NATIONAL LIGHTING PRODUCT INFORMATION PROGRAM

Specifier Reports

CFL Downlights

Downlight luminaires designed for compact fluorescent lamps

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Contents

Introduction

In many ways, the compact fluorescent lamp (CFL) has come to symbolize energy efficiency in lighting:

- Lamp manufacturers market screwbase CFLs as energy-saving replacements for incandescent lamps.
- Many energy conservation and environmental groups promote CFLs as a major part of lighting energy conservation programs.
- Many electric utilities promote screwbase CFLs as part of their residential demand-side management (DSM) programs.

Screwbase CFLs can directly replace incandescent lamps in existing luminaires, and many users install them in downlights. Although such an energy-saving strategy may seem well founded, a CFL's optical characteristics differ from those of an incandescent lamp, so installing a screwbase CFL in a luminaire designed for an incandescent lamp often alters the luminaire's light distribution. The size and shape of screwbase CFLs also make them difficult to install in luminaires that are designed for incandescent lamps. Even if the screwbase CFL fits into the luminaire, the energy savings that it provides may not persist because users can revert to an incandescent lamp very simply.

A specifier's concerns about the performance of screwbase CFL products often can be addressed by using luminaires that are designed specifically for CFLs ("dedicated" CFL luminaires), the ballast and lamp socket being an integral part of the luminaire. Manufacturers recently have developed and introduced many dedicated CFL luminaires, providing specifiers with several alternatives.

In this report, the National Lighting Product Information Program (NLPIP) provides information to help specifiers select dedicated CFL downlight luminaires, herein called "CFL downlights." This report details luminaire efficiency, spacing criterion, the effects of lamp position and temperature on light output, glare control, iridescence of the reflector material, and maintenance. The report also includes manufacturer-supplied product information and the results of NLPIP's application analyses and thermal performance tests.

The production of this report involved important contributions from many people. D. Abbott Vlahos took all of the photographs. S. Fleisher of Rensselaer Polytechnic Institute's School of Architecture assisted in constructing the thermal test chamber. Lighting Research Center (LRC) staff members A. Bierman, K. Conway, K. Heslin, Y. Ji, R. Leslie, D. Maniccia, N. Miller, M. Rea, and P. Schemenaur provided review comments.

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Downlight Types

Market Potential

More than 560 million downlights that use incandescent lamps are already installed in the United States, accounting for approximately 8% of total lighting energy use. More than 30 million downlights for incandescent lamps are sold annually in the United States (E Source 1993).

Horizontal-Lamp Downlights

The most common CFL downlights operate the lamp(s) in the horizontal position (see Figure 1). A horizontally mounted lamp allows the luminaire to have a relatively low overall height, so that it can more easily be integrated into a shallow ceiling plenum. These luminaires can operate one, two, or three lamps, and generally have wider light distributions than vertical-lamp downlights. Although the most common horizontal-lamp CFL downlights have round apertures, square apertures also are available.

Vertical-Lamp Downlights

Some CFL downlights operate the lamp in a base-up, vertical position (see Figure 2). They usually have a greater overall luminaire height than horizontal-lamp downlights. Most of these downlights use a single lamp, although a few are available that use two lamps. Vertical-lamp downlights often have a narrow light distribution.

Figure 1. CFL Downlight With Lamp in the Horizontal Position

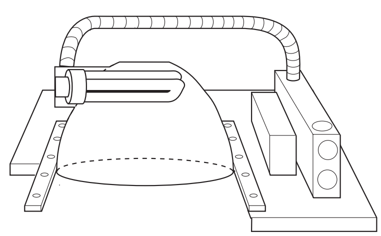
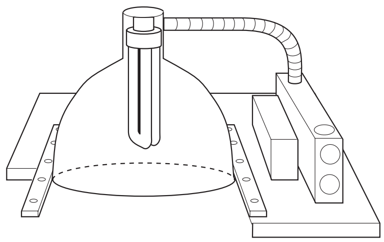


Figure 2. CFL Downlight With Lamp in the Vertical Position



CFL Nomenclature

The National Electrical Manufacturers Association (NEMA) has developed a generic, four-part designation system for compact fluorescent lamps. This system is used in North America:

CF + *Shape* + *Wattage* / *Abbreviated base designation*

CF designates all single-ended, self-supported compact fluorescent lamps.

Shape designations include:

T = twin parallel tubes
Q = four parallel tubes in a quad formation
S = square shaped
M = any other multiple tube shape

Wattage is the nominal active power of a lamp when operated on a reference ballast. The nominal wattage is followed by "W."

Abbreviated base designation is the American National Standards Institute (ANSI) designation for the base type.

Examples:
13-watt twin-tube lamp with a GX23 base: CFT13W/GX23
13-watt quad-tube lamp with a GX23-2 base: CFQ13W/GX23
22-watt quad-tube lamp with a GX32d-2 base: CFQ22W/GX32d
28-watt quad-tube lamp with a GX32d-3 base: CFQ28W/GX32d

Downlight Performance Issues

Luminaire Efficiency

Luminaire efficiency is the ratio of the light output emitted by a luminaire to the light output emitted by the lamp-ballast combination (IESNA 1993). Luminaire efficiency indicates how much of the lamp's light output the luminaire's optical system directs out of the luminaire. However, luminaire efficiency does not quantify the luminaire's ability to deliver light to a desired location, such as a task area. A different measure of luminaire performance, called the coefficient of utilization (see sidebar), addresses the delivery of light to a specific plane.

The standard photometric testing procedures used to determine the luminaire efficiency of a CFL downlight (IESNA 1985) can differ from typical application conditions in two important ways: lamp position and ambient temperature around the luminaire. Light output ratings for CFLs are measured under standard test conditions (IESNA 1991) that include base-up operation at a temperature of 25°C (77°F). However, the light output of a CFL varies depending on the lamp's position and temperature (Davis et al. 1994).

Lamp position. In luminaire photometric testing, the light output of the bare lamp(s) is first measured with the lamp operating in the position at which it operates in the luminaire. Manufacturers report luminaire efficiency as a percentage of this measured light output, rather than the lamp's rated light output.

CFL light output typically is less when the lamp is operated in a position other than base-up. NLPIP's previous testing of screwbase CFLs (Barrett 1993) found that operating CFLs base down may reduce light output by 0 to 25%, depending on the lamp type. Other tests showed that 26-W CFL quad lamps had reductions of up to 10% of base-up (rated) light output when the lamps were positioned horizontally (Davis et al. 1994). When specifying CFL downlights, specifiers should request operating-position multipliers from the lamp manufacturer to adjust the light output in their lighting design calculations if the lamp will not be operated in the vertical, base-up position.

Coefficient of Utilization (CU)

The CU for a luminaire is the ratio of the light output from the lamps that is received on a plane to the light output emitted by the lamp-ballast combination. For a given set of room conditions, a luminaire with a higher CU value is more effective at delivering light to a plane than one with a lower CU value.

Unlike luminaire efficiency, CU incorporates the effects of room surface reflectances and the geometry of the room. Luminaire manufacturers publish a table of CUs for various room geometries (expressed by the room cavity ratios) and ceiling, wall, and floor reflectances. Specifiers use CU to calculate the average illuminance on a plane, usually the work surface.

CFL Downlights for Insulated Ceilings

Insulated ceilings (IC) save energy by minimizing heat loss and heat gain, thus reducing a building's heating and cooling costs. Recessed downlights that are designed specifically for insulated ceilings usually are called IC-type downlights. They have little-to-no air leakage and can be installed in direct contact with ceiling insulation. Regular (non-IC) downlights should be installed in insulated ceilings only within a gasketed box made from non-heat-conductive materials.

Specifiers should evaluate the photometric reports for IC-type CFL downlights (and gasketed, boxed downlights) carefully. Photometric reports for non-IC CFL downlights may overstate luminaire efficiency when insulated ceilings are involved. For either the IC-type downlights or a boxed downlight, manufacturers can provide photometric reports specific to those downlights. Some manufacturers test their downlights with ceiling insulation, whereas others test downlights without ceiling insulation. Ceiling insulation increases the temperature at the lamp, reducing luminaire efficiency. Thus when comparing luminaire efficiency values for IC-type downlights, the specifier should make sure that all downlights being compared were tested under the same conditions.

Specifiers should also be aware that in insulated ceiling applications, vented CFL downlights have little or no advantage over non-vented ones. The purpose of venting a downlight is to lower the lamp ambient temperature through convective cooling and thus increase the light output. An insulated ceiling or a gasketed box defeats this purpose: it increases the temperature around the lamps and reduces light output. The reduction is greater for higher-wattage lamps. Most IC-type CFL downlights use only low-wattage lamps (up to two 13-W lamps).

Discomfort Glare and Visual Comfort Probability (VCP)

Discomfort glare is a sensation of discomfort or unease caused by light. Different types of luminaires create different levels of discomfort glare: some shield the emitted light from the viewer's eyes with louvers or other control media which creates little discomfort glare, whereas others diffuse the light and usually are very bright at normal viewing angles. VCP is a luminaire rating that expresses the percentage of people who, when viewing from a specified location and in a specified direction, would find the luminaire's brightness acceptable. Specifiers can either obtain the luminaire's VCP for standardized conditions from a photometric report or calculate it for a specific application using lighting analysis software.

Amalgam Lamps

Although many manufacturers of CFL downlights use vents to overcome light output reductions at high temperatures, some lamp manufacturers offer an alternative approach. CFLs that have a mercury amalgam maintain the lamp's light output over a wide range of temperatures, which can mitigate the light output reductions commonly experienced in unvented downlights. Amalgam lamps also tend to maintain relatively constant light output at different operating positions. However, amalgam CFLs can take more than 15 minutes to reach their full light output when turned on.

Ambient temperature. Photometric tests are conducted at a different temperature than that which is found in many applications. Most lamps within luminaires operate at ambient temperatures greater than 25°C, so the lamps' light output is less than the rated value (Davis et al. 1994; Serres and Taelman 1993; Roche 1993). Most CFL downlights have vents to reduce the temperature around the lamp, thereby improving light output. Siminovitch and Rubinstein documented the effects of various venting strategies (1992); NLPIP's evaluations of vented downlights are reported on p. 9.

The effects of the in-luminaire thermal conditions on the lamp's light output are captured in the luminaire efficiency and CU value reported in the photometric report, which makes a correction factor unnecessary for these effects. However, changes in light output caused by an ambient temperature *outside* the luminaire of other than 25° C are not captured in the photometric testing.

Luminaires that are recessed into a ceiling plenum usually have ambient temperatures from 25 to 40°C (77 to 104°F). In an existing building, the facility manager or building maintenance staff can directly measure the plenum temperature at several points near the recessed downlights. For a building in the design stage, the mechanical engineer can estimate the plenum temperature based on the type of heating and air-conditioning system. If the specifier expects that the plenum temperature will be greater than 30° C (86° F), NLPIP recommends that the specifier reduce the light output value used in lighting design calculations by 5 to 20% (the higher the temperature, the greater the reduction), or request detailed thermal performance data from the lamp manufacturer.

Spacing Criterion

Specifiers use the spacing criterion (SC) to estimate the limit of acceptable luminaire spacing to achieve uniform illuminance on a horizontal plane. Multiplying the SC by the luminaire mounting height (the distance between the horizontal work plane and the luminaire) establishes the maximum distance at which luminaires should be spaced (center-to-center) to assure uniform illuminance. If the actual spacing between the luminaires exceeds this maximum, the installation may produce nonuniform illuminance patterns.

The SC also indicates the width of the light distribution from the luminaire. A luminaire with a wide light distribution will have a greater SC than a luminaire with a narrow light distribution. Most of the horizontal-lamp CFL downlights that NLPIP evaluated for this report had SC values between 1.0 and 1.7, whereas all of the vertical-lamp CFL downlights had SC values less than 1.0. Thus, vertical-lamp downlights generally have narrower light distributions than horizontal-lamp downlights.

Glare

A CFL downlight has two possible sources of glare: the brightness of the lamp itself and the reflection of the lamp on a reflector surface (often referred to as "flashing"). Most manufacturers of CFL downlights provide photometric reports with detailed luminous intensity (candlepower) data and average luminance data at different viewing angles. Unfortunately, there is no straightforward way to use these data to estimate the potential for glare from a downlight.

One metric commonly used to assess the discomfort glare from a luminaire is visual comfort probability (VCP—see sidebar on p. 4). Most CFL downlight manufacturers do not provide VCP data on their photometric reports because this metric was developed for use with luminaires that have uniform luminance. However, recent research suggests that existing metrics such as VCP probably overestimate the discomfort glare from nonuniform luminaires, and so are adequate for evaluating acceptability of these luminaires in terms of discomfort glare (Waters et al. 1995).

NLPIP presents calculated VCP values for the conference room application analyses, summarized in Tables 8–10. Although VCP can be calculated precisely, its interpretation is much less precise. According to the Illuminating Engineering Society of North America (IESNA), differences in VCP of less than 5 points are not meaningful (IESNA 1993). NLPIP suggests that specifiers consider CFL downlights with VCP values greater than 60 as having "high" VCP; those between 40 and 70 as "medium"; and those less than 50 as "low."

The methods used to characterize glare, including VCP, are limited, so NLPIP suggests that specifiers obtain and view samples of CFL downlights as part of the specification process to visually evaluate the glare control characteristics in a realistic setting. The specifier should be sure to obtain a sample that has the same lamp, shielding, and reflector type that are being considered. The setting for the evaluation should approximate the ceiling height and viewing angles that users would experience in the actual installation.

To reduce glare, many manufacturers of CFL luminaires provide optional louver assemblies. Although these louvers can increase the VCP, they also decrease the luminaire efficiency. To illustrate, Table 1 compares the efficiency and VCP of pairs of similar horizontal-lamp downlights from five manufacturers for two common applications. For the seven pairs of downlights shown in this table, adding louvers to the downlight increased the calculated VCP, which indicates that the louvers reduced discomfort glare. However, the downlights with louvers also had lower efficiencies than the corresponding downlights without louvers. (The VCP calculation methods are described in the "Application Analyses" section on p. 7.)

Table 1. Efficiency and VCP Comparisons for Luminaires With and Without Louvers

Manufacturer	Lamp Type	Aperture (in.)	Luminaire Efficiency (%)		VCP (%)	
			No Louvers	Louvers	No Louvers	Louvers
Seven luminaires by five luminaires[a]						
Edison Price	2-CFT13W	8	72	59	37	64
Lightolier	2-CFT13W	8	59	57	58	63
Prescolite	2-CFT13W	7 3/4	78	60	37	45
Wila	2-CFQ13W	7	57	43	46	66
Six luminaires by four luminaires[a]						
Edison Price	2-CFQ18W	7	66	42	14	91
Staff	2-CFQ18W	7 1/2	55	42	58	87
Wila	2-CFQ18W	10	67	54	43	79

[a] See Figure 4 on p. 8.

Iridescence

Many CFL downlights have anodized aluminum reflectors. The anodizing process produces a laminated surface with a reflectance of approximately 90% at a lower cost than alternative materials with the same reflectance. However, when anodized aluminum reflects the light produced by the rare-earth phosphors used in CFLs, the various wavelengths of energy may be reflected from different depths in the material and at different angles. This results in a visible color separation in the reflected light: a rainbow-like appearance called iridescence. Although iridescence does not affect the measured photometric performance of a downlight, it does affect the downlight's appearance.

Most CFL downlight manufacturers offer reflectors made from low-iridescence materials as either a standard or an option. The methods used to minimize iridescence can affect the reflectance and the cost of the material. Before specifying a low-iridescence reflector, the specifier should request photometric data for the specific reflector from the downlight manufacturer, to see if the low-iridescence reflector reduces the luminaire efficiency.

Maintenance

To maintain their photometric performance, the reflectors of CFL downlights require regular cleaning. Downlights for incandescent A-lamps also often have specular reflectors, which require similar maintenance. Downlights for incandescent reflector lamps usually do not use reflectors in the luminaire, so they do not require regular cleaning.

CFL downlights should require relamping much less frequently than luminaires for incandescent lamps because the rated lamp life of a CFL is longer than that of an incandescent lamp. Replacing a CFL in a vertical-lamp downlight usually is not difficult because the lamp can be pulled straight down out of its socket. In horizontal-lamp downlights, the restricted space at the top of the luminaire can make it difficult both to remove the CFL from its socket and to install a new CFL. Most downlights have an opening in the reflector opposite the socket to ease relamping; these openings can cause some optical losses, but they also serve as thermal vents to remove heat from the ends of the lamps. At least one manufacturer offers a hinged socket assembly so that the lamp can be tipped down for easier relamping.

Ballasts for CFLs

Like all fluorescent lamps, CFLs require ballasts for lamp starting and operation. Traditionally, ballasts for CFLs have been either preheat or rapid-start magnetic types, and have been limited to one-lamp operation. Thus, a CFL downlight with two CFLs needed two ballasts.

A growing number of manufacturers now offer electronic ballasts, some of which can operate two, three, or even four CFLs. A CFL operated by an electronic ballast requires less power than the same lamp operated by a magnetic ballast. For example, the active power for an 18-W CFL operated by a magnetic ballast usually ranges from 22 to 25 W; when operated by an electronic ballast, its active power typically ranges from 18 to 20 W. Additionally, electronic ballasts weigh less than magnetic ballasts, and can offer dimming capabilities.

NLPIP did not evaluate ballasts as part of this project, but recommends that specifiers compare ballasts for CFLs using the same criteria as for other fluorescent lamp ballasts (Ji 1994). Metrics such as active power, ballast factor, and power factor are important in evaluating the performance of a CFL downlight system. Unfortunately, present standards for CFL ballasts only cover magnetic types. However, both the American National Standards Institute (ANSI) and the Canadian Standards Association (CSA) are developing standards that will apply to electronic CFL ballasts. The CSA standard should be adopted in the near future; however, it is limited to self-ballasted lamps and screwbase ballasts. NLPIP does not expect that relevant ANSI standards for electronic ballasts for CFLs will be finalized for at least one year.

Performance Evaluations

To evaluate presently available CFL downlights, NLPIP identified manufacturers of these products and requested that they submit product literature and photometric data. Fifteen manufacturers responded; all provided product literature, but only 13 provided photometric data. Using the manufacturer-supplied information, NLPIP compiled general information on the available products (see Tables 2–5). NLPIP used the photometric data to analyze simulated applications of CFL downlights; the "Application Analyses" section that follows describes these analyses and Tables 6–10 present the results.

NLPIP also conducted laboratory testing of samples of CFL downlights at the Lighting Research Center's laboratory in Watervliet, New York, to evaluate their thermal properties. For this testing, conducted in July and August 1994, NLPIP requested samples of specific downlights from manufacturers, based on the lamp type and the venting strategies used. The "Thermal Testing" sidebar on p. 9 describes this testing.

Application Analyses

NLPIP simulated the performance of CFL downlights and incandescent lamp downlights in two common applications: a corridor and a conference room, both with 9-foot (ft) [2.7-meter (m)] ceilings. For the corridor, NLPIP developed a "base-case" lighting layout using a downlight for a 100-watt (W) incandescent A19 lamp. Eight downlights were placed 6 ft (1.8 m) on center, a spacing commonly used for 2-ft x 2-ft or 2-ft x 4-ft ceiling systems. Figure 3 on p. 8 shows the lighting layout used for the corridor, and the sidebar at right describes how NLPIP selected the base-case downlight for the corridor.

For the conference room, NLPIP selected two base-case downlights and layouts. One base case arranged 35 downlights with 100-W incandescent A19 lamps in a uniformly spaced pattern. The other arranged 24 downlights with 150-W incandescent A21 lamps in a uniformly spaced pattern. Figure 4 on p. 8 shows the lighting layouts for the conference room. The sidebar at right describes how NLPIP selected the base-case downlights for the conference room.

Recommendations for replacing incandescent lamps with CFLs usually are based on equivalent lamp light output, so NLPIP selected CFL downlights that use lamps with approximately the same light output as the incandescent lamp used in the base case. For the applications in which the base-case downlight uses 100-W incandescent lamps [rated light output 1750 lumens (lm)], NLPIP selected CFL downlights that use either two 13-W CFLs (900 lm each) or one 26-W CFL (1800 lm). For the application in which the base-case downlight uses a 150-W incandescent lamp (2880 lm), NLPIP selected CFL downlights that use either two 18-W CFLs (1250 lm each) or three 13-W CFLs.

NLPIP selected downlights with either a clear reflector cone and no enclosure or a clear cone and a louvered enclosure. NLPIP chose CFL downlights for the analyses that had SC values appropriate for the respective layouts, unless otherwise noted in the tables.

Selecting Base-Case Downlights

NLPIP chose incandescent lamp downlights for the base-case conditions because CFL downlights often are proposed as an alternative to incandescent lamp downlights. To select the base-case incandescent lamp downlights used in the application analyses, NLPIP reviewed performance data for downlights from different manufacturers. For the 100-W incandescent A19 downlights, NLPIP compiled data for 29 downlights from eight manufacturers. For these 29 downlights, the median CU value (for the conference room conditions) was 0.67. NLPIP selected a Kurt Versen downlight (model C7321) with a CU value of 0.67 as the base-case downlight. For the 150-W incandescent A21 downlights, NLPIP reviewed 35 downlights from nine manufacturers. The median CU value for these downlights was 0.71. NLPIP selected an Edison Price downlight (model A21/6 COL) with a CU value of 0.70 as the base-case downlight.

New Lamp Types

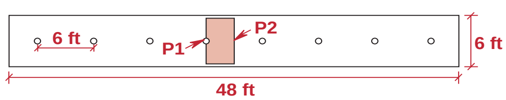
Manufacturers of CFL downlights continue to develop and introduce new products, taking advantage of new developments in CFLs. For example, a few manufacturers indicated to NLPIP that they now have or will soon add downlights that use newer, multiple-tube CFLs. NLPIP did not evaluate these products because they were introduced after NLPIP's analyses were completed. Table 2 on p. 11 provides telephone numbers for each of the manufacturers in this report, so that specifiers can contact the companies directly to learn about new products.

Uniformity Ratios

Although no standards for illuminance uniformity exist in North America, a number of sources suggest that a maximum-to-minimum illuminance ratio no greater than 1.3 to 1.4 is acceptable for applications where uniform illuminance is desired. For example, Odle and Smith (1963) reported a maximum acceptable ratio of 1.3. An interior lighting code in Great Britain requires a minimum-to-maximum illuminance ratio of at least 0.7; this converts into a maximum-to-minimum ratio not to exceed 1.43 (CIBSE 1984). This British code is typical of other European standards.

NLPIP used the Lumen-Micro™ lighting analysis program to calculate the illuminance (E) at a point directly under a luminaire near the center of each space (E_{P1}), the illuminance at a point between luminaires (E_{P2}), and the average illuminance of an area located near the center of each space (E_{avg}). Figures 3 and 4 indicate the individual points and the area. NLPIP also used Lumen-Micro to calculate the VCP for each luminaire used in the conference room, for a point and viewing direction as indicated in Figure 4. (NLPIP did not calculate VCP for the corridor application because it generally is not an important criteria for such applications.) NLPIP calculated the ratio of E_{P1} to E_{P2} as an expression of the uniformity of illuminance. The sidebar at left discusses standards for illuminance uniformity ratios such as E_{P1}/E_{P2}.

Figure 3. Luminaire Layout for Corridor



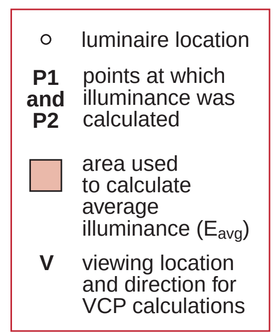
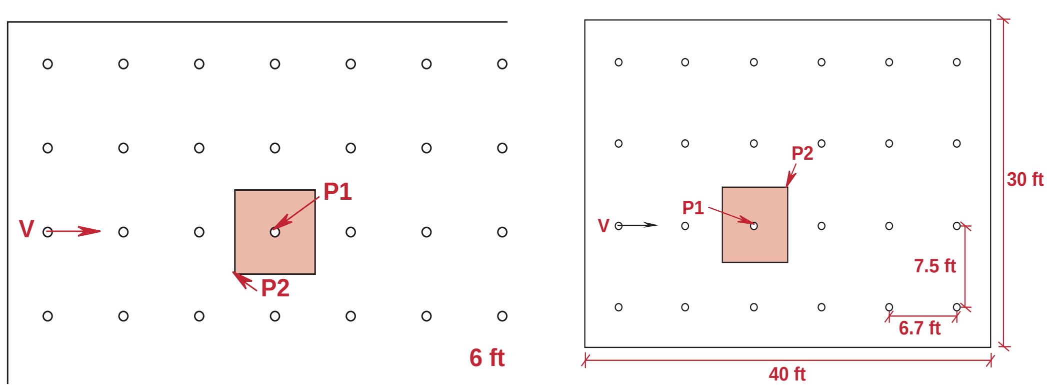


Figure 4. Luminaire Layouts for Conference Room



(a) 100-W A19 lamp base case (seven luminaires by five luminaires)

(b) 150-W A21 lamp base case (six luminaires by four luminaires)

Room reflectances were 80% for the ceiling, 50% for the walls, and 20% for the floor. Ceiling height was 9 ft.
1 ft = 0.304 m

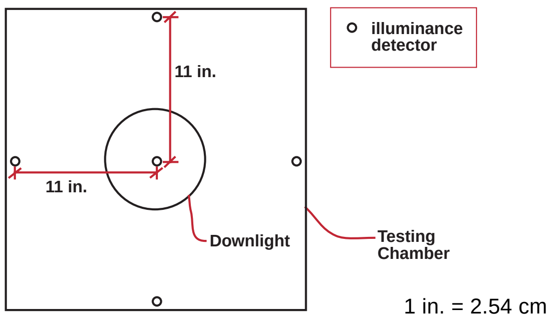
Thermal Testing

In addition to the application analyses, NLPIP tested 11 CFL downlights to evaluate the effectiveness of venting. The results also are useful for assessing the performance of vented downlights when used in a ceiling plenum that restricts the thermal environment around the downlight. NLPIP designed and constructed a testing chamber, shown below, in which downlights could be tested in either a restricted or an unrestricted thermal environment. For the unrestricted environment, NLPIP left the lid to the chamber open. NLPIP closed the lid for the restricted environment; the lid had a foam gasket to minimize air flow out of the chamber.

NLPIP tested two types of horizontal-lamp CFL downlights: five that use two CFT13W lamps and six that use two CFQ26W lamps. All of the downlights used magnetic ballasts. All of the downlights for 13-W lamps had ventilation holes located near the ends of the lamps opposite the sockets. Five of the downlights for 26-W lamps had similar ventilation holes; one was unvented. For each downlight at each test condition, NLPIP first operated the downlight until the thermal environment around the lamp was stable, then measured the room temperature (maintained at 25°C ± 1.5°C) and the lamp ambient temperature near the tips of the lamps and calculated the difference between these two temperatures. This difference shows the effect of the downlight on the lamp's operating temperature. NLPIP also measured the illuminances produced by the downlight using an array of illuminance detectors below the testing chamber (see figure at right).

The median change in temperature (ΔT) for the five vented downlights for 26-W lamps was 11.2°C in the unrestricted condition (lid open), whereas the ΔT for the one unvented downlight with 26-W lamps in the unrestricted condition was 22.2°C. Thus the vented downlights effectively reduced the operating temperature near the lamp tips relative to the unvented downlight. Based on previous testing (Davis et al. 1994), NLPIP estimates that this temperature reduction can account for a 10–15% increase in lamp light output and luminaire efficiency for vented downlights for 26-W lamps relative to unvented downlights.

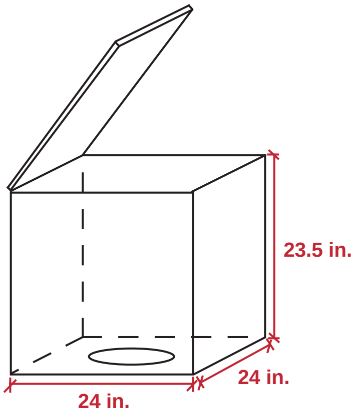
Positions of Illuminance Detectors (Plan View)



NLPIP found that operating the downlights in the restricted (lid closed) environment resulted in a median reduction in illuminance of 8% for the downlights with 13-W lamps, and a median reduction in illuminance of 19% for the downlights with 26-W lamps relative to illuminance in the unrestricted environment. This reduction is caused by the increased lamp ambient temperature in the restricted environment, and estimates the reduction in light output that would occur due to thermal effects if these downlights were used in an application with restricted air flow around the downlights.

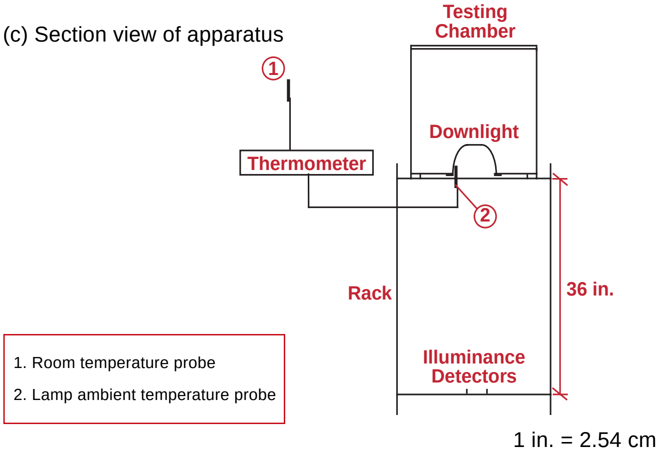
NLPIP's Thermal Testing Apparatus

(a) Testing chamber



(b) An NLPIP researcher examines a luminaire within the chamber

(c) Section view of apparatus



(d) An NLPIP researcher adjusts a luminaire

Data Tables

Tables 2–5 present product information that manufacturers supplied to NLPIP. Tables 6–10 present the data from NLPIP's application analyses. Brief definitions of the column headings used in the tables are provided below, in alphabetical order. Please refer to the text (page numbers in parentheses) for additional information.

Additional optical control: Describes any enclosure used on the downlights in NLPIP's application analyses, such as louvers.

Aperture: The diameter in the opening of the downlight, in inches (in.). Sometimes a manufacturer will categorize a downlight based on a whole-inch increment (that is, a downlight with a $6\frac{13}{16}$-in. aperture may be categorized as a 7-in. downlight); the apertures reported here are the actual apertures given on the manufacturers' specification sheets.

E_{avg}: The calculated average illuminance, as indicated in Figures 3 and 4, in footcandles (fc) (p. 8).

E_{P1}: The calculated illuminance at Point 1, as indicated in Figures 3 and 4, in footcandles (p. 8).

E_{P2}: The calculated illuminance at Point 2, as indicated in Figures 3 and 4, in footcandles (p. 8).

E_{P1}/E_{P2}: The ratio of the calculated illuminances at Point 1 and Point 2, used as a measure of the uniformity of the illuminance on the work plane (p. 8).

Electronic ballast option: Whether the downlight manufacturer offers an electronic ballast for each downlight (p. 6).

Enclosure(s): Options offered by the manufacturer for enclosing the downlight, such as lenses and louvers. Symbols used are defined in the footnotes for each table.

Height: The total height of the downlight, in inches.

IC option: Whether the manufacturer offers a version the downlight for insulated ceiling applications (p. 3).

Lamp type(s): The number of lamps used in the downlight, followed by the active power (in watts) of the lamps. If more than one lamp type is shown, the manufacturer offers the downlight with each of the lamp types. The "TT" column shows options for twin-tube lamps; the "QT" for quad-tube lamps; the "MT" for multiple-tube lamps (p. 2).

Luminaire efficiency: The luminaire efficiency from the photometric data provided to NLPIP by the manufacturer, in percent (p. 3).

VCP: The visual comfort probability for the downlight (pp. 4–5).

Venting: Whether the downlight has holes in the reflector assembly (p. 4).

Table 2. Manufacturer-Supplied Information: Telephone Numbers for Customer Inquiries

Manufacturer	Telephone Number
Capri	213-726-1800
Delray	818-982-3701
Edison Price	212-838-5212
Halo	708-956-8400
Indy	317-849-1233
Juno	708-827-9880
Kurt Versen	201-664-8200
Lightolier	800-217-7722
Lightron	914-562-5500
Metalux	912-924-8000
Omega	213-726-1800
Prescolite	510-562-3500
Staff	212-371-4400
Wila	305-652-1600
Zumtobel	201-340-8900

Telephone numbers are accurate as of July 1995.

Table 3. Manufacturer-Supplied Information: Square Downlights for Horizontal Lamps

Manufacturer	Trade Name	Aperture (in.)	Height (in.)	Lamp Type(s) (Number-W) CFT	Lamp Type(s) (Number-W) CFQ	Enclosure(s)[a]	Electronic Ballast Option	IC Option	Venting
Capri	Design/Build	$10^{1}/_{4}$	5	2-13	2-18, 2-26	■ ◗ ▼ ▲	yes	no	yes
Delray	NS	12	NS		2-26, 3-26	▼	no	NS	no
Halo	Quick-Ship	$8^{1}/_{4}$	$3^{1}/_{2}$	2-13		■	no	NS	no
Indy	NS	$10^{3}/_{4}$	$6^{3}/_{4}$	2-18, 3-18, 2-27, 3-27		▼	yes	no	yes
Kurt Versen	Quadlite	$6^{1}/_{4}$	6		2-13	●	no	no	yes
Lightolier	Calculite	11	$5^{1}/_{2}$	2-24, 2-27		▼	yes	no	no
Lightron	Series 205	$10^{1}/_{8}$	$6^{3}/_{4}$	2-13, 3-13	2-18, 3-18, 2-26, 3-26	▼	yes	no	no
Metalux	NS	12	$7^{1}/_{8}$	2-13, 2-18, 3-18		▼	no	NS	no
Omega	Architectural	12	$5^{7}/_{8}$	3-13, 2-18, 3-18		▼	yes	no	no
Prescolite	NS	$7^{9}/_{16}$	$4^{1}/_{8}$	2-9, 1-13		■	yes	no	no
Prescolite	Intelect	$7^{9}/_{16}$	$4^{1}/_{8}$	1-13		■	yes[b]	no	no
Prescolite	NS	10	$4^{1}/_{8}$	2-13	2-18, 2-26	■	yes	no	no
Prescolite	Intelect	10	$4^{1}/_{8}$	2-13	2-18, 2-26	■	yes[b]	no	no
Staff	NS	12	$5^{3}/_{4}$	2-18, 2-27		■ ▼	no	NS	no
Zumtobel	REK	$11^{15}/_{16}$	$5^{11}/_{16}$	2-18, 3-18		▼	yes	no	no

NS = not supplied
1 in. = 2.54 cm
[a] Enclosure: ●=open cone; ■=lens/diffuser; ◗=lens+baffle; ▼=louver; ▲=louver+baffle. Not every enclosure is available with every lamp type.
[b] Only available with electronic ballast.

Table 4. Manufacturer-Supplied Information: Round Downlights for Horizontal Lamps

Manufacturer	Trade Name	Aperture (in.)	Height (in.)	Lamp Type(s) (Number-W) CFT	CFQ	Enclosure(s)[a]	Electronic Ballast Option	IC Option	Venting
Capri	Commercial	6	6	2-9	2-13, 2-18	● ★ ■ ◗	yes	no	yes
Capri	Design/Build	6	6		2-13, 2-18	● ★ ■ ◗	yes	yes[b]	yes
Capri	Commercial	7 1/2	7	2-13	2-18, 2-26	● ★ ■ ◗	yes	no	yes
Capri	Commercial	9 3/4	8 1/2		2-26	● ★	yes	no	yes
Delray	NS	6	6		2-9, 2-13	● ★	yes	NS	yes
Delray	Retrofit	6	6		2-9, 2-13	● ★	yes	NS	yes
Delray	NS	6 13/16	6 11/16		2-13	● ★ ◗	yes	NS	yes
Delray	Retrofit	6 13/16	6 11/16		2-9, 2-13	● ★ ◗	yes	NS	yes
Delray	Retrofit	7 3/8	6 13/16		2-9, 2-13, 2-18, 2-26	● ■ ◗	yes	NS	yes
Delray	NS	7 13/16	5 11/16	2-13		●	yes	NS	yes
Delray	NS	7 13/16	6 11/16		2-18, 2-26	●	yes	NS	yes
Delray	NS	7 13/16	9 5/16	2-9		●	no	NS	yes
Delray	Retrofit	7 13/16	6 11/16		2-18, 2-26	●	yes	NS	yes
Delray	Retrofit	7 13/16	9 5/16	2-9, 2-13		●	yes	NS	yes
Delray	Retrofit	9 1/2	8 5/16	2-13	2-18, 2-26	● ■ ◗	yes	NS	yes
Edison Price	Baflux	7	3 3/16	2-9		▼	no	no	no
Edison Price	Duplux	7	5 7/8		2-18	● ■	yes	no	yes
Edison Price	Lenslux	7	3 3/16	2-9		■	no	no	no
Edison Price	Simplux	7	4 3/4	2-9		● ■	no	no	yes
Edison Price	Super Baflux	7	4 3/4		2-18	▼	yes	no	yes
Edison Price	Super Lenslux	7	4 3/4		2-18	■	yes	no	yes
Edison Price	Baflux	8	3 3/16	2-13		▼	no	no	no
Edison Price	Duplux	8	6 9/16		2-26	● ■	yes	no	yes
Edison Price	Lenslux	8	3 3/16	2-13		■	no	no	no
Edison Price	Simplux	8	5 5/8	2-13		● ■	no	no	yes
Edison Price	Super Baflux	8	4 3/4		2-26	▼	yes	no	yes
Edison Price	Super Lenslux	8	4 3/4		2-26	■	yes	no	yes

NS = not supplied
1 in. = 2.54 cm
[a] Enclosure: ●=open cone; ★=baffle; ■=lens/diffuser; ◗=lens+baffle; ▼=louver; ◆=decorative glass. Not every enclosure is available with every lamp type.
[b] IC option is only available for downlight with two CFQ13W lamps.

Table 4 (continued). Manufacturer-Supplied Information: Round Downlights for Horizontal Lamps

Manufacturer	Trade Name	Aperture (in.)	Height (in.)	Lamp Type(s) (Number-W) CFT	CFQ	Enclosure(s)[a]	Electronic Ballast Option	IC Option	Venting
Halo	Quick-Ship	5 3/8	5 15/16	2-13	2-28	● ★ ■	no	NS	no
Halo	NS	5 11/16	6 1/4	2-9		● ★	no	NS	yes
Halo	Architectural	7 3/8	6 5/8		2-18, 2-26	● ★	no	NS	yes
Halo	Architectural	7 3/8	7 5/8	2-13		● ★	no	NS	yes
Indy	NS	6	5 3/8		1-13, 2-13, 1-18, 2-18, 1-26, 2-26	● ★ ■ ◗ ▼	yes	no	yes
Indy	NS	7 3/8	6 5/8	1-13, 2-13	1-18, 2-18, 1-26, 2-26	● ★ ■ ◗ ▼ ◆	yes	no	yes
Indy	NS	8 9/16	6 5/8	1-13, 2-13	1-18, 2-18, 1-26, 2-26	●	yes	no	yes
Juno	Down-Lites	6	5 3/8	2-9	2-13	● ★ ■	yes	no	yes
Juno	Down-Lites	6 5/8	7 1/2	2-9		● ★	no	yes	yes
Juno	Down-Lites	7 1/2	6 3/8	2-9, 2-13	2-18, 2-26	● ★ ■	yes	no	yes
Kurt Versen	Quadlite	5 7/8	5		2-13	●	no	no	yes
Kurt Versen	Quadlite	5 7/8	5 1/2		1-18	●	no	no	yes
Kurt Versen	Twinlite CB	7 1/4	3 3/4	2-9, 2-13		▼	no	no	no
Kurt Versen	Quadlite	7 1/4	7 1/2		1-18, 1-26	●	no	no	yes
Kurt Versen	Quadlite CB	8 3/8	4 7/8		2-18, 2-26	▼	no	no	no
Kurt Versen	Quadlite	8 3/8	7 3/4		2-18, 2-26	●	no	no	yes
Lightolier	Calculite	6	6	2-9	1-13, 2-13	● ★	yes	no	yes
Lightolier	Lytecaster	6 3/4	3 7/8	2-13		● ★ ■ ▼ ◆	no	yes	no
Lightolier	Calculite	7	3 1/2	2-9		▼	yes	no	no
Lightolier	Calculite	7	5 1/4	2-9		●	yes	no	no
Lightolier	Calculite	7 3/16	5 3/4	2-13	1-18, 2-18, 2-26	■	yes	no	yes
Lightolier	Calculite	7 3/8	6 7/8		1-18, 2-18, 1-26, 2-26	● ★	yes	no	yes
Lightolier	Calculite	7 3/8	7 1/4	1-13, 2-13		● ★	yes	no	yes
Lightolier	Calculite	8	3 1/2	2-13		▼	yes	no	no
Lightolier	Calculite	8	5 1/4	2-13		●	yes	no	no
Lightolier	Calculite	8	5 1/2	2-13		●	yes	no	yes
Lightolier	Calculite	8	6 3/8		2-18, 2-26	▼	yes	no	no
Lightolier	Calculite	8 1/2	5 1/8	2-13	2-18, 2-26	▼	yes	no	yes

NS = not supplied
1 in. = 2.54 cm

[a] Enclosure: ●=open cone; ★=baffle; ■=lens/diffuser; ◗=lens+baffle; ▼=louver; ◆=decorative glass. Not every enclosure is available with every lamp type.

[b] IC option is only available for downlight with two CFQ13W lamps.

Table 4 (continued). Manufacturer-Supplied Information: Round Downlights for Horizontal Lamps

Manufacturer	Trade Name	Aperture (in.)	Height (in.)	Lamp Type(s) (Number-W) CFT	CFQ	Enclosure(s)[a]	Electronic Ballast Option	IC Option	Venting
Lightron	Series 206	5 7/8	4 5/8	2-9	2-13	●	yes	no	no
Lightron	Series 208	7 3/4	6 3/4	2-9, 2-13	2-18, 2-26	●	yes	no	yes
Omega	Specmaster	7	7 1/4		1-18, 1-26	●	yes	no	no
Omega	Pararound	8 1/8	3 1/2	2-13		▼	yes	no	no
Omega	Architectural	7 7/8	8 3/8		2-18, 2-26	● ★	yes	no	yes
Omega	Architectural	8	8 1/8	2-9, 2-13		● ★	yes	no	yes
Omega	Pararound	8 1/8	4	2-13	2-26	▼	yes	no	yes
Prescolite	NS	5 3/4	5 13/16	2-9, 2-13	2-18, 2-26	● ★	yes	no	yes
Prescolite	NS	7 3/4	3 3/4	2-9, 2-13		▼	yes	no	yes
Prescolite	NS	7 3/4	4 3/8		2-18, 2-26	▼	yes	no	yes
Prescolite	NS	7 3/4	6 11/16	2-9, 2-13		● ★	yes	no	yes
Prescolite	NS	7 3/4	7 9/16		2-18, 2-26	● ★	yes	no	yes
Prescolite	NS	9 5/16	8 1/2	2-13		● ★	yes	no	yes
Prescolite	NS	9 5/16	9 5/8		2-18, 2-26	● ★	yes	no	yes
Prescolite	NS	10	4 5/8	2-13	2-18, 2-26	■	yes	no	no
Prescolite	Intelect	10	4 5/8	2-13	2-18, 2-26	■	yes[c]	no	no
Staff	ESD	5 5/16	5 3/16	2-9		● ★ ■ ◆	no	NS	no
Staff	NS	6	6 3/4	2-9, 2-13	1-18, 1-26	● ■ ◆	no	NS	yes
Staff	V-Alu-Quad	6	6 3/4		2-13, 2-18	● ■ ◆	yes	NS	yes
Staff	NS	7 1/8	7 1/4		1-18, 1-26	●	yes	NS	yes
Staff	ESD	7 1/8	5 11/16	2-9, 2-13		● ■ ◆	no	NS	yes
Staff	Poly-Quad	7 1/8	6 1/2		2-13, 2-18	● ▼ ◆	yes	NS	no
Staff	NS	7 1/2	7 3/4	2-9, 2-13		● ■	no	NS	yes
Staff	SPD	7 1/2	3 1/8	2-9, 2-13		▼	no	NS	no
Staff	SPD	7 1/2	4 7/8		2-18, 2-26	▼	yes	NS	no
Staff	V-Alu-Quad	7 1/2	7 3/4		2-13, 2-18, 2-26	● ■ ◆	yes	NS	yes
Staff	ESD	8 5/8	7	2-9, 2-13		● ■ ◆	no	NS	yes

NS = not supplied

1 in. = 2.54 cm

[a] Enclosure: ●=open cone; ★=baffle; ■=lens/diffuser; ◗=lens+baffle; ▼=louver; ◆=decorative glass. Not every enclosure is available with every lamp type.

[b] IC option is only available for downlight with two CFQ13W lamps.

[c] Only available with electronic ballast.

Table 4 (continued). Manufacturer-Supplied Information: Round Downlights for Horizontal Lamps

Manufacturer	Trade Name	Aperture (in.)	Height (in.)	Lamp Type(s) (Number-W) CFT	Lamp Type(s) (Number-W) CFQ	Enclosure(s)[a]	Electronic Ballast Option	IC Option	Venting
Staff	Poly-Quad	8 5/8	7 1/8		2-18, 2-26	● ◆	yes	NS	no
Staff	NS	9	5 5/8		2-18, 2-26	▼	yes	NS	no
Staff	NS	9	8 5/8	2-9, 2-13		● ■ ◆	no	NS	no
Staff	V-Alu-Quad	9	8 5/8		2-18, 2-26	● ■ ◆	yes	NS	yes
Staff	NS	12	4 3/8	2-9, 2-13	2-13, 2-18, 2-26	■	yes	NS	no
Wila	Downlite	6	6 1/8		1-10, 2-10	● ■ ▼ ◆	yes	no	no
Wila	Downlite	7	6 7/8		1-13, 2-13	● ■ ▼ ◆	yes	no	no
Wila	Downlite	10	9 1/16		2-18, 3-18, 2-26, 3-26	● ■ ▼ ◆	yes	no	no
Wila	Flatlite	10	6		2-18, 3-18, 2-26, 3-26	● ■ ▼ ◆	yes	no	no
Wila	Louvrelite	10	6		2-18, 3-18, 2-26, 3-26	▼	yes	no	no
Zumtobel	OPTOS	6 1/4	6 5/8		2-13, 1-18, 2-18	● ◆	yes	no	no
Zumtobel	OPTOS	7 7/8	6 5/8		2-13, 1-18, 2-18, 1-26, 2-26	● ◆	yes	no	no
Zumtobel	OPTOS	7 7/8	6 5/8		1-18, 1-26	▼	yes	no	no

NS = not supplied
1 in. = 2.54 cm
a Enclosure: ●=open cone; ★=baffle; ■=lens/diffuser; ◗=lens+baffle; ▼=louver; ◆=decorative glass. Not every enclosure is available with every lamp type.
b IC option is only available for downlight with two CFQ13W lamps.
c Only available with electronic ballast.

Table 5. Manufacturer-Supplied Information: Round Downlights for Vertical Lamps

Manufacturer	Trade Name	Aperture (in.)	Height (in.)	Lamp Type(s) (Number-W) CFQ	Lamp Type(s) (Number-W) CFM	Enclosure(s)[a]	Electronic Ballast Option	IC Option	Venting
Capri	Pacesetter	$5^{1}/_{2}$	$7^{3}/_{4}$	1-13		● ★ ■	yes	yes	no
Delray	NS	$5^{7}/_{8}$	$10^{9}/_{16}$	1-18		● ★	yes	NS	no
Delray	NS	$5^{7}/_{8}$	$11^{1}/_{2}$	1-26		● ★	yes	NS	no
Delray	Retrofit	$5^{7}/_{8}$	$10^{9}/_{16}$	1-18		● ★	yes	NS	no
Delray	Retrofit	$5^{7}/_{8}$	$11^{1}/_{2}$	1-26		● ★	yes	NS	no
Delray	NS	$6^{1}/_{2}$	$10^{9}/_{16}$	1-18, 1-26		● ★ ◗	yes	NS	no
Delray	Retrofit	$6^{1}/_{2}$	$10^{9}/_{16}$	1-18, 1-26		● ★ ◗	yes	NS	no
Edison Price	Darklight	7	$10^{5}/_{16}$	1-18		●	yes	no	no
Edison Price	Darklight	8	$11^{5}/_{16}$	1-26		●	yes	no	no
Halo	Quick-Ship	$6^{5}/_{16}$	$8^{1}/_{8}$	1-22		● ★	no	NS	no
Halo	Quick-Ship	7	$10^{3}/_{8}$	1-28		● ★	no	NS	no
Indy	NS	6	9	1-13, 1-18		● ★	yes	no	yes
Indy	NS	$7^{3}/_{8}$	$10^{1}/_{8}$	1-13, 1-18 1-26	1-26, 1-32 1-42	● ★	yes	no	yes
Juno	Down-Lites	6	$7^{1}/_{4}$	1-13	1-18	● ★ ■	no	yes	no
Juno	Down-Lites	6	$10^{1}/_{2}$	1-26		● ★	yes	no	no
Juno	Down-Lites	$6^{5}/_{8}$	$5^{3}/_{4}$	1-13		■	no	yes	no
Juno	Down-Lites	$7^{1}/_{2}$	$10^{1}/_{8}$		1-26, 1-32	● ★	yes	no	no
Kurt Versen	Quadlite	$5^{7}/_{8}$	12	1-18, 1-26		●	no	no	no
Kurt Versen	Quadlite	$7^{1}/_{4}$	12	1-18, 1-26		●	no	no	no
Lightolier	Calculite	$4^{5}/_{16}$	$7^{1}/_{2}$	1-13		●	yes	no	no
Lightolier	Lytecaster	5	$6^{3}/_{4}$[b]	1-13		● ★ ■ ◆ ✕	no	yes	no
Lightolier	Calculite	6	$8^{1}/_{4}$	1-13		●	yes	no	no
Lightolier	Lytecaster	$6^{3}/_{4}$	$7^{3}/_{16}$[b]	1-13, 2-13		● ★ ■ ▼ ◆	no	yes	no
Lightolier	Calculite	$7^{3}/_{8}$	$10^{1}/_{2}$	1-18		●	yes	no	no
Lightolier	Calculite	$8^{3}/_{4}$	$11^{3}/_{4}$	1-26		●	yes	no	no
Lightron	Series 802	$7^{3}/_{4}$	$10^{3}/_{4}$		1-26, 1-32, 1-42	●	yes	no	no

NS = not supplied
1 in. = 2.54 cm

a Enclosure: ●=open cone; ★=baffle; ■=lens/diffuser; ◗=lens+baffle; ▼=louver; ◆=decorative glass; ✕=pinhole.
Not every enclosure is available with every lamp type.

b This height is for an open enclosure. Other enclosures may change the height.

Table 5 (continued). Manufacturer-Supplied Information: Round Downlights for Vertical Lamps

Manufacturer	Trade Name	Aperture (in.)	Height (in.)	Lamp Type(s) (Number-W) CFQ	CFM	Enclosure(s)[a]	Electronic Ballast Option	IC Option	Venting
Omega	Architectural	4 1/2	8 1/4	1-13		●	yes	no	no
Omega	Architectural	5 1/2	9 5/8	1-13		●	yes	no	no
Omega	Specmaster	7	12 3/8	1-18, 1-26	1-26, 1-32	●	yes	no	no
Prescolite	Intelect	5 3/4	10 9/16		1-26, 1-32	● ★	yes[c]	no	no
Prescolite	Intelect	7 3/4	11 15/16		1-26, 1-32	● ★	yes[c]	no	no
Prescolite	NS	7 3/4	11 25/32	1-18, 1-26		● ★	yes	no	no
Prescolite	Dual Reflector	7 3/4	12	1-18, 1-26		●	yes	no	no
Staff	NS	6 1/8	12 1/2	1-18, 1-26		● ◆	no	NS	no
Wila	Downlite	6	8 1/16	1-13, 1-18		● ■ ▼ ◆	yes	no	no
Wila	Downlite	7	9 7/16	1-18, 1-26		● ■ ▼ ◆	yes	no	no

NS = not supplied
1 in. = 2.54 cm
a Enclosure: ●=open cone; ★=baffle; ■=lens/diffuser; ◗=lens+baffle; ▼=louver; ◆=decorative glass; ✕=pinhole. Not every enclosure is available with every lamp type.
b This height is for an open enclosure. Other enclosures may change the height.
c Only available with electronic ballast.

Table 6. NLPIP's Application Analysis: Corridor Using Horizontal-Lamp Downlights

Manufacturer	Catalog Number	Lamp Used	Aperture (in.)	Additional Optical Control	Luminaire Efficiency[a] (%)	E_{avg} (fc)	E_{P1} (fc)	E_{P2} (fc)	E_{P1}/E_{P2}
Base case									
Kurt Versen	C7321	1-100A19	5 7/8	none	72.7	19	20	20	1.0
Apertures smaller than 6 in.									
Halo	H800-810C	2-CFT13W	5 5/8	none	59.8	13	14	14	1.0
Juno	PL807H-863C	2-CFQ13W	5 1/2	none	52.6	12	11	12	0.93
Kurt Versen	P622	2-CFQ13W	5 7/8	none	50.1	11	11	12	0.95
Lightron	206-13-CL-120V	2-CFQ13W	5 7/8	none	54.4	12	12	14	0.85
Prescolite	CFR613-372	2-CFT13W	5 3/4	none	54.3	13	12	14	0.92
Apertures between 6 and 7 in.									
Capri	PL17/120-T442	2-CFQ13W	6	none	53.9	11	11	12	1.0
Juno	PL809-844C	2-CFT13W	6 3/4	none	62.4	15	15	16	1.0

1 in. = 2.54 cm
1 fc = 10.76 lx
NLPIP's calculations are rounded to two significant figures.
Except where indicated, all downlights in this table are round.
a The source of all efficiency data is the manufacturer's own testing lab, except for the base-case downlight and products from Edison Price, Lightron, and Staff, whose efficiency data comes from Independent Testing Laboratories in Boulder, CO.

Table 6 (continued). NLPIP's Application Analysis: Corridor Using Horizontal-Lamp Downlights

Manufacturer	Catalog Number	Lamp Used	Aperture (in.)	Additional Optical Control	Luminaire Efficiency[a] (%)	E_{avg} (fc)	E_{P1} (fc)	E_{P2} (fc)	E_{P1}/E_{P2}
Apertures between 6 and 7 in. (continued)									
Kurt Versen	P682	2-CFQ13W	6 1/4[b]	none	41.2	11	11	13	0.89
Lightolier	8052CL/6213N120	2-CFQ13W	6	none	53.8	12	12	13	0.94
Lightolier	1110/1102D1	2-CFQ13W	6 1/4	none	52.2	11	11	11	1.0
Lightolier	1113/1102D1	2-CFQ13W	6 1/4	none	55.7	12	11	12	0.92
Lightolier	1113TCL/1102T1	2-CFT13W	6 3/8	none	54.0	12	12	12	1.0
Lightolier	1144/1102D1	2-CFQ13W	6 9/16	none	61.0	13	12	13	0.92
Lightolier	1146/1102D1	2-CFQ13W	6 9/16	none	65.5	14	14	15	1.0
Staff	760-81CL	2-CFQ13W	6	none	48.0	12	12	13	0.92
Apertures between 7 and 8 in.									
Capri	PL26/120-T462	2-CFT13W	7 1/2	none	66.0	15	14	15	0.94
Halo	H7891-9840C	2-CFT13W	7 3/8	none	67.4	16	16	15	1.1
Kurt Versen	P337CB	2-CFT13W	7 1/4	louvers	52.3	14	14	15	0.92
Kurt Versen	P632	1-CFQ26W	7 1/4	none	50.2	12	12	13	1.0
Lightolier	8055CL/7213HM120	2-CFT13W	7 3/8	none	64.8	15	14	16	0.90
Lightolier	8065CL/7126HM120	1-CFQ26W	7 3/8	none	68.2	16	15	18	0.86
Lightron	208-13-CL-120V	2-CFT13W	7 3/4	none	52.0	12	12	14	0.86
Omega	C4582V1-4582RC	2-CFT13W	7 1/8	louvers	55.3	14	15	16	0.94
Prescolite	CFR813-572	2-CFT13W	7 3/4	none	78.1	18	18	20	0.91
Prescolite	CFRCB813-CB8CL	2-CFT13W	7 3/4	louvers	60.0	15	14	17	0.85
Staff	780-28PCL/WH-NP-1	2-CFT13W	7 1/8	none	70.3	17	17	17	1.0
Staff	780-70CL	2-CFQ13W	7 1/8	none	63.6	14	15	16	1.0
Staff	713/HP-1/808CL	2-CFT13W	7 1/2	louvers	51.0	13	14	14	1.0
Staff	780-723CL-HP-1	2-CFT13W	7 1/2	none	66.5	17	16	18	0.93
Staff	780-80CL	2-CFQ13W	7 1/2	none	54.7	13	13	14	0.91
Wila	12611-7-2X13-S-SA	2-CFQ13W	7	none	57.4	13	12	13	0.88
Wila	12611-7-2X13-S-SA-ALS7	2-CFQ13W	7	louvers	42.5	9.9	8.9	11	0.84
Wila	12611-7-2X13-S-SA-ALW7	2-CFQ13W	7	louvers	37.2	8.0	7.3	8.7	0.85
Apertures between 8 and 9 in.									
Edison Price	SIMPLUX/8 120 COL	2-CFT13W	8	none	72.1	16	16	16	1.0
Edison Price	BAFLUX/8 120 COL	2-CFT13W	8	louvers	58.3	14	14	15	0.94

1 in. = 2.54 cm
1 fc = 10.76 lx
NLPIP's calculations are rounded to two significant figures.
Except where indicated, all downlights in this table are round.

[a] The source of all efficiency data is the manufacturer's own testing lab, except for the base-case downlight and products from Edison Price, Lightron, and Staff, whose efficiency data comes from Independent Testing Laboratories in Boulder, CO.

[b] This is a square downlight.

Table 6 (continued). NLPIP's Application Analysis: Corridor Using Horizontal-Lamp Downlights

Manufacturer	Catalog Number	Lamp Used	Aperture (in.)	Additional Optical Control	Luminaire Efficiency[a] (%)	E_{avg} (fc)	E_{P1} (fc)	E_{P2} (fc)	E_{P1}/E_{P2}
Apertures between 8 and 9 in. (continued)									
Lightolier	46520Z6/46520ZC	2-CFT13W	8	louvers	57.3	14	13	15	0.92
Lightolier	46522Z6/46522ZC	2-CFT13W	8	none	59.3	14	13	15	0.89
Omega	EY5082V1-5081RC	2-CFT13W	8	none	71.2	15	15	15	1.0
Omega	C5582V1-5582RC	2-CFT13W	8 1/8	louvers	64.3	16	17	18	0.93
Staff	710-26PCL/WH-NP-1	2-CFT13W	8 5/8	none	74.7	19	19	21	0.93
Apertures of 9 in. and larger									
Capri	PLS16/120-S54	2-CFT13W	10 1/4[b]	louvers	37.5	8.9	9.2	9.4	1.0
Prescolite	CFR10-672	2-CFT13W	9 5/16	none	85.1	20	19	23	0.84
Staff	710-923CL-HP-1	2-CFT13W	9	none	72.4	19	18	20	0.90

1 in. = 2.54 cm
1 fc = 10.76 lx
NLPIP's calculations are rounded to two significant figures.
Except where indicated, all downlights in this table are round.
[a] The source of all efficiency data is the manufacturer's own testing lab, except for the base-case downlight and products from Edison Price, Lightron, and Staff, whose efficiency data comes from Independent Testing Laboratories in Boulder, CO.
[b] This is a square downlight.

Table 7. NLPIP'S Application Analysis: Corridor Using Vertical-Lamp Downlights

Manufacturer	Catalog Number	Lamp Used	Aperture (in.)	Additional Optical Control	Luminaire Efficiency[a] (%)	E_{avg} (fc)	E_{P1} (fc)	E_{P2} (fc)	E_{P1}/E_{P2}
Base case									
Kurt Versen	C7321	1-100A19	5 7/8	none	72.7	19	20	19	1.0
All apertures									
Edison Price	DTT26/8 120 COL	1-CFQ26W	8	none	67.4	17	23	17	1.3
Kurt Versen	P626	1-CFQ26W	5 7/8	none	48.5	12	14	13	1.1
Kurt Versen	P672	1-CFQ26W	7 1/4	none	55.4	14	15	14	1.1
Lightolier	8060CL/8123	1-CFQ26W	8 3/4	none	62.3	17	23	17	1.4
Prescolite	CF122526-462	1-CFQ26W	7 3/4	none	67.5	16	21	16	1.3
Prescolite	CFV26-892	1-CFQ26W	7 3/4	none	50.4	14	17	14	1.3
Staff	760-23CL	1-CFQ26W	6 1/8	none	37.5	11	14	12	1.2
Wila	12127-7-1X26-S-SA	1-CFQ26W	7	none	68.5	17	20	17	1.2
Wila	12127-7-1X26-S-SA-ALS7	1-CFQ26W	7	louvers	51.4	13	15	13	1.2
Wila	12127-7-1X26-S-SA-ALW7	1-CFQ26W	7	louvers	49.1	12	14	12	1.2

1 in. = 2.54 cm
1 fc = 10.76 lx
NLPIP's calculations are rounded to two significant figures.
All downlights in this table are round.
[a] The source of all efficiency data is the manufacturer's own testing lab, except for the base-case downlight and products from Edison Price and Staff, whose efficiency data comes from Independent Testing Laboratories in Boulder, CO.

Table 8. NLPIP's Application Analysis: Conference Room (7x5 layout using horizontal-lamp downlights)

Manufacturer	Catalog Number	Lamp Used	Aperture (in.)	Additional Optical Control	Luminaire Efficiency[a] (%)	E_{avg} (fc)	E_{P1} (fc)	E_{P2} (fc)	E_{P1}/E_{P2}	VCP
Base case										
Kurt Versen	C7321	1-100A19	5 7/8	none	72.7	32	29	33	0.90	86
Apertures smaller than 6 in.										
Halo	H800-810C	2-CFT13W	5 5/8	none	59.8	27	28	26	1.1	37
Juno	PL807H-863C	2-CFQ13W	5 1/2	none	52.6	24	24	25	1.0	42
Kurt Versen	P622	2-CFQ13W	5 7/8	none	50.1	22	20	22	0.91	41
Lightron	206-13-CL-120V	2-CFQ13W	5 7/8	none	54.4	23	23	23	1.0	22
Prescolite	CFR613-372	2-CFT13W	5 3/4	none	54.3	24	24	24	1.0	18
Apertures between 6 and 7 in.										
Capri	PL17/120-T442	2-CFQ13W	6	none	53.9	24	22	24	0.93	37
Juno	PL809-844C	2-CFT13W	6 3/4	none	62.4	28	24	31	0.78	18
Kurt Versen	P682	2-CFQ13W	6 1/4[b]	none	41.2	18	16	16	1.0	64
Lightolier	8052CL/6213N120	2-CFQ13W	6	none	53.8	24	24	24	1.0	42
Lightolier	1110/1102D1	2-CFQ13W	6 1/4	none	52.2	22	21	23	0.94	46
Lightolier	1113/1102D1	2-CFQ13W	6 1/4	none	55.7	24	22	24	0.89	47
Lightolier	1113TCL/1102T1	2-CFT13W	6 3/8	none	54.0	24	24	24	1.0	42
Lightolier	1144/1102D1	2-CFQ13W	6 9/16	none	61.0	26	24	26	0.94	42
Lightolier	1146/1102D1	2-CFQ13W	6 9/16	none	65.5	28	26	29	0.90	52
Staff	760-81CL	2-CFQ13W	6	none	48.0	21	18	22	0.82	59
Apertures between 7 and 8 in.										
Capri	PL26/120-T462	2-CFT13W	7 1/2	none	66.0	30	30	29	1.0	50
Halo	H7891-9840C	2-CFT13W	7 3/8	none	67.4	31	27	35	0.77	73
Kurt Versen	P337CB	2-CFT13W	7 1/4	louvers	52.3	23	22	23	1.0	70
Kurt Versen	P632	1-CFQ26W	7 1/4	none	50.2	22	22	22	1.0	27
Lightolier	8055CL/7213HM120	2-CFT13W	7 3/8	none	64.8	29	28	29	1.0	51
Lightolier	8065CL/7126HM120	1-CFQ26W	7 3/8	none	68.2	30	28	29	1.0	46
Lightron	208-13-CL-120V	2-CFT13W	7 3/4	none	52.0	23	23	23	1.0	40
Omega	C4582V1-4582RC	2-CFT13W	7 1/8	louvers	55.3	25	24	24	1.0	66
Prescolite	CFR813-572	2-CFT13W	7 3/4	none	78.1	35	34	35	1.0	37
Prescolite	CFRCB813-CB8CL	2-CFT13W	7 3/4	louvers	60.0	27	24	29	0.83	45

1 in. = 2.54 cm
1 fc = 10.76 lx
NLPIP's calculations are rounded to two significant figures.
Except where indicated, all downlights in this table are round.

[a] The source of all efficiency data is the manufacturer's own testing lab, except for the base-case downlight and products from Edison Price, Lightron, and Staff, whose efficiency data comes from Independent Testing Laboratories in Boulder, CO.

[b] This is a square downlight

Table 8 (continued). NLPIP's Application Analysis: Conference Room (7x5 layout using horizontal-lamp downlights)

Manufacturer	Catalog Number	Lamp Used	Aperture (in.)	Additional Optical Control	Luminaire Efficiency[a] (%)	E_{avg} (fc)	E_{P1} (fc)	E_{P2} (fc)	E_{P1}/E_{P2}	VCP
Apertures between 7 and 8 in. (continued)										
Staff	780-28PCL/WH-NP-1	2-CFT13W	7 1/8	none	70.3	32	28	36	0.77	60
Staff	780-70CL	2-CFQ13W	7 1/8	none	63.6	27	28	26	1.1	48
Staff	713/HP-1/808CL	2-CFT13W	7 1/2	louvers	51.0	23	21	24	0.88	81
Staff	780-723CL-HP-1	2-CFT13W	7 1/2	none	66.5	30	26	32	0.79	50
Staff	780-80CL	2-CFQ13W	7 1/2	none	54.7	24	21	24	0.86	54
Wila	12611-7-2X13-S-SA	2-CFQ13W	7	none	57.4	26	23	27	0.85	46
Wila	12611-7-2X13-S-SA-ALS7	2-CFQ13W	7	louvers	42.5	19	15	20	0.74	66
Wila	12611-7-2X13-S-SA-ALW7	2-CFQ13W	7	louvers	37.2	16	14	16	0.87	30
Apertures between 8 and 9 in.										
Edison Price	SIMPLUX/8 120 COL	2-CFT13W	8	none	72.1	33	30	35	0.86	37
Edison Price	BAFLUX/8 120 COL	2-CFT13W	8	louvers	58.3	26	23	28	0.81	64
Lightolier	46520Z6/46520ZC	2-CFT13W	8	louvers	57.3	26	23	28	0.81	63
Lightolier	46522Z6/46522ZC	2-CFT13W	8	none	59.3	27	25	27	0.92	58
Omega	EY5082V1-5081RC	2-CFT13W	8	none	71.2	32	30	35	0.85	49
Omega	C5582V1-5582RC	2-CFT13W	8 1/8	louvers	64.3	29	28	28	1.0	75
Staff	710-26PCL/WH-NP-1	2-CFT13W	8 5/8	none	74.7	34	26	37	0.70	96
Apertures of 9 in. and larger										
Capri	PLS16/120-S54	2-CFT13W	10 1/4[b]	louvers	37.5	17	19	15	1.3	73
Prescolite	CFR10-672	2-CFT13W	9 5/16	none	85.1	39	37	40	0.93	52
Staff	710-923CL-HP-1	2-CFT13W	9	none	72.4	33	24	39	0.63	90

1 in. = 2.54 cm
1 fc = 10.76 lx
NLPIP's calculations are rounded to two significant figures.
Except where indicated, all downlights in this table are round.

a The source of all efficiency data is the manufacturer's own testing lab, except for the base-case downlight and products from Edison Price, Lightron, and Staff, whose efficiency data comes from Independent Testing Laboratories in Boulder, CO.

b This is a square downlight

Table 9. NLPIP's Application Analysis: Conference Room (7x5 layout using vertical-lamp downlights)

Manufacturer	Catalog Number	Lamp Used	Aperture (in.)	Additional Optical Control	Luminaire Efficiency[a] (%)	E_{avg} (fc)	E_{P1} (fc)	E_{P2} (fc)	E_{P1}/E_{P2}	VCP
Base case										
Kurt Versen	C7321	1-100A19	5 7/8	none	72.7	32	29	33	0.90	86
All apertures										
Edison Price	DTT26/8 120 COL	1-CFQ26W	8	none	67.4	29	43	26	1.7	63
Kurt Versen	P626	1-CFQ26W	5 7/8	none	48.5	21	25	20	1.2	52
Kurt Versen	P672	1-CFQ26W	7 1/4	none	55.4	25	28	23	1.2	62
Lightolier	8060CL/8123	1-CFQ26W	8 3/4	none	62.3	27	41	24	1.7	64
Prescolite	CF122526-462	1-CFQ26W	7 3/4	none	67.5	30	42	27	1.6	46
Prescolite	CFV26-892	1-CFQ26W	7 3/4	none	50.4	22	31	18	1.7	57
Staff	760-23CL	1-CFQ26W	6 1/8	none	37.5	16	23	14	1.6	96
Wila	12127-7-1X26-S-SA	1-CFQ26W	7	none	68.5	30	38	27	1.4	43
Wila	12127-7-1X26-S-SA-ALS7	1-CFQ26W	7	louvers	51.4	22	29	20	1.4	45
Wila	12127-7-1X26-S-SA-ALW7	1-CFQ26W	7	louvers	49.1	21	27	19	1.4	45

1 in. = 2.54 cm
1 fc = 10.76 lx
The spacing in this layout is greater than the maximum recommended spacing for each of the CFL downlights in this table, calculated using the SC.
NLPIP's calculations are rounded to two significant figures.
All downlights in this table are round.
[a] The source of all efficiency data is the manufacturer's own testing lab, except for the base-case downlight and products from Edison Price and Staff, whose efficiency data comes from Independent Testing Laboratories in Boulder, CO.

Table 10. NLPIP's Application Analysis: Conference Room (6x4 layout using horizontal-lamp downlights)

Manufacturer	Catalog Number	Lamp Used	Aperture (in.)	Additional Optical Control	Luminaire Efficiency[a] (%)	E_{avg} (fc)	E_{P1} (fc)	E_{P2} (fc)	E_{P1}/E_{P2}	VCP
Base Case										
Edison Price	A21/6 COL	1-150A21	6	none	67.1	33	34	32	1.1	60
Apertures smaller than 7 in.										
Capri	PL18/120-T442	2-CFQ18W	6	none	53.2	23	22	24	0.90	34
Indy	706R-81-SA	2-CFQ18W	5 1/2	none	51.6	22	21	22	1.0	36
Indy	708R-81-SA	2-CFQ18W	6 3/4	none	59.9	26	23	28	0.83	47
Juno	PL811H-883C	2-CFQ18W	6 3/4	none	59.3	25	23	28	0.81	58
Prescolite	CFR618-372	2-CFQ18W	5 3/4	none	44.7	19	18	20	0.91	25
Staff	760-88CL-HP1	2-CFQ18W	6	none	40.7	17	16	18	0.89	74

1 in. = 2.54 cm
1 fc = 10.76 lx
NLPIP's calculations are rounded to two significant figures.
Except where indicated, all downlights in this table are round.
[a] The source of all efficiency data is the manufacturer's own testing lab, except for the base-case downlight and products from Edison Price, Lightron, and Staff, whose efficiency data comes from Independent Testing Laboratories in Boulder, CO.

Table 10 (continued). NLPIP's Application Analysis: Conference Room (6x4 layout using horizontal-lamp downlights)

Manufacturer	Catalog Number	Lamp Used	Aperture (in.)	Additional Optical Control	Luminaire Efficiency[a] (%)	E_{avg} (fc)	E_{P1} (fc)	E_{P2} (fc)	E_{P1}/E_{P2}	VCP
Apertures between 7 and 8 in.										
Capri	PL28/120-T462	2-CFQ18W	7 1/2	none	58.7	25	25	26	1.0	52
Edison Price	DUPLUX/7 120 COL	2-CFQ18W	7	none	66.1	28	27	28	1.0	14
Edison Price	SB/7 120 COL	2-CFQ18W	7	louvers	41.7	18	18	16	1.1	91
Halo	H7881-9870C	2-CFQ18W	7 3/8	none	62.7	27	25	26	1.0	20
Lightolier	8056CL/7218HM120	2-CFQ18W	7 3/8	none	51.6	22	20	26	0.78	64
Lightron	208-18-CL-120V	2-CFQ18W	7 3/4	none	55.6	24	24	24	1.0	67
Omega	EY5083VI-5083RC	2-CFQ18W	7 7/8	none	55.9	24	22	24	0.94	34
Prescolite	CFR818-492	2-CFQ18W	7 3/4	none	58.8	25	23	28	0.80	100
Staff	780-73CL/WH	2-CFQ18W	7 1/8	none	58.5	25	25	23	1.1	17
Staff	780-78CL/WH-HP-1	2-CFQ18W	7 1/8	louvers	47.1	20	20	20	1.0	46
Staff	780-818CL-HP-1	2-CFQ18W	7 1/2	louvers	42.0	18	18	16	1.1	87
Staff	780-83CL	2-CFQ18W	7 1/2	none	54.8	23	21	24	0.88	58
Apertures between 8 and 11 in.										
Kurt Versen	P641	2-CFQ18W	8 3/8	none	62.6	27	27	26	1.0	48
Staff	710-75CL	2-CFQ18W	8 5/8	none	67.9	29	29	32	0.92	53
Staff	710-85CL	2-CFQ18W	9	none	65.8	28	22	30	0.74	94
Wila	13007-10-2X18-S-SA	2-CFQ18W	10	none	66.6	29	27	28	1.0	43
Wila	13007-10-2X18-S-SA-ALS10	2-CFQ18W	10	louvers	52.9	22	20	21	1.0	47
Wila	13201-10-2X18-S-SA	2-CFQ18W	10	louvers	54.3	23	19	24	0.79	79
Square downlights with apertures of approximately 1 ft by 1 ft										
Metalux	P3-2BX18S22I-RS	2-CFT18W	12	louvers	62.4	27	25	28	0.89	71
Metalux	P3-2BX18S33I-RS	2-CFT18W	12	louvers	49.6	21	21	22	1.0	79
Omega	H7111-LS4	3-CFT13W	11 1/2	louvers	68.8	32	33	31	1.1	54
Omega	H7111-LS9	3-CFT13W	11 1/2	louvers	57.8	27	28	26	1.1	68
Omega	H7141-LS9	2-CFT18W	11 1/2	louvers	58.5	24	23	25	0.94	73

1 in. = 2.54 cm

1 fc = 10.76 lx

NLPIP's calculations are rounded to two significant figures.

Except where indicated, all downlights in this table are round.

[a] The source of all efficiency data is the manufacturer's own testing lab, except for the base-case downlight and products from Edison Price, Lightron, and Staff, whose efficiency data comes from Independent Testing Laboratories in Boulder, CO.

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