LED Luminaire Design Guide

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INTRODUCTION

This application note provides guidelines for the process of designing high-power LEDs into luminaires. This document uses an indoor luminaire design as an example, but the process described can be applied to the design of any LED luminaire.

Lighting-class LEDs are now available that deliver the brightness, efficacy, lifetime, color temperatures, and white-point stability required for general illumination. As a result, these LEDs are being designed into most general lighting applications, including roadway, parking area, and indoor directional lighting. LED-based luminaires reduce total-cost-of-ownership (TCO) in these applications through maintenance avoidance (since LEDs last much longer than traditional lamps) and reduced energy costs.

There are over 20 billion light fixtures using incandescent, halogen, or fluorescent lamps worldwide. Many of these fixtures are being used for directional light applications but are based on lamps that put out light in all directions. The United States Department of Energy (DOE) states that recessed downlights are the most common installed luminaire type in new residential

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construction.[1] In addition, the DOE reports that downlights using non-reflector lamps are typically only 50% efficient, meaning half the light produced by the lamp is wasted inside the fixture.

In contrast, lighting-class LEDs offer efficient, directional light that lasts at least 50,000 hours. Indoor luminaires designed to take advantage of all the benefits of lighting-class LEDs can:

- Exceed the efficacy of any incandescent and halogen luminaire.
- Match the performance of even the best CFL (compact fluorescent) recessed downlights.
- Provide a lifetime five to fifty times longer than these lamps before requiring maintenance.
- Reduce the environmental impact of light: no mercury, less power-plant pollution, and less landfill waste.

DESIGN APPROACH

Luminaires or Lamps?

Designing LEDs into general illumination requires a choice between designing either a complete luminaire based on LEDs or an LED-based lamp meant to install into an existing fixture. Generally, a complete luminaire design will have better optical, thermal and electrical performance than the retrofit lamp, since the existing fixture does not constrain the design. It is up to the designer to decide whether the total system performance of a new luminaire or the convenience of a retrofit lamp is more important in the target application.

Target Existing Luminaires

If the target application is better served by creating a new LED luminaire, then designing the luminaire's light output to match or exceed an existing luminaire has several advantages. First, an existing design is already optimized to target a known application, and can provide guidance for setting the design goals around light output, cost, and operating environment. Second, an existing design is already in an accepted form factor. Switching to the LED luminaire is easier for the end user if the form factors are the same.

Unfortunately, some LED luminaire manufacturers are misreporting or inflating claims of LED luminaire efficacy and lifetime characteristics. The lighting industry saw similar problems during the early years of CFL replacement bulbs. The lack of industry standards and wide variations in early product quality delayed the adoption of CFL technology for many years. The United States Department of Energy is aware that the same standards and quality problems may exist with early LED luminaires and that these problems may delay the adoption of LED light in a similar fashion. In response, it launched the DOE SSL Commercial Product Testing Program (CPTP) to test the claims of LED-luminaire makers. This program anonymously tests LED-based luminaires for the following four characteristics:

- Luminaire light output (lumens)
- Luminaire efficacy (lumens per watt)
- Correlated color temperaure (degrees Kelvin)
- Color-rendering index

DOE's CPTP sets a good precedent for LED luminaire design by focusing on the usable light output of a luminaire — not just the light output of the light source.

1 U.S. Department of Energy, Energy Efficiency and Renewable Energy. LED Application Series: Recessed Downlights.

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The Idea of a Lamp May Be Outdated

The long lifetime of LED light may make the idea of a lamp outdated. Lighting-class LEDs do not fail catastrophically like light bulbs. Instead, they can provide at least 50,000 hours of useful lifetime before they gracefully degrade below 70% of their initial light output (also called lumen maintenance). That's equal to 5.7 years if left on continuously!

However, in most lighting situations, the lights are switched off regularly. This off period can extend the lifetime of the LED well past three decades, as shown in Chart 1 (at right). After the years it will take for an LED luminaire to "burn out," LED lighting technology will be brighter, more efficient, and probably offer TCO savings over the older LED luminaire.

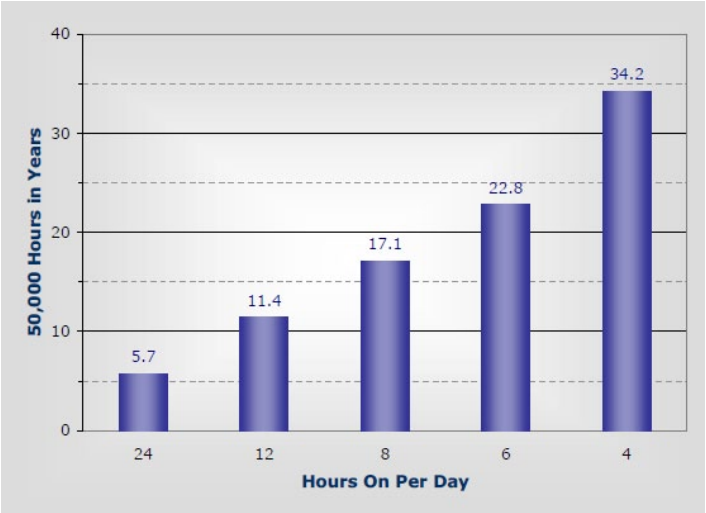

Chart 1: What 50,000 hours means in practical terms

Keep in mind how much environmental impact was avoided over that 50,000 hours of LED luminaire lifetime:

- At least 25 fewer incandescent bulbs were sent to landfills AND five times less energy used. (About 50% of power in the United States comes from burning coal, which releases mercury into the air.)
- Or, at least 5 fewer CFL bulbs containing mercury sent for disposal.

As mentioned previously, maintenance avoidance is an important benefit for LED luminaires. Therefore, designing the LED luminaire to deliver maximum lifetime and provide TCO savings is an excellent strategy to overcome the hurdle of the higher initial cost of LED-based luminaires.

DESIGN PROCESS

Table 1 lists a general process for designing high-power LEDs into a luminaire. The rest of the document walks through these design steps in order. To better illustrate these design concepts, this document includes example calculations for an LED luminaire meant to replace a 23-W CFL downlight. This design process is repeatable for all kinds of luminaires and not just the example included.

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Table 1: Process for designing high-power LEDs into luminaires

Step	Explanation
1. Define lighting requirements	• The design goals should be based either on an existing fixture's performance or on the application's lighting requirements.
2. Define design goals	• Specify design goals, which will be based on the application's lighting requirements. • The designer should specify any other goals that will influence the design, such as special optical requirements or being able to withstand high temperatures.
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 effiiciencies 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 needed to meet the design goals.
5. Consider all design possibilities and choose the best	• As with any design, there are many different ways to best achieve the design goals. • LED lighting is still a new field, so assumptions that work for conventional lighting sources may not apply to LED lighting design.
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 design to further refine the luminaire design. • Record observations and ideas for improvement.

1. DEFINE LIGHTING REQUIREMENTS

The LED luminaire must meet or exceed the lighting requirements for the target application. Therefore, the lighting requirements must be defined before establishing the design goals. For some applications, there are existing lighting standards that will define the requirements directly. For other applications, a good approach is to characterize an existing luminaire.

Table 2 (right) lists important characteristics to consider when characterizing an existing luminaire. The light output and power characteristics are always critical, while other characteristics may or may not be important, depending on the application.

All lighting companies can provide data files or documentation that detail the "critical" characteristics for each of their fixtures. The "potentially important" characteristics are more subjective or may not be listed in the manufacturer's documentation. In this case, it is up to the designer to characterize the existing luminaire.

Figure 1 illustrates the critical characteristics for the example CFL downlight. Table 3 shows the full characterization of the existing luminaire.

Table 2: Important characteristics of target luminaire

Importance	Characteristic	Units
Critical	Luminous flux	lumens (lm)
	Illuminance distribution	footcandles (fc)
	Electrical power consumption	watts (W)
Potentially Important	Luminaire aesthetics	
	Price	
	Lifetime	hours
	Operating temperatures	°C
	Operating humidity	% RH
	Color temperaure	K
	CRI	
	Manufacturability	
	Ease of installation	
	Form factor	

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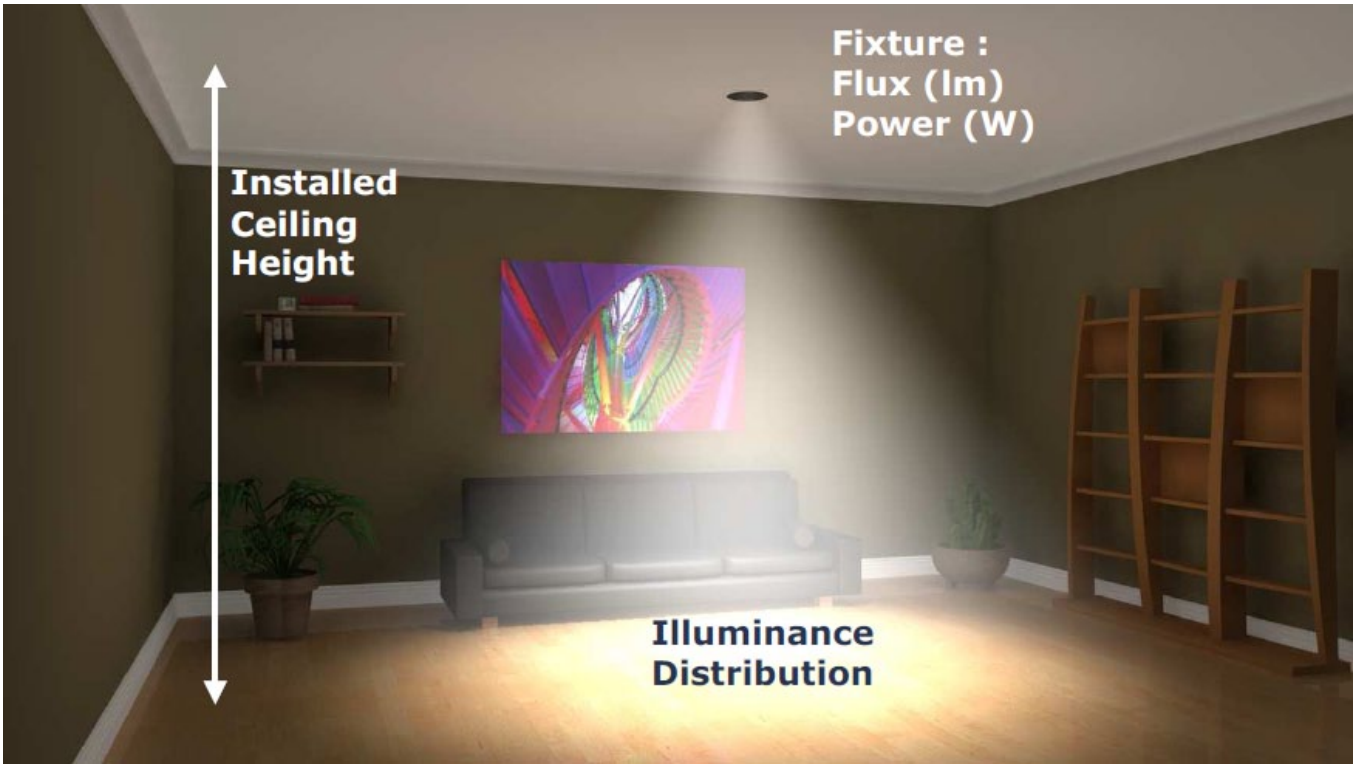

Figure 1: Critical characteristics for example CFL downlight

Table 3: Example CFL downlight characterization

Part	Characteristic	Unit	Value
Lamp	Technology		CFL
	Light output	lm	1,500
	Power	W	23
	Efficacy	lm/W	65
	Lifetime	hrs	10,000
	Average selling price		US $6
Fixture	Coefficient of utilization (CU)	%	54
	Light output	lm	810
	Power (excluding ballast)	W	23
	Efficacy	lm/W	35
	ASP		US $20

2. DEFINE DESIGN GOALS

With the lighting requirements defined, the design goals for the LED luminaire can be set. Just as when defining the lighting requirements, the critical design goals will be related to light output and power consumption. Make sure to include other design goals that may also be important for the target application, including operating environment, bill-of-materials (BOM) cost, and lifetime.

Table 4 lists the design goals for the example LED luminaire.

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Table 4: Design goals for CFL downlight-replacement luminaire

Characteristic	Unit	Goal	Notes
Light output	lm	810	
Illuminance distribution	fc		Same shape as target; matching or better illuminance
Power (excluding driver)	W	23	
Efficacy	lm/W	35	
Lifetime	hours	50,000	
CCT	K	4,000	
CRI		75	
Circular opening	in	6	
Maximum ambient temp.	°C	55	Commercial building with vented ceilings
High volume BOM cost		US $50	

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

One of the most important parameters in the design process is how many LEDs are required to meet the design goals. The rest of the design decisions revolve around the number of LEDs, since it directly impacts the light output, power consumption, and cost of the luminaire.

It is tempting to calculate the number of LEDs by looking at the typical luminous flux listed on an LED's data sheet and divide the target lumens from the design goals by that number. However, this approach is too simplified and will lead to a design that will not meet the application's lighting requirements.

An LED's luminous flux depends on a variety of factors, including drive current and junction temperature. To accurately calculate the necessary number of LEDs, the inefficiencies of the optical, thermal and electrical systems must be estimated first. Personal experience with previous prototypes, or the example numbers provided in this document, can serve as a guide to estimate these losses. This section walks through the process of estimating these system losses.

Optical System Efficiency

Optical system efficacy is estimated by examining light loss. There are two main sources of light loss to estimate:

1. **Secondary Optics**

   Secondary optics are any optical system that is not part of the LED itself, such as a lens or diffuser placed over the LED. The losses associated with secondary optics vary depending on the particular element used. Typical optical efficiency through each secondary optical element is between 85% and 90%.

2. **Light Loss Within the Fixture**

   Fixture light loss occurs when light rays from the light source strike the fixture housing before hitting the target. Some light is absorbed by the fixture housing, while some is reflected back into the fixture. The efficiency of the fixture is dictated by placement of the light source, the shape of the fixture housing, and materials used in the fixture housing. As Figure 2 shows, the directional nature of LED light enables much higher fixture efficiencies than is possible with omni-directional light sources.

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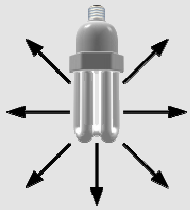
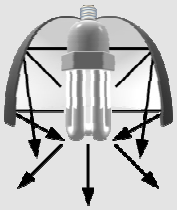
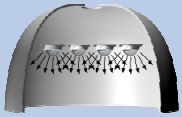
Light Source	Light-Source Efficacy	Coefficient of Utilization	Fixture Efficacy
CFL	 65 lm/W	 54%	35 lm/W
XLamp® XR-E Neutral White LED	58 lm/W	 77%	44 lm/W

Figure 2: Comparison of CFL & LED coefficient of utilization

For the example luminaire, there will only be secondary optics loss if the luminaire requires secondary optics. The main purpose of secondary optics is to change the light output pattern of the LED. Chart 2 compares the beam angle of the Cree XLamp XR-E LED to the light output pattern of the target fixture. The beam angle of the bare LED is similar enough to the target fixture that no secondary optic is required. Therefore, there is no optical loss due to secondary optics for the example luminaire.

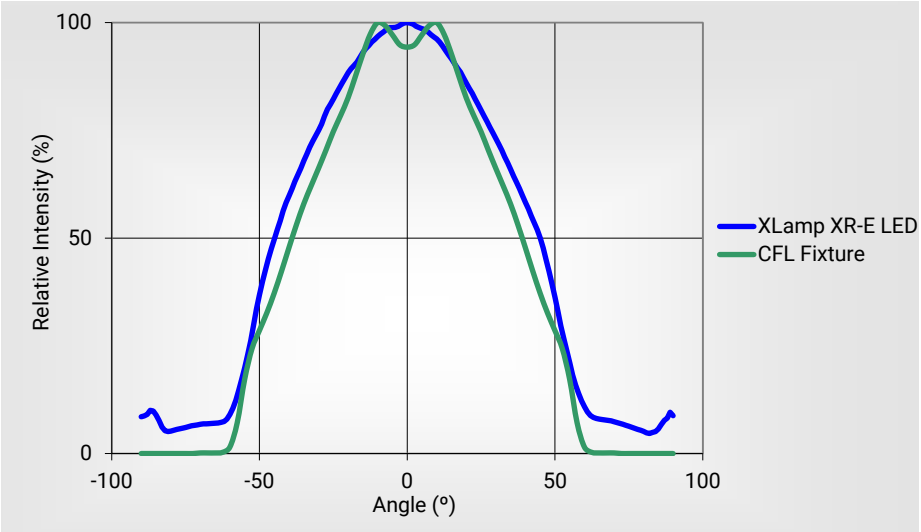


Chart 2: Light ouput vs. angle for CFL fixture & XLamp XR-E LED

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To calculate fixture loss for the CFL example, we assumed 85% reflectivity for the fixture reflector cup and that 60% of the light will hit the reflector cup. Therefore, the optical efficiency will be:

Optical Efficiency = (100% x 40%) + (85% x 60%)

Optical Efficiency = 91%

Thermal Loss

LEDs will decrease in relative flux output as junction temperature (Tj) rises. Most LED data sheets list typical luminous flux at Tj = 25 °C, while most LED applications use higher junction temperatures. When using Tj > 25 °C, the luminous flux must be derated from the value listed on the LED's data sheet.

LED data sheets include a chart showing the relative light output versus junction temperature, such as the one shown in Chart 3 (right) for XLamp XR-E white LEDs. By choosing either a specific relative light output or a specific junction temperature, this graph shows the value for the other characteristic.

For the CFL example, this luminaire is only designed for commercial buildings with vented ceilings. Based on the listed design goals, this design will prioritize light output, efficacy and lifetime.

XLamp XR-E LEDs are rated to provide an average of 70% lumen maintenance after 50,000 hours, provided the junction temperature is kept at 80 °C or lower. Therefore, the appropriate maximum junction temperature for the CFL example is 80 °C. This corresponds to a minimum relative luminous flux of 85%, as shown in Chart 3. This 85% relative luminous flux is the thermal efficacy estimate for the example luminaire.

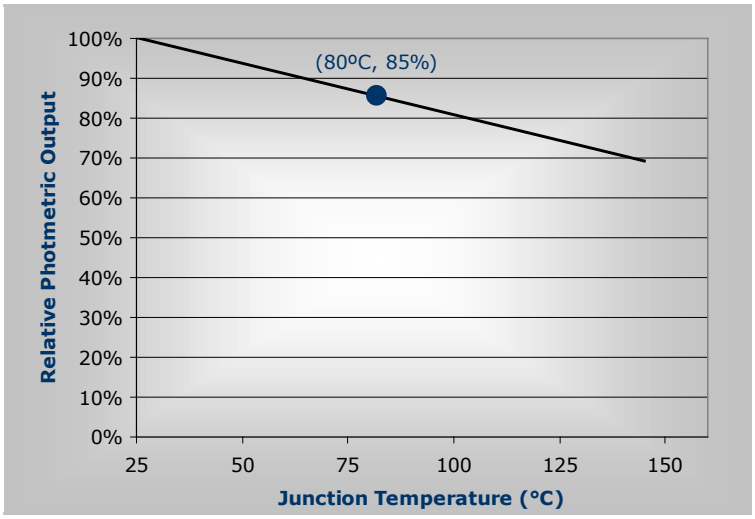

Chart 3: Example relative intensity vs junction temperature graph for XLamp XR-E white LED

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Electrical Loss

The LED driving electronics convert the available power source (e.g., wall-plug AC or battery) to a stable current source. Just as with any power supply, this process is not 100% efficient. The electrical losses in the driver decrease the overall luminaire efficacy by wasting input power on heat instead of light. The electrical loss should be taken into account when beginning the LED system design.

Typical LED drivers have efficiencies between 80% and 90%. Drivers with efficiency over 90% will have much higher costs. Be aware that driver efficiency can vary with output load, as shown in Chart 4. Drivers should be specified to run at greater than 50% output load to maximize efficiency and minimize cost.

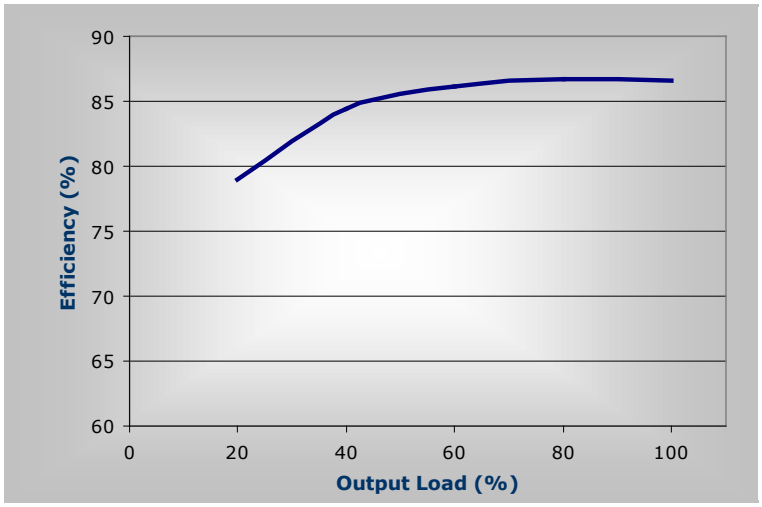

Chart 4: Example efficiency vs load graph for LED driver

For indoor applications, 87% is a good estimate for driver efficiency. Drivers meant for outdoor use or very long lifetimes will probably have lower efficiency.

Table 5 summarizes the efficiencies of the optical, thermal and electrical systems for the example luminaire.

Table 5: Summary of example CFL replacement efficiencies

System	Efficiency	Type
Optical	91%	Light
Thermal	85%	Light
Electrical	87%	Power

4. CALCULATE NUMBER OF LEDS NEEDED

Actual Lumens Needed

With all the system efficiencies estimated, the actual number of LED lumens required to achieve the design goals can be calculated. For this calculation, only the light efficiencies (optical and thermal) are used. The electrical efficiency affects only the total power consumed and fixture efficacy, not the amount of light coming out of the luminaire. The calculation of "actual lumens needed" for the example luminaire is shown below:

Actual Lumens Needed = Target Lumens / (Optical Efficiency x Thermal Efficiency)

Actual Lumens Needed = 810 / (91% x 85%)

Actual Lumens Needed = 1,050 lm

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Operating Current

Another decision to be made is what operating current to use for the LEDs. Operating current plays an important role in determining the efficacy and lifetime of the LED luminaire. Increasing the operating current will result in more light output from each LED, thus reducing the number of LEDs needed. However, increasing operating current also has several drawbacks, shown in Table 6. Depending on the application, these drawbacks may be acceptable trade-offs for the higher per-LED lumen output.

For the example luminaire, lifetime and efficacy are top priority design goals. The luminaire will run at the minimum operating current listed on the XLamp XR-E LED data sheet (350 mA) to maximize LED efficacy and lifetime.

Table 6: Drawbacks of high operating current in LED luminaires

Drawback	Explanation
Reduced efficacy	Higher operating current reduces the efficacy of current generation power LEDs. In general, the size of the power supply will increase as operating current increases, since it takes more power to generate the same number of lumens.
Reduced maximum ambient temperature **OR** Decreased lifetime	Higher current will increase the temperature difference between the LED junction and the LED's thermal path. In practical terms, since the maximum junction temperature is already decided, this reduces the maximum ambient temperature for the luminaire. If instead of lowered maximum ambient temperature, the maximum junction temperature is raised, the LED will degrade in light output faster over its operational life.

Number of LEDs

After deciding on operating current, the lumen output of each LED can be calculated. Since the thermal loss of the LED has already been taken into account through the actual-lumens-needed calculation, the numbers specified in LED-supplier documentation can be used directly without further interpretation.

For this calculation, it is important to use the minimum flux listed for your LED order code and not the typical number on the data sheet. Most LED companies sell to minimum flux ranges. By designing against this minimum number, you are ensuring that all luminaires made with that LED order code meet the target requirements.

The example luminaire will use XLamp XR-E LEDs at 4000 K CCT with minimum luminous flux of 67.2 (P2 flux bin) @ 350 mA. The number of LEDs is calculated below.

Number of LEDs = Actual Lumens Needed / Lumens per LED

Number of LEDs = 1,050 lm / 67.2 lm

Number of LEDs = 16 LEDs

5. CONSIDER ALL DESIGN POSSIBILITIES & CHOOSE THE BEST

With the number of LEDs calculated, consider all the possibilities to accomplish the design goals. Since each LED is a small light source and has a much longer lifetime than traditional light sources, LEDs can be integrated into luminaires with new and unusual design elements. Designers can take full advantage of LED light's directionality and wide variety of available secondary optics to create original designs.

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At the same time, keep in mind that there are many different regulations that constrain the design choices. Providing a comprehensive list of worldwide standards applicable to LED luminaires is beyond the scope of this document, but Table 7 gives examples of regulations that will apply in some portions of the world.

Table 7: Example standards that pertain to LED lighting

Type of Standard	Example Standards for Lighting
EMI (Electro-Magnetic Interference)	• FCC CFR Title 47 Part 15 • EN61000 • EN55015
Safety	• UL 1310, Class 2 • UL 48
Efficiency	• California Title 24, Part 6, of the California Code of Regulations: California's Energy Efficiency Standards for Residential and Nonresidential Buildings

The rest of this section explains three design options for each system of our example LED luminaire: optical, thermal and electrical. For each system, guidelines for choosing the best option are provided.

Optical System Options

1. **Bare LEDs & existing lamp reflector**

   As discussed earlier, the beam angle of the existing CFL fixture and the LEDs are very similar. So, one available option is to use no secondary optics. This option provides the lowest cost and lowest optical loss for the system. Using fewer components and less labor makes the luminaire easier and cheaper to assemble.

   The drawback is the multiple-source shadow effect, explained on the next page. Also, if the light distribution of the LED is significantly different than the target luminaire's distribution, then this option is not available.

2. **LEDs with secondary optics & existing lamp reflector**

   Secondary optics are optical elements used in addition to the LED's primary optic to shape the LED's light output. The general types of secondary optics are reflecting (where light is reflected off a surface) or refracting (where light is bent through a refractive material, usually glass or plastic). Secondary optics are available either by buying a standard, off-the-shelf part or by designing a custom optic through ray-trace simulation with an optical source model.

   By using a secondary optic per LED, the beam angle of each LED can be customized to provide the exact light output pattern necessary. For instance, the beam angle of each LED can be narrowed to make the luminaire optimized for spot lighting instead of general lighting.

   There are several drawbacks to this approach. First, the luminaire will have higher cost because of additional components and more complicated assembly. Second, since the optics are attached to each LED, there may still be multiple-source shadowing. Finally, the secondary optics will reduce the optical system efficacy.

3. **Bare LEDs, existing lamp reflector & diffuser**

   Instead of using one optic per LED, a diffuser can be used over the entire LED array to spread the light. The benefits of this approach are a wider beam angle than is possible with the bare LEDs and eliminating the multiple-source shadow effect.

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As with Option 2, the drawbacks are higher cost and reduced optical system efficacy. This is also not an option if the light distribution must be narrower than the bare LED, since diffusers can only spread light, not collect it.

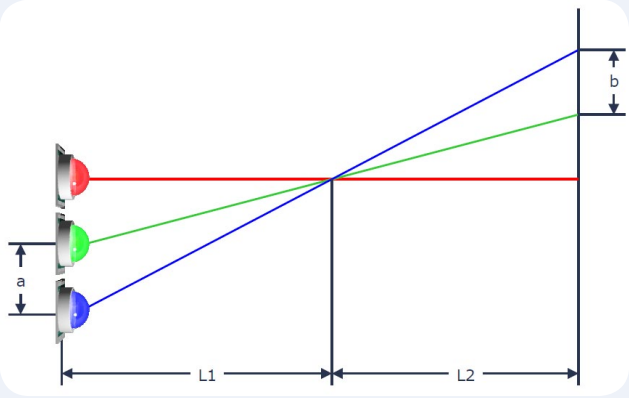
Illuminance distribution, the multiple-source shadow effect, and aesthetics will usually drive the decisions on the optical system. Option 2 is the only option if the light output must be narrower than the bare LED. If not, Option 1 is better in terms of cost, efficacy and brightness. However, both Options 1 and 2 will exhibit the multiple-source shadow effect.

Also, users looking up at Options 1 and 2 will notice each individual LED. Users of Option 3 will see only a diffuse, uniform light source.

Multiple-Source Shadow Effect

Multiple-source shadow effect is a phenomenon where an object placed between multiple light sources and a surface will create multiple shadows. Most people have seen multiple light bulbs mounted above a sink in a bathroom. If you have noticed multiple shadows of yourself on the wall behind you, then you have seen the multiple-source shadow effect.

LEDs placed close together create multiple shadows that are close together. The appearance of these close shadows may be undesirable in the target application. It is the designer's job to determine how important the multiple shadow effect is for the target application and whether it is worth additional optical loss to add a diffuser to minimize this effect.



b = (a x L2) / L1

a = LED spacing

b = Shadow spacing

L1 = Distance between LED & object

L2 = Distance between object & surface

Thermal System Options

1. **Existing fixture housing**

   The lowest-cost option is to reuse the fixture housing of an existing design as the housing and heat sink for the LED luminaire.

   Obviously, this is not an option for new luminaire designs. Also, most existing housings are made of steel, which is a poor thermal conductor. Generally, a steel housing will be a bad choice for a heat sink.

2. **Off-the-shelf heat sink**

   Another option is to buy an off-the-shelf heat sink. This heat sink will be a proven design and come with full specifications from the manufacturer.

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However, it may not be optimized in performance, size or shape for the target application.

3. Custom heat sink

A custom solution provides the best opportunity to optimize the heat sink for the application but has several drawbacks.

This option requires the designer to have access to thermal simulation software or access to a third party with thermal design expertise. Tooling and manufacturing fees may drive the per-unit cost of the custom heat sink higher than an off-the-shelf design.

Target luminaire cost, available heat sink development time, and target maximum ambient temperature will usually drive the decisions for the thermal system. In general, Option 2 is better for situations where low cost is more important than maximum ambient temperature. Option 3 is better when maximum ambient temperature is more important (e.g., outdoor lighting or indoor lighting in unconditioned spaces).

The example LED luminaire will use an off-the-shelf heat sink with a thermal resistance of 0.47 °C/W. With the heat sink thermal resistance value, the maximum ambient temperature can be calculated with the following formula:

$$T_j = T_a + (R_{th\ b\text{-}a} \times P_{total}) + (R_{th\ j\text{-}sp} \times P_{LED})$$

T_j = LED junction temperature T_a = Ambient temperature
$R_{th\ b\text{-}a}$ = Heat sink thermal resistance
P_{LED} = Single LED power consumption
= (Operating current) x (Typical Vf @ Operating current)
P_{total} = Total power consumption = (# LEDs) x P_{LED}
$R_{th\ j\text{-}sp}$ = LED package thermal resistance

Example luminaire values:
$T_{j\ MAX}$ = 80 °C
$R_{th\ b\text{-}a}$ = 0.47 °C/W
P_{LED} = 0.35 A x 3.3 V = 1.155 W
P_{total} = 16 x 1.155 W = 18.48 W
$R_{th\ j\text{-}sp}$ = 8 °C/W

$$T_{a\ MAX} = T_{j\ MAX} - (R_{th\ b\text{-}a} \times P_{total}) - (R_{th\ j\text{-}sp} \times P_{LED})$$
$$T_{a\ MAX} = 80\ °C - (0.47\ °C/W \times 18.48\ W) - (8\ °C/W \times 1.155\ W)$$
$$T_{a\ MAX} = 80\ °C - 8.6856\ °C - 9.24\ °C$$
$$T_{a\ MAX} = 62\ °C$$

A maximum ambient temperature of 62 °C for the example luminaire is acceptable for this indoor application. For an operating environment needing higher maximum ambient temperature, either the maximum junction temperature should be raised (which may impact lifetime) or the thermal system ($R_{th\ b\text{-}a}$) improved (e.g., better heat sink).

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Electrical System Options

1. **Off-the-shelf LED driver**

   An existing LED driver will provide the quickest design time, since it is already available and will come with a reference circuit design. All parts will be tested for EMI and safety regulations and will typically have the lowest per-unit cost in volume.

   The drawbacks are that existing LED driver efficiencies are typically in the mid-80% range. Lifetime and operating temperatures may also be an issue, depending on the vendor and the application.

2. **Next-generation LED driver**

   As LED lighting is gaining in popularity, more semiconductor companies are turning their attention to optimizing LED driver designs. Another option is to partner with one of these companies on the next generation of LED drivers, which will have higher efficiencies and full regulatory approval.

   However, waiting for the product development may delay the development of the LED luminaire. Also, smaller companies may not be able to work together with a driver company on an unreleased product.

3. **Custom design**

   As with thermal design, a fully customized electrical system is an option. While it may be possible to get a higher efficacy than by using an off-the-shelf part, there are many potential drawbacks.

   The burden of development and regulatory approval is now on the designer. Even after development, the per-unit cost may be higher than an existing solution. Also, keep in mind that driver companies will continue to develop more efficient and cheaper drivers during the LED luminaire development period.

Available development resources and target efficiency will usually drive the decisions for the electrical system. In today's high-power LED environment, improvements in the overall luminaire efficacy are driven more by the LEDs themselves and not the drivers. It may be advantageous to get a product out sooner rather than trying to wait until the electrical design is perfect.

6. FINAL STEPS

Once the design decisions have been made, Table 8 details the final steps to build and evaluate a prototype luminaire.

Table 8: Final steps in LED luminaire design

Step	Explanation
Board layout	• Complete the circuit board layout. • Choose board material (FR4 vs. MCPCB) based on thermal and cost constraints. • Keep in mind how the layout and positioning of parts will affect the light output and thermal flow of the luminaire.
Build a prototype	• Building one prototype (or several) is a valuable way to validate the design. • Verify that the optical, thermal and electrical systems perform as they should. • Test how easy the unit is to assemble.
Test prototype against design goals	• Test the prototype to make sure it achieves all the design goals. • Testing can be done either internally or externally by a contracted luminaire-measuring company.
Finalize design & BOM	• Make final changes to the design (if any) based on the new information learned from analyzing the prototype. • Document the final design and bill of materials.
Draw conclusions	• How could the existing design be improved if a different design choice was made? • Are all of the original design goals still applicable, or are some less important than they seemed initially? • Are there other applications that would benefit from LED light?

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WHERE TO GET HELP

The entire LED luminaire design process can be overwhelming. Table 9 provides links to the current list of Cree partners that can assist getting to a final design.

Table 9: Cree XLamp LED solutions providers

Source for Help	Can Assist With
Cree XLamp LED Optics Solutions www.cree.com/led-components-and-modules/tools-and-support/solution-providers/secondary-optics-solution-providers	• Optical system design
Cree XLamp LED Driver Solutions www.cree.com/led-components-and-modules/tools-and-support/solution-providers/driver-solution-providers	• Electrical system design
Cree XLamp LED Distributors www.cree.com/led-components-and-modules/where-to-buy	• Thermal system design • Off-the-shelf optics & LED drivers • Board layout • Assembly • Small-quantity orders

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