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# Recommendations for Testing and Evaluating Luminaires Used in Directional Lighting

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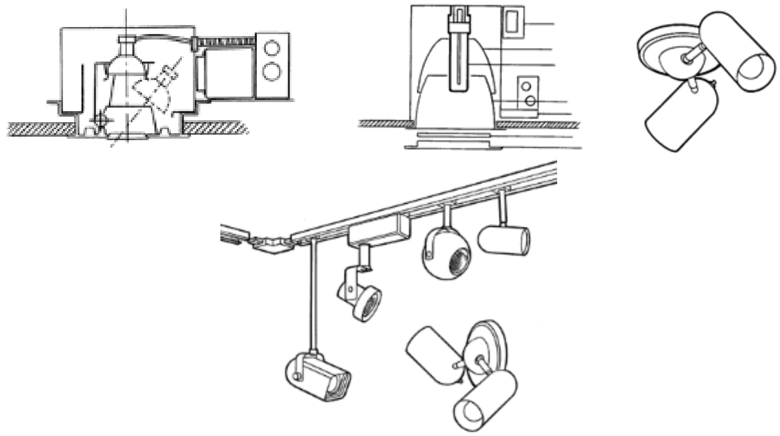
## Introduction

This document outlines a recommendation for testing and evaluating the performance of white light luminaires used in directional lighting. The methodology described in this document is intended for track, recessed, and ceiling- or wall-mounted luminaires designed for incandescent, compact fluorescent, light emitting diode (LED), or high-intensity discharge lamps. Representative examples are shown in the figure below. In its current version, this document does not address luminaires for linear fluorescent lamps.



This recommendation was developed by the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute in collaboration with members of the Alliance for Solid-State Illumination Systems and Technologies (ASSIST).

## Background

Lighting applications are primarily categorized as general lighting, directional lighting, and aesthetic lighting. Directional lighting provides illumination on the work plane or on an object that is incident predominantly from a particular direction. Direct, task, and accent lighting luminaires all provide directional lighting.

The IESNA Lighting Handbook defines a luminaire as “a device to produce, control, and distribute light. It is a complete lighting unit consisting of the following components: one or more lamps, optical devices designed to distribute the light, sockets to position and protect the lamps and to connect the lamps to a supply of electric power, and the mechanical components required to support or attach the luminaire” (Rea, 2000).

Presently, directional lighting luminaires are built for many types of electric light sources, including incandescent/tungsten halogen, compact fluorescent lamps (CFLs), high-intensity discharge (HID) lamps, and white light-emitting diodes (LEDs). The wealth of light source technologies available means that users can pick nearly any source to fill their lighting needs. The performance of each of these technologies—in terms of light output, color, luminous efficacy, and life—will vary depending on how they are implemented into the lighting application.

Many performance specifications presently used in the lighting industry assume the performance of the lamp (or lamp-ballast combination), tested under an ideal environment, as the performance of the complete luminaire. However, this assumption is not correct because light sources perform differently inside luminaires, and this performance changes depending on the application conditions (Jayasinghe et al. 2006; NLPIP, in press). Generally, the luminaire design (e.g., the optics used to transfer the flux from the source to the application, housing with proper thermal management, etc.) influences the overall light output, luminous efficacy, color, and life of the total system. Ultimately, the amount of luminous flux exiting the luminaire within the optical beam that illuminates the task, the color of the light within the optical beam, and the system (lamp, ballast [or driver]) life when used in an application[1] are the most useful performance characteristics for the end user. Further, to allow users to make meaningful comparisons between products, performance metrics developed for lighting applications must be technology-independent.

With certain technologies, the heat experienced by the light source and the ballast (or driver) affects the overall performance of the luminaire in terms of light output, color (appearance and rendering), lumen maintenance, lamp life, and ballast (or driver) life. To obtain realistic performance data for a luminaire, the test environment must mimic the actual environment where the luminaire would be used. Usually, indoor directional lighting luminaires operate in three different environments, namely:

- **Open air:** Here the light source and the ballast (or driver) have plenty of ventilation around them for convection heat transfer to keep them at appropriate temperatures.
- **Semi-ventilated:** Here the light source and the driver have limited ventilation around them for convection heat transfer. In certain applications, a non-IC luminaire would be considered for a semi-ventilated environment.
- **Enclosed:** Here the light source and the driver have almost no ventilation around them for convection heat transfer. An IC-rated luminaire is an example of a luminaire for an enclosed environment.

These environments affect the operating temperature of the luminaire, potentially causing it to perform differently in each environment. In order to understand the effect that heat has on luminaire performance, the operating temperature must be measured accurately in each environment (open air, semi-ventilated, enclosed). The intent here is to determine the performance of the luminaire at different temperatures. Knowing the luminaire performance at these three temperatures would allow users to predict performance in any temperature environment. For some technologies, certain temperature points within the light source or the ballast are known to have a direct relationship with performance. However, these temperature points are not accessible once the light source and ballast are packaged into a luminaire. Therefore, accessible temperature points must be identified that correlate to those known points that affect performance, or thermocouples that extend from the interior must be provided.

[1] Although there are other failure mechanisms that can cause a luminaire to fail in application, only the lamp and ballast (or driver) failure is considered in this document.

# Proposed Method

## *Measuring lamp/ballast (driver) operating temperature*

Manufacturers should identify and diagram thermocouple attachment points $T_s$ and $T_d$ for the light source and the ballast (or driver), respectively. Temperatures at these respective points have a direct relationship to the light source and the ballast (or driver) performance. Some examples of thermocouple attachment points are:

- For an LED or an LED array, a point on the LED circuit board that has a direct correlation to the junction temperature, which dictates the LED performance.
- For a CFL, a point on the bulb wall closest to the lamp's cold spot, which dictates the CFL performance.
- For a ballast (or driver), a point on the case closest to the electrolytic capacitor or another weak component whose performance is affected by heat.

**Lamp/ballast (driver) operating temperature measurement**

**Step 1:** Place the luminaire in one of the three different testing environments (open air, semi-ventilated, or enclosed), per UL 1598, section 16, Test procedures and apparatus (2000). (See Appendix C below on p. 13 for details on constructing the semi-ventilated and enclosed testing environments.)

**Step 2:** Attach temperature sensors to the lamp and the ballast (or driver, if needed) at the manufacturer-specified locations.

**Step 3:** Turn the luminaire on for a certain number of hours for seasoning the light source (see Appendix A below on p. 9, "Testing conditions: Lamp seasoning"). (IESNA LM-54-99, 1999).

**Step 4:** If the luminaire was turned off after the seasoning, turn on the luminaire and allow it to operate for a certain number of hours so that the light output flux reaches stability. Different lamp technologies may have different stabilization timeframes (see Appendix A below on p. 9, "Testing conditions: Luminaire stabilization – preburning").

**Step 5:** Measure the temperature values from $T_s$ and $T_d$ (example: five times at 2-minute intervals and calculate the average values).

**Step 6:** If the luminaire is intended for application in any other environment, repeat this procedure for the other testing environments (open air, semi-ventilated, or enclosed) per UL 1598, section 16 (2000).

## *Measuring lumens, luminous efficacy, CCT, CRI, chromaticity, and beam distribution*

Both an integrating sphere and a goniophotometer can be used to obtain the luminous flux exiting the luminaire in the application condition. Sphere photometry can be used with a modified procedure (see "Integrating sphere measurement" section below on p. 7) for measuring luminous flux and the spectral power distribution of the beam, from which luminous efficacy, CCT, CRI, and chromaticity (CIE x, y coordinates) can be calculated. Goniophotometry can be used for measuring the intensity distribution of the beam exiting the luminaire in the application condition (IESNA LM-75-01, 2001), from which luminous flux and luminous efficacy can be calculated (Rea, 2000). Presently, goniophotometers are not set up to measure color properties. Alternative equipment such as the Flux-O-Meter has the capability to measure both the luminous flux and the spectral power distribution of the luminaire (Bierman, 2007). The Flux-O-Meter measures the illuminance and spectral power distribution at many points around a virtual sphere surrounding the luminaire being tested. The luminaire's luminous flux can be calculated by integrating the illuminance over the virtual sphere's area, and its color properties can be determined at each measurement point or averaged across all measurements. As an additional advantage, the Flux-O-Meter does not require a minimum distance between the sensors and the luminaire, and it is relatively insensitive to positioning, size, color, and shape of the luminaire being tested.

**Integrating sphere measurement**

**Step 1:** Inside the integrating sphere, place the lamp and ballast (or driver） or the entire luminaire in a test enclosure (see Appendix B below on p. 11 for details of the luminaire test enclosure for sphere photometry) and ensure that the lamp and ballast (or driver) have the same operating condition as tested in Step 1 for the temperature measurement (see "Lamp/ballast [driver] operating temperature measurement" section above on p. 6).

**Step 2:** Turn the luminaire on and allow it to operate for a certain number of hours so that the light output flux reaches stability (see Appendix A below on p. 9, "Testing conditions: Luminaire stabilization – preburning").

**Step 3:** Measure the radiant energy at each wavelength in the visible spectrum and calculate luminous flux and power consumption of the lamp/ballast (or driver) or the entire luminaire, per the IESNA Lighting Handbook (Rea, 2000).

**Step 4:** Calculate the luminous efficacy, CCT, CRI, and CIE x,y coordinates of the beam exiting lamp or the entire luminaire.

**Step 5:** If the luminaire is intended for application in any other environment, repeat this procedure at temperatures corresponding to the other testing environments (open air, semi-ventilated, or enclosed).

**Goniophotometer measurement**

**Step 1:** Place the luminaire in one of the three different testing environments (open air, semi-ventilated, or enclosed). (See Appendix C below on p. 13 for details on constructing the non-IC and IC testing environments.)

**Step 2:** Turn the luminaire on and allow it to operate for a certain number of hours so that the luminous flux reaches stability (see Appendix A below on p. 9, "Testing conditions: Luminaire stabilization – preburning").

**Step 3:** Measure the intensity distribution of the beam exiting the luminaire (refer to IESNA LM-20-94, 1994; LM-41-98, 1998; and LM-46-04, 2004).

**Step 4:** Calculate luminous flux and luminous efficacy of the luminaire in the testing environment (Rea, 2000).

**Step 5:** Generally, goniophotometers do not allow for spectral power distribution measurements. To obtain colorimetry information (i.e., CRI, CCT, chromaticity) in this case, operate the luminaire in each of the three different testing environments (open air, semi-ventilated, or enclosed) and project the beam exiting the luminaire onto a diffuse and spectrally neutral white screen. Divide the area of the screen equally into a grid of nine squares. Measure the color properties of the beam using a photometrically calibrated color sensor at the center of each square. Acceptable instruments include (a) luminance or illuminance meters with built-in color sensors to measure CRI, CCT, and chromaticity directly, or (b) spectrophotometers that measure relative or absolute spectral power distributions. Because LED spectrum can shift with temperature, colorimetry data must be reported at the three different $T_s$ values corresponding to the sensor temperature while operating in the three corresponding application conditions (open air, semi-ventilated, or enclosed).

**Alternative measurement method**

Because the intent is to determine the performance of the luminaire in different temperature environments, alternative methods can be employed. As an example, absolute photometric data (for flux) can be measured at one temperature value ($T_s$ when operating at 25ºC ambient) using one of the above mentioned methods. Then the fixture can be placed inside a thermal chamber and the temperature ($T_s$) can be changed by changing the ambient temperature inside the chamber; then the relative flux and color can be measured using the above mentioned methods. With these measured data, the light output and color values as a function of temperature ($T_s$) can be determined for the luminaire.

If the luminaire manufacturer decides to use the LED manufacturer's data for color and how it changes with temperature, the values must correspond to the exact LED bin category. The procedure used for measuring the performance must be clearly explained in the data sheet.

# Appendix A: Photometric Measurements

The procedures described below are taken from existing standards published by the Illuminating Engineering Society of North America (IESNA) and the Commission Internationale de L'Éclairage (CIE) and are to be used as further guidance to setting up and conducting the tests described in this document.

## *Selection of luminaires*

Luminaires selected for test should be clean and representative of the manufacturer's regular product. Ballasts (or drivers) regularly furnished as part of the luminaire should be used to operate the lamps during the test and should be mounted in their normal locations within the luminaire (IESNA LM-41-98, 1998).

## *Photometric measurements*

**Testing conditions**

**Air movement.** The luminaire (or test lamp during calibration) shall be tested in relatively still air. A maximum airflow of 0.08 meter/second (15 ft./minute) is suggested (IESNA LM-46-04, 2004).

**Lamp seasoning.** Test lamps should be seasoned for a certain number of hours such that their characteristics remain constant during the test to be conducted (IESNA LM-54-99; IESNA LM-46-04, 2004).

**Luminaire stabilization – preburning.** The luminaire requires a certain number of hours from start to allow the lamp and ballast (driver) to reach normal operating temperatures before starting the performance testing. Restarting of the lamp during the test should be avoided. However, if restarting is necessary, the test should be continued only when complete stabilization of the luminaire is again achieved. The lamp is considered stabilized when monitoring light output over a period of 30 minutes produces differences of sequential readings no greater than 0.5% with a minimum of three readings taken approximately 15 minutes apart (IESNA LM-41-98, 1998).

**Test voltage.** The luminaire shall be operated at its rated voltage or current. If the rated voltage or current is a range, the center value shall be used as a test condition (IESNA LM-49-01, 2001).

**Instrumentation.** Instruments shall be selected and used with care to ensure accurate measurements. Instruments should be calibrated a minimum of once per year. Instrument indications should have good reproducibility. The effect, if any, of instruments on measured quantities shall be addressed. See IESNA LM-28-89, *IES Guide for the Selection, Care and Use of Electrical Instruments in the Photometric Laboratory* (1998) for detailed information.

**Position sensitivity.** Lamps such as discharge lamps are sensitive to the effects of orientation. Manufacturer's guidelines for lamp position for best stability and proper operation should always be consulted. Lamp seasoning should also be completed in the same orientation as the intended orientation during testing. Many luminaires are constructed in such a way that they should be photometered only in their normal mounting position. This precaution may be necessary to avoid mechanical disturbances because of sag, warping, or shift in position of critical light controlling components, or to avoid temperature variations due to changes in air flow (IESNA LM-41-98, 1998).

**Photodetectors.** Use photodetectors with a spectral response that follows the CIE spectral luminous efficiency (Vλ) curve (IESNA LM-41-98, 1998).

### Measurement of intensity distribution

A goniophotometer provides a means of mounting the test sample and rotating it through the required angular traverses. For more details about goniophotometers, see IESNA LM-75-01, *Goniophotometer Types and Photometric Coordinates* (2001). For more details about goniophotometer measurement, see IESNA LM-46-04, *Photometric Testing of Indoor Luminaires Using High Intensity Discharge or Incandescent Filament Lamps* (2004), IESNA LM-41-98, *Approved Method for Photometric Testing of Indoor Fluorescent Luminaires* (1998), and IESNA LM-20-94*, Photometric Testing of Reflector-Type Lamps* (1994).

### Measurement of total luminous flux

Total luminous flux for the luminaire may be obtained with the integrating sphere. Inside the integrating sphere, air movement is minimized and temperature is not subject to the fluctuations usually present in a temperature-controlled room. Appropriate corrections shall be made unless substitution standards agree in spectral power distribution, physical size, and shape with the luminaire under test. When the test luminaire and the calibrating lamp are not of the same physical size and shape, compensation for differences in self-absorption shall be made (CIE 84, 1989).

### Measurement of color

The color of a luminaire may be specified in terms of its chromaticity coordinates, and these are best obtained by calculation from the spectral power distribution. The measurement can be carried out by placing the luminaire inside an integrating sphere.

CIE publication 127 (CIE 127-1997) recommends that "The wavelength resolution of the spectroradiometer used to measure the spectral power distribution of a LED luminaire should be better than 1 nm to enable it to follow the steep slopes of the spectral distribution near the half intensity levels. The uncertainty of the wavelength scales should be less than 0.5 nm if the characteristic wavelengths are to be specified with the necessary accuracy. The sensitivity of the spectroradiometer should be high enough to measure all parts of the distribution with a resolution better than 1% of the level at the peak wavelength. After compensation, any zero error in the output signal of the spectrometer should be less than ±0.1% of the level at the peak wavelength." (CIE 127-1997) For further guidance on spectroradiometric measurement procedures and possible sources of error, see Commission Internationale de L'Éclairage publication CIE 063-1984, *The Spectroradiometric Measurement of Light Sources*.

### Beam angle

The beam angle is designated as the total angular spread of the cone intercepting the 50 percent of the maximum intensity (Rea, 2000). The beam angle may be obtained by calculation from the intensity distribution data.

## Appendix B: Luminaire Test Enclosure for Sphere Measurements

The objective is to create a luminaire test enclosure for sphere photometry that can keep the lamp and the ballast (or driver) at operating temperatures similar to what they would be in real-life applications. Figures B1 and B2 show the schematic of the proposed test enclosure. The function of this enclosure is to test directional lamps or luminaires, similar to the one typically used in testing reflector lamps in integrating spheres (IESNA LM-20-1994). The main difference with this proposed enclosure is that it has heaters to raise the temperature within the enclosure in order to maintain the lamp and ballast (driver) temperatures ($T_s$ and $T_d$) at values similar to those measured inside the luminaire in application. The outside of this test enclosure and the necessary mounting rods are all painted white (similar to the paint used in integrating spheres).

**Figure B1.** Luminaire test enclosure for sphere measurements of directional lamps such as MR and PAR lamps.

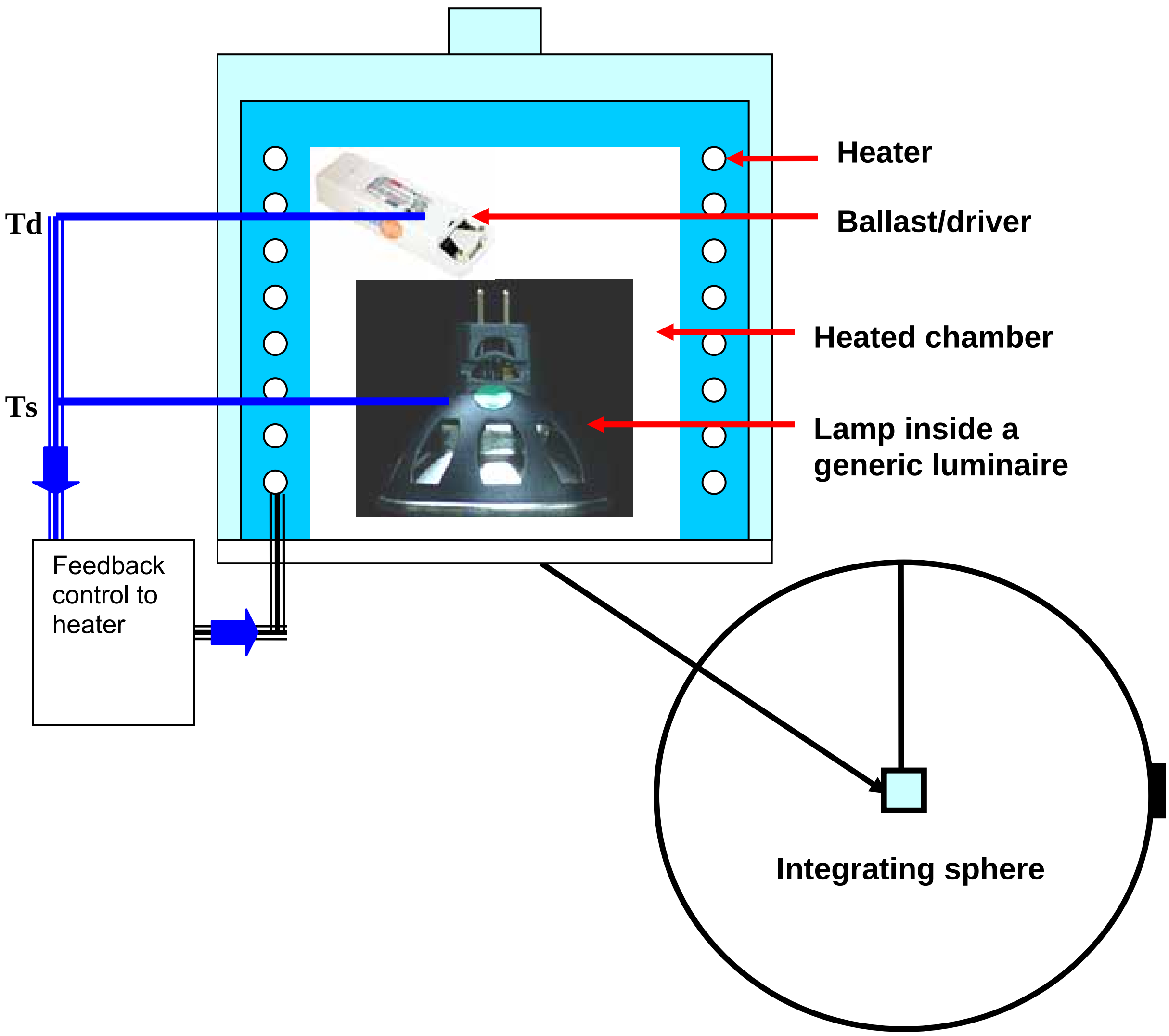
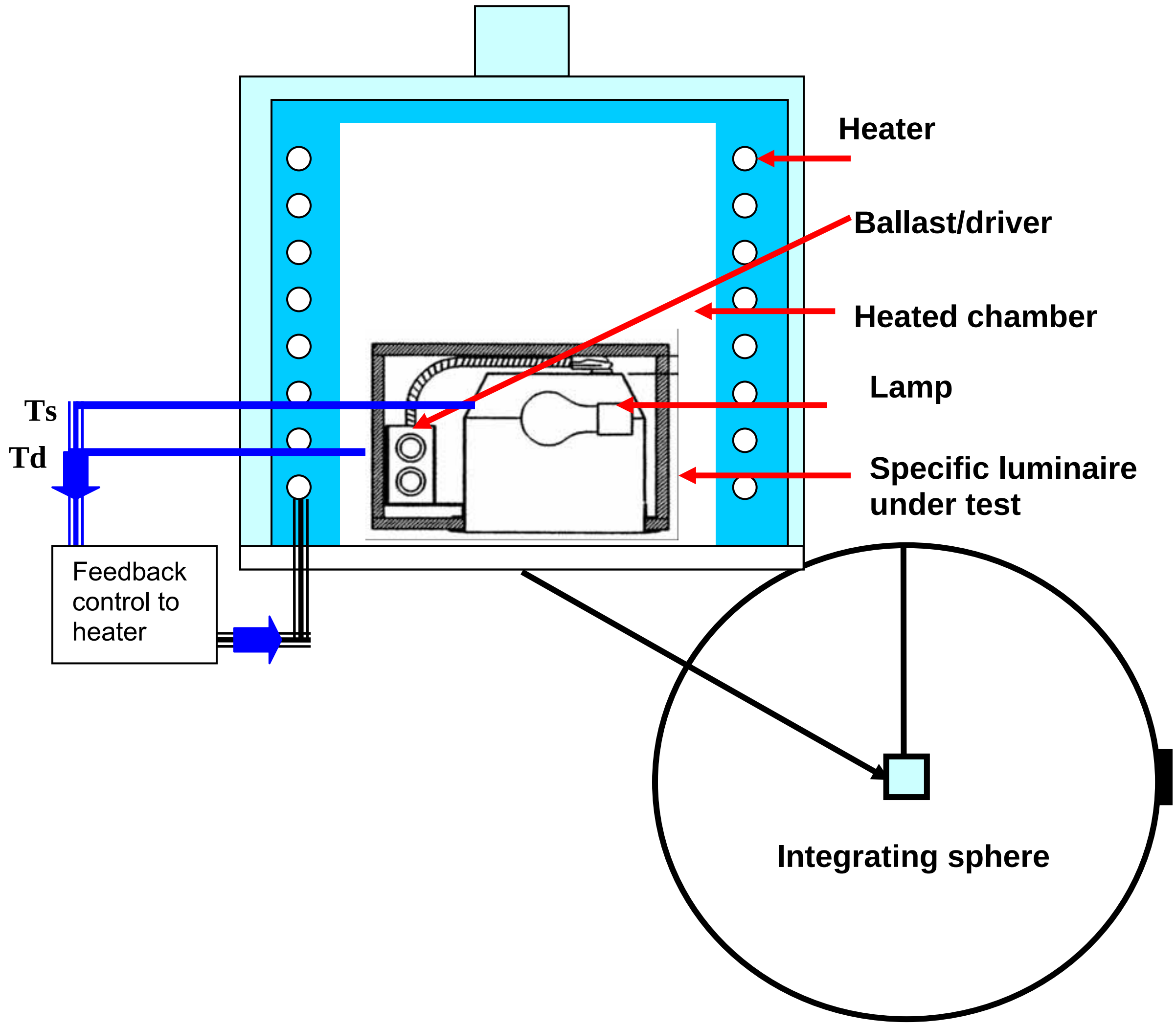


**Figure B2.** Luminaire test enclosure for sphere measurements of directional luminaires, such as recessed downlights for incandescent or compact fluorescent lamps.



## Appendix C: Temperature Measurement Test Boxes

According to the luminaire rating (open air, non-IC, or IC-rated), the luminaire is placed in one of the three different environments (open air, semi-ventilated, or enclosed). Thermocouples are attached to the lamp and the ballast (or driver) at the manufacturer-specified locations.

Figure C1 and Figure C2 illustrate the test boxes for recessed semi-ventilated and enclosed luminaires according to the guidelines provided by UL 1598 (2000). Both boxes are rectangular and have four sides, a top, and a bottom constructed of plywood panels with the butt joints secured with wood screws or nails. An aperture cut in the bottom surface gives access to a recessed can mounted inside the box.

The sides and top of the test box as shown in Figure C1 shall be 13 mm (0.5 in) from the lamp housing or heat-producing components, or in contact with permanently attached parts that are more than 13 mm (0.5 in) from the lamp housing or heat-producing components.

The four sides of the test box shown in Figure C2 have a minimum distance of 215 mm (8.5 in) from the nearest part of the lamp housing or other heat-producing components. Thermal insulation of the loose-fill type shall be poured into the test box through the open top, in progressive layers, without applying any compacting procedure.

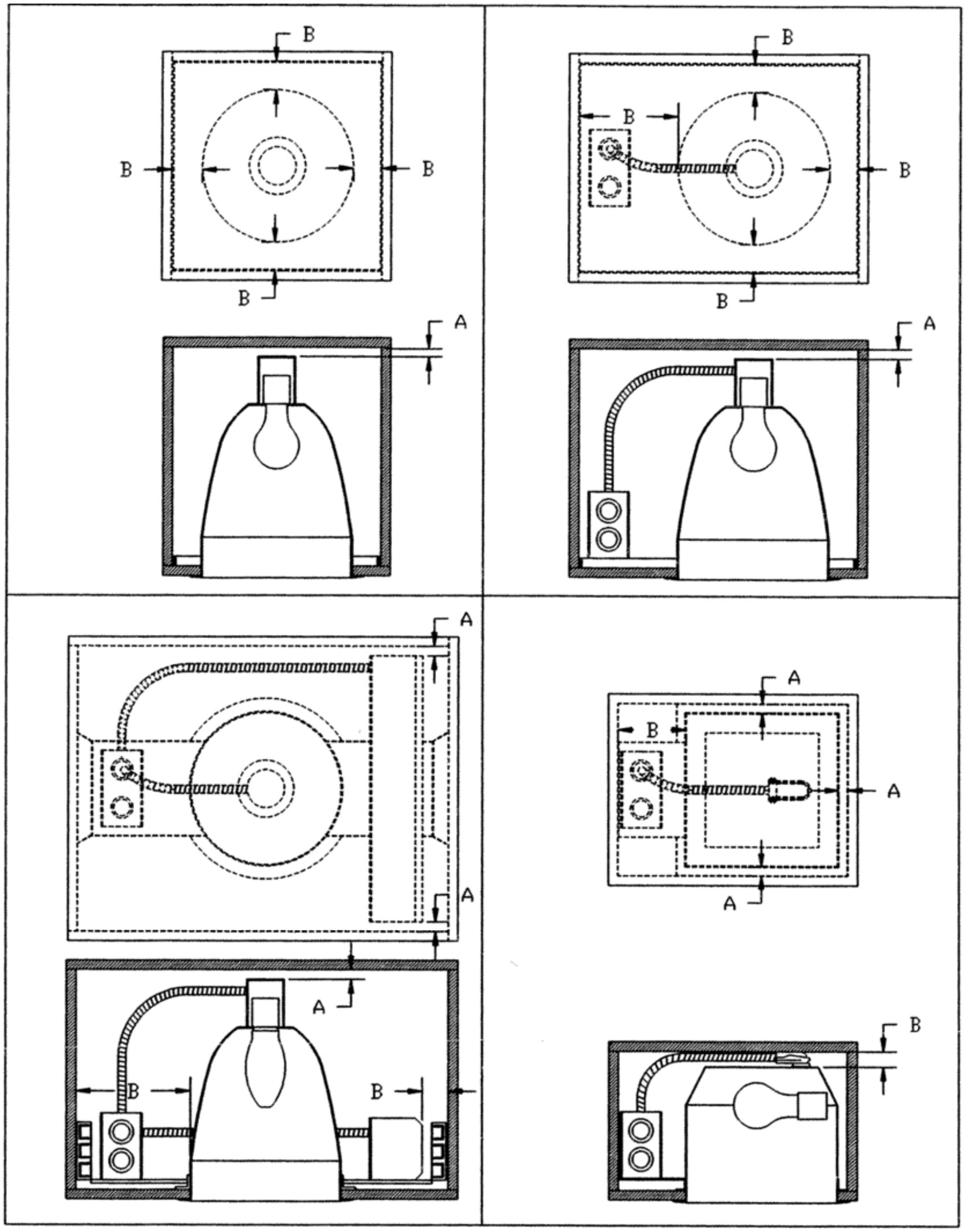



**Figure C1.** Test box for a semi-ventilated, recessed ceiling-mounted luminaire, as recommended by UL 1598. The upper drawings are the top view and the lower drawings are a side view. Dimension A is 13 mm (0.5 in), Dimension B is more than 13 mm (0.5 in), and permanently attached parts are in contact with the test box (UL 1598, 2000).

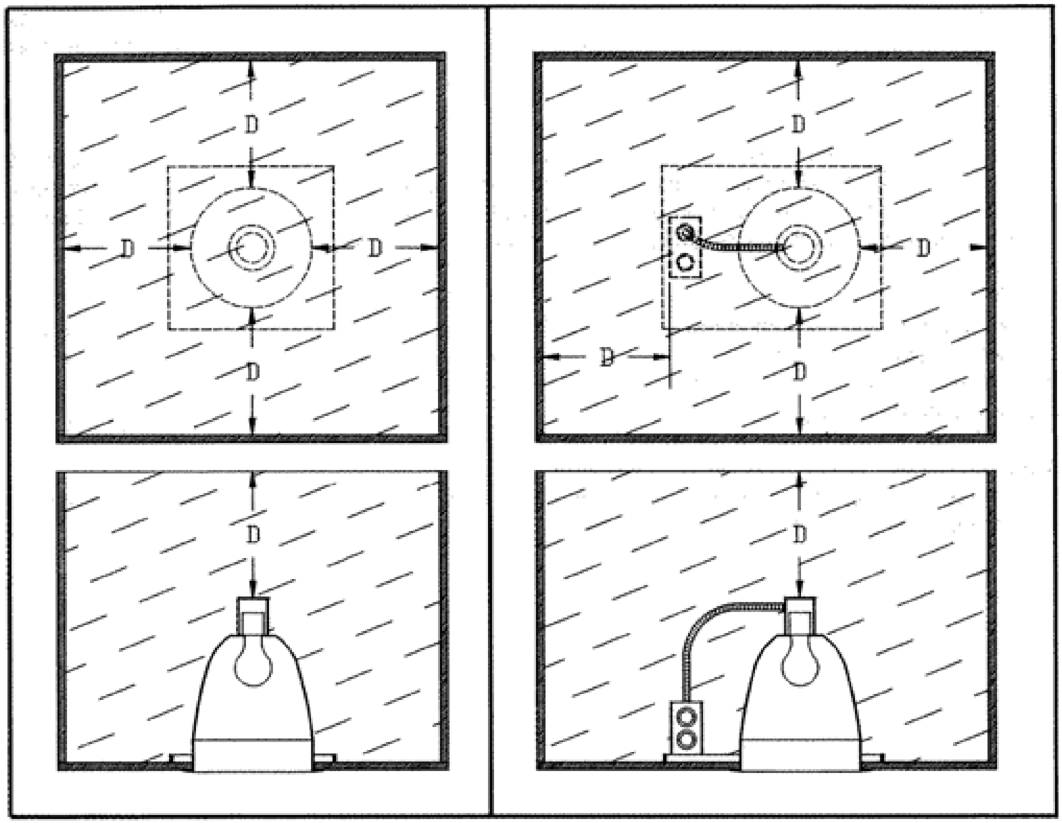



**Figure C2.** Test box for an enclosed recessed ceiling-mounted luminaire, as recommended by UL 1598. The upper drawings are the top view and the lower drawings are a side view. Dimension D is 215 mm (8.5 in) from the nearest part of the lamp housing or other heat-producing part (UL 1598, 2000).

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## About ASSIST

ASSIST was established in 2002 by the Lighting Research Center at Rensselaer Polytechnic Institute to advance the effective use of energy-efficient solid-state lighting and speed its market acceptance. ASSIST's goal is to identify and reduce major technical hurdles and help LED technology gain widespread use in lighting applications that can benefit from this rapidly advancing light source.