Comparing Light-Emitting Diode (LED) Street and Area Lighting to Traditional Lighting Technologies

Case Study

Demonstration Results from Melon Drive in Benton County, Tennessee

Today, high-intensity discharge (HID) lights, such as high-pressure sodium and metal-halide lamps, prevail when it comes to illuminating streets, parking lots, and walkways. But high-power light-emitting diodes (LEDs) promise a brighter future in outdoor illumination. Their capacity to send a more pleasing light in one direction makes them an ideal candidate to replace conventional outdoor lighting.

In 2008, the Tennessee Valley Authority (TVA) and Benton County Electric System partnered with the Electric Power Research Institute (EPRI) to launch an investigation into the use of LED technology for area lighting. The goal of the project—called the LED Street and Area Lighting Demonstration—was to discover a better light bulb, one that not only meets the outdoor lighting requirements of consumers but also uses less electricity in doing so. This case study discusses the results of TVA's and Benton County Electric System's encounter with this new technology—their expectations and how the new technology performed in the field.

Assessing Outdoor LED Lighting Products

Before any evaluation of LED lighting could begin in earnest, the investigators—both from the utilities and from EPRI—set out to understand the nature of electrical lighting. First, how does one determine how efficiently a lamp transforms electricity into serviceable illumination? Typically, the light output of a light fixture and the amount of power that it consumes are measured concurrently. The resulting value of light output—measured in lumens—is divided by the power input—measured in watts—to arrive at a ratio called efficacy, which signifies the efficiency of the light fixture.

Early laboratory reports using traditional methods of assessment indicated an unimpressive performance for the fixtures using LED technology. But field demonstrations painted a different story. One of the most productive

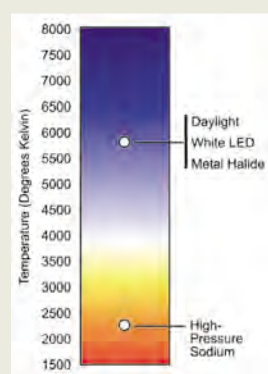
Color Rendition: An Important Criterion for Lighting Technologies

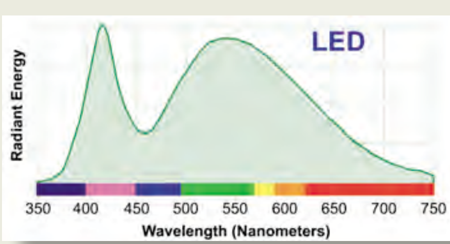
The human eyes are designed for maximal vision in unobstructed daylight. In this so-called *white light*, both types of photoreceptors of the eye—called *rods* and *cones*—are active, accurately rendering the colors of objects. White light is actually a mix of different wavelengths in the visible spectrum. Perceiving such a light, our eyes average out all the different frequencies to arrive at a single color.

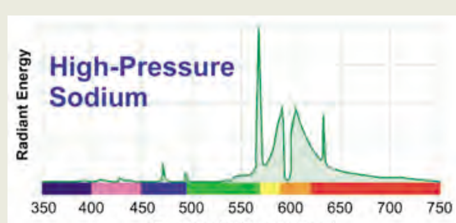
In search of daylight, manufacturers of outdoor LEDs coat each LED with a phosphor material to shift some of the stark blue light toward the yellow range, resulting in a broad-spectrum white light. However, white light doesn't come cheap. The more phosphor that a manufacturer uses to shift light, the greater the cost and the less efficient the LED.

The light output from an example LED lamp is continuous from 350 nm to over 750 nm, whereas a typical HPS lamp emits a prominent yellow light, hampering accurate rendition of color.

The correlated color temperature (CCT) is an index used to grade the quality of light. Unobstructed daylight has a CCT of about 5800 K, within the range of LED fixtures in the marketplace. On the other hand, the light from an HPS lamp is in the orange range, once again hampering accurate color rendition.







advantages of LED lighting, and a characteristic not accounted for with traditional assessment methods, is that the light shines where you want it to, and little of it is wasted. Conventional lamps for street and area lighting radiate light in nearly all directions, resulting in about 30% of the light traveling skyward or trespassing into unintended places. Early reports from the field readily confirmed a superior overall efficiency and uniformity of coverage provided by the LED fixtures.

Field Measurements and Challenges

The selected test method for the field assessment was the pre/post test design, which involves measuring the power to and light output from existing HID lighting (called the control fixtures), swapping the existing lighting with LED lighting (called the treatment fixtures), and then measuring input power and light output from the new lights. This test method excludes potentially confounding factors such as the environment and the height of lamp poles, factors that both control and treatment lights shared during the experiment.

Before TVA and Benton County Electric System considered adopting LED lighting on a broad scale, objective metrics had to be drafted, measurement equipment had to be commissioned, and the measurement protocol described above had to be executed. EPRI worked with multiple manufacturers of LED lighting and tabulated specifications that were used to select one manufacturer's equipment to install. Benton County Electric System identified several sites and worked with TVA and EPRI to select the site best qualified based on the selection criteria. A successful site had to meet several criteria, such as a dedicated electrical circuit for all fixtures under test, minimal light trespass, and separation from trees that throw shadows upon the test area. Unlike a laboratory setup, it is often impossible to locate a perfect site, so compromises were made.

One of the barriers to measuring light output was the amount of time required by an investigator to complete the measurements on a large parking lot or long street—a daunting task when executed manually. To be accurate and replicable, manual measurement of light required an investigator to operate within a grid, painstakingly measuring light in each cell, often while in uncomfortable positions. For the Demonstration, and with funding provided in part by TVA, EPRI investigators designed a computer-controlled Mobile Light Measurement System, or Scotty, a four-wheel, technology-laden, remotely controlled vehicle similar in appearance to the U.S. Mars Rover.

Gathering Data from Melon Drive in Benton County

Located between Nashville and Memphis, Tennessee, the city of Camden is the county seat of Benton County. The population of Benton County is listed as approximately 16,500 in the 2010 U.S. Census. Camden proper is listed as having a population of approximately 3,800 in that same census.

Benton County Electric System, the local power distributor and site host, selected Melon Drive in Camden as the site for the demonstration. Both Benton County and Camden City have agriculturally focused/based economies. So, this rural community offered an excellent opportunity to demonstrate a cutting-edge lighting technology in a smaller community where the fixtures would be highly visible.

Melon Drive is a residential street located on the Northern side of Camden. In addition to the benefits of the site mentioned above, this site also offered the opportunity to retrofit some existing HID fixtures in an established neighborhood and provided an excellent location for the residents of Benton County to provide feedback to TVA, Camden City officials, and Benton County officials on their opinion of the demonstration technology.

Employing the Scotty to Measure Light

Collection of photometric data was a significant challenge at the onset of the LED Street and Area Lighting Demonstration. Measurements had to be made near the ground where light is incident upon walking surfaces. Moreover, the measurements had to be made on an exact grid. These two requirements—the height of the measurement and its grid location—posed a difficulty for investigators.

The Scotty relieves the investigators of this burden. Using a global positioning system (GPS), the Scotty is able to determine its position on the earth to within two centimeters. With its precision light meters pointed skyward, it is capable of recording light data onto its onboard computer at up to five times per second as an operator maneuvers the Scotty throughout a high-resolution grid located beneath the light fixture being tested.

As noted above, Melon Drive is a surface street within an established neighborhood of homes. This site offered a space where the fixtures could be observed regularly and easily by all of the involved parties. This fact meant that both the power savings and the site photometric performance received high priority when evaluating, installing, and maintaining the site. Along with engineers from EPRI and TVA, Camden City officials and engineers from Benton County Electric System were interested in providing both an adequately lit street and energy savings.

When lamp fixtures are considered for site installation, the area and environment around the site must be considered as well. In many applications, this means the use of decorative fixtures such as those shown in Figure 1. The decorative fixtures in Figure 1 were not part of the Melon Drive/Benton County demonstration (it is important to always make fixture selections that maintain the desired aesthetics and feel for a site). When decorative features are utilized on a site, the main advantage of LED technology—that is, putting light only where it is needed—is lost in the decorative form factor. Figure 1 clearly shows the wasted energy in the form of light shining into the branches of the tree as well as glare, which is true of both HPS and LED. It is because of the waste that the Department of Energy and its ENERGY STAR program have not created a category for the decorative form factor, whereas there is discussion of a new category for the "shoebox" or "cobrahead" form factor used in parking areas and streets.

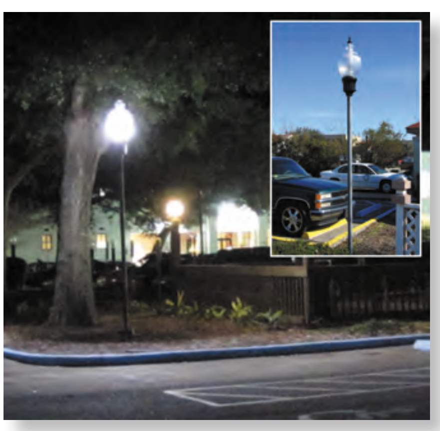


Figure 1—An LED Fixture, an Older Fixture (to the Right), and the Decorative Form Factor (Inset, Photographed During Daylight)

Prior to the installation of the LED street and area lighting (LEDSAL), Melon Drive was illuminated with several HPS fixtures. Each lamp was rated at 150 watts, and each ballast was rated at 38 watts for a total rated power consumption of 188 watts for each control fixture. However, when demonstration investigators attempted to measure the power consumption of those fixtures, the readings were inconsistent with the 188-watt rating, with measurements as high as 420 watts. Apparently, the lighting circuits were feeding other, unidentified phase-to-phase loads. Instead of untangling the circuits and isolating the existing HPS fixtures to obtain a "pre" measurement for each HPS lamp, the investigators used the rated value of the lamp/ballast fixture.

The demonstration team replaced seven of the HPS fixtures located on street-side poles with LED lighting fixtures and monitored five of those over a 28-month period. A line crew used six-inch metal arms to install each LED fixture on each wooden pole. Figures 2 shows the pre/post illumination on Melon Drive. The project team selected LED fixtures rated at 100 watts (a sampled fixture was measured at 99.2 watts), and based on the power rating of the existing HPS fixtures, the team expected a reduction in power of about 47%.

During a period of 28 months, the team used three values to analyze energy use, compare energy use, and draw conclusions about the effectiveness of the LED fixtures:

- Rated power of the control fixtures: The original HPS fixture (lamp and ballast) was rated at 188 watts.
- Measured power of a single random treatment sample: When the LED fixtures were installed, one fixture was selected at random, and its power consumption was measured at 99.2 watts (a difference of less than 1% from the rated power). That measured value was extrapolated to the other four LED fixtures.
- Continuously measured power of the five treatment fixtures: The LED fixtures were monitored over a period of 28 months. This data stream enabled the team to validate the power rating of the manufacturer. Indeed, the measured energy usage was about 8% more than the energy use calculated from the rated power, on average.

Figure 2 provides an approximation of the difference between the HPS lights and the retrofit LED lights for the street. The photographs

Figure 2—Melon Drive Before Installation of LED Fixtures (Left) and After (Right)

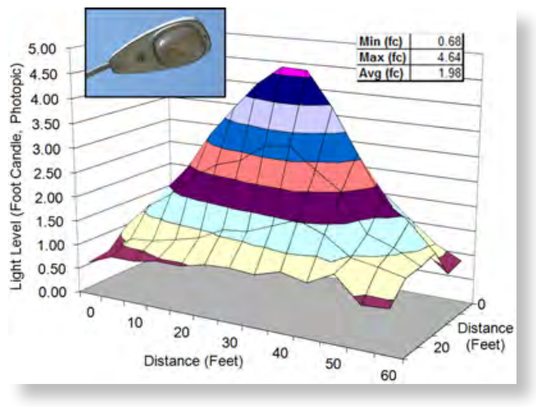


Figure 3—Photometric Data Taken with the Scotty for an HPS Fixture

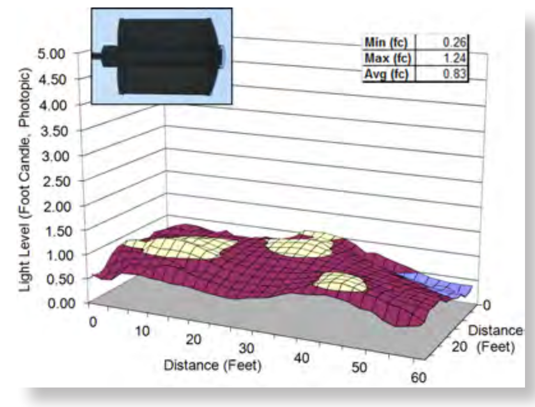


Figure 4—Photometric Data Taken with the Scotty for an LED Fixture

highlight the difference in quality of light (the HPS has a color temperature of about 2000 K, while the LED temperature is about 6000 K). The whiter almost blue color emitted from the LED gives the appearance of more light even though the LED actually produces less light when measured using traditional techniques. In addition to appearing whiter, the light output from the LED fixtures appears more even on the ground. This observation was verified by the photometric design received from the manufacturer and measurements taken by the Scotty.

Figures 3 and 4 above, provide photometric data from the Scotty. The data shows that the HPS fixtures provided intense lighting directly below the fixture, with intensity falling sharply with distance from the area directly below the fixture. Although the average light output of the LED fixtures was less than that of the HPS fixtures, they provided an even distribution of light over the whole measured area. This is a good representation of even light distribution.

Figure 5 illustrates the projected energy use of the control fixtures, the projected energy use of the treatment fixtures, and the measured energy use of the treatment fixtures for each day over the course of the 28-month period of measurement. Note that there are gaps in the data, indicating that the data was missing or corrupt. The reason for the sinusoidal pattern of the projected values is the variation in the duration of darkness (night) as the earth revolves around the sun. These values were taken from the U.S. Navy Astronomical Applications Department. The calculated values are based on the exact geographic coordinates of Melon Drive.

Data analysis compared the rated control fixtures to the calculated treatment fixtures. Table 1 shows the daily energy savings averaged over the entire duration of the 28-month study. It is

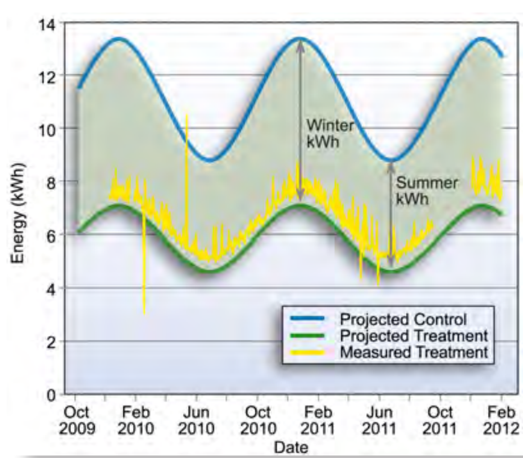


Figure 5—Daily Energy Use Over the Demonstration Interval at Melon Drive

Table 1—Comparison of Performance and Energy Savings of HPS/LED Technologies Over 28 Months

	HPS	LED
System Maximum Power Consumption (W)	940*	583
Average Single-Fixture Power Consumption (W)	188*	99.2
Average Calculated Daily Energy Usage (kWh)	11.4*	6.0*
Average Measured Daily Energy Usage (kWh)	N/A	6.5
Calculated Energy Savings** (kWh)	5.4 (47%)	

* Unknown phase-to-phase loads rendered HPS measurements unusable, so calculated values are used (System Maximum = 5 x Fixture Power = 5 x 188 = 940 W).

** Calculation of daily energy savings was performed using calculated usage values.

clear that the savings were substantial over the 28-month monitoring period. The savings were also seasonal: That is, the energy savings were greater in the winter, as shown in Figure 5.

At other sites of the Energy Efficiency Demonstration, the demonstration team discovered that the ambient temperature around the fixture affected power consumption and lumen output. Generally, LED-based fixtures consume more power during winter than during summer, as shown in Figure 6, but note that the light output also increases in cold temperatures. Temperature does not affect the power consumption of HID fixtures—such as metal-halide and HPS.

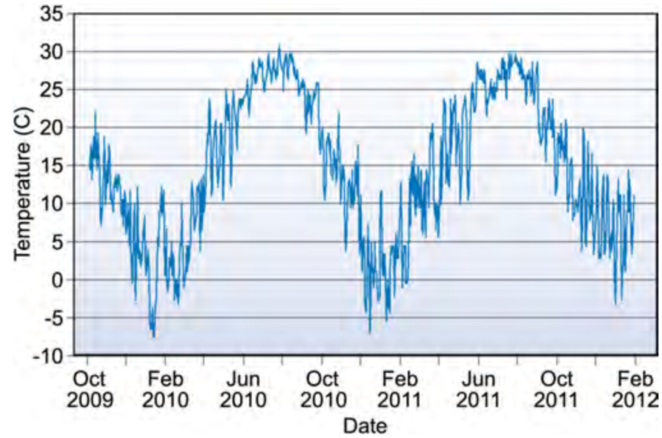


Figure 7—Daily-Average Temperatures for Camden, Tennessee, over the Duration of the Demonstration

Figure 7 shows the daily average temperature for Camden. Although Camden is not in a cold climate, the data shows that the temperature does get fairly cold in the winter months.

Another important factor of the efficiency of lighting is the amount of time that the fixture is on versus the amount of time it needs to be on. If a fixture operates longer than is required, then a potential for energy savings exists. For example, the blue trace in Figure 8 shows the number of dark hours per day expected for Camden (provided by the U.S. Naval Observatory). These dark hours are the times when the fixtures should be on. However, as shown by the green trace, the fixtures were often on longer than actual darkness. These upward spikes are evidence of overlighting that might be remedied to save energy. On the other hand, areas that are not adequately illuminated (downward spikes) pose safety risks.

The Camden site provided slightly more than the amount of lighting necessary to illuminate the street and sidewalks. Over the measurement period, there were 264 hours of excessive lighting duration, which accounted for only 3% of the total time. There were 39 hours of insufficient lighting duration, which accounted for less than 1% of the total duration of LED lamp operation.

It was found that the use and proper placement of lighting sensors allow for proper lighting of an area. Storms and overcast days can sometimes trigger streetlights, so the sensitivity of these devices must be adjusted to provide lighting when necessary. Lighting research has found that pre-programmed light timers deviate from the proper number of hours (both above and below) more than light sensors.

Adoption of the Technology

Utilities seek technologies that they can champion and advance to their customers. TVA and Benton County Electric System had similar

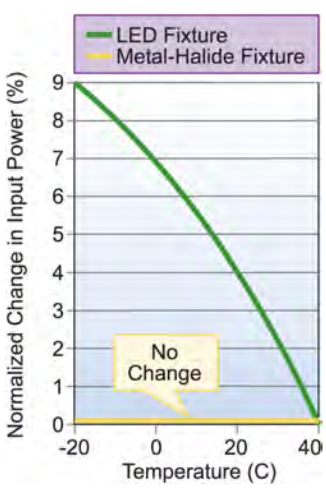


Figure 6—The Effect of Temperature on the Input Power of LED Fixtures

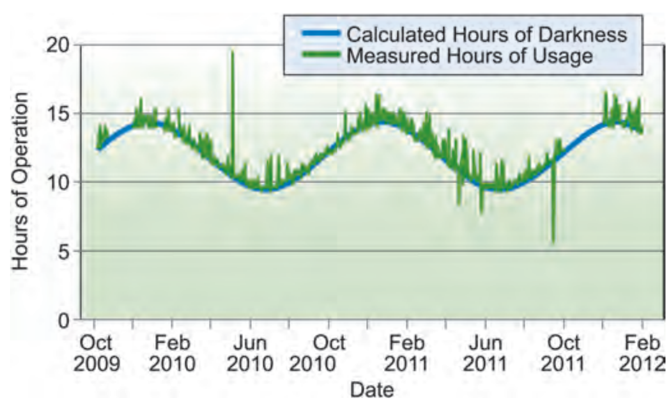


Figure 8—Comparison of How Long the LED Fixtures Operated Versus the Projected Number of Hours of Darkness

goals for the Demonstration and therefore wished to fully understand the LED lighting technology before promoting it to broader application within their service territories.

TVA and Benton County Electric System discovered several disadvantages of LED lighting during the Demonstration. Two of these issues were unexpected driver failures and sensitivity to power quality issues. By studying LED fixtures in the lab and in the field, TVA and EPRI discovered that some LEDSALs offer lower efficacy values than traditional HID lamps, lower immunity to electrical disturbances, less flexibility in replacing the LED light sources, and high cost of initial installation.

In addition to the issues discovered both at Camden and at other EPRI LEDSAL Demonstration sites throughout the United States, the site at Benton County revealed another problem: the operation of a LEDSAL system that interfered with the operation of a HAM radio. The resolution of this problem was achieved by the addition a specifically tuned ferrite bead on the input power lead. This issue is discussed in depth in the following EPRI report, which can be downloaded via the EPRI website.

Investigation of an Electromagnetic Interference (EMI) Problem Involving Light-Emitting Diode Streetlights and an Amateur Radio Transceiver, EPRI, Palo Alto, CA: 2011. 1024599.

Notwithstanding the disadvantages and issues with LEDSALs, it should be noted that as the investigation continued, advantages that offset the disadvantages were discovered. Although the cost of installing LED lighting is greater than the installation cost for conventional lighting (up to 10 times higher in some cases), budgeted costs for the maintenance of conventional lighting typically exceed the initial costs of the installation of LED based fixtures. Because LEDs are designed to last longer than HID lighting—a lifespan as much as 100,000 hours according to some manufacturers—they offer the potential of substantially reduced maintenance costs, if they meet or exceed their advertised lifespan. This reduced cost of maintenance can provide a valid reason for real-world adoption of LED-based fixtures over conventional technologies. Additionally, their real-world energy savings—engendered by a fixture design that wastes very little light—offset the mediocre performance of LED lighting in the laboratory.

Over time, the lumen output of LED fixtures can degrade. The lifecycle estimates given by manufacturers are typically given for the point when degradation beings to takes place. Heat can also have an impact on fixtures. Increased heat can accelerate the degradation of the epoxy packaging, phosphor, and the LED die, as well as decrease the life of the power supply. The light spectrum can also drift with age. During the 28 months when the street was monitored, measurements taken by the Scotty indicated no significant degradation of the light level in Camden.

Also, because LED lighting is able to direct more light where it is needed, there may be less demand for poles, especially when the fixture can be adjusted to increase the area of overlap between fixtures. Ultimately, this advantage will allow those who adopt the LED technology to use fewer light fixtures and thus fewer poles. However, when fixtures have a fixed direction for the light output, more poles may be needed to bring the light spreads closer and to prevent dark bands.

The total cost of the fixture over time must also be taken into account. The cost to replace LED drivers can vary—depending on a few factors—between $120 and close to $300. Labor costs will also vary because some fixtures require complete removal and transportation to the utility's shop for service, whereas HID fixtures can be repaired on the pole. In fact, the entire fixture must be replaced if a few LEDs fail. Furthermore, each form factor of LED fixture is different, so only original parts can be used for maintenance or repair. These factors can increase the cost of the fixture over its lifetime. Other considerations that should be addressed to determine return on investment include labor rates in the area for service, the light level of the fixture over time, cost of power in the area, and the potential energy savings over the currently implemented technology.

Conclusion

In some applications, LED light fixtures provide acceptable illumination and energy savings. However, saving energy is not necessarily the same as saving money. Many city engineers and politicians are surprised to learn that a 50% reduction in energy use does not typically equal a 50% reduction in the electricity bill. Fifteen-percent is a more accurate number. Why? The other 35% covers infrastructure costs, such as pole and wire depreciation and maintenance. Because these costs are not vigorously publicized by vendors, care is required when calculating simple payback.

There are many factors that influence a decision to accept or reject LED lighting technologies, and authorities on the subject are neither vocal nor unified in their guidance. Standards for LEDs are evolving, but a consensus does not yet exist on the proper application of LED technologies for outdoor lighting. Improvements in LEDs, optics, and control electronics continue, and costs are decreasing. However, the tangled differences in light color and performance variables complicate direct comparison to traditional lighting technologies. The bottom line is that from a performance aspect, LED technologies are up to the task of replacing conventional lighting and saving a significant amount of energy. Ultimately, end users—nighttime pedestrians and drivers—win because of the nature of the light. More light strikes intended surfaces, and that light is a more pleasing bluish light. However, like many new technologies, the cost of retrofitting existing light fixtures, at least for now, remains a challenge.

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