Mesopic Street Lighting Demonstration and Evaluation Final Report

for
Groton Utilities
Groton, Connecticut

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Executive Summary

Can a white light source tuned to how humans see at night under low light levels—one with lower wattage and photopic light output—replace a high-pressure sodium (HPS) street lighting system and still provide equal or greater perceptions of visibility, safety, and security? If so, when and where should this lighting system be used? The Lighting Research Center (LRC) conducted research with funding from Groton Utilities that investigated these questions in the context of two installations within the City of Groton, Connecticut. One installation on Meridian Street replaced 100-watt HPS cutoff cobra head street lights with 55-watt induction (electrodeless) lamps and cutoff, cobra head fixtures. A second installation on Shennecossett Road examined the replacement of 100-watt HPS lights with 70-watt ceramic metal halide, cutoff, cobra head street lights. In both installations, the replacement white light sources (induction and ceramic metal halide) were tuned to optimize human vision under low light levels while remaining in the white light spectrum.

The human vision system has two types of receptors in the retina, cones and rods, to transmit visual signals to the brain. The current system of photometry to determine the amount of light needed to perform a task, regardless of the time of day or lighting

conditions, is based on how the eye's cones function. Cones are the dominant visual receptor under photopic (daylight) lighting conditions. Rods function primarily under dark (scotopic) conditions. Under mesopic lighting conditions, which are typically found outdoors at night, a combination of cones and rods perform the vision function. Therefore, outdoor electric light sources that are tuned to how humans see under mesopic lighting conditions can be used to reduce the luminance of the road surface while providing the same or better visibility. This light source must account for how both the cones and rods in the eye see. Light sources with shorter wavelengths, which produce a "cooler" (more blue and green) light, are needed to produce better mesopic vision.[1,2] Based on this understanding, the LRC developed a means of predicting visual performance under low light conditions. This system is called the unified photometry system.[3]

The LRC developed the unified photometry system based on a series of laboratory studies.[4,5] Simulated driving studies verified the validity of the fundamental findings predicted by the unified photometry system.[6,7] but demonstrated that off-axis detection was strongly affected by other visual factors such as target contrast and size. In effect, adopting lighting systems based upon the unified system of photometry would improve visual performance *more* than would be predicted by changes in spectrum and light level alone. A recent field study to examine target detection by subjects driving along a closed track found that targets illuminated by metal halide lamps can be more quickly detected by the subjects than those made visible by HPS lamps.[2] The results from the range of studies conducted to date dramatically underscore the benefits of the unified photometry system for improving visual performance and reducing energy consumption.[8]

Two different lighting technologies were tested during the Groton research on two segments of different roadways. These technologies were selected based on their commercial availability or the ability to commercialize the product, and their ability to reduce energy while maintaining visual performance in accordance with the unified photometry system. The first technology was a 55-watt induction lamp and driver with 6500 K correlated color temperature (CCT). At 6500 K CCT, the lamp has a high scotopic-to-photopic (S/P) ratio (2.88) and optimizes mesopic vision while remaining in the white light spectrum. Induction lamps also are good at retaining their lumen output in both hot and cold ambient temperatures. Their lamp life (60,000 hours) is also good and should reduce street light maintenance costs. The second technology utilized was a 70-watt ceramic metal halide lamp at 4000 K CCT. The S/P ratio is 1.6 and lamp life is 20,000 hours. In both cases, the S/P ratios of the lamps chosen are much higher than that of the HPS lamp with a 0.63 S/P ratio. Based on the unified photometry system, the wattage for both the induction lamp and the metal halide lamp could be less than the HPS system while providing similar visual performance.

Responses to surveys conducted before the installation of the new light sources and after the installations revealed that area residents perceived higher levels of visibility, safety, security, brightness, and color rendering as both drivers and pedestrians with the new lighting systems than with the standard HPS systems. The new lighting systems used

30% to 50% less energy than the HPS systems. These positive results were achieved through tuning the light source to optimize mesopic vision. Using less wattage and photopic illuminance also reduces the reflectance of the light off the road surface. Light reflectance is a major contributor to light pollution (sky glow).[23]

The findings of the research conducted in Groton concur with similar research conducted by the LRC in Easthampton, Massachusetts, and in Austin, Texas, and with research conducted by Fotios et al. in England.[14] This body of research found that drivers and pedestrians perceived they could see better and felt safer with light sources tuned toward the needs of mesopic vision.

Economic analyses were conducted to determine if either the induction or ceramic metal halide street light systems could cost effectively replace the existing HPS street lighting. In the simple payback analysis, the induction lamp has long payback periods of 7.1 years for new installations and 13.9 years for retrofitting existing HPS installations. The ceramic metal halide street lighting provides negative benefits, and therefore produces an infinite negative return primarily because of higher maintenance costs. Utilities normally consider annualized ownership and operating economic analysis to be more appropriate. This type of analysis is similar to how electric rates are set. The annual utility ownership and operating costs for the induction street lighting system is $22.20 less than the 100-watt HPS street lighting it could replace. Similarly, a lifecycle economic analysis shows that the 55-watt induction lamp has a $282.90 savings over its 27-year life compared to the 100-watt HPS. The metal halide street lighting produces negative savings.

Recommendations based on research findings are:

- Efficient white light sources tuned to mesopic vision conditions with high scotopic-to-photopic ratios are recommended as replacements for high-pressure sodium (HPS) street lighting. These light sources should have a correlated color temperature of approximately 6500 K and provide approximately 65 to 70 (photopic) lumens per watt.
- The 55-watt induction street lighting system at 6500 K CCT is an energy-efficient replacement for 100-watt HPS street lighting and should be pursued for new street light installations. It should also be examined as a retrofit for existing 100-watt HPS street lighting.
- The 70-watt ceramic metal halide lighting system is not a good substitution for 100-watt HPS street lighting systems and should not be pursued, primarily because the economics of the metal halide system are poor compared to 100-watt HPS systems.
- White light-emitting diodes (LEDs) should be considered as replacements for HPS street lighting in about three years time when their efficacy is higher and their cost has reached reasonable levels to be economically viable. Groton Utilities may want to consider postponing decisions on street light replacements until white LEDs become economically available.
- The unified photometry system should be used to determine replacement wattages of various size street lights based on lamp S/P ratio and, for new installations, Illuminating Engineering Society of North America (IESNA) recommended

luminance values for the type of street being illuminated. For existing street lighting, measurements of existing luminance values can be calculated by measuring illuminance and roadway surface reflectance. The luminance values can be entered into the unified photometry system to determine appropriate replacement lighting systems that will provide equal visual performance.