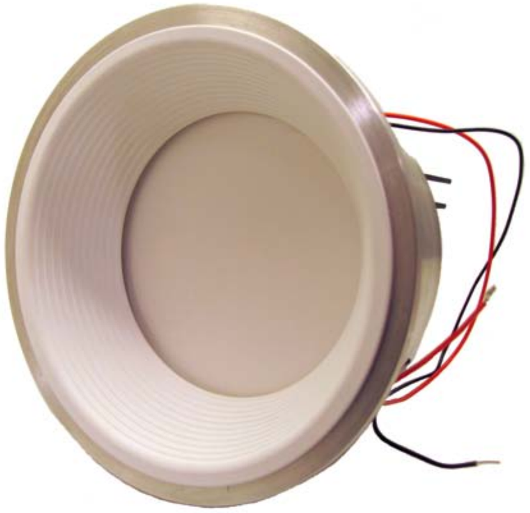
Cree® XLamp® LED Operating Capacity



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INTRODUCTION AND EXECUTIVE SUMMARY

This document demonstrates the application of a concept Cree calls LED operating capacity, maximizing the utilization of an LED rather than driving the LED at its binning current. The design shows that driving an LED at its designed current capacity presents options for cost reduction.

In today’s LED marketplace, there are many high-power LEDs to choose from for any given lighting project. However, not all LEDs are created equal and special care has to be exercised to create a high-performance, reliable LED lighting product. One key parameter for an LED-based luminaire design is forward driving current, as it determines the lumen output, efficacy, and lifetime of the final luminaire.

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What is LED operating capacity?

High-power LEDs are binned according to lumen output at a set current level. A single current level is chosen as the binning current and the industry has traditionally used 350 mA. Advancements in LED technology have resulted in LEDs with an operating range up to a maximum LED drive current that may be higher than the binning current. Driving an LED close to the maximum specified drive current can deliver much more light than at the binning current. The potential to drive an LED to what it is capable of is what we call LED operating capacity, the luminous flux produced at the maximum drive current.

Figure 1 shows the difference in efficacy between the light output at the binning current and the light output at the maximum drive current. Driving LEDs above the binning current results in more lumens per LED, resulting in fewer LEDs and a lower system cost. Driving LEDs above the binning current takes advantage of LED operating capacity that is otherwise unused.

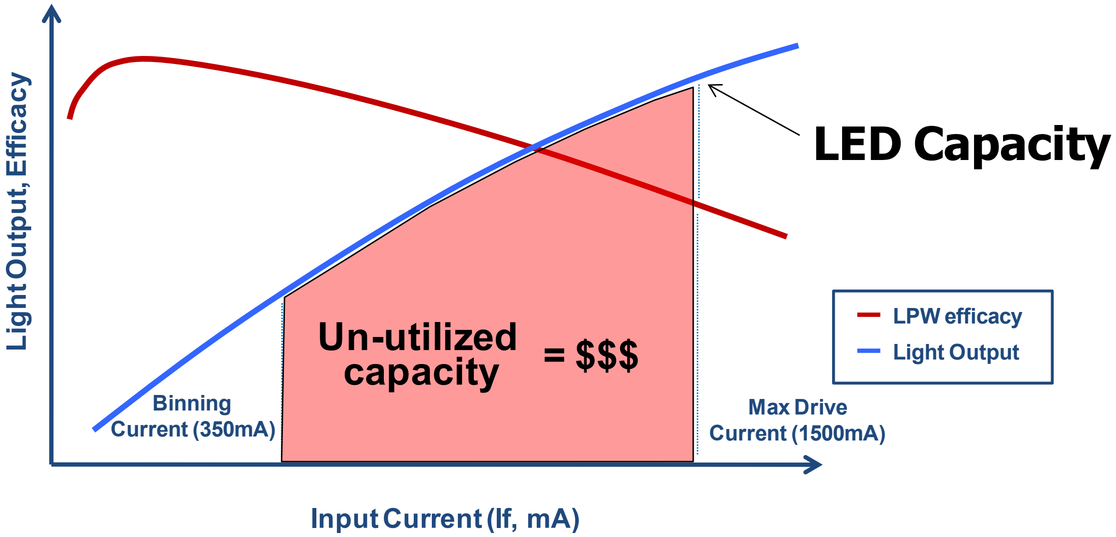

Figure 1: Unused LED operating capacity above an LED's binning current

Please note that other factors may play a role in the driving current limit, such as ENERGY STAR® minimum efficacy requirements, system thermal performance and LED L70 lifetime.

This reference design demonstrates the LED operating capacity concept in the context of a 6-inch recessed downlight fixture using Cree's XLamp XP-G high-power LED. Designed to operate over a wide range of forward drive currents, from 0.35 A to 1.5 A, the XLamp XP-G LED provides ample opportunity to show the benefits of driving an LED well above the binning current. We produced 2 downlight designs. Design 1 uses 12 XP-G LEDs at the LED's 0.35 A binning current; Design 2 uses 5 LEDs at 1 A. The 5-LED downlight produces light output and light distribution nearly identical to the 12-LED downlight from less than half the number of LEDs. Both downlights meet ENERGY STAR™ efficacy, correlated color temperature (CCT) and color rendering index (CRI) requirements. Taking advantage of an LED's operating capacity becomes an attractive option for applications requiring maximum lumen output at a reduced cost.

DESIGN APPROACH/OBJECTIVES

In the "LED Luminaire Design Guide"[1] 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	• The design goals can be based either on an existing fixture or on the application's lighting requirements.
2. Define design goals	• 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	• 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	• 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	• 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	• 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 goal is to demonstrate applying the concept of LED operating capacity in a 6-inch downlight design. This is best shown by creating a downlight that fulfills real-world requirements.

1. DEFINE LIGHTING REQUIREMENTS

Table 2 shows a ranked list of desirable characteristics to address in a downlight reference design.

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

Importance	Characteristics	Units
Critical	Price	$
	Manufacturability	
	Luminous flux (steady-state)	lumen (lm)
	Efficacy	lumens per watt (lm/W)
	Luminous distribution	
	Color uniformity	
	Form factor	
Important	Lifetime	hours
	Operating temperatures	°C
	Operating humidity	% relative humidity
	CCT	K
	CRI	100-point scale
	Ease of installation	

Table 2: Some ranked design criteria for an LED downlight

Although the prime purpose of this reference design is to demonstrate applying the concept of LED operating capacity, it is useful to show that driving an LED above its binning current need not preclude meeting requirements such as ENERGY STAR. Table 3 and Table 4 summarize the ENERGY STAR requirements for luminaires.[2]

Luminaire Type	ENERGY STAR Requirements		
	Luminaire Efficacy (Initial)	Luminaire Minimum Light Output (Initial)	Luminaire Zonal Lumen Density Requirement
Downlights: • recessed • surface • pendant • SSL downlight retrofits	42 lm/W	≤ 4.5” aperture: 345 lumens > 4.5” aperture: 575 lumens	Luminaire shall deliver a minimum of 75% of total initial lumens within the 0-60° zone (axially symmetric about the nadir)

Table 3: ENERGY STAR luminous efficacy, output and zonal lumen density requirements

Characteristic	Minimum Goal
Light source life requirements: all luminaires	The LED package(s) / LED module(s) / LED array(s), including those incorporated into LED light engines or GU24 based integrated LED lamps, shall meet the following L70 lumen maintenance life values (refer to Lumen Maintenance Requirements in the next section): 25,000 hours for residential grade indoor luminaires 35,000 hours for residential grade outdoor luminaires 35,000 hours for commercial grade luminaires Lumen maintenance life projection claims in excess of the above requirements shall be substantiated with a TM-21 lumen maintenance life projection report.

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[2] ENERGY STAR® Program Requirements , Product Specification for Luminaires (Light Fixtures), Eligibility Criteria, Version 1.1 www.energystar.gov/ia/partners/prod_development/new_specs/downloads/luminaires/Final_Luminaires_Program_Requirements.pdf

Characteristic	Minimum Goal
Lumen maintenance requirements: directional and non-directional luminaires	The LED package(s) / module(s) / array(s), including those incorporated into LED light engines or GU24 based integrated LED lamps, shall meet the following L70(6k) rated lumen maintenance life values, in situ: • L70(6k) ≥ 25,000 hours for residential indoor • L70(6k) ≥ 35,000 hours for residential outdoor, or commercial Compliance with the above shall be documented with a TM-21 lumen maintenance life projection report as detailed in TM-21, section 7. The report shall be generated using data from the LM-80 test report for the employed LED package/module/array model ("device"), the forward drive current applied to each device, and the in situ TMP_{LED} temperature of the hottest LED in the luminaire. In addition to LM-80 reporting requirements, the following information shall be reported: • sampling method and sample size (per LM-80 section 4.3) • test results for each TS and drive current combination • description of device including model number and whether device is an LED package, module or array (see Definitions) • ANSI target, and calculated CCT value(s) for each device in sample set • Δ u'v' chromaticity shift value on the CIE 1976 diagram for each device in sample set • a detailed rationale, with supporting data, for application of results to other devices (e.g. LED packages with other CCTs) Access to the TMP_{LED} for the hottest LED may be accomplished via a minimally sized hole in the luminaire housing, tightly resealed with a suitable sealant if created for purposes of testing. All thermocouple attachments and intrusions to luminaire housing shall be photographed.
CCT requirements: all indoor luminaires	The luminaire (directional luminaires), or replaceable LED light engine or GU24 based integrated LED lamp (non-directional luminaires) shall have one of the following nominal CCTs: • 2700 Kelvin • 3000 Kelvin • 3500 Kelvin • 4000 Kelvin • 5000 Kelvin (commercial only) The luminaire, LED light engine or GU24 based integrated LED lamp shall also fall within the corresponding 7-step chromaticity quadrangles as defined in ANSI/NEMA/ANSLG C78.377-2008.
Color rendering requirements: all indoor luminaires	The luminaire (directional luminaires), or replaceable LED light engine or GU24 based integrated LED lamp (non-directional luminaires) shall meet or exceed Ra ≥ 80.
Color angular uniformity requirements: directional solid state indoor luminaires	Throughout the zonal lumen density angles detailed above, and five degrees beyond, the variation of chromaticity shall be within 0.004 from the weighted average point on the CIE 1976 (u',v') diagram.
Color maintenance requirements: solid state indoor luminaires only	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, as demonstrated by either: • the IES LM-80 test report for the employed LED package/array/module model, or • as demonstrated by a comparison of luminaire chromaticity data in LM-79 reports at zero and 6,000 hours, • or as demonstrated by a comparison of LED light engine or GU24 based integrated LED lamp chromaticity data in LM-82 reports at zero and 6,000 hours.
Source start time requirement: directional and non-directional luminaires	Light source shall remain continuously illuminated within one second of application of electrical power.
Source run-up time requirements: directional and non-directional luminaires	Light source shall reach 90% of stabilized lumen output within one minute of application of electrical power.
Power factor requirements: directional and non-directional luminaires	Total luminaire input power less than or equal to 5 watts: PF ≥ 0.5 Total luminaire input power greater than 5 watts: Residential: PF ≥ 0.7 Commercial: PF ≥ 0.9
Transient protection requirements: all luminaires	Ballast or driver shall comply with ANSI/IEEE C62.41.1-2002 and ANSI/IEEE C62.41.2-2002, Class A operation. The line transient shall consist of seven strikes of a 100 kHz ring wave, 2.5 kV level, for both common mode and differential mode.
Operating frequency requirements: directional and non-directional luminaires	Frequency ≥ 120 Hz Note: This performance characteristic addresses problems with visible flicker due to low frequency operation and applies to steady-state as well as dimmed operation. Dimming operation shall meet the requirement at all light output levels.

Characteristic	Minimum Goal
Noise requirements: directional and non-directional luminaires	All ballasts & drivers used within the luminaire shall have a Class A sound rating. Ballasts and drivers are recommended to be installed in the luminaire in such a way that in operation, the luminaire will not emit sound exceeding a measured level of 24 dBA.
Electromagnetic and radio frequency interference requirements: directional and non-directional luminaires	Power supplies and/or drivers shall meet FCC requirements: • Class A for power supplies or drivers that are marketed for use in a commercial, industrial or business environment, exclusive of a device which is marketed for use by the general public or is intended to be used in the home. • Class B for power supplies or drivers that are marketed for use in a residential environment notwithstanding use in commercial, business and industrial environments.

Table 4: ENERGY STAR luminaire requirements

2. DEFINE DESIGN GOALS

The design goals for this project are given in Table 5.

Characteristic	Unit	Minimum Goal	Target Goal
Light output	lm	900	> 900
Luminous distribution		Both fixtures identical	
Power	W	20	< 20
Luminaire efficacy	lm/W	45	55
Lifetime	hours	35,000	35,000
CCT	K	3000	3000
CRI		80	> 80
Power factor		0.9	> 0.9
Max ambient temperature	°C	30	40

Table 5: Design goals

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

We used Cree's Product Characterization Tool (PCT) tool to determine the drive current for each design.[3]

For the 900-lumen target, we used a typical 85% optical efficiency and 83% driver efficiency. We also estimated solder point temperatures of 65 °C and 75 °C for the two designs.

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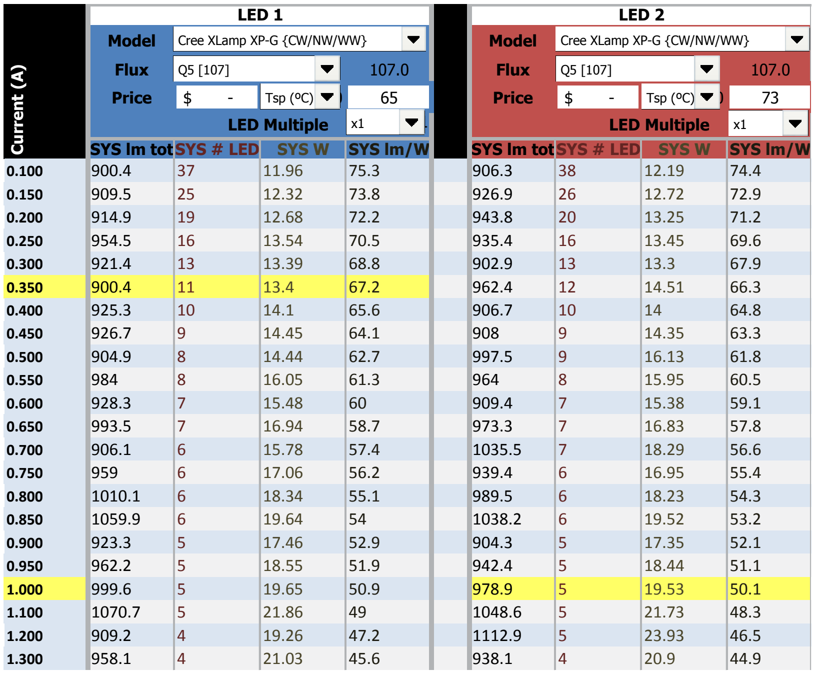
[3] PCT is available at: pct.cree.com



LED 1
Model: Cree XLamp XP-G {CW/NW/WW}
Flux: Q5 [107] 107.0
Price: $ - Tsp (ºC) 65
LED Multiple: x1

LED 2
Model: Cree XLamp XP-G {CW/NW/WW}
Flux: Q5 [107] 107.0
Price: $ - Tsp (ºC) 73
LED Multiple: x1

Current (A)	LED 1				LED 2			
	SYS lm tot	SYS # LED	SYS W	SYS lm/W	SYS lm tot	SYS # LED	SYS W	SYS lm/W
0.100	900.4	37	11.96	75.3	906.3	38	12.19	74.4
0.150	909.5	25	12.32	73.8	926.9	26	12.72	72.9
0.200	914.9	19	12.68	72.2	943.8	20	13.25	71.2
0.250	954.5	16	13.54	70.5	935.4	16	13.45	69.6
0.300	921.4	13	13.39	68.8	902.9	13	13.3	67.9
0.350	900.4	11	13.4	67.2	962.4	12	14.51	66.3
0.400	925.3	10	14.1	65.6	906.7	10	14	64.8
0.450	926.7	9	14.45	64.1	908	9	14.35	63.3
0.500	904.9	8	14.44	62.7	997.5	9	16.13	61.8
0.550	984	8	16.05	61.3	964	8	15.95	60.5
0.600	928.3	7	15.48	60	909.4	7	15.38	59.1
0.650	993.5	7	16.94	58.7	973.3	7	16.83	57.8
0.700	906.1	6	15.78	57.4	1035.5	7	18.29	56.6
0.750	959	6	17.06	56.2	939.4	6	16.95	55.4
0.800	1010.1	6	18.34	55.1	989.5	6	18.23	54.3
0.850	1059.9	6	19.64	54	1038.2	6	19.52	53.2
0.900	923.3	5	17.46	52.9	904.3	5	17.35	52.1
0.950	962.2	5	18.55	51.9	942.4	5	18.44	51.1
1.000	999.6	5	19.65	50.9	978.9	5	19.53	50.1
1.100	1070.7	5	21.86	49	1048.6	5	21.73	48.3
1.200	909.2	4	19.26	47.2	1112.9	5	23.93	46.5
1.300	958.1	4	21.03	45.6	938.1	4	20.9	44.9

Figure 2: PCT view of the number of LEDs used and driving current

The PCT yields the following results:

Design 1: At 350 mA, it appears that 11 LEDs are sufficient, but the light output barely meets the goal and, to be safe, we chose to use 12 LEDs.

Design 2: Five LEDs can achieve 900 lm at 900 mA; however, this requires a custom-made driver. Because the driver can be placed external to the downlight and does not have a space constraint, we chose to use an off-the-shelf driver at 1 A instead.

Thermal Requirements

The 6-inch downlight in this reference design is of a simple geometry and we decided to make a custom aluminum housing, shown in Figure 3. We decided to use a commercially available heat sink, shown in Figure 4, attached to the back of the housing to dissipate the thermal load.[4]

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[4] Part number 637303B03000, AAVID Thermalloy website: www.aavidthermalloy.com/product-group/led

Figure 3: Custom-made aluminum housing

Figure 4: Heat sink

We performed thermal simulations of both luminaire designs to ensure this thermal design is sufficient. We assumed that ~75% of the input power is converted to heat and the rest to light. We included the 6-inch can and a ceiling in the simulation to mimic a real-life application condition.

Figure 5 shows the thermal simulation results for the 12-LED design at 350 mA. The simulated T_{SP} is 55 °C.

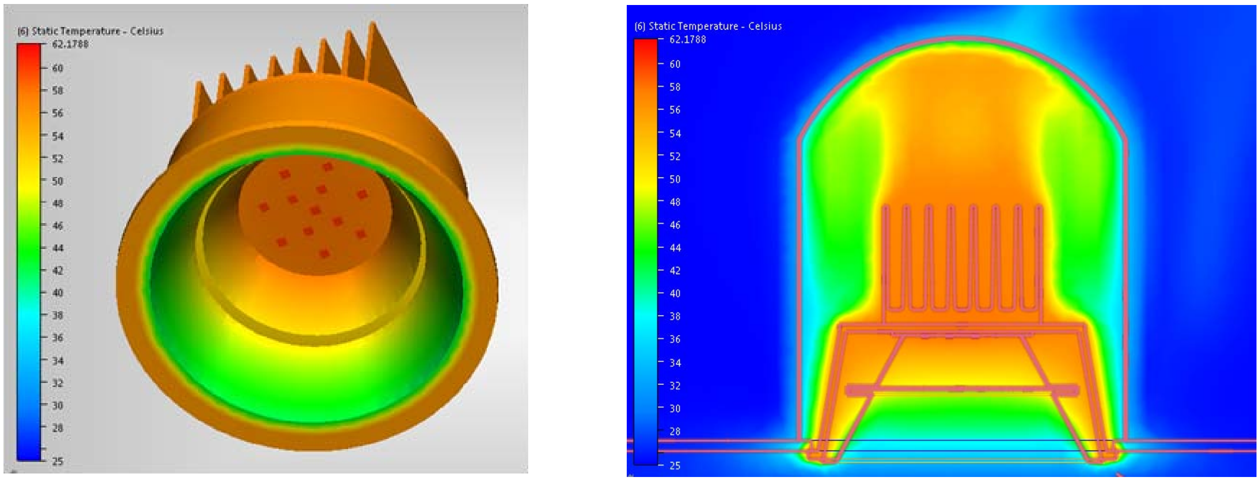

Figure 5: Figure 5: Thermal simulation of 12-LED downlight (left) and downlight mounted in ceiling (right)

Figure 6 shows the thermal simulation results for the 5-LED design at 1000 mA. The simulated T_{SP} is 73 °C.

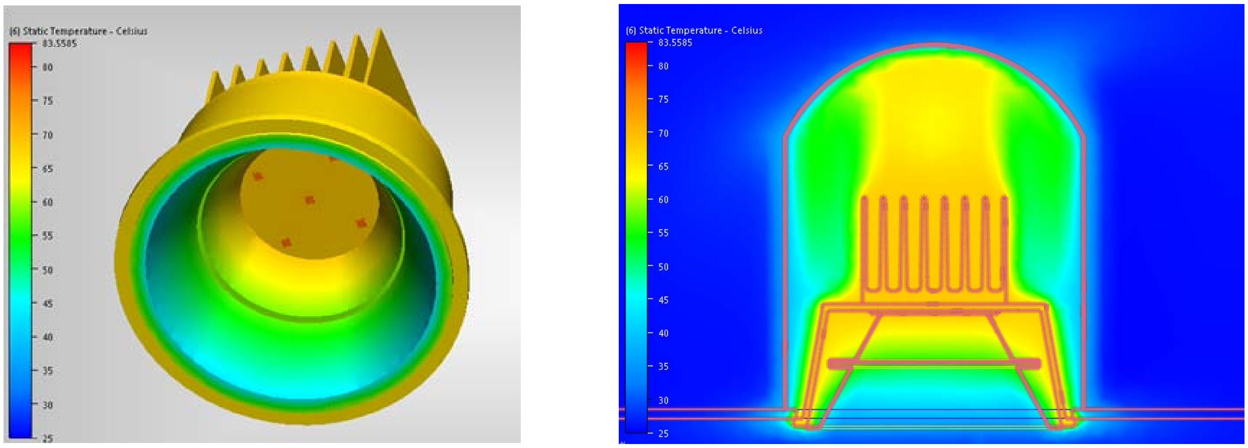

Figure 6: Thermal simulation of 5-LED downlight (left) and downlight mounted in ceiling (right)

Driver

Because the driver for a 6-inch downlight can be located next to the housing above the ceiling, there is no driver size limit. Thus there is no need to design a custom driver for this reference design. We decided to use off-the-shelf drivers from Thomas Research.[5] Both drivers are standard current-type devices with ~87% efficiency.

350-mA driver for 12-LED downlight **1000-mA driver for 5-LED downlight**

Figure 7: Drivers

Secondary Optics

In a multiple-LED lighting system, a diffuser is a popular secondary optic used to minimize glare and hot spots and to distribute light evenly. In many cases, a white reflector is used between the LED and the diffuser to form a recycling

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[5] 350 mA driver part number LED20W-24-C0700, 1000 mA driver part number LED25W-24-C1040; Thomas Research website: www.thomasresearchproducts.com/led_drivers.htm

cavity to maximize light output. In this reference design, we tried a number of combinations of reflectors and diffusers and found that a white reflective paper, a diffuser from Bright View Technologies,[6] and a commercial downlight trim kit[7] to hold everything together form a successful secondary optic for this design.

Figure 8: Diffuser lens

4. CALCULATE THE NUMBER OF LEDS

Design 1 uses 12 XP-G LEDs from the Q5 luminous flux group driven at 350 mA each.

Design 2 uses 5 XP-G LEDs from the Q5 luminous flux group driven at 1000 mA each.

5. CONSIDER ALL DESIGN POSSIBILITIES

Using the methodology described above, we determined a suitable combination of LEDs, components and drive conditions. This section describes how Cree assembled the downlights and compares the results of the two designs.

6. COMPLETE THE FINAL STEPS: IMPLEMENTATION AND ANALYSIS

This section illustrates some of the techniques used to create a working prototype downlight using the XLamp XP-G LED.

Prototyping Details

1. We verified the component dimensions to ensure a correct fit.
2. Following the recommendations in Cree's Soldering and Handling Application Note for the XP-G LED,[8] we reflow soldered the LEDs onto the metal core printed circuit board (MCPCB) with an appropriate solder paste type and reflow profile. We cleaned the flux residue with isopropyl alcohol (IPA).

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[6] Part number P001,Bright View Technologies website: www.brightviewtechnologies.com

[7] Halo website: www.residential-landscape-lighting-design.com/store/ppf/manufacturer_id/17/manufacturer_categories.asp

[8] Cree XLamp XP Family LED Soldering and Handling, Application Note AP25
www.cree.com/products/pdf/XLampXP_SolderingandHandling.pdf

3. We soldered the driver input wires to the MCPCB. We tested the connection by applying power to the LEDs to verify that they lit.
4. We applied a thin layer of thermal conductive compound to the back of the MCPCB and secured the MCPCB to the aluminum housing with screws.
5. We applied a thin layer of thermal conductive compound to the back of aluminum housing and secured the finned heat sink with screws.
6. We secured the white reflective paper to the MCPCB with double-sided tape.
7. We secured the diffuser cover trim to the aluminum housing.
8. We connected the LED DC input wires to the driver DC output wires with connectors.
9. We performed final testing.

Results

We compare 2 downlight designs with different numbers of LEDs running at different currents to achieve the same lumen output. The results show that driving an LED to its operating capacity allows designers to lower cost while retaining performance and reliability.

Thermal Results

Cree verified the board temperature with a thermocouple and an infrared (IR) thermal imaging camera to confirm that the thermal dissipation performance of the heat sink aligns with our simulations. The solder point temperature of the 12-LED downlight was 52 °C. The solder point temperature of the 5-LED downlight was 74 °C. Both results are in close agreement with the simulations and show that the heat sink is sufficient for this design.

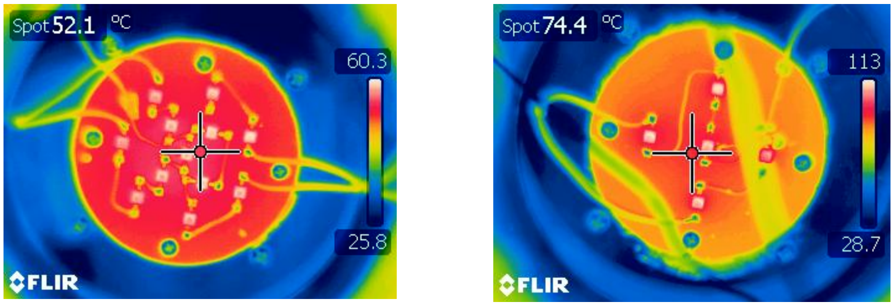

Figure 9: Thermal results for 12-LED (left) and 5-LED (right) XP-G downlights

Estimated LED lifetime

We used Cree’s TM-21 Calculator Tool to project the lifetime of the XP-G LED used in this downlight. Figure 10 shows the calculated and reported lifetimes, determined using the TM-21 projection algorithm, for the XP-G LED at 500-mA input current at 3 solder-point temperatures.

LED	**XLamp XP-G White**		
I	**500 mA**		
Data Set	7	8	9
Tsp	**45°C**	**55°C**	**85°C**
Sample Size	25	25	25
Test Duration	10,080 hrs	10,080 hrs	10,080 hrs
α	*-1.322E-06*	3.963E-07	*-1.060E-06*
β	1.005E+00	1.006E+00	9.996E-01
Calculated Lifetime	α<0; see Reported Lifetime	L70(10k) = 914,000 hours	α<0; see Reported Lifetime
Reported Lifetime	**L70(10k) > 60,500 hours**	**L70(10k) > 60,500 hours**	**L70(10k) > 60,500 hours**

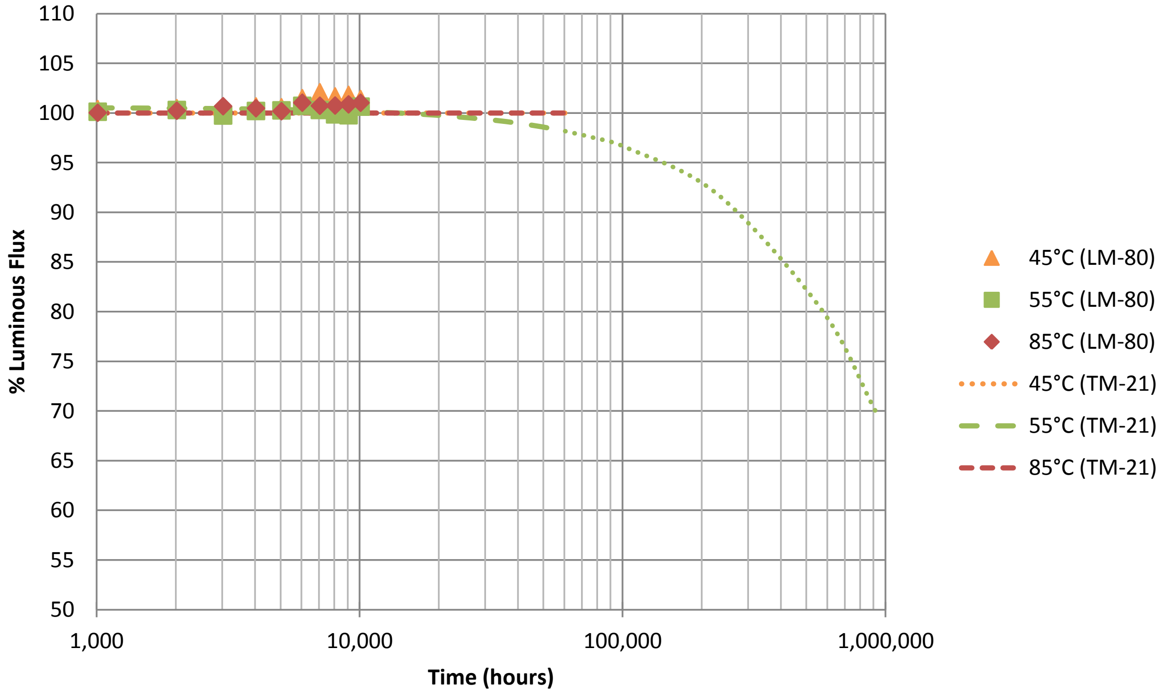

Figure 10: XP-G TM-21 data at 500 mA

Figure 11 shows the calculated and reported lifetimes for the XP-G LED, interpolated from the data shown in Figure 10, at the measured 52 °C T_{SP} of the 12-LED lamp, but with a drive current of 500 mA, higher than the 350 mA used in the reference design. With a reported L70(10k) lifetime greater than 60,500 hours and a calculated L70(10k) lifetime of 914,000 hours, we expect the 12-LED downlight to easily meet the ENERGY STAR lifetime requirement.

LED	**XLamp XP-G White**		
I	**500 mA**		
	Ts1	Tsi (Interpolated)	Ts2
Tsp	**45°C**	**52°C**	**55°C**
Tsp	318.15 K	325.15 K	328.15 K
Ea/kB	N/A		
A	N/A		
α	*-1.322E-06*	N/A	3.963E-07
β	1.005E+00	N/A	1.006E+00
Calculated L70	α<0; see Reported Lifetime	L70(10k) = 914,000 hours	L70(10k) = 914,000 hours
Reported L70	L70(10k) > 60,500 hours	**L70(10k) > 60,500 hours**	L70(10k) > 60,500 hours
Calculated Lifetime		L70(10k) = 914,000 hours	
Reported Lifetime		**L70(10k) > 60,500 hours**	

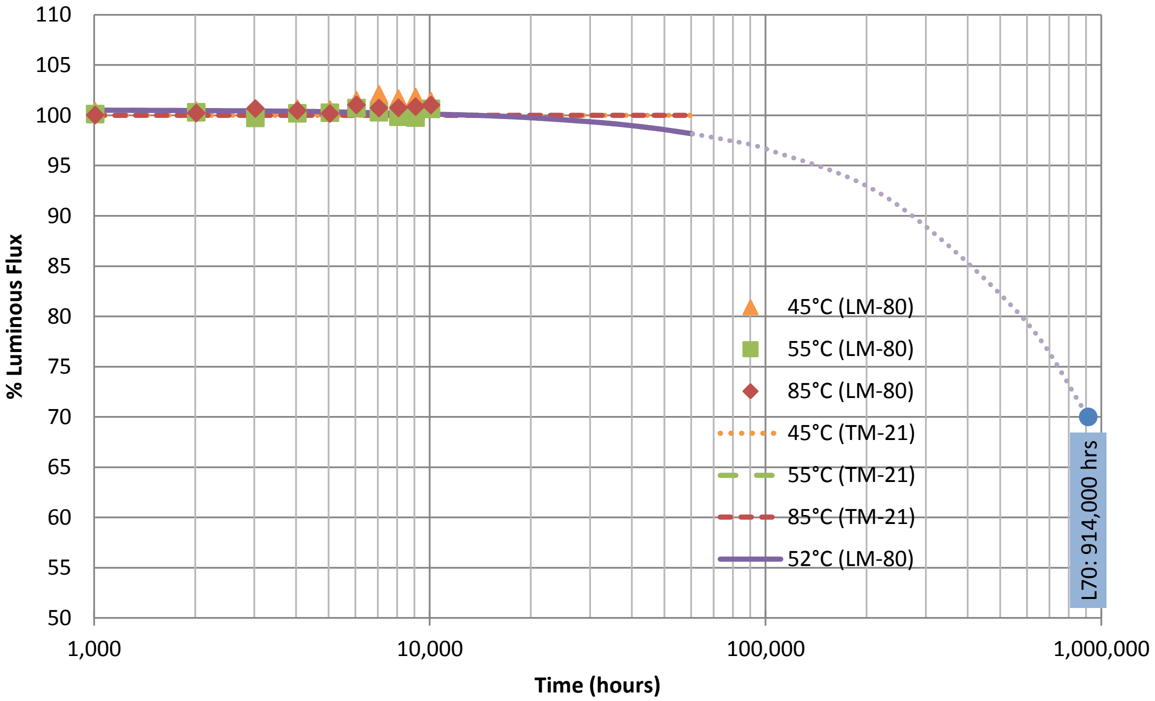

Figure 11: TM-21 report for XP-G at 500 mA at 52 °C T_{SP}

Figure 12 shows the calculated and reported lifetimes, determined using the TM-21 projection algorithm, for the XP-G LED at 1000 mA input current at 3 solder point temperatures.

LED	XLamp XP-G White		
I	1000 mA		
Data Set	10	11	12
Tsp	**55°C**	**85°C**	**105°C**
Sample Size	20	20	20
Test Duration	10,080 hrs	10,080 hrs	6,048 hrs
α	*-4.219E-06*	1.284E-06	5.561E-06
β	9.847E-01	1.016E+00	1.007E+00
Calculated Lifetime	α<0; see Reported Lifetime	L70(10k) = 290,000 hours	L70(6k) = 65,500 hours
Reported Lifetime	**L70(10k) > 60,500 hours**	**L70(10k) > 60,500 hours**	**L70(6k) > 36,300 hours**

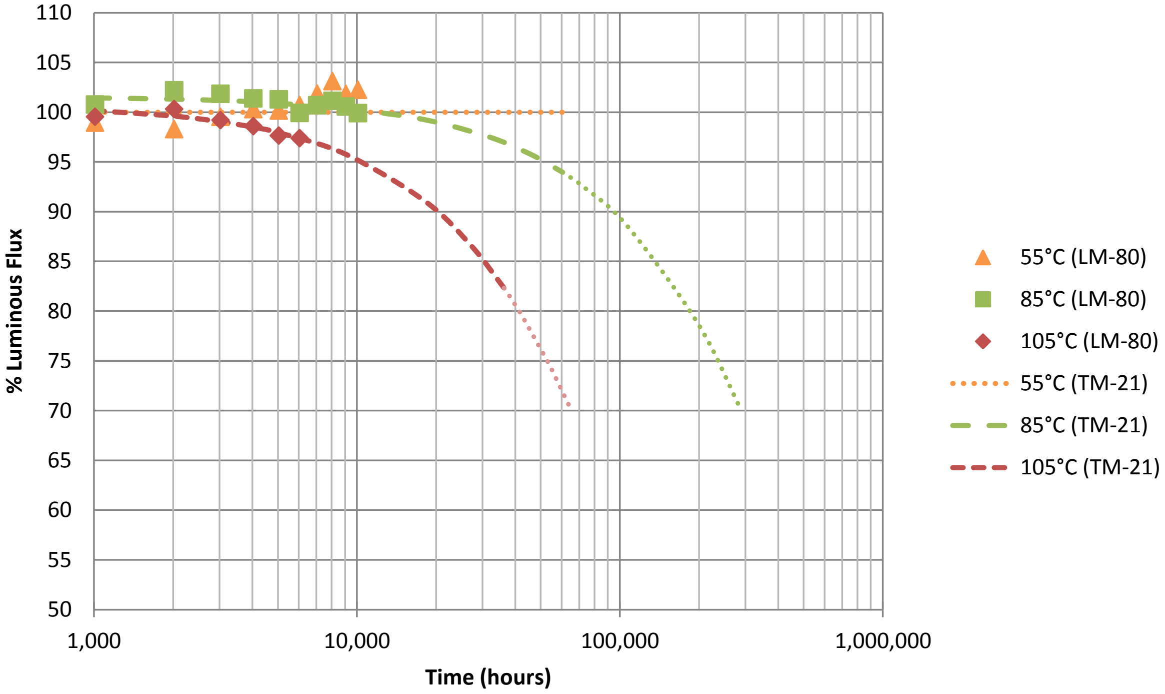

Figure 12: XP-G TM-21 data at 1000 mA

Figure 13 shows the calculated and reported lifetimes for the XP-G LED, interpolated from the data shown in Figure 10, at the measured 74 °C T_{SP} of the 5-LED lamp. With a reported L70(10k) lifetime greater than 60,500 hours and a calculated L70(10k) lifetime of 290,000 hours, we expect the 5-LED downlight to also easily meet the ENERGY STAR lifetime requirement.

LED	**XLamp XP-G White**		
I	**1000 mA**		
	Ts1	Tsi (Interpolated)	Ts2
Tsp	**55°C**	**74°C**	**85°C**
Tsp	328.15 K	347.15 K	358.15 K
Ea/kB	N/A		
A	N/A		
α	*-4.219E-06*	N/A	1.284E-06
β	9.847E-01	N/A	1.016E+00
Calculated L70	α<0; see Reported Lifetime	L70(10k) = 290,000 hours	L70(10k) = 290,000 hours
Reported L70	L70(10k) > 60,500 hours	**L70(10k) > 60,500 hours**	L70(10k) > 60,500 hours
Calculated Lifetime		L70(10k) = 290,000 hours	
Reported Lifetime		**L70(10k) > 60,500 hours**	

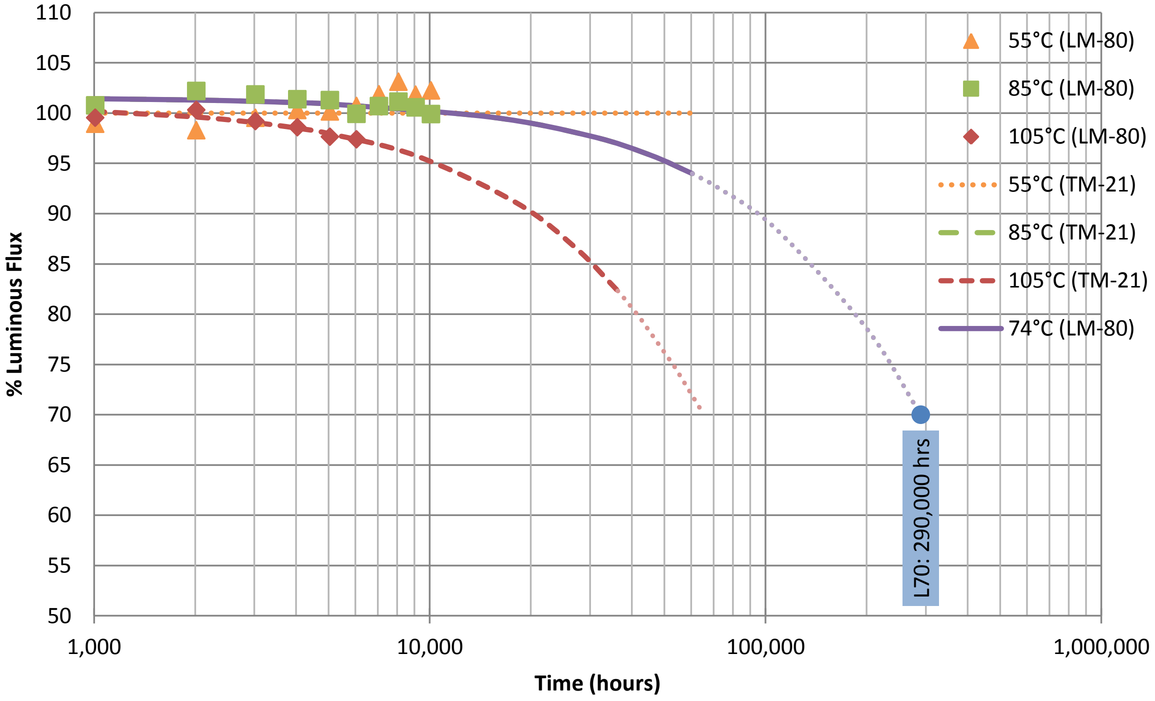

Figure 13: TM-21 report for XP-G at 1000 mA at 74 °C T_{SP}

Optical and Electrical Results

We tested the two prototype downlight designs in a two-meter sphere for 30 minutes to obtain the results in Table 6.[9] As the table shows, both designs meet the 900 lm target for the design. Both designs also meet the ENERGY STAR efficacy and CRI requirements. The 12-LED design uses about 25% less power and produces about 15 lm/W more than the 5-LED design. However, the 5-LED design uses less than half the number of LEDs, which offers a significant savings.

Note than the lifetime values are for the XP-G LED and do not reflect for the lifetime of the other components of the downlights.

Characteristic	Unit	12-LED Downlight	5-LED Downlight
Light output (30 min on time)	lm	943	930
Current	mA	350	1000
Power	W	14.5	19.2
Efficacy	lm/W	65.0	48.4
CCT	K	3000	3020
Driver efficiency	%		
L70(10k) reported lifetime	hours	> 60,500 @ 500 mA	> 60,500 @ 1000 mA
L70(10k) calculated lifetime	hours	914,000 @ 500 mA	290,000 @ 1000 mA
CRI		80.6	80.2
T_{SP}	°C	52	74
T_J (calculated)	°C	57	89

Table 6: 12-LED and 5-LED XP-G downlight comparison

We also tested the intensity distribution of the 2 designs. Figure 14 shows that the intensity distribution of the 2 downlights is very similar. The 5-LED downlight has almost exactly the same intensity distribution as the 12-LED downlight using 60% fewer LEDs. The diffuser distributes the light evenly despite the difference in LED numbers and location.

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[9] Testing was performed at the Cree facilities in Santa Barbara, CA.

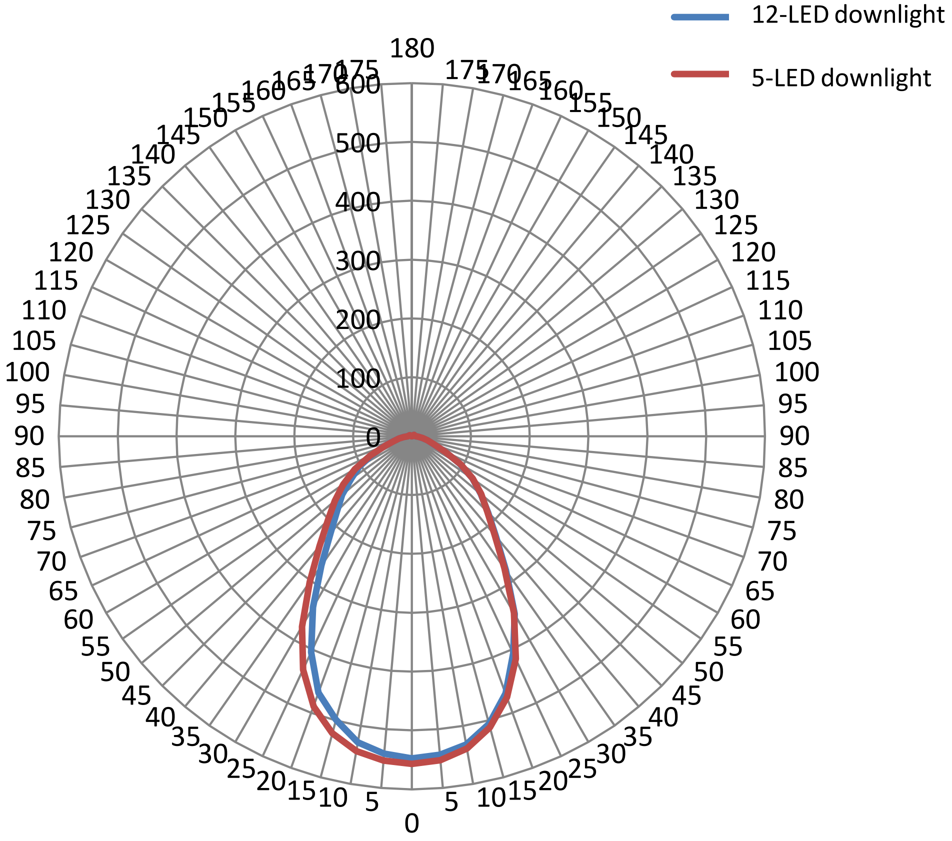

Figure 14: Angular luminous intensity distribution of 12-LED and 5-LED XP-G downlights

CONCLUSIONS

This reference design demonstrates the LED operating capacity concept by applying it to a 6-inch downlight design using Cree XLamp XP-G high-power LEDs. The 5-LED downlight matches the light output of the 12-LED downlight using 60% fewer LEDs. Both downlights deliver the target lumen output and efficacy. With the XP-G LED's maximum drive current of 1.5 A, even this reference design leaves some LED operating capacity unused. Even higher drive currents provide opportunities for additional light output and reduction in the number of LEDs used. Any lighting design must balance numerous factors including efficiency, thermal management, chromaticity and long-term reliability,[10] and the application of the LED operating capacity concept gives lighting designers and engineers the option of using fewer LEDs, thereby reducing cost without sacrificing performance or reliability.

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[10] For additional information on operating XLamp LEDs at or above the maximum drive current, see Pulsed Over-Current Driving of XLamp LEDs: Information and Cautions, Application Note AP60, www.cree.com/products/pdf/XLamp-Pulsed-Current.pdf