypton slows the evaporation of the tungsten more effectively than argon does, so lamp life is not adversely affected by the increased filament temperature.

By adding krypton, lamp manufacturers can reduce lamp wattage while maintaining light output and lamp life comparable to those of the higher-wattage, argon-filled lamps. However, the krypton-filled lamps are more costly to manufacture than the argon-filled lamps. Some manufacturers market krypton-filled R lamps under the same “energy-saving” banner as the argon-filled reflector lamps discussed previously. To distinguish between the two types, specifiers should read the lamp catalog notes or the packaging because manufacturers generally note if a lamp is krypton-filled. Unlike the argon-filled energy-saving reflector lamps, the krypton-filled R lamps meet the EPACT efficacy requirements.

Table 1. EPACT Efficacy Requirements for Incandescent Reflector Lamps and Efficacies of Selected Common R and PAR Lamps

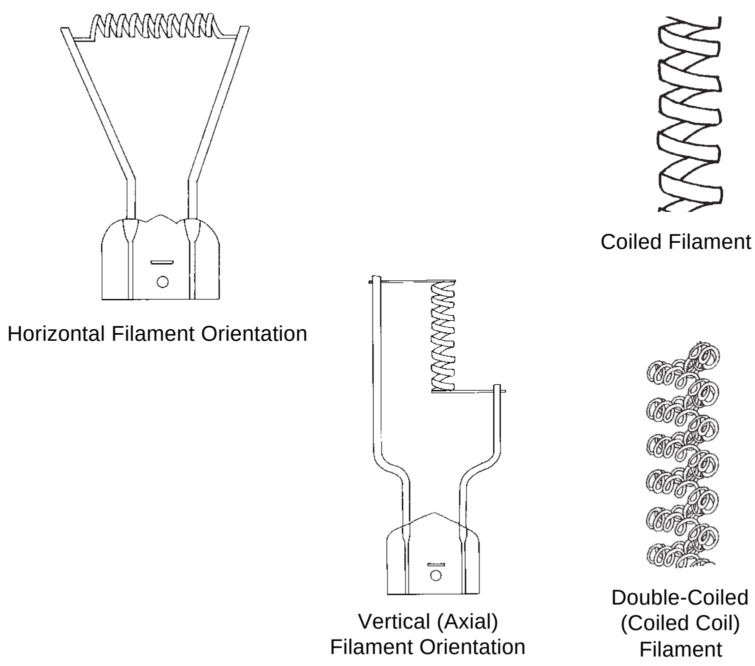
Nominal Lamp Wattage (W)	EPACT Minimum Required Lamp Efficacy (LPW)	Efficacies of Selected Common R Lamps (LPW)	Efficacies of Selected Common PAR Lamps (LPW)
40–50	10.5	11 (50-watt R30)	6 (50-watt PAR36)
51–66	11.0	12 (65-watt R30)	10 (55-watt PAR38)
67–85	12.5	11 (75-watt R30)	10 (75-watt PAR38)
86–115	14.0	12 (100-watt R40)	13 (100-watt PAR38)
116–155	14.5	13 (150-watt R40)	12 (150-watt PAR38)
156–205	15.0	10 (200-watt R40)	14 (200-watt PAR56)

Meets present EPACT minimum efficacy requirement

Filament Design

Most incandescent lamps, including R and PAR lamps, have a filament mounted horizontally on the filament supports. The filament itself is usually coiled (like a tiny spring) or double-coiled (like a tiny spring wound into a helix; also called coiled coil). The more coiled a filament is, the more efficacious it is, because the heat that is emitted from one part of the filament can be absorbed by another part, increasing the overall filament temperature.

Halogen lamp filaments also are coiled or double-coiled but usually are oriented vertically, parallel to the center-beam axis of the lamp. This axial orientation makes it easier to direct the light with reflectors and improves optical control.



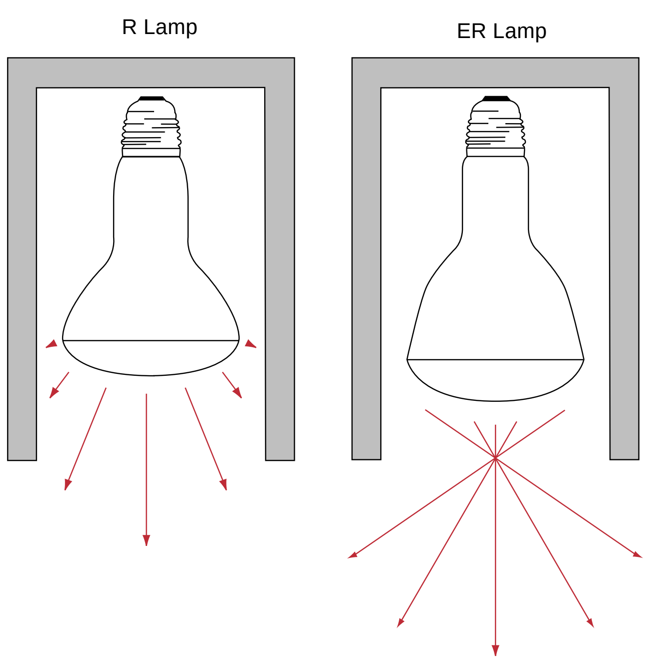
(Adapted from IESNA 1993)

Ellipsoidal Reflector (ER) and Bulged Reflector (BR) Lamps

Ellipsoidal reflector (ER) lamps are similar to common R lamps except that the reflector is ellipsoidal rather than parabolic. An ellipsoidal reflector has two focal points. The filament of an ER lamp is located at one focal point. Light from the filament reflects off the ellipsoidal reflector, out of the lamp, and through the other focal point, which is located outside the lamp.

When an R lamp is recessed deeply into a cylindrical luminaire, such as a recessed downlight or track luminaire, light at the edge of the beam can strike the inside of the luminaire. Some of that light is absorbed, especially if the inside of the luminaire is black, which is a common strategy for reducing glare. Conversely, light from an ER lamp is directed across the center of the beam through the second focal point and out of the luminaire. Most of the light exits the luminaire, so less light is wasted (see Figure 1). Thus, although ER lamps are no more efficacious than common R lamps, they can deliver light more effectively out of a deep luminaire. For this reason, ER lamps are exempt from the EPACT efficacy requirements.

Figure 1. Performance of an R Lamp Compared to That of an ER Lamp in a Recessed Luminaire



An ER lamp is designed optically to aim more light out of a deep, recessed luminaire than an R lamp does.

One manufacturer offers another type of common reflector lamp that has a reflector designed to concentrate light at the center of the beam. These bulged reflector (BR) lamps also result in less wasted light when they are deeply recessed into luminaires. Like ER lamps, BR lamps are exempt from the EPACT efficacy requirements.

Halogen PAR Lamps

Halogen lamps, also called tungsten-halogen lamps, are incandescent lamps that have halogens (iodine, bromine, chlorine, or fluorine) added to the argon gas fill. In a common incandescent lamp, the tungsten that evaporates from the filament collects on the glass bulb, blackening the bulb wall and reducing light output. In a halogen lamp, the evaporated tungsten combines with the halogen before the tungsten comes in contact with the bulb wall, forming a gaseous compound. The tungsten-halogen compound circulates inside the lamp until it comes close to the filament, where the high temperature breaks down the compound into halogen vapor and solid tungsten.

Because of this regenerative cycle, which limits bulb blackening, a halogen PAR lamp has less lumen depreciation (see Figure 2); the light output does not decrease over time as quickly as that of a common PAR lamp. A halogen PAR lamp may also have a longer lamp life than a common PAR lamp. Lamp life may not be extended because the redeposited halogen will not always deposit at the weakest point on the filament.

The filament in a halogen lamp is enclosed in a small capsule (see Figure 3) to maintain the proper environment for the halogen cycle. This capsule often is made of a quartz glass because quartz can withstand the high temperatures and pressures at which halogen lamps operate. Unlike the thick glass used in PAR lamps, the glass used in R lamps is too thin to contain the glass particles that would result if the capsule should burst, so halogen R lamps are not manufactured.

Because halogen lamps operate at higher temperatures than common incandescent lamps, halogen lamps have higher lamp efficacies. Thus, halogen PAR lamps can operate at lower active power than the common PAR lamps they are designed to replace. Halogen PAR lamps meet EPACT efficacy requirements.

Halogen PAR lamps typically produce less light than the common PAR lamps they are designed to replace. Manufacturers compensate for the lower light output by designing the optics of halogen PAR lamps so that they produce narrower beams than do comparable common PAR lamps. This concentrates more light at the center of the beam; consequently, halogen PAR lamps produce a maximum beam intensity that is usually greater than that of the common PAR lamps that they are designed to replace.

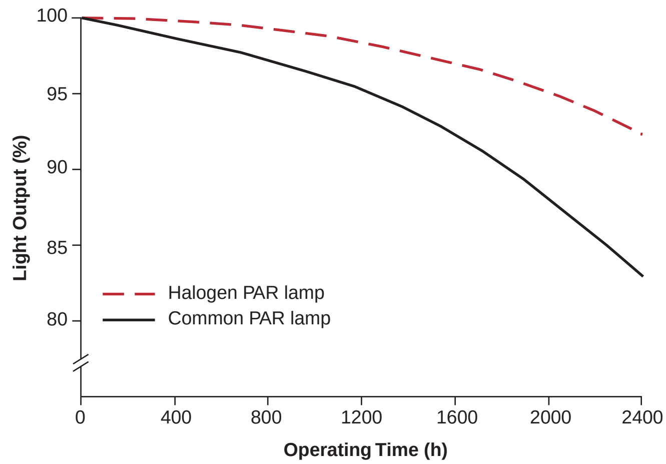
Diodes in Halogen PAR Lamps

Some halogen PAR lamp manufacturers include a diode in the lamp's circuitry to decrease filament voltage and to extend lamp life. A diode is an electronic component that allows current to flow in only one direction. When a lamp with a diode is operated on alternating current, the lamp does not draw current for half of the current wave's period. Thus, on a 60-hertz power supply, the lamp operates on a cycle where it is on for approximately 8 milliseconds (ms) and then off for approximately 8 ms. This oscillation is visible to some people, who perceive it as lamp flicker. Most manufacturers have eliminated diodes from halogen PAR30 and PAR38 lamps, although some may still use them in halogen PAR20 and PAR16 lamps. The use of a diode is not indicated on the lamp packaging or on the lamp itself; thus, the specifier should check with the manufacturer if the use of a diode is a concern.

Halogen Infrared PAR Lamps

Halogen infrared PAR lamps contain a specially shaped quartz capsule that is coated internally with an infrared-reflecting film. The film reflects much of the infrared energy back onto the filament, which increases the filament temperature. The reflective film allows halogen infrared PAR lamps to operate at wattages lower than those of the lamps they are intended to replace while producing higher efficacies. A manufacturer of halogen infrared PAR lamps claims efficacies as high as 20 LPW, approximately 40% higher than those of other halogen PAR lamps (GE Lighting 1993). Halogen infrared PAR lamps meet EPACT efficacy requirements.

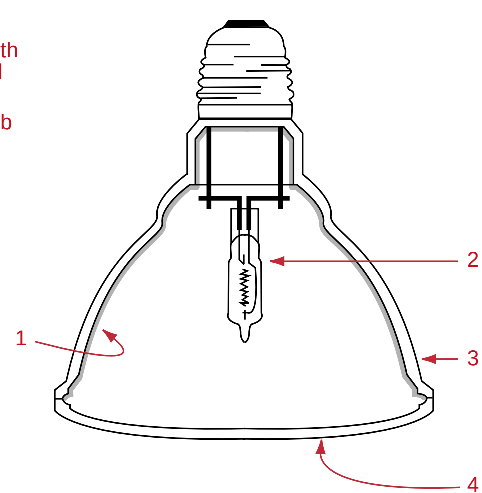
Figure 2. Lumen Depreciation of a Common PAR Lamp Compared to That of a Halogen PAR Lamp



(Adapted from IESNA 1993)

Figure 3. Cross Section of a Halogen PAR Lamp

1 Reflective coating
2 Quartz capsule with vertically mounted tungsten filament
3 Pressed-glass bulb
4 Glass lens



Screwbase Compact Fluorescent Lamp Reflector Products

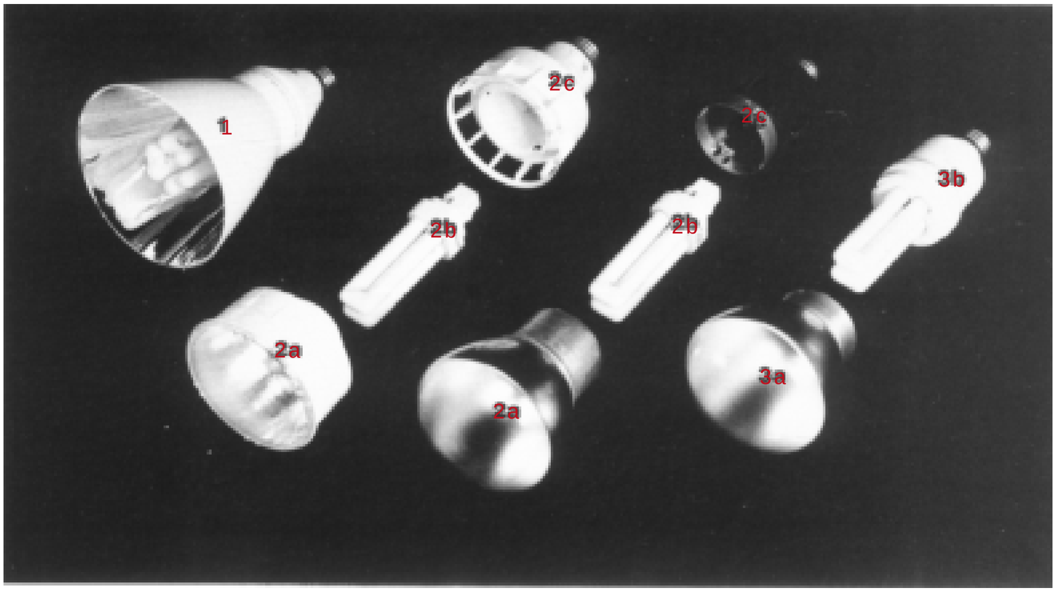
Fluorescent lamp efficacies generally are much higher than incandescent lamp efficacies because more of the input energy is converted into light. Efficacies for compact fluorescent lamps (CFLs) range from 45 to 70 LPW. However, adapting fluorescent lamp technology to reflector lamp applications presents several problems.

CFL reflector products are either modular, with a lamp, ballast, and reflector that are separate, or self-ballasted, with a lamp and ballast that are permanently joined and a reflector that is either permanently joined or separate (see Figure 4). Most self-ballasted CFL reflector products are slightly smaller than comparable modular CFL reflector products, but both types are typically longer and wider than incandescent reflector lamps. Even the shortest CFL reflector products are wider near the base than incandescent reflector lamps. The added size of the screwbase ballast can make it difficult for CFL reflector products to fit into some luminaires that are designed for incandescent reflector lamps.

A CFL emits light from a larger area than an incandescent lamp's filament does. As a result, it is more difficult to precisely direct the light with small reflectors and lenses, so the beam spreads of CFL reflector products are wider than those of most incandescent reflector lamps.

Over time, the light output of a CFL decreases primarily because the phosphors become less effective. The light output of a CFL can also be reduced when its operating temperature and position do not match standard test conditions, which often is the case in reflector lamp applications. Additional information about screwbase CFL products is available from NLPIP in *Specifier Reports: Screwbase Compact Fluorescent Lamp Products* (1993).

Figure 4. Types of CFL Reflector Products



1 Self-ballasted CFL reflector product with an integral reflector

2 Components of a modular CFL reflector product:
- 2a Reflector
- 2b CFL
- 2c Screwbase ballast

3 Self-ballasted CFL reflector product with a separate reflector
- 3a Reflector
- 3b Self-ballasted CFL

Performance Characteristics

Active Power

Active power is total input power—the rate at which electric energy is used by a lamp, measured in watts. Tables 4–10 list the active power reported by manufacturers for products that are designed to replace 75-, 100-, and 150-watt incandescent R and PAR lamps. For modular CFL reflector products, the active power listed does not include ballast losses; this may increase the total active power by 2 to 5 watts.

Light Output

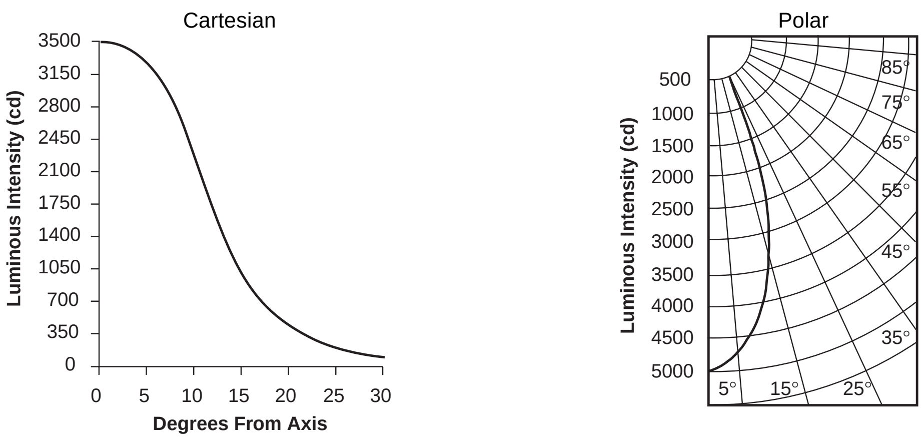
In their catalogs and product specification sheets, lamp manufacturers describe the light output of reflector lamps in terms of both the quantity of light produced and how it is distributed. Common measures that they report are initial light output, candlepower distribution, maximum beam intensity, and beam spread. Some manufacturers do not report all of these measures. NLPIP obtained initial light output, maximum beam intensity, and beam spread data from manufacturers for most of the products included in this report; these appear in Tables 4–10.

Initial light output. For most lamp types, lamp catalogs contain the manufacturer's rating for initial light output in lumens. A lamp's light output slowly decreases from the initial value. This lumen depreciation occurs at different rates for different technologies.

Most manufacturers do not publish initial light output ratings for PAR lamps in their catalogs. Instead, they provide beam spread and maximum beam intensity data. The initial light output information is available from manufacturers on request. For R lamps, initial light output ratings usually are reported in catalogs, but beam spread and maximum beam intensity data usually are not.

Candlepower distribution. For most applications, the initial light output of a reflector lamp is not as informative as the distribution of the lamp's luminous intensity (candlepower). The most common method of reporting this distribution is the candlepower distribution curve, which illustrates the candlepower of the beam at different angles (see Figure 5). Candlepower distribution curves are not included in lamp catalogs but may be included in product specification sheets.

Figure 5. Two Methods of Plotting Candlepower Distribution Curves



Candlepower distribution curves present luminous intensity data at different angles with respect to the axis of the lamp. The data may be plotted using either Cartesian or polar coordinate systems. Cartesian coordinates are normally used to present reflector lamp data; polar coordinates are normally used to present luminaire data.

Maximum beam intensity. In catalogs and specification sheets, a reflector lamp manufacturer usually reports a lamp's maximum beam intensity as the center beam candlepower (CBCP), which is expressed in candelas (cd) and sometimes referred to as maximum beam candlepower (MBCP). The maximum beam intensity is reported as the average intensity of a narrow cone around the center of the beam. GE Lighting, OSRAM SYLVANIA, and Philips Lighting report CBCP values as the average of several initial intensities measured within a 10° cone for flood and narrow flood lamps and within a 5° cone for spot and narrow spot lamps. See p. 9 for more information about flood and spot lamps.

Beam spread. In their catalogs, lamp manufacturers usually express the beam spread of a lamp by listing either its beam angle, the angle at which the lamp produces 50% of the maximum beam intensity, or its field angle, the angle at which the lamp produces 10% of the maximum beam intensity. When comparing lamps, specifiers should note whether beam angle or field angle is reported. See p. 9 for more information about beam spread.

Beam Appearance

Two lamps with identical or similar CBCPs and beam spreads may produce different brightness patterns on the same surface. NLPIP refers to these brightness patterns as "beam appearance." Beam appearance can be greatly affected by characteristics of the beam such as the smoothness of the intensity decreasing from the center and the sharpness of the beam edge. These characteristics cannot be determined from reported photometric data.

Certain beam appearances often are associated with the lamp technology. Common reflector lamps distribute light more smoothly than most of their recommended replacements. For example, a halogen PAR lamp's beam appearance may contain a center "hot spot."

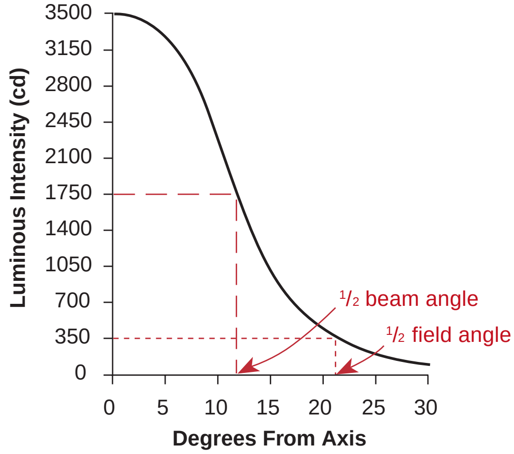
NLPIP evaluated the beam appearance of each lamp by observing the brightness pattern on a wall. The procedure is described in detail on pp. 20–21, and the results are reported in Tables 11–14.

The Beam Spread of Reflector Lamps

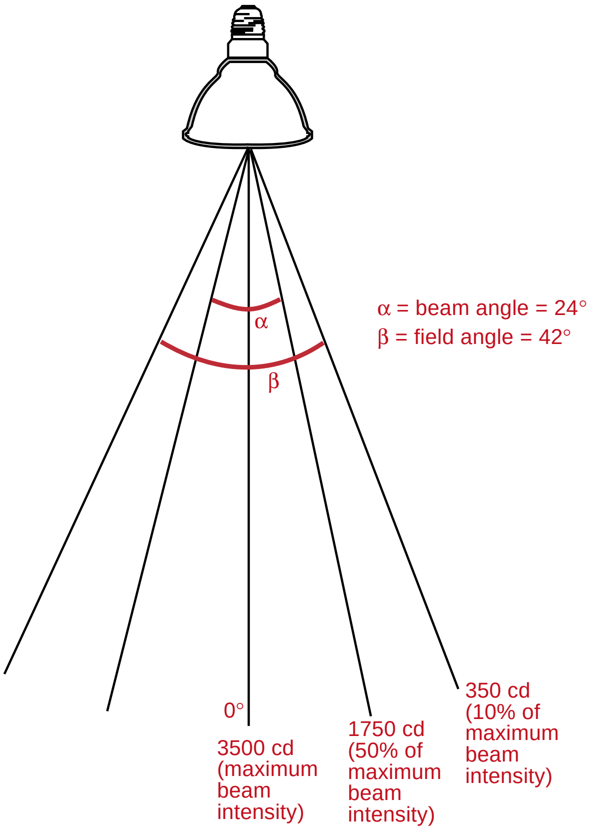
In catalogs and product specification sheets, the beam spread of a reflector lamp can be reported either as a beam angle or a field angle. The beam angle is the angle at which the lamp produces 50% of the beam's maximum intensity (two times the angle from the maximum beam intensity to 50% of the maximum beam intensity). The field angle is the angle at which the lamp produces 10% of the beam's maximum intensity (two times the angle from the maximum beam intensity to 10% of the maximum beam intensity).

Example of Beam and Field Angles

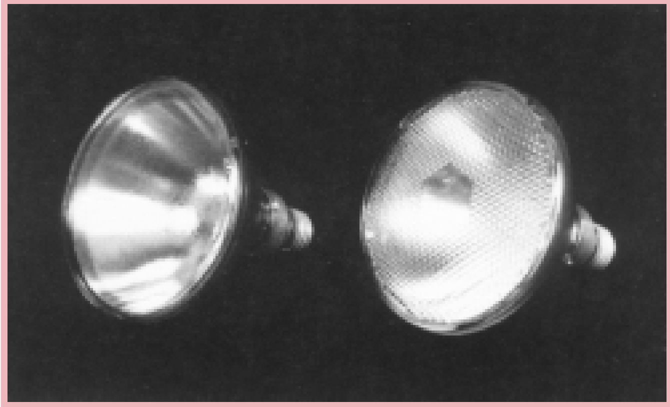
Beam and field angles from a candlepower distribution curve:



Beam and field angles represented schematically:

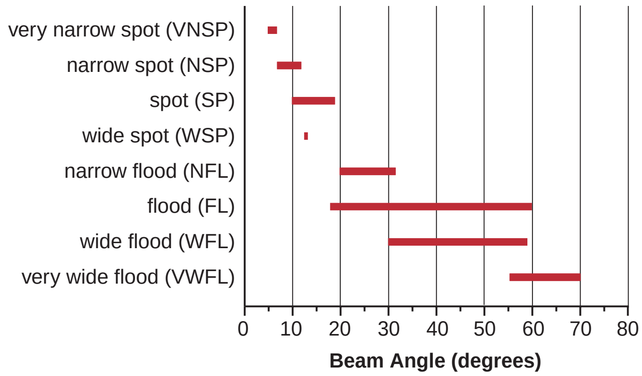


Manufacturers also may assign a descriptive term to each lamp type, such as "spot" or "flood," to characterize the beam spread. As shown below, the type of PAR lamp often can be distinguished by the lens: spot lamps have smooth lenses (left) and flood lamps have stippled lenses (right).



These terms are not standardized. More refined descriptions such as narrow flood, wide flood, very wide flood, narrow spot, and wide spot are used by manufacturers to describe their products, but these terms also are arbitrary. For example, NLPIP found a product called a wide flood that has a smaller beam angle than another manufacturer's narrow flood lamp. The following chart indicates the range of beam angles reported for different categories of reflector lamps from a sampling of manufacturers' catalogs. The abbreviation for each category, which is used in lamp nomenclature, is shown in parentheses.

The Range of Beam Angles for R and PAR Lamps



The National Electrical Manufacturers Association (NEMA) has developed a categorization system for use by manufacturers in their catalogs. For reflector lamps with beam angles greater than or equal to 13°, the angle is rounded to the nearest 5° increment in the catalog description. For lamps with beam angles less than 13°, the angle is rounded to the nearest 1° increment.

Color

Two measures commonly are used to specify lamp color: correlated color temperature (CCT) and color rendering index (CRI). Tables 4–10 list the CCT and CRI values as reported by the manufacturers. NLPIP did not evaluate CCT or CRI values for this report.

CCT. CCT describes the color appearance of a light source in terms of a reference light source (blackbody radiator) operated at a given temperature, which is measured in kelvin (K). Lamps with CCTs of 3100 K or lower usually are considered warm sources having a yellow-white appearance. Lamps with CCTs of 4000 K and higher usually are considered cool sources having a blue-white appearance. Mid-range lamps are also available with CCTs between 3100 and 4000 K. The CCTs of common reflector lamps are typically 2700 to 2800 K. The CCTs of halogen PAR lamps range from 2800 to 3050 K, and the CCTs of halogen infrared PAR lamps range from 2850 to 2875 K. The CCTs of fluorescent lamps are determined mostly by the blend of phosphors used, so many CCTs are possible. Common CCTs for CFL reflector products are 2700, 2800, 3000, 3500, and 4100 K.

CRI. The CRI of a lamp describes the degree of color shift that objects undergo when illuminated by a lamp, compared with those same objects when illuminated by a reference source of comparable CCT. To determine a lamp's CRI value, eight standard colors are illuminated by both the lamp and the reference light source. The average of the eight color shifts is reported as the CRI value. The smaller the shift, the higher the CRI value, with a maximum of 100. In general, a lower CRI value indicates that some colors may appear unnatural when illuminated by the lamp.

Because CRI is based on a reference source with the same CCT as the test lamp, the CRI values of lamps with very different CCTs should not be compared. In addition, specifiers should be aware that two lamps with the same CRI value can render colors differently. To evaluate how different lamps render color, specifiers should perform visual, side-by-side comparisons of lamps illuminating objects. Most lamp manufacturers have color-comparison boxes available for this purpose. Incandescent reflector lamps typically have CRI values above 95. Typical CFL reflector products have CRI values ranging from 80 to 85.

Lamp Life

Lamp life is reported by lamp manufacturers as average rated life, which is the number of hours at which half of the lamps in a large test group are still operating under standard test conditions. Thus, half of a batch of lamps of the same type can be expected to fail before the average rated life, and half can be expected to operate beyond the average rated life. Unlike incandescent lamps, fluorescent lamps have lamp lives that are affected by the frequency of switching. Standard test conditions that are used for manufacturers' ratings require that fluorescent lamps be switched off for 20 minutes after every 3 hours of operation.

Most non-halogen, incandescent reflector lamps have an average rated life of 2000 hours. The average rated life for halogen PAR lamps ranges from 2000 to 6000 hours, depending on lamp size and wattage (higher-wattage lamps generally have longer lamp life). Halogen infrared PAR lamps have an average rated life of 3000 hours. CFL reflector products generally have an average rated life of 10,000 hours. Tables 4–10 list the average rated lamp lives reported by the manufacturers. NLPIP did not evaluate lamp life for this report.

Other Considerations

Size, Shape, and Weight

Halogen PAR lamps are essentially the same size, shape, and weight as the common PAR lamps that they are intended to replace; hence they do not present relamping problems. Energy-saving R lamps, ER lamps, and krypton-filled R lamps are similar in size, shape, and weight to common R lamps, so they too do not present relamping problems.

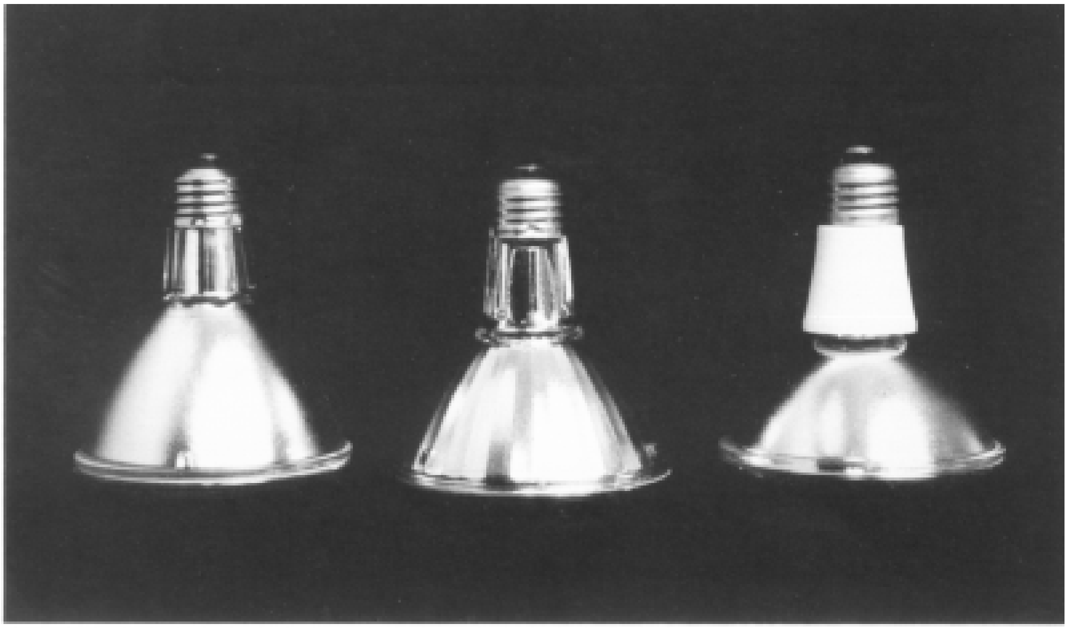
Some other types of replacements for common R lamps may pose relamping problems because of their size, shape, or weight. Most halogen PAR lamps are shorter than the R lamps that they are intended to replace. When a PAR lamp, especially a flood type, is recessed in a deep, cylindrical luminaire, much of the light at the edge of the beam can be trapped inside the luminaire. Some manufacturers offer long-neck versions of halogen PAR lamps (Figure 6) that help overcome this problem. In addition, socket extension adapters can be used to provide a better fit for the lamp in a luminaire. Halogen and halogen infrared PAR lamps use thicker glass than R lamps, so they are heavier. The additional weight generally does not cause difficulties.

Installing CFL reflector products as replacements for R lamps may be difficult because the CFL reflector products tend to be wider near the base and longer than R lamps. The weight of a CFL reflector product, which is concentrated mostly in the ballast, should not be a concern for most luminaires, although the weight of a magnetic ballast could cause a track luminaire to tip. Specifiers should select products with electronic ballasts if minimizing the weight of the product is important.

Availability

Many of the incandescent R lamps and halogen PAR lamps that NLPIP purchased for this report were available from local electrical distributors. Lamps generally were delivered within one to two weeks of ordering. The long-neck halogen PAR lamps were more difficult to obtain, with lead times of three to six weeks. In one case, the manufacturer was just beginning to make the lamps, and delivery took approximately six to eight weeks. CFL reflector products were available within three to four weeks. One CFL manufacturer required a minimum quantity for orders, which made it difficult for NLPIP to obtain a small number of samples.

Figure 6. Long-Neck Halogen PAR Lamps



Simple Payback

In Tables 2 and 3, simple payback calculations are shown to illustrate the economic viability of the alternative lamps. However, these analyses are limited because they do not account for the time value of money or lamp replacement costs. More robust analyses, such as discounted payback, return on investment, and net present value, depend greatly on the financial assumptions made by the specifier or purchaser. Tables 2 and 3 provide the lamp data needed to perform these other economic analyses.

Economics

The selection of a replacement lamp depends on electrical and photometric factors and economic factors, such as replacement cost and potential energy savings. As an example of how these factors can be used to compare products, Tables 2 and 3 show the photometric and economic performances for some of the lamps that are suggested by manufacturers as replacements for common 150-watt PAR38 flood lamps and 75-watt R30 flood lamps, respectively. Specific products from any individual manufacturer may differ in performance from the general data shown in these tables.

Table 2 shows that all four examples of replacement lamps for the 150-watt PAR38 flood lamp have simple paybacks of less than four months. All four also have narrower beam angles and lower initial light output than the base case lamp. Replacement 1 (a 90-watt halogen PAR38 flood lamp) closely matches the overall photometric performance of the base case lamp and has the shortest payback (1.5 months). However, Replacement 2 (a 60-watt halogen infrared PAR38 flood lamp) has the greatest savings in energy costs, a similar photometric performance, and 50% longer lamp life.

Table 3 shows that three of the replacements for the 75-watt common R30 flood lamp have simple paybacks of less than 19 months, and one (Replacement 4, a 13-watt modular CFL reflector flood product) has a longer simple payback of 27.5 months because of its high initial cost. However, Replacement 4 has the lowest annual lamp replacement cost (US$2.21) of the replacement lamps because of its 10,000 hour life and modular components. The CFL reflector products yield the highest energy savings but produce wider beams and significantly lower CBCPs than the base case lamp. Replacement 1 (a 60-watt krypton-filled R30 flood lamp) matches the overall photometric performance of the base case lamp most closely and has the shortest payback. However, it has the lowest energy cost savings and shorter life than the other replacement lamps.

Using lower-wattage lamps decreases the amount of heat generated in a space, which reduces the cooling load on the air conditioning system and usually further increases energy savings. Tables 2 and 3 show the cooling load reduction per lamp for each replacement lamp, in tons. The cooling load reductions resulting from the replacement of 500 lamps also are shown and indicate that significant reductions in cooling loads can be attained.

Table 2. Comparisons of Replacements for 150-Watt PAR38 Flood Lamps

	Base Case	Replacement 1	Replacement 2	Replacement 3	Replacement 4
Lamp Type	**150-Watt Common PAR38 Flood**	**90-Watt Halogen PAR38 Flood**	**60-Watt Halogen Infrared PAR38 Flood**	**75-Watt Halogen PAR38 Flood**	**75-Watt Long-Neck Halogen PAR30 Flood**
Electrical and Photometric Comparisons					
Active Power (W)[a]	150	90	60	75	75
Power Reduction (W)	NA	60	90	75	75
Life (h)[a]	2000	2000	3000	2500	2000
CBCP (cd)[a]	3100	4000	3630	4500	2800
Beam Angle[a]	36°	30°	29°	27°	30°
Initial Light Output (lm)[a]	1740	1270	1150	1140	950
Relative Light Output	100%	73%	66%	66%	55%
Relative CBCP	100%	129%	117%	145%	90%
Relative Beam Angle	100%	83%	81%	75%	83%
Beam Appearance[b]	Smooth	Two-contour	Two-contour	Variegated	Smooth
Economic Comparisons: Simple Payback					
Lamp Cost[c]	$2.50	$4.50	$8.50	$8.50	$7.00
Incremental Investment per Lamp	$0.00	$2.00	$6.00	$6.00	$4.50
Annual Energy Cost Savings per Lamp[d]	NA	$15.60	$23.40	$19.50	$19.50
Simple Payback (mo)[e]	NA	1.5	3.1	3.7	2.8
Economic Comparisons: Lamp Replacement Cost					
Annual Lamp Replacement Cost per Lamp[f]	$3.25	$5.85	$7.37	$8.84	$9.10
Annual Lamp Replacement Cost for 500 Lamps	$1625	$2925	$3685	$4420	$4550
Economic Comparisons: Cooling Load					
Cooling Load Reduction per Lamp (t)[g]	NA	0.017	0.026	0.021	0.021
Cooling Load Reduction for 500 Lamps (t)	NA	8.5	12.8	10.7	10.7

NA = not applicable

[a] Lamp data are based on manufacturer-supplied performance data.

[b] Evaluations of beam appearance are explained on pp. 20–21.

[c] Costs are based on estimates given to NLPIP by an Albany, New York, electrical distributor in July 1994.

[d] Annual energy cost savings per lamp (US$/yr) = power reduction (W) × burn hours per year (h/yr) × energy rate (US$/kWh) ÷ 1000 W/kW. The number of burn hours per year is assumed to be 2600 h/yr, based on 10 hours per day, five days per week, 52 weeks per year. The energy rate is assumed to be US$0.10/kWh.

[e] Simple payback (mo) = incremental investment per lamp (US$) ÷ annual energy cost savings per lamp (US$/yr) × 12 mo/yr.

[f] Annual lamp replacement cost per lamp (US$/yr) = [burn hours per year (h/yr) ÷ life (h)] × lamp cost (US$). The number of burn hours per year is assumed to be 2600 h/yr.

[g] Cooling load is given in tons (t), the common measure for determining necessary HVAC equipment size. Cooling load reduction per lamp (t) = power reduction (W) × 3.413 Btu/Wh ÷ 12,000 (Btu/h)/t.

Table 3. Comparisons of Replacements for 75-Watt R30 Flood Lamps

	Base Case	Replacement 1	Replacement 2	Replacement 3	Replacement 4
Lamp Type	**75-Watt Common R30 Flood**	**60-Watt Krypton-Filled R30 Flood**	**50-Watt Long-Neck Halogen PAR30 Wide Flood**	**20-Watt Self-Ballasted CFL Reflector Flood**	**13-Watt Modular CFL Reflector Flood**
Electrical and Photometric Comparisons					
Active Power (W)[a]	75	60	50	20	13
Power Reduction (W)	NA	15	25	55	62
Life (h)[a]	2000	2000	2500	10,000	10,000
CBCP (cd)[a]	470	510	500	370	280
Beam Angle[a]	72°	65°	58°	100°	80°
Initial Light Output (lm)[a]	900	775	650	800	900
Relative Light Output	100%	86%	72%	89%	100%
Relative CBCP	100%	109%	106%	79%	60%
Relative Beam Angle	100%	90%	81%	139%	111%
Beam Appearance[b]	Smooth	Smooth	Smooth	Variegated	Variegated
Economic Comparisons: Simple Payback					
Lamp Cost[c]	$1.50	$3.00	$8.00	$23.00[d]	$38.50[e]
Incremental Investment per Lamp	$0.00	$1.50	$6.50	$21.50	$37.00
Annual Energy Cost Savings per Lamp (US$/yr)[f]	NA	$3.90	$6.50	$14.30	$16.12
Simple Payback (mo)[g]	NA	4.6	12.0	18.0	27.5
Economic Comparisons: Lamp Replacement Cost					
Annual Lamp Replacement Cost per Lamp[h]	$1.95	$3.90	$8.32	$5.98	$2.21[e]
Annual Lamp Replacement Cost for 500 Lamps	$975	$1950	$4160	$2990	$1105
Economic Comparisons: Cooling Load					
Cooling Load Reduction per Lamp (t)[i]	NA	0.004	0.007	0.016	0.018
Cooling Load Reduction for 500 Lamps (t)	NA	2.1	3.6	7.8	8.8

NA = not applicable

[a] Lamp data are based on manufacturer-supplied performance data.

[b] Evaluations of beam appearance are explained on pp. 20–21.

[c] Costs are based on estimates given to NLPIP by an Albany, New York, electrical distributor in July 1994.

[d] The lamp cost for this self-ballasted product is the price for the entire unit (lamp, ballast, and reflector).

[e] The lamp cost for this modular product includes the price of the lamp, ballast, and reflector. Replacement costs would include only the price of the lamp (approximately US$8.50, assuming that the ballast and reflector last over the life of several lamps).

[f] Annual energy cost savings per lamp (US$/yr) = power reduction (W) × burn hours per year (h/yr) × energy rate (US$/kWh) ÷ 1000 W/kW. The number of burn hours per year is assumed to be 2600 h/yr, based on 10 hours per day, five days per week, 52 weeks per year. The energy rate is assumed to be US$0.10/kWh.

[g] Simple payback (mo) = incremental investment per lamp (US$) ÷ annual energy cost savings per lamp (US$/yr) × 12 mo/yr.

[h] Annual lamp replacement cost per lamp (US$/yr) = [burn hours per year (h/yr) ÷ life (h)] × lamp cost (US$). The number of burn hours per year is assumed to be 2600 h/yr.

[i] Cooling load is given in tons (t), the common measure for determining necessary HVAC equipment size. Cooling load reduction per lamp (t) = power reduction (W) × 3.413 Btu/Wh ÷ 12,000 (Btu/h)/t.

Alternative Technologies

The technologies previously discussed in this report are options for replacing reflector lamps through relamping. Options also exist for new construction or for applications where luminaires will be replaced. These options are more expensive than simply replacing lamps.

Low-Voltage Systems

Low-voltage lamps (typically 12 volts) are used for display and accent lighting because they have very precise, sharply defined beam patterns, and they are smaller than PAR and R lamps. They are available in many beam spreads.

For interior-lighting applications, downlights, recessed and semi-recessed adjustable accent lights, and track luminaires are available for low-voltage lamps. Luminaires for low-voltage lamps are usually more expensive than those for 120-volt incandescent lamps because a transformer is required to reduce the line voltage to 12 volts. Lamp costs are also higher. Magnetic and electronic transformers are available for 120-, 240-, 277-, and 347-volt line voltages. Both magnetic and electronic transformers can be used with dimmers; specifiers should verify that the dimmers and transformers are compatible. For track luminaires, track heads that use electronic transformers are smaller and lighter than track heads that use magnetic transformers. To reduce the size and weight of the luminaires, transformers may be located in the ceiling away from the luminaire.

Luminaires for CFLs

In some applications, insufficient light output or size or weight considerations may preclude the use of screwbase CFL products in a luminaire that is designed for incandescent lamps. In these cases, or for new construction, luminaires that are designed for CFLs are another option. For interior-lighting applications, recessed downlights, wall-washers, and track luminaires are available that use 7-, 9-, or 13-watt twin-tube lamps; 9-, 13-, 18-, or 26-watt quad-tube lamps; or 18-watt long twin-tube lamps. Magnetic ballasts usually are supplied with these luminaires, but electronic ballasts and dimming ballasts are available for some lamps. Retrofit kits can convert a recessed downlight that is designed for an incandescent lamp into a luminaire dedicated to CFLs.

High-Intensity Discharge (HID) Systems

Luminaires that use HID lamps are another option for new construction and for renovations. Downlights, recessed and semi-recessed adjustable accent lights, and track luminaires are available for low-wattage, high-pressure sodium and low-wattage, metal halide lamps. High color rendering, high-pressure sodium lamps are available in wattages from 35 to 100 watts, with CRI values of 70 or greater and CCTs of 2500 to 2800 K. Low-wattage, metal halide lamps (150 watts or less) are available in medium-screwbase, double-ended, and medium-screwbase PAR types. Their CRI values range from 65 to 96 and they are available with CCTs of 2700 to 4200 K.

HID lamps require ballasts. Magnetic ballasts are available for all HID lamps, and electronic ballasts are available for the double-ended metal halide and for most of the high color rendering, high-pressure sodium lamps. Luminaires for HID lamps are heavy and bulky because of the ballasts. A track head weighs approximately 10 pounds (5 kilograms) and a recessed adjustable luminaire can weigh up to 50 pounds (23 kilograms).

The use of luminaires for metal halide PAR lamps in display lighting is increasing. These lamps have candlepower distributions that are greater than those of incandescent PAR lamps, and they have higher lamp efficacies and longer life. For example, a 100-watt metal halide PAR lamp provides approximately four times as much light as a 100-watt halogen infrared PAR lamp and has a lamp life that is 2.5 times longer.

The CCT of any HID lamp may depend on operating position and may shift as the lamp ages. Color shift occurs more often in metal halide than in high-pressure sodium lamps because metal halide lamps contain a more complex chemical mix. Manufacturers claim that the newer low-wattage HID lamps have very little color shift over lamp life.

Performance Evaluations

Manufacturer-Supplied Performance Data

NLPIP sent questionnaires to lamp manufacturers asking for recommended replacements for 14 common reflector lamps (flood and spot versions of 150PAR38, 100PAR38, 75PAR38, 150R40, 100R40, 75R40, and 75R30 lamps) that will be eliminated as a result of the EPACT efficacy requirements.

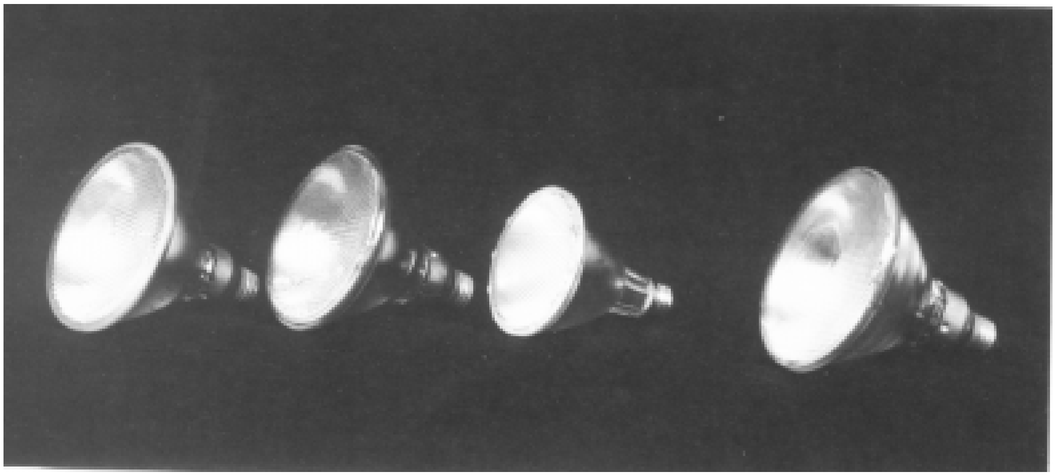
Manufacturers were asked to submit performance data for up to five replacement 120-volt lamps in each category; these data are listed in Tables 4–10.

NLPIP-Measured Data

From December 1993 to February 1994, NLPIP performed evaluations at the Lighting Research Center's Niagara Mohawk Lighting Research Laboratory in Watervliet, New York. NLPIP evaluated the photometric performance and the beam appearance of base case lamps and their manufacturer-recommended replacements. Four categories of 120-volt lamps often used in architectural lighting were selected as base cases: 150-watt common PAR38 flood and spot lamps and 75-watt common R30 flood and spot lamps. Figures 7 and 8 show representative replacements for 150-watt common PAR38 flood lamps and 75-watt common R30 flood lamps, respectively.

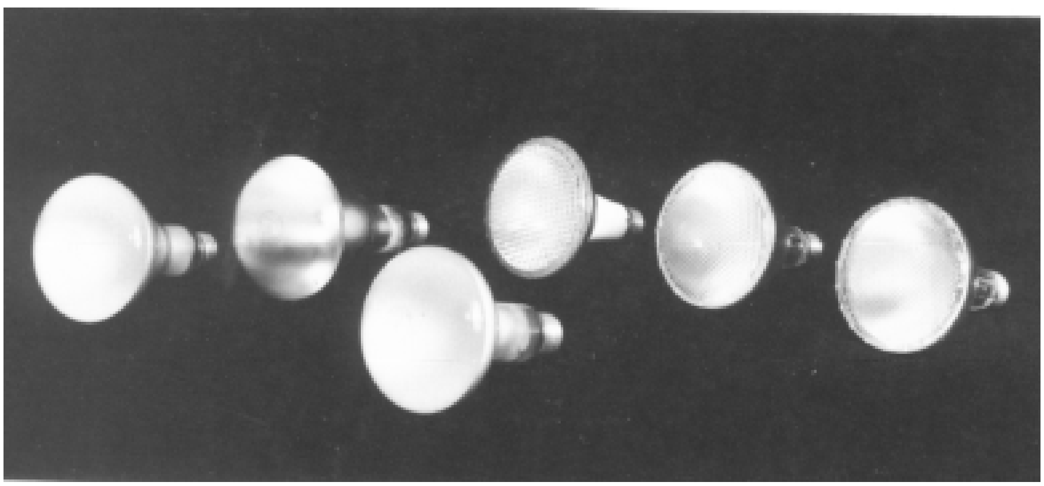
Forty-four types of incandescent R and PAR lamps, three types of ER lamps, and nine types of CFL reflector products were tested. For most lamp types, manufacturers donated two samples, and NLPIP purchased two samples on the open market. In a few cases, NLPIP was unable to test four samples because samples were either unavailable or failed during testing. A total of 206 lamps from seven manufacturers were tested. The results of the testing are listed in Tables 11–14.

Figure 7. Replacements for 150-Watt Common PAR38 Flood Lamps



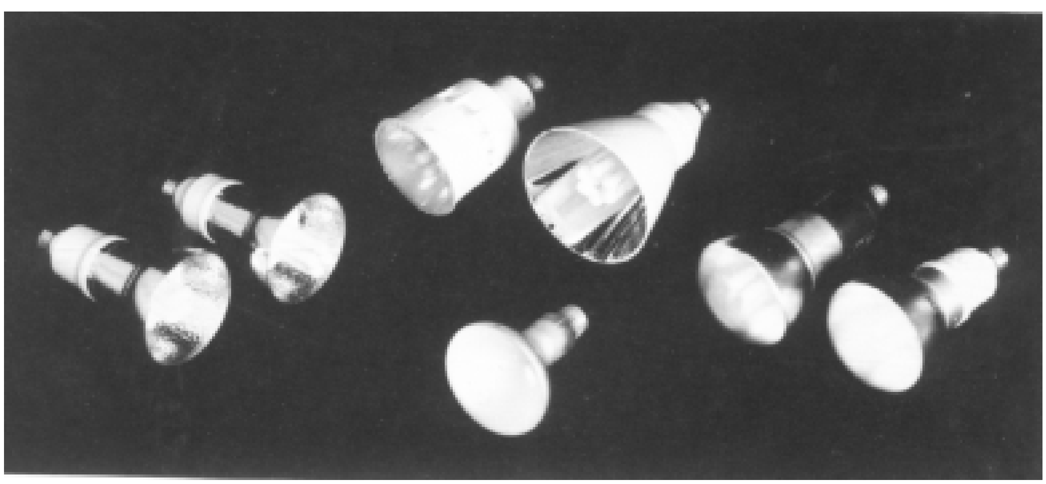
Some of the different lamps recommended by manufacturers as replacements for 150-watt common PAR38 flood lamps. From left to right: 90-watt halogen PAR38, 60-watt halogen infrared PAR38, 75-watt long-neck halogen PAR30, 150-watt common PAR38.

Figure 8. Replacements for 75-Watt Common R30 Flood Lamps



a

Some of the different lamps recommended by manufacturers as replacements for 75-watt common R30 flood lamps, one of which is shown in the foreground of each photo. Figure 8a shows typical incandescent reflector lamps; from left to right: 60-watt krypton R30, 75-watt ER30, 50-watt long-neck halogen PAR30, 50-watt long-neck halogen PAR30, 50-watt halogen PAR30. Figure 8b shows typical CFL reflector products; see Figure 4 on p. 6 for another view of these types of products.

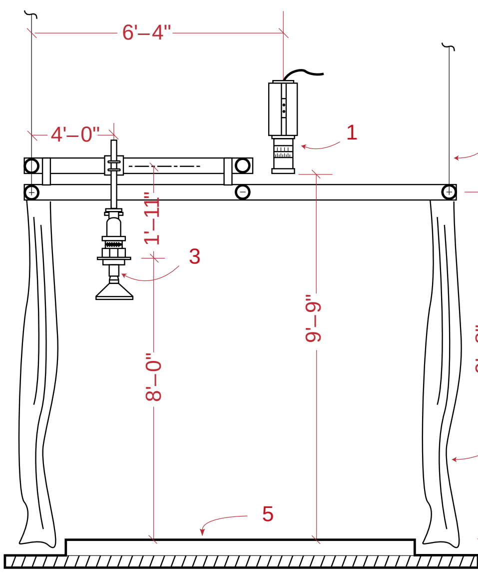


b

The CapCalc Imaging Photometer

The CapCalc imaging photometer uses a monochrome charged-coupling-device (CCD) camera interfaced with a computer to capture the luminance values of all the pixels within the camera's field of view. CapCalc can record the luminance of any individual pixel and can calculate the average luminance of any selected area within the image. CapCalc also can identify the points within the image with the highest and lowest luminances and report those luminance values (Rea and Jeffrey 1990).

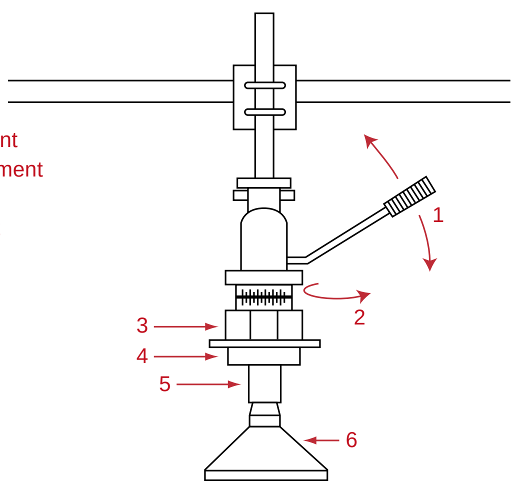
Figure 9. Section View of the Photometric Testing Setup



1 in. = 2.54 cm
1 ft = 0.305 m

The diagram is not drawn to scale.

Figure 10. Detail of the Adjustable Mounting for the Lamp Socket



For many lamp samples, the angle of maximum luminance was not precisely aligned with the axis of the lamp. The adjustable mounting permitted researchers to aim each lamp so that the maximum luminance was directed straight downward on the measurement surface.

Testing Procedures

Photometric evaluations. Figures 9 and 10 show the setup and details of the testing apparatus used by NLPIP for the photometric evaluation of lamps. The evaluations were performed by aiming each test lamp downward from a height of 8.0 ft (2.4 m) onto a diffuse white surface. The measurement surface was a 9.0- × 9.0-ft (2.7- × 2.7-m) muslin sheet that was stretched across a wooden frame. The muslin was sized, primed, and then painted with a highly reflective white theatrical paint (Roscolux Tough Prime #605017; Roscolux Off Broadway Paint, Color: White-white #5351) to provide a reflectance distribution that closely matched that of a perfect lambertian surface. (A lambertian surface is a uniformly diffusing surface.)

To eliminate extraneous light, the apparatus was enclosed with black photographer's felt. Except for an L-shaped area where luminance was measured (shown in Figure 11), the white muslin surface also was covered with black felt to reduce the amount of scattered light in the photometer's optical system. A CapCalc imaging photometer (see sidebar) was attached to the ceiling and aimed at the white surface. CapCalc was used to measure the luminances within the L-shaped area of the diffuse white surface.

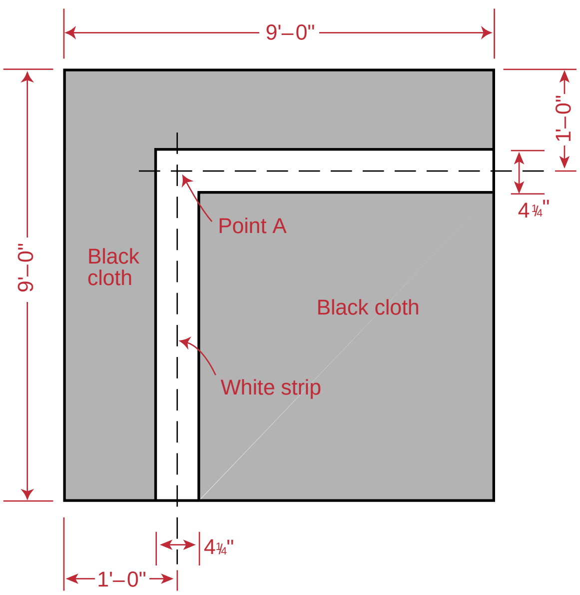
Before testing, CFLs were operated (seasoned) for a minimum of 100 hours, and incandescent lamps were seasoned for at least 1% of their lamp life, in accordance with recommendations of the Illuminating Engineering Society of North America (IESNA 1991).

Immediately prior to measurement, the incandescent reflector lamps were operated for 15 minutes on a rack located in the room. They were then moved to the test socket and operated for at least an additional 5 minutes. The CFL reflector products were operated for 30 minutes on the rack and, once moved to the test socket, were operated for an additional 15 minutes.

The lamps were aimed at Point A, shown in Figure 11. To center the beam's maximum intensity at Point A, an illuminance meter was placed at this point, and the aiming of the lamp was adjusted until the highest illuminance reading was noted. The illuminance meter was then removed, and CapCalc was used to measure the luminances of the surface. All other lighting in the room remained off during the measurements.

NLPIP used the CapCalc data to calculate the center beam luminance ($L_{0°}$), the average luminance (L_{avg}), and the beam diameter. NLPIP developed and used this method, which differs from standard photometric procedures, because of the large number of lamps evaluated. Figure 11 shows how NLPIP derived these values; the results are listed in Tables 11–14.

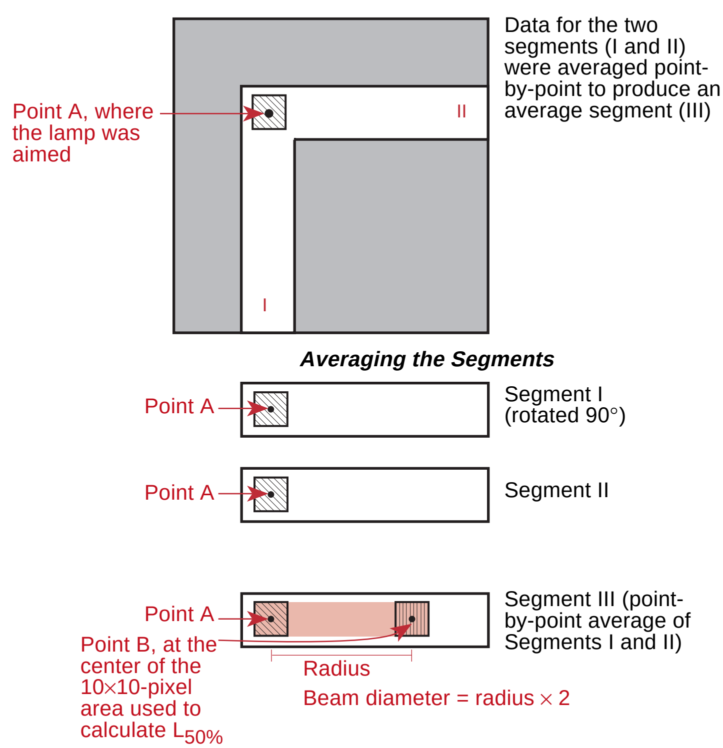
Figure 11a. Plan View of the Muslin Measurement Surface



To reduce scattered light, black cloth was used to cover most of the white muslin surface. A strip of muslin in the shape of an "L" 4.25 in (10.8 cm) wide was left exposed. Each test lamp was aimed at the bend in the "L" shape (Point A), and CapCalc was used to measure the luminances within the white strip. The data for both segments of the "L" (Segments I and II in Figure 11b) were averaged to produce an average luminance profile (represented by the Segment III in Figure 11b). The luminance values within a 10×10-pixel area surrounding the center point (Point A) were averaged to obtain the center beam luminance, $L_{0°}$, which was also the maximum luminance. Successive 10×10-pixel areas along the center of the Segment III were averaged to find the area with an average luminance equal to 50% of $L_{0°}$. Point B indicates the center point of this area. The beam diameter reported in Tables 11–14 is two times the distance between Point A and Point B. The average luminance (L_{avg}) was calculated by averaging the luminances of the 10×10-pixel areas around Point A, Point B, and each point in between.

The diagrams are not drawn to scale.

Figure 11b. Areas Used to Derive Luminance Values and Beam Diameter



Key

- 10×10-pixel area used to calculate $L_{0°}$
- 10×10-pixel area used to calculate $L_{50\%}$
- Area over which 10×10-pixel areas were searched to find $L_{50\%}$ and used to calculate L_{avg}

1 in. = 2.54 cm 1 ft = 0.305 m

Beam appearance evaluations. The testing setup for the visual evaluation of beam appearance is illustrated in Figure 12. The muslin surface was mounted to a wall and the black cloth was removed to expose the entire white surface. A lamp socket was mounted on a tripod; the back of the socket was 8.0 ft (2.4 m) from the muslin surface. The centerline of the socket was mounted 4 ft 10 in. (1.5 m) above the floor. The beam for each lamp was evaluated by two NLPIP researchers, who stood directly behind the tripod. The researchers first viewed the beam appearances produced by each of the lamp types and defined the beam appearance categories described below. Then, the researchers viewed all lamp samples and assigned each lamp to a beam appearance category. The two reseachers either independently agreed or reached consensus on each lamp's assignment to a beam appearance category. Figure 13 shows sample beam appearances, and Tables 11–14 list the results of the evaluations.

These evaluations show that similar products can vary significantly in beam appearance. NLPIP recommends that specifiers visually evaluate the beam appearance of reflector lamp products before selecting an appropriate product.

Smooth: Distributions with an even reduction in brightness from the center of the beam to the distinct beam edge. Most of the incandescent R lamps produced smooth distributions.

Cloud: Distributions with an uneven reduction in brightness from the center of the beam to the beam edge. The beam edge is much less distinct than that of the smooth distribution. A variety of lamp types produced cloud distributions.

Two-contour: Distributions with two regions: a bright, smooth region and a dimmer outer ring. Only halogen PAR lamps produced two-contour distributions.

Ripple: Distributions with a series of bright and dark concentric rings, similar to the ripple effect caused by a pebble dropped into a pond. In the data tables, ripple patterns are defined by the number of rings that were visible. Only halogen PAR lamps produced ripple distributions.

Variegated: Four of the lamp types tested produced distributions that did not fit into one of the four primary categories. For example, two types of CFL reflector products produced a smooth distribution with a bright, x-shaped pattern at the center of the beam. One type of CFL reflector product produced a distribution with a six-pointed, star-shaped shadow in the center of the beam and two bright streaks emanating from each point of the star. Two types of halogen PAR lamps produced a distribution with a distinct, bright stripe that passes through a dark center surrounded by a wider, brighter ring. All of these products are categorized as "variegated" in Tables 11–14.

Figure 12. Setup for Visual Evaluation of Beam Appearance

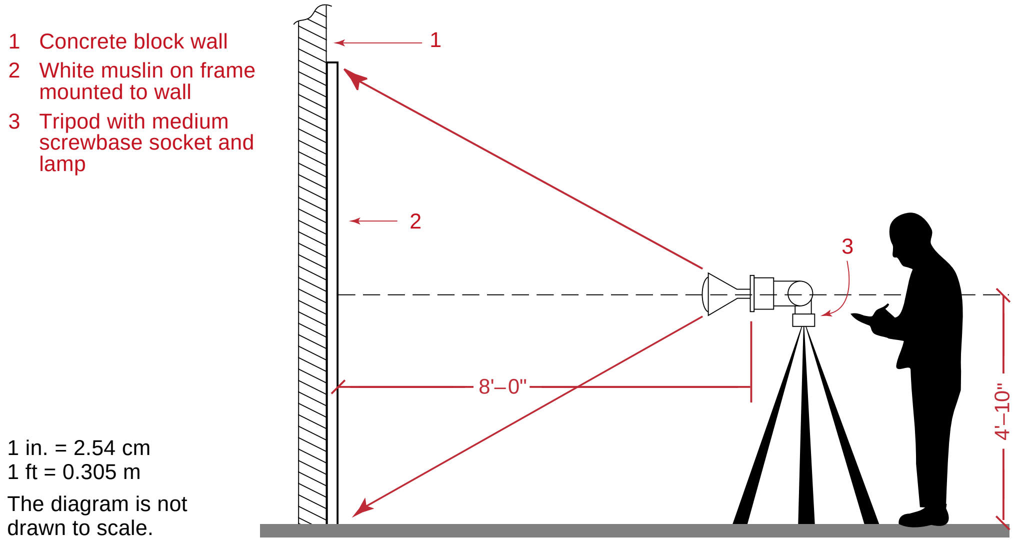
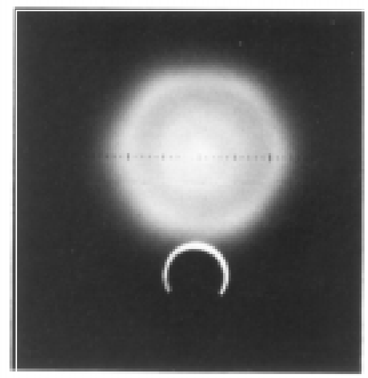


Figure 13. Examples of Beam Appearances

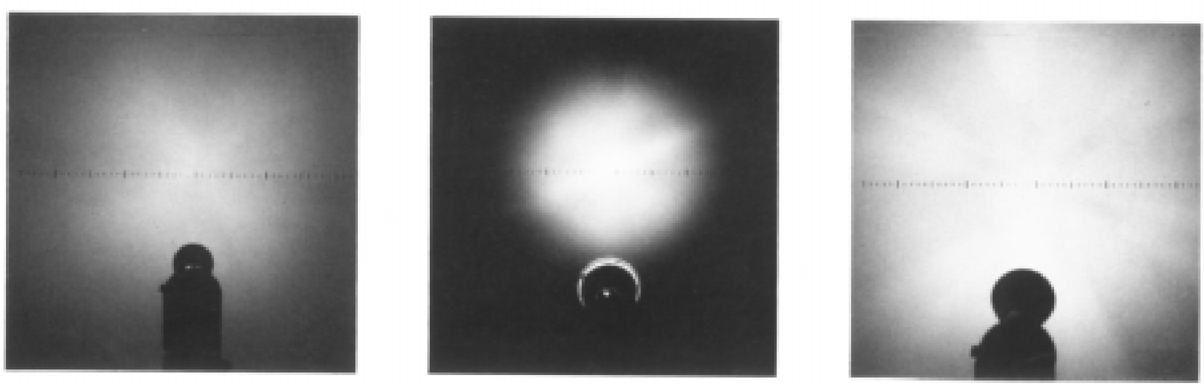
Smooth

Cloud

Two-contour



Ripple (five rings)



Examples of Variegated Beam Appearances

Note: the horizontal row of marks passing through the center of each photo is a scale indicator on the muslin.

Results

Tables 11–14 show the results of NLPIP's lamp testing. Each table provides data for one of the four base case lamp categories, described on p. 16. In each lamp category, the manufacturer's base case lamp is listed, followed by the recommended replacement lamps. Some manufacturers do not offer common R and PAR lamps and did not supply a base case lamp.

To help specifiers compare lamps, NLPIP normalized some of the data presented in Tables 11–14. Data for each manufacturer's recommended replacement lamps are shown in relative units compared with data for their respective base case lamps. When a manufacturer did not supply a base case lamp, NLPIP chose as a base case the base case lamp that had the lowest CBCP.

For each of the photometric measurements, base case data were assigned a value of 100. Data for recommended replacement lamps were then reported as a percentage of the base case data. The manufacturer-supplied beam angles were converted into beam diameters before normalizing so that they could be compared to the NLPIP-measured beam diameters. In Tables 11–14, the actual base case values are reported in parentheses. The column headings indicate whether the data were provided by the manufacturer or were measured by NLPIP.

For evaluating center beam intensity, specifiers should compare the columns "Relative CBCP (Manufacturer)" and "Relative $L_{0°}$ (NLPIP)" to see if the replacement products performed as claimed and to directly compare a replacement product to a base case product. For evaluating beam diameter, compare the "Relative Beam Diameter (Manufacturer)" and "Relative Beam Diameter (NLPIP)" columns. The other NLPIP-measured data, "Relative L_{avg}" and "Beam Appearance," do not directly correlate with any manufacturer-supplied data but are provided for a more complete evaluation of the products.

The following observations were made from NLPIP's evaluations.

150PAR38 Flood (Table 11). In this category, 13 types of products were tested: three base case and 10 replacement products. All of the replacement lamps were halogen or halogen infrared PAR lamps. Of the replacement lamps, one was rated with a CBCP lower than that of its respective base case lamp; in NLPIP's testing, five had measured center beam luminances lower than those of their respective base case lamps. Nine replacement lamps produced smaller measured beam diameters than did their respective base case lamps.

150PAR38 Spot (Table 12). In this category, 12 types of products were tested: three base case and nine replacement products. All of the replacement lamps were halogen or halogen infrared PAR lamps. Of the replacement lamps, one was rated with a CBCP lower than that of its respective base case lamp; in NLPIP's testing, three had measured center beam luminances lower than those of their respective base case lamps. Four replacement lamps were rated as having equal or larger beam angles (converted to beam diameter by NLPIP) than their respective base case lamps. One of these replacement lamps produced a measured beam diameter larger than that of its respective base case lamp. The other three replacement lamps produced measured beam diameters that were less than 70% of the base case lamps' beam diameters.

75R30 Flood (Table 13). In this category, 19 types of products were tested: three base case and 16 replacement products (one krypton-filled R lamp, one ER lamp, five halogen PAR lamps, and nine CFL reflector products). The eight 13-watt CFL reflector products had measured center beam luminances ranging from 23 to 54% of those of their respective base case lamps; the 20-watt CFL reflector product had a measured center beam luminance that was 82% of its respective base case lamp's center beam luminance. For the other replacement lamps, measured center beam luminances ranged from 90 to 453% of those of their respective base case lamps. All nine CFL reflector products, as well as two halogen PAR lamps, produced larger measured beam diameters than did their respective base case lamps.

75R30 Spot (Table 14). In this category, 14 types of products were tested: three base case and 11 replacement products (one krypton-filled R lamp, three ER lamps, five halogen PAR lamps, one halogen infrared PAR lamp, and one CFL reflector product). The CFL product had a measured center beam luminance that was 6% of its respective base case lamp's center beam luminance; it also had a larger measured beam diameter (407%). For the other ten replacement products, rated CBCPs ranged from 75 to 364% of those of their respective base case lamps, whereas measured center beam luminances ranged from 48 to 427%. Three replacement lamps produced smaller measured beam diameters than did their respective base case lamps.

Testing of Modular CFLs

NLPIP used an OSRAM SYLVANIA 13-watt Double Dulux lamp when testing the Prolight, Teron, and Mitor magnetically ballasted products and a General Electric 13-watt Double Biax, four-pin lamp when testing the Mitor electronically ballasted products. For measurements of the bare-lamp (no reflector attached) light output of these lamps, NLPIP sent one of each lamp to Lighting Sciences, Inc., in Scottsdale, Arizona. Lighting Sciences, Inc., measured the light output of these lamps in a vertical, base-up burning position at 120 volts on a reference ballast. The measured light output of both lamps (720 and 734 lm) was 15 to 20% below their rated light output (860 and 900 lm).

Lighting Sciences, Inc., also measured the light output of the OSRAM SYLVANIA lamp operated by a Prolight ballast with the reflector attached in a base-up position operating at 120 volts. The measured light output with the reflector attached (353 lm) was slightly less than 50% of the measured bare-lamp light output (720 lm).

Apparent Overheating of CFLs

While seasoning one CFL manufacturer's products, NLPIP observed an apparent overheating problem. Prolight submitted two samples each of four different modular ballast and reflector products. Prolight also provided 16 OSRAM SYLVANIA 13-watt quad-tube CFLs for NLPIP's testing. These 16 lamps were seasoned with the modular reflectors attached, using the eight product samples submitted by Prolight and eight samples purchased by NLPIP. After 100 hours of continuous operation, all 16 lamps showed discoloration (browning) of the plastic lamp base. The phosphor coating was cracked at the bridge in all of these lamps after seasoning, and in some lamps, the coating also started to crack at the lamp base. A few of the lamps became stuck in the ballast socket. When these lamps were pulled out, the bases separated from the lamp tubes. The lamp-base discolorations probably were caused by heat buildup at the base; the reflector attachments may have contributed to the heat buildup. Overheating can cause early lamp failures, so lamp manufacturers specify maximum base temperatures for CFL products. NLPIP did not measure base temperature and did not conduct lamp life tests for this report. In addition, NLPIP did not test either the Prolight modular ballast and reflector products or the OSRAM SYLVANIA lamps with other products to determine if the same results occurred outside of this particular combination.

Data Tables

Tables 4–10 present product information that was supplied by manufacturers to NLPIP. Tables 11–14 present the data that were collected during NLPIP's evaluations. The column headings in Tables 4–14 are explained below in the order in which they appear.

Active Power. The total input power, in watts (W). Ballast losses are not included for the modular CFL reflector products. See p. 7.

CBCP. Center beam candlepower (CBCP) is the maximum luminous intensity, expressed in candelas (cd). See p. 8.

Beam Angle. The angle at which the luminous intensity of the light is 50% of the maximum value. See pp. 8–9.

Initial Light Output. The light output in lumens (lm), after lamp seasoning. See p. 7.

Average Rated Life. The number of hours at which half of a large group of product samples have failed. The rated life is a median value; any lamp or group of lamps may vary from the published rated life. See p. 10.

CCT. Correlated color temperature (CCT) is a measure of the color appearance of the light produced by a lamp in terms of the temperature, in kelvin (K), of a reference light source heated to a specific temperature. See p. 10.

CRI. Color rendering index (CRI) is a value that describes "the degree of color shift objects undergo when illuminated by a lamp as compared with those same objects when illuminated by a reference source of comparable CCT" (IESNA 1993). The smaller the color shift, the higher the CRI value, with a maximum of 100. See p. 10.

Efficacy. The initial light output divided by the active power, expressed in lumens per watt (LPW).

Minimum Required Efficacy. The minimum lamp efficacy required by EPACT, expressed in lumens per watt (LPW). See p. 3.

Relative CBCP (Manufacturer). The normalized center beam candlepower based on manufacturer-supplied values. See p. 22.

Relative $L_{0°}$ (NLPIP). The normalized center beam luminance based on NLPIP-measured values. See pp. 19 and 22.

Relative Beam Diameter (Manufacturer). The normalized beam diameter based on manufacturer-supplied beam angles. See p. 22.

Relative Beam Diameter (NLPIP). The normalized beam diameter based on NLPIP-measured values. See pp. 19 and 22.

Relative L_{avg} (NLPIP). The normalized average luminance based on NLPIP-measured values. See pp. 19 and 22.

Beam Appearance. The description of the beam's image on a wall as determined by subjective visual evaluations of each lamp. The descriptive categories used are Smooth, Cloud, Two-contour, Ripple (listed with the number of contours visible; for example, 4C indicates four contours), and Variegated. See pp. 20–21.

List of Tables by Lamp Category

Table 4. Manufacturer-Supplied Performance Data for 150PAR38/FL and 150PAR38/SP Lamps and Recommended Replacements

Manufacturer		Catalog Number	Description	Active Power (W)	CBCP (cd)
150PAR38/FL					
GE Lighting	**Base Case**	150PAR38/FL	Common PAR38	150	3,100
	Replacement 1	90PAR/H/FL30°	Halogen PAR38	90	4,000
	Replacement 2	60PAR/HIR/FL30°	Halogen infrared PAR38	60	3,630
	Replacement 3	100PAR/HIR/40°	Halogen infrared PAR38	100	3,900
	Replacement 4	75PAR/H/NFL25°	Halogen PAR38	75	4,000
	Replacement 5	75PAR30L/H/30°	Long-neck halogen PAR30	75	2,800
JSL Lighting Corporation	**Base case lamps not supplied by manufacturer**				
	Replacement 1	90PAR38/FL[a]	Halogen PAR38	90	4,000
OSRAM SYLVANIA INC.	**Base Case**	150PAR/FL	Common PAR38	150	4,000
	Replacement 1	90PAR/CAP/FL	Halogen PAR38	90	4,000
	Replacement 2	75PAR/CAP/FL	Halogen PAR38	75	3,500
Philips Lighting	**Base Case**	150PAR38/FL	Common PAR38	150	3,400
	Replacement 1	60PAR38/H/FL	Halogen PAR38	60	3,500
	Replacement 2	75PAR38/H/FL	Halogen PAR38	75	4,500
	Replacement 3	90PAR38/H/FL	Halogen PAR38	90	4,500
150PAR38/SP					
GE Lighting	**Base Case**	150PAR38/SP	Common PAR38	150	12,000
	Replacement 1	90PAR/H/SP10°	Halogen PAR38	90	18,500
	Replacement 2	60PAR/HIR/SP10°	Halogen infrared PAR38	60	18,500
	Replacement 3	75PAR/H/NSP8°	Halogen PAR38	75	18,400
	Replacement 4	75PAR30L/H/10°	Long-neck halogen PAR30	75	11,000
	Replacement 5	75PAR30/H/NSP11°	Halogen PAR30	75	15,000
JSL Lighting Corporation	**Base case lamps not supplied by manufacturer**				
	Replacement 1	90PAR38/SP[a]	Halogen PAR38	90	11,500
OSRAM SYLVANIA INC.	**Base Case**	150PAR/SP	Common PAR38	150	11,500
	Replacement 1	90PAR/CAP/SP	Halogen PAR38	90	11,500
	Replacement 2	75PAR/CAP/WSP	Halogen PAR38	75	12,000
Philips Lighting	**Base Case**	150PAR38/SP	Common PAR38	150	10,500
	Replacement 1	60PAR38/H/SP	Halogen PAR38	60	13,500
	Replacement 2	75PAR38/H/SP	Halogen PAR38	75	14,500
	Replacement 3	90PAR38/H/SP	Halogen PAR38	90	14,500

NS = not supplied

Only 120-volt lamps are listed, except where noted.

[a] This product is a 130-volt lamp.

Beam Angle	Initial Light Output (lm)	Average Rated Life (h)	CCT (K)	CRI	Efficacy (LPW)	Minimum Required Efficacy (LPW)
36°	1,740	2,000	2,775	100	12	14.5
30°	1,270	2,000	2,925	100	14	14.0
29°	1,150	3,000	2,875	100	19	11.0
40°	2,000	3,000	2,925	100	20	14.0
26°	1,070	2,500	2,850	100	14	12.5
30°	950	2,000	2,850	100	13	12.5
30°	NS	2,500	3,000	100	NS	14.0
30°	1,740	2,000	2,700	100	12	14.5
30°	1,345	2,500	3,000	100	15	14.0
30°	1,070	2,500	3,000	100	14	12.5
30°	1,730	2,000	2,700	100	12	14.5
28°	890	2,000	3,000	100	15	11.0
27°	1,140	2,500	3,000	100	15	12.5
28°	1,350	2,500	3,000	100	15	14.0
16°	1,740	2,000	2,775	100	12	14.5
10°	1,270	2,000	2,925	100	14	14.0
10°	1,150	3,000	2,875	100	19	11.0
8°	1,070	2,500	2,850	100	14	14.0
10°	950	2,000	2,850	100	13	12.5
11°	1,100	2,000	2,850	100	15	12.5
15°	NS	2,500	3,000	100	NS	14.0
15°	1,740	2,000	2,700	100	12	14.5
15°	1,345	2,500	3,000	100	15	14.0
13°	1,070	2,500	3,000	100	14	12.5
12°	1,730	2,000	2,700	100	12	14.5
12°	890	2,000	3,000	100	15	11.0
10°	1,140	2,500	3,000	100	15	12.5
12°	1,350	2,500	3,000	100	15	14.0

Table 5. Manufacturer-Supplied Performance Data for 100PAR38/FL and 100PAR38/SP Lamps and Recommended Replacements

Manufacturer		Catalog Number	Description	Active Power (W)	CBCP (cd)
100PAR38/FL					
GE Lighting	**Base Case**	100PAR38/FL/85[a]	Energy-saving PAR38	85[a]	2,000
	Replacement 1	60PAR/HIR/FL40°	Halogen infrared PAR38	60	2,100
	Replacement 2	75PAR30/H/FL35°	Halogen PAR30	75	2,500
	Replacement 3	75PAR30L/H/40°	Long-neck halogen PAR30	75	1,800
	Replacement 4	50PAR30/HIR/FL35°	Halogen infrared PAR30	50	2,400
	Replacement 5	45PAR/H/FL30°	Halogen PAR38	45	1,700
OSRAM SYLVANIA INC.	**Base Case**	100PAR/FL	Common PAR38	100	2,400
Philips Lighting	**Base Case**	100PAR38/FL	Common PAR38	100	2,400
	Replacement 1	60PAR38/H/FL	Halogen PAR38	60	3,500
100PAR38/SP					
GE Lighting	**Base Case**	100PAR38/SP/85W[a]	Energy-saving PAR38	85[a]	6,800
	Replacement 1	75PAR30L/H10°	Long-neck halogen PAR30	75	11,000
	Replacement 2	60PAR/HIR/SP10°	Halogen infrared PAR38	60	18,500
	Replacement 3	75PAR/H/NSP8°	Halogen PAR38	75	18,400
	Replacement 4	45PAR/H/SP11°	Halogen PAR38	45	8,800
	Replacement 5	75PAR30/H/NSP11°	Halogen PAR30	75	15,000
OSRAM SYLVANIA INC.	**Base Case**	100PAR/SP	Common PAR38	100	6,600
Philips Lighting	**Base Case**	100PAR38/SP	Common PAR38	100	8,000
	Replacement 1	60PAR38/H/SP	Halogen PAR38	60	13,500

Only 120-volt lamps are listed.

[a] GE does not manufacture common 100PAR38 lamps and suggested this energy-saving PAR lamp as the base case.

Beam Angle	Initial Light Output (lm)	Average Rated Life (h)	CCT (K)	CRI	Efficacy (LPW)	Minimum Required Efficacy (LPW)
37°	930	2,000	2,700	100	11	12.5
39°	1,150	3,000	2,875	100	19	11.0
36°	1,100	2,000	2,850	100	15	12.5
40°	950	2,000	2,850	100	13	12.5
33°	1,000	3,000	2,850	100	20	10.5
32°	540	2,000	2,800	100	12	10.5
30°	1,200	2,000	2,750	100	12	14.0
29°	1,250	2,000	2,700	100	13	14.0
28°	890	2,000	3,000	100	15	11.0
15°	930	2,000	2,700	100	11	12.5
10°	950	2,000	2,850	100	13	12.5
10°	1,150	3,000	2,875	100	19	11.0
8°	1,070	2,500	2,850	100	14	12.5
11°	540	2,000	2,800	100	12	10.5
11°	1,100	2,000	2,850	100	15	12.5
15°	1,200	2,000	2,750	100	12	14.0
12°	1,250	2,000	2,700	100	13	14.0
12°	890	2,000	3,000	100	15	11.0

Table 6. Manufacturer-Supplied Performance Data for 75PAR38/FL and 75PAR38/SP Lamps and Recommended Replacements

Manufacturer		Catalog Number	Description	Active Power (W)	CBCP (cd)
75PAR38/FL					
GE Lighting	**Base Case**	75PAR38/FL	Common PAR38	75	1,750
	Replacement 1	45PAR/H/FL30°	Halogen PAR38	45	1,700
	Replacement 2	60PAR/HIR/FL40°	Halogen infrared PAR38	60	2,100
	Replacement 3	50PAR30L/H/30°	Long-neck halogen PAR30	50	1,750
	Replacement 4	50PAR30/HIR/FL35°	Halogen infrared PAR30	50	2,400
	Replacement 5	50PAR30/H/FL35°	Halogen PAR30	50	1,600
JSL Lighting Corporation	**Base Case**	75PAR38/FL	Common PAR38	75	1,750
	Replacement 1	45PAR38/FL[a]	Halogen PAR38	45	1,800
Mitor	**Base case lamps not supplied by manufacturer**				
	Replacement 1	FL16-PAR[b]	Self-ballasted CFL, magnetic ballast[c]	13	NS
	Replacement 2	EL18-A40	Modular CFL, electronic ballast	18	NS
OSRAM SYLVANIA INC.	**Base Case**	75PAR/FL	Common PAR38	75	1,800
	Replacement 1	45PAR/CAP/FL	Halogen PAR38	45	1,800
Philips Lighting	**Base Case**	75PAR38/FL	Common PAR38	75	1,500
	Replacement 1	45PAR38/H/FL	Halogen PAR38	45	2,000
Teron Lighting	**Base case lamps not supplied by manufacturer**				
	Replacement 1	RFL-LZ-13Q-P	Modular CFL, magnetic ballast	13	NS
75PAR38/SP					
GE Lighting	**Base Case**	75PAR38/SP	Common PAR38	75	4,400
	Replacement 1	45PAR/H/SP11°	Halogen PAR38	45	8,800
	Replacement 2	75PAR/H/NFL25°	Halogen PAR38	75	4,000
	Replacement 3	50PAR30L/H/10°	Long-neck halogen PAR30	50	7,000
	Replacement 4	60PAR/HIR/SP10°	Halogen infrared PAR38	60	18,500
	Replacement 5	50PAR30/H/NSP11°	Halogen PAR30	50	10,500
JSL Lighting Corporation	**Base Case**	75PAR38/SP	Common PAR38	75	4,800
	Replacement 1	45PAR38/SP[a]	Halogen PAR38	45	4,500
OSRAM SYLVANIA INC.	**Base Case**	75PAR/SP	Common PAR38	75	4,500
	Replacement 1	45PAR/CAP/SP	Halogen PAR38	45	4,500
Philips Lighting	**Base Case**	75PAR38/SP	Common PAR38	75	4,800
	Replacement 1	45PAR38/H/SP	Halogen PAR38	45	5,800
Teron Lighting	**Base case lamps not supplied by manufacturer**				
	Replacement 1	RFL-LZ-13Q-P	Modular CFL, magnetic ballast	13	NS

NA = not applicable NS = not supplied

Only 120-volt lamps are listed, except where noted.

[a] This product is a 130-volt lamp.

[b] The manufacturer supplied data for this product but expressed the opinion that 13-watt CFL reflector products presently available cannot match the performance of 75-watt reflector lamps.

Beam Angle	Initial Light Output (lm)	Average Rated Life (h)	CCT (K)	CRI	Efficacy (LPW)	Minimum Required Efficacy (LPW)
33°	765	2,000	2,700	100	10	12.5
32°	540	2,000	2,800	100	12	10.5
39°	1,150	3,000	2,875	100	19	11.0
30°	575	2,000	2,800	100	12	10.5
33°	1,000	3,000	2,850	100	20	10.5
36°	670	2,000	2,800	100	13	10.5
33°	900	4,000	2,700	97	12	12.5
32°	NS	2,500	3,000	100	NS	10.5
NS	850	10,000	2,700	82	65	NA[d]
NS	1,200	10,000	2,700	82	66	NA[d]
30°	765	2,000	2,700	100	10	12.5
32°	520	2,500	3,000	100	12	10.5
29°	750	2,000	2,700	100	10	12.5
28°	630	2,500	3,000	100	14	10.5
NS	900	10,000	2,700	82	69	NA[d]
17°	765	2,000	2,700	100	10	12.5
11°	540	2,000	2,800	100	12	10.5
26°	1,070	2,500	2,850	100	14	12.5
10°	575	2,000	2,800	100	12	10.5
10°	1,150	3,000	2,875	100	19	11.0
11°	670	2,000	2,800	100	13	10.5
16°	900	4,000	2,500	97	12	12.5
15°	NS	2,500	3,000	100	NS	10.5
15°	765	2,000	2,700	100	10	12.5
15°	520	2,500	3,000	100	12	10.5
12°	750	2,000	2,700	100	10	12.5
12°	630	2,500	3,000	100	14	10.5
NS	900	10,000	2,700	82	69	NA[d]

[c] This product has a modular reflector.

[d] CFLs are not covered in the EPACT requirements.

Table 7. Manufacturer-Supplied Performance Data for 150R40/FL and 150R40/SP Lamps and Recommended Replacements

Manufacturer		Catalog Number	Description	Active Power (W)	CBCP (cd)
150R40/FL					
GE Lighting	**Base Case**	150R40/FL	Common R40	150	1,400
	Replacement 1	60PAR/HIR/WFL55°	Halogen infrared PAR38	60	1,250
	Replacement 2	75ER30	ER30	75	1,200
	Replacement 3	120ER40	ER40	120	1,700
	Replacement 4	60PAR/HIR/FL40°	Halogen infrared PAR38	60	2,100
	Replacement 5	75PAR30L/H/60°	Long-neck halogen PAR30	75	900
OSRAM SYLVANIA INC.	**Base Case**	150R/FL	Common R40	150	1,300
	Replacement 1	90PAR/CAP/WFL	Halogen PAR38	90	1,500
	Replacement 2	75ER30	ER30	75	1,500
Philips Lighting	**Base Case**	150R40/FL	Common R40	150	1,300
	Replacement 1	60PAR38/H/FL	Halogen PAR38	60	3,500
	Replacement 2	75PAR38/H/FL	Halogen PAR38	75	4,500
	Replacement 3	90PAR38/H/FL	Halogen PAR38	90	4,500
	Replacement 4	120ER40	ER40	120	2,627
150R40/SP					
GE Lighting	**Base Case**	150R40/SP	Common R40	150	4,600
	Replacement 1	60PAR/HIR/FL30°	Halogen infrared PAR38	60	3,630
	Replacement 2	75PAR/H/NFL25°	Halogen PAR38	75	4,000
	Replacement 3	90PAR/H/FL30°	Halogen PAR38	90	4,000
	Replacement 4	100PAR/HIR/FL35°	Halogen infrared PAR38	100	5,500
OSRAM SYLVANIA INC.	**Base Case**	150R/SP	Common R40	150	7,000
Philips Lighting	**Base Case**	150R40/SP	Common R40	150	7,000
	Replacement 1	60PAR38/H/SP	Halogen PAR38	60	13,500
	Replacement 2	75PAR38/H/SP	Halogen PAR38	75	14,500
	Replacement 3	90PAR38/H/SP	Halogen PAR38	90	14,500
	Replacement 4	120ER40	ER40	120	2,627

NA = not applicable

Only 120-volt lamps are listed.

[a] In some cases only field angles were reported; these values are in parentheses.

[b] Ellipsoidal reflector (ER) lamps are exempt from EPACT.

Beam Angle[a]	Initial Light Output (lm)	Average Rated Life (h)	CCT (K)	CRI	Efficacy (LPW)	Minimum Required Efficacy (LPW)
59°	1,900	2,000	2,750	100	13	14.5
53°	1,150	3,000	2,875	100	19	11.0
42°	850	2,000	2,700	100	11	NA[b]
45°	1,425	2,000	2,750	100	12	NA[b]
39°	1,150	3,000	2,875	100	19	11.0
60°	1,025	2,000	2,850	100	14	12.5
(110°)	1,900	2,000	2,750	100	13	14.5
55°	1,345	2,500	3,000	100	15	14.0
36°	850	2,000	2,700	100	11	NA[b]
60°	1,900	2,000	2,700	100	13	14.5
28°	890	2,000	3,000	100	15	11.0
27°	1,140	2,500	3,000	100	15	12.5
28°	1,350	2,500	3,000	100	15	14.0
33°	1,228	2,000	2,700	100	10	NA[b]
25°	1,900	2,000	2,750	100	13	14.5
29°	1,150	3,000	2,875	100	19	11.0
26°	1,070	2,500	2,850	100	14	12.5
30°	1,270	2,000	2,925	100	14	14.0
33°	2,000	3,000	2,925	100	20	14.0
(37°)	1,900	2,000	2,750	100	13	14.5
20°	1,900	2,000	2,750	100	13	14.5
12°	890	2,000	3,000	100	15	11.0
10°	1,140	2,500	3,000	100	15	12.5
10°	1,350	2,500	3,000	100	15	14.0
33°	1,228	2,000	2,700	100	10	NA[b]

Table 8. Manufacturer-Supplied Performance Data for 100R40/FL and 100R40/SP Lamps and Recommended Replacements

Manufacturer		Catalog Number	Description	Active Power (W)	CBCP (cd)
100R40/FL					
GE Lighting	**Base Case**	100R40/FL	Common R40	100	770
	Replacement 1	60PAR/HIR/WFL55°	Halogen infrared PAR38	60	1,250
	Replacement 2	75PAR30L/H/60°	Long-neck halogen PAR30	75	900
	Replacement 3	75ER30	ER30	75	1,200
	Replacement 4	FLE20TBX/RFL/HPF	Self-ballasted CFL, electronic ballast[c]	20	370
OSRAM SYLVANIA INC.	**Base Case**	100R/FL	Common R40	100	900
	Replacement 1	75ER30	ER30	75	1,500
	Replacement 2	45PAR/CAP/VWFL	Halogen PAR38	45	600
Philips Lighting	**Base Case**	100R40/FL	Common R40	100	790
	Replacement 1	60PAR38/H/FL	Halogen PAR38	60	3,500
	Replacement 2	75PAR38/H/FL	Halogen PAR38	75	4,500
100R40/SP					
GE Lighting	**Base Case**	100R40/SP	Common R40	100	2,970
	Replacement 1	60PAR/HIR/FL30°	Halogen infrared PAR38	60	3,630
	Replacement 2	75PAR30L/H/30°	Long-neck halogen PAR30	75	2,800
	Replacement 3	50PAR30/HIR/NFL	Halogen infrared PAR30	50	2,850
	Replacement 4	75PAR/H/NFL25°	Halogen PAR38	75	4,000
OSRAM SYLVANIA INC.	**Base Case**	100R/SP	Common R40	100	5,000
	Replacement 1	45PAR/CAP/SP	Halogen PAR38	45	4,500
	Replacement 2	90PAR/CAP/FL	Halogen PAR38	90	4,000
Philips Lighting	**Base Case**	100R40/SP	Common R40	100	4,250
	Replacement 1	60PAR38/H/SP	Halogen PAR38	60	13,500
	Replacement 2	75PAR38/H/SP	Halogen PAR38	75	14,500
	Replacement 3	100BR25/25	BR25	100	2,100

NA = not applicable NS = not supplied

Only 120-volt lamps are listed.

[a] In some cases only field angles were reported; these values are in parentheses.

[b] Ellipsoidal reflector (ER) lamps are exempt from EPACT.

[c] This product has an integral reflector.

[d] CFLs are not covered in the EPACT requirements.

[e] Bulged reflector (BR) lamps are exempt from EPACT.

Beam Angle[a]	Initial Light Output (lm)	Average Rated Life (h)	CCT (K)	CRI	Efficacy (LPW)	Minimum Required Efficacy (LPW)
64°	1,190	2,000	2,700	100	12	14.0
53°	1,150	3,000	2,875	100	19	11.0
60°	1,025	2,000	2,850	100	14	12.5
42°	850	2,000	2,700	100	11	NA[b]
100°	800	10,000	2,700	82	40	NA[d]
(120°)	1,200	2,000	2,750	100	12	14.0
36°	850	2,000	2,700	100	11	NA[b]
55°	520	2,500	3,000	100	12	10.5
60°	1,160	2,000	2,700	100	12	14.0
28°	890	2,000	3,000	100	15	11.0
27°	1,140	2,500	3,000	100	15	12.5
24°	1,190	2,000	2,700	100	12	14.0
29°	1,150	3,000	2,875	100	19	11.0
30°	950	2,000	2,850	100	13	12.5
23°	1,000	3,000	2,850	100	20	10.5
26°	1,070	2,500	2,850	100	14	12.5
(36°)	1,200	2,000	2,750	100	12	14.0
15°	520	2,500	3,000	100	12	10.5
30°	1,345	2,500	3,000	100	15	14.0
20°	1,160	2,000	2,700	100	12	14.0
12°	890	2,000	3,000	100	15	11.0
10°	1,140	2,500	3,000	100	15	12.5
25°	1,100	2,000	2,700	100	11	NA[e]

Table 9. Manufacturer-Supplied Performance Data for 75R40/FL and 75R40/SP Lamps and Recommended Replacements

Manufacturer		Catalog Number	Description	Active Power (W)	CBCP (cd)
75R40/FL					
GE Lighting	**Base Case**	75R40/FL	Common R40	75	570
	Replacement 1	60R30/FL/WM	Krypton-filled R30	60	510
	Replacement 2	FLE20TBX/RFL/HPF	Self-ballasted CFL, electronic ballast[b]	20	370
	Replacement 3	50PAR30L/H/60°	Long-neck halogen PAR30	50	550
	Replacement 4	FLE15DBX/RFL	Self-ballasted CFL, electronic ballast[b]	15	250
	Replacement 5	60PAR/HIR/WFL55°	Halogen infrared PAR38	60	1,250
Mitor	**Base case lamps not supplied by manufacturer**				
	Replacement 1	EL13-A40[d]	Modular CFL, electronic ballast	13	NS
	Replacement 2	FL16-A40[d]	Self-ballasted CFL, magnetic ballast[e]	13	NS
	Replacement 3	FL16-R40[d]	Self-ballasted CFL, magnetic ballast[e]	13	NS
	Replacement 4	EL18-A40	Modular CFL, electronic ballast	18	NS
OSRAM SYLVANIA INC.	**Base Case**	75R/FL	Common R40	75	460
	Replacement 1	45PAR/CAP/VWFL	Halogen PAR38	45	600
	Replacement 2	75PAR/CAP/FL	Halogen PAR38	75	3,500
Philips Lighting	**Base Case**	75R40/FL	Common R40	75	590
	Replacement 1	45PAR38/H/FL	Halogen PAR38	45	2,000
	Replacement 2	75BR40/FL	BR40	75	NS
	Replacement 3	SL*18/R40	Self-ballasted CFL, magnetic ballast[e]	18	NS
ProLight	**Base case lamps not supplied by manufacturer**				
	Replacement 1	QCR 38	Modular CFL, magnetic ballast	13	568
	Replacement 2	QCR 38 S	Modular CFL, magnetic ballast	13	462
	Replacement 3	QCR 38 F	Modular CFL, magnetic ballast	13	389
	Replacement 4	QCR 38 P	Modular CFL, magnetic ballast	13	369
Teron Lighting	**Base case lamps not supplied by manufacturer**				
	Replacement 1	RFL-LZ-13Q-R40	Modular CFL, magnetic ballast	13	NS
75R40/SP					
Philips Lighting	**Base Case**	75R40/SP	Common R40	75	3,150
	Replacement 1	45PAR38/H/SP	Halogen PAR38	45	5,800
	Replacement 2	75BR40/SP	BR40	75	NS
Teron Lighting	**Base case lamps not supplied by manufacturer**				
	Replacement 1	RFL-LZ-13Q-R40	Modular CFL, magnetic ballast	13	NS

NA = not applicable   NS = not supplied

Only 120-volt lamps are listed.

[a] In some cases only field angles were reported; these values are in parentheses.

[b] This product has an integral reflector.

[c] CFLs are not covered in the EPACT requirements.

[d] The manufacturer supplied data for this product but expressed the opinion that 13-watt CFL reflector products presently available cannot match the performance of 75-watt reflector lamps.

Beam Angle[a]	Initial Light Output (lm)	Average Rated Life (h)	CCT (K)	CRI	Efficacy (LPW)	Minimum Required Efficacy (LPW)
65°	890	2,000	2,700	100	12	12.5
65°	775	2,000	2,750	100	13	11.0
100°	800	10,000	2,700	82	40	NA[c]
60°	630	2,000	2,800	100	13	10.5
104°	625	10,000	2,700	82	42	NA[c]
53°	1,150	3,000	2,875	100	19	11.0
NS	850	10,000	2,700	82	65	NA[c]
NS	850	10,000	2,700	82	65	NA[c]
NS	850	10,000	2,700	82	65	NA[c]
NS	1,200	10,000	2,700	82	67	NA[c]
(120°)	850	2,000	2,700	100	11	12.5
55°	520	2,500	3,000	100	12	10.5
30°	1,070	2,500	3,000	100	14	12.5
60°	850	2,000	2,650	100	11	12.5
28°	630	2,500	3,000	100	14	10.5
NS	704	5,000	NS	100	9	NA[f]
NS	800	10,000	2,700	100	44	NA[c]
42°	900	10,000	2,700; 3,500; 4,100	83+	69	NA[c]
45°	900	10,000	2,700; 3,500; 4,100	83+	69	NA[c]
47°	900	10,000	2,700; 3,500; 4,100	83+	69	NA[c]
50°	900	10,000	2,700; 3,500; 4,100	83+	69	NA[c]
NS	900	10,000	2,700	82	69	NA[c]
20°	850	2,000	2,650	100	11	12.5
12°	630	2,500	3,000	100	14	10.5
NS	704	5,000	NS	100	9	NA[f]
NS	900	10,000	2,700	82	69	NA[c]

[e] This product has a modular reflector.

[f] Bulged reflector (BR) lamps are exempt from EPACT.

Table 10. Manufacturer-Supplied Performance Data for 75R30/FL and 75R30/SP Lamps and Recommended Replacements

Manufacturer		Catalog Number	Description	Active Power (W)	CBCP (cd)
75R30/FL					
GE Lighting	**Base Case**	75R30/FL	Common R30	75	470
	Replacement 1	60R30/FL/WM	Krypton-filled R30	60	510
	Replacement 2	50PAR30L/H/60°	Long-neck halogen PAR30	50	550
	Replacement 3	FLE20TBX/RFL/HPF	Self-ballasted CFL, electronic ballast[b]	20	370
	Replacement 4	75ER30	ER30	75	1,200
	Replacement 5	75PAR30L/H/60°	Long-neck halogen PAR30	75	900
Mitor	**Base case lamps not supplied by manufacturer**				
	Replacement 1	EL1B-A30[e]	Modular CFL, electronic ballast	13	NS
	Replacement 2	FL16-A30[e]	Self-ballasted CFL, magnetic ballast[f]	13	NS
	Replacement 3	FL16-R30[e]	Self-ballasted CFL, magnetic ballast[f]	13	NS
	Replacement 4	EL18-A30	Modular CFL, electronic ballast	18	NS
OSRAM SYLVANIA INC.	**Base Case**	75R30/FL	Common R30	75	470
	Replacement 1	50PAR30/LN/CAP/WFL	Long-neck halogen PAR30	50	500
Philips Lighting	**Base Case**	75R30/FL	Common R30	75	430
	Replacement 1	50PAR30/H/FL	Halogen PAR30	50	1,250
	Replacement 2	75PAR30/H/FL	Halogen PAR30	75	2,200
ProLight	**Base case lamps not supplied by manufacturer**				
	Replacement 1	QCR 30	Modular CFL, magnetic ballast	13	280
	Replacement 2	QCR 30 S	Modular CFL, magnetic ballast	13	195
	Replacement 3	QCR 30 F	Modular CFL, magnetic ballast	13	172
	Replacement 4	QCR 30 P	Modular CFL, magnetic ballast	13	174
Teron Lighting	**Base case lamps not supplied by manufacturer**				
	Replacement 1	RFL-LZ-13Q-R32	Modular CFL, magnetic ballast	13	NS

NA = not applicable   NS = not supplied

Only 120-volt lamps are listed.

[a] In some cases only field angles were reported; these values are in parentheses.

[b] This product has an integral reflector.

[c] CFLs are not covered in the EPACT requirements.

[d] Ellipsoidal reflector (ER) lamps are exempt from EPACT.

[e] The manufacturer supplied data for this product but expressed the opinion that 13-watt CFL reflector products presently available cannot match the performance of 75-watt reflector lamps.

[f] This product has a modular reflector.

Beam Angle[a]	Initial Light Output (lm)	Average Rated Life (h)	CCT (K)	CRI	Efficacy (LPW)	Minimum Required Efficacy (LPW)
72°	900	2,000	2,700	100	12	12.5
65°	775	2,000	2,750	100	13	11.0
60°	630	2,000	2,800	100	13	10.5
100°	800	10,000	2,700	82	40	NA[c]
42°	850	2,000	2,700	100	11	NA[d]
60°	1,025	2,000	2,850	100	14	12.5
NS	850	10,000	2,700	82	65	NA[c]
NS	850	10,000	2,700	82	65	NA[c]
NS	850	10,000	2,700	82	65	NA[c]
NS	1,200	10,000	2,700	82	67	NA[c]
(130°)	850	2,000	2,700	100	11	12.5
58°	650	2,500	3,000	100	13	10.5
65°	850	2,000	2,650	100	11	12.5
40°	610	2,000	3,000	100	12	10.5
40°	1,000	2,000	3,000	100	13	12.5
80°	900	10,000	2,700; 3,500; 4,100	83+	69	NA[c]
69°	900	10,000	2,700; 3,500; 4,100	83+	69	NA[c]
75°	900	10,000	2,700; 3,500; 4,100	83+	69	NA[c]
75°	900	10,000	2,700; 3,500; 4,100	83+	69	NA[c]
NS	900	10,000	2,700	82	69	NA[c]

Table 10 (continued). Manufacturer-Supplied Performance Data for 75R30/FL and 75R30/SP Lamps and Recommended Replacements

Manufacturer		Catalog Number	Description	Active Power (W)	CBCP (cd)
75R30/SP					
GE Lighting	**Base Case**	75R30/SP	Common R30	75	1,350
	Replacement 1	60R30/SP/WM	Krypton-filled R30	60	1,600
	Replacement 2	50PAR30L/H/30°	Long-neck halogen PAR30	50	1,750
	Replacement 3	50PAR30/H/FL35°	Halogen PAR30	50	1,600
	Replacement 4	50PAR30/HIR/FL35°	Halogen infrared PAR30	50	2,400
	Replacement 5	75ER30	ER30	75	1,200
OSRAM SYLVANIA INC.	**Base Case**	75R/30SP	Common R30	75	1,600
	Replacement 1	50ER30	ER30	50	1,200
	Replacement 2	50PAR30LN/CAP/NFL	Long-neck halogen PAR30	50	1,750
Philips Lighting	**Base Case**	75R30/SP	Common R30	75	1,840
	Replacement 1	50PAR30/H/SP16	Halogen PAR30	50	4,200
	Replacement 2	75PAR30/H/SP16	Halogen PAR30	75	6,700
	Replacement 3	75ER30	ER30	75	1,550
Teron Lighting	**Base case lamps not supplied by manufacturer**				
	Replacement 1	RFL-LZ-13Q-R32	Modular CFL, magnetic ballast	13	NS

NA = not applicable NS = not supplied

Only 120-volt lamps are listed.

[a] In some cases only field angles were reported; these values are in parentheses.

[b] Ellipsoidal reflector (ER) lamps are exempt from EPACT.

[c] CFLs are not covered in the EPACT requirements.

Beam Angle[a]	Initial Light Output (lm)	Average Rated Life (h)	CCT (K)	CRI	Efficacy (LPW)	Minimum Required Efficacy (LPW)
30°	900	2,000	2,700	100	12	12.5
30°	775	2,000	2,750	100	13	11.0
30°	575	2,000	2,800	100	12	10.5
36°	670	2,000	2,800	100	13	10.5
33°	1,000	3,000	2,850	100	20	10.5
42°	850	2,000	2,700	100	11	NA[b]
(50°)	850	2,000	2,700	100	11	12.5
36°	525	2,000	2,700	100	11	NA[b]
32°	650	2,500	3,000	100	13	10.5
25°	850	2,000	2,650	100	11	12.5
16°	610	2,000	3,000	100	12	10.5
16°	1,000	2,000	3,000	100	13	12.5
30°	629	2,000	2,650	100	8	NA[b]
NS	900	10,000	2,700	82	69	NA[c]

Table 11. NLPIP-Measured Data for 150PAR38/FL Lamps and Manufacturer-Recommended Replacements

Manufacturer		Catalog Number	Rated Active Power (W)	Description
GE Lighting	**Base Case**	150PAR38/FL	150	Common PAR38
	Replacement 1	90PAR/H/FL30	90	Halogen PAR38
	Replacement 2	60PAR/HIR/FL30	60	Halogen infrared PAR38
	Replacement 3	100PAR/HIR/40	100	Halogen infrared PAR38
	Replacement 4	75PAR/H/NFL25	75	Halogen PAR38
	Replacement 5	75PAR30L/H/30	75	Long-neck halogen PAR30
JSL Lighting Corporation	**Base case lamps not supplied by manufacturer**			
	Replacement 1[c]	90PAR38/FL	90	Halogen PAR38
OSRAM SYLVANIA INC.	**Base Case**	150PAR/FL	150	Common PAR38
	Replacement 1	90PAR/CAP/FL	90	Halogen PAR38
Philips Lighting	**Base Case**	150PAR38/FL	150	Common PAR38
	Replacement 1	60PAR38/H/FL	60	Halogen PAR38
	Replacement 2	75PAR38/H/FL	75	Halogen PAR38
	Replacement 3[e]	90PAR38/H/FL	90	Halogen PAR38

1 ft = 0.305 m

For each lamp type, data were collected and averaged for four samples except where noted.

[a] Diameters were calculated for a six-foot distance based on manufacturer-supplied beam angles and were then normalized to the base case lamp values. Values in parentheses are manufacturer-supplied beam angles, in degrees.

Table 12. NLPIP-Measured Data for 150PAR38/SP Lamps and Manufacturer-Recommended Replacements

Manufacturer		Catalog Number	Rated Active Power (W)	Description
GE Lighting	**Base Case**	150PAR38/SP	150	Common PAR38
	Replacement 1	90PAR/H/SP10°	90	Halogen PAR38
	Replacement 2	60PAR/HIR/SP10°	60	Halogen infrared PAR38
	Replacement 3[b]	75PAR/H/NSP8°	75	Halogen PAR38
	Replacement 4	75PAR30L/H/10°	75	Long-neck halogen PAR30
JSL Lighting Corporation	**Base case lamps not supplied by manufacturer**			
	Replacement 1[c]	90PAR38/SP	90	Halogen PAR38
OSRAM SYLVANIA INC.	**Base Case**[d]	150PAR/SP	150	Common PAR38
	Replacement 1	90PAR/CAP/SP	90	Halogen PAR38
Philips Lighting	**Base Case**	150PAR38/SP	150	Common PAR38
	Replacement 1	60PAR38/H/SP	60	Halogen PAR38
	Replacement 2	75PAR38/H/SP	75	Halogen PAR38
	Replacement 3[d]	90PAR38/H/SP	90	Halogen PAR38

1 ft = 0.305 m

For each lamp type, data were collected and averaged for four samples except where noted.

[a] Diameters were calculated for a six-foot distance based on manufacturer-supplied beam angles and were then normalized to the base case lamp values. Values in parentheses are manufacturer-supplied beam angles, in degrees.

Relative CBCP (Manufacturer) (%)	Relative $L_{0°}$ (NLPIP) (%)	Relative Beam Diameter (Manufacturer)[a] (%)	Relative Beam Diameter (NLPIP) (%)	Relative L_{avg} (NLPIP) (%)	Beam Appearance
100 (3100 cd)	100 (221 cd/m^2)	100 (36°)	100 (4.4 ft)	100 (122 cd/m^2)	Smooth
129	145	82	74	104	Two-contour[b]
117	115	80	80	90	Two-contour
126	166	112	82	133	Ripple-4C
129	111	71	76	81	Two-contour
90	96	82	73	75	Smooth
129	95	82	77	71	Ripple-4C
100 (4000 cd)	100 (280 cd/m^2)	100 (30°)	100 (3.7 ft)	100 (133 cd/m^2)	Smooth
100	74	100	116	79	Ripple-5C
100 (3400 cd)	100 (301 cd/m^2)	100 (30°)	100 (3.5 ft)	100 (136 cd/m^2)	Smooth
103	75	93	95	71	Two-contour
132	98	90	92	85	Variegated[d]
132	117	93	89	101	Variegated[d]

[b] "Hot spot" was visible in the center of the beam.

[c] Two donated samples were tested.

[d] This distribution had a distinct, bright stripe passing through a dark center surrounded by a wider, brighter ring.

[e] One purchased and two donated samples were tested.

Relative CBCP (Manufacturer) (%)	Relative $L_{0°}$ (NLPIP) (%)	Relative Beam Diameter (Manufacturer)[a] (%)	Relative Beam Diameter (NLPIP) (%)	Relative L_{avg} (NLPIP) (%)	Beam Appearance
100 (12,000 cd)	100 (556 cd/m^2)	100 (16°)	100 (2.3 ft)	100 (172 cd/m^2)	Smooth
154	192	62	55	116	Two-contour
154	164	62	62	107	Ripple-5C
153	151	50	61	98	Two-contour
92	97	62	60	69	Two-contour
110	85	125	55	57	Two-contour
100 (11,500 cd)	100 (1246 cd/m^2)	100 (15°)	100 (1.4 ft)	100 (256 cd/m^2)	Smooth
100	50	100	118	56	Smooth[e]
100 (10,500 cd)	100 (698 cd/m^2)	100 (12°)	100 (1.9 ft)	100 (190 cd/m^2)	Cloud
129	129	100	69	83	Two-contour
138	155	83	52	93	Ripple-7C
138	146	100	52	90	Ripple-7C

[b] One purchased and one donated sample were tested.

[c] Two donated samples were tested.

[d] One purchased and two donated samples were tested.

[e] "Hot spot" was visible in center of the beam.

Table 13. NLPIP-Measured Data for 75R30/FL Lamps and Manufacturer-Recommended Replacements

Manufacturer		Catalog Number	Rated Active Power (W)	Description
GE Lighting	**Base Case**	75R30/FL	75	Common R30
	Replacement 1	60R30/FL/WM	60	Krypton-filled R30
	Replacement 2	50PAR30L/H/60°	50	Long-neck halogen PAR30
	Replacement 3	FLE20TBX/RFL/HPF	20	Self-ballasted CFL, electronic ballast[b]
	Replacement 4	75ER30	75	ER30
	Replacement 5	75PAR30L/H/60°	75	Long-neck halogen PAR30
Mitor	**Base case lamps not supplied by manufacturer**			
	Replacement 1	EL1B-A30	13	Modular CFL, electronic ballast
	Replacement 2	FL16-A30	13	Self-ballasted CFL, magnetic ballast[e]
	Replacement 3	FL16-R30	13	Self-ballasted CFL, magnetic ballast[e]
OSRAM SYLVANIA INC.	**Base Case**	75R30/FL	75	Common R30
	Replacement 1	50PAR30/LN/CAP/WFL	50	Long-neck halogen PAR30
Philips Lighting	**Base Case**	75R30/FL	75	Common R30
	Replacement 1	50PAR30/H/FL	50	Halogen PAR30
	Replacement 2	75PAR30/H/FL	75	Halogen PAR30
ProLight	**Base case lamps not supplied by manufacturer**			
	Replacement 1	QCR 30	13	Modular CFL, magnetic ballast
	Replacement 2	QCR 30 S	13	Modular CFL, magnetic ballast
	Replacement 3[h]	QCR 30 F	13	Modular CFL, magnetic ballast
	Replacement 4	QCR 30 P	13	Modular CFL, magnetic ballast
Teron Lighting	**Base case lamps not supplied by manufacturer**			
	Replacement 1[i]	RFL-LZ-13Q-R32	13	Modular CFL, magnetic ballast

1 ft = 0.305 m

NS = not supplied

For each lamp type, data were collected and averaged for four samples except where noted.

[a] Diameters were calculated for a six-foot distance based on manufacturer-supplied beam angles and were then normalized to the base case lamp values. Values in parentheses are manufacturer-supplied beam angles, in degrees.

[b] This product has an integral reflector.

[c] This distribution had a six-pointed, star-shaped shadow in the center of the beam and two bright streaks emanating from each point of the star.

[d] “Hot spot” was visible in the center of the beam.

[e] This product has a modular reflector.

[f] Manufacturer provided a field angle for the base case lamp and a beam angle for the replacement lamp.

[g] This distribution had a bright, x-shaped pattern at the center of the beam.

[h] Two donated and one purchased samples were tested.

[i] Two purchased samples were tested.

Relative CBCP (Manufacturer) (%)	Relative $L_{0°}$ (NLPIP) (%)	Relative Beam Diameter (Manufacturer)[a] (%)	Relative Beam Diameter (NLPIP) (%)	Relative L_{avg} (NLPIP) (%)	Beam Appearance
100 (470 cd)	100 (29 cd/m^2)	100 (72°)	100 (6.7 ft)	100 (21 cd/m^2)	Smooth
109	118	88	90	112	Smooth
117	123	79	91	117	Smooth
79	82	164	146	83	Variegated[c]
255	334	53	93	240	Smooth[d]
191	198	79	121	192	Smooth
NS	45	NS	130	50	Smooth
NS	52	NS	141	43	Smooth
NS	24	NS	174	26	Smooth
100 (470 cd)	100 (34 cd/m^2)	F.A.: 130°[f]	100 (5.4 ft)	100 (24 cd/m^2)	Smooth
106	90	B.A.: 58°[f]	106	80	Smooth[d]
100 (430 cd)	100 (29 cd/m^2)	100 (65°)	100 (6.1 ft)	100 (21 cd/m^2)	Smooth
291	303	57	72	225	Cloud
512	453	57	82	343	Cloud
65	54	132	108	52	Variegated[g]
45	41	108	105	40	Variegated[g]
40	39	120	105	38	Smooth
40	38	120	108	37	Smooth
NS	23	NS	207	23	Smooth

Table 14. NLPIP-Measured Data for 75R30/SP Lamps and Manufacturer-Recommended Replacements

Manufacturer		Catalog Number	Rated Active Power (W)	Description
GE Lighting	**Base Case**	75R30/SP	75	Common R30
	Replacement 1	60R30/SP/WM	60	Krypton-filled R30
	Replacement 2	50PAR30L/H/30°	50	Long-neck halogen PAR30
	Replacement 3	50PAR30/H/FL35°	50	Halogen PAR30
	Replacement 4[b]	50PAR30/HIR/FL35°	50	Halogen infrared PAR30
	Replacement 5	75ER30	75	ER30
OSRAM SYLVANIA INC.	**Base Case**	75R/30SP	75	Common R30
	Replacement 1[c]	50ER30	50	ER30
	Replacement 2[c]	50PAR30LN/CAP/NFL	50	Long-neck halogen PAR30
Philips Lighting	**Base Case**[d]	75R30/SP	75	Common R30
	Replacement 1	50PAR30/H/SP16	50	Halogen PAR30
	Replacement 2	75PAR30/H/SP16	75	Halogen PAR30
	Replacement 3	75ER30	75	ER30
Teron Lighting	**Base case lamps not supplied by manufacturer**			
	Replacement 1[c]	RFL-LZ-13Q-R32	13	Modular CFL, magnetic ballast

1 ft = 0.305 m

NS = not supplied

For each lamp type, data were collected and averaged for four samples except where noted.

[a] Diameters were calculated for a six-foot distance based on manufacturer-supplied beam angles and were then normalized to the base case lamp values. Values in parentheses are manufacturer-supplied beam angles, in degrees.

[b] One purchased and two donated samples were tested.

[c] Two purchased samples were tested.

[d] One donated and two purchased samples were tested.

Relative CBCP (Manufacturer) (%)	Relative $L_{0°}$ (NLPIP) (%)	Relative Beam Diameter (Manufacturer)[a] (%)	Relative Beam Diameter (NLPIP) (%)	Relative L_{avg} (NLPIP) (%)	Beam Appearance
100 (1350 cd)	100 (116 cd/m^2)	100 (30°)	100 (3.1 ft)	100 (50 cd/m^2)	Cloud
119	125	100	91	114	Cloud
130	106	100	102	104	Smooth
119	74	121	137	87	Ripple-3C
178	102	111	174	152	Smooth
89	84	143	134	104	Smooth
100 (1600 cd)	100 (187 cd/m^2)	100 (50°)	100 (2.1 ft)	100 (58 cd/m^2)	Cloud
75	48	70	144	65	Cloud
109	56	61	179	81	Ripple-3C
100 (1840 cd)	100 (103 cd/m^2)	100 (25°)	100 (2.0 ft)	100 (33 cd/m^2)	Cloud
228	362	63	83	278	Ripple-7C
364	427	63	88	357	Ripple-6C
84	92	121	167	135	Cloud
NS	6	NS	407	9	Smooth

Resources

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