

Cree® XLamp® LED Wall Sconce Reference Design

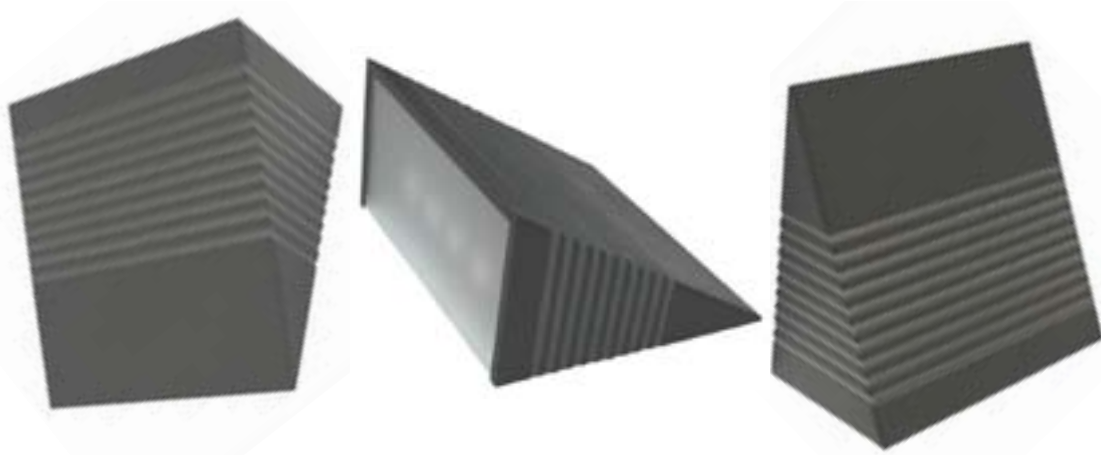


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INTRODUCTION

The sconce is a broad category of decorative lighting fixtures that are mounted on interior or exterior walls. The first sconces were used to support torches or candles and later, gas lights and electric lamps. The word is derived from the Latin *absconsus* and the French *esconce*, meaning covering or protection.

Modern sconces come in many different shapes and sizes and utilize various socket-based lamp technologies: filament-based incandescent, linear quartz halogen, compact or linear fluorescent and ceramic metal halide, to name a few. Sconces generally have a shade or cover and are mounted to direct light upward toward the ceiling, downward toward the floor or back toward the wall. They can be used for ambient, task or accent lighting.

This application note details a prototype Cree XLamp LED-based wall sconce design. The purpose of this document is to show how to design and build a custom luminaire that is tailored to match or exceed the performance of existing types of fixtures. By following these steps, it is possible to create unique XLamp LED-based wall sconce designs that offer significant operational cost savings compared to halogen, fluorescent and incandescent counterparts.

DESIGN APPROACH/OBJECTIVES

In the “LED Luminaire Design Guide”¹ application note, Cree advocates a 6-step framework for creating LED luminaires. All Cree reference designs use this framework, and the design guide’s summary table is reproduced below.

Step	Explanation
1. Define lighting requirements	<ul style="list-style-type: none"> The design goals can be based either on an existing fixture or on the application’s lighting requirements.
2. Define design goals	<ul style="list-style-type: none"> Specify design goals, which will be based on the application’s lighting requirements. Specify any other goals that will influence the design, such as special optical or environmental requirements.
3. Estimate efficiencies of the optical, thermal & electrical systems	<ul style="list-style-type: none"> Design goals will place constraints on the optical, thermal and electrical systems. Good estimations of efficiencies of each system can be made based on these constraints. The combination of lighting goals and system efficiencies will drive the number of LEDs needed in the luminaire.
4. Calculate the number of LEDs needed	<ul style="list-style-type: none"> Based on the design goals and estimated losses, the designer can calculate the number of LEDs to meet the design goals.
5. Consider all design possibilities and choose the best	<ul style="list-style-type: none"> With any design, there are many ways to achieve the goals. LED lighting is a new field; assumptions that work for conventional lighting sources may not apply.
6. Complete final steps	<ul style="list-style-type: none"> Complete circuit board layout. Test design choices by building a prototype luminaire. Make sure the design achieves all the design goals. Use the prototype to further refine the luminaire design. Record observations and ideas for improvement.

Table 1: Cree 6-step framework

THE 6-STEP METHODOLOGY

The major goal for this project was to demonstrate a straightforward wall sconce design using Cree XLamp LEDs that meets or exceeds the performance of sconces on the market.

1. DEFINE LIGHTING REQUIREMENTS

Because wall sconces are decorative fixtures, aesthetics and form factor are perhaps the most important design criteria. In addition, a desirable fixture is low in power consumption and able to efficiently illuminate the area where it is installed. Besides the physical appearance of the fixture, it is important that the luminaire deliver light that is pleasant to look at and enhances the nearby space and objects. Although pleasantness and enhancement can be subjective assessments, there are specific metrics, listed in Table 2 below, that can quantify luminaire performance.

¹ LED Luminaire Design Guide, Application Note AP15, www.cree.com/products/pdf/LED_Luminaire_Design_Guide.pdf

Importance	Characteristics	Units
Critical	Aesthetics	N/A
	Form Factor	N/A
	Luminous flux	Lumens (lm)
	Luminance/Illuminance	candela/m ² or lux
	Electrical power	Watts (W)
	Meet safety standards	Agency listing/mark
Important	Price	US Dollars
	Lifetime	Hours
	Correlated color temperature (CCT)	Kelvin
	Color rendering index (CRI)	100 pt scale
	Manufacturability	\$
	Ease of installation	Time = \$
	Comply w/ENERGY STAR	Has label
	Compatible w/controls	Yes/No
	End-of-life disposition	Cost to recycle

Table 2: Design criteria

Sconces can be classified into several broad categories based on their shape and appearance (e.g., “arm” or “pocket”), the type of shade (e.g., opaque, translucent), where they are used (e.g., hallways, entryways) or other functionality. A sconce can be a basic, low-cost fixture consisting of little more than a bracket with a single light bulb socket and a simple glass or metal cover or it can be an elaborate, ornamental fixture using multiple light sources and luxury materials. The goal for this reference design was to choose a simple, yet elegant, fixture style that effectively maximizes the benefits of LEDs over other, traditional light sources.

Because of the ubiquitous and versatile nature of this class of luminaire, it was a challenge to narrow our focus down to a single example. The candidate luminaires we considered as a basis for our design are shown below in Figure 1.² They range in retail price from \$129 to \$250 and are rated for wattages from 26 W to 200 W using either compact fluorescent (CFL), incandescent or halogen lamps.

² Source of photos: www.allmodernlighting.com

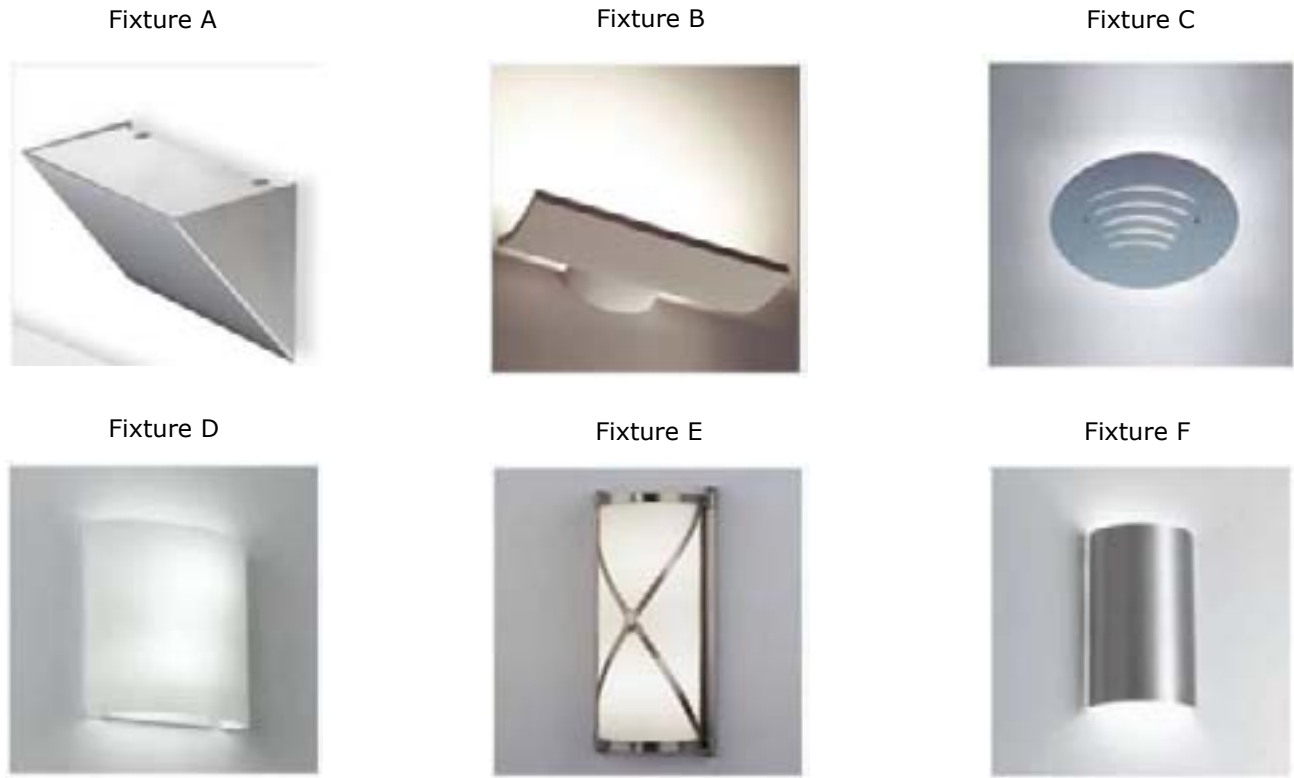


Figure 1: Candidate luminaires

A sample of each luminaire was measured for photometric and electrical performance.³ A summary of the data is presented in Table 3. For the most part, the fixture efficiency values, which are calculated by dividing the rated lamp lumens by the actual measured lumens out of the fixture, are astoundingly low. Therefore, it follows that the fixture and system efficacies tend to be overwhelmingly low—as little as 2 lumens per watt for two of the luminaires. While each of these luminaire styles could be duplicated using Cree XLamp LEDs and be expected to outperform its counterpart by a significant margin, we chose fixture A as the basis for this reference design.

³ Photometric performance was measured in a 2-meter integrating sphere. Electrical performance was measured using an AC power analyzer. Measurements were taken at the Cree facility in Durham, NC.

	Fixture					
	A	B	C	D	E	F
Lamp type	Halogen	Halogen	Halogen	Incandescent	CFL	Incandescent
Input power (watts)	137	154	186	148	22	80
Power factor	1.00	1.00	1.00	1.00	0.55	1.00
Radiant flux (watts)	3.26	16.22	4.70	11.53	2.56	3.37
Lamp-rated lumens	2200	2200	3000	2110	1600	920
Fixture lumens	266	1845	435	1391	582	306
Chromaticity x coordinate	0.491	0.454	0.481	0.452	0.397	0.458
Chromaticity y coordinate	0.411	0.411	0.416	0.415	0.384	0.410
Peak wavelength (nm)	848	845	847	845	611	845
CCT	2316	2791	2467	2848	3631	2719
System efficacy (lm/W)	1.9	12	2.3	9.4	26	3.8
Radiant efficiency	2.4%	10.5%	2.5%	7.8%	11.6%	4.2%
Fixture efficiency	12.1%	83.0%	14.5%	65.9%	36.4%	33.3%
CRI (AVG)	98.6	98.6	98.6	98.2	84.8	99.3
CRI (R9)	96.4	94.8	94.8	94.3	28.9	96.5

Table 3: Candidate luminaire test results

Fixture A was measured to obtain a polar plot intensity distribution,⁴ shown in Figure 2, which we used as a baseline for our fixture. Note that the total lumens out is about 11% lower than it was measured in the sphere, because the lamp was measured at 110 V instead of 120 V, resulting in about 12% less power.

LUMENS/LAMP: 237.4328
 NO. OF LAMPS: 1
 LUMINOUS OPENING: POINT SOURCE
 Width: 0.00 (Feet)
 Length: 0.00
 Height: 0.00
 INPUT WATTS: 120.2

ZONAL LUMEN SUMMARY			
Zone	Lumens	% Lamp	% Luminaire
0-30	73.4	30.9	30.9
0-40	114.8	48.4	48.4
0-60	188.3	79.3	79.3
60-90	49.1	20.7	20.7
0-90	237.4	100.0	100.0

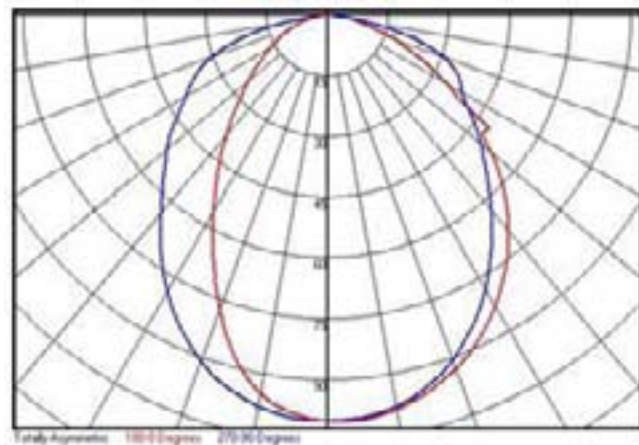


Figure 2: Polar plot Intensity distribution for halogen sconce (note the downward orientation)

⁴ Measurements were taken using a type A goniophotometer at the Cree facility in Morrisville, NC.

Cree considered whether this reference design would be eligible to qualify for the ENERGY STAR® Program. The two standards⁵ previously in effect, one for solid-state lighting luminaires and another for residential light fixtures, have been replaced by a new Environmental Protection Agency standard.⁶ The previous standards did not specifically address wall sconce fixtures but the new standard does mention wall sconces. However, sconces are categorized as non-directional luminaires, which have more stringent requirements than the previous standards. This document is concerned only with the current requirements.

The ENERGY STAR requirements:⁷

Characteristic	Requirement
CCT	The luminaire must have one of the following nominal CCTs and fall within the corresponding 7-step chromaticity quadrangles as defined in ANSI/NEMA/ANSI C78.377-2008. 2700 K 3000 K 3500 K 4000 K
Color Maintenance	The change of chromaticity over the first 6,000 hours of luminaire operation shall be within 0.007 on the CIE 1976 (u', v') diagram.
CRI	Indoor luminaires shall have a minimum CRI of 80.
Off-state power	Luminaires shall not draw power in the off state.
Luminous efficacy	42 lm/W
Lumen maintenance requirement	$L_{70} > 25,000$ hours
Power Factor (PF)	Total luminaire input power < 5 W: PF > 0.5 Total luminaire input power > 5 W: PF > 0.7 for residential PF > 0.9 for commercial
Warranty	3-year warranty
Thermal management	Measured temperature at the hottest location on the driver case shall be less than or equal to the manufacturer recommended maximum during in situ operation.
Operating frequency	≥ 120 Hz

Table 4: General ENERGY STAR requirements

2. DEFINE DESIGN GOALS

The design goals for this project:

5 ENERGY STAR Program Requirements for Solid State Lighting Luminaires Eligibility Criteria – Version 1.1 http://www.energystar.gov/ia/partners/product_specs/program_reqs/SSL_prog_req_V1.1.1.pdf

ENERGY STAR Program Requirements for Residential Light Fixtures Eligibility Criteria – Version 4.2 http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/fixtures/RLF_V4_2_FINAL.pdf

6 ENERGY STAR Program Requirements Product Specification for Luminaires (Light Fixtures) Eligibility Criteria - Version 1.0 http://www.energystar.gov/ia/partners/prod_development/new_specs/downloads/luminaires/ES_Luminaires_V1_Final_Specification.pdf

7 Ibid.

Characteristic	Unit	Minimum Goal	Target Goal
Luminaire light output	lm	400	500
Illuminance/luminous profile	Lux	Same	Better
System power	W	15	12
Luminaire efficacy	lm/W	40	50
Lifetime	hours	35,000	50,000
CCT	K	3500	2700
CRI		80	85
Maximum ambient temperature	°C		49

Table 5: Design goals

The efficacy targets may seem low. However, they factor in thermal, optical, and electrical losses and are based on the assumption that the source efficacy will range from 80-90 lm/W.

3. ESTIMATE EFFICIENCIES OF THE OPTICAL, THERMAL & ELECTRICAL SYSTEMS

The XLamp MX-6, XP-E and XP-G LEDs are candidates for use in this application. We chose to work with the XP family of LEDs because they can meet ENERGY STAR requirements even in high drive current configurations and provide good optical control.

Figure 3 is an examination of basic LED electrical data and optical output from Cree’s Product Characterization Tool (PCT).⁸ An 85% optical efficiency is typical for diffused optics. Drivers for low voltage applications such as this typically operate at 80% efficiency. We expect that the aluminum housing in this design will offer good thermal dissipation so we assume junction temperatures between 55 and 65°C.

⁸ Available at <http://pct.cree.com>

CREE LED System Comparison Report																			
System Target Lumens :		500		Optical Efficiency:				85%				Electrical Efficiency:				80%			
Current (A)	LED 1				LED 2				LED 3										
	Model	Qes XLamp XP-E (QV/W/W)	Model	Qes XLamp XP-E (QV/W/W)	Model	Qes XLamp XP-G (QV/W/W)	Model	Qes XLamp XP-G (QV/W/W)											
	Rev	04 [80.6]	Tj (°C)	55	Rev	04 [80.6]	Tj (°C)	55	Rev	03 [92.9]	Tj (°C)	65							
Price	1	-	Price	1	-	Price	1	Price	1	-	Price	1	-						
	SYS Inlet	SYS In/W	SYS W	SYS #LED	SYS Inlet	SYS In/W	SYS W	SYS #LED	SYS Inlet	SYS In/W	SYS W	SYS #LED							
0.100	500	65.7	7.7	22	500	55.2	9.06	25	504	62.1	8.1	24							
0.150	518	80	8.8	26	510	54.5	9.35	27	512	62.4	8.2	26							
0.200	516	57.3	6	22	521	50.7	10.5	34	525	62.5	8.25	22							
0.250	540	55.4	9.75	20	528	50.5	10.45	31	530	59.7	8.88	20							
0.300	504	52.5	9.0	8	550	47.8	11.5	20	504	58.0	8.0	8							
0.350	504	50.1	10.06	7	512	47	10.9	8	504	58.4	8.08	7							
0.400	574	48.9	11.75	7	568	45.1	12.6	8	574	58.6	10.55	7							
0.480	540	46.4	11.68	6	555	44.2	12.81	7	582	54.9	10.08	6							
0.500	594	45	15.2	6	516	43	12	6	505	58.5	9.44	5							
0.550	590	45.1	12.31	5	564	42.2	15.88	6	590	52.4	10.5	5							
0.600	570	42.8	13.68	5	594	40.4	14.7	6	595	51.5	11.56	5							
0.650	620	40.5	15.06	5	590	39.8	15.81	5	512	50.7	10.1	4							
0.700	512	38.9	13.15	4	580	38.8	14.44	5	544	49.5	11	4							
0.750	540	37.8	14.5	4	590	37.9	15.06	5	578	48.4	11.9	4							
0.800	568	36.8	15.45	4	615	36.8	16.89	5	608	47.5	12.8	4							
0.850	592	35.7	16.0	4	512	35.9	14.25	4	640	46.7	15.7	4							
0.900	616	34.7	17.75	4	552	35.1	15.15	4	501	45.6	10.99	3							
0.950	626	33.7	18.9	4	552	34.4	16.05	4	522	44.8	11.66	3							
1.000	660	32.9	20.08	4	572	33.8	16.9	4	546	44.1	12.88	3							

Figure 3: Cree Product Characterization Tool data

4. CALCULATE THE NUMBER OF LEDS NEEDED

Based on the photometric targets, Cree designed a 4-LED configuration of XP-G LEDs and an 8-LED configuration of XP-E LEDs. The characteristics of XP family LEDs suggest that the ENERGY STAR requirements can be met. The XP-E and XP-G LEDs have a CRI close to those of halogen and incandescent lamps and offer many options for optical design.

Thermal performance

Thermal simulations were done on the initial design using ANSYS, Inc. simulation software.⁹ The simulation results in Figure 4 show that the maximum temperature for the 4-LED configuration of XP-G LEDs at 700 mA in a 25°C ambient temperature will be approximately 67°C. The simulation results in Figure 5 show that the maximum temperature for the 8-LED configuration of XP-E LEDs at 350 mA in a 25°C ambient temperature will be approximately 53°C. Note that the surface temperature of the luminaire will remain well below 55°C. By comparison, the surface temperature of fixture A was measured to be over 103°C.¹⁰

9 Cree used ANSYS DesignSpace, <http://www.ansys.com/products/structural-mechanics/products.asp>

10 Measurement was taken at the Cree facility in Durham, NC.

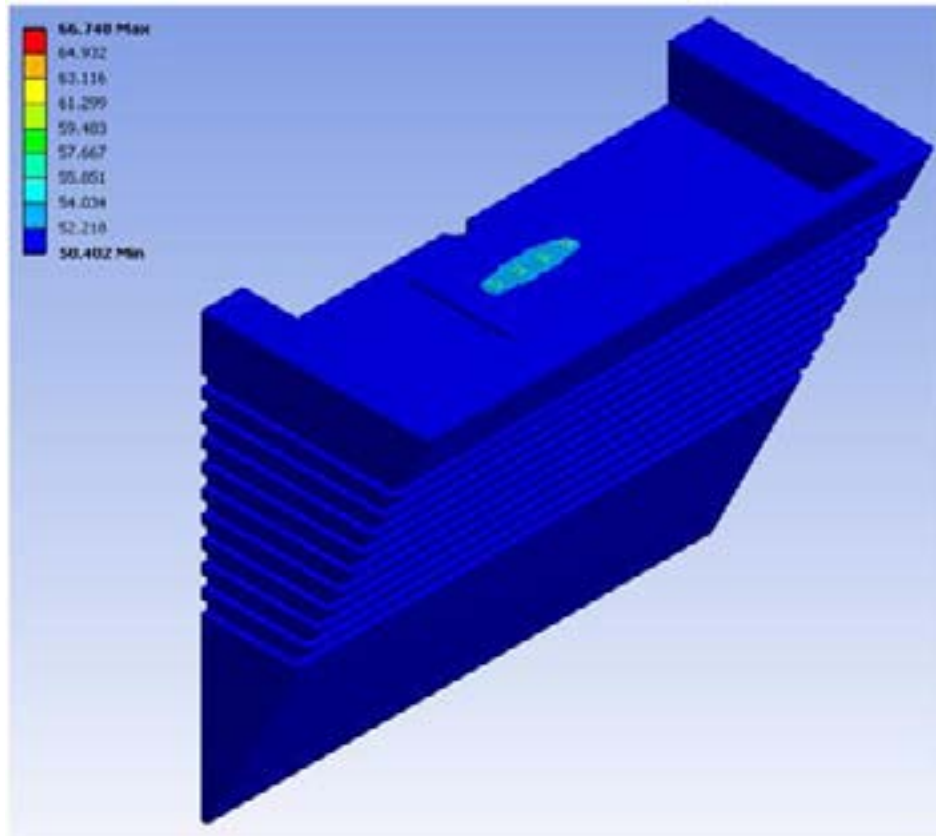


Figure 4: Thermal simulation results for 4-LED XP-G prototype sconce

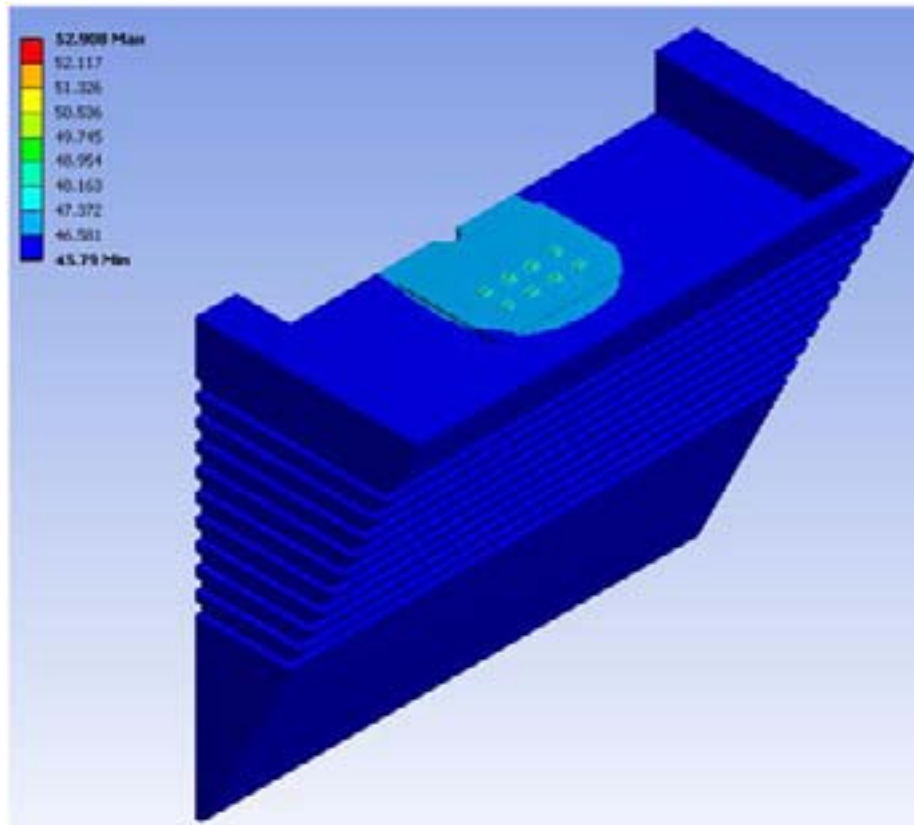


Figure 5: Thermal simulation results for 8-LED XP-E prototype sconce

5. CONSIDER ALL DESIGN POSSIBILITIES

The thermal simulation results allowed the thickness of the walls of the fixture to be reduced, thereby reducing the fixture’s weight. The estimated weight of the fixture is 0.9 kg (2 lbs.).

Specify LED driver

There are many ways to design a heat sink that can dissipate the necessary heat and fit within the sconce. In this design, Cree chose to construct the sconce such that the aluminum base and sides of the sconce serve as the heat sink.

There are also many ways to drive the LEDs. Cree chose a non-dimmable driver from Thomas Research¹¹ for the 4-LED XP-G prototype sconce and a dimmable driver from OnSemi¹² for the 8-LED XP-E prototype sconce.

¹¹ 700 mA Thomas Research 20 W driver LED20W-24-C0700

¹² 350 mA OnSemi dimmable driver evaluation board NCL30000LED1GEVB

Fixture design

As noted previously, there are many design possibilities for a wall sconce. Cree’s design choice, depicted in diagrams that follow, mimics the design of the comparison fixture A. STEP and SolidWorks files for the sconce are available on the Cree website.¹³

Making the base/heat sink out of four separate pieces of aluminum made the prototype easier to build than machining the parts out of a solid block of metal.

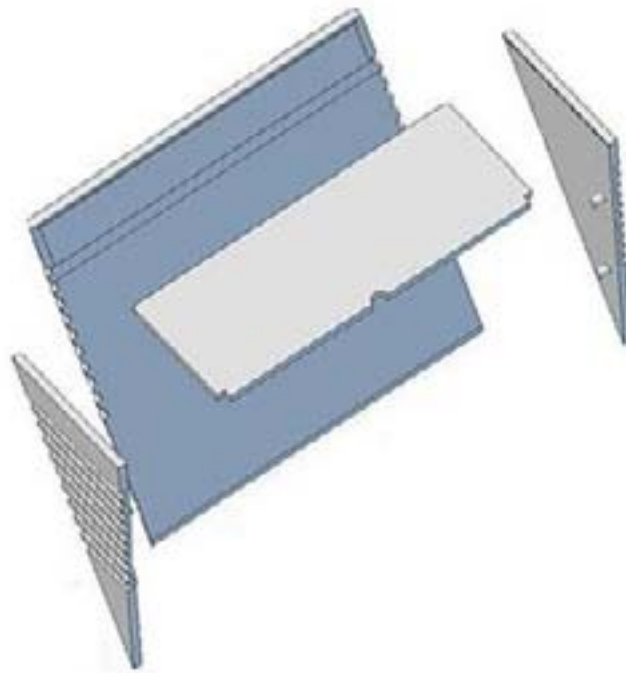


Figure 6: Base/heat sink design

The mounting bracket design, shown in Figure 7, allows the prototype sconces to be mounted in both upward- and downward-facing positions.

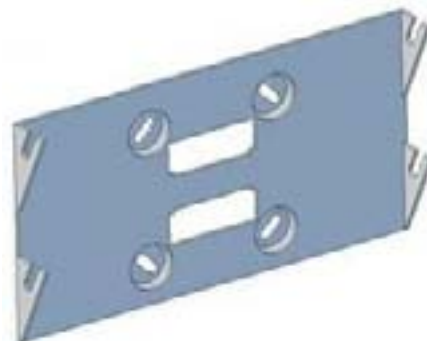


Figure 7: Mounting bracket design

¹³ STEP file: http://www.cree.com/XLampModels/XLamp_sconce_STEP.stp
 SolidWorks files: http://www.cree.com/XLampModels/XLamp_sconce_SW.zip

Figure 8 shows the prototype design in upward- and downward-facing orientations.

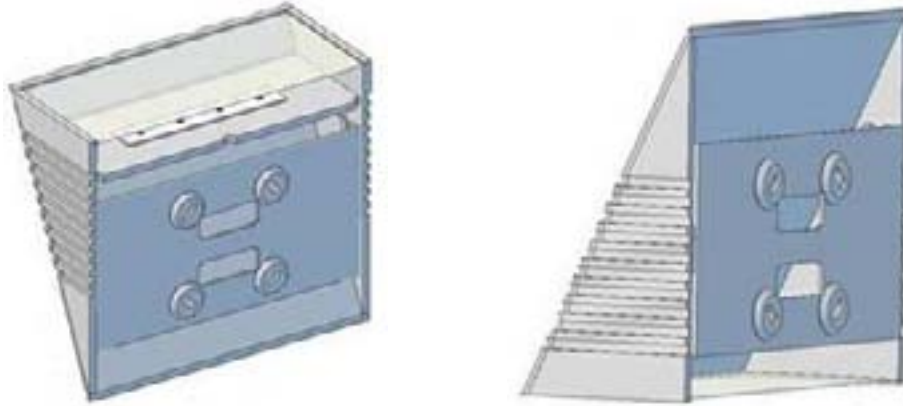


Figure 8: Prototype sconce facing upward and downward

Figure 9 shows the printed circuit board (PCB) layout for the 4-LED XP-G prototype. Figure 10 shows the PCB design for the 8-LED XP-E prototype.



Figure 9: PCB layout for XP-G prototype sconce

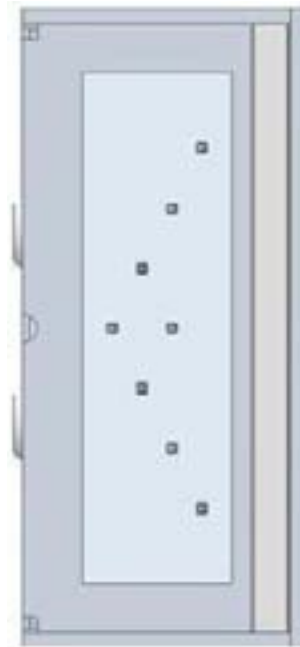


Figure 10: PCB layout for XP-E prototype sconce

Figure 11 is a front view of the prototype sconce.

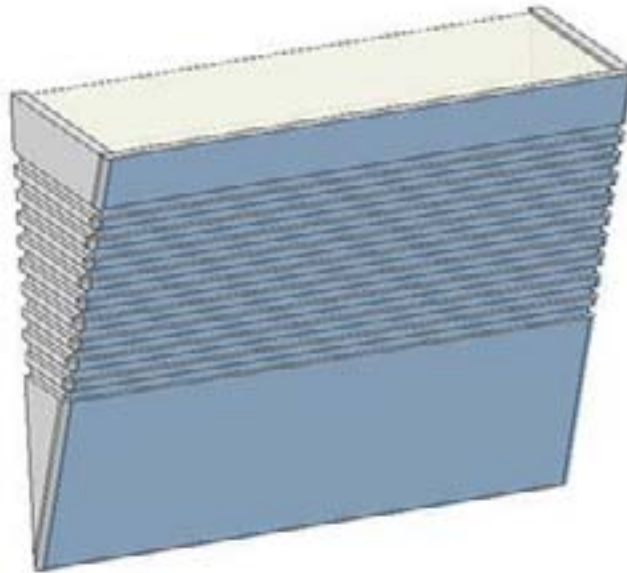


Figure 11: Front view of prototype sconce

6. COMPLETE FINAL STEPS

In this section, Cree shows views of the prototype sconces and provides the photometric results obtained.

Design implementation

Two prototype sconces were constructed following the designs shown above. Following are views of the completed prototypes.

Figure 12 shows the completed mounting bracket.



Figure 12: Mounting bracket

Figure 13 and Figure 14 show the PCB layouts for the XP-G and XP-E prototype sconces.

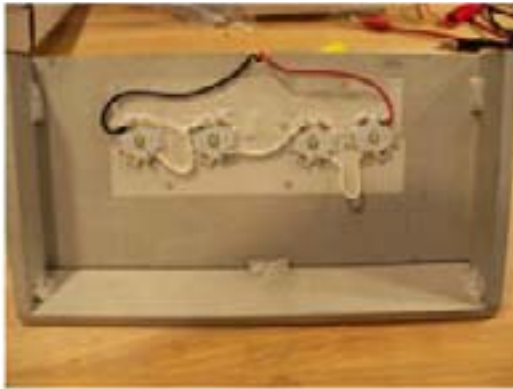


Figure 13: XP-G prototype sconce PCB layout

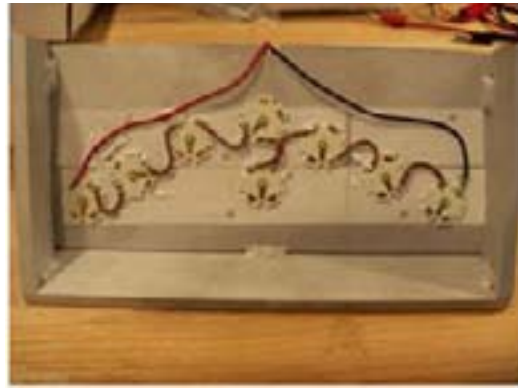


Figure 14: XP-E prototype sconce PCB layout

Figure 15 and Figure 16 show the drivers for the XP-G and XP-E prototype sconces.



Figure 15: Driver for XP-G prototype sconce



Figure 16: Driver for XP-E prototype sconce

Figure 17 and Figure 18 show the XP-G and XP-E prototype sconces without a diffuser.



Figure 17: XP-G prototype sconce without diffuser



Figure 18: XP-E prototype sconce without diffuser

Figure 19 and Figure 20 show the XP-G and XP-E prototype sconces with a diffuser.



Figure 19: XP-G prototype sconce with diffuser



Figure 20: XP-E prototype sconce with diffuser

Results

The XP-G prototype sconce was measured¹⁴ to obtain a polar plot intensity distribution, shown in Figure 22.

LUMENS/LAMP:	454.5541		
NO. OF LAMPS:	1		
LUMINOUS OPENING:	POINT SOURCE		
Width:	0.00 (Feet)		
Length:	0.00		
Height:	0.00		
INPUT WATTS:	10.5		
ZONAL LUMEN SUMMARY			
<u>Zone</u>	<u>Lumens</u>	<u>% Lamp</u>	<u>% Luminaire</u>
0 - 30	139.6	30.7	30.7
0 - 40	205.8	45.3	45.3
0 - 60	318.0	70.0	70.0
60 - 90	136.5	30.0	30.0
0 - 90	454.6	100.0	100.0

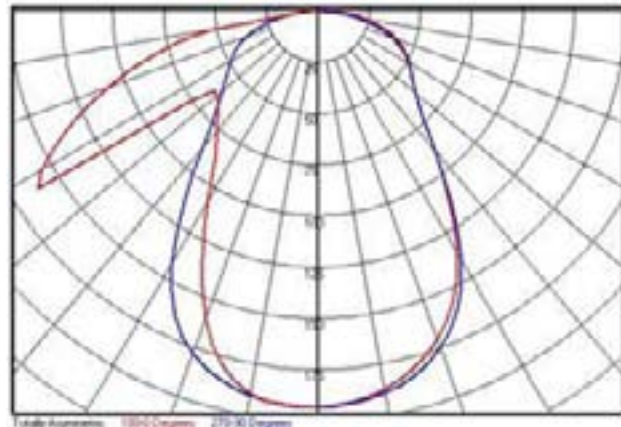


Figure 22: Polar plot intensity distribution for XP-G prototype sconce (note the downward orientation)

Figure 23 shows the results of lighting simulations¹⁵ for the XP-G prototype sconce and fixture A.

¹⁴ Measurements were taken using a type A goniophotometer at the Cree facility in Morrisville, NC.

¹⁵ IES files containing polar plot intensity distribution data measured using a type A goniophotometer were input into DIALux software to create the simulations. <http://www.dialux.com/>

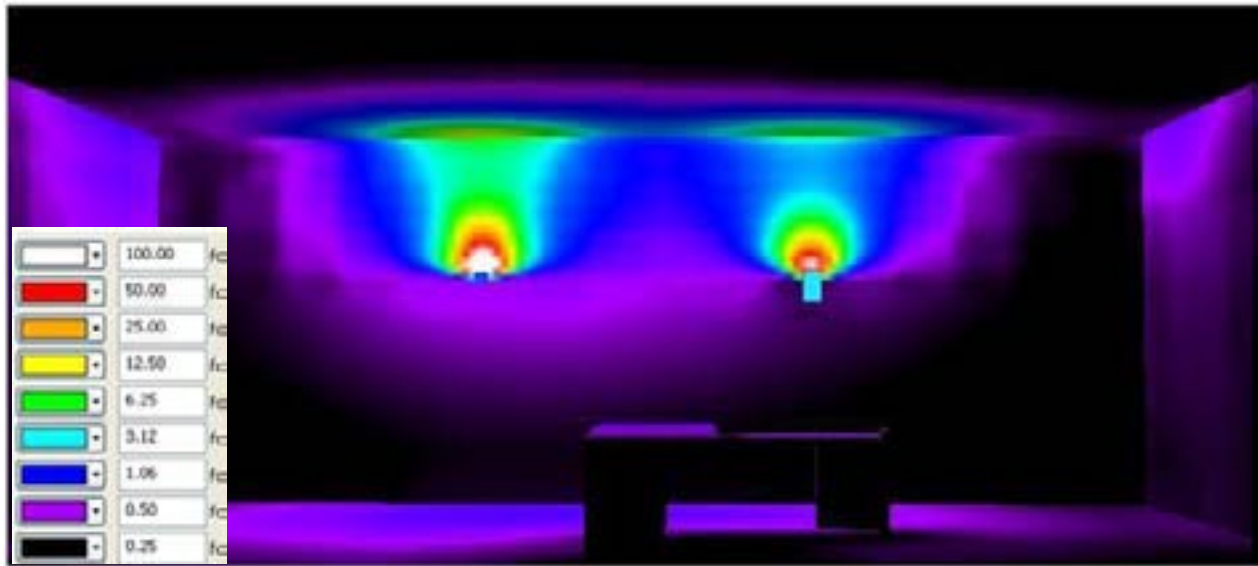


Figure 23: Lighting simulation for XP-G prototype sconce (left) and fixture A (right)

Table 6 and Table 7 show photometric and chromaticity data for the XP-G prototype sconce. The efficacy is much better than halogen (and other alternatives) and meets the design goal. With and without a diffuser, the prototype sconce meets the minimum light output design goals. The CCT and CRI of the XP-G prototype sconce meet ENERGY STAR requirements.

	Lumens	Current	Voltage	PF	Watts	Lm/W
no diffuser	604	0.087	120	0.98	10.2	59
with diffuser	510	0.087	120	0.98	10.2	50

Table 6: Photometric data for XP-G prototype sconce

	x coord	y coord	u' coord	v' coord	CCT	CRI avg	R9
no diffuser	0.4478	0.4029	0.2581	0.5226	2814	85	32
with diffuser	0.4506	0.4047	0.2591	0.5237	2787	85	33

Table 7: Chromaticity data for XP-G prototype sconce

Figure 24 shows how well the light output of the XP-G prototype sconce compares with that of halogen fixture A, while using 91% less power. Note the chromaticity difference in the light from the 2400 K halogen sconce compared to the 2800 K XP-G prototype sconce.



Figure 24: Comparison of halogen (left) to XP-G prototype sconce (right)

Measured Tsp

Table 8 shows solder point temperature (Tsp) and junction temperature (Tj) for both prototype sconces.

Sconce	Tsp	Current	Voltage per LED	Tj
4-LED XP-G	39°C	700 mA	3.10 V	52°C
8-LED XP-E	40°C	350 mA	3.17 V	50°C

Table 8: System temperature data

Based on Cree’s LM-80 testing of the XLamp XP-E and XP-G LEDs and industry standard extrapolation methods, the prototype sconce provides the ENERGY STAR 25,000 hour rated lifetime and should last for at least 50,000 hours.

Cost of ownership

For the cost of ownership calculations that follow:

- Assume that electricity costs \$0.10 per kWh.
- Assume that fixture A and the XP-G LED prototype fixture cost the same.
- The calculations don’t factor in the replacement cost of the LED fixture.

Table 9 compares the cost of ownership of fixture A to that of the XP-G prototype sconce over the 60,000-hour lifetime of the XP-G LED. Fixture A not only uses significantly more energy but also requires 30 halogen lamps.

Sconce	Lamp wattage	Rated lamp life-time	Replacement lamp cost	Cost of ownership
Fixture A	135	2,000	\$1.65	\$859.50
4-LED XP-G	12	60,000	-	\$72.00

Table 9: Cost of ownership calculations

Table 10 shows the payback expected from the XP-G prototype sconce after 3 years of use in several situations. Sconces in commercial buildings such as hotels are more likely to run 24 hours per day than sconces in residential applications that typically operate fewer hours per day.

Usage	Payback
24 hours/day	\$344.69
12 hours/day	\$173.17
4 hours/day	\$57.17

Table 10: Payback after 3 years

CONCLUSIONS

This reference design demonstrates the possibility of designing a wall sconce that uses Cree XLamp XP family LEDs to achieve performance that meets or exceeds that of other light sources. In this design, the fixture was designed around the LED. There are many other design approaches that could be explored including smaller versions, high-output versions delivering more than 1000 lm and multi-color versions. Other types of sconces may also be suited for using LED replacement bulbs. Because of their small form factor, there are virtually unlimited sconce design possibilities using Cree XLamp LEDs.