Photo: Pacific Northwest National Laboratory

Yuma, AZ—the site of an LED installation in extremely high temperatures.

LED Performance Under Tough Conditions

Three DOE Gateway applications show how LED luminaires respond to rigorous outdoor environments

BY JAMES BRODRICK

Although LED lighting has already made impressive inroads in outdoor applications, there's still a lot we don't know about how the technology will fare when faced with especially challenging conditions. Three recent U.S. Department of Energy Gateway studies *(http://energy.gov/eere/ssl/gateway-demonstrations)* add to our understanding of how LED lighting performs when baking under the desert sun, when punished by vibration and weather on a well-traveled highway bridge, and when facilitating critical tasks on commercial airliners at a major airport.

Photo: Pacific Northwest National Laboratory

Quartz metal halide fixtures (top) were replaced by LED luminaires (two per pole) on the U.S.-Mexico border.

YUMA, AZ, SECTOR BORDER PATROL AREA

Thermal management of LED lighting is hard enough in high-flux applications such as street and area lighting, but the challenge is compounded when the environment features high temperatures as well. To learn more about the effects such environments have on the lumen and color maintenance, luminaire efficacy and luminaire component lifetimes of high-flux LED luminaires, the DOE's Gateway program documented an LED retrofit of the incumbent quartz metal halide (QMH) area lighting along a 7.2-mile stretch of the Yuma, AZ, Sector Border Patrol Area between the U.S. and Mexico, where sunset temperatures can exceed 100 deg F.

Two LED luminaires were installed on each of three poles on the U.S.-Mexico border in February 2014 as part of a trial installation, with a December 2014 Gateway report describing how the LED system equaled or bettered the QMH system in terms of both uniformity and illuminance, when comparing the initial output of the LED system and the maintained output of the QMH system. This initial trial was intended as a short-term test before proceeding with the complete installation of more than 400 luminaires. Although unexpected delays in the full installation have prevented the detailed evaluations originally planned, the six installed LED luminaires continue to be monitored. Illuminance measurements were recorded in February 2014, after installation; in September 2014, at about 2,500 hours of operation; in March 2015, at about 5,000 hours of operation; and in September 2015, at about 7,000 hours of operation.

These measurements over time show illuminance to be changing faster than anticipated. The distribution of illuminance has also changed, with values nearest to the pole increasing while the values farther away from the pole have decreased. The average horizontal illuminance decreased by 25 percent near the primary fence marking the border, and the vertical illuminance decreased by 34 percent on the primary fence. The largest change in distribution occurred between the initial measurement and 2,500 hours of operation, and those changes persisted after 7,000 hours of operation, with no shift detected in the color of the light.

While the field measurements document the overall effects of a high-temperature environment on the LED lighting system, they tell us nothing about the causes, which are the focus of ongoing Gateway research. The most likely culprits for the changes observed were dirt accumulation combined with possible changes to the lenses or other luminaire optical elements.

The luminaires in the Yuma Sector Border Patrol Area are subjected to high temperatures almost on a 24/7 basis. During the daytime, they're often exposed to high ambient temperatures and direct solar radiation, and then when those two factors begin to subside at sunset, the luminaires turn on and generate their own internal heat. Between the initial measurements taken in February 2014 and the 7,000-hour measurements taken in September 2015, the daily high temperature exceeded 100 deg F on nearly 40 percent of the days (233 out of 599).

A better understanding of the causes of the observed changes requires several layers of investigation, including finding out the effects of the solar radiation and ambient thermal conditions on the internal temperature of the luminaires. The two luminaires documented with the illuminance measurements have been removed and replaced with two new luminaires that are a bit different. In each of these new luminaires, the manufacturer installed nine thermocouples in various locations, including next to LED chips, on the driver and on the housing interior. The temperature measurements are being recorded every minute by data loggers, which will continue to record data over the course of a year to enable a better understanding of temperature inside the luminaire. These temperature measurements, along with continued analysis of the removed luminaires, will continue to be reported.

The Yuma Sector retrofit is a DOE Federal Energy Management Program Energy Savings Performance Contract ENABLE project administered through the General Services Administration.

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Testing continues, but highlights from the initial readings include:

- The illuminances are changing more rapidly than anticipated.
- The distribution of illuminance has changed, depending on the distance to the pole.
- There was no measured shift in the color of the light.

See the full reports at *http://energy.gov/eere/ssl/gateway-demonstration-outdoor-projects* for more details, and stay tuned for future reports.

I-35W BRIDGE, MINNEAPOLIS

One of the country's oldest exterior LED installations in continuous operation, the LED lighting system on the I-35W bridge in Minneapolis was implemented in September 2008 in place of a conventional high-pressure sodium (HPS) system. In August 2009, the DOE published a Gateway report comparing the energy use and illuminance levels of the LED system with a simulated HPS baseline. Additional testing was conducted during the first three years of this project and reported in a second Gateway document published in September 2014. The results of that additional testing are instructive, because they comprise the first detailed account of longer-term performance of LED lighting in the field.

The additional testing was divided into three distinct sets. The first set involved two LED luminaires that were tested before being installed on the bridge, and a third luminaire that was not installed on the bridge but instead was tested for 6,000 hours in a laboratory for the purposes of comparison. In May 2013, Gateway and the Minnesota Department of Transportation (MnDOT) conducted follow-up testing on the two bridge luminaires—first in their as-is condition and then again after cleaning.

The second set of testing involved the monitoring of illuminance levels on the bridge, using a mobile monitoring system (MMS) designed by the Virginia Tech Transportation Institute. Seven sets of these measurements were collected by MnDOT between April 2009 and October 2011.

Photo: Courtesy of FIGG©

	Aug 2008	Apr 2013	% Change
Power (W)	243.9	233.3	-4%
Light output (lm)	16,399	13,194	-20%
Efficacy (lm/W)	67.2	56.6	-16%

Table 1. Data for luminaire 200-A after 20,300 hours of operation.

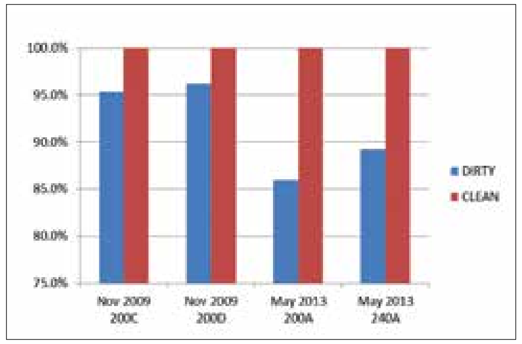

Figure 1. Measured dirt depreciation after 5,000 hours of operation in 2009 and 20,300 hours of operation in 2013.

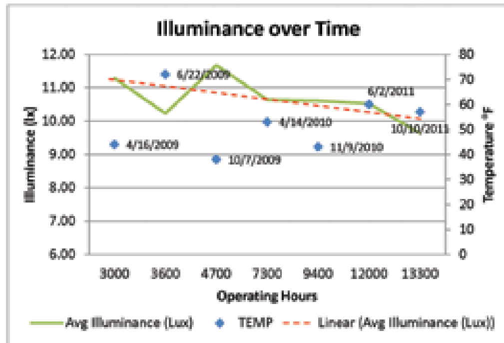

Figure 2. Average illuminance levels from the MMS.

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The findings add to our knowledge of the longer-term performance of LED lighting in the field:

- Dirt depreciation at 20,300 hours measured an average of 12 percent.
- Independent of dirt accumulation, there was an overall 18 percent reduction in light output after that same interval.
- Overall, the bridge's LED lighting system continues to offer effective operation, with the few issues encountered not unexpected, given the early stage of SSL development at the time of purchase.

See the full report at *http://energy.gov/eere/ssl/gateway-demonstration-outdoor-projects* for more details.

In the third set of testing, two luminaires (not the ones that were pretested) that showed a marked reduction in illuminance were removed from the bridge in November 2009, tested in their as-is condition and then retested after cleaning.

Even though the luminaires installed on the I-35W bridge represent a very early state of LED lighting technology, they were nevertheless found to still be robust and effective when tested in May 2013. Not only was their performance reliable in comparison to a conventional HPS baseline, but they were still providing value for MnDOT. When the second report was being prepared, the bridge's lights had seen 25,000 hours of cumulative operation and would have required at least one complete relamping if, instead of LED, an HPS system had been installed in 2008. And that's not taking into consideration the premature failures that are to be expected with any traditional lamp-based technology.

Because of the technology's early stage of development when the LED system was purchased, the few issues that were encountered were not surprising. After about 20,000 hours of operation, the two pretested luminaires averaged an 18 percent decline in light output, independent of dirt accumulation (**Table 1**). This was attributed in part to a slight and unexplained reduction in input power, but also to normal LED lumen depreciation, as well as to a bubble issue in the optical gel that was subsequently resolved by the manufacturer.

Average dirt depreciation was 4 percent after 5,000 hours and 12 percent after 20,300 hours (**Figure 1**), suggesting the importance of periodic cleaning of the luminaires in applications where maintaining road illuminance is critical. The luminaire that remained in the testing lab showed some change in color properties after 6,000 hours—notably, an 800K decrease in CCT, a decrease in R9, and an increase in D_{uv} of 0.01 toward the yellow-green region. Determining the cause of this color shift was beyond the scope of the project, but it may have been due to a change in the phosphor used in the LED packages.

During the 10,000 hours of operation that the MMS was used, there was a 10 percent decrease in measured average ground illuminance (**Figure 2**), which reflects the cumulative impact of multiple factors whose relative contributions can't be determined from the illuminance data alone.

DOE GATEWAY ROUNDUP

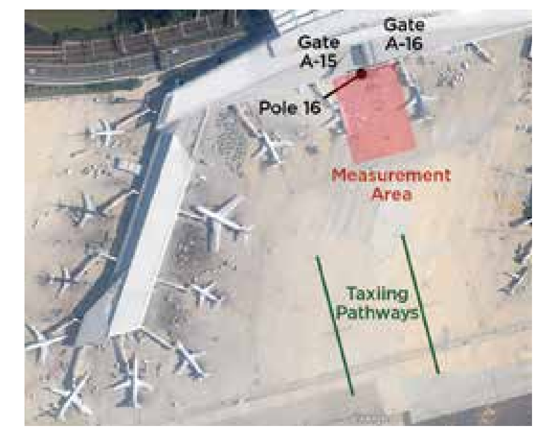
Photo: Pacific Northwest National Laboratory

PHILADELPHIA INTERNATIONAL AIRPORT

There are a few exterior applications where LED luminaires have yet to prove they can match the photometric and economic performance of incumbent high-intensity discharge (HID) systems. One is high-mast lighting, which involves area lighting with mounting heights of 65 ft or more. Traditionally served by 750-W or 1,000-W HID lamps, high-mast lighting applications require outputs that exceed those provided by most of the LED luminaires currently available for exterior applications. What's more, the high drive currents that are often used in higher-output LED luminaires can reduce the luminaire efficacy, due in part to thermal effects related to the higher drive current.

To learn more about the performance of LED lighting in high-mast applications, Gateway documented a trial LED installation for the apron lighting at Philadelphia International Airport (PHL). Apron lighting is critical because it provides task lighting for baggage loading and offloading in the aircraft belly, tow-tractor hookup, fueling operations, preflight check by the pilots and minor maintenance at the gate. It poses an especially difficult lighting challenge, because high light levels are required, luminaire locations are limited to one side of perimeter zones and long throws are needed to provide the light required for tasks that extend the entire length of aircraft. This requires luminaires with very high lumen packages and good optical control. As far as we know, no U.S. passenger airports have yet to convert their apron lighting systems to LED.

In the summer of 2013, PHL, with Gateway assistance, began examining ways to reduce the energy consumption of its apron lighting. PHL also hoped



An aerial view of Terminal A, where the trial LED installation took place in the apron area immediately in front of Pole 16.

		ANNUAL ENERGY USE (kWh)		
TERMINAL	NO. OF LUMINAIRES	HPS (1100 W)	HIGH OUTPUT LED (831 W)	MED OUTPUT LED (533 W)
A	106	477,938	361,060	231,582
B	37	166,827	126,030	80,835
C	32	144,283	108,999	69,912
D	48	216,425	163,499	104,868
E	69	311,110	235,030	150,747
F	98	441,867	333,810	214,105
TOTAL	390	1,758,450	1,328,429	852,049

Annual energy use for the apron lighting system at PHL.

to reduce maintenance and light pollution and increase safety. To minimize the complexity and cost of installing the new lighting system, PHL chose to replace the existing high-pressure sodium (HPS) luminaires on a one-for-one basis with an LED luminaire for a trial installation in the apron area at one of six concourses. An initial trial installation of three luminaires, conducted in October 2014, led to recommended improvements in the system design and evaluation procedures. Consequently, a second trial installation was conducted in May 2015 and provided a better solution, which, if fully implemented, would bring energy savings of between 24.5 percent and 51.5 percent, depending on the mix of high- and medium-output LED luminaires installed.

The Trial 2 evaluation demonstrated that the LED solution provided higher illuminances than the incumbent HPS system throughout the key task areas from 45 ft to 180 ft from the terminal building. In fact, the illuminances produced by the LED system were more than 100 percent higher than those from the HPS system from 60 ft to 135 ft, even with two of the LED luminaires functioning at less than their full output. This demonstrates the potential for greater energy savings with medium-output LED luminaires for the majority of gates with smaller apron areas, rather than with the high-output luminaires used in the Trial 2 installation.

Part of the difficulty in assessing the adequacy of the illuminances throughout the evaluation area comes from the lack of any established design criteria for the apron areas at airports. The relevant IES Recommended Practice (RP-14) was withdrawn and has not been updated or replaced. Until new guidance is provided by the FAA or IES, airport facility managers and designers must rely on their own experiences and past guidance in establishing lighting performance criteria for airport aprons.

The PHL trial evaluations illustrate that lighting-system optimization could bring substantial additional energy savings by leveraging some of the inherent advantages of LEDs. Because LED luminaires use many smaller sources, each of which can have its own discrete optics, there's a possibility of optimizing the distribution of light to address specific task needs, with lower illuminances that are adequate throughout much of the apron and higher illuminances only where necessary. What's more, the inherent dimmability of LEDs provides opportunities for reducing the illuminances in the areas around certain gates where no activity is scheduled, resulting not only in deeper energy savings but also in a reduction in any contributions from the apron lighting system to light pollution. Although it wasn't considered at PHL, an apron lighting control system with some combination of motion detection, time scheduling and manual override capability could provide substantial benefits in these areas. ☐

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High-mast applications can be demanding. Lessons learned from this project include:

- Need for establishing clear design criteria and constraints for the LED project. The only way to fairly evaluate the large number of options available for a large-scale LED project is to establish some clear criteria at the outset of the project.
- Importance of trial installations and mock-ups. While detailed computer analyses can help to assess illuminances in different areas of an application, they cannot replace the visual experience of viewing a trial installation under realistic conditions.
- Careful review of calculations of photometric quantities. The PHL staff received many inquiries from a number of luminaire manufacturers and sales agencies, who often provided computer analyses that failed to accurately reflect the system requirements.

See the full report at *http://energy.gov/eere/ssl/gateway-demonstration-outdoor-projects* for more details, including a list of sales ploys to avoid.

THE AUTHOR

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