Cree® XLamp® XP-E High-Efficiency White LED A21 Reference Design

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INTRODUCTION

With the growing worldwide concern over global warming, many countries have committed to the Kyoto Protocol and attended the Copenhagen Climate Summit, both aimed at reducing carbon emissions. One of the measures to achieve this goal in developed countries is to phase out the use of energy inefficient incandescent lamps over a period of years.

Compact fluorescent lamps (CFL) are a mature incandescent replacement. Although more efficient than incandescent lamps, CFLs contain mercury, raising environmental concerns. With advancing LED technology providing advantages in energy efficiency and environmental friendliness, LED lighting has much potential to become the primary incandescent lamp replacement.

To demonstrate this potential, this reference design details a 60-watt equivalent A21 lamp using the Cree XP-E high-efficiency white (HEW) LED. We chose the A21 form factor because it is a commonly used size and, compared to an A19 lamp, provides additional space to dissipate the heat produced by a 10-watt

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input. With world-class efficacy and a non-directional lighting profile, the XP-E HEW LED is a great choice for a high lumen output retrofit lamp.

The goal of this reference design is a 60-watt equivalent A21 retrofit lamp. Even the most environmentally conscious customers are unwilling to compromise on lamp performance to take advantage of energy savings. A successful design must therefore consider customers' needs balanced with performance, quality, and cost. This design combines Cree XLamp XP-E HEW LEDs with an open-market heat sink, optics, and driver to create a snow-cone style A21 retrofit lamp.

To demonstrate the design flexibility of the XP-E HEW LED, this reference design targets lamps for both the U.S. and Asian markets, with a high efficacy version and a lower cost version for each market. U.S. and Asian customers prefer different color temperatures of light and this reference design accommodates that difference.

DESIGN APPROACH/OBJECTIVES

In the "LED Luminaire Design Guide" application note, Cree advocates a 6-step framework for creating LED luminaires.[1] 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

One of the objectives of this effort is to produce a design that addresses the requirements of several markets. The goal is to accomplish this by changing only the LEDs in the various A21 lamps.

1. DEFINE LIGHTING REQUIREMENTS

Table 2 shows a ranked list of desirable characteristics to address in an A21 reference design.

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

Importance	Characteristics	Metric
Critical	Luminous flux	Lumens (lm)
	Efficacy	Lumens per watt (lm/W)
	Luminous distribution	
	Color uniformity	
	Form factor	
Important	Price	$
	Lifetime	Hours
	Operating temperatures	°C
	Operating humidity	% relative humidity
	Correlated color temperature (CCT)	K
	Color rendering index (CRI)	100-point scale

Table 2: Ranked design criteria for A21 retrofit lamp

Table 3 below summarizes the ENERGY STAR requirements for all integral LED lamps.[2]

Characteristic	Requirements
CCT and Duv	Lamp must have one of the following designated CCTs (per ANSI C78.377-2008) consistent with the 7-step chromaticity quadrangles and Duv tolerances below. Nominal CCT / Target CCT (K) and Tolerance / Target Duv and Tolerance: 2700 K / 2725 ± 145 / 0.000 ± 0.006 3000 K / 3045 ± 175 / 0.000 ± 0.006 3500 K / 3465 ± 245 / 0.000 ± 0.006 4000 K / 3985 ± 275 / 0.001 ± 0.006
Color maintenance	The change of chromaticity over the minimum lumen maintenance test period (6,000 hours) shall be within 0.007 on the CIE 1976 (u’, v’) diagram.
CRI	Minimum CRI (Ra) of 80. R9 value must be greater than 0.
Dimming	Lamps may be dimmable or non-dimmable. Product packaging must clearly indicate whether the lamp is dimmable or not dimmable. Manufacturers qualifying dimmable products must maintain a web page providing dimmer compatibility information.
Warranty	3-year warranty
Allowable lamp bases	Must be a lamp base listed by ANSI.
Power factor	Lamp power < 5 W and low voltage lamps: no minimum PF Lamp power > 5 W: PF > 0.70
Minimum operating temperature	-20 °C or below
LED operating 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.
Electromagnetic and radio-frequency interference	Must meet appropriate FCC requirements for consumer use (FCC 47 CFR Part 15)
Audible noise	Class A sound rating
Transient protection	Power supply shall comply with IEEE C62.41-1991, 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 voltage	Lamp shall operate at rated nominal voltage of 120, 240 or 277 VAC, or at 12 or 24 VAC or VDC.

Table 3: ENERGY STAR requirements for integral LED lamps

2 ENERGY STAR® Program Requirements for Integral LED Lamps Eligibility Criteria – Version 1.4, Table 4 www.energystar.gov/ia/partners/product_specs/program_reqs/Integral_LED_Lamps_Program_Requirements.pdf

Table 4 summarizes the ENERGY STAR requirements for non-standard lamps.[3]

Criteria Item	ENERGY STAR Requirements
Minimum luminous efficacy	• LED lamp power < 10 W: 50 lm/W • LED lamp power ≥ 10 W: 55 lm/W
Minimum light output	200 lumens
Rapid-cycle stress test	No specific distribution is required. Must submit goniophotometry report showing luminous intensity distribution produced by the lamp.
Lumen maintenance	≥ 70% lumen maintenance (L70) at 25,000 hours of operation.
Rapid-cycle stress test	Cycle times: 2 minutes on, 2 minutes off. Lamp cycled once for every 2 hours of L_{70} life.

Table 4: ENERGY STAR requirements for non-standard lamps

Although not directly applicable to this A21 lamp, Table 5 summaries ENERGY STAR requirements for omnidirectional replacement lamps.[4]

<table>
<tr><th>Criteria Item</th><th colspan="2">ENERGY STAR Requirements</th></tr>
<tr><td>Minimum luminous efficacy</td><td colspan="2">• LED lamp power < 10 W: 50 lm/W
• LED lamp power ≥ 10 W: 55 lm/W</td></tr>
<tr><td rowspan="3">Minimum light output</td><td colspan="2">Lamp shall have minimum light output (initial total luminous flux) at least corresponding to the target wattage of the lamp to be replaced, as shown below. Target wattages between the given levels may be interpolated.</td></tr>
<tr><td>Nominal wattage of lamp to be replaced (watts)</td><td>Minimum initial light output of LED lamp (lumens)</td></tr>
<tr><td>60</td><td>800</td></tr>
<tr><td>Luminous intensity distribution</td><td colspan="2">Products shall have an even distribution of luminous intensity (candelas) within the 0° to 135° zone (vertically axially symmetrical).
Luminous intensity at any angle within this zone shall not differ from the mean luminous intensity for the entire 0° to 135° zone by more than 20%.
At least 5% of total flux (lumens) must be emitted in the 135° to 180° zone.
Distribution shall be vertically symmetrical as measured in 3 vertical planes at 0°, 45° and 90°.</td></tr>
<tr><td>Maximum lamp diameter</td><td colspan="2">Not to exceed target lamp diameter</td></tr>
<tr><td>Maximum overall length (MOL)</td><td colspan="2">Not to exceed MOL for target lamp</td></tr>
<tr><td>Lumen maintenance</td><td colspan="2">≥ 70% lumen maintenance (L_{70}) at 25,000 hours of operation</td></tr>
<tr><td>Rapid-cycle stress test</td><td colspan="2">Cycle times must be 2 minutes on, 2 minutes off. Lamp will be cycled once for every 2 hours of L_{70} life.</td></tr>
</table>

Table 5: ENERGY STAR requirements for replacement omnidirectional lamps

Because this reference design targets the Asian market, we benchmarked the Korean KSC7651[5] and Japanese JIS C 7501[6] standards, excerpted in Table 6 and Table 7 below.

3 Ibid., Table 6 www.energystar.gov/ia/partners/product_specs/program_reqs/Integral_LED_Lamps_Program_Requirements.pdf
4 Ibid., Table 7A www.energystar.gov/ia/partners/product_specs/program_reqs/Integral_LED_Lamps_Program_Requirements.pdf
5 KSC7651 www.standard.go.kr/CODE02/USER/0B/03/SerKS_View.asp#
6 JIS C 7501 www.techstreet.com/cgi-bin/basket?action=add&item_id=3749386

CCT (K)	CCT Tolerance (K)	CRI
6500	7040-6020	70
5700	6020-5310	70
5000	5310-4745	70
4500	4746-4260	70
4000	4260-3710	70
3500	3710-3220	70
3000	3220-2870	70
2700	2870-2580	70

Table 6: Korean KSC7651 standard excerpt

From the Japanese standard:

Power	Luminous Flux
25 W	230 lm
40 W	440 lm
50 W	600 lm
60 W	760 lm
75 W	1000 lm
100 W	1430 lm

Table 7: Japanese JIS C 7501 excerpt

2. DEFINE DESIGN GOALS

In many everyday uses, customers' main concern is a lamp's luminous distribution in the 0 to 90° zone. Customers also expect uniform color and brightness. Due to the difficult ENERGY STAR requirement for luminous distribution in the 90 to 180° zone and a driver electronics lifetime requirement of 25,000 hours, it is beyond the scope of this reference design to achieve a balance between performance and cost. Further, this design targets a snow-cone-style retrofit lamp.

For an A19-lamp design that can meet ENERGY STAR requirements for a 60-W lamp, please see Cree's TrueWhite design.[7]

The Cree XP-E HEW LED is a versatile high-power component that offers a wide range of input current levels and color temperatures. This reference design focuses on a high efficacy version and a lower-cost version of an A21 retrofit lamp, each with two color points: 3000 K and 5000 K.

7 www.creeledrevolution.com/blog/2011/01/27/cree-demonstrates-60-watt-equivalent-led-light-bulb/

The design goals for this project as derived from the information above:

Characteristic	Unit	Minimum Goal	Target Goal
Light output	lm	800	> 800
Luminous distribution		Identical to incandescent: 0° to 90° zone	Identical to incandescent: 0° to 90° zone
Power	W	10	< 10
Efficacy	lm/W	45	55
Lifetime	Hours	50,000	50,000
CCT	K	3000/5000	3000/5000
CRI		80/70	> 80/70
Maximum ambient temperature	°C	30	40

Table 8: Design goals

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

This reference design requires a highly efficient and highly reliable driver, an efficient diffuser and sufficient heat dissipation.

LED Component Performance

Compared to the other XP-family packages, the XP-E HEW LED offers advantages of high efficacy due to its package design and larger light emitting area. The XP-E HEW's larger light emitting area and more diffuse lighting effect is ideal for use with a diffuser in this lamp application, reducing the effect of bright hot spots and improving color and brightness uniformity.

There are many flux and color bins to choose from to fit different applications. Figure 1 and Figure 2 show standard binning codes for the 5000-K and 3000-K versions of this design.

XLamp XP-E HEW LED 标准订购代码 – 白光				
最小光通量 (lm) @ 350 mA*		色度区域	订购代码*	色温 (CCT)
组	通量 (lm)			
		户外白 (2600 K – 5300 K)		
R4	130	3A, 3B, 3C, 3D, 3R, 3S, 3T, 3U, 4A, 4B, 4R, 4S	XPEHEW-01-0000-00GC1	5000 K
		3A, 3B, 3C, 3D, 3R, 3S, 3T, 3U, 4A, 4B, 4C, 4D, 4R, 4S, 4T, 4U	XPEHEW-01-0000-00GD1	4750 K
		3C, 3D, 3T, 3U, 4A, 4B, 4C, 4D, 4R, 4S, 4T, 4U	XPEHEW-01-0000-00GC2	4500 K
		3C, 3D, 3T, 3U, 4A, 4B, 4C, 4D, 4R, 4S, 4T, 4U, 5A1, 5A2, 5A3, 5A4, 5B1, 5B2, 5B3, 5B4, 5R, 5S	XPEHEW-01-0000-00GD2	4500 K
		4A, 4B, 4C, 4D, 4R, 4S, 4T, 4U, 5A1, 5A2, 5A3, 5A4, 5B1, 5B2, 5B3, 5B4, 5R, 5S	XPEHEW-01-0000-00GC3	4300 K
		3A, 3B, 3C, 3D	XPEHEW-01-0000-00GE3	5000 K
		3C, 3D, 4A, 4B	XPEHEW-01-0000-00GF4	4750 K
		4A, 4B, 4C, 4D	XPEHEW-01-0000-00GE4	4500 K
		4C, 4D, 5A1, 5A2, 5A3, 5A4, 5B1, 5B2, 5B3, 5B4	XPEHEW-01-0000-00GF5	4300 K
		5A1, 5A2, 5A3, 5A4, 5B1, 5B2, 5B3, 5B4, 5C1, 5C2, 5C3, 5C4, 5D1, 5D2, 5D3, 5D4	XPEHEW-01-0000-00GE5	4000 K

Figure 1: XP-E HEW 5000-K binning codes

XLamp XP-E HEW LED 标准订购代码 – 白光				
最小光通量 (lm) @ 350 mA*		色度区域	订购代码	色温 (CCT)
组	通量 (lm)			
暖白 (2600 K - 3700 K)				
Q2	87.4	7C1, 7C2, 7C3, 7C4, 7D1, 7D2, 7D3, 7D4, 8A1, 8A2, 8A3, 8A4, 8B1, 8B2, 8B3, 8B4	XPEHEW-L1-0000-00AF8	2900 K
		8A1, 8A2, 8A3, 8A4, 8B1, 8B2, 8B3, 8B4, 8C1, 8C2, 8C3, 8C4, 8D1, 8D2, 8D3, 8D4	XPEHEW-L1-0000-00AE8	2700 K
Q3	93.9	6C1, 6C2, 6C3, 6C4, 6D1, 6D2, 6D3, 6D4, 7A1, 7A2, 7A3, 7A4, 7B1, 7B2, 7B3, 7B4	XPEHEW-L1-0000-00BF7	3200 K
		7A1, 7A2, 7A3, 7A4, 7B1, 7B2, 7B3, 7B4, 7C1, 7C2, 7C3, 7C4, 7D1, 7D2, 7D3, 7D4	XPEHEW-L1-0000-00BE7	3000 K
		7C1, 7C2, 7C3, 7C4, 7D1, 7D2, 7D3, 7D4, 8A1, 8A2, 8A3, 8A4, 8B1, 8B2, 8B3, 8B4	XPEHEW-L1-0000-00BF8	2900 K
		8A1, 8A2, 8A3, 8A4, 8B1, 8B2, 8B3, 8B4, 8C1, 8C2, 8C3, 8C4, 8D1, 8D2, 8D3, 8D4	XPEHEW-L1-0000-00BE8	2700 K
Q4	100	6A1, 6A2, 6A3, 6A4, 6B1, 6B2, 6B3, 6B4, 6C1, 6C2, 6C3, 6C4, 6D1, 6D2, 6D3, 6D4	XPEHEW-L1-0000-00CE6	3500 K
		6C1, 6C2, 6C3, 6C4, 6D1, 6D2, 6D3, 6D4, 7A1, 7A2, 7A3, 7A4, 7B1, 7B2, 7B3, 7B4	XPEHEW-L1-0000-00CF7	3200 K
		7A1, 7A2, 7A3, 7A4, 7B1, 7B2, 7B3, 7B4, 7C1, 7C2, 7C3, 7C4, 7D1, 7D2, 7D3, 7D4	XPEHEW-L1-0000-00CE7	3000 K
		7C1, 7C2, 7C3, 7C4, 7D1, 7D2, 7D3, 7D4, 8A1, 8A2, 8A3, 8A4, 8B1, 8B2, 8B3, 8B4	XPEHEW-L1-0000-00CF8	2900 K
		8A1, 8A2, 8A3, 8A4, 8B1, 8B2, 8B3, 8B4, 8C1, 8C2, 8C3, 8C4, 8D1, 8D2, 8D3, 8D4	XPEHEW-L1-0000-00CE8	2700 K
Q5	107	6A1, 6A2, 6A3, 6A4, 6B1, 6B2, 6B3, 6B4, 6C1, 6C2, 6C3, 6C4, 6D1, 6D2, 6D3, 6D4	XPEHEW-L1-0000-00DE6	3500 K
		6C1, 6C2, 6C3, 6C4, 6D1, 6D2, 6D3, 6D4, 7A1, 7A2, 7A3, 7A4, 7B1, 7B2, 7B3, 7B4	XPEHEW-L1-0000-00DF7	3200 K
		7A1, 7A2, 7A3, 7A4, 7B1, 7B2, 7B3, 7B4, 7C1, 7C2, 7C3, 7C4, 7D1, 7D2, 7D3, 7D4	XPEHEW-L1-0000-00DE7	3000 K
R2	114	6A1, 6A2, 6A3, 6A4, 6B1, 6B2, 6B3, 6B4, 6C1, 6C2, 6C3, 6C4, 6D1, 6D2, 6D3, 6D4	XPEHEW-L1-0000-00EE6	3500 K

Figure 2: XP-E HEW 3000-K binning codes

We selected an outdoor white LED, order code XPEHEW-01-0000-00GC1 (bin code XPEHEW-01-3A0-R4-G-01), for the 5000 K version and selected a neutral white LED, order code XPEHEW-L1-0000-00DE7 (bin code XPEHEW-L1-73A-Q5-G-01), for the 3000 K version. By not selecting LEDs from the brightest bins, we ensured that this design meets its design goals using LEDs that are readily available.

Thermal Requirements

Despite LEDs having efficacy higher than conventional incandescent and fluorescent lighting sources, a typical high-power LED converts as much as 80% of its input power to heat. The XP-E HEW LED advances photonic conversion limits, having a very high light-conversion efficiency of up to 35%. Thus 65% of the heat from the input power, along with the thermal load from the driver, needs to be effectively dissipated through a well-matched heat sink to achieve a good system design that minimizes LED optical loss and ensures lumen maintenance and reliability. To meet the 10 W input power target, we chose an open-market A21 form factor heat sink/housing. Our simulation and actual testing proved this to be a good choice for this design.

Figure 3: Thermal housing assembly

To achieve reliable thermal simulation results, we first have to determine the correct operating power range. We used the Cree Product Characterization Tool (PCT) to estimate power and lumen output.[8] We conducted several thermal simulations based on the PCT results to obtain meaningful results. As shown in Figure 4, we entered the target lumen output of 820 lm, an optimistic 95% optical efficiency, 85% driver efficiency, and 70 °C junction temperature (T_J). Our starting point was the more difficult low-cost version; there are fewer LEDs running at higher current in this version. From the PCT, we selected five LEDs at 600 mA and 10.65 W.

Current (A)	LED 1			
	Model	Cree XLamp XP-E HEW {CW/NW/WW}		
	Flux	R4 [130]	Tj (ºC)	70
	Price	$ -		
	SYS lm/W	SYS # LED	SYS lm tot	SYS W
0.100	107.1	25	850	7.94
0.150	103.7	17	850	8.2
0.200	103.6	13	871	8.41
0.250	99.5	10	820	8.24
0.300	96	9	864	9
0.350	93.5	8	880	9.41
0.400	90.9	7	868	9.55
0.450	88.8	6	828	9.32
0.500	86.7	6	906	10.45
0.550	85	5	820	9.65
0.600	83.1	5	885	10.65
0.650	80.7	5	940	11.65
0.700	79.4	5	1000	12.59

Figure 4: PCT data for five-LED XP-E HEW

Our thermal simulation, shown in Figure 5, yields an estimated T_{SP} of 78 °C.[9]

8 Cree's Product Characterization Tool: //pct.cree.com/

9 Cree used NIKA EFD Pro V8.2 with Pro E Wildfire
http://www.mentor.com/products/mechanical/products/floefd/
http://www.ptc.com/products/creo-elements-pro/

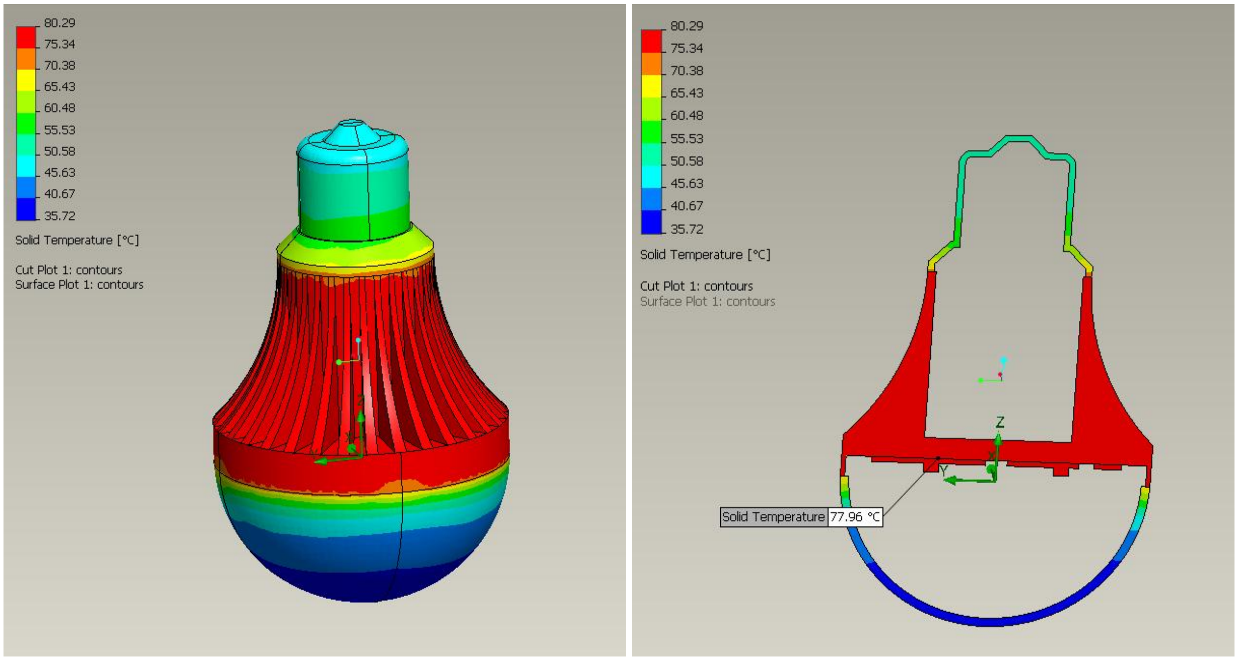


Figure 5: Steady-state thermal simulation of five-LED XP-E HEW lamp

For the eight-LED lamp, we again used the PCT with similar input parameters, as shown in Figure 6.

Current (A)	LED 1			
	Model	Cree XLamp XP-E HEW {CW/NW/WW}		
	Flux	R4 [130]	Tj (ºC)	80
	Price	$ -		
	SYS lm/W	SYS # LED	SYS lm tot	SYS W
0.100	107.8	25	825	7.65
0.150	104.1	17	833	8
0.200	102.3	13	845	8.26
0.250	97.3	11	869	8.93
0.300	95.2	9	846	8.89
0.350	91.8	8	856	9.32
0.400	90.2	7	854	9.47
0.450	86.9	7	938	10.79
0.500	85	6	882	10.38
0.550	83.4	6	960	11.51
0.600	81.7	5	860	10.53
0.650	79.4	5	915	11.53
0.700	78.2	5	975	12.47

Figure 6: PCT data for 8-LED XP-E HEW

Our thermal simulation yields an estimated T_{SP} of 70 °C.

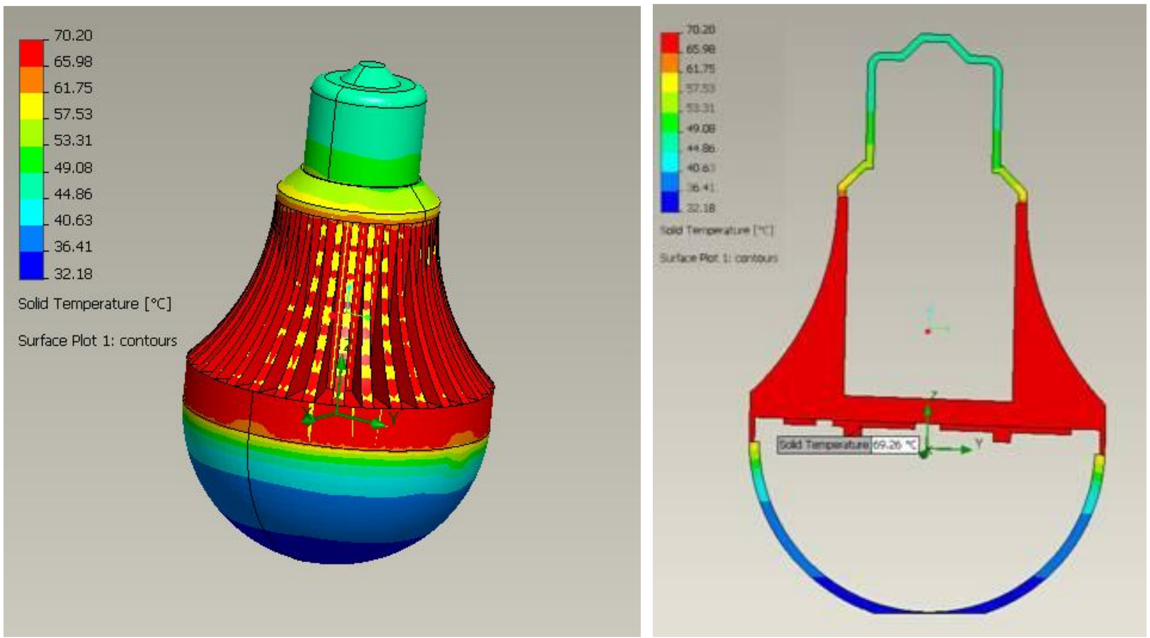


Figure 7: Thermal simulation for an eight-LED XP-E HEW lamp

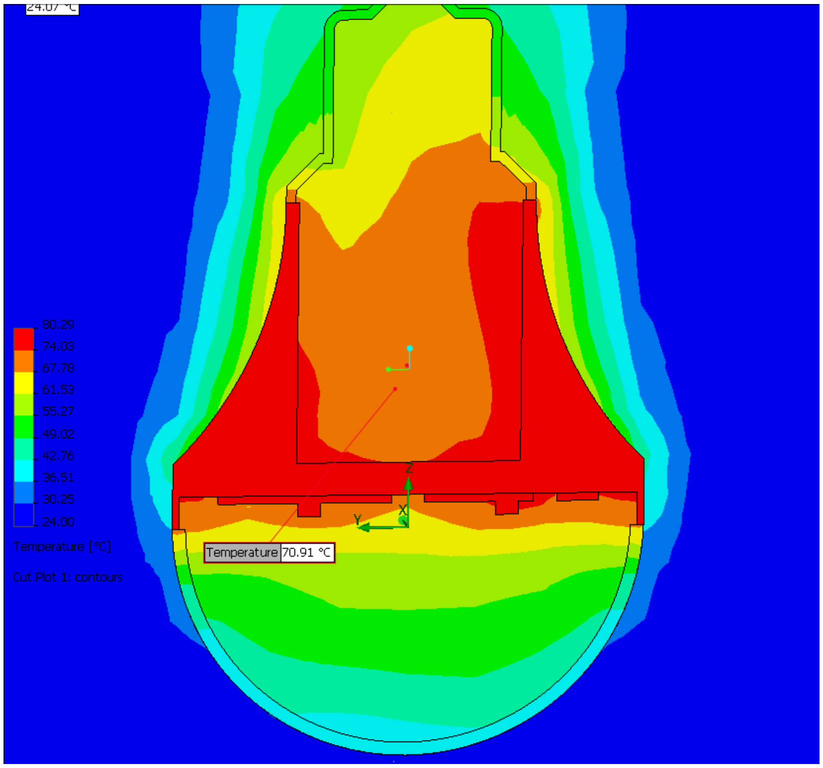


Figure 8: Thermal simulation showing driver housing temperature of 8-LED lamp

Driver Electronics

The choice of a driver is limited by the size of the lamp cavity and the working temperature, in addition to need for high efficiency and low cost. We selected a driver solution from iWatt, employing a unique digital LED driver integrated circuit (IC) featuring primary side regulation. The circuit uses iWatt's iW1692 IC with single-end flyback topology, an EFD20 transformer and valley-fill power factor correction.[10] Also, eliminating an optocoupler results in increased efficiency and minimizes the parts count, reducing cost.

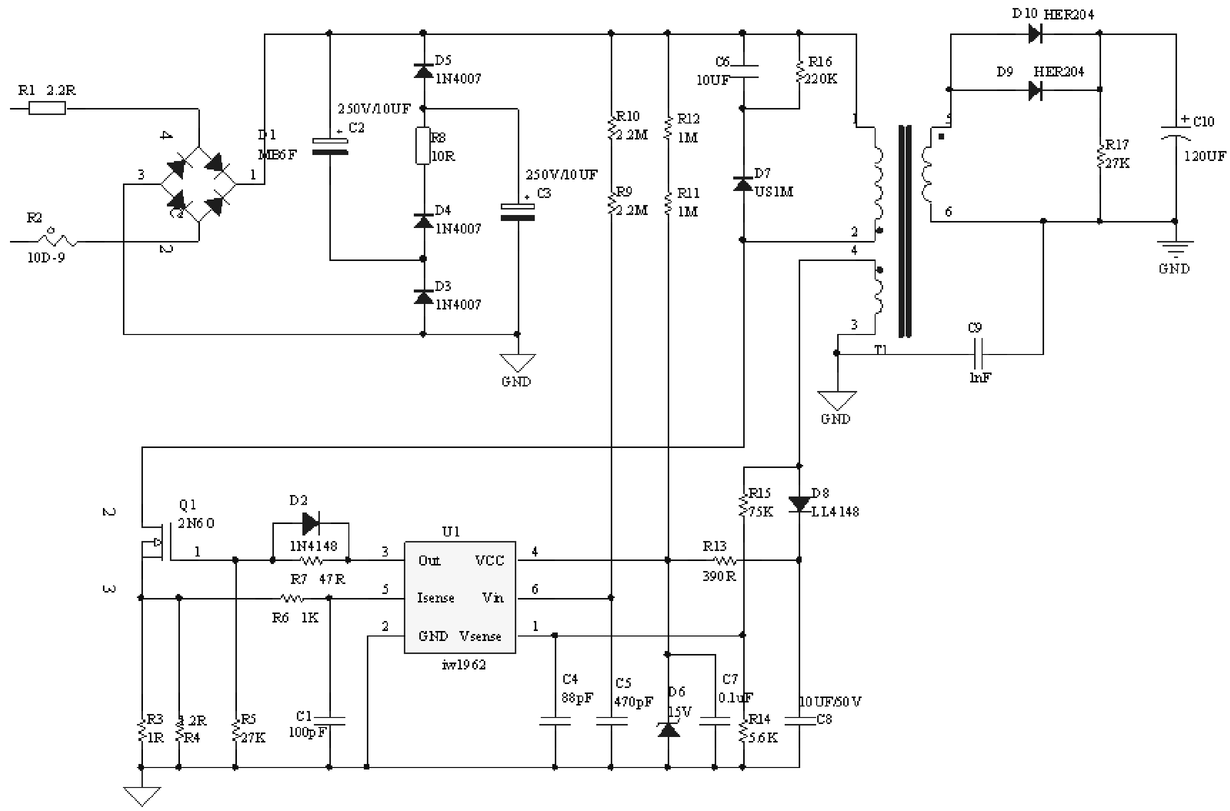


Figure 9: XP-E HEW A21 driver circuit design

Secondary Optics

The major factors to consider for a good diffuser are material, diffusion level and transmittance. In general, the higher the diffusion level, the lower the transmittance. Thus, a suitable balance needs to be made. Considering cost, we chose a diffuser cap with a medium diffusion level, shown in Figure 10.

The final optical performance of the lamps shows this to be a suitable diffuser cap.

Figure 10: Diffuser cap

10 Website: www.iwatt.com/iw1692.php

4. CALCULATE THE NUMBER OF LEDS NEEDED

To meet the design goals, we chose to use 8 XP-E HEW LEDs for the high efficacy version of the A21 lamp and 5 LEDs for the lower cost version. In both versions, the light output and efficacy of the XP-E HEW LED enables a relatively small number of LEDs to produce light output equivalent to a 60 W incandescent lamp.

5. CONSIDER ALL DESIGN POSSIBILITIES AND CHOOSE THE BEST

For this design, we chose to use an A21 kit from Shenzhen How Nice Optoelectronics Co., Ltd. that includes an aluminum housing/heat sink, plastic driver enclosure, metal E26 screw base, and optical diffuser.[11]

The LED layout on the metal core printed circuit board (MCPCB) is a major factor in the overall appearance of the lamp output. A good layout avoids bright and dim spots. After examining the light output from various LED layouts, we determined a center LED within a circular pattern to be most suitable for both the 5-LED and 8-LED designs. The caliper in the following figures shows the LED spacing in millimeters in the various layouts.

Figure 11: Five LEDs in geometric pattern

Figure 12: Five LEDs in circular pattern

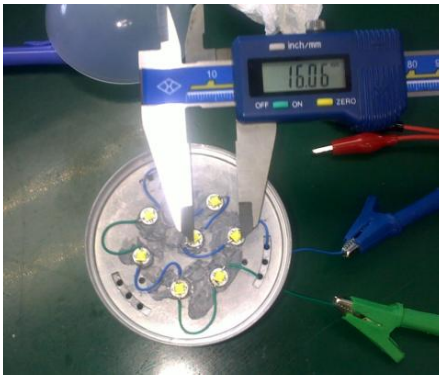


Figure 13: Eight LEDs in circular pattern

6. COMPLETE THE FINAL STEPS

Using the methodology described above, we determined a suitable combination of XLamp XP-E HEW LEDs, components and drive conditions. This section describes the techniques Cree used to assemble A21 replacement lamps based on the design and compares the results with our goal, to create a 60 W equivalent XP-E HEW A21 retrofit lamp.

11 Website: www.haolisi.com/en/main.asp

Prototyping Details

1. We verified the component dimensions to ensure a correct fit.

Figure 14: XP-E HEW A21 lamp components

2. Following the XLamp XP-family recommendations,[12] we reflow soldered the XP-E HEW LEDs onto the MCPCB with an appropriate solder paste and reflow profile.
3. We cleaned the flux residue with isopropyl alcohol.
4. We applied a thin layer of thermal conductive compound to the back of the MCPCB and secured the MCPCB to the heat sink with screws.
5. We inserted the driver into the lamp housing, fed the DC wires through the through hole and soldered them to the corresponding terminal pads on the MCPCB.
6. We soldered the driver input wires to the E26 base.
7. We tested the connection by applying power to the E26 base and checked that the LED was illuminated.
8. After the functional check, we assembled the lamp housing and the E26 base. This kit uses a snap-in design. Other kit designs may vary.
9. We screwed the diffuser cap to the lamp housing.
10. We performed final testing.

Results

Thermal Results

Cree verified that the thermal dissipation performance of the heat sink aligns with our simulations. A thermocouple was secured to an LED to measure the solder point temperature. The steady-state solder point temperature of the 5-LED lamp was 80 °C. The solder point temperature of the 8-LED lamp was 68 °C. Both results are in close agreement with the simulations and show that the heat sink is sufficient for this design.

12 “Cree XLamp XP Family Soldering & Handling” http://www.cree.com/products/pdf/XLampXP_SolderingandHandling.pdf

Estimated LED Lifetime

We used Cree's TM-21 Calculator Tool to project the lifetime of the XP-E HEW LED used in this A21 lamp. Figure 15 shows the calculated and reported lifetimes, determined using the TM-21 projection algorithm, for the XP-E HEW LED at 500 mA input current at 3 solder point temperatures.

LED	**XLamp XP-E High-Efficiency White**		
I	**500 mA**		
Data Set	7	8	9
Tsp	**45°C**	**55°C**	**85°C**
Sample Size	25	23	21
Test Duration	8,064 hrs	8,064 hrs	8,064 hrs
α	3.329E-06	1.805E-06	3.515E-06
β	1.016E+00	1.012E+00	9.943E-01
Calculated Lifetime	L70(8k) = 112,000 hours	L70(8k) = 204,000 hours	L70(8k) = 99,900 hours
Reported Lifetime	**L70(8k) > 48,400 hours**	**L70(8k) > 48,400 hours**	**L70(8k) > 48,400 hours**

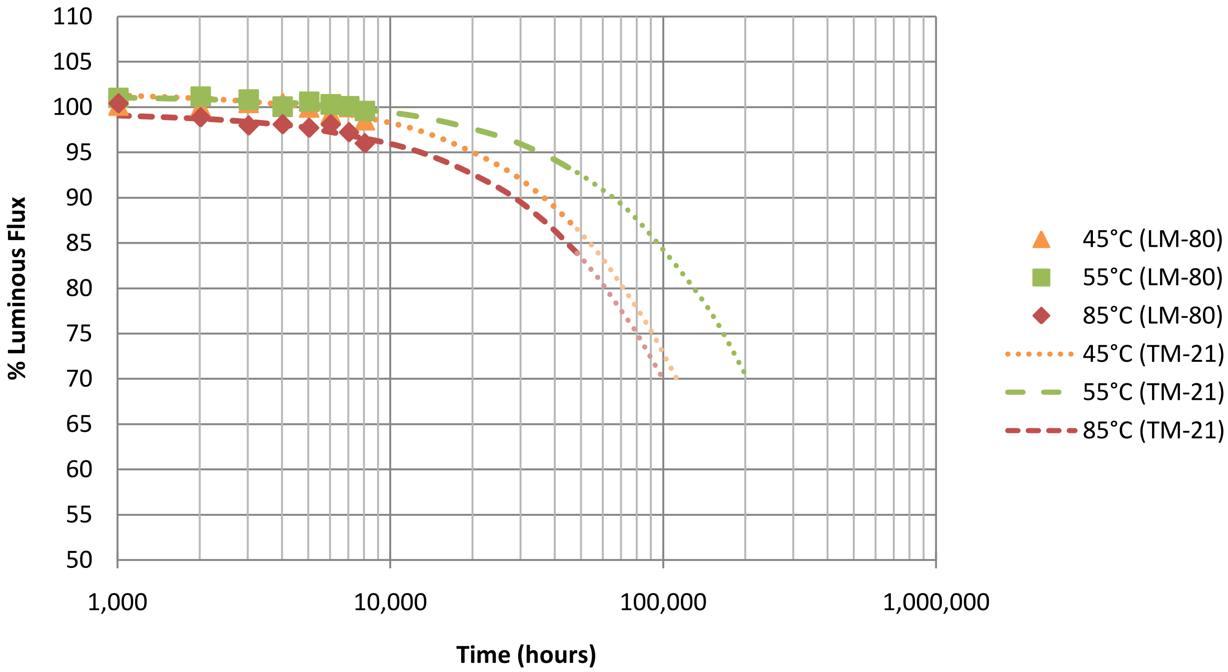


Figure 15: XP-E HEW TM-21 data

Figure 16 shows the calculated and reported lifetimes for the XP-E HEW LED, interpolated from the data shown in Figure 15, at the measured 80 °C T_{SP} of the 5-LED lamp. With a reported L70(8k) lifetime greater than 48,400 hours and a calculated L70(8k) lifetime of 116,000 hours, we expect the 5-LED A21 lamp to easily meet the ENERGY STAR lifetime requirement.

LED	**XLamp XP-E High-Efficiency White**		
I	**500 mA**		
	Ts1	Tsi (Interpolated)	Ts2
Tsp	**55°C**	**80°C**	**85°C**
Tsp	328.15 K	352.15 K	358.15 K
Ea/kB	2610.22		
A	5.1410E-03		
α	1.805E-06	3.104E-06	3.515E-06
β	1.012E+00	1.003E+00	9.943E-01
Calculated L70	L70(8k) = 204,000 hours	L70(8k) = 116,000 hours	L70(8k) = 99,900 hours
Reported L70	L70(8k) > 48,400 hours	**L70(8k) > 48,400 hours**	L70(8k) > 48,400 hours
Calculated Lifetime		L70(8k) = 116,000 hours	
Reported Lifetime		**L70(8k) > 48,400 hours**	

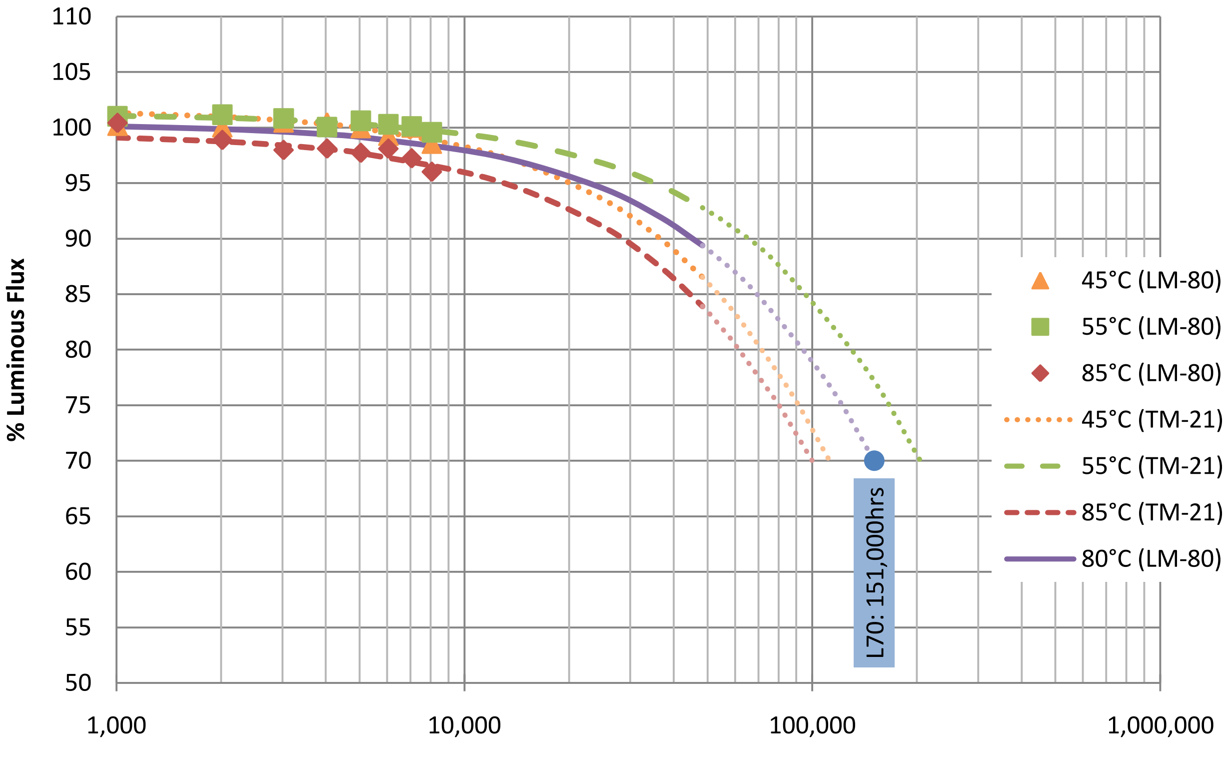


Figure 16: XP-E HEW TM-21 data for five-LED A21-lamp T_{SP}

Figure 17 shows the calculated and reported lifetimes for the XP-E HEW LED, interpolated from the data shown in Figure 15, at the measured 68 °C T_{SP} of the 8-LED lamp. With a reported L70(8k) lifetime greater than 48,400 hours and a calculated L70(8k) lifetime of 151,000 hours, we expect the 8-LED A21 lamp to also easily meet the ENERGY STAR lifetime requirement.

LED	**XLamp XP-E High-Efficiency White**		
I	**500 mA**		
	Ts1	Tsi (Interpolated)	Ts2
Tsp	**55°C**	**68°C**	**85°C**
Tsp	328.15 K	340.15 K	358.15 K
Ea/kB	2610.22		
A	5.1410E-03		
α	1.805E-06	2.390E-06	3.515E-06
β	1.012E+00	1.003E+00	9.943E-01
Calculated L70	L70(8k) = 204,000 hours	L70(8k) = 151,000 hours	L70(8k) = 99,900 hours
Reported L70	L70(8k) > 48,400 hours	**L70(8k) > 48,400 hours**	L70(8k) > 48,400 hours
Calculated Lifetime		L70(8k) = 151,000 hours	
Reported Lifetime		**L70(8k) > 48,400 hours**	

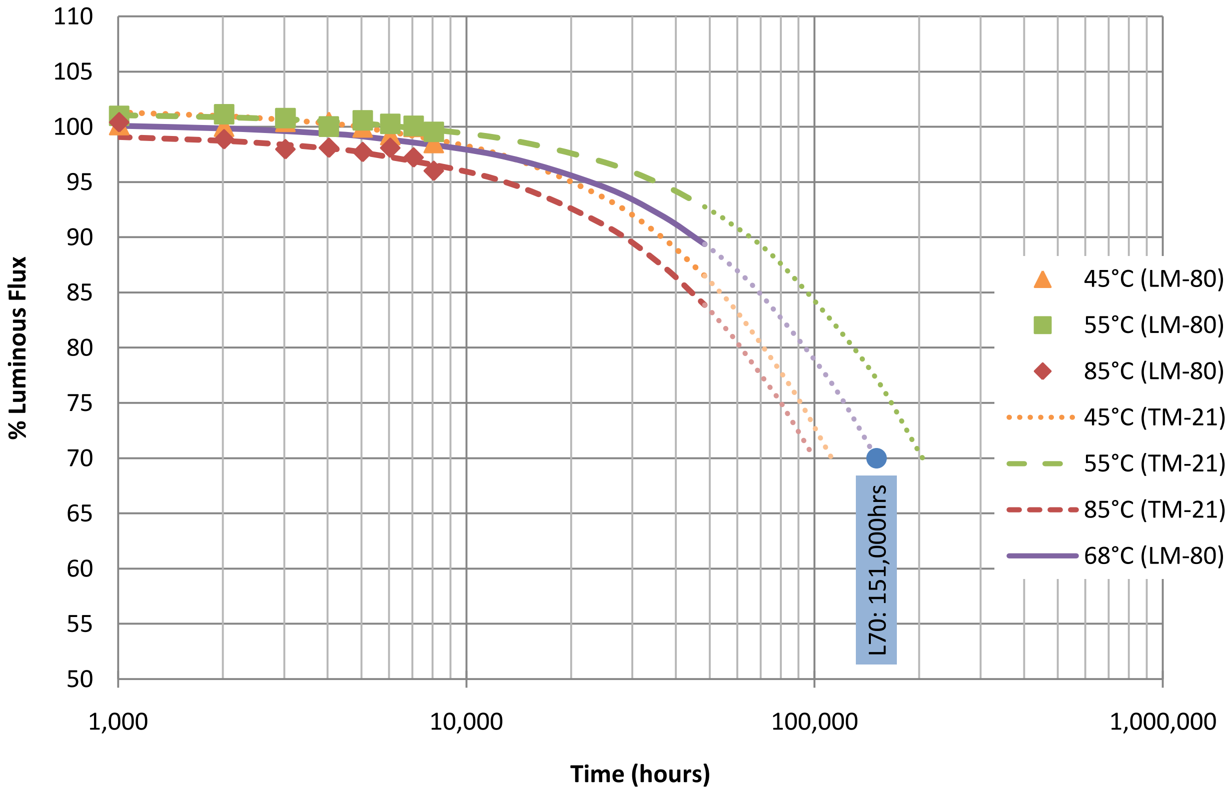


Figure 17: XP-E HEW TM-21 data for eight-LED A21 lamp T_{SP}

Based on Cree's LM-80 testing of the XLamp XP-E HEW LED and, using TM-21 industry standard extrapolation methods, Cree expects this A21 lamp to attain both an ENERGY STAR compliant L70 rating of 25,000 hours and meet the target design goal of an L70 rating of 50,000 hours.

Considering the estimated solder point temperatures of the two lamps, we expect that most drivers have a similar lifetime.

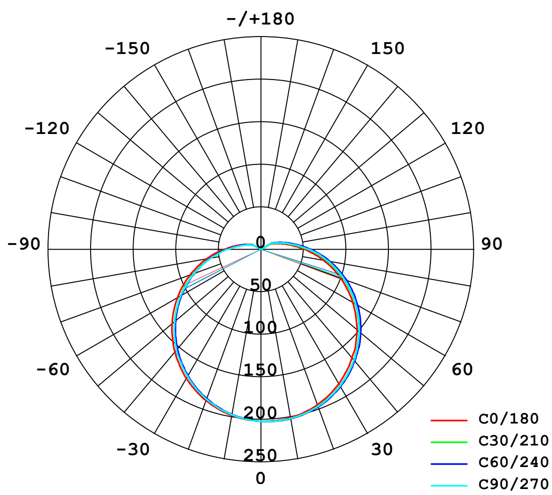
Visual Performance

Table 9 shows the performance of the XP-E HEW A21 lamps. The lamps meet the Korean and Japanese standards excerpted earlier and easily exceed the ENERGY STAR 50/55 lm/W efficacy requirement.

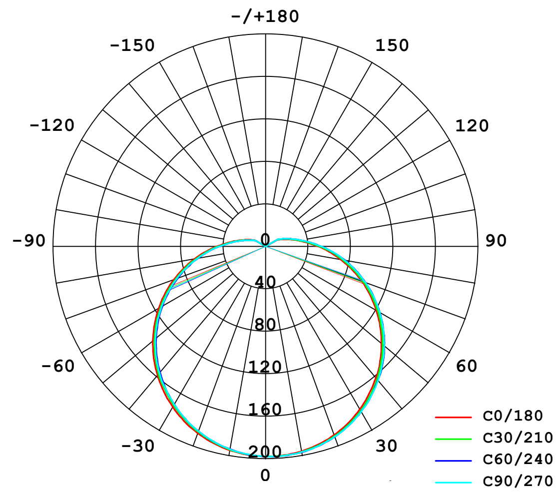
Characteristic	Units	5 LED 5000 K	8 LED 5000 K	5 LED 3000 K	8 LED 3000 K
Light output (10-min on time)	lm	843	836	740	832
Current	mA	513	433	577	580
Power	W	10.4	8.8	11.7	11.8
Efficacy	lm/W	82	96	63	71
CCT	K	5060	4960	3077	3075
Driver efficiency	%	91.8	91.9	92.0	92.1
Lifetime	Hours	50,000	50,000		
CRI		70	70	83	83
Viewing angle	°	134.3	136.2	132.7	134.7

Table 9: XP-E HEW A21-lamp performance

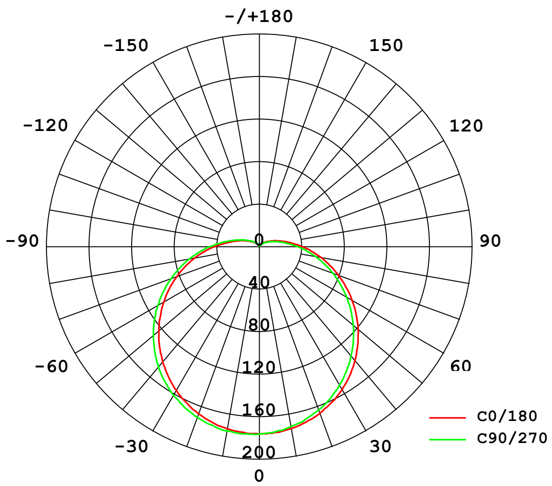
Figure 18 is a plot of the angular luminous intensity distribution for the XP-E HEW A21 retrofit lamps. By design, a snow-cone lamp is more "forward directing" than an omnidirectional incandescent lamp. The luminous distribution curves in Figure 18 show a smooth change over the viewing angle, giving an evenly lit surface. The full width half medium (FWHM) of the distribution is 133° to 136°. We believe this is acceptable for a directional lamp that is used in applications in which light in the 90 to 180° zone not a critical requirement.



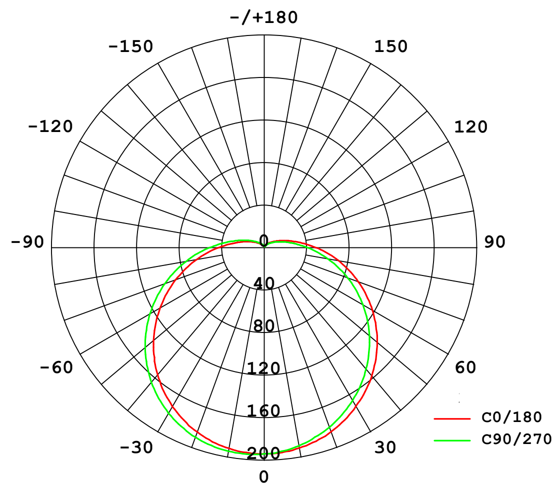
5-LED 5000 K FWHM: 134°



8-LED 5000 K FWHM: 136°



5-LED 3000 K FWHM: 133°



8-LED 3000 K FWHM: 135°

Figure 18: Angular luminous intensity distribution of XP-E HEW A21 lamps

Figures 19 to 22 show the illuminance of the XP-E HEW A21 lamps at various distances from the light source.

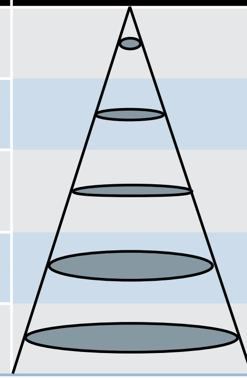
Height		Illuminance					Diameter	
		Eavg	Emax	Eavg	Emax			
1 m	3.3 ft	2.8 fc	18.9 fc	30.6 lx	202.9 lx		474.0 cm	15.6 ft
2 m	6.6 ft	0.7 fc	4.7 fc	7.6 lx	50.7 lx		948.1 cm	31.1 ft
3 m	9.8 ft	0.3 fc	2.1 fc	3.4 lx	22.5 lx		1422.1 cm	46.7 ft
4.m	13.1 ft	0.2 fc	1.2 fc	1.9 lx	12.7 lx		1896.1 cm	62.2 ft
5 m	16.4 ft	0.1 fc	0.8 fc	1.2 lx	8.1 lx		2370.1 cm	77.8 ft

Figure 19: Five-LED 5000-K lamp illuminance – 134° beam angle

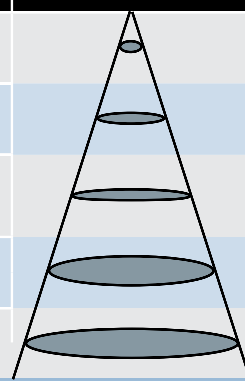
Height		Illuminance					Diameter	
		Eavg	Emax	Eavg	Emax			
1 m	3.3 ft	2.6 fc	18.4 fc	27.7 lx	198.4 lx		496.6 cm	16.3 ft
2 m	6.6 ft	0.6 fc	4.6 fc	6.9 lx	49.6 lx		993.3 cm	32.6 ft
3 m	9.8 ft	0.3 fc	2.0 fc	3.1 lx	22.0 lx		1489.9 cm	48.9 ft
4.m	13.1 ft	0.2 fc	1.2 fc	1.7 lx	12.4 lx		1986.5 cm	65.2 ft
5 m	16.4 ft	0.1 fc	0.7 fc	1.1 lx	7.9 lx		2483.1 cm	81.5 ft

Figure 20: Eight-LED 5000 K lamp illuminance – 136° beam angle

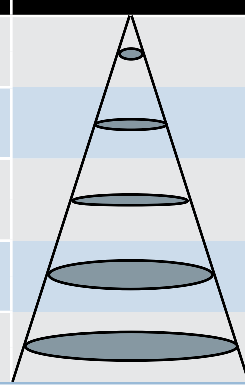
Height		Illuminance					Diameter	
		Eavg	Emax	Eavg	Emax			
1 m	3.3 ft	2.7 fc	16.5 fc	28.7 lx	177.2 lx		456.2 cm	15.0 ft
2 m	6.6 ft	0.7 fc	4.1 fc	7.2 lx	44.3 lx		912.5 cm	29.9 ft
3 m	9.8 ft	0.3 fc	1.8 fc	3.2 lx	19.7 lx		1368.7 cm	44.9 ft
4.m	13.1 ft	0.2 fc	1.0 fc	1.8 lx	11.1 lx		1825.0 cm	59.9 ft
5 m	16.4 ft	0.1 fc	0.7 fc	1.1 lx	7.1 lx		2281.2 cm	74.8 ft

Figure 21: Five-LED 3000-K lamp illuminance - 133° beam angle

Height		Illuminance					Diameter	
		Eavg	Emax	Eavg	Emax			
1 m	3.3 ft	2.7 fc	18.1 fc	29.6 lx	194.6 lx		479.4 cm	15.8 ft
2 m	6.6 ft	0.7 fc	4.5 fc	7.4 lx	48.6 lx		958.8 cm	31.5 ft
3 m	9.8 ft	0.3 fc	2.0 fc	3.3 lx	21.6 lx		1438.2 cm	47.2 ft
4.m	13.1 ft	0.2 fc	1.1 fc	1.8 lx	12.2 lx		1917.6 cm	62.9 ft
5 m	16.4 ft	0.1 fc	0.7 fc	1.2 lx	7.8 lx		2397.0 cm	78.6 ft

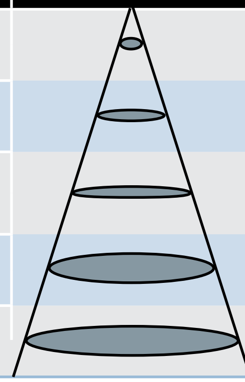


Figure 22: Eight-LED 3000 K lamp illuminance – 135°beam angle

CONCLUSIONS

The intent of this design is to demonstrate the ease of incorporating Cree's XLamp XP-E HEW LED into an A21 retrofit lamp meeting ENERGY STAR and Asian market requirements for a 60 W equivalent lamp. The XP-E HEW LED works well in this application. It has excellent efficacy and its light distribution with a diffuser produces uniform lighting without hot spots. It does this while using 20% of the energy of a 60 W incandescent lamp and lasting 10 times longer.

Due to the kit nature of this design implementation, some improvements a committed design team with appropriate resources could make include: a dimmable power supply, a custom heat sink/housing design and, for the 5-LED 3000 K lamp, a higher drive current. This design shows the level of performance that is possible with the Cree XLamp XP-E HEW LED but is certainly not the only way that a good XP-E HEW LED-based A21 lamp can be designed.

An opportunity exists to transform the lighting industry from energy inefficient incandescent lamps and environmentally unfriendly CFLs to high efficiency, long-lasting LED lamps. The Cree XLamp XP-E HEW LED is a strong candidate to play a significant role in this transformation.