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Recommendations for Testing and Evaluating Under-cabinet Luminaires

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Introduction

This document outlines a recommendation for testing and evaluating the photometric and life performance of white light under-cabinet luminaires for all light source technologies. 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

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).

Under-cabinet luminaires are usually mounted under a cabinet, shelf, or similar structural surface to be in close proximity of the task and to produce localized lighting. They can be found under kitchen cabinets, in closets, and in other spaces containing work surfaces covered by cabinetry or shelving. They usually contain low-wattage incandescent, tungsten-halogen, linear or compact fluorescent lamps (CFLs), or white light-emitting diodes (LEDs). Under-cabinet luminaires are generally task lights that provide either directional or diffuse light and complement the general lighting in the space (Rea, 2000).

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. And in order to understand the effect that heat has on luminaire performance, the operating temperature must be measured accurately. Certain temperature points within a light source or ballast are known to have a direct

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[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.

relationship with performance. However, these temperature points are not accessible once the light source and ballast (or driver) are packaged into a luminaire. Therefore, accessible temperature points must be identified that correlate to those known points that affect performance.

Proposed Method

Typically in under-cabinet lighting applications, the distance between the light source and the illumination task plane is small. Therefore, for accurate illuminance calculations in this application, near-field photometry is more appropriate than traditional far-field photometry. Furthermore, the amount of flux illuminating the task plane is the most useful, not all the flux that exits the luminaire. Therefore, when determining the luminaire luminous efficacy, one must consider only the light that is useful for lighting the task and the total power used by the fixture.

Luminaire luminous efficacy = (Total lumens on the task / Total fixture power)

Measuring task illuminance, illuminance uniformity, useful luminous flux, and the luminaire luminous efficacy

The task illuminance, illuminance uniformity, useful luminous flux, and luminaire luminous efficacy can be measured using the following procedure.

Step 1: Turn the luminaire on for a certain number of hours for seasoning the light source (see Appendix A below on p. 7, “Testing conditions: Lamp seasoning”). (IESNA LM-54-99, 1999).

Step 2: Inside the test alcove, mount the luminaire onto the top plywood piece per the manufacturer’s recommendation for installing the luminaire (see Appendix B below on p. 8 for details of the luminaire test alcove for near-field photometry).

Step 3: Turn the luminaire on and allow it to operate for a certain number of hours so that the light output reaches stability (see Appendix A below on p. 7, “Testing conditions: Luminaire stabilization – preburning”).

Step 4: When taking measurements on the horizontal plane, cover the top (top plywood piece), vertical (middle plywood piece), and horizontal (bottom plywood piece) surfaces with a piece of black cloth (e.g., duvetyn) or other light-absorbing material (such as Edmund Optics flock paper[2]) to avoid light interference between the vertical surface and the horizontal surface, and between the top plywood piece and the horizontal plane. Alternatively, all three surfaces can be painted with a low reflectance matte black paint, such as Rosco TV Black # 05740.[3] It is also important to reduce the contribution from extraneous lighting on the measurement surfaces. If the testing cannot be performed in a dark room, block any ambient and reflected light with light-absorbing material around the testing alcove.

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[2] Available from http://www.edmundoptics.com/onlinecatalog/displayproduct.cfm?productID=1502&search=1
[3] Available from http://www.rosco.com/us/scenic/tv_paint.asp

Step 5: Place the illuminance meter at the center of one individual grid square on the bottom plywood surface and record the horizontal illuminance E_{ij}. E is in the unit of footcandles. Repeat for all squares.

Step 6: Calculate the luminous flux, Φ_h (lm), reaching the bottom plywood surface in the area of interest:

$$\Phi_h = \Sigma E_{ij} \times A$$

Where A is the area of an individual square in (ft^2).

Step 7: Calculate the average horizontal illuminance (fc) on the bottom plywood surface:

$$E_{average} = \Sigma E_{ij} / (i \times j)$$

Step 8: Repeat steps 4 to 7 to obtain the useful luminous flux Φ_v (lm) for the vertical surface.

Step 9: Record the luminaire input power, P, in watts.

Step 10: The luminaire luminous efficacy is given by:

$$\text{Luminaire luminous efficacy} = ((\Phi_h + \Phi_v) / P)$$

Step 11: The reported data shall also include the recorded illuminance measurements for each grid square, as shown in Appendix C: Sample Report Form. The report may include multiplying factors for surface colors other than black, so that users can adjust the illuminance measurements to match their application.

Usually, for under-cabinet lighting applications it is desirable to have 20 to 30 fc (average) on the horizontal surface and 5 to 10 fc on the vertical back surface.

CCT, CRI, and chromaticity

Presently, no testing method has been established for measuring the color properties of the beam of under-cabinet luminaires. Therefore, use the data provided by the white light source manufacturers for CCT, CRI, and CIE x,y values.

Measuring luminaire life

For life-testing under-cabinet light fixtures, luminaires must be mounted to a plywood surface similar to the top plywood piece of the test alcove described in Appendix B below. The mounting is done according to the manufacturer's recommendation for installing the luminaire in application. The plywood should extend 1 inch all around from the luminaire. Thermocouples must be attached to the temperature measurement points identified by the manufacturer for monitoring the lamp and driver temperatures.

For life-testing LED luminaires, follow the procedures explained in *ASSIST recommends. . . LED life for general lighting* (ASSIST, 2005).

For long-life light sources, the luminaire life shall be taken as the ballast (or driver) life, as the ballast (driver) components may have a shorter life than the light source.

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, 1999; 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 and current. 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 a 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* (1989) for detailed information.

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

Appendix B: Test Condition and Near-field Photometry Measurements

The objective is to create an under-cabinet luminaire test condition for near-field photometry that can keep the lamp and the ballast (or driver) at operating temperatures similar to what they would be in real-life applications. Figure B1 shows the schematic of the proposed test alcove. Its dimensions are similar to a typical under-cabinet space found in North America. The alcove shall have three sides made of one-half inch thick plywood, joined at right angles (UL, 2000). The depths are 12 and 24 inches for the top and bottom plywood pieces, respectively, and the height of the middle plywood piece needs to be determined so that the distance between the top surface of the illuminance meter detector and the bottom surface of the luminaire is 18 inches.

The test under-cabinet luminaire shall be mounted onto the top plywood piece per the manufacturer's recommendation for mounting the luminaire in the application. If no mounting recommendation is given, mount the luminaire at the front edge of the plywood. The plywood shall project a minimum of 12 inches beyond the light opening of the luminaire in either direction. Table B1 lists the most common luminaire lengths and their associated minimum test alcove lengths. Figure B1(a) is the top view, and Figure B1(b) is a section through the center of the top view. Table B2 shows performance data from five under-cabinet luminaires tested at the Lighting Research Center using the procedures and test alcove described in this document.

Draw a grid on the middle and bottom pieces of plywood, as shown in Figure B2. The individual sections of the grid shall be square, and the squares shall be 4-inch by 4-inch. Alternatively, the grid size can be different, but in no case shall the squares be larger than 6-inch by 6-inch. The originating point of the grid on the bottom surface shall be the grid square whose center coincides with the centerline of the luminaire's light opening. The grid shall project a minimum of 12 inches beyond the length of the light opening of the luminaire in either direction.

Table B1. Test alcove lengths for common luminaire lengths.

Luminaire length (in.)	Minimum test alcove length (in.)
12	36
18	42
36	60
48	72

Figure B1. Plan and side views of the luminaire test alcove for near-field photometry measurements.

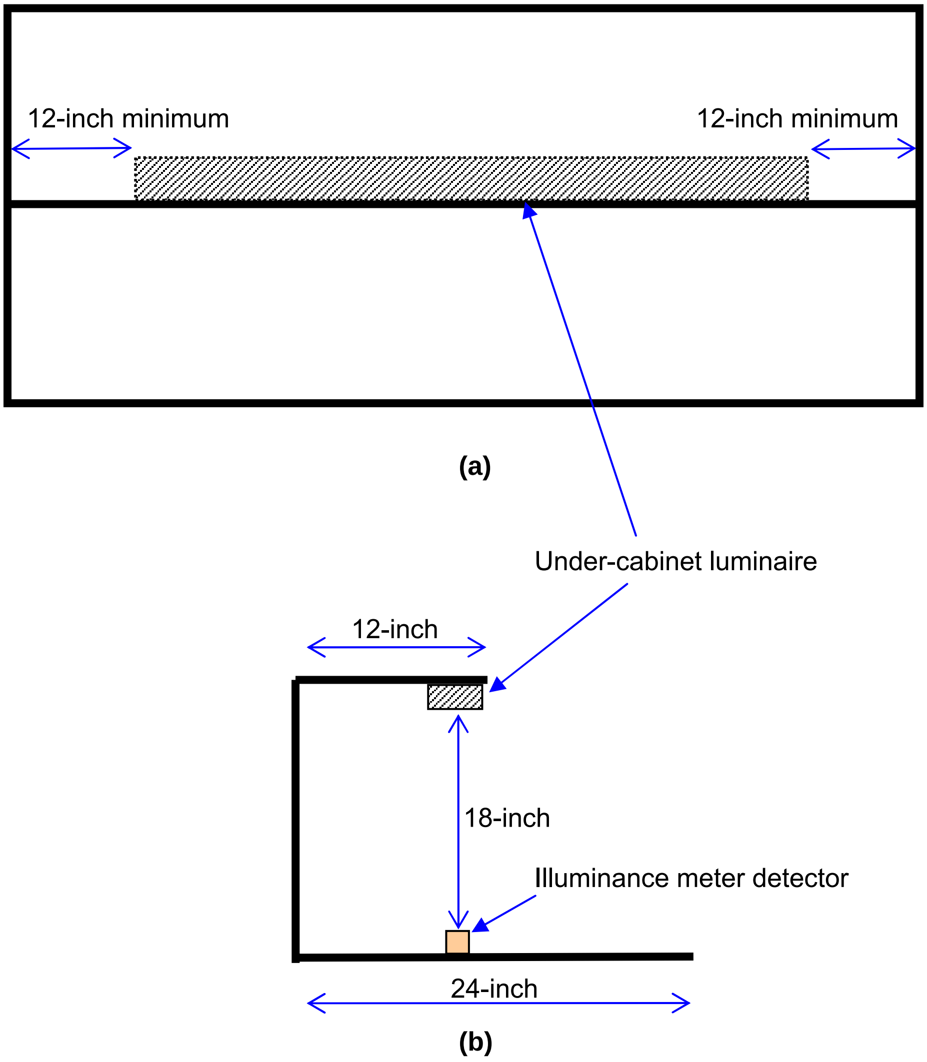


Figure B2. Illuminance measurement test grid for a 12-inch-long luminaire.

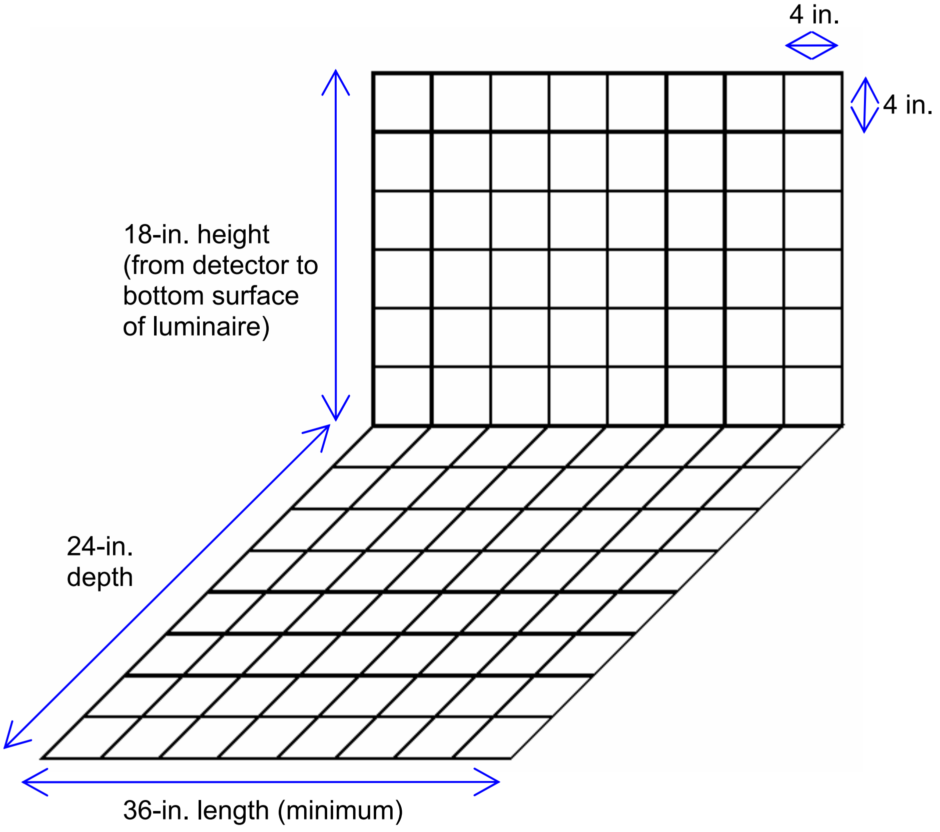


Table B2. Performance measurements for five under-cabinet luminaires using the test procedure outlined in this document and traditional integrating sphere measurements.*

* These are sample data. These measurements may change with changes to the test procedures outlined in this document.

		Linear halogen	**F8T5 sample 1**	**F8T5 sample 3**	**LED prototype 1**	**LED prototype 2**
Grid	Luminaire length (in)	12	12	20	12	12
	Horizontal flux (lm)	53	91	180	111	173
	Horizontal test area	36-in by 24-in	36-in by 24-in	44-in by 24-in	36-in by 24-in	36-in by 24-in
	Horizontal minimum illuminance (fc)	1	3	5	4	8
	Horizontal maximum illuminance (fc)	37	31	49	35	51
	Horizontal average illuminance (fc)	**9**	**15**	**26**	**18**	**29**
	Horizontal uniformity (average:minimum)	**7:1**	**5:1**	**5:1**	**4:1**	**3:1**
	Vertical flux (lm)	23	107	256	69	109
	Vertical test area	36-in by 20-in	36-in by 20-in	44-in by 20-in	36-in by 20-in	36-in by 20-in
	Vertical minimum illuminance (fc)	0.05	2	5	1	2
	Vertical maximum illuminance (fc)	17	67	160	34	60
	Vertical average illuminance (fc)	**5**	**21**	**44**	**14**	**22**
	Vertical uniformity (Top$_{average}$:Bottom$_{average}$)	**7:1**	**1:1**	**4:1**	**2:1**	**4:1**
	(Luminaire + Driver) Input power (W)	18.1	8.2	13.8	7.7	7.6
	(Luminaire + Driver) Voltage (V)	119.0	119.5	118.8	119.8	120.0
	(Luminaire + Driver) Current (A)	0.16	0.11	0.20	0.07	0.06
	Ambient temperature (ºC)	23	23	23	23	23
	Luminaire operating temperature* (ºC)	38.2	33.6	44.8	30.6	35.5
	Application flux (lm)	**76**	**198**	**437**	**180**	**283**
	Application efficacy (lm/VA)	**4.0**	**14.9**	**18.7**	**22.7**	**36.5**
	Application efficacy (lm/W)	**4.2**	**24.1**	**31.5**	**23.2**	**37.4**
Sphere	**Luminaire light output (lm)**	**88**	**281**	**623**	**222**	**420**
	(Luminaire + Driver) efficacy (lm/W)	**5**	**33**	**42**	**29**	**56**
	CCT	2591	3044	2813	5887	7542
	CRI	100	87	82	76	71
	Driver input current (A)	0.16	0.13	0.22	0.07	0.07
	Driver input voltage (Vac)	119.9	120.0	120.2	120.1	120.1
	Driver input power (W)	18.4	8.6	14.7	7.8	7.6

*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.

Appendix C: Sample Report Form

Product information: **Date:** March 10, 2007

Luminaire description and catalog number LRC LED undercabinet lighting prototype

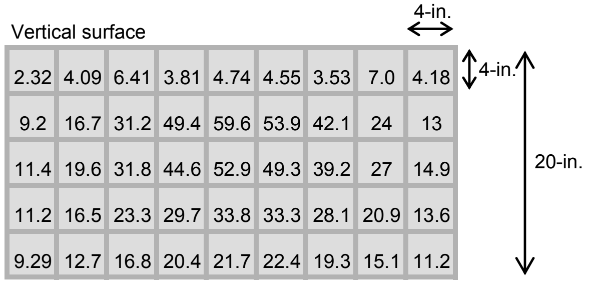
Light source	Five 1-W white LEDs	
	Correlated color temperature	7542
	Color rendering index	71
	Chromaticity coordinates (CIE 1931 xy)	(0.3015, 0.3035)
Fixture length (in)	12 inches	

Photometric testing:

Grid size 4-in. by 4-in.

Vertical test area	20-in. by 36-in.
Vertical overall average illuminance	22.0 fc
Vertical luminous flux	110.0 lm

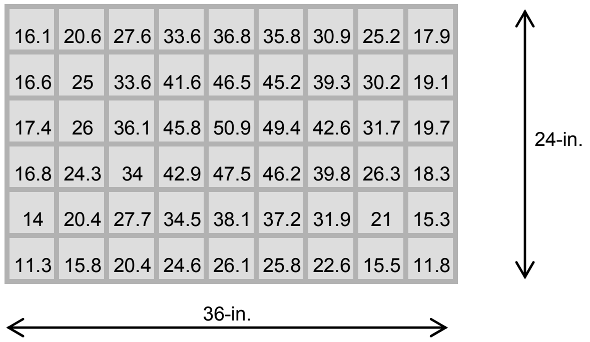
Vertical surface



2.32	4.09	6.41	3.81	4.74	4.55	3.53	7.0	4.18
9.2	16.7	31.2	49.4	59.6	53.9	42.1	24	13
11.4	19.6	31.8	44.6	52.9	49.3	39.2	27	14.9
11.2	16.5	23.3	29.7	33.8	33.3	28.1	20.9	13.6
9.29	12.7	16.8	20.4	21.7	22.4	19.3	15.1	11.2

Horizontal test area	24-in. by 36-in.
Horizontal overall average illuminance	29.1 fc
Horizontal luminous flux	174.6 lm

Horizontal surface



16.1	20.6	27.6	33.6	36.8	35.8	30.9	25.2	17.9
16.6	25	33.6	41.6	46.5	45.2	39.3	30.2	19.1
17.4	26	36.1	45.8	50.9	49.4	42.6	31.7	19.7
16.8	24.3	34	42.9	47.5	46.2	39.8	26.3	18.3
14	20.4	27.7	34.5	38.1	37.2	31.9	21	15.3
11.3	15.8	20.4	24.6	26.1	25.8	22.6	15.5	11.8

SUMMARY:

Total luminous flux reaching the application area	284.6 lm
Fixture input power	7.6 W
Application Efficacy	37.4 lm/W
Fixture input voltage	120.1 V
Fixture input current	0.07 A
Ambient temperature	22.7 ºC
Fixture operating temperature (Ts)	35.5 ºC

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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.