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Yuma (AZ) Sector border lighting, showing the 40-foot pole height of the LED luminaires (on the first pole) and the 64-foot height of the incumbent QMH luminaires.

SSL EVALUATION

Area Lighting Yuma Sector Border Patrol Area, AZ

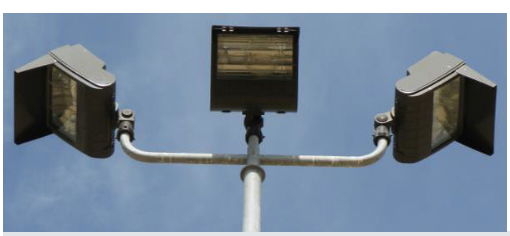
A unique GATEWAY evaluation on a stretch of border between the U.S. and Mexico looked at how high-flux LED lighting performed over nearly four years in a high-temperature environment.

High-flux lighting applications in high-temperature environments present a formidable challenge for LEDs. The higher the luminous flux from a luminaire, the more difficult it can be to properly dissipate the heat, to prevent damage to the electronic components and LED packages—and this is made even more difficult by high-temperature environments. To learn more about how this type of environment affects LED lumen and color maintenance, luminaire efficacy, and luminaire component life-times, the U.S. Department of Energy's (DOE) GATEWAY program documented the LED retrofit of the incumbent quartz metal halide (QMH) area lighting along a 7.2-mile stretch of the Yuma (Arizona) Sector Border Patrol Area between the U.S. and Mexico, where temperatures at sunset can exceed 100° F.

Although a border lighting application is unique, high-flux and high-temperature applications are not, and in the U.S. they include high-security exterior lighting (such as correctional facilities and military bases) and, more generally, street and area lighting.

A Trial Installation

The Yuma Sector retrofit is a DOE Federal Energy Management Program (FEMP) Energy Savings Performance Contract (ESPC) ENABLE project. The goal was to achieve a minimum energy savings of 50% while maintaining existing light levels, and the application also presented an opportunity to improve lighting quality. The specific area of interest was between the primary fence marking the U.S.–Mexico border, and a secondary fence set back 125 feet from the primary fence.



Incumbent QMH luminaires (left) and LED luminaires (right). Because pole diameter narrowed as the height increased, a custom tenon was necessary to fit the diameter of the pole after it was shortened.

Night is when the most activity occurs in the Yuma Sector Border Patrol Area, so it was important to ensure that the lighting system would help the agents perform their duties as well as reduce energy use. The advanced optical system of the selected luminaires improved the uniformity of the lighting system, despite a 24-foot reduction in pole height. The combination of the optics and lower pole height reduced stray light considerably.

In February 2014, two LED luminaires were installed on each of three sequen-tial poles as a trial installation of the proposed design solution. This new LED system was found to equal or better the QMH system in terms of both uniformity and illuminance. Illuminance measure-ments were recorded initially in February 2014, then again in September 2014 at 2,500 hours of operation, in March 2015 at 5,000 hours of operation, in September 2015 at 7,000 hours of operation, and in September 2016 at 11,000 hours of operation. Additionally, four second-generation LED luminaires installed as part of the full installation in September 2016 were evaluated initially and again in August 2017 after 4,000 hours of operation.

Long-Term Monitoring over Two Generations

The distribution of light produced by the LED luminaires changed considerably in the first 2,500 hours of operation, and the trend continued after 5,000 and 7,000 hours of operation. Comparing the 7,000-hour measurements to the initial measurements reveals several important changes in the illuminances delivered by the lighting system:

- The average horizontal illuminance decreased by 25% in the three measurement rows closest to the primary fence marking the border.
- The average vertical illuminance decreased by 34% on the primary fence.
- The distribution of illuminance changed, with values nearest to the pole increasing by more than 10% while the values decreased farther away from the pole; the greatest decreases were at the points farthest from the pole.

The cause of these changes was unknown, but dirt depreciation was expected to explain most if not all of them. So two luminaires were removed and tested in a photometric laboratory, first dirty and then after cleaning. The testing revealed that luminous intensity values at angles where peak intensity occurs decreased due to dirt by 15% to 26%, while the intensity directly beneath the luminaire increased due to dirt by 16% to 21%—results consistent with the illuminance measurements recorded in Yuma.

A final opportunity to measure the first-generation LED system came in September 2016 at 11,000 hours of operation. The measured illuminance of these luminaires in a clean state at 11,000 hours was found to have decreased by more than 50% compared to initial measurements after installation. While several possible reasons for this unexpected result are explained in the report, the root cause remains unknown.

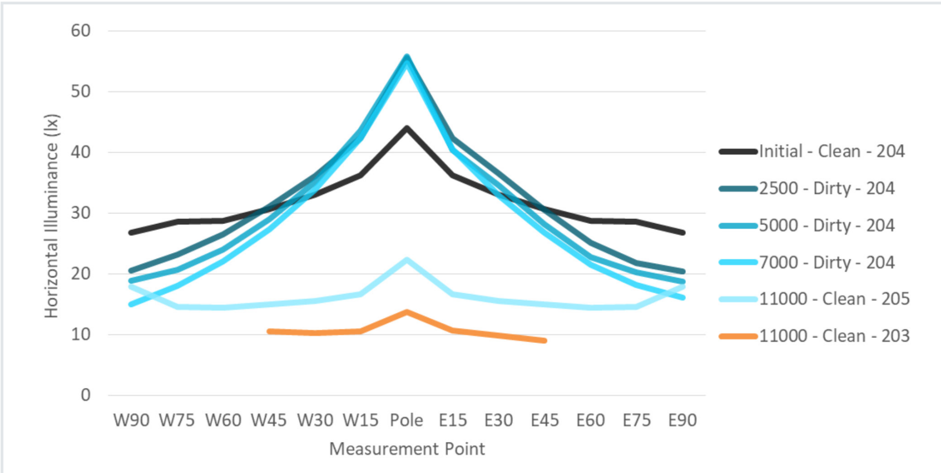
The second-generation LED system that was installed in September 2016 was evaluated in August 2017 at 4,000 hours of operation, allowing for a comparison to the initial measurements as well as a comparison to the performance of the first-generation LED system. After 4,000 hours of operation, the second-generation system was performing similarly to the first-generation system after 5,000 hours of operation. One difference was that the second-generation luminaires exhibited color-over-angle variability that produced noticeable color differences on the illuminated sand beneath the system.

Key Lessons Learned

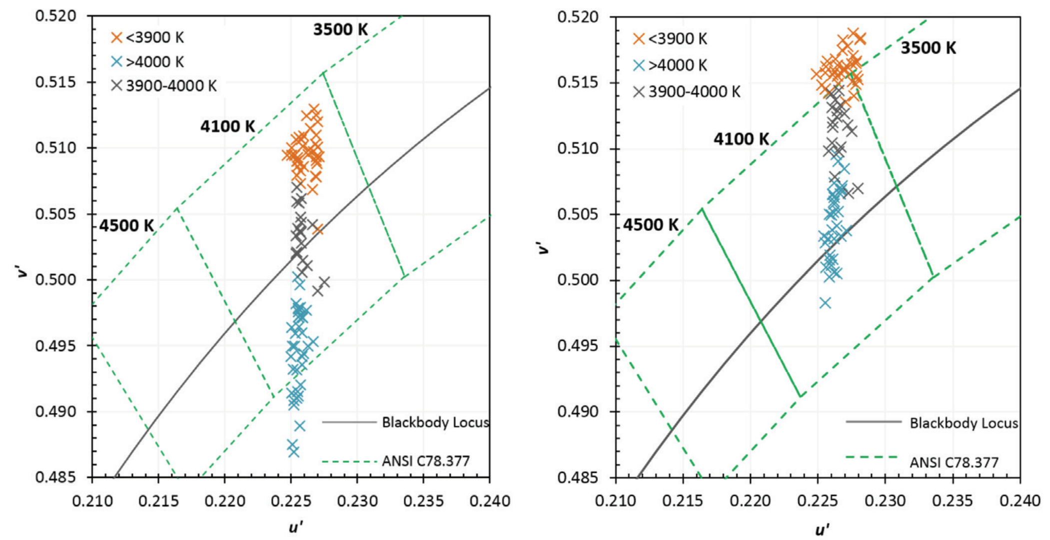
As with many other documented cases, the LED lighting systems installed in Yuma provided substantial benefits in energy reduction, lighting uniformity, and maintenance savings compared to the incumbent QMH. Reductions in light output due to dirt depreciation during the initial operating period (7,000 hours for the first-generation luminaires and 4,000 hours for the second generation) were similar to those predicted using Illuminating Engineering Society luminaire dirt depreciation estimation methods, and were similar to those reported for several other LED systems evaluated by the GATEWAY program.

The laboratory measurements confirmed the effect of dirt not only on lumen output, but also on the distribution of light exiting the luminaire. The change in distribution raises an important question for manufacturers, specifiers, and researchers: How should lighting system designs account for distribution changes due to dirt accumulation? Careful optical design may lead to superior illuminance uniformity during pre-installation photometric analyses; however, the results from this investigation demonstrate that the uniformity will change as the luminaires accumulate dirt.

Illuminance levels produced by the first-generation luminaires decreased dramatically between 7,000 and 11,000



Measured illuminances along east-west line centered at pole 204 at four different measurement times, and for poles 205 and 203 at 11,000 hours. The trial installation luminaires were initially clean, and then cleaned again at 11,000 hours. The numeric values in the labels along the horizontal axis indicate the distance from the pole in feet, and the letter indicates the direction (east or west) from the pole. Illuminance values were normalized for a 25 °C (77 °F) condition.



Second-generation LED lighting system chromaticity: initial (left) and 4,000 hours (right). The chromaticity coordinates are plotted on the CIE 1976 Chromaticity Diagrams (u', v'). The diagrams are scaled to isolate the 4100 K range of the ANSI C78.377-2017 bin, outlined in green. Colored data points represent the initial CCT values: orange < 3900 K, 3900 K ≤ gray ≤ 4000 K, blue > 4000 K.

operating hours. The root cause for this is not known at this time. It may be that the causes were related to the unique conditions of the trial installation of first-generation luminaires, but it also may be that the high-temperature environment contributed to these effects.

Over 4,000 hours of operation, the measured spectral power distributions (SPDs) and related color characteristics for the second-generation luminaires changed to a greater extent than expected. The high-temperature environment in Yuma may have caused, or at least contributed to, these effects, although luminaire design characteristics can also contribute to accelerated shifts in SPD.

The second-generation luminaires exhibited color-over-angle variability that produced noticeable color differences on the illuminated sand beneath the system. Determination of SPD and related color metrics at different angles is not currently included in standardized luminaire photometric testing. This type of variability may not be as noticeable in other applications, but the Yuma result demonstrates that as solid-state lighting (SSL) technology continues to evolve, the nature and the extent of the data that product developers, manufacturers, and specifiers need in order to evaluate the performance of products and systems are also changing. The development of relevant testing and reporting procedures and metrics of acceptability necessarily lags behind the identification of the need for certain types of data.

The results from the Yuma GATEWAY evaluation highlight the gap that still exists between laboratory-based performance testing of LED lighting products and systems, and their performance in the field. While standard test methods such as LM-80, and defined calculation techniques such as TM-21 and TM-28, provide a critical part of the information needed for SSL, the results from this project show that system and field application conditions can make it difficult to predict installed performance over time. These predictions are likely more difficult in extreme conditions, such as those encountered in the Yuma evaluation.

While the initial energy, lighting quality, and maintenance benefits relative to the incumbent HID system were well documented and produced very satisfactory results for Customs and Border Protection, the evaluation raises questions regarding the long-term performance of LED lighting systems in high-temperature environments. Ongoing improvement of current test methods and standards for LED luminaires, as well as new approaches to product and system development, are needed to improve performance of LED lighting systems.

Final reports on GATEWAY outdoor demonstration projects are available for download at energy.gov/eere/ssl/gateway-outdoor-projects. ■

GATEWAY evaluations showcase high-performance LED products for general illumination in commercial, municipal, and residential applications. Evaluations yield real-world experience and data on the performance and cost effectiveness of lighting solutions. For more information, see energy.gov/eere/ssl/gateway-evaluations.

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