Comparison of Reflective and Refractive Optics for LED Light Sources in Outdoor Lighting Applications

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ABSTRACT
Many manufacturers have been using either reflective or refractive optics in their LED luminaires to accomplish a specific lighting task. The advantages and sacrifices of both methods have not been fully investigated, since the investment needed to explore and research both technologies thoroughly are cost expensive. This paper intends to summarize the relative advantages of both technologies, based on experience with existing outdoor LED luminaire optical designs.

KEYWORDS: LED, outdoor, optics, lens, reflector

1. Introduction
For use in outdoor lighting applications, the use of LED light sources has to be augmented by secondary light guides that can produce extensive beamforming of the near Lambertian light distribution of LED packages. The secondary optics can be a system consisting of lenses, reflectors, or a combination of both. In outdoor lighting, the Lambertian distribution of raw LED packages, diffusers, and remote phosphor systems used in indoor lighting systems do not usually meet the lighting requirements for street, area or floodlighting, thus we will omit from our further discussions.

Factors effecting the performance of the LED luminaires include light distribution, efficiency, glare, reliability and cost. In our study we would like to assess both technologies from these aspects.

2. Comparison of reflective and refractive optical technologies
For comparing the two technologies side-by-side, we have used two specific LED light engines for comparison. Both light engines have 40 identical white high power LEDs, each LED emitting 300 lumens of luminous flux output for simplicity’s sake. The two light sources depicted in Figures 1 and 2 are only different in optical and thermal aspects, but the LED types and numbers are the same. The printed circuit board assembly containing the LEDs in Figure 1 can accommodate 16, 24, 32, 40 or 48 pieces of high-power LEDs within the same reflector optic, depending on the required light level. The configurability of the light engine is the same

Figure 1 The reflective benchmark LED light engine.

Figure 2 The refractive LED light engine.

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for the LED board in Figure 2: There are 3 lens array parts that can be combined in different combinations and with different LED boards. The printed circuit board assemblies compatible with the lens arrays can accommodate either 32, 40, 56, 64, 72, 90, or 120 LEDs depending on the required light levels. Note that not all 120 lens cavities are used in all configurations.

Both optical systems, the lens and the reflector, have been selected to have the same optical efficiency of 83%. The material which the lens is made from has 90% transmissivity in the visible spectrum of the human eye (optical-grade polycarbonate), and the reflective surfaces of the reflectors have an overall reflectivity of 87% (optical-grade aluminium).

The 90% transmissivity of the lens material means that a bulk material transmits 90% of the light coming from one side to the other. This value has been taken out of the material datasheet of the supplier, measured by the standard ASTM D 1003. The optical efficiency of LED light engine (luminous flux emitted from the optics divided by the luminous flux coming from the LED board) has less than 90%, because in a freeform lens geometry needed to produce a batwing light distribution for roadway applications, there are total internal reflection causes Fresnel losses.

For more information on lens losses see this white paper for example:

https://ledlight.osram-os.com/wp-content/uploads/2013/10/Optical-Calculation-for-SSL-Applications-10-29-13.pdf

The 87% of surface reflection is also a material-specific parameter. In a reflector system, there are multiple light rays emitted from the source, from which some exit the system without any interaction with the reflectors, and suffer one or more than one reflections from the reflector surfaces. This causes the optical efficiency to be different than 87%.

Both light engines are protected by the same low-Fe content transparent cover glass.

2.1 Light distribution

The resultant light distribution caused by the beam-forming of the secondary optics can vary from narrow to wide beam angles. The first effect, the beam deviation is generally less effective through refraction, since the efficiency of energy transfer decreases by the degree of beam deviation due to internal reflections\(^1\),\(^2\). The advantage of reflection on the surface of a reflector and total internal reflections inside lenses is that the efficiency is not dependent on the beam deviation angle\(^3\).

Still, the other inefficiency of beam control is the absorption of light when travelling through a medium, e.g. lens materials. Also, light reflecting from a material of greater index of refraction has a loss coming from reflectivity of the surface material\(^4\),\(^5\).

The combined effect of the above phenomenon is that at narrow beam angles, lenses with total internal reflections are usually the most efficient, but applications requiring very wide beam angles can be more efficiently achieved by reflectors with high reflectivity.

We have modified the original lens and reflector designs to vary the beam angle. In Figures 3 and 4, the different light intensity distributions of the lens and reflector, respectively, are plotted on polar diagrams. In Figure 5, the resultant optical efficiencies show that...
while the efficiency of the reflector improves, the efficiency of the lens decreases at higher maximum intensity angles. In application, this means that the reflective light engines are more suitable for long pole distance road lighting installations.

Since the chosen two optical systems are optimized for different road arrangements, only the relative change in efficiencies are shown. This study was limited to two selected light engines, therefore exceptions to the above tendency can be found when repeating this exercise with optical components that exhibit different light distributions.

2.2 Glare

Glare is a human perception quality that has been quantified via various calculation methods and definitions. Generally speaking, the perceived direct glare of a luminaire is greater as the difference of between the high and low luminance values in the proximity of each other increases. Shortly put, it can be thought of the measure of luminance inhomogeneity.

High values of glare can cause discomfort and the disability to see low luminance fields in our view.

Thus if we have the same amount of luminous flux coming out from two luminaires to be compared, the one that has a greater luminous surface will have the lower glare. Thus, optical designers wish to expand the luminous exit surfaces as much as possible to avoid glare.

Of course, there is another way of reducing glare, which will affect the light distribution: louvres and spill shields. These are geometrical obstacles for casting a shadow onto the observer. Usually the shadow is cast into directions where the illumination can be sacrificed, otherwise the shielded luminaire can’t satisfy the lighting requirements.

It is difficult to give a summarized view comparing reflective and refractive technologies concerning glare, since the same light distributions can be achieved by guiding the light through different paths from source to destination and thus the exit surface areas can also result being different when comparing luminaires with same light distributions.
The viewpoint of the observer.

A quantitative analysis was also performed on both luminance maps, and the results can be read from Table 1.

It can be seen that the refractive light engine produces significantly higher maximum and average luminance values than the reflective system. Since both systems employ the same amount of LED luminous flux and produce the same amount of luminous flux, it can be said that the reflective system is less likely to exhibit glare than the refractive type system.

2.3 Reliability

It is also important to discuss the reliability of products with reflective or refractive optical technologies where the materials of the parts are polymers. The first difference between lenses and reflectors is that light actually travels inside optic in case of a lens, while light never enters the material of the reflectors. This causes stress on the lens material that can cause degradation of polymers usually used in outdoor luminaires that can decrease lumen and color maintenance over lifetime. The second difference is the surface flux density of visible (and some infrared) light over the optical component. In case of lenses, the collecting surface has to surround the LED light source and thus the luminous flux density is greater than in case of reflectors, where the surface of the reflectors can be positions at a distance from the light sources. The irradiance of the surfaces can indirectly degrade the any coating material or damage the substrate via heating. This will reduce the lumen maintenance of the luminaire.

Using polymer materials, LED systems using reflectors can achieve a better lumen and color maintenance than their lens counterparts. Upon using glass as lens material or aluminium as reflector substrate, the degradation can be greatly reduced. Of course, the latter options can require higher investment or possibly higher part costs.

We have conducted a study of the two benchmark LED light engines by calculating the greatest illuminance values (Emax) at the inner surfaces of the lens and the reflector. The higher the illuminance, the higher the irradiation and resultant degradation from LED-emitted visible light. In Figures 11 through 14 these illuminance maps are shown.

We have conducted a quantitative analysis of the two illuminance maps, and the results in Mlx (SI standard 1lx (lux)=1lm/m²) and kW/m² are shown in Table 2. The refractive optical component suffers more than tenfold greater internal irradiation than the reflector. Due to this, greater degradation can be expected from the lens during light engine lifetime.

To complement the aforementioned simulation results, we’ve also conducted thermal measurements on the two benchmark light engines. The infrared images created during this can be seen in Figures 15 and 16. We used these images to locate the positions of highest temperatures to be used for thermocouple measurements.

The thermocouple measurement results are shown in Table 3. The values of Psystem are total system power values dissipated in the luminaire, including driving circuits, electrical, thermal and optical losses. The types of LED chips and drivers were the same for both types of systems. The temperature values that have been

![Figure 9 Luminance map of the refractive light engine view from the observer.](image1)

![Figure 10 Luminance map of the reflective light engine view from the observer.](image2)

![Table 1 Comparison of luminance values of direct glare study.](table1)
measured by thermocouples very analyzed and the maximum value is shown as $T_{\text{max\_meas}}$. The maximum temperature values that the optical materials can withstand are shown as $T_{\text{limit}}$. These values are the RTI (relative temperature index) properties taken from supplier datasheets and verified by internal acceptance testing according to the UL746B standard.

In Table 3, we are comparing two light engines at the same system power, but different LED count. The data
from Table 3 indicates not only the fact that refractive optics suffer greater thermal stresses resulting from irradiation but that transparent polymers have a lower temperature limit that can accommodate this stress.

2.4 Cost

When comparing reflector and lens parts designed for fulfilling the same outdoor street lighting requirements, usually the reflector parts tend to be bigger in size, and use more material than their lens counterparts. This usually means that material costs of the lenses are lower than reflectors, and transportation costs of the luminaires can be reduced in case of refractive technologies.

In Table 4, we are showing an exemplary cost analysis for the two benchmark optical systems. Even though the specific material costs are the same, since the geometry limitations of reflective technology causes a requirement for greater amount of material needed for a given luminous flux used for the lighting application.

3. Conclusions

In this paper, we have looked at different performance, reliability and cost aspects of reflective and refractive optical technologies when used for LED outdoor lighting. From Table 5, it seems that both technologies have their advantages in various aspects.

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References

(1) Ding, Y., Liu, X., Zheng, Z.-R. and Gu, P-F.: Freeform LED lens for uniform illumination, Opt. Express, 16-17, pp. 12958‒12966 (2008). Doi: 10.1364/OE.16.012958
(2) Wang, K., Liu, S., Chen, F., Qin, Z., Liu, Z. and Luo, X.: Freeform LED lens for rectangularly prescribed illumination, J. Opt. A, Pure Appl. Opt., 11-10.
(3) Chen Qiaoyun Zhu Xiangbing Ni Jian and Chen Jin: A LED reflector design for uniform illumination, China Illuminating Engineering Journal, 2011-02 (2011).
(4) Yim, H.-D., Lee, D.-J., Kim, Y. G. and O, B.-H.: Beam pattern analysis of LED reflector design and simplification of the functional design, Korean Journal of Optics and Photonics, 23-5, pp. 222–226 (2012). Doi: 10.3807/KJOP.2012.23.5.222
(5) Cvetkovic, A., Dross, O., Chaves, J., Benítez, P., Miñano, J. C. and Mohedano, R.: Etendue-preserving mixing and projection optics for high-luminance LEDs, applied to automotive headlamps, Opt. Express, 14-26, p. 113014 (2006).

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