20.4 Human factor issues with LEDs

LED sources are substantially different from filament lamps used in most present-day automotive lighting applications in a number of important ways:

• LEDs have higher luminous efficacies (in lm/W) than filament sources, meaning they can produce higher intensities or broader beam patterns for the same amount of energy, or have a similar light output with lower energy requirements.

• The narrowband spectral output of colored LEDs produces a highly saturated color appearance, in
contrast to broadband sources such as filament lamps, which require filters in order to produce colored illumination (Fig. 20.3).

- White phosphor-converted LEDs can be produced with a higher correlated color temperature (CCT) than filament lamps, which results in a more bluish color appearance.
- LEDs have very rapid onset and offset times: 10–20 ns, including the decay time of yttrium aluminum garnet (YAG) phosphors, compared to about 80–250 ms for filament lamps.

**Figure 20.3: Spectral distributions of yellow and red LED and (filtered) filament sources.**

The photometric, colorimetric and temporal properties of LED sources can also influence drivers' ability to see and respond to potential hazards in and along the roadway. For vehicle headlamp systems, the spectral distribution of typical phosphor-converted white LEDs, based on blue InGaN devices in combination with YAG phosphors, has a larger proportion of short-wavelength (blue) light than the spectral distribution of filament sources like incandescent and halogen lamps (Fig. 20.4). This difference is relevant to visual performance while driving, because at light levels commonly experienced while driving at night, which result in asphalt pavement luminances between 0.1 cd/m$^2$ and 1 cd/m$^2$ (He et al., 1997), the visual detection of hazards is supported by a combination of cone and rod visual receptors in the eye.
Figure 20.4: Spectral distributions of white LED and (unfiltered) filament sources.

However, photometric quantities such as illuminance (in lx), luminance (in cd/m²), luminous intensity (in cd) and luminous flux (in lm) are entirely based on the spectral response of the cone receptors in the eye. Cone receptors are used exclusively for seeing at light levels typically experienced outdoors and indoors during the daytime, which is usually between 10 and 1000 cd/m². This apparent discrepancy between the way light is measured and how we see matters because, collectively, rod receptors are more sensitive to short visible wavelengths (such as blue and green light) than cone receptors (Rea et al., 2004). Thus, the usual photometric quantities (lx, cd/m², cd and lm) can underestimate a driver's ability to see under LED sources at night, relative to his or her ability to see under filament lamps.

A unified photometric system has recently been published by the Commission internationale de L’Éclairage (CIE) to quantify the relative role of rods and cones (CIE, 2010) in seeing at night. As a consequence, it could be possible to obtain equivalent nighttime visual performance using LED sources that produce light levels that are 20% to 30% lower than those produced by filament lamps (Van Derlofske and Bullough, 2006).

Another visual response that may favor LEDs over filament sources is the perception of roadway scene brightness, according to a brightness model developed by Rea et al. (2011). This response appears to have increased short- wavelength sensitivity. Figure 20.5 shows the predicted roadway scene brightness under headlamps using filament, HID and LED sources.

The relatively high amount of short- wavelength spectral power in white LED illumination might also have some possible negative impacts for vehicle lighting, however. When headlamps of different colors produce equivalent conventional photometric quantities, disability glare (a reduction in visual performance that is caused by scatter in the eyes from a bright light) is not influenced by the spectral content of the headlamp illumination (Schreuder, 1976). This is not the case for discomfort glare, which is defined as an annoying or painful sensation that is experienced when viewing a bright light in the visual scene of interest.

Like the perception of roadway scene brightness, discomfort glare also exhibits increased sensitivity to short- wavelength light (Bullough, 2009). It is not fully understood whether, or to what extent, increased discomfort glare affects driving safety. There is some evidence that shows that when drivers experience discomfort glare from oncoming headlamps, they are more likely to exhibit driving behaviors such as increases in head movements and increased throttle variability, which in
turn have been found to be correlated with an increased crash risk (Bullough et al., 2008).

Regarding the visual detection of vehicle signal lights, because LEDs have substantially shorter onset times than filament lamps, they can have some advantages, especially for vehicle brake lamps. Bullough (2005) demonstrated that visual reaction times to the onset of a colored light signal, such as a brake light or turn signal, could be predicted using a threshold quantity of light energy (in candela) received at drivers’ eyes. When a tungsten filament lamp is first switched on there is a relatively gradual increase in illumination from the filament and it can take up to 250 ms to reach full brightness. LEDs have practically instantaneous rise times and can produce the threshold quantity of light energy more quickly. As a result, LEDs elicit shorter visual reaction times than filament sources of the same nominal color and peak luminous intensity (Bullough et al., 2002).

Importantly, because the rate of deceleration of a braking vehicle is linked to the same action that turns on the brake light itself (pressing the brake pedal), shorter light source rise times can provide a stopping distance benefit of nearly 7 m for a driver following a braking vehicle (Sivak et al. 1994), a small but sometimes practically significant increase.

![Figure 20.5: Relative brightness of roadway pavement surfaces illuminated by photometrically equated light sources (halogen, HID and LED).](image)

### 20.5 Energy and environmental issues

Because they have higher luminous efficacies compared to filament sources, automotive lighting systems using LED sources can have substantially reduced power requirements. In separate studies, Hamm (2009) and Schoettle et al. (2009) estimated the typical wattages for conventional filament source-based vehicle lighting systems and for LED lighting systems. The average of their estimates for different lighting and signaling functions are summarized in Table 20.4. Also listed in Table 20.4 are estimated values for the total annual hours of use for each type of lighting system, based on driving patterns in the United States (Buonarosa et al., 2008). Table 20.4 also includes the resulting total annual lighting energy use for filament- and LED-based automotive lighting systems.
Table 20.4: Estimated power and energy use of filament lamp and LED automotive lighting systems

<table>
<thead>
<tr>
<th>Function</th>
<th>Power per vehicle (W/vehicle)</th>
<th>Annual energy use (kWh/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Filament source</td>
<td>LED source</td>
</tr>
<tr>
<td>Low-beam headlamp</td>
<td>124</td>
<td>87</td>
</tr>
<tr>
<td>High-beam headlamp</td>
<td>132</td>
<td>64</td>
</tr>
<tr>
<td>Daytime running lamp</td>
<td>48</td>
<td>18</td>
</tr>
<tr>
<td>Position lamp</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td>Front turn signal</td>
<td>52</td>
<td>14</td>
</tr>
<tr>
<td>Rear turn signal</td>
<td>52</td>
<td>10</td>
</tr>
<tr>
<td>License plate lamp</td>
<td>17</td>
<td>2</td>
</tr>
<tr>
<td>Reverse lamp</td>
<td>43</td>
<td>7</td>
</tr>
<tr>
<td>Center high-mounted stop lamp</td>
<td>34</td>
<td>4</td>
</tr>
<tr>
<td>Brake signal</td>
<td>52</td>
<td>11</td>
</tr>
<tr>
<td>Tail lamp</td>
<td>14</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total annual energy use</strong></td>
<td><strong>45.9</strong></td>
<td><strong>18.5</strong></td>
</tr>
</tbody>
</table>

Under the assumption that each kWh of lighting energy use on a vehicle powered by gasoline corresponds to CO₂ emissions of 1.29 kg (Schoettle et al., 2009), the total reduction in annual energy use that would be expected to accompany a shift from filament lamps to LEDs for automotive lighting would be 27.4 kWh/year, and would correspond to an annual reduction of CO₂ emissions of about 35 kg/year for each automobile.

20.6 Future trends

LED automotive lighting systems are already common for signal lighting applications, and have been introduced for forward headlamp systems. The rapid advances in luminous efficacy will continue to make them increasingly attractive for automotive use.

The solid-state construction of LED systems, modular configurations and relative ease of intensity control through current modulation or pulse width modulation provide significant promise for energy-saving vehicle lighting systems that can adapt in real time to changing roadway, traffic and weather patterns using AFS technologies. These advantages of LEDs will likely make dynamic rear signal lighting systems practical as well.

20.7 Sources of further information and advice

For additional information about automotive lighting in general including the growing use of LED sources, consult Wördenweber et al. (2007). An overview of the components of the roadway transportation lighting system, including automotive lighting, roadway lighting and traffic signals, is provided by Bullough (2011). For an extensive discussion of the human factor aspects of lighting for transportation, Boyce (2009) is an excellent resource. Research from the National Highway Traffic Safety Administration on vehicle lighting systems can be found online at [http://www.nhtsa.gov/Research/Human+Factors](http://www.nhtsa.gov/Research/Human+Factors), and reports from the Lighting Research Center at Rensselaer Polytechnic Institute are available online at [http://www.lrc.rpi.edu/programs/transportation/TLA/PublicInformation.asp](http://www.lrc.rpi.edu/programs/transportation/TLA/PublicInformation.asp).

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### 20.9 References


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