evluma

LED Streetlight Glare

Causes & Solutions

The rapid and ongoing shift from legacy bulb-type streetlights to LED technology in municipalities around the world has resulted in a dramatic increase in community complaints about the brightness and glare of the replacement luminaires. This whitepaper describes the different types of glare generated by streetlights, the major causes, and viable solutions for addressing them.

The LED Conversion

For decades, High Intensity Discharge (HID) bulb-type lamps have been the primary method of illumination for streetlights and outdoor area lights. These lamps typically utilize screw-in High Pressure Sodium (HPS) or newer Metal Halide (MH) bulbs that resemble larger household incandescent bulbs but run at much higher wattages, with a much higher lumen output. The bulbs require special ballasts to drive them, lose light output over time, and need to be replaced every 3-to-5-years.

As LEDs have become both more powerful and more efficient, they have become a viable and cost-effective replacement for the legacy HID lamps. This has driven the rapid adoption we have witnessed over the past decade. The operating cost savings of LEDs are significant for two reasons. First, the energy efficiency of LEDs enables them to deliver an equivalent amount of light with an energy savings of 60% or greater versus the HID-based lamps. Second, the long-term maintenance costs associated with HID-bulb replacements are significantly reduced, as the operating life of the LEDs is 10-20 years or more, with minimal degradation of light quality. As such, the business case easily justifies the higher initial cost of retrofitting the HID fixtures with LED luminaires.

As with any transition to a new technology, there are some differences between the old and new that can lead to dissatisfaction in some applications. The light generated from the LED fixtures can be both objectively and subjectively “different” than that generated from the HID fixtures, and this can result in a negative experience for drivers, pedestrians, and residents affected by the change

What is Glare?

Glare is the resulting difficulty of seeing objects in the presence of bright light. In the context of street lighting, the bright light can come directly from a luminaire or be reflected off surfaces, such as the roadway or surrounding features. There are two types of glare, known as Discomfort Glare and Disability Glare. They have different causes and different impacts on our visual performance.

Discomfort Glare is the result of light from sources (like a streetlight) that are much brighter than the surrounding brightness (such as that of a night sky). If the glare level is high enough, it induces the desire to turn away from the source. Discomfort Glare does not necessarily impair vision and does not have an established standard for measurement. Assessment is typically through a qualitative rating ranging from just noticeable to unbearable.

Disability Glare is the result of stray light within the eye produced by light sources and reflected light in the field of view which reduces the overall contrast between objects and the background. It can cause temporary loss of vision but is not necessarily uncomfortable and does not induce the desire to turn away from the light source. Another difference is that Disability Glare can be calculated and quantified through standardized methods.

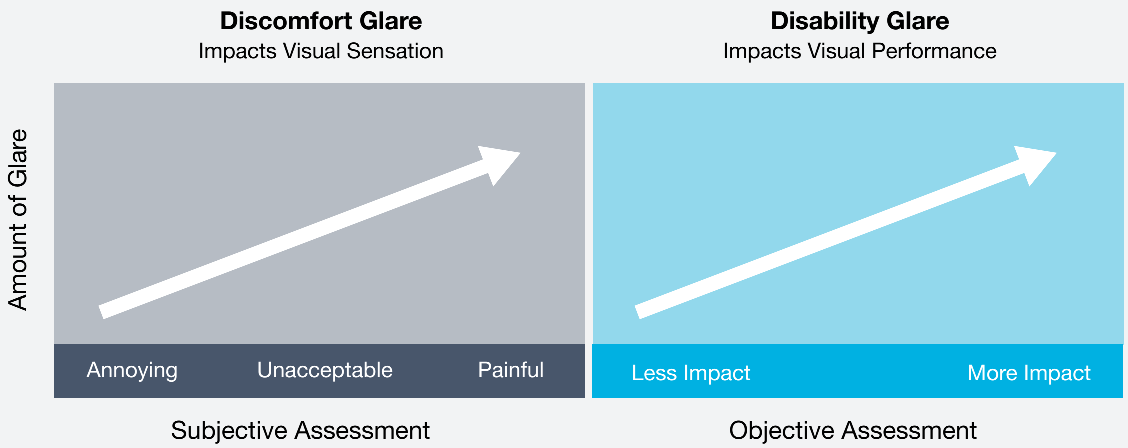


Figure 1. While Discomfort Glare is influenced by the amount of light from the source luminaire, Disability Glare is influenced by the amount of light experienced at the eye, independent of the luminaire's light level.

While Discomfort Glare is influenced by the amount of light from the source luminaire, Disability Glare is influenced by the amount of light experienced at the eye, independent of the luminaire's light level. While both types of glare can be experienced at the same time, Discomfort Glare affects vision sensation while Disability Glare affects actual visual performance. As such, both types of glare may be perceived as undesirable, and both may impact the behavior of a driver or pedestrian; Discomfort Glare by causing distraction or the desire to look away; Disability Glare by impairing visibility.

Vision Concepts

Human eyes have two primary light receptors within the retina, cones and rods, which are optimized for either daytime or nighttime vision. These receptors work in tandem to change the eye's sensitivity so that it can operate in light levels ranging from faint moonlight to midday sunlight.

At higher ambient light conditions, the cones in the center of our field of view have dominant sensitivity. This supports recognition of objects, performance of detailed visual tasks, and the ability to perceive a broad range of colors.

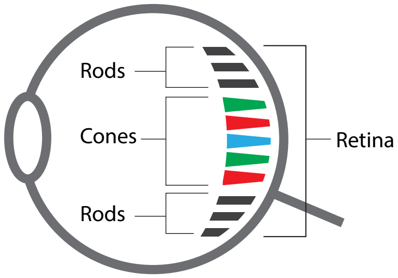


Figure 2. Light Receptors in the Human Eye

At lower ambient light conditions, the rods have dominant sensitivity around the periphery of the eye and away from the direct field of view. They enable enhanced peripheral vision, but the field of view is at a reduced resolution, which can make it harder to perform visual tasks. There is also a reduction in color depth and a shift in sensitivity in the color spectrum towards blue light.

Both receptors can be active to varying degrees in moderate or changing light conditions. Our eyes also adjust to the general lighting level over time, achieving and adjusting an adaptation level between the cones and rods that effectively calibrates our sensitivity to the current ambient light.

The higher the ambient light and adapted light levels, the less sensitive the eyes will be to other bright light sources in the field of view—such as oncoming headlights in midday sunlight. Conversely, the lower the adapted light level, the more sensitive the eye will be to bright sources, and the more likely it is to experience glare.

The goal of streetlighting is to provide enough ambient light to raise the eye's adapted light level and reduce sensitivity to other bright sources that may enter the field of view.

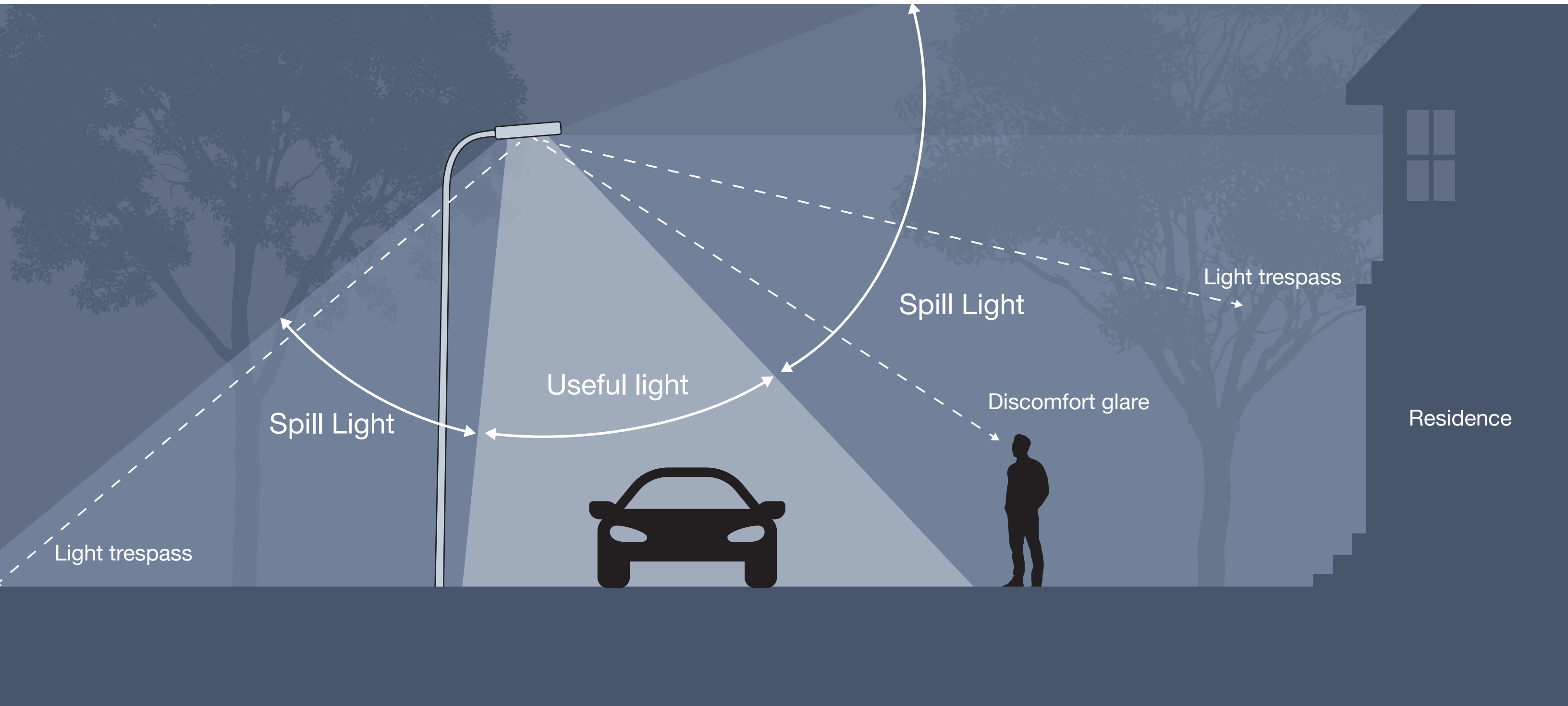
Causes of Discomfort Glare

As introduced above, Discomfort Glare is a function of the light level of the luminaire in the direction of the observer. If there is a significant difference between the source level of the luminaire and the eye's adapted light level to a darkened sky, it can be overwhelmed by trying to process too much light.

Cause 1: Light Trespass

Many community complaints about streetlight glare are related to **Light Trespass, also known as Spill Light**, which is any light that spills outside of the intended lighting area. The spill light is typically emitted at a higher angle than the useful light and "trespasses" onto private property or into residential windows (See Figure 3).

Figure 3.
Discomfort Glare

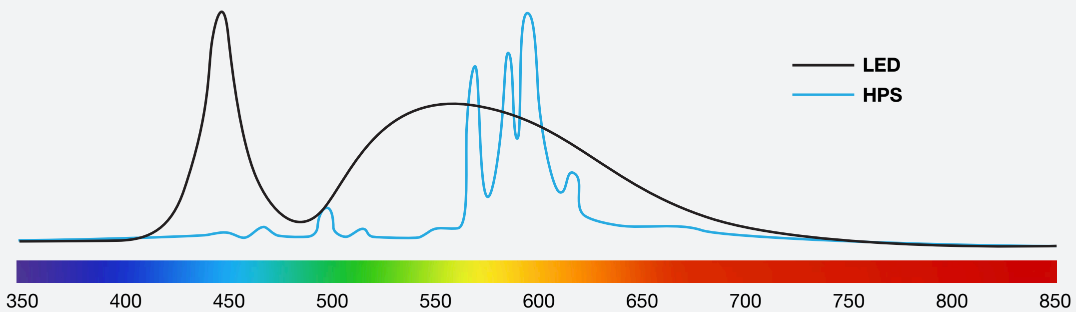


A resident around the property at night or in a darkened house will adapt to the lower ambient light level. Upon looking in the direction of the trespassing light source, the major difference in light levels may be high enough to trigger Discomfort Glare.

Cause 2: Blue Light

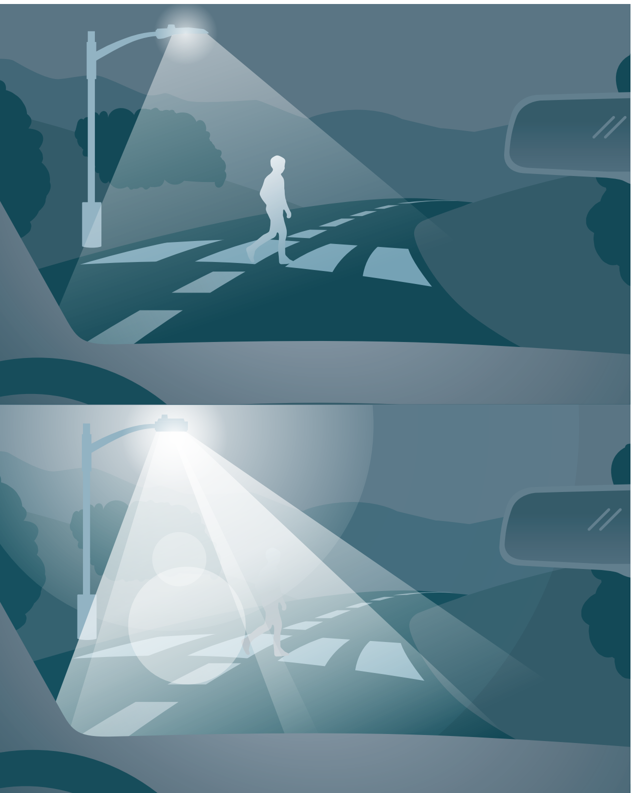
Retrofitting an existing HID streetlight with an LED source may also increase the amount of light emitted in the blue wavelength. A person's eyes that are adapted to nighttime ambient levels of light may be more sensitive to the blue light in the trespassing LED light even at the same measured lighting levels as the HID.

Figure 4. Blue light in LED vs HPS bulb



A driver or pedestrian within the lighted target area may have a higher adapted level of ambient light and be less sensitive to the direct light from the luminaire—including any LED blue light content. However, it is still possible to experience Discomfort Glare within the target lighted area if there are exceptionally bright sources relative to the overall lighting level. This can be particularly acute for drivers or pedestrians entering the target lighted area from an area with lower ambient light levels, as their eyes take time to adjust.

Figure 5. Effect of Disability Glare for Drivers

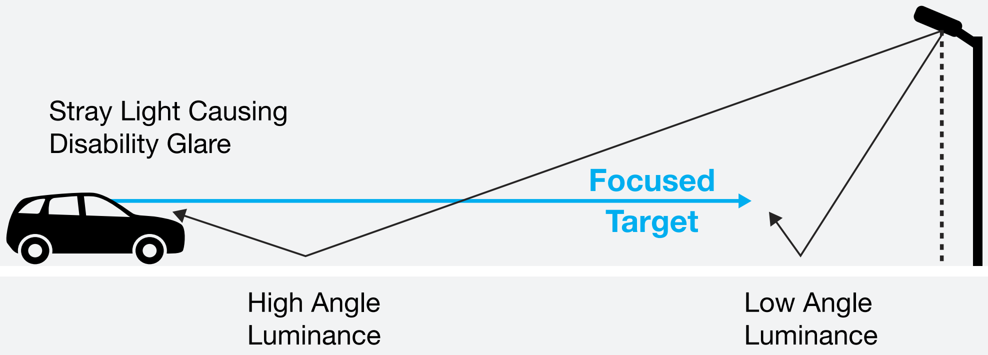


Causes of Disability Glare

Disability Glare is the result of stray light entering our eyes at higher or lower angles than the narrow area on which we are focused. This stray light gets scattered within the eye and interferes with the overall contrast of the field of view, making it difficult to distinguish objects from the background. Unlike Discomfort Glare, there is little or no visual sensation, but instead a loss of visual function (See Figure 5).

A streetlight emits light at both low and high angles relative to the roadway surface (See Figure 6). The light striking the roadway surface is called **illuminance**, while the light reflected from a surface is called **luminance** and is the perceived brightness of the light by the eye. The low angle light reflects nearer to the streetlight and creates the luminance detected by the eye in our focused target area.

Figure 6. Disability Glare from High Angle Stray Light



The high angle light reflects further from the streetlight, entering the driver's eyes at a low angle as **Stray Light**, outside the focused area of view. As the driver progresses forward, the high angle light can also enter the eye directly from above. The Stray Light gets scattered around the eye's retina which produces a haze or veil superimposed over the focused image which reduces overall contrast of the field of view. This makes it more difficult or impossible to distinguish objects from the background (See Figure 3).

The Stray Light creating this "haze" is known as **veiling luminance**, and it is the primary metric used for calculating Disability Glare in streetlighting standards. Sensitivity to veiling luminance varies in individuals and is known to increase with age. Drivers on a roadway can face both Disability Glare from high angle Stray Light that reduces field-of-view contrast, and Discomfort Glare from light sources that have too much intensity for the eye's adapted level.

Solutions for Reducing Glare

The different solutions that exist for reducing glare vary based on the type of glare they address. Additionally, it is important to note that a solution for correcting one form of glare can have either a positive or negative effect on the other type. It is generally accepted that reducing Disability Glare also reduces Discomfort Glare; however, the reverse is not always true. A solution to reduce Discomfort Glare can have the effect of increasing Disability Glare.

The following discussion highlights typical solutions to glare, their advantages, and their limitations.

Solution 1: Reducing Brightness

As the major cause of Discomfort Glare is the result of too much light in relation to the eye's adapted level, then reducing the brightness of a luminaire is one quick approach. Municipalities can choose to install luminaires with lower lumen output, or to install luminaires that have the ability to adjust the light output level to reduce brightness. This may reduce the glare to a tolerable level, but it comes at the expense of reduced light brightness or coverage area.

However, simply reducing the output level of a luminaire to correct Discomfort Glare will have no effect on Disability Glare. This is because the metric used for Disability Glare is calculated as the ratio of the veiling luminance at any point compared to the average luminance level of the roadway. It is about how the light is entering the eye, rather than how much light is entering the eye. Increasing or decreasing the brightness of the luminaire will have an equal effect on both the veiling luminance and the average luminance calculated, and therefore has no effect on the ratio.

Solution 2: Installing a Light Trespass Shield

Another approach to addressing Discomfort Glare is the installation of a Light Trespass shield. As Discomfort Glare is often the result of Spill Light beyond the intended target area, then providing a shield that blocks light from entering private property and residential windows can be a very effective solution. All streetlight vendors provide some form of shield that can be installed on the luminaire, typically to reduce Spill Light behind the luminaire. Some include shields that can be installed on the front or sides as well (See Figure 7).

Similar to reducing the luminaire's light level, a Light Trespass shield will typically have no effect on Disability Glare. This is mainly because the direction of the light being blocked, such as behind or in front of the pole, is not in the offending direction of the veiling luminance on the roadway that affects drivers. Adding shields on the sides of the luminaire would likely reduce Disability Glare, but it would also significantly reduce the amount of light on the roadway, making the streetlight less effective in its primary function.

Solution 3: Lowering Color Temperature

As highlighted in the discussion of cones and rods, as the eye adapts to lower light levels, it also becomes more sensitive to blue light from LED sources. While not a perfect correlation, there is an association between color temperature of the luminaire and amount of blue light present in the spectrum. Higher color temperatures, such as 4000k and above, contain more blue light compared to lower color temperatures such as 3000k and below, which may be perceived as "warmer" (See Figure 8). By comparison, traditional HPS luminaires emit almost no blue light. This is the major reason for recent initiatives to reduce the color temperature of streetlights as low as possible, not only to help reduce sensitivity to glare, but also to minimize the impact the light has on other human and animal physiological systems. However, there are trade-offs that must be balanced when moving to lower color temperatures, including luminaire cost, reduced power savings, and perceived lighting quality.

Figure 7. Light Trespass Shields

Figure 8. Color Temperature

Most current streetlight luminaires do not have the ability to tune color temperatures as a feature and require that the streetlight be replaced in order to adjust color temperature. This is due to the complexity and cost of adding this feature at the power levels required for streetlights. While such a replacement may correct the glare problem, it also may not, as the problem may stem from too much light being output. Reducing color temperature has more to do with aesthetics and comfort, as again, it has been shown to have little or no impact on reducing Disability Glare.

Figure 9. The secondary lens is installed over the primary optic and transforms that output in some way.

Solution 4: Installing a Secondary Lens

One of the most effective ways to address both Discomfort and Disability Glare is to install a secondary lens on the luminaire. Nearly all LED luminaires require a **primary optic** or lens over the LED chips to alter the output from a simple blob of light to a desired uniform distribution on the roadway. Legacy HID luminaires achieved this by using reflectors behind the bulb to shape the light, with available lenses to seal the bulb compartment.

The design of the LED's primary optics largely determines how light is emitted, at what angles, and the intensity per angle. Different primary optics are used to change the light distribution for different road types and sizes. The primary optics are also the main source of different types of glare, and there is a wide variation in the glare performance across different luminaire manufacturers.

The secondary lens is installed over the primary optic and transforms that output in some way. Legacy HID lamps similarly offered different types of secondary lenses to augment the reflector light output for different scenarios, including glare control. The secondary lens can have many shapes and sizes, from a simple flat piece of clear glass to a molded cover with diffusion properties (See Figure 9). They can be added by the manufacturer as an orderable feature or installed in the field—although most manufacturers do not offer secondary lens options at all.

The secondary lens can be effective in two ways. The first is in reducing the high angle light being emitted from the luminaire and directing more light toward lower angles. Since much of Discomfort Glare is associated with higher angle Spill Light, that light will be reduced with an associated reduction in the glare. And, since Disability Glare is also the result of high angle light reflections, reducing high angle light output is also effective in reducing that type of glare.

The downside to reducing the high angle light may be overall ability of the luminaire to satisfy the design criteria of the roadway regarding specific pole spacing and light uniformity requirements. It is a balancing act of matching the secondary lens to the primary optic to minimize performance losses while gaining glare control.

The other way the secondary lens can be effective is in diffusing the luminaire light source. Diffusion is created by adding small particles, surface texture, or optical elements to a lens that creates scattering of light rays into different angles. Applying a secondary lens with diffusion can lessen the intensity of the light, as the angles of light from the primary optic are now redirected and reduced.

Diffusion is especially effective in reducing Discomfort Glare, as it reduces spikes of high intensity light from the primary optic, as well as reducing total light output. The impact of diffusion on disability glare can also be positive, but it is not entirely predictable. In some cases, diffusion can actually increase discomfort glare, as the scattered light may also be emitted at higher angles than it would be without the secondary lens.

The reduction in total light output that results from a diffused secondary lens can also have a negative impact on the efficiency of the luminaire, as it reduces the light output relative to power utilization. This is due to some light being blocked by the diffusion, which may require the application of more power in order to achieve a desired level of light output. Diffusion can further impact the overall performance of the secondary lens with regard to meeting the specific streetlight design specifications for uniformity and must be accounted for in lighting design plans.

Despite these challenges, a well-designed secondary lens that balances these competing needs can have a significant effect on both Discomfort and Disability Glare without significantly reducing the overall performance of the luminaire.

Summary & Conclusion

The conversion to LED streetlights has highlighted issues with glare from the new luminaires. There are two types of glare involved, Discomfort Glare and Disability Glare. Discomfort Glare is the result of too much brightness emitting from the luminaire, which causes a physical sensation subjectively rated from annoying to unbearable. Disability Glare is caused by stray light entering the eye at angles from sources or reflecting surfaces that causes a loss of visual performance. Several solutions exist for managing Discomfort Glare to varying degrees, including reducing brightness, installing trespass shields, and lowering color temperature, but they are not effective in reducing Disability Glare. A well-designed secondary lens applied over the primary optic is the most effective mechanism for managing both Discomfort and Disability Glare.

References

ANSI/IES RP-8-21 – Recommended Practice for Lighting Roadways and Parking Facilities

FWHA Lighting Handbook 2012 - Federal Highway Administration