

Light Emitting Plasma Outdoor Lighting Scaled Field Placement

ET Project Number: ET12PGE3171



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Issued: November 30, 2012

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ACKNOWLEDGEMENTS

Pacific Gas and Electric Company's Emerging Technologies Program is responsible for this project. It was developed as part of Pacific Gas and Electric Company's Emerging Technology – Scaled Field Placement program under internal project number ET12PGE3171. Heschong Mahone Group conducted this technology evaluation for Pacific Gas and Electric Company with overall guidance and management from David Lewbin and Philip Broaddus. For more information on this project, contact D2LO@pge.com.

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ABBREVIATIONS AND ACRONYMS

CIE	International Commission on Illumination
CRI	Color rendering index
HMG	Heschong Mahone Group
HPS	High Pressure Sodium
IES	Illuminating Engineering Society
kWh	KiloWatt hours
LEP	Light Emitting Plasma
OSHA	Occupational Safety and Health Administration
PF	Power factor
PG&E	Pacific Gas and Electric Co.
RF	Radio frequency
W	Watts

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EXECUTIVE SUMMARY

PROJECT GOAL

The goal of this study is to provide recommendations for the integration of emerging technologies into energy efficiency incentive programs for exterior lighting applications in Pacific Gas & Electric Company ("PG&E") territory. These recommendations are to be guided by the results of a field monitoring and evaluation study currently underway.

This study evaluates the performance of a test installation of Light Emitting Plasma (LEP) lighting and a wireless lighting control system, as compared to incumbent High Pressure Sodium (HPS) lighting, in a high mast application at a study site in northern California. The study evaluates energy savings resulting from the installation of LEP fixtures in place of the existing HPS fixtures, as well as the potential savings available from the wireless control system installed with the LEP fixtures. In addition, the study assesses illuminance levels and the visual quality provided by the LEP fixtures.

Results and study activities presented in this report represent the first phase of an ongoing study that will continue through August 2013.

PROJECT DESCRIPTION

This study evaluates the performance of an installation of 12 LEP fixtures on a single 80' lighting pole at the study site in Northern California. Results of the LEP performance are compared to the performance of an existing installation of HPS lighting currently in use at the site. This interim report presents findings on three aspects of lighting performance:

- Energy Use
- Illuminance Levels – photopic and scotopic
- Visual Quality

The LEP fixtures are proposed to provide significant energy savings compared to HPS, according to the manufacturer. A typical HPS fixture in use at the study site uses as much as 1280 W, whereas the manufacturer projects the LEP fixtures to use 560 W. In addition, the LEP lighting is projected to provide improved visual quality with higher correlated color temperature (CCT) and higher Color Rendering Index (CRI), as well as comparable light levels.

In order to test the performance of the LEP lighting, the Heschong Mahone Group, Inc. (HMG) conducted field monitoring of energy use and illuminance output. The first phase of the study presented in this report measured energy use from one test LEP lighting pole and one baseline HPS lighting pole concurrently. The study also measured illuminance levels in the area between each of the two study poles.

The overall field monitoring at the site began on August 24, 2012, and will continue until June 30, 2013. To date, field monitoring has been completed for a comparative analysis of the LEP and HPS lighting at full output, and those results are presented in this report. Following this initial phase, the study will be expanded to evaluate additional LEP lighting installed at the site, as well as the energy savings potential provided by the wireless control system.

PROJECT FINDINGS/RESULTS

HMG monitored the energy performance and illuminance output from one LEP pole with 12 fixtures and compared these against the performance of an existing HPS pole with 12 fixtures. The baseline HPS pole had all lamps and ballasts replaced so that the HPS fixtures were at their peak output and thus provided an equivalent baseline to compare against the new LEP pole. While the HPS pole has 12 fixtures, two of these fixtures are on an emergency circuit that is not monitored by HMG. However, HMG has extrapolated data from the 10 monitored fixtures to all 12 fixtures on the HPS pole so that the results between the two poles are comparable.

This study is ongoing, with complete findings to be published in a Final Emerging Technology Study Report in August 2013.

Energy Savings:

Overall, LEP lighting represents a significant energy savings opportunity over HPS in high-mast applications. As shown in Figure 1, the LEP lighting (12 fixtures) uses less than half the energy of the HPS lighting (12 fixtures) at full output. Further, the control system installed along with the LEP fixtures provides additional savings by not turning the LEP lighting ON until it is necessary. On the example day shown below the HPS pole is turned ON at 4:54pm based on a preset schedule, but the LEP pole is programmed in relation to daily changes in sunrise and sunset times, and is turned ON at 7:05pm, ten minutes after sunset.

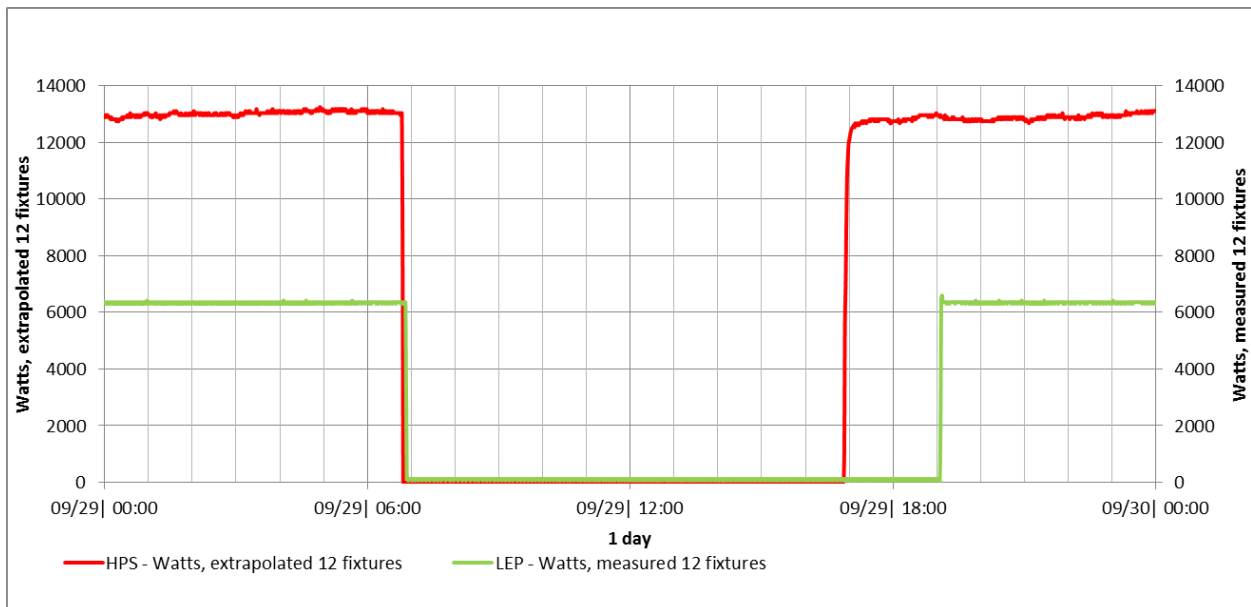


FIGURE 1. EXAMPLE DAILY ENERGY USE COMPARISON, HPS (RED) VS. LEP (GREEN)

Energy use details for an example monitoring period are shown below in Table 1. As shown in the table, although the average power savings of the LEP pole at full output is 51%, the overall energy use savings for the monitoring period is 58% due to the added savings provided by the control system which schedules the LEP lighting more precisely than the timer used on the HPS lighting.

TABLE 1. EXAMPLE ENERGY USE COMPARISON, SEPTEMBER 24 – OCTOBER 1

	TOTAL ENERGY USE, SEPTEMBER 24 TO OCTOBER 1 (KWH)	AVERAGE POWER AT FULL OUTPUT (W)
HPS	1257	12944
LEP	529	6347
Difference	-728 (-58%)	-6597 (-51%)

Note that the LEP energy savings are slightly offset by the fact that the control system, the power supplies, and the drivers in each LEP fixture draw a small amount of power at all times, even when the lighting is turned off.

Illuminance Results:

Illuminance performance of the LEP lighting shows significantly less illuminance than the existing HPS fixtures using the traditional photopic¹ illuminance criteria. Table 2, summarizes typical photopic illuminance conditions at the site. For the area most directly impacted by the LEP pole, the average photopic illuminance is 43 lux, which is significantly less than the minimum average of 54 lux required by the Occupational Safety and Health Administration (OSHA).

TABLE 2. EXAMPLE PHOTOPIC ILLUMINANCE MEASUREMENTS

	AVERAGE (LUX)	MAXIMUM (LUX)	MINIMUM (LUX)	MAX:MIN	AVG:MIN
HPS	78	126	24	5.25:1	3.25:1
LEP	43	69	17	4.06:1	2.55:1

However, photopic illuminance measurements are one part of the answer, and are not always the best representation of nighttime vision conditions. Looking at scotopic² illuminance results in Table 3, the LEP fixture provides higher illuminance than HPS.

TABLE 3. EXAMPLE SCOTOPIC ILLUMINANCE MEASUREMENTS

	AVERAGE (LUX)	MAXIMUM (LUX)	MINIMUM (LUX)	MAX:MIN	AVG:MIN
HPS	60	93	24	3.88:1	2.51:1
LEP	71	142	24	5.92:1	2.96:1

Despite the lower measured photopic light levels at the site, employees at the study site report that the LEP lighting appears brighter than the existing HPS lighting, and that it renders colors better, improving visibility.

¹ Photopic illuminance is the standard measure of the amount of light incident on a surface, and is based on the human eye's spectral response under daylight or interior lighting conditions. For more information see the "Photopic, Scotopic, and Mesopic vision" section.

² Scotopic illuminance is based on the human eye's spectral response under very dark conditions when only the rod photoreceptors are active. For more information see the "Photopic, Scotopic, and Mesopic vision" section.

PROJECT RECOMMENDATIONS

Initial results from the LEP fixture energy monitoring are encouraging in terms of energy savings. Further investigation is needed regarding power consumption of the LEP fixtures when they are turned OFF, and will be conducted as part of continuing project tasks.

Initial results from illuminance measurements provide a mixed picture with lower photopic illuminance, but higher scotopic illuminance than the existing HPS lighting. This issue needs further investigation and will be conducted as part of continuing project tasks.

The findings presented here need further vetting through the longer term monitoring currently being conducted. Full findings and recommendations will be presented in a Final Emerging Technology Study Report, following the completion of the continuing study, to be published in August 2013.

INTRODUCTION

This study originated from a PG&E Contract Work Authorization for the Heschong Mahone Group, Inc. (hereinafter "HMG"). This study evaluates the performance of an installation of Light Emitting Plasma (LEP) lighting and wireless lighting controls as an alternative to the existing High Pressure Sodium (HPS) in a high-mast application at a study site in northern California. The LEP lighting provides the potential for energy savings, more dynamic control capability, and improved visual quality over HPS lighting.

STUDY SCOPE

This study is being conducted in two phases: an initial study, presented here, and an ongoing expanded study. The expanded study will build on the findings of the initial study, with longer term field monitoring and a wider variety of test conditions.

INITIAL STUDY

The initial study was primarily focused on the direct comparison of the performance of a single LEP pole with a single HPS pole at full output. Energy monitoring for this initial study was conducted between August 24 and October 1, 2012. Illuminance measurements for the initial study were taken on September 20 and October 18, 2012.

This report presents interim findings based on the field monitoring of the two poles at full output.

EXPANDED STUDY

The expanded study will include energy monitoring of three additional LEP poles (the baseline HPS pole was retrofitted to LEP on November 15, 2012), and will continue to measure illuminance levels at the study site at least once per month. The expanded study will also evaluate capabilities of the wireless control system installed with the LEP lighting. Field monitoring for the expanded study will be completed by June 30, 2013.

This expanded study will build on the initial findings reported here and will examine additional performance aspects, as follows:

- Long term LEP lighting performance, such as lumen depreciation, over approximately 10 months
- Illuminance and visual quality performance of an expanded installation of LEP lighting at the study site
- Additional energy savings opportunities provided by the wireless control system
- Energy savings and lighting performance impacts of using eight fixtures per pole instead of twelve

Findings from the expanded study, as well as full recommendations will be presented in a Final Emerging Technology Study Report to be published in August 2013.

STUDY SITE

This study was carried out at Ports America Outer Harbor Terminal, LLC (hereinafter referred to as "the study site"), a privately operated port terminal facility within the Port of Oakland in Oakland, CA. The terminal facility is used to load and unload cargo from some of the largest cargo container ships in the world. The facility is capable of processing over 487,000 cargo containers per year. Ships arrive and depart at all times of day and night, so nighttime lighting is crucial to the operations of the facility.

BACKGROUND

High-mast lighting presents a unique and specific challenge. Typically used in industrial or infrastructural applications, such as large parking areas, major highways and interchanges, airports, and port facilities, high-mast lighting is required to provide relatively uniform illumination across very large areas from a limited number of locations. High-mast lighting also has the advantage of limiting glare, by placing the light source very high and out of the typical field of view.

Because of the specific requirements of high-mast lighting, this segment has been dominated by HPS sources, like those currently in use at the study site for this study. HPS lighting can provide very large amounts of light relatively efficiently compared to other light sources. However, HPS lighting presents several important problems.

First of all, the color and visual quality of HPS light is relatively poor. The orange-yellow color is poorly suited to nighttime conditions, and renders colors poorly. Metal halide sources can provide better visual quality than HPS, but also typically require more energy to produce comparable light levels.

The other problem of high-mast lighting is that even with relatively efficient HPS sources, it uses large amounts of energy. High-mast HPS fixtures can use as much as 1280 W each, and typical high-mast poles use between two and twelve fixtures each.

While LED technology has been replacing HPS lighting in many applications, high-mast lighting remains somewhat out of reach for LEDs. Typical LED luminaires use large arrays of small LED chips to equal the light output of comparable single-lamp sources such as linear fluorescent or HPS. In a high-mast application, the LED array would have to be prohibitively large to match the output of an HID source, and even then the relatively low intensity of the individual LED chips may not be capable of reaching the long distances required by high mast lighting.

By contrast, LEP technology seems ideally suited to high-mast applications. The LEP modules used in this study provide a high-intensity white light from a single small source, using significantly less energy than a comparable HPS luminaire. The small size of the LEP source allows for more precise optical control, and the high intensity of the light ensures that it can be effectively delivered to the large areas common to high-mast applications.

EMERGING TECHNOLOGY/PRODUCT

The first electrode-less plasma lamps were invented by Nikola Tesla in the 1890s, but subsequent iterations of plasma lighting encountered a variety of challenges and limitations, such as limited lamp life, high heat, and high power requirements.³

A new system used in the LEP products in this study was first developed in 2000. The LEP lamp itself is a small quartz electrode-less capsule, the size of a large pill. The key to the system is the ceramic resonator that the lamp capsule is embedded in. This ceramic resonator concentrates a radio frequency (RF) field, energizing the capsule without

³ http://en.wikipedia.org/wiki/Plasma_lamp, accessed November 28, 2012

electrodes. The concentrated radio frequency creates a plasma state inside the capsule, which emits a high-intensity white light.

Figure 2, below, shows a diagram of this process. The diagram was developed by Luxim, the manufacturer of the LEP modules used in this study.



FIGURE 2. DIAGRAM OF HOW LIGHT EMITTING PLASMA WORKS (IMAGE SOURCE: LUXIM)

The process shown in Figure 2, as described by Luxim is as follows:

Step 1

An RF circuit is established by connecting an RF power amplifier to a ceramic resonator known as the "puck". In the center of the puck is a sealed quartz lamp that contains metal halide materials and other gases.

Step 2

The puck, driven by the power amplifier, creates a standing wave confined within its walls. The electric field is strongest at the center of the lamp, which causes ionization of the gases, creating a glow.

Step 3

The ionized gas in turn heats up and evaporates the metal halide materials forming an intense plasma column within the lamp. This plasma column is centered within the quartz envelope and radiates light very efficiently.

(Source: <http://www.luxim.com/technology/how-lep-works>)

The high intensity white light that LEP produces makes it competitive with HID sources, such as HPS and Metal Halide, in a variety of applications, such as exterior roadway and parking lot, industrial high bay, and high-mast applications. Because of its small size and high light output, LEP is also an alternative to LED for high intensity scenarios that require precise optical control, or a concentrated beam, which cannot be delivered as successfully by large arrays of LED chips.

Because this form of LEP lighting is so new, it is relatively untested in real world scenarios, and it is not well known in a lighting market heavily saturated with LED products. In addition, there has been some concern that the radio frequencies used to energize the lamp may interfere with the wireless control systems that are sometimes used to control large outdoor lighting installations that LEP lighting is well suited to.

SCALED FIELD PLACEMENT OBJECTIVES

The objective of this interim report is to present initial findings on the performance of a high-mast installation of LEP lighting, as compared to the existing HPS lighting in use at the study site. The performance of the LEP lighting is being evaluated on three key factors:

- **Energy Use**
This report presents initial findings on the difference in energy use between HPS and LEP lighting.
- **Illuminance**
The report presents illuminance measurements taken at the site comparing illuminance levels from the HPS and LEP poles.
- **Light Quality**
The report discusses light quality aspects associated with HPS and LEP lighting, including initial responses from employees at the study site.

TECHNOLOGY/PRODUCT EVALUATION

This report compares initial performance of one existing HPS pole to a pole retrofitted with LEP fixtures. Each pole is 80 feet tall, and has 12 fixtures.

The existing fixtures use 1000 W HPS lamps. In the interest of providing a direct comparison, the baseline HPS pole that was monitored for this study had a full lamp and ballast replacement prior to the start of the study to ensure that it was fully functional and the power consumption was close to manufacturer specifications. In addition, light level measurements at the HPS pole were not taken until after a sufficient burn-in period of at least 100 hours to allow the gases in the lamps to stabilize.

The LEP fixtures are manufactured by Bright Light Systems, using LEP modules from Luxim, and wireless controls from Vasona Labs. The manufacturer's specification sheet states that the LEP fixtures use two LEP modules, for a total of 560 W per fixture⁴.

An early installation of LEP lighting at the study site experienced multiple fixture failures that were believed to be caused by power quality issues at the site. The power at the study site experiences voltage spikes which may have overloaded the electronics in the LEP fixtures, causing them to fail. In order to avoid future problems, a power filter was installed on subsequent LEP poles, including the test pole monitored in this study. The filter⁵, essentially a kind of transformer, absorbs the voltage spikes and prevents them from reaching the LEP fixtures. The need for the filter, and its function in the LEP system will be further investigated in the expanded study.

Figure 3, below, shows a typical LEP fixture from Bright Light Systems, similar to those installed at the study site.

⁴ www.brightlightpro.com/support/datasheets/BLP1000.pdf

⁵ Input Line Reactor, manufactured by TCI (Trans-Coil International), model number KDRULA4H



FIGURE 3. TYPICAL LEP FIXTURE INSTALLED AT THE SITE (IMAGE SOURCE: BRIGHT LIGHT SYSTEMS)

In order to evaluate the performance of the LEP lighting, the study examined three factors, described in detail below: energy use, illuminance levels, and visual quality.

ENERGY USE MONITORING

Energy use was monitored at both the baseline HPS pole and the test LEP pole, as described in detail in the Technical Approach/Test Methodology section.

The monitored energy use data presented in this report compares the energy use of 12 LEP fixtures to 12 HPS fixtures. Note that each lighting pole at the site has 10 fixtures that are powered by a primary power source and controlled using a timer, and two fixtures that are powered by a separate power source and controlled by a photosensor. These two separately powered fixtures are considered "emergency fixtures" and are typically only turned on if the other 10 fixtures fail. Because the LEP fixtures are controlled by a separate wireless control system, the photocell and timer were bypassed on the LEP pole, allowing all 12 LEP fixtures to turn on each night. The energy monitoring equipment monitored all 12 fixtures on the LEP pole (see Data Validation Test Results), but only monitored the primary power source for the 10 main HPS fixtures. However, results in this report are presented by extrapolating data from the 10 fixtures to all 12 fixtures on the HPS pole to provide a direct comparison to the LEP pole.

This study compares both power (W) and energy use (kWh) of the LEP and HPS lighting. In addition to these key parameters, other variables provided by the data logging system are discussed in the assessment of the LEP lighting technology. The variables available for review are discussed in more detail in the Technical Approach/Test Methodology section, below.

ILLUMINANCE LEVELS

Illuminance is the measurement of the quantity of light incident on a surface. For this study, HMG measured illuminance levels from the test LEP pole and the baseline

HPS pole. Illuminance levels were measured with all 12 HPS fixtures turned on, in order to provide an equal comparison to the LEP pole with 12 fixtures. Details of the measurement process are described below in the Technical Approach/Test Methodology section.

The study site is required to meet the Occupational Safety and Health Administration (OSHA) requirements for light levels. The relevant OSHA light level requirements are as follows:

- Minimum average of 5 footcandles in work areas (54 lux)
- Minimum average of 1 footcandle in non-work areas (11 lux)

The OSHA requirements are specified in footcandles, but the study measurements were taken in lux (the metric unit of illuminance), so lux values are shown above for reference as well. In addition to comparing the illuminance of the LEP and HPS lighting, the study seeks to confirm that the LEP lighting meets the OSHA light level requirements.

One complication of measuring illuminance under nighttime conditions is the visual adaptation of the human eye in low light conditions. In order to provide the most complete understanding of the illuminance conditions at the site the study will measure both photopic and scotopic illuminance. The issue of photopic versus scotopic vision is discussed in detail below.

PHOTOPIC, SCOTOPIC, AND MESOPIC VISION

The human eye behaves differently under different lighting conditions. Under typical interior and daylight brightness conditions, the visual response is dominated by the cone photoreceptors in the eye, which perceive colors and fine details. This is called photopic vision. Photopic illuminance describes light levels under these conditions, based on the photopic action spectrum adopted by the CIE (International Commission on Illumination) in 1924. Standard illuminance meters use the photopic action spectrum to determine light levels.

However, under very low brightness conditions, the visual response is dominated by the rod photoreceptors, which do not perceive color, and are more sensitive to peripheral vision. This is called scotopic vision. Under scotopic vision, the eye is more sensitive to the green and blue spectrum of light, causing these portions of the spectrum to appear brighter than normal. Scotopic illuminance describes the visual perception of light levels under these conditions, based on the scotopic action spectrum adopted by the CIE in 1951.

Completely scotopic or rod-dominated vision is limited to very low brightness conditions where little or no ambient light is present. It is almost impossible for vision to be fully scotopic under any artificially lit conditions. However, in typical exterior nighttime environments, the eye transitions between photopic and scotopic vision. The spectral sensitivity shift towards the blue end of the spectrum of light begins to occur under these conditions. This transitional state is called mesopic vision, and neither photopic illuminance nor scotopic illuminance can adequately describe perceived light levels under mesopic vision, as the eye transitions between cone-dominated and rod-dominated vision.

Unfortunately, there is not yet an internationally accepted standard for measuring mesopic light levels. Several strategies to model mesopic light levels have been developed based on photopic and scotopic illuminance measurements. A mesopic

analysis is not included in this interim report, but will be included in the final report on the expanded study.

In order to provide the most complete understanding of the visual conditions at the study site, both photopic and scotopic illuminance levels were measured.

In addition, studies have shown that so-called "scotopically enhanced" lighting, which is shifted toward the blue part of the visible spectrum, appears brighter than more typical white light sources.

In relation to the technologies evaluated by this study, LEP lighting would be considered a "scotopically enhanced" light source, with a color temperature of 5200K (blue-white). On the other hand, HPS lighting typically has a color temperature of 2100K (yellow-orange). Based on these factors, the LEP lighting is expected to appear brighter than the incumbent HPS lighting at the site.

Although it is not explicitly stated, it is assumed that the OSHA requirements are based on photopic illuminance levels, since all illuminance standards are currently based on photopic footcandles. However, both photopic and scotopic measurements are presented below to provide a more thorough understanding of the lighting conditions at the site.

VISUAL QUALITY

Illuminance is only one of many aspects of light quality and performance. Other visual quality aspects, such as color rendering can also impact perceived brightness, visual comfort, and user satisfaction. For example, the LEP manufacturer reports a color rendering index (CRI) of up to 75 (out of 100), whereas typical HPS lamps have CRIs in the low 20s.

In order to explore these issues of visual comfort and user satisfaction, HMG had informal discussions with employees at the study site as well as the electricians who installed the fixtures to understand how the "occupants" of the site have responded to the test LEP lighting. So far these discussions have been limited to a site engineer and two site supervisors. The expanded study will attempt to survey the workers who perform the bulk of the work under the LEP lighting at the site.

TECHNICAL APPROACH/TEST METHODOLOGY

FIELD TESTING OF TECHNOLOGY

This study compares a test installation of LEP high mast lighting with the existing HPS lighting at the study site. The diagram in Figure 4, below, shows the test area for the study, where the red dot indicates the LEP study pole, the blue dot indicates the baseline HPS study pole used in the study, and the yellow dot indicates the electrical substation that provides power to the lighting in the area and an early test installation of LEP lighting that is not a part of this study.

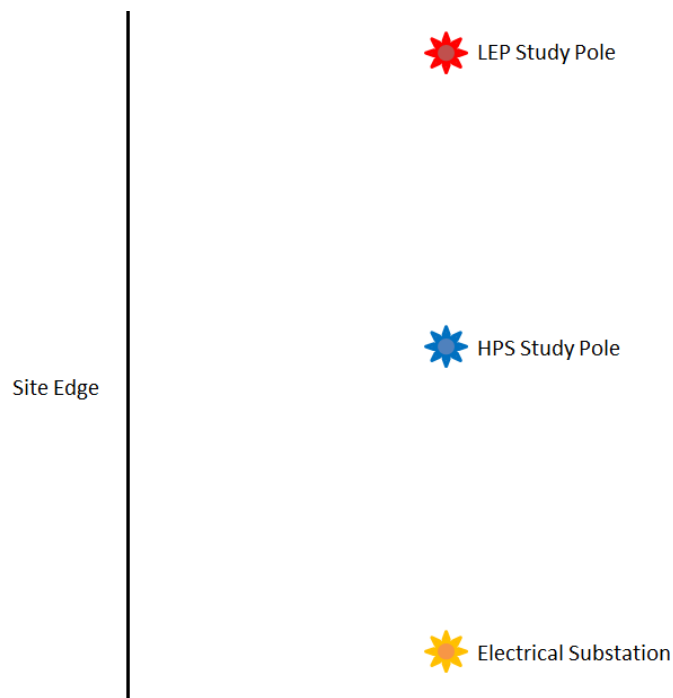


FIGURE 4. DIAGRAM OF STUDY LOCATION, RED DOT INDICATES LEP TEST POLE, BLUE DOT INDICATES BASELINE HPS POLE, YELLOW DOT INDICATES POWER SUBSTATION

Each lighting pole is 80 feet tall, and contains 12 fixtures. Existing HPS lighting is controlled by an automatic time-clock control system that turns the lights on at night, and off again in the morning. Over the duration of the study, the HPS lighting was turning on each afternoon between 4:45 and 4:55pm, and turning off each morning between 6:15 and 7:00am. Ten of the 12 fixtures on the HPS pole are controlled by this time-clock system, while the other two fixtures are controlled by a photocell, and only turn on if the other ten fixtures are not functioning properly.

On the test LEP pole, all 12 HPS fixtures were replaced with new LEP fixtures. The LEP fixtures are controlled wirelessly using a digital control system. Each fixture is capable of being controlled individually, but for the purposes of this report, all fixtures were controlled together. Initially, the LEP fixtures were programmed to turn on 30 minutes after sunset, and to turn off 30 minutes before sunrise. Later in the study, the LEP fixture programming was adjusted to turn on 10 minutes after sunset, and turn off 10 minutes before sunrise each day, in order to ensure sufficient illumination at all times.

The study measured energy use at both the baseline HPS pole and the test LEP pole, as well as illuminance levels in the area between the two poles and the site edge.

INSTRUMENTATION PLAN

The instrumentation plan for this project involves two distinct aspects: the energy monitoring equipment, and the illuminance measurement equipment. The equipment used in this project is described in the sections below.

POWER METERS AND DATA LOGGERS

Energy monitoring is carried out using a HOBO U-30 data logger system from Onset (<http://www.onsetcomp.com/products/data-loggers/u30-gsm>), which uses a cellular network to transmit data to Onset's online server, "Hobolink," where the data can be accessed in real time. The system uses E50B2 power and energy meters (<http://www.onsetcomp.com/products/sensors/t-ver-e50b2>) to measure electricity use and power quality.



FIGURE 5. HOBO U30 REMOTE MONITORING SYSTEM FROM ONSET



FIGURE 6. E50B2 POWER AND ENERGY METER FROM ONSET

The E50B2 power meters use current transformers (CTs), and directly connected voltage leads to measure energy use. The power meters measure the following variables:

- Volt-ampere reactive hours (VARh)
- Watt hours (Wh)
- Amp hours (Ah)

Those measurements recorded by the power meter are then transmitted to the U30 logger using pulse-input adapters. The pulse-input adapter transmits the values measured by the power meter to the logger in a series of pulses. The pulses are scaled depending on the variable being measured.

For example, for each Wh used by one of the LEP fixtures, the power meter sends a pulse to the data logger. In a typical one minute logging interval for an LEP fixture, the power meter will send 9 pulses to the data logger. In other words, the LEP fixture uses 9 Wh per minute. This Wh value can be converted to Watts (W) using the following equation:

EQUATION 1. WH TO W CONVERSION

$$W = Wh/h$$

Therefore in this example, the conversion is as follows:

EQUATION 2. WH TO W CONVERSION

$$W = 9 W / (60 \text{ seconds} / 3600 \text{ seconds}) = 540 W$$

As shown in Equation 2, the 9 Wh is divided by the length of the measurement interval, in hours, to determine that the Wattage for that one minute interval is 540W. However, it should be noted that this example reveals the relatively low precision of the pulse-input adapter at single measurement points. Using this conversion, each Wh pulse recorded in a one minute interval translates to 60 W. In other words, a minute with 8 pulses would represent 480 W, and a minute interval

with 10 pulses would represent 600 W. A longer time interval would provide more precision. Although the pulse data is relatively imprecise at the individual reading level, individual values can be averaged over longer periods of time to create more precise data. In addition, the pulse data is an effective way to measure cumulative energy use data over time (kWh, etc.).

Similar to the Wattage example above, the values measured by the power meter, and recorded by the data logger can be converted to the following variables:

- Volt-ampere reactive (VAR)
- Volt-amps (VA)
- Volts (V)
- Power factor (PF)
- Watts (W)
- Kilowatt hours (kWh)
- Kilowatts (kW)

The study used two logger systems to allow simultaneous monitoring on both the baseline HPS pole, and the LEP study pole.

The baseline HPS pole was monitored at the power mains to the pole, because all fixtures on the HPS pole are operated together. Energy use at the LEP study pole was monitored at the mains and at a sample of two individual circuits to provide additional information on the performance of the LEP fixtures.

DATA VALIDATION TESTING

Initial data collected by the data logging system raised concerns about:

- Higher than expected wattage on the full LEP pole
- Higher than expected wattage on the LEP pole when lighting was turned off
- Very low power factor on the LEP pole when lighting was turned off (between 0.1 and 0.2, where typical lighting systems have power factors above 0.9)
- Lower than expected wattage on the two individual fixture circuits
- Lower than expected power factor on the two individual fixture circuits

In order to confirm the values that were reported by the Hobo logging system, HMG conducted a separate power monitoring test using Dent ElitePro SP power meters, which provided instantaneous results on-site during the testing. Using the Dent meters HMG monitored the LEP pole in the same configuration as the Hobo logging system. In addition to replicating the test conditions, HMG also tested the other circuits that are not individually monitored, starting with all fixtures on, and turning off breakers one by one in order to try and isolate any abnormalities in the data. The individual circuit testing was carried out twice, once with all the LEP fixtures at full power, and once with the fixtures turned off.

Overall, this validation process confirmed the results of the Hobo monitoring system, provided a more complete understanding of the energy monitoring situation, and resolved the concerns identified above such that there is a high level of confidence in the reported results. A detailed discussion of the outcome of the data validation is

included in the Data Validation Test Results section below. HMG will repeat a similar validation process for the additional monitoring as part of the expanded study.

ILLUMINANCE METER

Illuminance measurements were taken using a Solar Light SL-3101 Scotopic/Photopic illuminance meter.

A new meter was purchased for the project, and was calibrated by the manufacturer on February 16, 2012.



FIGURE 7. SOLAR LIGHT SL-3101 SCOTOPIC/PHOTOPIC ILLUMINANCE METER

TEST PLAN

Monitoring and measurement plans for the study are outlined in the sections below. For the duration of the testing period for this interim report, the baseline HPS and the test LEP lighting were operating and were monitored simultaneously. As such, the baseline HPS data and the test LEP data cover the same period of time, measured under the same conditions.

BASELINE ENERGY MONITORING

Power meters and data loggers were installed on the baseline HPS pole on July 27, 2012. On the baseline HPS pole, one power meter was used to monitor energy use at the power mains in the electrical panel at the base of the pole. These power mains control 10 of the 12 fixtures on the pole. Energy monitoring equipment is described in detail above, in the Power Meters and Data Loggers section.

In order to provide the most equal comparison to the test LEP pole, all lamps and ballasts were replaced on the baseline HPS pole so that all 12 fixtures on the pole were fully functional (see Technology/Product Evaluation, above). Following these repairs, the baseline HPS pole was fully functional starting the night of August 24.

LEP PRODUCT ENERGY MONITORING

As with the baseline HPS pole, power meters and data loggers were installed on the test LEP pole on July 27, 2012. On the test LEP pole, three power meters were used. One power meter monitored energy use at the power mains in the electrical panel which controls all 12 LEP fixtures on the pole. Two additional power meters were used to monitor energy use at two individual circuits, which each control a single LEP fixture.

Immediately following the initial LEP installation two of the LEP fixtures were not functioning properly and had to be replaced. Several weeks later, another LEP fixture was not functioning properly, with only one of the two LEP modules working, and had to be replaced. The malfunctioning LEP fixture was replaced on September 24, and the LEP pole was fully functional starting that night. These fixture issues are reflected in the monitored data for the full pole, but did not affect either of the two individual fixtures that were monitored for the study.

ENERGY MONITORING CONDITIONS

Both the test LEP lighting and the baseline HPS lighting were monitored simultaneously since the installation of the loggers in July. However, it took several weeks to replace lamps and ballasts on the baseline HPS pole so that all fixtures were functioning for the comparison. As described above, the energy monitoring equipment measured the energy use of 12 fixtures on the LEP pole, and 10 fixtures on the HPS pole. In order to provide an equal comparison, the energy use data for the HPS presented here was extrapolated to represent 12 fixtures as follows:

EQUATION 3. EXTRAPOLATED HPS WATTS

$$\text{Extrapolated HPS Watts} = \text{Measured HPS Watts} / (10/12)$$

Analysis of the comparative energy use for the study began on August 24, once all the HPS fixtures on the baseline pole were fully functional.

In addition, the control schedule on the LEP fixtures was adjusted on September 22. Up until that point, the LEP lighting was turning on 30 minutes after sunset, and turning off 30 minutes before sunrise. However, after observing conditions at the site, HMG and management at the study site asked for the schedule to be adjusted to turn the lighting on earlier to ensure adequate illumination at the site. Starting on September 22, the LEP lighting turned on 10 minutes after sunset and turned off 10 minutes before sunrise.

Energy monitoring data presented in this report was collected at 60 second intervals. Later in the study, starting on October 23, the monitoring interval was extended to every 120 seconds, in order to provide more precise results (see pulse-input adapter discussion in the Power Meters and Data Loggers section). Energy use data recorded by the data logger was transmitted via cellular signal to the Hobolink online server every 15 minutes. HMG and PG&E staff had access to the data on the Hobolink server over the duration of the study.

Simultaneous monitoring continued until October 1, when the logging system on the test LEP pole malfunctioned and stopped logging data, as discussed in detail below. Energy use data presented below is primarily from the monitoring period from August 24 to October 1. The malfunctioning logger has since been repaired and reinstalled, and will continue to monitor energy use for the expanded study.

LOGGING DATA LOSS

Beginning on October 1, 2012, the logging system connected to the LEP pole stopped communicating data to the online Hobolink server. HMG coordinated with Onset on several different troubleshooting strategies, including an attempt at restarting the logger remotely, a hard restart of the logger on site, and an attempt at making a hardwired connection to the logger. All of these attempts failed, and the logger had to be returned to the manufacturer for repair.

The problem was traced to the GSM module that provides the cellular connection and communicates the data to the Hobolink server. The logger was repaired and reinstalled at the site on October 23, 2012. Unfortunately, no data was recorded for the LEP pole between October 1 and October 23, 2012.

The loss of data does not affect the results presented in this interim report because the data collected between August 24 and October 1 provided sufficient information for analysis of the HPS and LEP poles at full output.

ILLUMINANCE MEASUREMENTS

Horizontal illuminance measurements were taken at ground level at pre-determined points defined by a 20' x 20' grid layout that extended throughout the rectangular area between the baseline HPS pole and the test LEP pole, and between those two light poles and the edge of the site as shown in Figure 8.

In addition to the horizontal measurements, vertical measurements were taken at heights of 20' and 40' above the ground, at pre-determined points at 40' intervals between each pole and the site edge. This illuminance measurement area was chosen to minimize influence from any surrounding light sources.

Both photopic and scotopic illuminance levels were measured using a Solar Light scotopic/photopic illuminance meter, as described in the Instrumentation Plan section, above.

Although footcandles is the familiar unit of illuminance measurement in the United States, the Illuminating Engineering Society (IES) has transitioned to using the metric unit of "lux." As such, this study recorded illuminance measurements in lux rather than footcandles. The conversion of footcandles to lux is as follows:

EQUATION 4. FOOTCANDLE TO LUX CONVERSION

$$1 \text{ footcandle} = 10.76 \text{ lux}$$

Or, as a simple rule of thumb, 1 footcandle is approximately 10 lux.

During a site visit on August 30, 2012, the illuminance measurement grid was marked out at the site. Measurement points were marked on the ground with spray paint. Each point was marked with two perpendicular lines, where the intersection of the two lines indicates the measurement point. Vertical measurement points were also indicated by a "V" next to the measurement point markings. Figure 8, below, shows a diagram of illuminance measurement locations at the site. The "H" markings in the diagram indicate points where only horizontal measurements were taken; "V" indicates points where both horizontal and vertical measurements were taken.

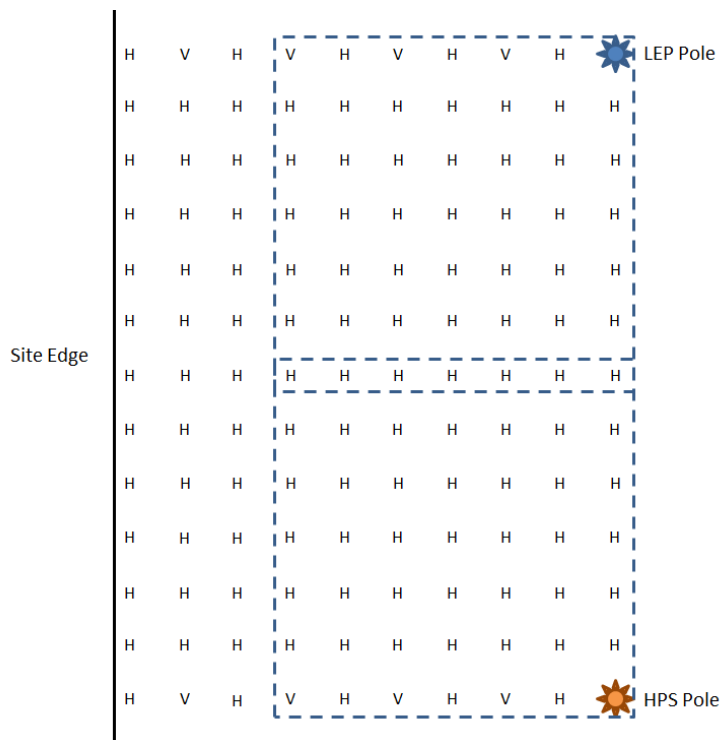


FIGURE 8. DIAGRAM OF ILLUMINANCE MEASUREMENT LOCATIONS

In order to provide an equal illuminance comparison between the LEP and HPS poles, the photocell controlling the emergency fixtures on the HPS pole was taped over during illuminance measurements, forcing the two additional fixtures to turn ON.

Illuminance measurements were taken on site at least once per month following the marking of the grid. Illuminance measurements presented in this report were taken at the site on September 20, and October 18.

In order to provide a direct comparison, the values recorded at all measurement points up to 120' between the poles, and up to 120' toward the water line were used to evaluate the individual LEP and HPS poles. This adjusted area was chosen because 120' represents the typical midpoint between two poles in the broader site area, and therefore this area represents all the points that are most directly influenced by each respective pole. In addition, under typical working conditions, equipment along the site edge provides supplemental illumination in the working area beyond 120'. These adjusted measurement areas are indicated in Figure 8 with dashed lines. Using this adjusted measurement area provides a comparison of the influence of the two poles, while still allowing for the influence of surrounding light sources that are present under real-world conditions.

RESULTS

The interim results of the study indicate that the LEP lighting represents a significant reduction in energy use compared to the existing HPS lighting. The illuminance measurements taken at the site tell a less clear story. The HPS lighting performs much better using photopic illuminance, but the LEP lighting performs better using scotopic illuminance. In addition, the site engineer and the installing electricians reported that the LEP lighting appears brighter and provides better color rendition than the HPS lighting at the site.

OVERALL ENERGY USE

Overall, the test LEP lighting represents a significant energy savings compared to the existing baseline HPS lighting. The energy savings results from both the lower wattage of the LEP lighting, and the increased savings precision of the wireless control system.

Table 4, below, summarizes the total energy use for the initial monitoring period from noon on August 24 to noon on October 1.

TABLE 4. TOTAL ENERGY USE, AUGUST 24 – OCTOBER 1

	TOTAL ENERGY USE, AUGUST 24 TO OCTOBER 1 (KWH)	AVERAGE POWER AT FULL OUTPUT (W)
HPS - extrapolated	6634	12934
LEP	2535	6145
Difference	-4099 (-62%)	-6789 (-52%)

An important detail shown in Table 4 is that the typical power used by the LEP pole at full output is only 52% less than the HPS pole, but the total energy use savings of 62% is much greater. The additional energy savings comes from two main sources. First, as discussed above, one of the LEP fixtures was not fully functional for most of the initial monitoring period resulting in less energy use on the LEP pole. This individual non-functioning LEP module, out of a total of 24 on the LEP pole, only accounts for about 4% of the typical LEP pole energy use. The other source of added energy savings is the more precise schedule allowed by the wireless control system on the LEP lighting.

Table 5, below, shows two examples of the schedules for the HPS and LEP lighting. The first example, the night of August 24 and 25, was during the more aggressive control schedule period, where the lighting was programmed to turn on 30 minutes after sunset, and turn off 30 minutes before sunrise. The second example, the night of September 24 and 25, is after the schedule was reprogrammed to turn lighting on 10 minutes after sunset, and turn off 10 minutes before sunrise.

TABLE 5. EXAMPLE LIGHTING SCHEDULES

	TIME ON	TIME OFF	TOTAL ON TIME
HPS 8/24-25	4:54pm	6:16am	13 hours, 22 minutes
LEP 8/24-25	7:31pm	5:30am	9 hours, 59 minutes
Difference	-2 hours, 37 minutes	-46 minutes	-3 hours, 23 minutes
HPS 9/24-25	4:53pm	6:44am	13 hours, 51 minutes
LEP 9/24-25	7:11pm	6:49am	11 hours, 22 minutes
Difference	-2 hours, 18 minutes	+5 minutes	-2 hours, 29 minutes

In both cases the LEP lighting is on for a significantly shorter amount of time than the HPS lighting. However, it should be noted that after the LEP schedule was adjusted, the LEP lighting turned off 5 minutes later than the HPS lighting. In addition to potential energy savings, the more precise schedule ensures that proper illumination is provided at the site at all times.

If the energy use comparison is isolated to the period where all LEP fixtures were fully functional and after the control schedule had been changed the savings is slightly reduced, but still substantial. Table 6 shows the energy use for this period, from September 24 through October 1.

TABLE 6. TOTAL ENERGY USE, SEPTEMBER 24 – OCTOBER 1

	TOTAL ENERGY USE, SEPTEMBER 24 TO OCTOBER 1 (kWh)	AVERAGE POWER AT FULL OUTPUT (W)
HPS - extrapolated	1257	12944
LEP	529	6347
Difference	-728 (-58%)	-6597 (-51%)

As shown in Table 6, even when all LEP fixtures are fully functional, and the control schedule was adjusted to more conservative timing, the LEP lighting still provides a 58% energy saving over the existing HPS lighting.

DAILY ENERGY USE EXAMPLES

In order to provide more detailed analysis of the energy use comparison, data for several individual days is presented below. These examples will help to clarify the energy characteristics of the HPS and LEP lighting.

Figure 9, below, shows the energy use of the HPS and LEP poles on August 26. The HPS pole is shown in red, while the LEP pole is shown in green.

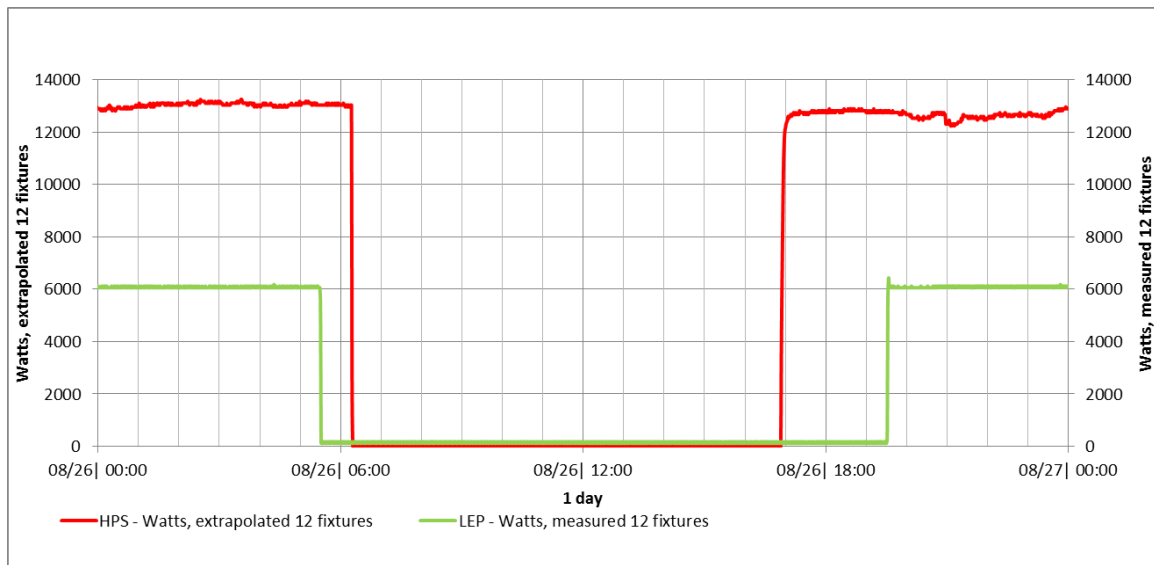


FIGURE 9. DAILY ENERGY USE, AUGUST 26, HPS POLE (RED) VS. LEP POLE (GREEN)

The aggressive scheduling for the LEP pole that was in place until September 22 is clearly evident in the graph in Figure 9. The LEP lighting turns off more than half an hour before the HPS lighting in the morning, and turns on two and a half hours after the HPS lighting in the evening.

Table 7, below, shows the performance characteristics for this day in more detail. The full output value for the LEP pole reflects the fact that one of the lamps in one of the fixtures was not functioning at this time. This adds to savings from the control schedule to result in an overall 63% energy savings from the LEP lighting compared to the baseline HPS lighting.

TABLE 7. DAILY OPERATION DETAILS, AUGUST 26

	OFF TIME	ON TIME	AVERAGE POWER AT FULL OUTPUT (W)	AVERAGE POWER WHEN OFF (W)	TOTAL ENERGY USE, 8/26 (kWh)
HPS Pole	6:17am	4:54pm	12845	0	172
LEP Pole	5:30am	7:31pm	6082	142	63
Difference	-43 minutes	-2 hours, 37 minutes	-6763 (-53%)	+142	-109 (-63%)

Although the LEP pole uses approximately 53% less energy than the HPS pole at full power, the LEP pole continues to use power when the lights are turned off because the control system, drivers, and power supplies in each fixture are constantly drawing a small amount of power. Even so, because of the aggressive schedule of the control system, the LEP pole uses 63% less energy than the HPS pole over the course of the day.

Figure 10, below, shows the energy use of the HPS and LEP poles on September 29. The HPS pole is shown in red, while the LEP pole is shown in green. The data in Figure 10 shows the typical LEP pattern after the schedule was adjusted.

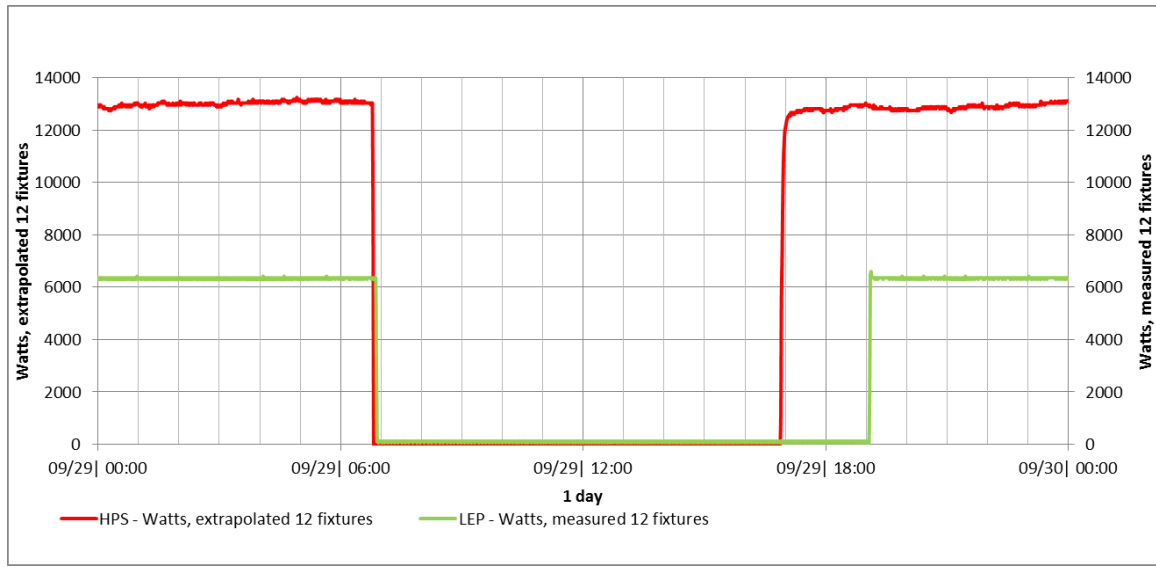


FIGURE 10. DAILY ENERGY USE, SEPTEMBER 29, HPS POLE (RED) VS. LEP POLE (GREEN)

When the lighting is on at full power, the LEP pole uses approximately 50% of the energy that the HPS pole uses. The added precision of the wireless control system on the LEP fixtures generates additional savings, although not as much as the data shown in Figure 9 and Table 7, above. In the data shown in Figure 10, the LEP lighting still turns on over two hours after the HPS lighting. This time difference will change depending on the season and the length of the day, but this increased precision represents a substantial energy savings opportunity.

Table 8, below, shows the operational characteristics for September 29 in more detail.

TABLE 8. DAILY OPERATION DETAILS, SEPTEMBER 29

	OFF TIME	ON TIME	AVERAGE POWER AT FULL OUTPUT (W)	AVERAGE POWER WHEN OFF (W)	TOTAL ENERGY USE, 9/29 (kWh)
HPS Pole	6:50am	4:53pm	12935	0	180
LEP Pole	6:53am	7:05pm	6352	106	76
Difference	+3 minutes	-2 hours, 13 minutes	-6583 (-51%)	+106	-104 (-58%)

Although total energy savings will vary depending on the day, and the differences in the control schedule, it is clear that the LEP lighting system provides substantial energy savings over the existing HPS lighting. Again, the LEP lighting uses some energy even when the lighting is turned off, but that extra energy is almost negligible compared to the overall energy savings provided by the LEP lighting.

compared to the HPS lighting.

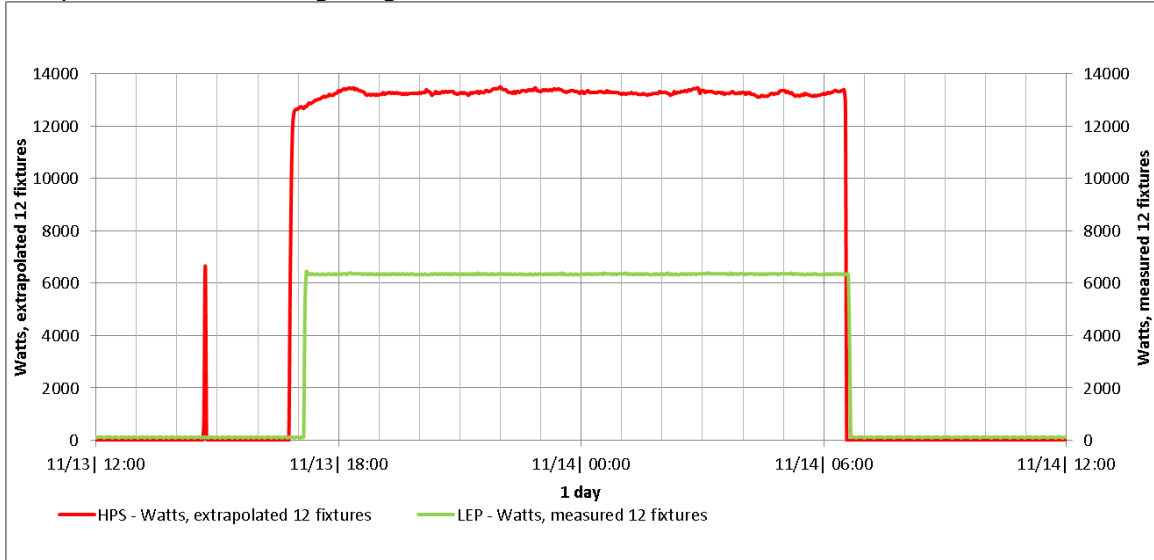


Figure 11 shows the daily use pattern for a more recent day when the LEP lighting schedule more closely matches that of the HPS lighting. In this example, the data is shown from noon to noon, instead of midnight to midnight.

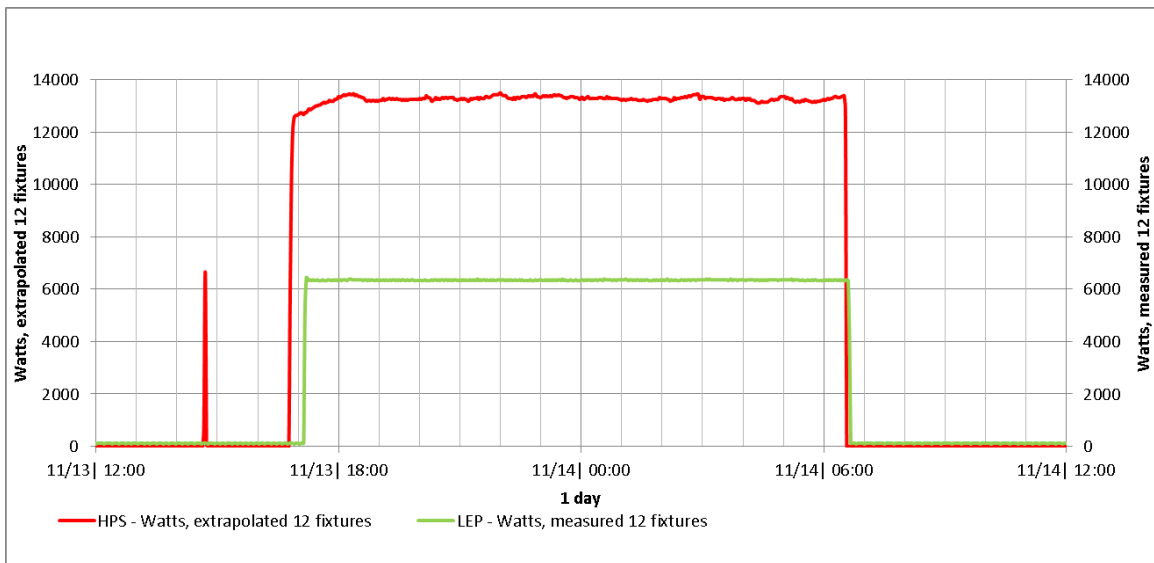


FIGURE 11. DAILY ENERGY USE, NOVEMBER 13-14, HPS POLE (RED) VS. LEP POLE (GREEN)

Although the magnitude of the energy use is similar to the examples shown above, the advantage of the control schedule is nearly eliminated.

Table 9, below, shows the operation details for the night of November 13 to 14.

TABLE 9. DAILY OPERATION DETAILS, NOVEMBER 13-14

	ON TIME	OFF TIME	AVERAGE POWER AT FULL OUTPUT (W)	AVERAGE POWER WHEN OFF (W)	TOTAL ENERGY USE, 11/13-11/14 (kWh)
HPS Pole	4:48pm	6:32am	13248	0	182

	ON TIME	OFF TIME	AVERAGE POWER AT FULL OUTPUT (W)	AVERAGE POWER WHEN OFF (W)	TOTAL ENERGY USE, 11/13-11/14 (kWh)
LEP Pole	5:10pm	6:38am	6348	114	87
Difference	-18 minutes	+6 minutes	-6900 (-52%)	+114	-95 (-52%)

Now that the schedule for the LEP and HPS are almost equal, the energy use savings is also nearly equal to the demand savings. On a similar control schedule, the LEP lighting results in a 52% energy savings, as compared to the HPS lighting. As the data shows, the relatively small load that the controls system, drivers, and power supplies draw even when the lighting is turned off, is practically negligible in the overall energy use.

DATA VALIDATION TEST RESULTS

As described above, initial energy use data results raised several questions (see Data Validation Testing). The concerns identified after an initial review of the data were as follows:

- Higher than expected wattage on the full LEP pole
- Higher than expected wattage on the LEP pole when lighting was turned off
- Very low power factor on the LEP pole when lighting was turned off (between 0.1 and 0.2, where typical lighting systems have power factors above 0.9)
- Lower than expected wattage on the two individual fixture circuits
- Lower than expected power factor on the two individual fixture circuits

The data validation testing proved crucial in clarifying the data that was shown by the Hobo logging system. The Dent meter confirmed the values shown by the Hobo logging system for the full LEP pole. The circuit testing revealed that one of the breakers was controlling three LEP fixtures, instead of one fixture as expected. The higher than expected values were the result of monitoring all 12 fixtures on the LEP pole, rather than just the expected 10 "non-emergency" fixtures. The circuit testing also revealed that the higher than expected wattage when the LEP lighting is turned off is the result of the control system, drivers, and power supplies within each fixture, which constantly draw power, even when the lights are turned off. The circuit testing showed that this wattage was evenly distributed across the 12 fixtures. Finally, the Dent meter showed low power factors when the lighting is turned off, consistent with the values that the Hobo logging system reported.

However, on the individual fixtures, the Dent meter showed values that were inconsistent with the Hobo logger data. The Dent meter values were similar to what was expected for the individual fixtures, suggesting that there was a problem with the Hobo logging system. The problem was traced to a setting on the power meters. Since each breaker has two lines that both power the individual fixtures, the power meters were originally set up to monitor the power as a two line system. However, since the two lines are powered by separate phases of the three phase power at the panel, the power meter is more appropriately set up to monitor the power as a three phase system. Once this change was made, the wattage and power factor values shown on the Hobo logging system were consistent with those shown by the Dent meter, and with the expected power use for the fixtures.

DIRECT COMPARISON OF LEP AND HPS FIXTURES

Although the actual conditions at the study site varied over the course of the study, it is possible to estimate a direct energy use comparison between the LEP lighting and the HPS lighting, if all other conditions are equal.

This direct comparison of a 12-fixture HPS pole and a 12-fixture LEP pole uses the assumptions outlined below. All power assumptions are taken from measured data during the period between September 24 and October 1 when both poles were fully functional.

- HPS pole power at full: 12944W (extrapolated)
- LEP pole power at full: 6347W
- HPS pole power with lights off: 0W
- LEP pole power with lights off: 106W
- Average daily ON time: 12 hours
- Average daily OFF time: 12 hours

Average daily energy use for each pole is calculated as follows:

EQUATION 5. ESTIMATED AVERAGE DAILY ENERGY USE

$$\text{Average Daily kWh} = ((\text{power at full} * 12 \text{ hours})/1000) + ((\text{power at OFF} * 12 \text{ hours})/1000)$$

Annual energy use is calculated as follows:

EQUATION 6. ESTIMATED ANNUAL ENERGY USE

$$\text{Annual energy use (kWh)} = \text{Average Daily kWh} * 365 \text{ days}$$

Table 10 summarizes the results of this direct comparison.

TABLE 10. DIRECT COMPARISON ESTIMATE

	POWER AT FULL OUTPUT (W)	POWER WHEN OFF (W)	AVERAGE DAILY ENERGY USE (kWh)	ANNUAL ENERGY USE (kWh/YEAR)
HPS Pole	12944	0	155	56,575
LEP Pole	6347	106	77	28,105
Difference	-6597 (-51%)	+106	-78 (-50%)	-28,470 (-50%)

Although the LEP pole uses 51% less power at full output than the HPS pole, when the energy use is estimated over a day or a year, using equal schedules on both poles, the LEP lighting is estimated to use 50% less energy than the HPS lighting due to the energy that the LEP lighting uses even when turned off.

ILLUMINANCE LEVELS

The standard method for measuring light levels uses photopic illuminance. However, as discussed above, photopic illuminance does not fully represent the response of the human eye in low light and nighttime situations. On the other hand, nighttime visual conditions in an artificially illuminated environment such as the study site are not

fully scotopic either. This presents a challenge in evaluating the illuminance performance of the LEP lighting in comparison to the HPS lighting.

Illuminance measurements taken at the site are presented in the sections below. In order to provide a more complete understanding of the visual conditions at the site, both photopic and scotopic illuminances are presented in the results below (see Photopic, Scotopic, and Mesopic vision). For the expanded study, we will also review mesopic illuminance levels but these are not available for the current report.

HORIZONTAL ILLUMINANCE MEASUREMENTS

The study site is required to meet OSHA requirements for illuminance levels. For work areas at maritime facilities OSHA requires a minimum average of five footcandles (54 lux). Figure 12, below, shows a three dimensional plot of photopic horizontal illuminance levels measured on the established measurement grid between the two study poles and the site edge. The LEP pole is at the top left corner of the graph, and the HPS pole is at the the top right corner of the graph.

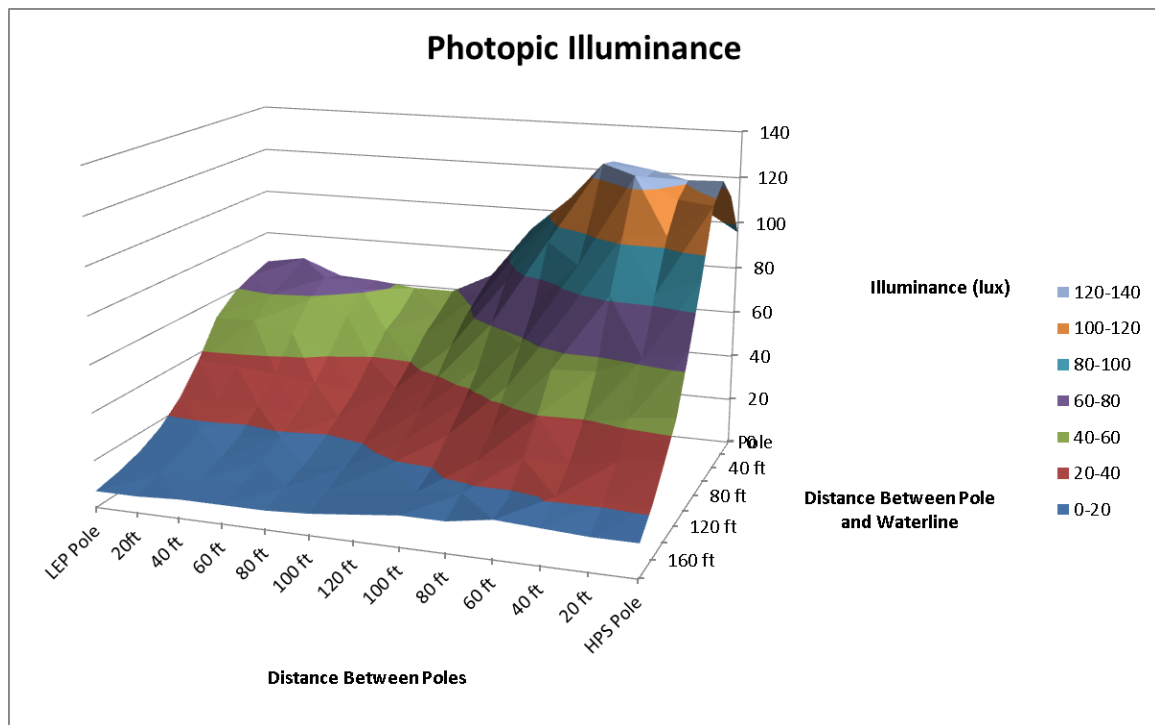


FIGURE 12. PHOTOPIC HORIZONTAL ILLUMINANCE MEASUREMENTS

Because of the yellow-orange color of the HPS lighting, it performs much better than the LEP lighting using photopic illuminance measurements. According to the graph in Figure 12, the maximum illuminance near the HPS pole is nearly twice that of the maximum illuminance near the LEP pole.

Another way to look at this data is presented below in Table 11. The table presents common metrics for evaluating lighting performance.

Using the adjusted measurement area described above (see Illuminance Measurements), Table 11 shows the average, maximum and minimum illuminance for each pole, as well as two common uniformity ratios that are used in IES

standards to evaluate outdoor lighting. The lower the uniformity ratio, the less variation in light levels within a given area. Generally, for working conditions such as the study site, low uniformity ratios are preferred, as they require less adaptation by the eye. For reference, typical IES recommendations for parking lot lighting suggest that uniformity ratios should be no more than 4:1 (average:minimum).⁶

TABLE 11. PHOTOPIC ILLUMINANCE DATA (ADJUSTED AREA)

	ADJUSTED AVERAGE (LUX)	MAXIMUM (LUX)	MINIMUM (LUX)	MAX:MIN	AVG:MIN
HPS	78	126	24	5.25:1	3.25:1
LEP	43	69	17	4.06:1	2.55:1

As the data in Table 11 shows, the HPS lighting provides higher overall photopic light levels, but the LEP lighting is more uniform. However, the lighting from both poles is well within the 4:1 uniformity recommendation (average:maximum).

The primary concern with the data shown in Table 11 is that the adjusted average does not meet the minimum average illuminance level required by OSHA for maritime work areas (54 lux).

However, these photopic illuminance measurements only tell part of the story. The study also measured scotopic illuminance levels.

Figure 13, below, shows a three dimensional plot of the scotopic horizontal illuminance levels measured on the established measurement grid. Compared to the photopic illuminance measurements shown in Figure 12, the results are almost exactly reversed. This is a result of the higher color temperature (more blue-green in color) of the LEP lighting, which appears brighter under scotopic vision conditions.

⁶ ANSI/IESNA RP-8-00, American National Standard Practice for Roadway Lighting

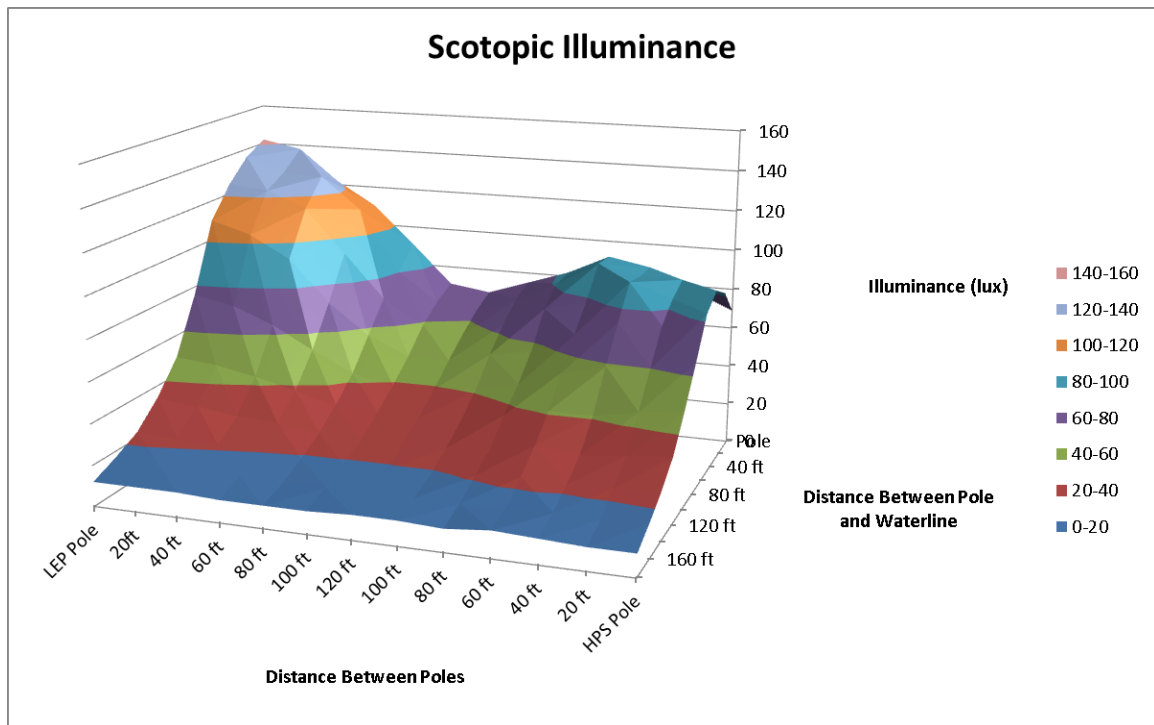


FIGURE 13. SCOTOPIC ILLUMINANCE MEASUREMENTS

The story is similar with the scotopic illuminance data, as shown in Table 12. Although the LEP lighting has higher overall illuminance values, the HPS lighting is more uniform. Again, Average:Minimum uniformity ratios for both HPS and LEP are well within recommended limits. In this case, both the HPS and the LEP lighting meet the minimum average illuminance level required by OSHA.

TABLE 12. SCOTOPIC ILLUMINANCE DATA (ADJUSTED AREA)

	ADJUSTED AVERAGE (LUX)	MAXIMUM (LUX)	MINIMUM (LUX)	MAX:MIN	AVG:MIN
HPS	60	93	24	3.88:1	2.51:1
LEP	71	142	24	5.92:1	2.96:1

Further analysis will be required to better understand the light level conditions at the site, as they are perceived by the human eye. The photopic and scotopic measurements do not sufficiently describe the visual quality of the light under nighttime conditions. The final report on the expanded study will include a mesopic analysis in order to better understand the light levels at the site as they are perceived by the human eye. The expanded study will also examine how the perceived light levels relate to the OSHA illuminance requirements.

VERTICAL ILLUMINANCE MEASUREMENTS

In addition to horizontal illuminance levels at the ground, the study also measured vertical illuminance levels at 20' and 40' above the ground. These measurements were intended to represent the light levels on the sides of shipping containers stacked at the study site.

Photopic vertical illuminance measurements are shown below in Figure 14, and scotopic vertical illuminance measurements are shown in Figure 15. Both figures show LEP and HPS illuminance values at 20' above the ground, and 40' above the ground, as well as the difference between the LEP and HPS values for each height.

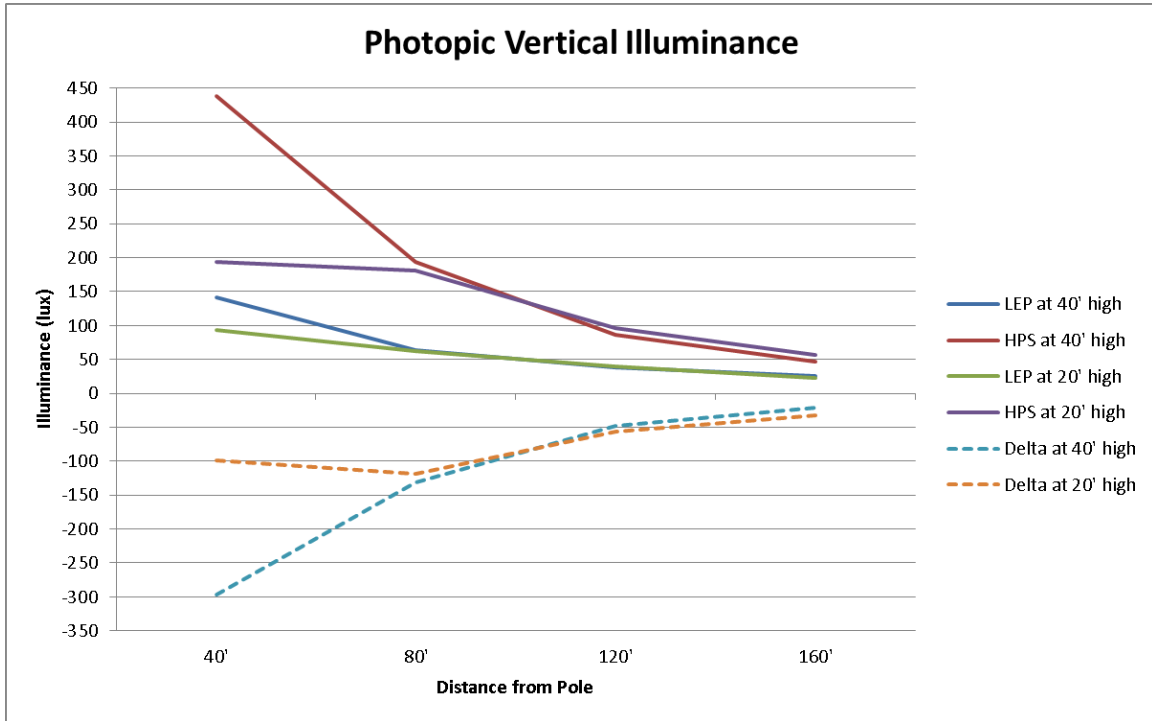


FIGURE 14. PHOTOPIC VERTICAL ILLUMINANCE

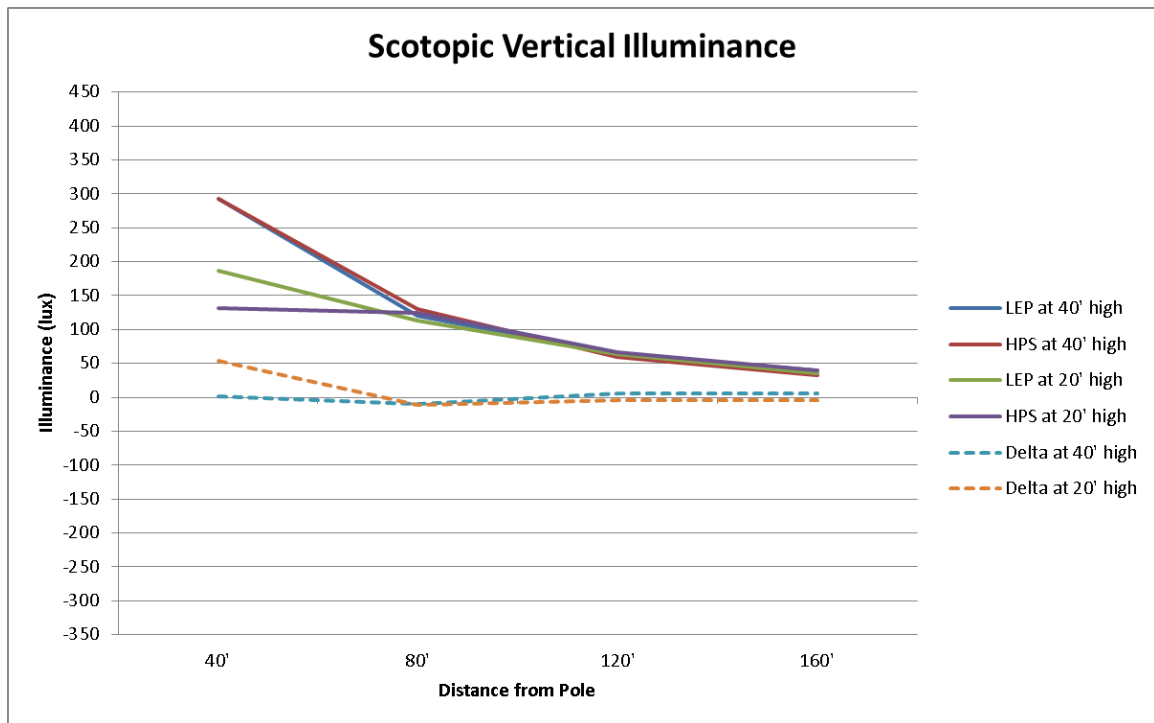


FIGURE 15. SCOTOPIC VERTICAL ILLUMINANCE

While the photopic values shown in Figure 14 show distinct differences between the HPS and LEP lighting, with the HPS lighting providing significantly higher illuminance, the scotopic values in Figure 15 are almost indistinguishable.

Generally, the vertical illuminance measurements are slightly higher than corresponding horizontal measurements, but not so disparate as to cause glare or visual discomfort. The illuminance values suggest that the LEP lighting will provide sufficient illumination to maintain legibility of shipping container markings.

VISUAL QUALITY

Despite the difference in photopic illuminance levels, user response to the test LEP lighting has been uniformly positive.

Employees at the study site report that the LEP lighting appears brighter than the HPS lighting, and that it renders colors more clearly. In a setting such as the study site, improved visual quality can help improve efficiency and productivity, as well as maintain safe operations.

In addition, the study site has decided to expand the installation of the LEP lighting to additional poles in the area, suggesting that the customer is satisfied with the visual quality and performance of the light.

EVALUATIONS

Overall, all factors being equal (schedule, number of fixtures, etc.), the LEP lighting is estimated to provide a 50% energy savings over the existing HPS lighting. However, the light level measurements present a concern for the test LEP lighting. The average photopic illuminance level in the area immediately surrounding the LEP pole was well below the minimum level required by OSHA. While the scotopic illuminance levels for the LEP pole were higher, it is not clear that these measurements would be acceptable to meet OSHA requirements. A mesopic illuminance analysis in the final report on the expanded study will explore this issue further, but it is unclear whether mesopic illuminance would be an accepted metric for meeting the OSHA standards.

In addition, both the LEP lighting and the wireless control system experienced problems over the course of the study. Two of the twelve LEP fixtures experienced failures immediately following installation, and had to be replaced. Another fixture experienced a failure several weeks after installation, and also had to be replaced. In addition, the wireless control system has experienced several challenges where the control system has been unable to communicate with one or all of the fixtures, resulting in an inability to adjust the LEP lighting as needed.

These issues will be further explored as the study continues. In addition to the performance aspects discussed in this interim report, the expanded study will also address the following issues:

- Long term LEP lighting performance, such as lumen depreciation, over the course of ten months
- Illuminance and visual quality performance of an expanded installation of LEP lighting at the study site
- Additional energy savings opportunities provided by the wireless control system
- Energy savings and lighting performance impacts of using eight fixtures per pole instead of twelve

Findings from the expanded study will be presented in a Final Emerging Technology Study Report, to be published in August 2013.

RECOMMENDATIONS

Initial results from the LEP fixture energy monitoring are encouraging in terms of energy savings. Further investigation is needed regarding power consumption of the control system, drivers, and power supplies in each fixture that constantly draw power even when the lighting is turned off. This investigation will be conducted as part of continuing project tasks.

Initial results from illuminance measurements provide a mixed picture with the LEP lighting providing lower photopic illuminance than the HPS lighting, but higher scotopic illuminance. This issue needs further investigation and will be conducted as part of continuing project tasks.

This interim report provides early findings which need further vetting through the longer term monitoring currently being conducted. Full findings and recommendations will be

presented in a Final Emerging Technology Study Report, following the completion of the continuing study, to be published in August 2013.

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