

# All Facts for Choosing LED Optics Correctly

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Putting together a functioning LED lighting solution always includes the specification of the optical performance of the product. As with many emerging technologies, LED technology being no exception, it may be very challenging to specify and choose the best components to fulfil the requirements set. The main reason is that there are no standards available. Lack of standards easily leads to varying interpretation of the parameters by different suppliers and it may mean that a wrong or non-optimal component is chosen.

Because of that reasons it is important to enlighten the real content of the optical parameters such as FWHM, Efficiency, Materials and Lifetime, to allow customers to better understand which optical component is best for which application and how to choose it in a correct way.

## Efficiency

Optical efficiency of a component is normally defined by measuring how much of the total lumens sent into that component come out of it, through the optical surfaces defined. If we take as an example a common collimator lens for an LED, it means that first the total lumens of the LED are measured in an integrating sphere (Figure 1). As a second step, the lens to be measured is placed on top of the LED and all other surfaces but the light out-coming (front) surface is covered with black, absorbing cylinder. And again all the lumens out of this system are measured in the same integrating sphere. The efficiency is the ratio of these two lumen values, multiplied with 100, to get out the result in %.



Figure 1: Measuring efficiency of a lens takes place in an integrating sphere.

Now, it is important to understand that this efficiency gives an impression of how good an optical system is in terms of handling the light sent into it, e.g., this value for a lens of good quality may be 91%. But this 91% does not at all characterize how good a lens is for a given application. It does not give the person, specifying his lighting system, any information

of how much of the light comes in his needed area or angle – in other words what would the "useful" efficiency of the component be. To understand it, we need to continue specifying more parameters.

## Shape of a Light Distribution Curve

In illumination engineering it is very important to see the total shape of the light distribution curve. A light distribution curve is a 2D- or polar diagram -characterization of the performance and it tells for an experienced eye what in detail to expect of the component, e.g., how narrow the light distribution is, are there any discontinuation points to be expected (shadows) or what the relative intensity is in HV 0 degree vs. 30 degrees. A Full Width Half Maximum (FWHM) angle has been defined, in relative terms, for a symmetrical optics with its maximum intensity in the middle of its light distribution (horizontal and vertical 0 degree), to be the angle, where the intensity of illumination has dropped to 50% from its maximum peak value. Furthermore, many advanced companies define a further so-called 10% value, which is the angle, where the intensity of the illumination has dropped to 10% of its maximum peak value. This is a very useful parameter, e.g., when specifying optical components with an extremely narrow light distribution. The closer the 10% value is to the FWHM value the more light is really focused in the important narrow beam and the less stray light you have outside of the main beam.

Now, one may wonder, why to use two values for a component, FWHM and 10% value, why is not FWHM itself sufficient? The reason is that FWHM value is not unambiguous, and it can even be misused to mislead a person specifying his system.

Let's take a simple example with imaginative lenses A and B (Figure 2). Lens A is a lens with relatively bad optical efficiency and additionally, a proportionally big share of light falls outside of the centre beam area, i.e., its 10% value is a wide-angle value. Due to the shape of its light distribution curve – a flat curve with no really high peak in the middle, but more or less a "hill" type of a shape – it still has a FWHM value of +/- 5 degrees.

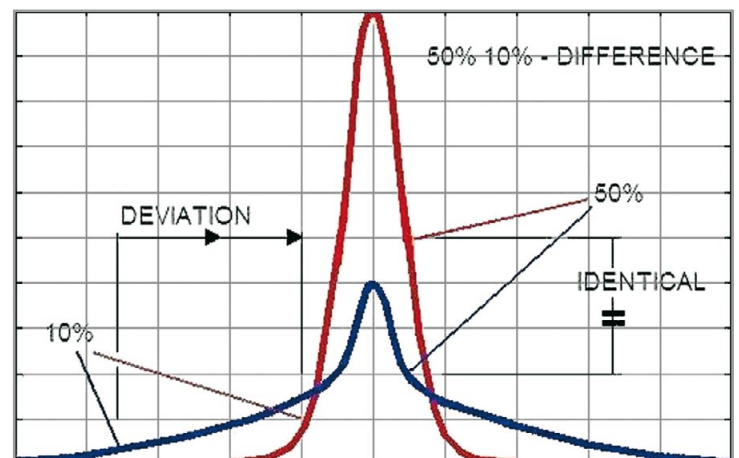


Figure 2: FWHM value does not give unambiguous information of an optical component. These two lenses have the same FWHM value, but they perform in a very different way.

The other lens, Lens B, is a lens with high optical efficiency, with very concentrated beam and a narrow-angle 10% value. Its curve shape reminds of a Himalayan mountain instead the hill for lens B. The surprising fact is that this lens has the same FWHM value of +/- 5 degrees, as lens A. How can it be possible? Putting the absolute (not relative) curves of these 2 lenses on top of each other in the same diagram, shows that lens B gives 5x the light than lens A, but still the FWHM values are identical! The conclusion of this simple example is that different lenses cannot be compared against each other just using FWHM values. FWHM does not give the answer to the question how much absolute light is distributed in the specified angle or area. More facts are needed, 10% value already gives a good hint of how an optical component performs.

### Cd/Im Value

When the person specifying an optical system has the information of optical efficiency, FWHM and 10% value and in addition the cd/Im value, one might think the optical system is fully specified. The cd/Im (candela per lumen) is a very important complement, as it specifies the height of the light distribution curve in absolute scale. In other words, it enables putting the curves of several different optics in one and the same diagram to see which optical component gives most light in the angle or area needed for an application. However, one must remember that cd/Im value needs to be seen in combination with the other values specified above. The reason is that it is relatively easy to manipulate this value to be high on its own, if efficiency and curve shape are being sacrificed. There are too many bad examples of this: a component making a high peak in the middle, while the shape of the curve is of low quality and total efficiency of the system is low. In other words, this value has to be analyzed very carefully.

### IES or EULUMDAT Files

Lighting industry traditionally uses these file types to characterize their products. Now these files are available for most LED optics on request, too. In practice the files are fully digitalized versions of the light distribution curve discussed above, i.e. they contain all the information needed: efficiency, FWHM, 10% value, cd/Im and much more.

What is very important to remember is always to ask for the measured data with detailed information of components and methods used, not to accept simulated data. Unfortunately some companies work with theoretical, simulated data only. This data may sometimes give much better values than the real data and lead to misunderstandings or even wrong component choices.

### Plastic Materials

It is of extreme importance, always to use optical components, which are made of documented, high-quality plastic materials. My recommendation is to use automotive or medical grade PMMA (acrylic) or PC (poly carbonate) in all normal LED applications. These well-documented, tested materials guarantee a long lifetime for the

component without deteriorating performance over the component lifetime. - A long lifetime means a period of ten up to twenty years of continuous use. - Close to UV wavelength radiation from LEDs, sunshine, moisture and physical stress require much of the material used and normal materials are not made to withstand these conditions. Molecule chains get cracked and molecules change their appearance and performance, if the plastic material is not of sufficient grade.

It is explicit necessary to advise against using cheap lenses made of PS (Poly Styrene) or SAN (Styrene Acryl Nitride) or similar cheap plastics. Another critical component type is a plastic reflector with metal coating and protective surface treatment for environmental protection. Typical for all these cheap materials is a low weight in comparison to PMMA or PC, which makes it relatively easy to recognize them. The cheap price is due to low material price per kilogram, faster speed in molding or poor process in coating / protecting reflective surfaces. Very often this cheap price may turn to be very high in the long run, when lenses turn yellow, milky or the metal surface turns matt and the efficiency and appearance of the light changes much from the original specified one. Also from the beginning on, the optical performance and characteristics for these lenses normally are lower than for the ones made out of quality materials, due to low quality molds used in production, too.

### LED Specific Optics vs. General Optics Used for Different LEDs

Many companies offer so-called general lenses that are offered for various LED types and only adjusted by height to get them on the correct focal plane. Using the same lens for a light source that is different from the one the lens was originally designed for, leads automatically to decreased performance. Speaking with the terms defined above, at least efficiency is affected, cd/Im ratio, too, and normally also the shape of the light distribution curve (FWHM, 10% value), even if, in the best case, the illumination looks nice. How much the decreased effect is in reality, depends on how big the difference to the original light source is (Figure 3).

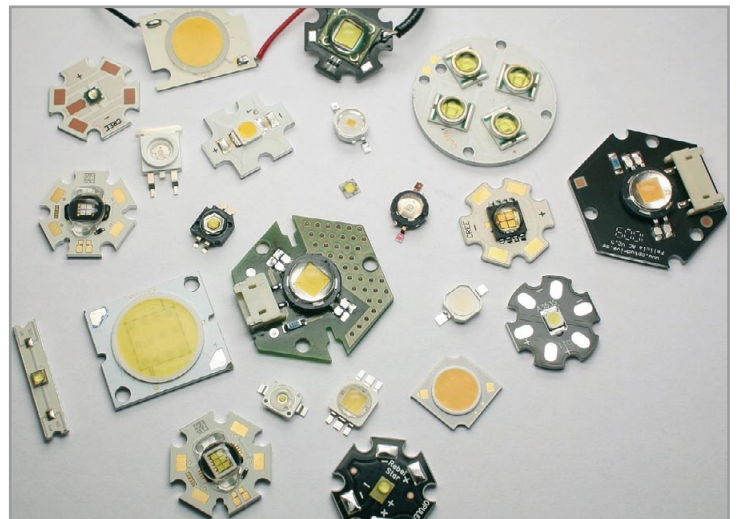


Figure 3: Differences between LEDs make it impossible to make a universal optical component for all or a multiple of them.

The only really sustainable way of making excellent optics is to design it separately for every light source. It is of course a much more expensive way to go, as optical grade injection molding tools are very expensive and design time for each lens is long, too, but only with light source specific optics measured efficiencies of more than 90% and measured high cd/lm values can be reached.

## Differences in Performance for Different Lens Types

One may simplified say that the easier and the more controlled the requested light distribution is, the better is the performance. Spoken in practical terms, often a pure collimator lens has the best overall performance, for the best ones highly over 90%. Making optical versions of the same collimator design by changing e.g. its top surface normally leads to decreased efficiency, the grade of decrease depending on the complexity of the change and the machining quality of the changed surfaces. In worst cases the decrease may be significant – up to 10-15% drop in performance.

If an optical component is from the very beginning designed for an asymmetric distribution, the performance is not compromised in the same way as when making versions based on e.g., a collimator design. High performance values above 90% efficient can be reached, as e.g. LEDIL's STRADA lenses. However, if a lens design is very challenging e.g. due to tilting the distribution strongly, or making it extremely wide, or an extreme batwing distribution is needed; it normally decreases the efficiency values. Therefore, always optical components of similar type and similar size must be compared; otherwise the performance comparison is not on a fair basis.

## Size of Optics Matters

Generally spoken, the bigger the optical component is, the more accurate it is and the better the performance is (Figure 4). But it is also generally understood that big components often are pricey, and in many applications the benefit from the LEDs comes from decreasing the size or, alternatively, the space available may be needed e.g. for electronics components.

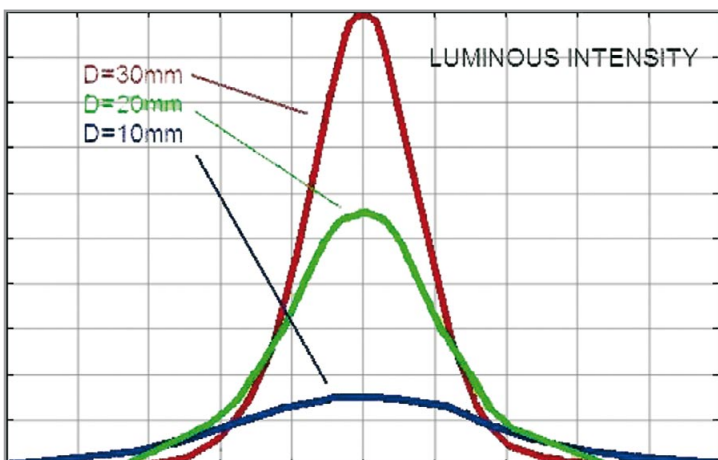


Figure 4: The bigger the size of the optical component is, the more accurate the component is (difference in beam shape).

Over the years, some component sizes have become an industry standard. A good example of such standard sizes is the so-called 21 mm round lens. This size is very optimal for the modern small point light source types of LEDs, such as Luxeon Rebel, Cree XP, Osram Oslon or Nichia 119. The performance would not become significantly better for standard applications, even if the size was increased. Making the same lens smaller to 16 mm can still keep the good efficiency at over 90%, but cd/lm values would drop slightly, as accuracy would decrease due to proportionally bigger light source vs. lens. Going even smaller, to less than 10 mm, would mean also a drop in efficiency, as again proportionally the light source would grow so large that a small lens can no more capture the light in an efficient way. Practically spoken an efficiency of 80-85% could be reached in this particular case.

For most modern LEDs, 21mm size seems to be sufficient to satisfy the needs in most applications. In many applications customers choose smaller lenses, 16 mm or even less than 10 mm, because of the reasons mentioned or to be able to populate even more LEDs per area given. It is notable that an increased size to 26 or 30 mm or even larger only is needed for special applications, where a very narrow distribution, typically a total FWHM of 3-4 degrees is specified, or for complex distributions, where light is refracted using several different optical elements.

## Reflector vs. Lens

For all modern small light sources with one to four dies and a primary lens, the best solution to use, from optical point of view, always is a lens. The explanation, why a lens is the best, is simple: in a lens, the beam can be controlled very well. There are at least three surfaces for use, while for a reflector there is only one, or, for a reflector system, two surfaces. The efficiency of a lens also is very high, if the optical system is designed in an advanced way, using free-form technology. For lenses in general, it is possible to achieve an efficiency of at least 90% for most applications; for the all trickiest ones at least 85%. For a reflector it is possible to achieve a reflectance of 90% for the metal-coated surfaces, but the overall beam control is far less efficient compared to a lens.

It makes sense to use a reflector design, when the size of the light source is large and the light source consists of an array of dies under a common phosphor layer. Examples of such light sources are e.g. the most Citizen and Bridgelux LEDs. For these LEDs, making a lens would mean to design a huge lens, to enable capturing of the light in a controlled way. As making a huge lens also means high costs, to avoid these, it makes more sense to design a reflector or reflector system. The efficiency and \$/lm of a light fixture with this kind of an optical design remains at a good level: what is lost in optical efficiency due to the size and multi-nature of the light source is gained back in the good thermal efficiency of the system and lower price of the light source itself, compared to point light source types of LED.

## Mixing of Different Lenses in One Application

Quite often, a request for a specific light pattern can easily be achieved by using several different standard lenses. A simple example of this is a normal car head lamp: there needs to be one specific solution for the low-beam light, while the high beam light can be achieved by using another optical system and the daytime running lamp using a third one. It does not make sense to try to make all this with one optical element only – would be all too complicated and expensive.

In general illumination, there are many similar examples: an object needs to be illuminated with a spot lamp, while the surrounding area also needs some light – not as much, but it needs to be illuminated as well. This can in practice be done with a narrow spot lens for the object itself, while a wide-angle lens in the same light fixture takes care of the general illumination around the spot beam.

Another good example of mixing can be found in street lighting (Figure 5): the requirements vary a lot from case to case and it is very difficult to directly address all needs with a single optical solution. Instead, the idea is to provide customers with a selection of standard components, which mixed can achieve any light distribution requested. It is a much simpler and more flexible approach than making special optics for each case separately. Of course this approach requires a very wide selection of lenses only a few optic suppliers can offer.

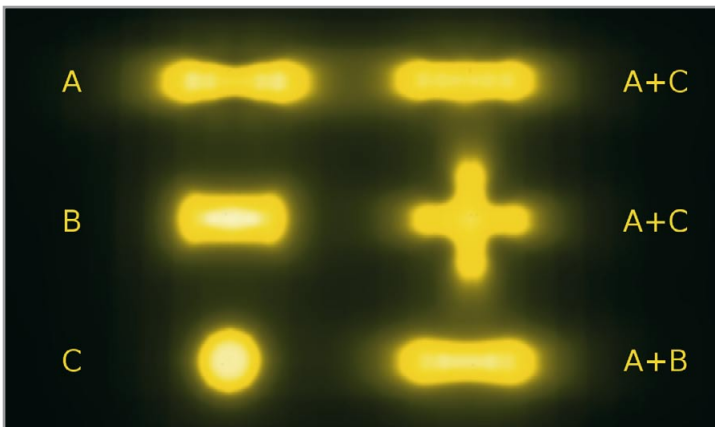


Figure 5: The performance of single lenses of the types A, B and C on the left hand side and the result when mixing them on the right hand side are demonstrated. With a clever mixing many different pattern can be achieved.

## Cost of Assembly

A very important aspect in using optical components is to try to decrease the cost of assembly, while maintaining the accurate positioning principle needed for any good optical design. The rule generally is that the better the optical efficiency of an optical component is, the more sensitive it is for correct placement. In other words, the ease of assembly shall never jeopardize the accuracy of the positioning. In many cases, glue and/or positioning pins have been the solution. The increase of use of optical assemblies for LEDs has, however, also increased the need for better, more production-friendly solutions. One good possibility to solve this challenge is to use adhesive tape of high quality and of automotive grade. It makes the assembly work very easy, while maintaining the accuracy needed.

Another solution for easy assembly is to use snap hooks, which go through the PCB and self-lock the optical component to the PCB. The challenge here is to define the thickness of the PCB with narrow enough tolerances. If this tolerance definition is narrow enough, this solution is superior in costs compared to any other solution.

## Conclusion

Optical components for LEDs play an all more important role in deciding the success of a light fixture. It is a real challenge for every fixture designer to be able to specify the optical components in a correct way, to enhance the properties of the fixture, while keeping the costs down. There are quite a lot of parameters to take care of for each application and project anew. To satisfy the demands of the client the parameters of different optical solutions have to be compared very carefully and in detail.