NLPIP
NATIONAL LIGHTING PRODUCT INFORMATION PROGRAM

Specifier Reports

The objective source of lighting product information

CFL Residential Downlights

Insulated Ceiling, Airtight Luminaires

Volume 12 Number 1, January 2008

NLPIP
NATIONAL LIGHTING PRODUCT INFORMATION PROGRAM

Program Sponsors

California Energy Commission

Iowa Energy Center

Lighting Research Center

New York State Energy Research and Development Authority

About NLPIP

The National Lighting Product Information Program (NLPIP) was established in 1990. NLPIP is administered by the Lighting Research Center (LRC), the world's leading university-based center devoted to lighting excellence.

NLPIP's mission is to help lighting specifiers and other lighting decision-makers choose wisely by providing the most complete, up-to-date, objective, manufacturer specific information available on energy-efficient lighting products. Priority is given to information not available or easily accessible from other sources. NLPIP tests lighting products according to accepted industry procedures or, if such procedures are not available or applicable, NLPIP develops interim tests that focus on performance issues important to specifiers or end users.

In 1998, NLPIP Online debuted at www.lrc.rpi.edu/programs/nlpip, making the information provided by NLPIP even more accessible to lighting specifiers and other interested people. NLPIP Online includes PDF files of *Specifier Reports, Lighting Answers, Lighting Diagnostics,* and several searchable databases containing manufacturer-reported data and test results.

To ensure its continued objectivity, NLPIP does not accept funding from manufacturers.

ISSN 1067-2451

NLPIP
NATIONAL LIGHTING PRODUCT INFORMATION PROGRAM
Specifier Reports
Volume 12 Number 1 January 2008

CFL Residential Downlights

Insulated Ceiling, Airtight Luminaires

Contents

Introduction **5**
CFL Downlight Components and Operation **8**
Lamps 9
Apertures 9
Ballasts 9
CFL Downlight Installation **9**
CFL Downlight Performance **10**
Thermal Considerations 10
Light Output 10
Ballast Case Temperature and Life 11
Optical Components 12
Reflector 12
Baffle 12
Lens 12
Efficacy 12
Lamp Light Output 13
Ballast Factor 13
Active Power 13
Luminaire Efficiency 13
Performance Evaluations **14**
Evaluation Methodology 14
NLPIP Testing Procedure 15
Temperature Test Box 15
Temperature Measurements 15
Photometric Measurements 16
Electrical Measurements 17
Results 18
Ballast Case Temperature 18
Light Output 18
Efficacy 19
Pilot Tests 20
Accessories Test 20
Screwbase Lamps Test 22
Further Information **28**
References 28

Introduction

Residential downlights are becoming more common in both new construction and remodeling. Their clean, low-profile appearance and the impression that they provide high-quality lighting appeal to many consumers. Since 1980, the trend in residential new construction and remodeling has been to install recessed downlights as the predominant luminaire. The average number of downlights per home varies widely; some homes have none while others have as many as 100 or more (Banwell and Figueiro 2002). It is commonplace to find as many as 30 to 40 downlights installed in moderate-sized (1800–3000 square feet) new homes, and 80 to 90 installed in larger (3100–5000 square feet) homes. One-third of the downlights in a home are typically installed in the kitchen (Siminovitch and Page 2003).

Luminaires may be categorized in four ways: commodity-grade residential; specification-grade residential; commodity-grade commercial; or specification-grade commercial.

Size, cost, materials, and the information provided by the manufacturer distinguish residential downlights from commercial downlights. Luminaire quality and cost distinguish commodity grade from specification grade. Higher-end residences typically use specification-grade luminaires because they offer more aiming choices than commodity grade, they accept more accessories such as louvers and spread lenses, and they integrate better quality reflector design. Residential environments are assumed to be less harsh than commercial environments; therefore, the materials need not be as rugged, usually resulting in lighter weight and lower cost. Manufacturers provide limited testing and product services for commodity-grade residential luminaires compared to the extensive photometric data and services that are usually available for specification-grade residential as well as commodity- and specification-grade commercial luminaires. Photometric data enable consumers to obtain information about the active power of the lamp and ballast, light distribution, and the efficiency of the luminaire, thus helping them to make educated purchase decisions (NLPIP 1999b).

Considering the claimed higher efficacy and reduced maintenance provided by compact fluorescent lamp (CFL) technology compared to incandescent, CFL downlights are the logical downlight of choice. Yet in 2001, the existence of CFLs in residential buildings accounted for only 2% of all light sources (Navigant 2002), and a study conducted in 2000 showed that only 0.4% of recessed downlights used CFLs (U.S. Census Bureau 2003). Of the 400 million downlights installed in homes today, nearly all use incandescent lamps.

This report presents photometric, electrical, and thermal performance data for selected CFL residential downlights. Lamps using a mogul, medium, or other screw base are not included in this report because they are not eligible to earn ENERGY STAR® approval under version 4.0 of the program's Residential Lighting Fixture Specification. Information on spacing criterion and glare, common to both commercial and residential luminaires, can be found in *Specifier Reports: CFL Downlights* (NLPIP 1995). Information on color, horizontal and vertical illuminance, and total harmonic distortion (THD) can be found in *Specifier Reports: Energy-Efficient Ceiling-Mounted Residential Luminaires* (NLPIP 1999b).

Conventional recessed downlights can waste energy in several ways. Incandescent (A) lamps, reflector (R) lamps, and parabolic aluminized reflector (PAR) lamps require 60–100 watts (W) each at an average efficacy of only 14 lumens per watt (lm/W). Each incandescent lamp has a life of 750–2000 hours (h). A luminaire that is not airtight, allowing conditioned air to migrate or leak into unconditioned spaces such as attics, can contribute to increased heating and cooling costs. The efficacy of CFLs is up to five times that of incandescent lamps—65–80 lm/W. At 10,000–12,000 h, a CFL's life is approximately ten times greater. While CFL downlights theoretically have the potential to save energy over their incandescent counterparts, they have not been well received in residential applications for several reasons. CFL downlights:

- are more expensive than incandescent downlights;
- have had limited availability compared to incandescent downlights;
- have been unreliable due to premature ballast failures;
- have exhibited poor color rendering and poor light output compared to incandescent lamps;
- have been difficult to service because of inaccessible ballasts due to luminaire design;
- are more difficult to dim, requiring additional wiring and components.

When the U.S. Environmental Protection Agency's (US EPA) *Residential Light Fixture Specification Version 4.0* and California's *Title 24 Energy Efficiency Standards* were revised in October 2005, insulated ceiling-rated (IC) and airtight-rated (AT) CFL downlights became the pre-eminent recommendation for energy-efficient residential downlights in insulated ceilings. Important issues for homeowners choosing luminaires are how much light the downlight produces and how often the homeowner will have to replace the lamp. Elevated temperatures also play an important role in light output and ballast reliability. If the ballast fails, the homeowner may face a bigger problem than just lamp replacement. This report addresses those issues and evaluates a sampling of ENERGY STAR-qualified ICAT luminaires (as listed on the ENERGY STAR product list dated February 2006).

What does it mean to be airtight in accordance with ASTM E283?

ASTM Active Standard E283-04 is titled: *Standard Test Method for Determining Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen*. Therefore, ASTM E283 is a window and door leakage measurement standard that was adapted for use with recessed downlights. Since ENERGY STAR 4.0 and Title 24 require fixtures that are IC-rated to also be AT-rated, in order to be certified airtight both ENERGY STAR 4.0 and Title 24 state: "… housing must have leakage less than 2.0 cubic feet per minute (CFM) at 75 pascals (Pa) or 1.57 lb/ft^2 when tested in accordance with ASTM E283 and shall be sealed with a gasket or caulk." Pascal is the International System of Units (SI) unit of pressure or stress. The threshold is set at 2.0 CFM with a fixed pressure of 75 pascal pressure differential across the housing. This equates to a 25 mph wind speed.

The IC rating originated as part of the Washington State code to promote energy-efficient building envelopes. The State of Washington introduced the Reduced Air-Leakage Requirement into the energy codes in 1992 because of concerns of moisture-laden air from conditioned space being introduced into cold attics, thus causing condensation that leads to roof and ceiling damage. A side benefit of the requirement is reduced energy use. Beginning with the 1995 Model Energy Code (which became the International Energy Conservation Code in 1998), subsequent national codes have adopted the requirement (including 39 states as of 2007).

ENERGY STAR

ENERGY STAR-qualified homes are at least 15% more energy efficient than homes built to the 2004 International Residential Code (IRC), a stand-alone residential code that provides minimum regulations for one- and two-family dwellings of three stories or less. The ENERGY STAR label is awarded to a home of three stories or less if it has been verified to meet the US EPA's guidelines for energy efficiency.

Independent Home Energy Raters assist ENERGY STAR builder partners in choosing the most appropriate energy-saving features for their homes. These features include effective insulation, high performance windows, tight construction and ducts, efficient heating and cooling systems, and lighting and appliances. Raters conduct onsite testing and inspection to verify a home's qualification for the ENERGY STAR label.

Updates to the stringent requirements for residential lighting by the US EPA's ENERGY STAR Version 4.0 specification (US EPA 2005) took effect in October 2005. The goal of ENERGY STAR 4.0 is to encourage consumers to use high-quality, energy-efficient technologies. While compliance is voluntary, builders understand that meeting ENERGY STAR specifications signifies a considerably more efficient, quality residence for their customers than a non-ENERGY STAR-qualified home. ENERGY STAR-certified lighting factors into the points needed to achieve an ENERGY STAR home rating. Presently, approximately 3500 builders of new homes in the United States build to ENERGY STAR specifications.

The luminaires must employ dedicated, pin-based lamps using high-efficiency electronic ballasts. Downlights that are rated for insulated ceilings must be approved for zero-clearance insulation contact (IC) by an Occupational Safety and Health Administration (OSHA) Nationally Recognized Testing Laboratory (NRTL); they must be airtight (AT) according to ASTM E283 and sealed with a gasket or caulk (ASTM 2004). The luminaire components also must satisfy minimum efficacy requirements, which consider the lamp-ballast combination.

California's Title 24 Specifications

Unlike ENERGY STAR, compliance with Title 24 is mandatory in the State of California for new construction, remodeling, or any activity requiring a building permit. Updates to the requirements for residential lighting in California's Title 24 Energy Efficiency Standards (CEC 2005) took effect in October 2005, the same time as ENERGY STAR 4.0 specifications.

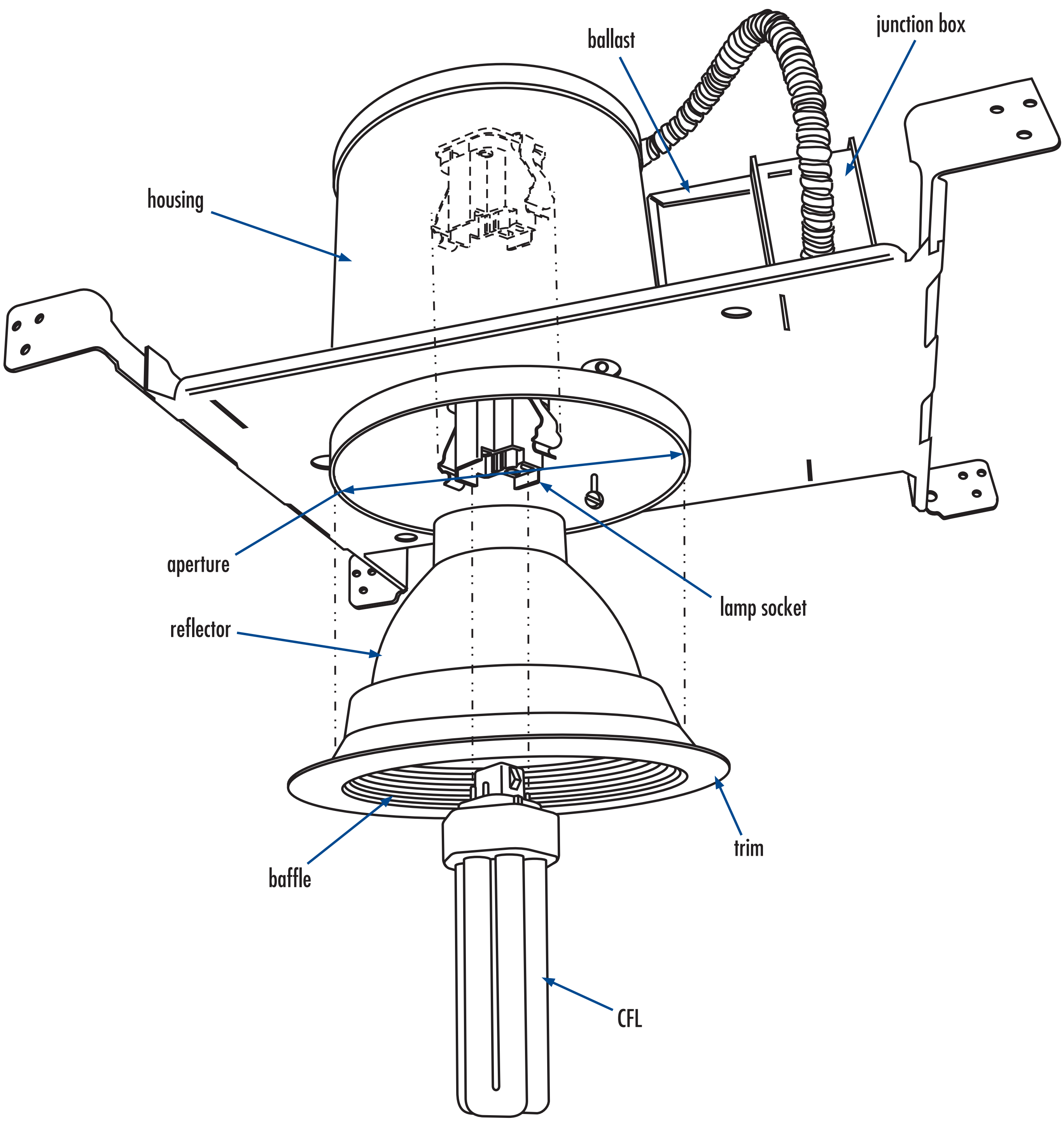
The requirements of Title 24 specifications overlap with ENERGY STAR 4.0 in several areas with regard to recessed CFL downlights. Like ENERGY STAR, the luminaires must employ dedicated, pin-based lamps using high-efficiency electronic ballasts. Downlights that are rated for insulated ceilings must be approved for zero-clearance insulation contact (IC) by an OSHA Nationally Recognized Testing Laboratory; and they must be airtight (AT) according to ASTM E283 and sealed with a gasket or caulk (ASTM 2004). The luminaire components also must satisfy minimum efficacy requirements; however, the Title 24 minimum efficacy requirement only considers the lamp—not the lamp/ballast combination considered by ENERGY STAR 4.0.

CFL Downlight Components and Operation

CFL luminaires may function as fixed downlights, projecting emitted light downward onto a horizontal surface. They are also used as wallwashers, directing their distribution onto vertical surfaces.

Residential CFL downlights are characterized by a variety of components and operating features. Most downlights consist of a housing, lamp socket, CFL, ballast, and junction box for wiring to the electrical circuit (Figure 1). Several trim and performance features may be incorporated into baffles, reflectors, and lenses or diffusers.

Figure 1. Exploded view of a recessed CFL downlight



Lamps

Lamp geometries include twin tube, double-twin tube (quad tube), and triple-twin tube (triple tube) as well as some spiral configurations. Pin-based CFLs are commonly rated at 9, 13, 18, 26, 32, or 42 watts (W). Lamps are available as non-amalgam or amalgam. Non-amalgam lamps are more sensitive to temperature variations, while the more common amalgam lamps are more stable. Lamp performance is discussed in the section "Thermal Considerations" on page 10. The optimal position for light output and color maintenance is vertical base-up. However, horizontal orientation allows for a lower luminaire height, which may help in shallow plenums or places where vertical spacing is at a premium.

Apertures

Apertures can be round or square with nominal aperture diameters of 4, 5, 6, or 7 inches (in.), for round models. The aperture size influences the number of holes needed in the ceiling to provide a desired target illuminance. Larger apertures will accommodate larger lamp sizes and larger "pools" of light.

Ballasts

Ballasts have transitioned from the former core-and-coil magnetic type, which were heavier and noisier (humming), to the newer electronic type, which are lighter and quieter. Electronic ballasts are more energy efficient than magnetic ballasts because they operate at higher frequencies and have lower heating (I^2R) losses.

Depending on the type of ballast used, some luminaires can be dimmed. Ballasts dim fluorescent lamps by reducing the lamp current, and therefore save energy (and reduce energy costs). Most dimming ballasts are of the electronic variety, and some products on the market claim to dim reliably to as low as 0.5–2.5% of full light output. The installed costs for these ballasts and their associated control systems are higher than for non-dimming electronic ballasts.

CFL Downlight Installation

Insulated ceilings save energy by minimizing heat loss and heat gain, thus reducing a building's heating and cooling costs. Recessed luminaire housings that are in direct contact with thermal insulation, such as the ceiling of the top floor of a house, must be IC-rated. Non-IC-rated housings can be used away from insulation, such as the first floor ceiling of a two-story home, and basement ceilings. IC-rated housings are typically constructed of single wall aluminum, 0.027–0.040 in. (0.69–1.02 mm) thick, to allow for heat dissipation and to reduce weight. Many are available in both new construction and remodel versions. Remodel, or retrofit, luminaires are typically designed to allow installation through a new or existing ceiling cutout, rather than to the exposed framing of new construction. (Note: This report does not evaluate remodel luminaires.)

While airtight insulated ceiling housings save heating and cooling energy, the energy advantages of CFL downlights may be less than expected because of the impact of heat on CFL performance when enclosed in a luminaire. This is not the case for incandescent downlights.

CFL Downlight Performance

CFL downlights require ballasts, lamps, optics, and mechanical components, which together comprise the overall luminaire system. This system includes thermal, electrical, and optical factors and is affected by the environment in which it operates; all of these factors can affect overall performance. CFL downlight performance can be measured by light output, power, and efficacy.

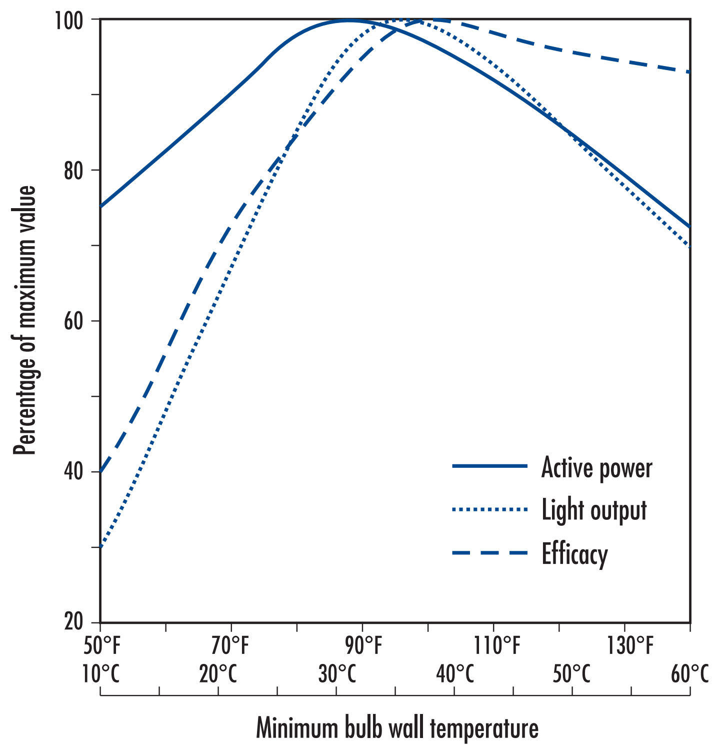
Thermal Considerations

Heat management is particularly important for CFL downlights. Heat can impact the performance of both the lamp and ballast in a downlight. In ICAT-rated luminaires, airflow and heat dissipation are significant issues. Incandescent luminaires do not react adversely to temperature variations; CFLs, on the other hand, are very sensitive to ambient and local temperature fluctuations.

Light Output

CFLs perform best at an optimal ambient temperature of 77 ±2°F (25 ±1°C). Deviation from this temperature can result in reduced light output. Figure 2 shows the change in light output and active power as a function of the lamp's bulb wall temperature, which is affected by ambient temperature. CFLs contain liquid and pellet-dosed mercury that settles at the coldest spot in the lamp. This cold spot controls the light output, power, and efficacy of non-amalgam lamps. Other temperatures result in reduced mercury vapor pressure, which causes reduced light output. Lamp operating position also impacts light output. The mercury settles at a different location, resulting in a different temperature that leads to reduced light output when the lamp is mounted in a position other than base-up.

Figure 2. Typical fluorescent lamp temperature characteristics



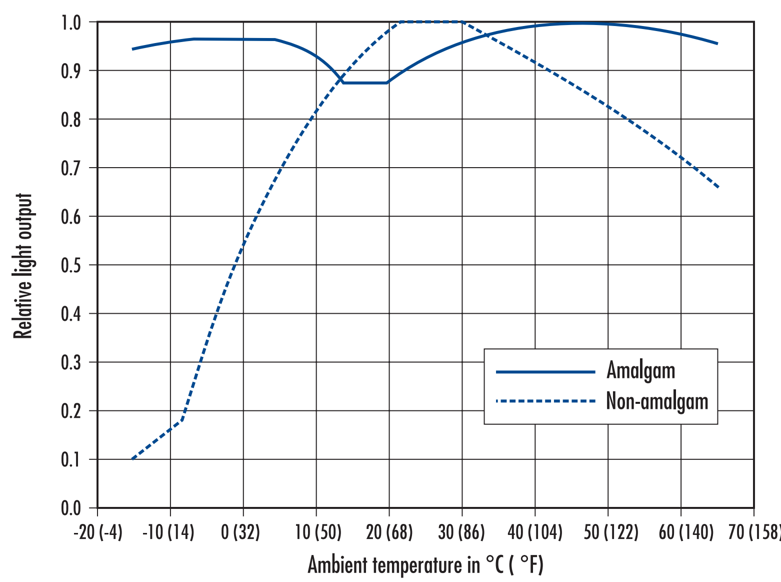
Source: Adapted from *IES Handbook 9th ed.* (Rea 2000)

Exact shape of curves will depend on lamp and ballast type; however, all non-amalgam fluorescent lamps have curves of the same general shape since this depends on mercury vapor pressure.

Amalgam lamps contain a mercury alloy that allows consistent light output over a wide range of temperatures and mitigates differences in light output based on the lamp's operating position. With early amalgam products, the warm-up time was as long as 15 minutes to reach full light output. Using these amalgam lamps in rooms such as the kitchen where frequent switching may occur was not recommended. However, recent amalgam technologies have shown improved warm-up times.

IC-rated recessed luminaires, and to a lesser extent non-IC rated recessed luminaires, may have lower light output due to lamp operation above their optimum temperature range. This occurs especially with non-amalgam lamps 26 W and higher, even though required ballast temperature and UL housing temperature requirements are met. Light output reduction in excess of 50% is possible with non-amalgam CFLs. The loss is typically closer to 20% with premium amalgam lamps (Figure 3).

Figure 3. Comparison of relative light output vs. ambient temperature for two CFL designs in a base-up operating position



Source: Adapted from *IES Handbook 9th ed.* (Rea 2000)

Ballast Case Temperature and Life

Ballast life is usually several times longer than lamp life. Because ballasts are typically affixed to luminaires, their failure can determine the life of the luminaire. When placed inside recessed downlights, the ballast case can reach very high temperatures, not only reducing the life of the capacitor, compromising ballast performance and causing premature luminaire failure, but also posing a fire hazard if the temperature is above the operating limit. Since heat has been found to be the predominant factor in premature ballast failure, and ICAT luminaires are most vulnerable to heat, ENERGY STAR ICAT-rated luminaires are subjected to stringent durability testing procedures. For that reason, the LRC developed durability testing procedures that include ballast case temperatures (LRC 2003); ENERGY STAR implemented these procedures in 2004.

The maximum ballast case operating temperature limit of 194°F (90°C), specified by Underwriters Laboratories (UL) UL 1598, is based on safety rather than ballast performance (UL 2004). To measure ballast case operating temperature for performance, the thermal probe location and the maximum allowable ballast case operating temperatures differ from those required in UL testing. In general, the maximum allowable temperature for performance is lower than UL requirements. Some manufacturers specify a maximum ballast case operating temperature (t_c) to ensure good product performance. Ballast manufacturers are beginning to provide the location of a hot spot on the ballast case where the temperature is measured and must not exceed a maximum recommended temperature.

Optical Components

Luminaire accessories such as reflectors, baffles, and lenses provide optical control and glare reduction.

Reflector

A reflector is a device used to redirect the flux from a light source by the process of reflection. Reflectors can be specular or diffuse. A specular reflector has a highly polished surface, which reflects and redirects the light from the lamps in a generally downward direction, at an angle equal to that of the incoming ray. Diffuse reflectors have a matte surface that reflects light equally in all directions.

Differences in both the apparent color of light and light output may also result from the reflector chosen. Light emitted from a bronze finish reflector will appear different than light emitted from the same lamp in a pewter finish reflector. Clear specular or white reflectors produce higher light output than darker reflectors. Reflector design that allows for a deeply recessed lamp affects both the distribution of light and the resulting cutoff angle, a technique used to reduce glare.

Baffle

A single opaque or translucent element that shields the direct view of a light source at certain angles, a baffle absorbs or blocks unwanted light, or reflects or redirects light. In luminaires, a baffle can either replace the reflector or be an integral part of the reflector component located adjacent to the luminaire aperture.

Lens

A lens controls, or refracts, the distribution of light and offers more precise lighting control than a diffuser. In luminaires, a lens is a glass or plastic element that changes the direction and controls the distribution of light rays. A lens can be clear, frosted, or fresnel, which is a stepped flat lens with a textured back that produces a smooth, soft-edged, defined beam of light. The lens can also act as a diffuser, which reduces intensity and potential glare from the luminaire. Whether a luminaire is lensed or unlensed alters the light output as well as the distribution. For more information, refer to *Specifier Reports: Energy-Efficient Ceiling-Mounted Residential Luminaires* (NLPIP 1999b).

Efficacy

The efficacy (measured in lm/W) of a luminaire is the ratio of the luminaire's light output divided by the active power of the luminaire for a particular lamp-ballast system. The efficacy can be based on actual measurements of the luminaire's light output and active power. Efficacy can also be approximated as follows based on manufacturers' published data for the lamp, ballast, and luminaire.

$$\text{efficacy} = \frac{\text{lamp light output} \times \text{ballast factor} \times \text{luminaire efficiency}}{\text{active power}}$$

The efficacy of the luminaire is always lower than efficacy of the lamp because the luminaire absorbs some light. For fluorescent lamps, efficacy of the luminaire is also affected by the lamp operating position and the ambient temperature near the lamp, which is influenced by the luminaire.

Lamp Light Output

When selecting a downlight, an important consideration is how much light is needed. The light output from the lamp is the starting point. This information can be found on lamp packaging or in manufacturers' catalogs. The light output is determined by standard testing methods with the lamp operated in a base-up position (for single-ended lamps) or a horizontal position (for double-ended lamps). With the lamps operating at 77 ±2°F (25 ±1°C) ambient temperature, measurements are obtained using a reference ballast (except for self-ballasted CFLs). Changes in lamp position and ambient temperature affect lamp light output.

Ballast Factor

The light output of a fluorescent lamp varies, depending on the particular ballast used. Ballast factor is defined as the ratio of a fluorescent lamp's light output (operated by a particular ballast) to the light output of the same lamp operated by a reference ballast. For example, when a 26-W CFL is operated on a reference ballast, its rated light output is 1800 lm. When this lamp is operated on commercial ballast "X," its light output might be 1674 lm. When operated on commercial ballast "Y," its light output might be 1584 lm. Thus, ballast "X" has a ballast factor of 0.93 (1674 lm/1800 lm), and ballast "Y" has a ballast factor of 0.88 (1584 lm/1800 lm). Typical values of ballast factor range from 0.8 to 1.2. Ballast factors outside this range could result in damage to the lamp and result in shorter lamp life.

Active Power

Active power is the input power (measured in W) of the lamp-ballast combination used in the luminaire. The active power is usually reported in ballast catalogs and includes the lamp power and the power of the ballast. Since the lamp power is influenced by the lamp's operating temperature, the active power of the lamp-ballast combination will also be affected by temperature.

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 (Rea 2000). 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 or object. A different measure of luminaire performance, called the "coefficient of utilization," addresses the delivery of light to a specific plane. "Application efficacy" discusses the delivery of light to specific solid angles (see the sidebar, "Application Efficacy," on this page).

Luminaire efficiency is obtained from standard photometry testing, which specifies the use of a goniophotometer in a black room with a 77 ±2°F (25 ±1°C) ambient temperature. To measure luminaire efficiency, the luminaire is first installed in the goniophotometer in the same position that it would occupy in practice. The luminaire's light distribution and total light output are then measured. Next, the lamp or lamps are taken out of the luminaire and installed in the goniophotometer in the same position as inside the luminaire, using the same ballast. Luminaire efficiency is then calculated as the ratio of the total light output from the luminaire to the total light output from the bare lamp(s), expressed as a percentage.

Variations in ambient temperatures may affect the luminaire's light output, and therefore its efficiency. However, the use of an amalgam lamp minimizes this effect. Luminaire efficiency is not usually measured in an elevated temperature environment, which would likely reduce the luminaire efficiency.

Application Efficacy

A successful lighting application must deliver light where it is needed. Light that is absorbed by the luminaire or directed into areas other than where needed is wasted. Application efficacy (AE) measures the effectiveness with which a luminaire delivers light to those locations where it is needed to meet the design objectives. AE is defined for a luminaire, or lamp used as a luminaire, as the average luminous flux within a specific solid angle per unit power. It is measured in lumens (lm) per steradian (sr), or intensity in candelas (cd) per watt (W) (Rea and Bullough 2001).

Performance Evaluations

The goal of NLPIP's evaluation was to gain a better understanding of the effects of an elevated temperature environment on system performance. This section discusses evaluation methods and provides a detailed description of the testing procedures for photometric, electrical, and temperature measurements used for the primary tests, as well as a description of supplementary pilot testing. The goal of the first pilot test (accessories test) was to study the effects on efficacy of the luminaire using different trims, baffles, and lenses. The purpose of the second pilot test (screwbase lamps test) was to study the efficacy of a screwbase ICAT luminaire with different types of lamps installed. The report concludes with a discussion of the evaluation results.

Evaluation Methodology

In February 2006, NLPIP evaluated pin-based compact fluorescent recessed downlights that were qualified under ENERGY STAR 4.0. The products selected were all ICAT-rated downlights and were intended for operation in an elevated temperature environment.

NLPIP tested 13 ICAT luminaires from the ENERGY STAR-qualified products list. While products from all eligible manufacturers were selected, products that were not yet in production were not included in this report. NLPIP purchased two samples of each product through distributors and tested one sample. NLPIP selected ICAT downlight combinations with the most common features available to test for this report. These features included:

- 26-W CFL
- non-dimmable ballast
- nominal 6 in. round aperture
- white reflector and baffle
- new construction-type luminaire
- fixed downlight (no tilt adjustment)

For testing, NLPIP chose a pin-based amalgam CFL that was compatible with all chosen luminaires. An amalgam lamp was selected because the light output of amalgam lamps is more stable with respect to temperature than non-amalgam lamps (Figure 3). After seasoning the lamp for 100 h, NLPIP determined its light output on a reference ballast using an integrating sphere. A second lamp, also seasoned and its light output determined, served as a backup.

Prior to installing the chosen luminaires in their test setups, NLPIP measured ballast case temperatures with each ballast removed from its luminaire and operating a lamp on a test rack. This was accomplished for comparison with ballast case temperatures measured with the luminaires operating in an insulated ceiling test apparatus.

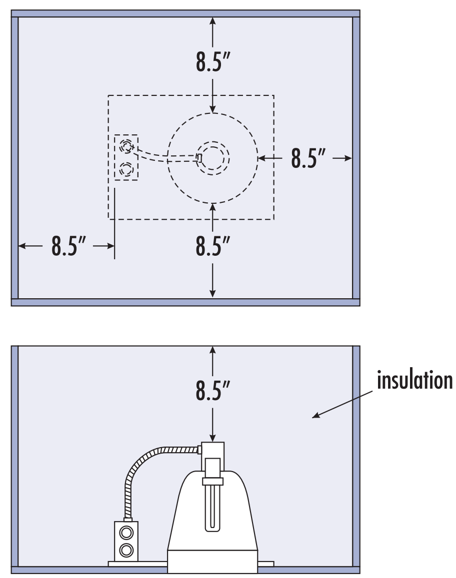
NLPIP Testing Procedure

Temperature Test Box

To provide the thermal environment for testing ICAT luminaires, NLPIP constructed wooden temperature test boxes in accordance with UL 1598 to simulate typical worse-case conditions used by manufacturers for safety testing. This manner of testing standardized the evaluation method for all luminaires.

Figure 4 shows the test box specifications adapted from a diagram in UL 1598. The test boxes were constructed of 0.5-in. (1.3 cm) thick plywood panels with open tops. A hole in the bottom of each test box accommodated the luminaire apertures. The sides of each test box were 8.5 in. (21.6 cm) from the nearest part of each lamp housing or heat producing part. The boxes were filled 8.5 in. (21.6 cm) above the highest point on each luminaire with loose cellulose insulation; no compacting procedure was applied.

Figure 4. Temperature test box detail



Adapted from UL 1598 (UL, 2004)

Temperature Measurements

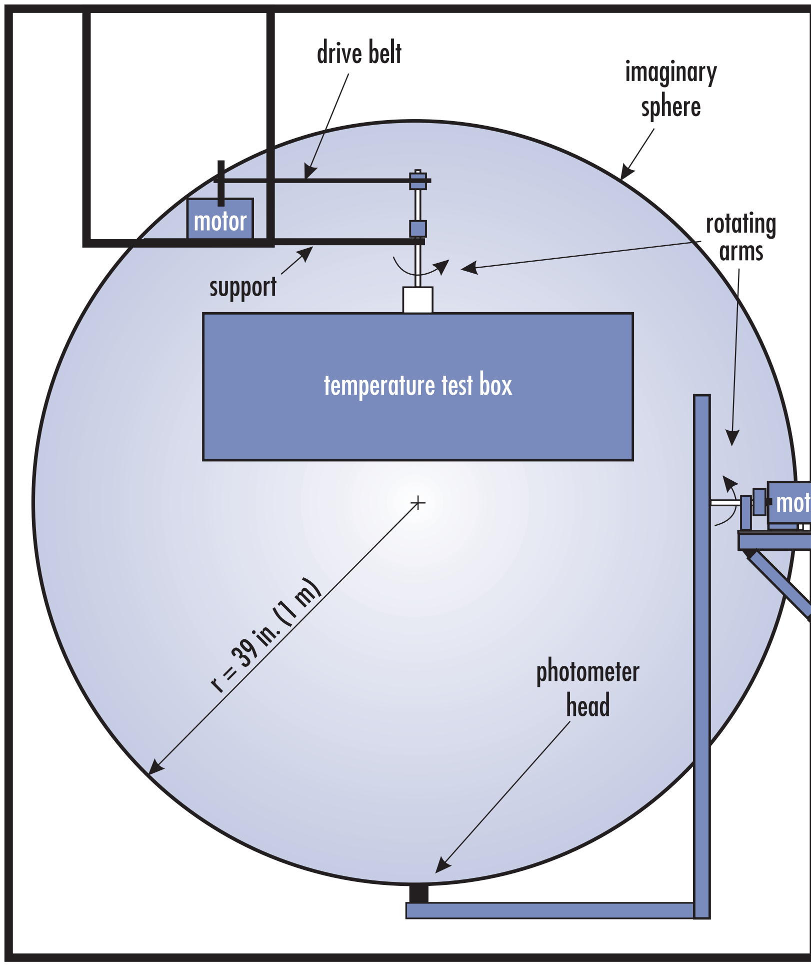
NLPIP measured the ballast case temperature of each luminaire for two conditions: open-air and elevated temperature. The temperature was measured with type J thermocouples affixed to specific locations on each ballast case. In most cases, manufacturers' labels indicated the thermocouple locations. For those ballasts lacking a label location, NLPIP determined the thermocouple location from the appropriate NEMA/ALA ballast matrix (NEMA 2005; 2006a; 2006b). Thermocouples were soldered directly to metal ballast cases or melted into the surface of plastic ballast cases at the specified locations.

Open-air measurements were performed with the ballasts removed from the luminaires and operating bare lamps on a test rack for a minimum of 8 h to allow their temperatures to stabilize. The elevated temperature environment was provided by the test boxes filled with cellulose insulation. The luminaires were installed in the integrating flux meter and operated for a minimum of 8 h to allow for thermal and photometric stabilization. NLPIP recorded the ambient and ballast case temperatures immediately prior to taking the photometric measurements.

Photometric Measurements

In order to measure the light output, or total luminous flux, emitted from the luminaires while installed in their temperature test boxes, NLPIP constructed an integrating flux meter. After the test boxes were operated for 8 h, they were mounted to the center of this apparatus on a rotating post. As shown in Figure 5, a photometer head was attached to the end of a long arm, which rotated around the test boxes. The test box mounting post, photometer arm, and all necessary hardware were mounted to an aluminum framework inside a small room. A computer and controlling electronics were located just outside the room along with the power supply and measurement equipment for the luminaire.

Figure 5. Integrating flux meter



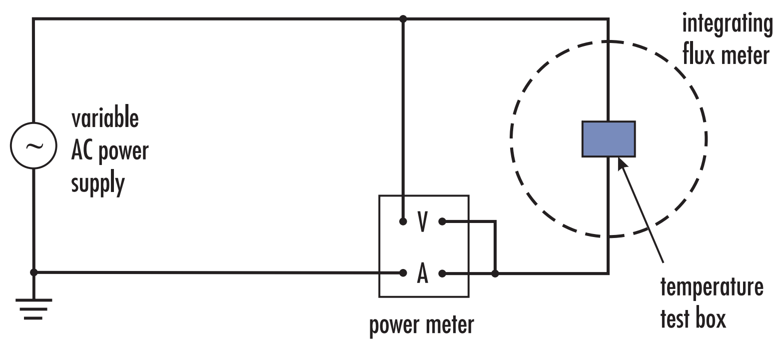
During the test, the arm rotated the photometer head in complete circles around the test box on the surface of an imaginary sphere. At the same time, the vertical support rotated the test box through a complete circle. In this way, the photometer head measured the light output over the entire surface of the imaginary sphere. The photometer head measured the illuminance with a sampling rate of 2000 readings per second. The illuminance measurements were then integrated over the surface area of the sphere to obtain the luminous flux. For a more complete discussion of the principles involved, see CIE Technical Report 84, "The Measurement of Luminous Flux" (CIE 1989).

Electrical Measurements

Figure 6 shows the power supply and measurement circuit used for testing the luminaires. NLPIP operated the luminaires following the guidelines in IESNA LM-41-98. Specifically, the input voltage to each ballast was controlled to within 0.2% of the rated value (120 ±0.24 V).

Prior to beginning the photometric test procedure, NLPIP recorded the system voltage, current, power, and power factor, taking these measurements on the input side of the ballast with a power meter. The measured system power and the light output obtained from the integrating flux meter were used to calculate the efficacy for each luminaire.

Figure 6. Power supply and measurement circuit

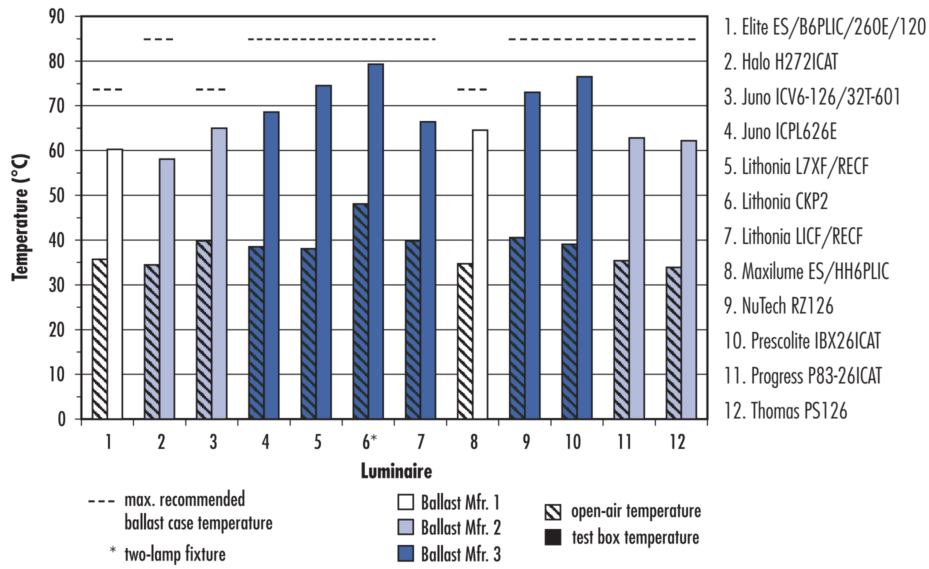


Results

Ballast Case Temperature

Figure 7 shows the ballast case temperatures recorded for the open-air and elevated temperature conditions. All recorded ballast case temperatures were below the manufacturers' maximum recommended values, which are indicated by horizontal dashed lines. The temperatures recorded with the luminaires installed in the test boxes averaged 85.1°F (29.5°C) higher than the open-air temperatures. As noted in the figure, Luminaire 6 was a two-lamp luminaire; the additional load of an extra lamp is likely a factor in the higher ballast case temperature for this luminaire.

Figure 7. Ballast case temperature

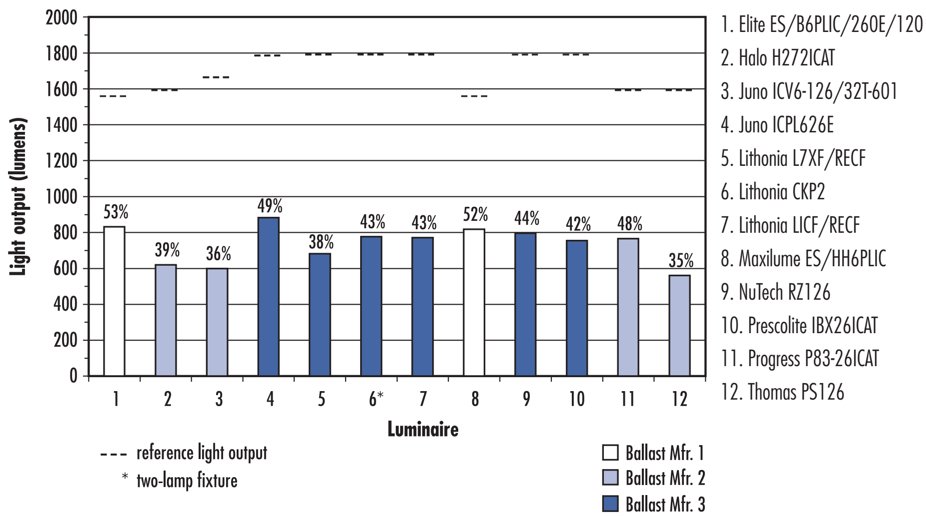


Light Output

Figure 8 shows the light output results for the measured luminaires. NLPIP measured the light output of the test lamp under standard conditions, using a reference ballast (ANSI 1997, 2002, 2005; IEC 2000). The light output of the test lamp under the standard conditions measured 1627 lm. The reference light output for each combination of test lamp and ballast was determined by multiplying the light output measured under the standard conditions (1627 lm) by the ballast factor of the ballast used in each luminaire. NLPIP obtained the ballast factor from the manufacturer's catalog or Web site. The dashed lines indicate these reference light output values for each luminaire. Each luminaire's efficiency is shown above its corresponding bar as a percentage of the reference value.

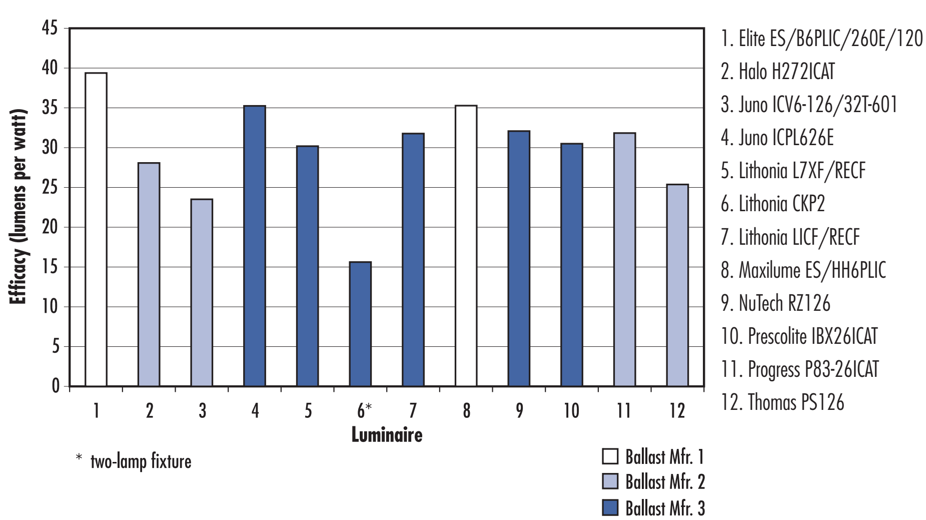
The light output of the luminaires averaged 753 lm, which was 947 lm, or 44%, of the average reference light output of 1700 lumens. Because Luminaire 6 was a two-lamp luminaire, its total light output was divided in half when plotted in Figure 8.

Figure 8. Light output values



Efficacy
NLPIP calculated the efficacy of each luminaire by dividing the light output obtained from the integrating flux meter by the input power to each luminaire, as measured by the power meter, as shown in Table 3. Input power was lower than rated power due to their enclosed environment—an insulated box. In all cases, therefore, measured power was lower than manufacturer-rated power. These efficacies (Figure 9) ranged from 23.5–39.4 lm/W and had a calculated average of 31.7 lm/W.

Figure 9. Efficacy



Pilot Tests

NLPIP performed two pilot tests, the accessories test and the screwbase lamps test, to study other factors that could affect luminaire efficacy. In the accessories test, NLPIP selected one of the luminaire models from the main study and determined the efficacy with various reflectors, baffles, and lenses attached to the luminaire. The trim was white in all cases. A similar pin-based amalgam lamp was used for this test, and the same test methods described for the primary study were employed. In the screwbase lamps test, the luminaire chosen was similar in construction to the compact fluorescent luminaire used in the accessories test.

Accessories Test

In the first pilot test, NLPIP used Luminaire 4, Juno model ICPL626E, with different reflectors, baffles, and lenses attached to the luminaire. Figure 10 shows three different views of each reflector, baffle, and lens. The first view shows the reflector, baffle, or lens accessory installed in the luminaire, which was mounted inside a temperature test box with a mock finished ceiling board. The next two views show the accessory at different angles along with the lamp for size comparison.

Figure 10. Reflectors, baffles, and lenses for first pilot test

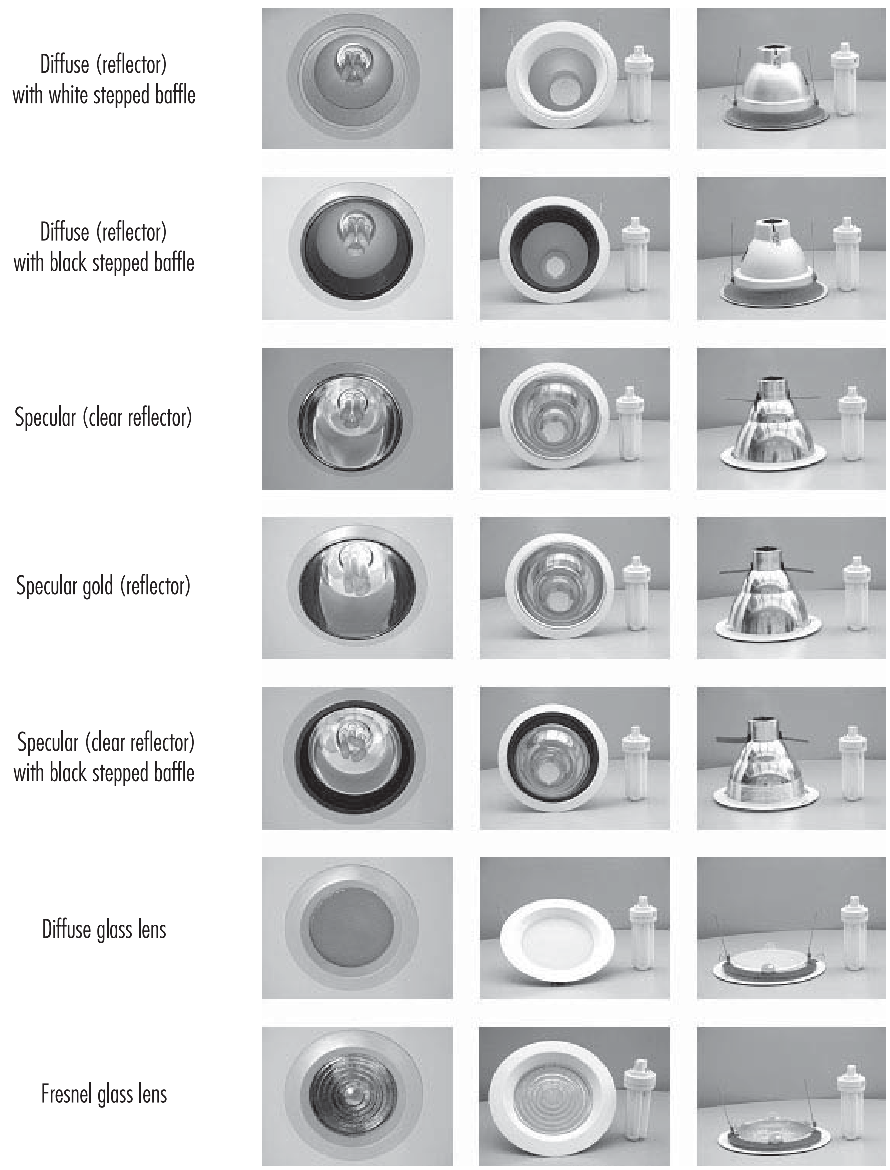


Figure 11 shows the ballast case temperatures during the accessories test. The first condition, a white baffle attached to the luminaire's aperture, was the same condition used in the primary testing with Luminaire 4. The ballast case temperatures for the various accessories ranged from 151.2–177.1°F (66.4–80.6°C). The highest ballast case temperatures in the testing occurred with lenses attached to the luminaire. However, all ballast case temperatures were below the manufacturer's recommended maximum value. This particular luminaire did not allow lenses to be installed with other reflectors or baffles.

Figure 11. Ballast case temperatures—pilot test Juno model ICPL626E

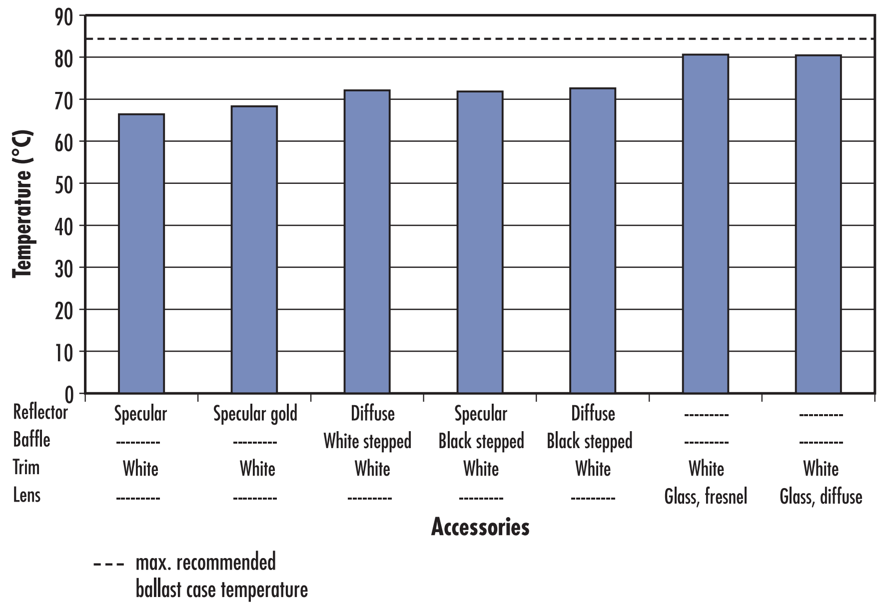
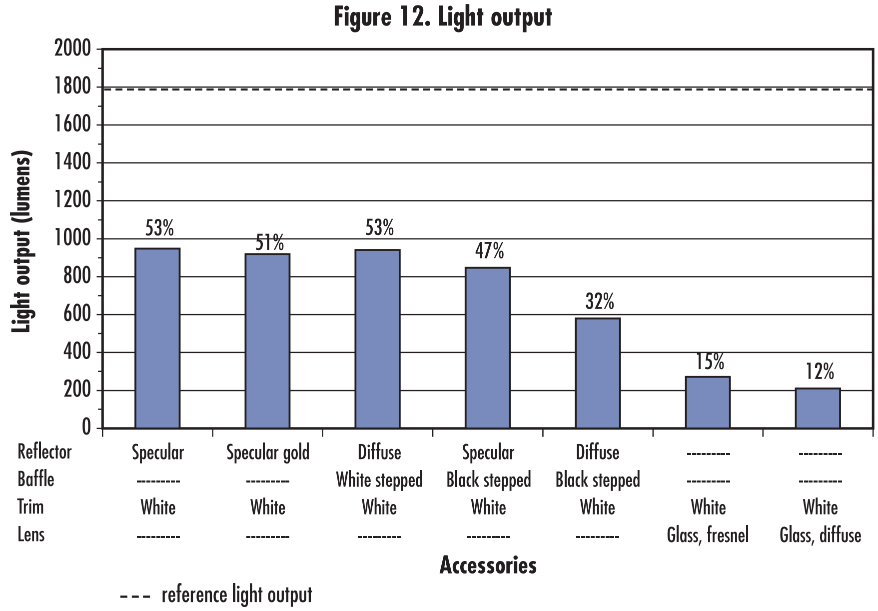


Figure 12 shows the luminaire's light output during the accessories test. The lamp used for this test was the same model used for the primary testing; its light output on the reference ballast was 1623 lm. The ballast used in this luminaire had a ballast factor of 1.10; therefore, the reference light output for this combination of test lamp and ballast was 1785 lm (1623 lm x 1.10).

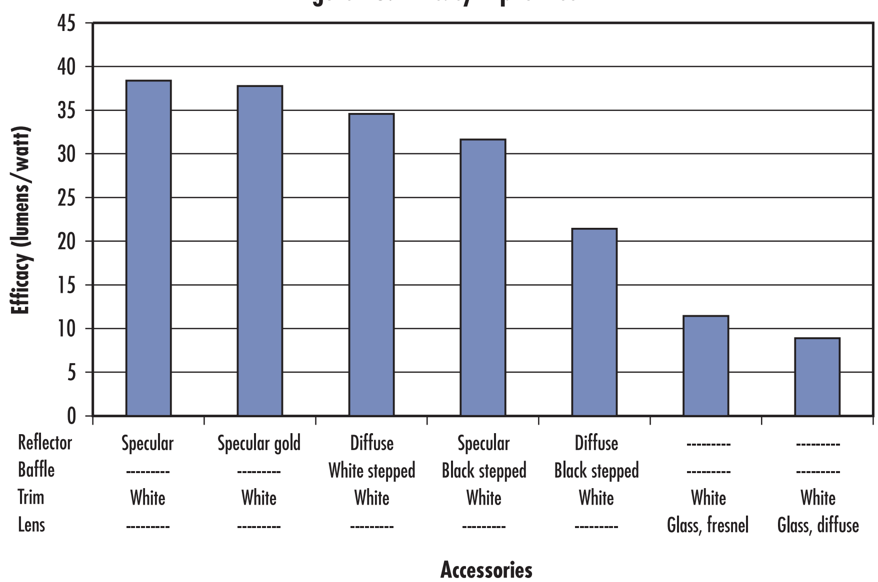
Figure 12. Light output



Reflectors with black step baffles generally resulted in lower light output compared to similar style reflectors with white baffles or with no baffles. However, the black baffle did not affect the light output of the specular reflector as much as it did for the diffuse reflector. The two lenses resulted in the lowest light output from the luminaire (12% and 15% of the reference light output). The lenses are more restrictive in terms of allowing light to exit the luminaire, and they increase the ambient temperature near the lamp, which causes a decrease in light output at temperatures greater than 77°F (25°C).

Figure 13 shows the efficacies of Juno model ICPL626E (Luminaire 4) with different reflectors, baffles, and lenses installed. As Figure 12 shows for light output, the efficacy was lower for luminaires with black baffles and for both lenses. The efficacy with the clear reflector was the highest of all the accessories, despite the fact that the light output was the same as for the diffuse reflector with white baffle (Figure 13). With the clear specular reflector, the ballast operated at a lower temperature (Figure 11) and a lower power. These conditions most likely resulted in a lower lamp temperature as well. The lower power would typically result in lower light output; however, the combination of a lower lamp temperature and the greater optical efficiency of the clear specular reflector probably allowed the light output from the luminaire to be the same as for the diffuse reflector with white baffle. With the same light output but lower power, the luminaire had a higher efficacy with the clear specular reflector.

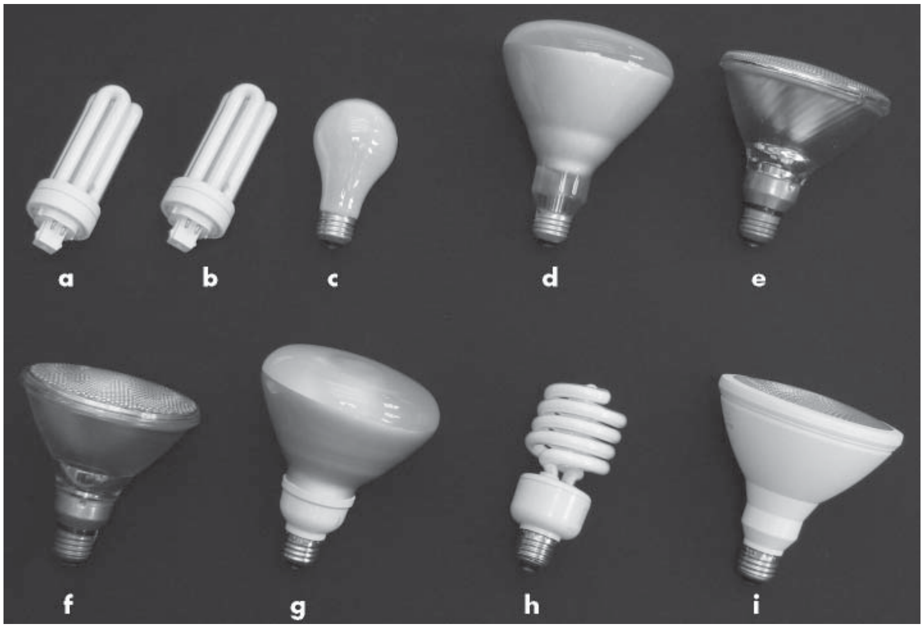
Figure 13. Efficacy—pilot test



Screwbase Lamps Test

For the second pilot test, the screwbase lamps test, NLPIP selected an ICAT luminaire with a screwbase socket intended for incandescent lamps and determined the efficacy using various types of screwbase lamps. This luminaire was similar in construction to the compact fluorescent luminaire used in the accessories test. The lamps chosen were four 100-W incandescent lamps, two compact fluorescent lamps, and a metal halide (MH) lamp. The incandescent lamps chosen were an A lamp, a BR flood lamp, a halogen PAR 38 flood lamp, and a halogen IR flood lamp. The compact fluorescent lamps chosen were a 27-W spiral and a 19-W R40 flood lamp. They were chosen for their claimed equivalence to incandescent lamps. The 27-W spiral claimed equivalence to 100-W incandescent lamps; and the 19-W R40 flood lamp claimed that its light output was comparable to 85-W incandescent lamps. These lamps are shown in Figure 14.

Figure 14. Lamps used in this study

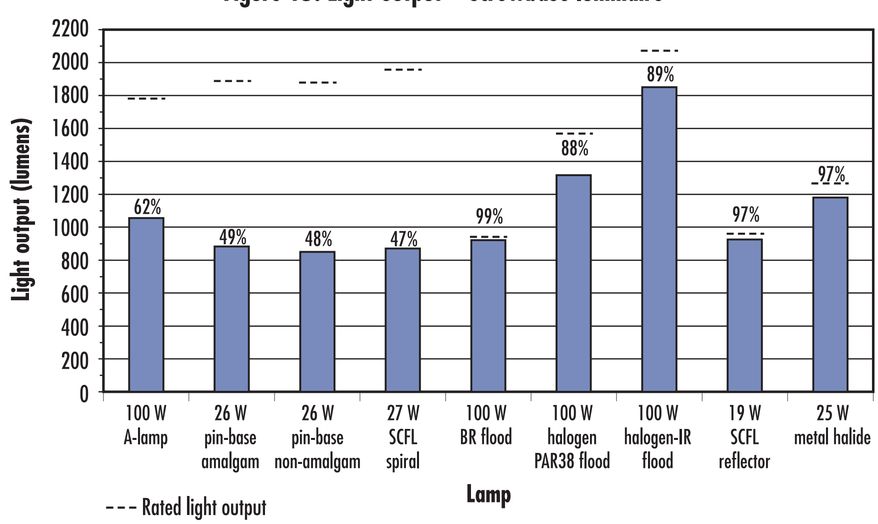


a) 26-W amalgam pin-based compact fluorescent
b) 26-W non-amalgam pin-based compact fluorescent
c) 100-W A-lamp
d) 100-W BR flood lamp
e) 100-W halogen PAR 38 flood lamp
f) 100-W halogen IR flood lamp
g) 19-W screwbase compact fluorescent reflector lamp
h) 27-W screwbase compact fluorescent spiral lamp
i) 25-W metal halide reflector lamp

The light output values of the screwbase luminaire (Juno model IC2) with various screwbase lamps installed are shown in Figure 15. The dashed lines indicate the lamp's rated light output. For comparison, the rated light output of the pin-based amalgam and non-amalgam lamps are included. These lamps were tested using Juno model ICPL626E (Luminaire 4), which was very similar in construction.

Efficacies, as calculated from the lamps' rated light output and rated power, are shown in Figure 16. As with rated light output, the calculated efficacy of the luminaires using the pin-based amalgam and non-amalgam lamps are included for comparison.

Figure 15. Light output—screwbase luminaire



The results of this test show the performance that may be expected for different replacement options in this type of luminaire. In general, the efficacy is much lower for the incandescent lamps compared to the other options. The efficacies of the luminaire using the reflector lamps are much closer to their calculated values than the spiral CFL and the pin-based amalgam and non-amalgam lamps, which were triple-tube construction. This suggests that a large portion of the light generated by the spiral and triple-tube lamps is trapped by the luminaire in contrast to the reflector lamps, which direct more of their light directly out of the luminaire. The measured light output of the five reflector lamps averaged 94% of their open-air rated light output values, while the light output values of the remaining lamps averaged just 52% of their open-air rated values. The 19-W compact fluorescent reflector lamp performed better than its calculated efficacy due to a lower power requirement (17.7 W), while its light output was 97% of its open-air rated value.

Figure 16. Efficacy—screwbase luminaire

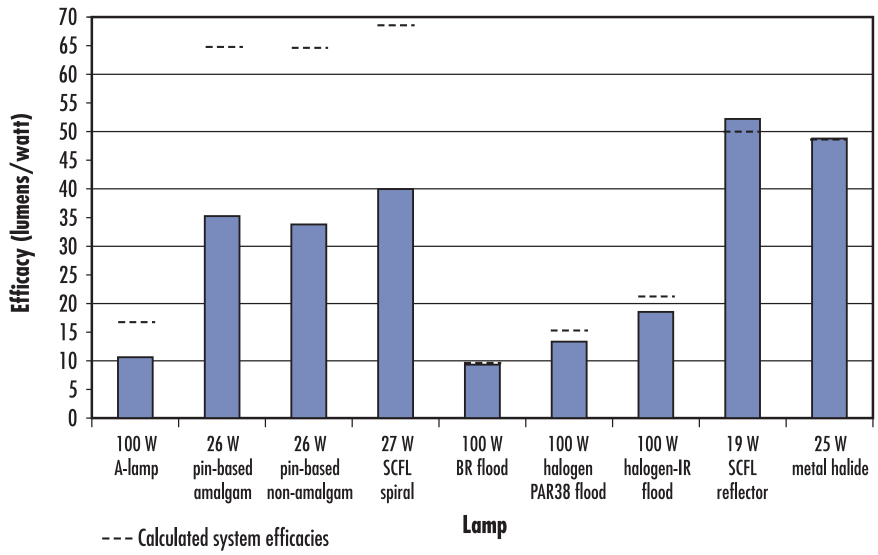


Table 1. Manufacturer's Data Tables for 26-watt Residential Recessed CFL ICAT Luminaires, ENERGY STAR-qualified as of May 30, 2006

Manufacturer/ Brand Name	Product Number	Aperture (in.)	Height (in.)	Lamp				Input Voltage (V)	Dimming Option	Photometric Report Supplied
				Lamp Orientation	Type [a]	Socket	Rated Power [b] (W)			
Cooper Halo	H272ICAT	6	7.00	V	Quad, Triple, Twin Tube	G24q-3/ GX24-3	26	120	No	No
Elite	B6PLIC	6	7.25	V	Triple Tube	GX24q-3	26	120/277	Yes	No
Juno	ICPL626E [c]	6	7.50	V	Triple Tube [d]	GX24q-3	26	120	No	No
Juno Aculux	ICV6-126/32T-601	6	9.50	V	Triple Tube	GX24q-3	26/32	120/277	Yes [e]	Yes
Lithonia	L7XF RECF	6	7.38	V	Quad, Triple Tube	GX24q-3	13/18/26	120	No	No
Lithonia	CKP62	6	7.38	V	Triple Tube	GX24q-3	(2) 26	120	No	No
Lithonia	LI6F RECF	6	7.38	V	Triple Tube	GX24q-3	26	120	Yes	No
Maxilume	HH6PLIC	6	7.75	H	Quad, Triple, Twin Tube	GX24q-3	26	120/277	Yes	Yes
NuTech	RZ126	6	4.25	H	Quad, Triple Tube	GX24q-3	26	120/277	Yes	Yes
Prescolite	IBX26ICAT	6	7.50	V	Triple Tube	G24q-3	26	120	No	No
Progress	P83-26ICAT	6	7.50	V	Quad Tube	G24q-3/ GX24q-3	26	120	No	No
Thomas	PS126	6	7.50	V	Triple Tube	GX24q-3	26	120	No	No

V = vertical; H = horizontal

[a] All lamps are 4-pin lamps

[b] Values provided by manufacturers' specification sheets

[c] Also available in remodel version

[d] Recommend GE or OSRAM SYLVANIA lamps only

[e] Not ENERGY STAR rated

Table 2. Manufacturer Contact Information

Company	Web site	Telephone
Cooper Lighting	www.cooperlighting.com	(770) 486-4800
Elite Lighting	www.iuseelite.com	(877) 375-5555
Juno Lighting	www.junolighting.com	(847) 827-9880
Lithonia Lighting	www.lithonia.com	(770) 922-9000
Maxilume	www.maxilume.com	(877) 375-5555
NuTech Lighting	www.nutechlighting.com	(212) 541-7397
Prescolite	www.prescolite.com	(864) 599-6000
Progress Lighting	www.progresslighting.com	(864) 599-6000
Thomas Lighting	www.thomaslighting.com	(502) 420-9600

Table 3. Primary Testing Data

Box #	Manufacturer	Model	Description	Ballast	Ballast factor	Lamp position	Ballast case temperature (°C) Open air	Ballast case temperature (°C) Insulated box	Active power (W) Rated	Active power (W) Measured	Luminaire Light output (lm)	Luminaire Efficacy (lm/W)
1	Elite	B6PLIC/26E/120	Specular metal reflector; white stepped baffle; white trim	Robertson RS0126CQ120	0.96	V	35.7	60.3	25	21.1	832	39.4
2	Cooper Halo	H272ICAT	Specular metal reflector; white stepped baffle; white trim	Universal CBT126L-120B	0.98	V	34.5	58.1	28	22.1	620	28.1
3	Juno Aculux	ICV6-126/32T-601	Specular metal reflector; white stepped baffle; white trim	Universal ES-1-CFH-42/32/26-120-G	1.02	V	39.8	65.0	28	25.5	599	23.5
4	Juno	ICPL626E	Diffuse metal reflector; white stepped baffle; white trim	Advance RCF-2S26-M1-LS-QS	1.10	V	38.5	68.6	29	25.1	883	35.2
5	Lithonia	L7XF RECF	White painted reflector; white stepped baffle; white trim	Advance RCF-2S26-M1-BS-QS	1.10	V	38.1	74.5	29	22.6	682	30.2
6*	Lithonia	CKP62	White painted reflector; white stepped baffle; white trim	Advance R CF-2S26-M1-BS-QS	1.10	V	48.1	79.3	29	49.8	777	15.6
7	Lithonia	LI6F26TRT120 RECF	White painted reflector; white stepped baffle; white trim	Advance RCF-2S26-M1-BS-QS	1.10	V	39.8	66.4	29	24.3	772	31.7
8	Maxilume	HH6PLIC	Specular metal reflector; white stepped baffle; white trim	Robertson RS0126CQ120	0.96	V	34.7	64.6	25	23.2	817	35.3
9	NuTech	RZ126	White plastic reflector; white stepped baffle; white trim	Advance RCF-2S26-M1-BS-QS	1.10	H	40.6	73.0	29	24.8	795	32.1
10	Prescolite	IBX26ICAT	White painted reflector; white stepped baffle; white trim	Advance RCF-2S26-M1-BS-QS	1.10	H	39.1	76.5	29	24.7	754	30.5
11	Progress	P83-26ICAT	White painted reflector; white stepped baffle; white trim	Universal CBT126L-120S	0.98	V	35.4	62.8	28	24.1	766	31.8
12	Thomas	PS126	Specular reflector; white stepped baffle; white trim	Universal CBT126L-120S	0.98	V	33.9	62.2	28	22.1	561	25.4

V = vertical; H = horizontal

Table 4. Accessory Test, Juno ICPL626E*, 26-Watt Amalgam Pin-based Fluorescent Lamp

Accessory	Insulated box ballast case temperature (°C)	Active power (W)	Power factor	Luminaire	
				Light output (lm)	Efficacy (lm/W)
Specular metal reflector; white trim	66.4	24.7	0.993	948	38.4
Specular gold finish metal reflector; white trim	68.3	24.4	0.993	919	37.8
Diffuse metal reflector; white stepped baffle; white trim	72.1	27.2	0.994	942	34.6
Specular metal reflector; black stepped baffle; white trim	71.8	26.7	0.993	846	31.6
Diffuse metal reflector; black stepped baffle; white trim	72.6	27.0	0.994	579	21.4
White trim; glass fresnel lens	80.6	23.7	0.992	271	11.4
White trim; diffuse glass lens	80.5	23.7	0.992	211	8.9

* - With 29-W ballast input power, 1.10 ballast factor, and 1710 lm lamp light output

Table 5. Screwbase Lamp Test, Juno IC2 with Diffuse Metal Reflector, White Stepped Baffle, and White Trim

Lamp	Lamp rated light output (lm)	Active Power (W)		Luminaire	
		Rated	Measured	Light output (lm)	Efficacy (lm/W)
100-W A lamp	1690	100	99.4	1055	10.6
26-W amalgam CFL*	1710	29	25.1	882.9	35.2
26-W non-amalgam CFL*	1710	29	25.2	850.2	33.8
27-W spiral SCFL	1850	27	21.8	870.9	40.0
100-W BR flood	935	100	98.9	921.8	9.3
100-W halogen PAR38 flood	1500	100	98.5	1316	13.4
100-W halogen IR flood	2070	100	99.9	1851	18.5
19-W reflector SCFL	950	19	17.7	925.0	52.2
25-W metal halide	1220	25	24.2	1180	48.8

* - Tested in similar luminaire Juno ICPL626E with a pin-base lamp socket

Further Information

NLPIP has published several reports about other topics regarding residential downlights that are not detailed in this report. These issues and where to find the in-depth information follow:

color: Two common parameters describe the color performance of a light source: correlated color temperature (CCT) and color rendering index (CRI). For more information, refer to *Specifier Reports: Energy-efficient Ceiling-mounted Residential Luminaires*, available at: www.lrc.rpi.edu/programs/NLPIP/PDF/VIEW/SR_Res_Lum.pdf.

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." For more information, refer to *Specifier Reports: CFL Downlights*, available at: www.lrc.rpi.edu/programs/NLPIP/PDF/VIEW/SRCFL_DL.pdf.

screwbase CFLs: CFL products may be used to replace incandescent lamps in luminaires with medium screwbase sockets. For more information, refer to *Specifier Reports: Screwbase Compact Fluorescent Lamp Products*, available at: www.lrc.rpi.edu/programs/NLPIP/PDF/VIEW/SR_SB_CFL.pdf.

spacing criterion (SC): To achieve uniform illuminance on a horizontal plane, spacing criterion is used to estimate the maximum recommended luminaire spacing. For more information, refer to *Specifier Reports: CFL Downlights*, available at: www.lrc.rpi.edu/programs/NLPIP/PDF/VIEW/SRCFL_DL.pdf.

total harmonic distortion (THD): A measure of the degree to which the current waveform is distorted from sinusoidal, expressed as a percentage. For more information, refer to *Specifier Reports: Screwbase Compact Fluorescent Lamp Products*, available at: www.lrc.rpi.edu/programs/NLPIP/PDF/VIEW/SR_SB_CFL.pdf.

References

American National Standards Institute (ANSI). 1997. *American National Standard for Electric Lamps: Fluorescent Lamps – Guide for Electrical Measurements*. ANSI C78.375-1997. Rosslyn, VA: NEMA.

———. 2002. *American National Standard for Lamp Ballasts – Reference Ballasts for Fluorescent Lamps.* ANSI C82.3-2002. Rosslyn, VA: ANSLG-NEMA.

———. 2005. *American National Standard for Electric Lamps: Single-Based Fluorescent Lamps – Dimensional and Electrical Characteristics*. ANSI_IEC C78.901-2005. Rosslyn, VA: ANSLG-NEMA.

ASTM. 2004. *ASTM E283 – 04: Standard Test Method for Determining Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen.* West Conshohocken, PA: ASTM International.

Banwell, Peter, and Mariana Figueiro. 2002. Energy-efficient design alternative to residential recessed downlights. *Right Light 5: Proceedings of the 5th international conference on energy-efficient lighting in Nice, France:* 109-117. Stockholm: ECEEE.

California Energy Commission (CEC). 2005. *Title 24, Part 6, of the California Code of Regulations: California's Energy Efficiency Standards for Residential and Nonresidential Buildings.* Sacramento, CA. Accessed 04/04/07 at www.energy.ca.gov/title24/index.html.

CIE. 1989. *CIE Technical Report: The measurement of luminous flux.* CIE No. 89. Commission International de l'Eclairage. Vienna.

Illuminating Engineering Society of North America (IESNA). 1998. *Approved Method for Photometric Testing of Indoor Fluorescent Luminaires*. IESNA LM-41-98. New York: IESNA.

International Electrotechnical Commission (IEC). 2000. *International Standard Amendment: 2 Single-capped fluorescent lamps – Performance Specifications.* IEC 60901. Geneva, Switzerland: IEC.

Lighting Research Center (LRC). 2003. *Durability Testing for ENERGY STAR Residential Light Fixtures, Final Project Report (Public Version)*. Project sponsor: United States Environmental Protection Agency (EPA). Troy, NY: Rensselaer Polytechnic Institute.

National Electrical Manufacturers Association (NEMA) and American Lighting Association (ALA). 2005. *NEMA/ALA Ballast Matrix – Robertson Worldwide – September 2005.* Accessed 12/18/06 at www.nema.org/lampballastmatrix/ballasts/Robertson BallastMatrix091405.xls.

———. 2006a. *NEMA/ALA Ballast Matrix – Advance – November 2006*. Accessed 12/18/06 at www.nema.org/lampballastmatrix/ballasts/AdvanceBallast110106.xls.

———. 2006b. *NEMA/ALA Ballast Matrix – Universal Lighting Technologies – December 2006*. Accessed 12/18/06 at www.nema.org/lampballastmatrix/ballasts/Universal Ballast Matrix 112006.xls.

Navigant Consulting, Inc. U.S. Department of Energy, and Office of Energy Efficiency and Renewable Energy Building Technologies Program. 2002. *U.S. lighting market characterization, Volume I: National lighting inventory and energy consumption estimate*. U.S. Department of Energy. Washington, D.C.

NLPIP. 1999. *Specifier Reports: Energy-efficient ceiling-mounted residential luminaires*. Lighting Research Center. Troy, NY: Rensselaer Polytechnic Institute. Available at: www.lrc.rpi.edu/programs/NLPIP/PDF/VIEW/SR_Res_Lum.pdf.

Rea, Mark S., Editor-in-chief. 2000. *IESNA Lighting Handbook: Reference & Application.* New York: Illuminating Engineering Society of North America.

Rea, Mark S., and John D. Bullough. 2001. Application efficacy. *J. Illum. Eng. Soc.* 30, (2): 73-96. New York: IESNA.

Siminovitch, Michael, and Erik Page. 2003. *Energy-Efficient Downlights for California Kitchens, Consultant Report.* Prepared by Lawrence Berkeley National Laboratory for California Energy Commission, Public Interest Energy Research Program. Berkeley, CA.

Underwriters Laboratories, Inc. 2004. *Standard for Safety for Luminaires, UL 1598.* CSA International. Northbrook, IL.

U.S. Census Bureau. 2003. *Electric Lighting Fixtures: 2001*. Table 2, Quantity and Value of Shipments of Electric Lighting Fixtures: 2000 and 1999. pp. 3-7. Washington, DC: U.S. Department of Commerce.

United States Environmental Protection Agency (US EPA). 2005. *ENERGY STAR Program Requirements for Residential Light Fixtures, Version 4.0*. Washington, D.C. Accessed 12/18/06 at www.energystar.gov/ia/partners/prod_development/revisions/downloads/fixtures/RLF_V4FINALSpec.pdf

Resources

Barrett, James R. 1993. *Specifier reports: Screwbase compact fluorescent lamp products.* Vol. 1, Issue 6. Lighting Research Center, Rensselaer Polytechnic Institute, Troy, NY.

Horowitz, Noah. 1999. *Lighting the way to energy savings: How can we transform residential lighting markets? Volume 2 - Background and reference.* Natural Resources Defense Council. Washington DC.

Ledbetter, M. et al. 2005. *CFLs in recessed downlights: Technical challenges*. Right Light 6, Shanghai, P.R.China.

McCullough, J. et al. 2006. *Using Pin-Based Compact Fluorescent Lamps in Residential Recessed Downlights.* United States Department of Energy (DOE). Washington, D.C.

NLPIP. 1999. S*pecifier Reports: Screwbase compact fluorescent lamp products*. Lighting Research Center. Troy, NY: Rensselaer Polytechnic Institute. Available at: www.lrc.rpi.edu/programs/NLPIP/PDF/VIEW/SR_SB_CFL.pdf.

———. 1995. *Specifier Reports: CFL downlights.* Lighting Research Center. Troy, NY: Rensselaer Polytechnic Institute. Available at: www.lrc.rpi.edu/programs/NLPIP/PDF/VIEW/SRCFL_DL.pdf.

CFL Residential Downlights

Volume 12 Number 1, January 2008

Principal Investigator:
Patricia Rizzo

Authors: Patricia Rizzo
Chris Gribbin
Conan O'Rourke

Editor: Keith E. Toomey

Program Director:
Conan O'Rourke

Layout, Graphics and Photography:
Dennis Guyon

Specifier Reports

Technical review of this report was provided by Jeff McCullough, Pacific Northwest National Laboratory, and Russ Leslie, Lighting Research Center. NLPIP lists reviewers to acknowledge their contributions to the final publication. Their participation in the review process does not necessarily imply approval or endorsement of this report.

Production of this report involved important contributions from many staff members at the Lighting Research Center, including Andrew Bierman, Joann Coffey, Howard Ohlhous, Martin Overington, Jenny Taylor, and Yutao Zhou.

National Lighting Product Information Program Publications

Guide to Fluorescent Lamp-Ballast Compatibility, 1996
Guide to Specifying High-Frequency Electronic Ballasts, 1996
Guide to Selecting Frequently Switched T8 Fluorescent Lamp-Ballast Systems, 1998

Specifier Reports

Power Reducers, 1992; *Specular Reflectors*, 1992; *Cathode-Disconnect Ballasts*, 1993; *Exit Signs*, 1994; *Reflector Lamps*, 1994; *CFL Downlights*, 1995; *HID Accent Lighting Systems*, 1996; *Occupancy Sensors*, 1998; *Lighting Circuit Power Reducers*, 1998; *Screwbase Compact Fluorescent Lamp Products*, 1999; *Energy-Efficient Ceiling-Mounted Residential Luminaires*, 1999; *Dimming Electronic Ballasts*, 1999; *Electronic Ballasts*, 2000; *Parking Lot and Area Luminaires*, 2004; *Low-wattage Metal Halide Lighting Systems*, 2006; *Photosensors*, 2007

Specifier Reports Supplements

Exit Signs, 1995, 1998; *Energy-Efficient Ceiling-Mounted Residential Luminaires*, 2000;*HID Accent Lighting*, 2000; *Screwbase Compact Fluorescent Lamp Products*, 2000

Lighting Answers

Multilayer Polarizer Panels, 1993; *Task Lighting for Offices*, 1994; *Dimming Systems for High-Intensity Discharge Lamps*, 1994; *Electromagnetic Interference Involving Fluorescent Lighting Systems*, 1995; *Power Quality*, 1995; *Thermal Effects in 2' x 4' Fluorescent Lighting Systems*, 1995; *T10 and T9 Fluorescent Lamps*, 1995; *T5FT Lamps and Ballasts*, 1996; *Controlling Lighting with Building Automation Systems*, 1997; *Alternatives to Halogen Torchieres*, 2000; *T5 Fluorescent Systems*, 2002; *MR16 Lamps*, 2002; *Mid-wattage Metal Halide Lamps*, 2003; *Light Pollution*, 2003; *LED Lighting Systems*, 2003; *Adaptable Ballasts*, 2003; *Full-Spectrum Light Sources*, 2003; *Light Sources and Color*, 2004; *T8 Fluorescent Lamps*, 2006; *High-wattage Fluorescent Lamps*, 2006; *Photovoltaic Lighting*, 2006

Lighting Diagnostics

Dimming T8 Fluorescent System Problems, 2006

NLPIP
NATIONAL LIGHTING PRODUCT INFORMATION PROGRAM
Specifier Reports

The objective source of lighting product information

CFL Residential Downlights

Insulated Ceiling, Airtight Luminaires

Volume 12 Number 1, January 2008

To view or order publications online,
visit the LRC web site:

www.lrc.rpi.edu

or contact:

Lighting Research Center
21 Union Street
Troy, NY 12180-3352
Phone: 518.687.7100
Fax: 518.687.7120
Email: lrc@rpi.edu

Lighting Research Center
Rensselaer