NLPIP Lighting Answers
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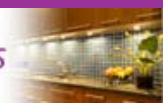
LED Residential Under-cabinet Luminaires



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Abstract

Lighting Answers: LED Residential Under-cabinet Luminaires provides information about LED under-cabinet **luminaires** that were available in consumer-oriented retail stores in the Albany, New York, area in the spring of 2009. The four available linear under-cabinet luminaires intended for kitchen applications were tested to determine the amount of light each provides on countertop and backsplash areas, the uniformity and color of the light, and the **efficacy** of the luminaires. Traditional linear under-cabinet luminaires—two fluorescent and two incandescent xenon models—were tested for comparison. This report discusses the results of the performance testing, energy and financial savings, and other considerations such as warranties.

Introduction

In the spring of 2009, National Lighting Product Information Program (NLPIP) staff visited stores in the Albany, New York, area where people would typically buy lamps (commonly referred to as light bulbs) and luminaires for their homes to determine what LED products were available. These stores included discount retailers, wholesale clubs, supermarkets, drug stores, home improvement stores, and hardware stores. The results are described in the NLPIP document *Lighting Answers: Availability of LED Lighting Products for Consumers*.

One type of LED product found during the store survey was under-cabinet luminaires, which are mounted to the underside of upper cabinets in order to provide counter-top illumination or are mounted under upper shelves and in display cases. These luminaires have either linear or puck forms, and some can be “linked” or electrically connected together, so multiple luminaires can be installed more easily.

At the time of the spring 2009 survey, nine puck and six linear under-cabinet luminaires were identified through this survey, as shown in Table 1. Other under-cabinet luminaires were available through channels other than the stores visited for this survey. For example, some manufacturers produce LED under-cabinet luminaires intended for the commercial marketplace to illuminate office desks; these products were not surveyed or tested.

Table 1. LED under-cabinet luminaires available in the Albany, New York area during the period from May 23 through June 4, 2009.*

Type	Brand	Model	Store(s)	Price (US$)	Manufacturer's data on package			Notes
					Luminous flux (lumens)	Power (W)	Life	
Puck	Ace	3224037	Ace Hardware	34.99	NS	2.5/puck	NS	3 pucks
	Hampton Bay	403-144	The Home Depot	39.96	NS	2/puck	NS	3 pucks, dimming
	Hampton Bay	830-758	The Home Depot	33.97	NS	0.68/puck	NS	3 pucks
	Hampton Bay	834-355	The Home Depot	49.96	NS	0.23/puck	NS	10 mini-pucks
	Hampton Bay	957-254	The Home Depot	14.96	NS	2.6	20 yr	1 puck
	Hampton Bay	980-984	The Home Depot	29.92	NS	2.6/puck	20 yr	3 pucks
	Lights of America	7200 LED BN	Ace Hardware	12.99	NS	2.5	NS	1 puck
	Utilitech	283277	Lowe's	49.00	NS	NS	50,000 hr	3 linked pucks
	Utilitech	288741	Lowe's	21.98	NS	2.25	50,000 hr	4" rectangle
Linear	GE	10408	The Home Depot	54.96	NS	5	NS	12" linkable strip
	GE	10409	The Home Depot	64.98	NS	6	NS	18" linkable strip
	GE	10432	The Home Depot	19.97	NS	1.5	NS	Add-on 12" strip for GE model 10434
	GE	10434	The Home Depot	39.97	NS	1.5	NS	"Accent lighting," 12" strip
	Utilitech	283278	Lowe's	59.00	NS	5.5	50,000 hr	18" strip
	Utilitech	283520	Lowe's	24.98	NS	NS	NS	18" strip

* "NS" indicates information not supplied on package.

NLPIP staff purchased and tested four of the six available LED linear under-cabinet luminaires. Based upon the text and photographs on the packages of the GE 10434 and GE 10432, these two models are intended to provide accent lighting for bookshelves, rather than illumination on countertops. Because the intended use of these two models (and therefore their design goals and performance) is markedly different than those intended for kitchens, they were not included for performance testing. In addition to the four LED models, two fluorescent and two xenon incandescent luminaires were tested for further comparison. The eight models that NLPIP researchers tested are shown in Table 2. Bar coding stickers visible in the photographs were part of the NLPIP tracking methodology and were not found on the luminaires when they were purchased.

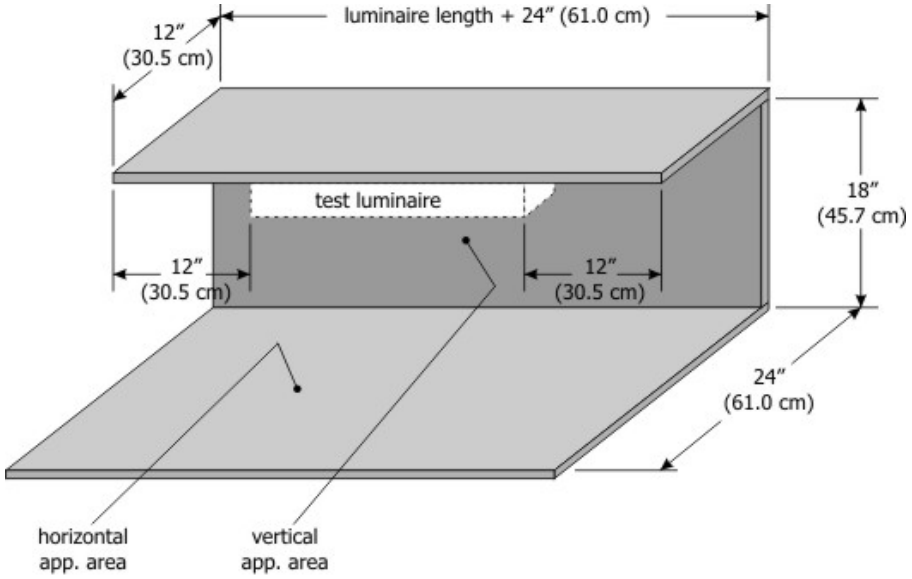
Table 2. Under-cabinet luminaires tested by NLPIP.

Light source	Brand	Model	Store(s)	Price (US$)	Length given on package [in. (cm)]	Photograph
LED	GE	10408	The Home Depot	54.96	12 (30.5)	
	GE	10409	The Home Depot	64.98	18 (45.7)	
	Utilitech	283278	Lowe's	59.00	18 (45.7)	
	Utilitech	283520	Lowe's	24.98	18 (45.7)	

Fluorescent	GE	10113	The Home Depot	25.78	18 (45.7)	
	Utilitech	069486	Lowe's	16.98	18.25 (46.4)	
Xenon (incandescent)	GE	10136	The Home Depot	46.97	18 (45.7)	
	Utilitech	283542	Lowe's	34.98	17.6 (44.8)	

NLPIP tested the under-cabinet fixtures based on *ASSIST recommends* testing procedures, described in the publication *Volume 2, Issue 3: Recommendations for Testing and Evaluating Under-cabinet Luminaires.* The *ASSIST recommends* test procedure defines an application area for under-cabinet fixtures (intended to simulate a kitchen counter and back splash) consisting of a horizontal area 24 inches (61.0 cm) deep and a vertical area 18 inches (45.7 cm) high, with a width extending 12 inches (30.5 cm) beyond the length of the luminaire on each side, as shown in Figure 1.

Figure 1. Under-cabinet luminaire test apparatus.



The *ASSIST recommends* program has published two documents to help select under-cabinet lighting:

1. *Volume 2, Issue 1: A Homeowner's Guide to Residential Under-cabinet Lighting: Getting Good Lighting for Your Kitchen Counters*

2. *Volume 2, Issue 2: How to Select Residential LED Under-cabinet Lighting*

NLPIP investigators tested the luminaires shown in Table 2 to evaluate important properties identified in these two documents.

How much light do LED under-cabinet luminaires produce?

Under-cabinet luminaires serve two general functions in the kitchen. First, under-cabinet luminaires can provide a sense of brightness for the homeowner without raising overall ambient light levels. Second, under-cabinet luminaires provide illumination for tasks performed on the counter, such as reading a recipe or chopping food. How much illumination is needed? The *Illuminating Engineering Society of North America (IESNA) Lighting Handbook, 9th Edition* (Rea 2000) recommends minimum illumination levels of 300 **lux** for general tasks and 500

lux for critical tasks such as chopping. However, McGuiness and Boyce (1984) found that an illumination level of 100 lux was sufficient for people to perform all kitchen tasks quickly and to feel satisfied with the light level.

The test apparatus, which simulates the geometry of a kitchen countertop and back splash, has black, non-reflective surfaces so as to measure only direct illumination. In an actual kitchen, a small amount of the light shining on the backsplash will be reflected onto the horizontal application surface, which gives the countertop additional lighting. This study purposely does not account for this additional light because backsplashes vary greatly from kitchen to kitchen. When NLPIP investigators covered the vertical back splash area with matte white paper for one LED luminaire, the average horizontal **illuminance** increased by 5%.

The Utilitech 283542 can be turned on to a high or low setting, and it can swivel forward and back. For these tests, it was turned to the highest light output setting and was swiveled so the bottom of the luminaire was horizontal, presumably indicating that the light was aimed directly downward.

As shown in Table 3, all but one luminaire (the Utilitech 283520) provided at least the light level recommended by McGuiness and Boyce (1984) and would provide sufficient illumination for kitchen tasks. If there were a high ambient light level in the kitchen added to the illumination from the Utilitech 283520, then the total could reach the recommended level, but often a person is shading the countertop from ambient light when standing at the counter. Therefore, NLPIP recommends using luminaires that provide more illumination than produced by this model when task illumination is a priority.

Table 3. Luminous flux and illuminance on horizontal surface provided by under-cabinet luminaires.

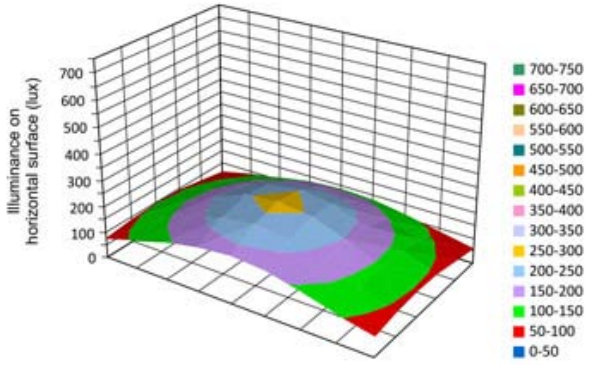
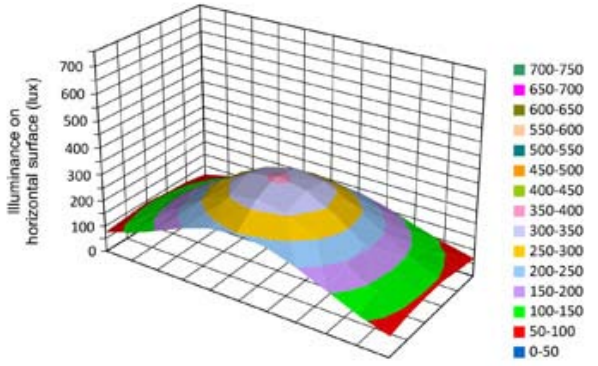
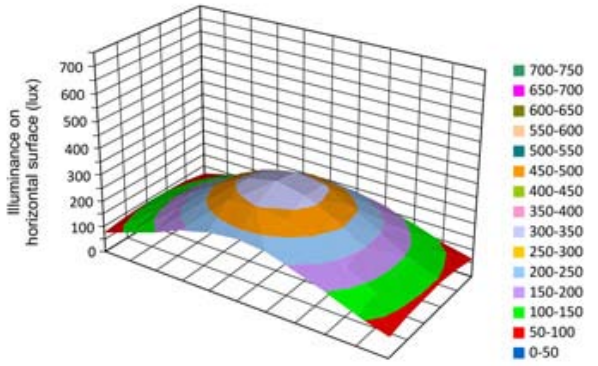
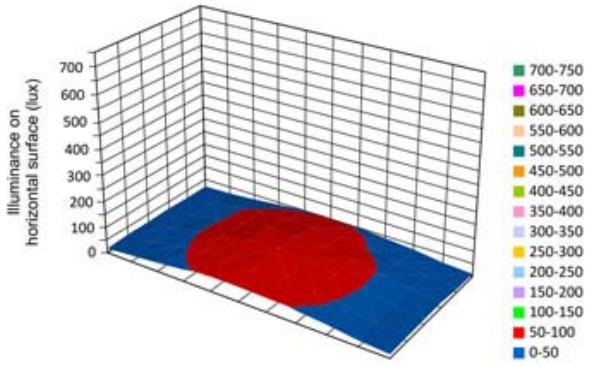
Light source	Brand	Model	Luminous flux (lm)			Illuminance on horizontal application area (lux)	
			Horizontal application area	Vertical application area	Total	Average	Maximum
LED	GE	10408	82.5	34.4	117	148	265
	GE	10409	127	51.0	178	186	360
	Utilitech	283278	115	77.7	175	169	331
	Utilitech	283520	30.7	15.3	46.0	45	92
Fluorescent	GE	10113	141	159	301	207	415
	Utilitech	069486	110	151	261	162	354
Xenon (incandescent)	GE	10136	222	45.8	267	325	747
	Utilitech	283542	157	65.8	223	230	449

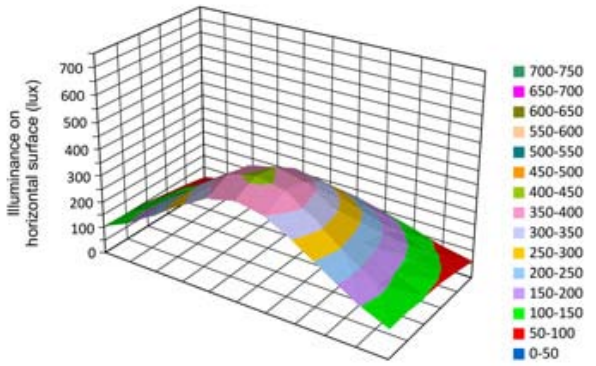
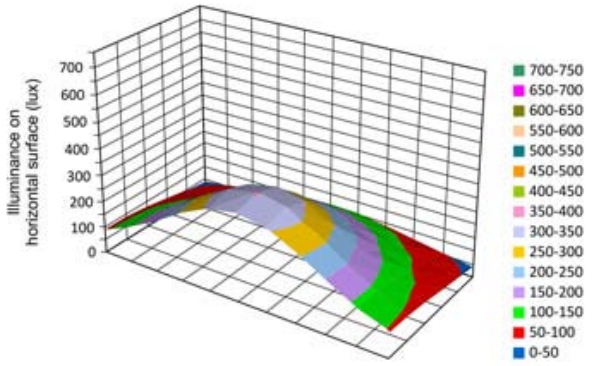
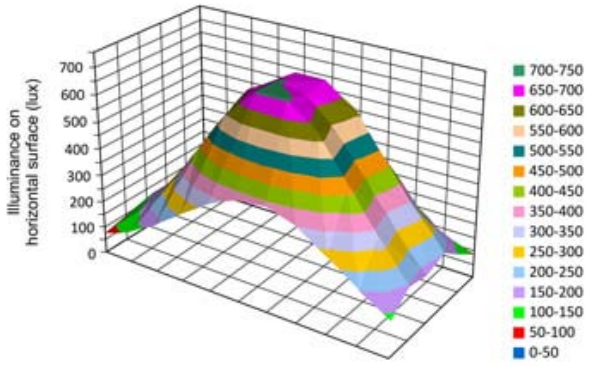
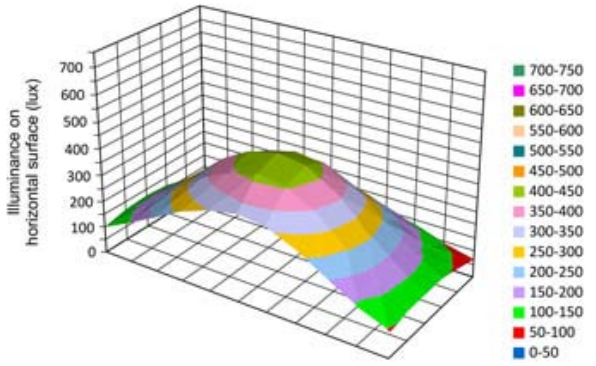
How uniform is the light produced by LED under-cabinet luminaires?

The IESNA recommends that the illumination in the area immediately surrounding the task area not be five times greater than or less than one fifth the illumination in the task area itself. *ASSIST recommends* suggests evaluating this **uniformity** ratio by comparing the average illuminance of the entire application area with the minimum value found on the application area. This average:minimum illuminance ratio should not exceed 5:1. Good uniformity (a ratio less than 5:1) improves visual comfort and reduces shadows.

Table 4 shows the uniformity for the under-cabinet luminaires that NLPIP measured. The lower the ratio in the uniformity column, the better. Table 4 also includes plots of the illuminance on the horizontal application (countertop) area. The steeper the surface, the lower the uniformity. All of the luminaires had a uniformity ratio less than the recommended 5:1 except the GE 10136 (xenon incandescent), which slightly exceeded it. NLPIP found that all of the luminaires provided adequate uniformity, which can be further improved by installing multiple luminaires next to one another so their areas of illumination overlap.

Table 4. Uniformity of lighting within the application area on a horizontal surface.

Light source	Brand	Model	Uniformity on horizontal application area	Uniformity distribution
LED	GE	10408	2.4:1	
	GE	10409	3.0:1	
	Utilitech	283278	3.3:1	
	Utilitech	283520	3.1:1	

Fluorescent	GE	10113	3.5:1	
	Utilitech	069486	4.4:1	
Xenon (incan-descent)	GE	10136	5.9:1	
	Utilitech	283542	3.3:1	

How energy-efficient are LED under-cabinet luminaires?

Many people are interested in LEDs as a technology with the potential to reduce energy use and perhaps save money as a result. As an aid in determining which products use the least amount of energy, application efficacy describes how much light reaches the application area per unit of electrical input power. Application efficacy considers only the luminous flux falling on the application area, as defined in the Introduction, and disregards light falling on other areas, thus giving "useful light" per watt.

The last column of Table 5 shows the application efficacy of the under-cabinet luminaires tested by NLPIP. The higher the efficacy, the better. The luminous flux falling on the application area includes both the horizontal and vertical surfaces (the countertop and backsplash) in this analysis.

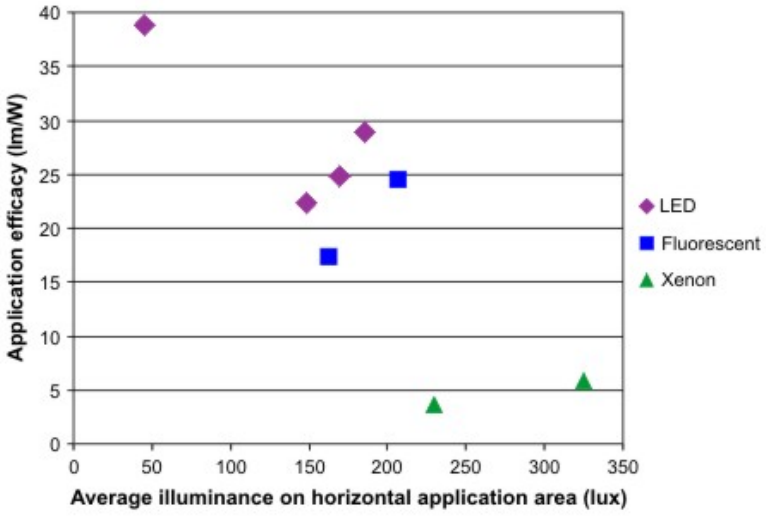
Table 5. Application efficacy of under-cabinet luminaires.

Light source	Brand	Model	Power, measured (W)	Application efficacy (lm/W)
LED	GE	10408	5.24	22.3
	GE	10409	6.20	29.0
	Utilitech	283278	7.03	24.9
	Utilitech	283520	1.19	38.8
Fluorescent	GE	10113	12.2	24.6
	Utilitech	069486	15.0	17.4
Xenon (incandescent)	GE	10136	46.3	5.8
	Utilitech	283542	61.6	3.6

The average application efficacy of the four LED luminaires was 28.8 lm/W, compared with an average 21.0 lm/W for the two fluorescent luminaires. The LED luminaires had a wide range of efficacies, illustrating that using an LED light source does not itself guarantee a highly efficacious luminaire. The two luminaires with xenon light sources averaged 4.7 lm/W, well below the LED and fluorescent luminaries.

Figure 2 shows the relationship between application efficacy and illuminance identified by light source type. As noted in the section, "How much light do LED under-cabinet luminaires produce?" NLPIP found that the luminaire with the highest application efficacy, the Utilitech 283520, provided less illumination than that recommended by McGuiness and Boyce (1984).

Figure 2. Application efficacy vs. horizontal illuminance of under-cabinet luminaires.



Will LED under-cabinet luminaires be cost effective?

Table 6 provides a calculation of the total cost of ownership of the under-cabinet luminaires using the following assumptions:

- Duration of installation = 10 years
- Cost of electricity = $0.1136/kWh (U.S. DOE)
- Time of operation = 3 hours/day

- LED luminaire life ≥ 11,000 hours
- Fluorescent lamp life = 7,500 hours
- Xenon lamp life = 8,000 hours
- Fluorescent lamp replacement cost = $4.80
- Xenon lamp replacement cost = $3.60
- Installation time for lamps that come with a plug (the LED and xenon models) = 0.5 hour
- Installation time for lamps that come with a wire lead (the fluorescent models) = 1.0 hour
- Installation labor rate = $56/ hour

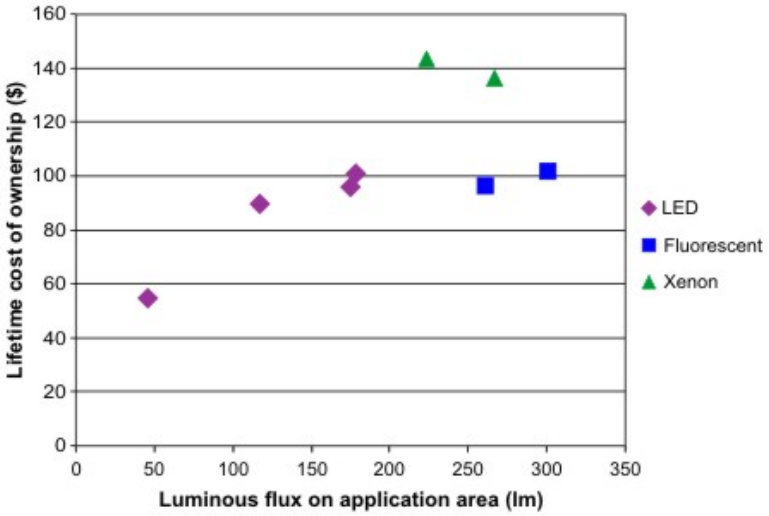
For the purposes of this economic analysis, the lifetime of the LED luminaires was assumed to be 11,000 hours or greater, meaning that the initial luminaire would last for at least 10 years. (Testing the actual lifetime of the under-cabinet luminaires was beyond the scope of this project.) The lamp life and lamp replacement cost of the fluorescent and xenon models and the installation labor rate are the values used in *ASSIST recommends Volume 2, Issue 1: A Homeowner's Guide to Residential Under-cabinet Lighting: Getting Good Lighting for Your Kitchen Counters*. The installation times are estimates based on NLPIP's experience installing these models for testing. These calculations use a simple cost analysis and do not include adjustments for the time value of money or inflation.

Table 6. Under-cabinet luminaire cost of ownership over 10 years.

Light source	Brand	Model	Initial price ($)	Initial installation labor cost ($)	Cost of electricity ($)	Lamp replacement cost ($)	Total cost of ownership ($)
LED	GE	10408	55	28	7	0	90
	GE	10409	65	28	8	0	101
	Utilitech	283278	59	28	9	0	96
	Utilitech	283520	25	28	1	0	54
Fluorescent	GE	10113	26	56	15	5	102
	Utilitech	069486	17	56	19	5	96
Xenon (incandescent)	GE	10136	47	28	58	4	136
	Utilitech	283542	35	28	77	4	143

The cost of ownership results are plotted in Figure 3 along with each luminaire's light output. The lower the cost of ownership, the better.

Figure 3. Cost of ownership over 10 years vs. light output of under-cabinet luminaires.



The luminaire with the lowest cost of ownership, the Utilitech 283520, provides less illumination than that recommended by McGuiness and Boyce (1984). The fluorescent luminaires have approximately the same cost of ownership as the other LED luminaires. However, the fluorescent models provide more light.

If the LED luminaires were to fail sooner than the assumed 11,000 hours of life, requiring that the entire luminaire be replaced, then their costs of ownership would be significantly higher than the fluorescent models and would approach those of the xenon models, which have high costs of ownership due to greater electricity use.

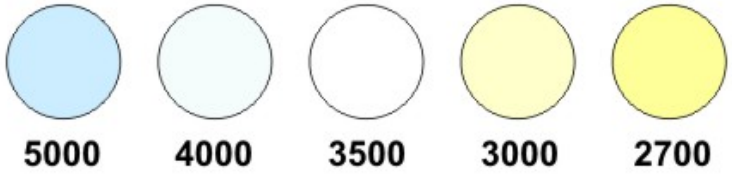
What other considerations are there when selecting an under-cabinet luminaire?

Additional factors to consider when purchasing an under-cabinet luminaire are the color of the light produced, warranty, the ability to electrically link multiple luminaires, and the shadows they create.

Light color

Correlated color temperature (CCT) indicates the "warmth" or "coolness" of the light, as shown in Figure 4. Lower CCTs provide a warmer appearance with a more yellow tone. Higher CCTs provide a cooler look with a bluer tone.

Figure 4. Color appearance.



ASSIST recommends Volume 2, Issue 1: A Homeowner's Guide to Residential Under-cabinet Lighting: Getting Good Lighting for Your Kitchen Counters suggests that for wood tones, warm-colored tiles, copper-toned metal backsplashes or warm-toned walls, look for warm CCTs in the 2700–3500 kelvin (K) range. For decorative glass tiles, glass shelves, cool-toned tiles or gray-toned metal colors, look for cool CCTs in the 3500–5000 K range. Also, consumers may want to match the color temperature of the overhead lighting in the kitchen. There is no good or bad color temperature; the consumer's preference, taking into account the above guidelines, should determine this specification. Table 7 shows the CCT values of the under-cabinet luminaires tested by NLPIP. The values listed are the weighted means for each luminaire calculated by measuring the CCT of the light falling on a grid of measurement points on the horizontal surface and weighted by the illuminance at each point.

Color rendering index (CRI) is a measure of a lamp's color rendering quality. Higher CRI values indicate that objects will appear more natural and viewers will be able to distinguish between different colors on those objects more easily. Table 7 shows the CRI of the under-cabinet luminaires tested by NLPIP. NLPIP staff measured the CRI of the LED under-cabinet luminaires using an integrating sphere following the IESNA LM-79 test standard. The CRI of the fluorescent luminaires was determined from the codes printed on the lamps by the manufacturers. The CRI of the xenon lamps is assumed to be 100 based upon the spectral power distribution of an incandescent filament.

Table 7. CCT of tested luminaires.

Light source	Brand	Model	CCT on horizontal surface (K)	CRI
LED	GE	10408	2852	68
	GE	10409	2872	68
	Utilitech	283278	3111	70
	Utilitech	283520	3864	73
Fluorescent	GE	10113	3090	80-90
	Utilitech	069486	3735	60-70
Xenon (incandescent)	GE	10136	2617	100
	Utilitech	283542	2525	100

The results of NLPIP testing shown in Table 7 indicate that the LED and fluorescent luminaires are available with either cool or warm light, while the xenon luminaires provide warm light.

Warranty

The under-cabinet LED luminaires identified for this study have no user-replaceable parts. Instead, the entire luminaire must be replaced. Despite the fact that manufacturers sometimes claim long lifetimes of LED products (e.g., the packaging of the Utilitech 283278 lists its lifetime as 50,000 hours) and that the cost of ownership is highly dependent on the lifetime, the warranty provided by manufacturers is similar to that of the fluorescent and xenon under-cabinet luminaires, as shown in Table 6. The packaging materials of only two of the luminaires provided details of the warranty, the Utilitech 283520 and Utilitech 283542; these luminaires are warranted "to be

free from defects in materials and workmanship for a period of (1) year from the date of original purchase by the consumer… [Good Earth Lighting] will repair or replace (at [their] option) the unit in the original color, and style if available, or in a similar color and style if the original item has been discontinued, without charge, exclusive of bulbs."

Table 8. Under-cabinet luminaire warranties.

Light source	Brand	Model	Warranty length*
LED	GE	10408	3 years
	GE	10409	3 years
	Utilitech	283278	NS
	Utilitech	283520	1 year (exclusive of bulb)
Fluorescent	GE	10113	3 years (exclusive of bulb)
	Utilitech	069486	1 year (exclusive of bulb)
Xenon (incandescent)	GE	10136	3 years (exclusive of bulb)
	Utilitech	283542	1 year (exclusive of bulb)

* NS - Information not supplied on package materials

Linking

Some luminaires offer the feature of allowing "linking" or wiring from one luminaire to the next, which can be useful when installing a row of luminaires under long cabinets. The fluorescent models come with wire leads that provide the flexibility to be wired to either a junction box, a lead with a plug, or to an adjacent luminaire.

Table 9. Under-cabinet luminaires' ability to electrically link to one another.

Light source	Brand	Model	Linking ability?
LED	GE	10408	Yes, built-in socket
	GE	10409	Yes, built-in socket
	Utilitech	283278	No
	Utilitech	283520	No
Fluorescent	GE	10113	Yes, direct wire
	Utilitech	069486	Yes, direct wire
Xenon (incandescent)	GE	10136	Yes, built-in socket
	Utilitech	283542	Yes, built-in socket

Dimming

None of the luminaires tested come with continuous dimming controls built in. The Utilitech 283542 can be turned on to a high or low setting.

NLPIP recommends using under-cabinet luminaires with a built-in dimmer switch or bilevel switch in order to give the user the flexibility to find a pleasing light level. Also, operating the luminaire at lower illumination levels when possible will save energy.

Aiming

The Utilitech 283542 is capable of tilting forward or backward to aim the light. The light distribution of other luminaires has a fixed direction — directly down toward the horizontal application area (countertop).

Shadows

Objects illuminated by under-cabinet luminaires with multiple lamps create multiple shadows on the counter surface, as shown in Figure 5, which some may find to be aesthetically displeasing. These discrete multiple shadows (left) are created by all of the LED models and the GE 10136 xenon model. The two fluorescent luminaires have lower-luminance light sources and a diffuser, so they create softer, graded shadows (right). The Utilitech 283542 is an intermediate case; sandblasted glass over the three halogen lamps provides a moderate amount of diffusion.

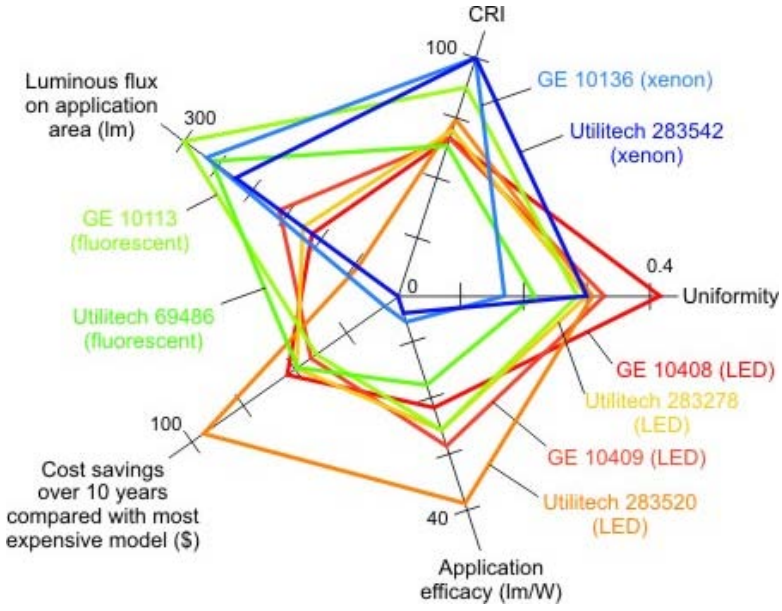
Figure 5. Discrete vs. soft shadows.

Summary

LEDs have strengths and weaknesses in comparison with other light sources. Figure 6 is a radar chart showing the strengths of each under-cabinet luminaire tested. The top-right axis shows the measured or estimated CRI of the light produced. The top-left axis shows the total luminous flux on the application area in lumens. The right axis is a measure of the uniformity. The value presented is the minimum illuminance on the horizontal application area divided by the average illumination on the horizontal application area (the inverse of the uniformity ratio shown in Table 4). The bottom-right axis shows the application efficacy in lumens per watt. The bottom-left axis shows the cost savings of the luminaire, represented as difference between the lifetime cost of the luminaire and the lifetime cost of the most expensive model. On all axes, the further the line is from the origin, the better.

In general, the LED models produce less light than the others but can result in a somewhat lower cost of ownership and better uniformity than the fluorescent models. The xenon models have the highest CRI and produce a similar amount of light as the fluorescent models but have low efficacy and are relatively expensive to own. The two fluorescent models tested produce about as much light as the xenon luminaires and are balanced on uniformity, cost savings, and application efficacy, in that their results do not tend to any extremes. There was a large difference in the CRI of the two fluorescent luminaires because they use different phosphor technologies.

Figure 6. Radar chart of LED under-cabinet luminaires showing luminous flux, CRI, uniformity, application efficacy, and cost savings.



Resources

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Lighting Answers: LED Residential Under-cabinet Luminaires

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Glossary

Sources of term definitions: National Lighting Product Information Program (NLPIP), Lighting Research Center's Lighting Education Online, the IEEE Standard Dictionary of Electrical and Electronics Terms (IEEE Std 100-1996).

color rendering index (CRI)	A rating index commonly used to represent how well a light source renders the colors of objects that it illuminates. For a CRI value of 100, the maximum value, the colors of objects can be expected to be seen as they would appear under an incandescent or daylight spectrum of the same correlated color temperature (CCT). Sources with CRI values less than 50 are generally regarded as rendering colors poorly, that is, colors may appear unnatural.
correlated color temperature (CCT)	A specification for white light sources used to describe the dominant color tone along the dimension from warm (yellows and reds) to cool (blue). Lamps with a CCT rating below 3200 K are usually considered warm sources, whereas those with a CCT above 4000 K usually considered cool in appearance. Temperatures in between are considered neutral in appearance. Technically, CCT extends the practice of using temperature, in kelvins (K), for specifying the spectrum of light sources other than blackbody radiators. Incandescent lamps and daylight closely approximate the spectra of black body radiators at different temperatures and can be designated by the corresponding temperature of a blackbody radiator. The spectra of fluorescent and LED sources, however, differ substantially from black body radiators yet they can have a color appearance similar to a blackbody radiator of a particular temperature as given by CCT.
efficacy	The ratio of light output (in lumens) to input power (in watts), expressed as lumens per watt (LPW).
illuminance	The density of luminous flux incident upon a surface. Illuminance is measured in footcandles (lumens/square foot) or lux (lumens/square meter). One footcandle equals 10.76 lux.
lamp rated life	The number of operating hours at which half of a large group of product samples are expected to fail. The rated life is a median value of life expectancy; individual lamp life may vary considerably from the published rated life and operating conditions (e.g., temperature, hours per start) may affect actual life because rated life is based on standard test conditions. In addition, the way a product fails can vary by technology. For example, incandescent lamps abruptly stop producing any light while LEDs are considered to have failed when their light output drops below a certain fraction of the initial level.
luminaire	A complete lighting unit consisting of a lamp or lamps and the parts designed to distribute the light, to position and protect the lamp(s), and to connect the lamp(s) to the power supply. (Also referred to as fixture.)
luminous flux	Luminous radiant power, measured in lumens. The overall light output of a lamp or luminaire.
lux (lx)	A measure of illuminance in lumens per square meter. One lux equals 0.093 footcandle.
power	The power used by a device to produce useful work (also called input power or active power). In lighting, it is the system input power for a lamp and ballast or driver combination. Power is typically reported in the SI units of watts.
uniformity	The degree of variation of illuminance over a given plane. Greater uniformity means less variation of illuminance. The uniformity ratio of illuminance is a measure of that variation expressed as either the ratio of the minimum to the maximum illuminance or the ratio of the minimum to the average illuminance.