LED Streetlight Application Assessment Project Pilot Study in Seattle, WA

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[Abstract] Recent studies have found that light emitting diode (LED) technology is becoming competitive for streetlight applications with the commonly employed high intensity discharge (HID) light sources such as high pressure sodium (HPS) and metal halide (MH). The expectation is that LED street lighting technology will not only provide more efficient light distribution and increased uniformity, but will also save energy and reduce maintenance costs.

Seattle City Light (SCL) has a street lighting system of nearly 84,000 street and area lights that use predominantly HPS light sources. Because of the potential benefits of installing LED luminaires as a replacement for these lights, SCL launched the *LED Streetlight Application Assessment Project Pilot Study* to evaluate LED luminaires for photometric performance, energy efficiency, economic performance, and the impact of the new lights on SCL streetlight system. Project findings will be used by SCL to develop a strategy for the installation of LED streetlights in developing an energy efficient lighting system.

The major elements of this project included LED luminaire selection, simulated photometric performance of selected LED products using AGI32, field photometric performance evaluation at selected test sites, and economic performance evaluation in comparison to HPS luminaires. In addition, since combining LED roadway luminaires with new light control systems provides many new options for overall light control, facilitating maintenance, increasing luminaire life, and further reducing operating costs, a preliminary review of current cutting-edge lighting control systems were explored.

Introduction

Recent studies have found that light emitting diode (LED) technology is becoming competitive for outdoor applications with the commonly employed high intensity discharge (HID) light sources such as high pressure sodium (HPS) and metal halide (MH). The expectation is that LED street lighting technology will not only provide more efficient light distribution and increased uniformity, but will also save energy and reduce maintenance cost.

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This study was conducted in collaboration with Pacific Northwest National Laboratory (PNNL), representing the DOE, and is part of the DOE Solid-State Lighting GATEWAY Demonstration program, which is designed to showcase emerging LED lighting products.

Objectives

SCL conducted this study to evaluate LED streetlights and their ability to bring energy-saving lighting to Seattle neighborhoods and streets. To assess benefits of LED streetlights, this project focused on the following key objectives:

- Select a suitable LED product(s) for use by SCL on residential roadways.
- Evaluate the lighting, economic, and energy consumption performance.
- Evaluate the ability for LED products to produce a 40 percent energy savings compared to existing HPS cobra head style luminaires.
- Develop a functional specification and recommendations for the installation and maintenance of these products.
- Identify next steps to increasing energy efficiency of LED lighting.

Study Area and Test Sites

Capitol Hill and South Park areas (Figure 1) were selected by SCL for this project. Factors considered during the study area selection included roadway type, community socioeconomic makeup, size of street level retail, mix of single family and multi-family housing, and other factors such as park fronts. Test Sites 2 and 10 in Capitol Hill Area and Test Sites 11 and 12 in South Park were included in the study.

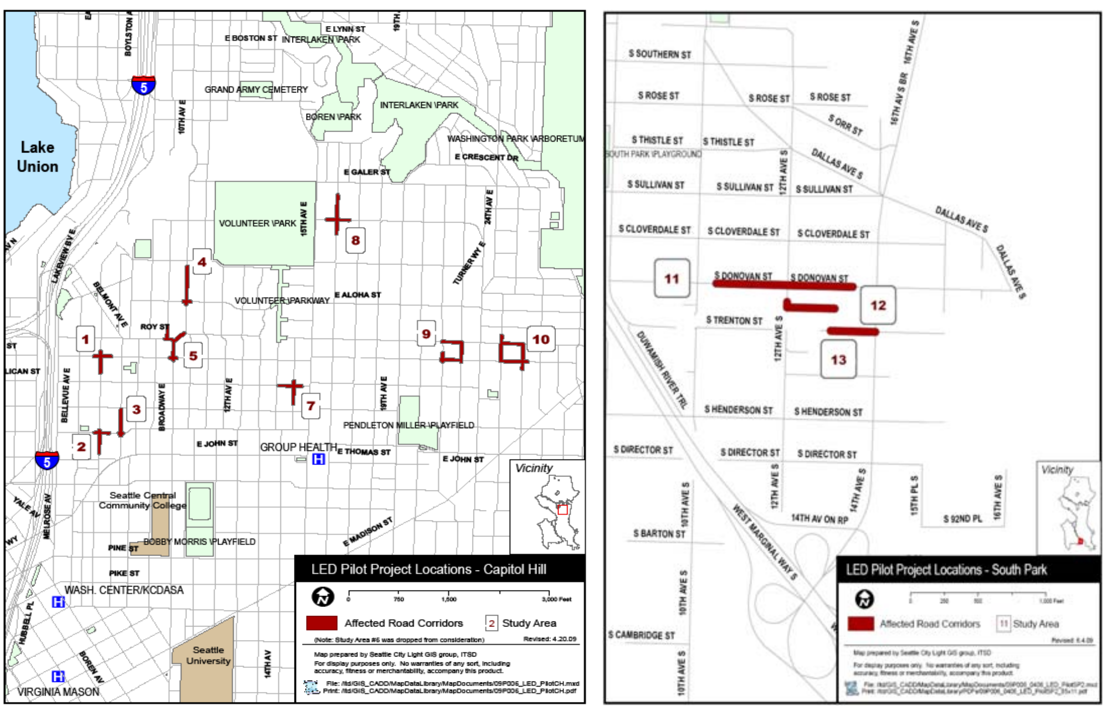

Figure 1 – Test Sites (Capitol Hill and South Park)

Luminaire Testing and Results

The SCL LED Application Assessment project pilot study was conducted in two stages. In the Stage I Capitol Hill test sites, SCL selected LED luminaires from two vendors, conducted computer simulation, and field testing. Before and after field comparisons for the replacement of HPS cobra head style luminaires with LED luminaires were conducted. The Stage II South Park test sites included selecting and testing up to three additional LED streetlight luminaires with an emphasis on luminaires that are considered “Made in America” as well as further testing select luminaires from Stage I. A field testing methodology was also developed for the Stage II test sites.

Aside from test site selection (previously discussed), the major elements of this pilot project included:

- LED luminaire selection.
- Simulated photometric performance evaluation of selected LED products.
- Field photometric performance evaluation.
- Economic performance evaluation in comparison to HPS luminaires.

Candidate LED luminaires were selected from criteria developed specifically for this study which included:

- Photometric performance (Stage I and II).
- Pricing (Stage I and II).
- “Made in America” status (Stage II only).
- Manufacturers’ production capabilities (Stage I and II).

In this document, rather than identifying vendors and luminaires by name, a coding system was developed in this project to identify the vendors and luminaires under test. The vendors are coded as “A”, “B”, “C”, “D”, “E”, and “F”, and their different types of luminaires are distinguished by numeric numbers. For example: a luminaire code A1 means Vendor A, Luminaire 1. The luminaires tested under Stage I included A1, B1, C1, D1, E1, and F1.

Under Stage I testing, it was found that the field tested Vendor A luminaires performed favorably. However, information gained from public feedback, indicated the color temperature was too cool (too blue) and created a somewhat dismal and unwelcoming environment. Since the Vendor A luminaire performed well in Stage I testing and was a “Made in America” product, it was added to the list of manufacturers to be tested under Stage II with the plan to test a warmer color temperature in the range of 4000°K to 4300°K (less blue with more red and yellow light) and change the light distribution from Type III to Type II. As with the Vendor A luminaire, the Vendor C luminaire would be tested at the warmer color temperature with a Type II distribution. Therefore luminaires A2, A3, C2, and C3 were added to the Stage II testing.

The performance of luminaires selected for testing was simulated using the lighting analysis software AGI32. Tests were conducted for a typical residential roadway section and for field conditions at each test site. Major factors considered when ranking the candidate luminaires included:

- Luminaire mounting height.
- Average maintained illuminance values.
- Uniformity ratios (average/minimum).
- Light pole spacing[1].

The light loss factor (LLF) used for the analysis assumed the following:

- Luminaire Dirt Depreciation factor (LDD): based on a clean to very clean environment and a seven-year maintenance cycle. A clean environment with an LDD of 0.85 was assumed for the initial luminaire selection. Additional simulation analysis under the Stage II test sites assumed a very clean environment with an LDD of 0.92.
- Lamp Lumen Depreciation factor (LLD): obtained from each of the luminaire manufacturers and based on the manufacturers LM-80 test data.

Selected LED luminaires were field tested for photometric performance at the Stage I and II sites. The LED photometric measurements were compared to measurements from existing HPS luminaires, City of Seattle Standards, and the Illuminance values recommended for local roadway facilities in the Illuminating Engineering Society of North America's, *RP-8-00 Reaffirmed 2005, American National Standard Practice for Roadway Lighting* (RP-8-00). The Stage I testing was conducted by PNNL and Stage II testing was conducted by the Lighting Design Lab (LDL).

Results Summary and Findings

The simulation and field test results from the Stage I and Stage II Study Areas show from an illuminance level perspective, LED luminaires are a viable option to replace existing HPS luminaires. Minimum illuminance levels, as published through the RP-8-00 can be met[2]. Seattle's average illuminance requirement is only met by some of the larger LED luminaires being tested under the study. These larger luminaires mean lower cost savings due to the larger LED arrays in use. Important findings from the computer simulation and field tests included:

1. Not all luminaires met the average maintained illuminance and uniformity values required by National or Local Standards. It is important to conduct simulation and field testing of each type of LED luminaires to understand their photometric performance.

2. Type II light distribution minimized back lighting onto private property more than the Type III distribution pattern. This was apparent in both the simulation and field tests.

3. In the Stage II South Park area field tests, the initial lumen output of the LED luminaires is approximately two times greater than the design year of the lighting system (in this case the design year of the system is seven years into the future). This additional lumen output is wasted energy. New control systems and dimmable drivers can be used to reduce initial lumen output and then increase it as the lamp

lumen depreciation increases. In theory, this means a longer life for the luminaire since it is being driven at a lower amperage during the first few years of its life. Based on the higher initial illuminance level value and not a depreciated future value if the extended life is beyond the desired period for luminaire replacement, this would make the lower wattage luminaries like A4 a viable and economic option.

4. Public feedback on the field installations at the Stage I test sites identified the "cooler" color temperatures from 5500°K to 6000°K created a dismal and unwelcoming environment. Subsequent installations of luminaires at the Stage II sites with a warmer color temperature from 4100°K to 4300°K created a more welcoming and comfortable environment.

5. General Stage I public feedback supported the pursuit of additional installations of LED luminaires.

6. Approximately 25 percent of Vendor C's luminaires installed in the test sites have failed (two out of eight) under Stage II. There have been no failures of the field installed luminaires from Vendor A.

7. A lamp dirt depreciation factor (LDD) of 0.92 was determined to be appropriate for residential streets.

Conservation Incentives

The following energy conservation incentive programs have been identified:

- **SCL Conservation Division**: With the installation of energy efficient streetlights, the SCL Conservation Division will pay back $0.22 per kilowatt-hour saved. The incentive amount is returned to SCL as a one-time rebate.
- **Washington State Transportation Improvement Board (TIB):** TIB has a selection process for agencies to apply for grants. TIB funding programs are available if the project falls under three categories: Urban Arterial Program, Urban Corridor Program, or Urban Sidewalk Program.
- **Department of Energy:** Provides funding and grants through various conservation energy programs. Local governments can apply for block grants to improve energy efficiency and renewable energy systems.
- **Qualified Energy Conservation Bonds**: These bonds are issued through state or local governments for financing governmental programs to reduce greenhouse gas emissions and other conservation purposes.
- **The Clinton Climate Initiative (CCI)**: CCI can help by advising on project management, purchasing, financing, and technology.

Economic Analysis -Simple Payback

The economic analysis focused on simple payback calculations methods and included SCL incentive rebates. The analysis was based on the replacement of 100-watt HPS luminaires (consuming 142 Watts) on residential roadways. Maintenance costs, energy rates and power consumption of existing luminaires were obtained from SCL. The following assumptions were included in the calculations:

- 15-year luminaire life cycle.
- Maintenance cycle of seven years.
- LED luminaire failure rates of 10 percent.
- $0.22 incentive rebate per kilowatt-hour saved.

Using simple economic payback calculations and setting aside energy conservation goals of 40 percent savings over currently used HPS luminaires, LED luminaires can be an economical alternative. With SCL conservation rebates of $0.22 included in the overall calculation for each kilowatt-hour saved, the following payback periods were realized for the Stage I and Stage II luminaires under study:

- Small LED array luminaires
    - Luminaire A1 (39 watts) – 1.9 years
    - Luminaire B1 (58 watts) – 3.3 years
- Medium LED array luminaires
    - Luminaire C2 (75 watts) – 4.7 years
    - Luminaire A2 (109 watts) – 6.1 years
- Large LED array luminaires
    - Luminaire C3 (137 Watts) – 13.8 years
    - Luminaire A3 (142 Watts) – 14.6 years

When the SCL energy conservation goal of 40 percent energy savings is taken into account, a luminaire must consume 85 watts of energy or less. Only luminaires A1, B1 and C2 fell into that category. However, A1 and B1 are not an option due to their photometric performance.

A continued improvement in LED luminaire efficacy is expected over the short term. This will continue to reduce costs and increase savings in operations costs. Taking advantage of new control systems with dimmable drivers is an option that can provide additional energy savings.

Recommendations

Luminaire

Based on the analysis conducted in this study, the following luminaire has been identified as a viable option for replacement of 100-watt HPS cobra head style luminaires in residential areas. These recommendations are being made not because the luminaire meets the 40 percent energy reduction goal, but because of their economic, photometric, and maintenance performance. The following recommendation is subject to change as LED products with better photometric and economic performance are available.

Recommendations (Luminaire):

1. **Luminaire A2: 60LED-Type II Distribution-4300K-525mA**
2. **General Recommendations: Type II Light Distribution, Correlated Color Temperature of 4000°K to 4300°K**

Luminaire A2 performed favorably with the following characteristics:

- Power consumption: 109 Watts
- Distribution: Type II
- Initial Lumens: 4,968 (60 LED Array)
- Correlated Color Temperature: 4300°K
- Color Rendering Index: 75 minimum
- Driver Current: 525mA
- Efficacy: 46 lumens/Watt
- IP Rating: IP66
- Weight: 16 lbs

The computer simulation test of the luminaire generates an illuminance level of 0.65fc, which falls between the RP-8-00 requirements. The field test revealed that the LED luminaires generally produced higher illuminance levels than the existing HPS luminaires.

As a late development in the study, Vendor A has released their new generation luminaires. The new generation luminaires are designed to provide better uniformity than the previous products. In an effort to provide up to date information, a review of the new generation luminaires showed better photometric performance with greater spacing and comparable uniformity than the previous products. It is anticipated that an economic evaluation of the new generation luminaire will yield similar results to the previous generation. The new generation luminaire should be considered as a replacement for the previous luminaire product. The new generation luminaire is as follows:

Luminaire A2 Rev. 11/02/09: 60LED-Type II Distribution-4300K-525m

Specification

A functional specification has been developed for SCL to use in purchasing LED luminaires and the evaluation of future luminaires for residential roadways. The specification is based on the research conducted on LED luminaires available on the market today, computer simulations, and field testing.

Recommendation (Specification):
Review specification every six months to take into account rapid advances in the LED lighting technology.

Luminaire Selection

LEDs are a new and rapidly developing technology in the roadway lighting arena. An understanding of industry lighting standards, manufacturing (including an in-depth understanding of heat dissipation), and testing of LED products is essential to making good decisions on luminaire selection.

Recommendation (Luminaire Selection):

1. **Utilize an LLD factor based on LM-80 tests.**
2. **Utilize an LDD factor of 0.92 for residential roadways.**
3. **Require independent LM-79 and LM-80 test results for all luminaire submittals.**

Recommended Next Steps

LEDs are an instant on/instant off technology with no start-up or re-strike time. Combining LED roadway luminaires with new light control systems provides many new options for overall light control, facilitating maintenance, increasing luminaire life, and further reducing operating costs. The following are benefits of incorporating lighting control systems with LED lighting technology include:

- **Dimming of Lighting Circuits after Hours:** This can be based on time of day or traffic volumes. Dimming of luminaires can provide reduced energy costs and prolong the life of the luminaire.

- **Step Dimming or Continuous Dimming:** Lighting systems are designed to meet standard illuminance levels at a future year with a given amount of lumen and dirt depreciation incorporated into the design. This means at initial installation, more lumens are being produced than required. Step or continuous dimming of a lighting system would reduce the initial lumen output to its design standard by reducing the drive current and then gradually increase that drive current at predefined time intervals to maintain the same lumen output over the life of the system (Figure 2). Based on the higher initial illuminance level value and not a depreciated future value if the extended life is beyond the desired period for luminaire replacement, this would make the lower wattage luminaries likeA4 a viable and economic option.

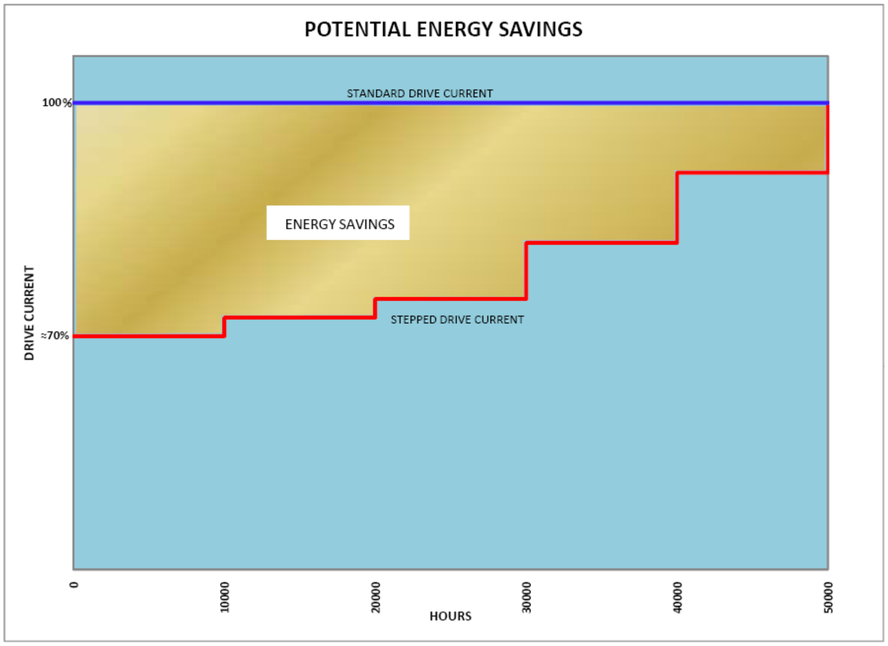

Figure 2 – Diming energy savings

- **Emergency Services Support:** If tied into traffic operations centers, emergency management centers, or electric utility operations centers lighting control systems can increase illuminance levels at select locations to facilitate emergency services and then be reduced back to normal levels when the emergency is over.

- **Pedestrian or Vehicle Activated Lighting Circuits:** Lit corridors with motion sensors incorporated into the luminaire, can be turned off or dimmed until a person or vehicle is in the vicinity. Dimming of luminaires can provide reduced energy costs and prolonged life.

- **Luminaire Health Monitoring:** Control systems can monitor the health of luminaire components such as LED drivers. Many benefits are available through luminaire monitoring:
    - Luminaires can be GPS located to provide maintenance with exact geographical locations reducing time in locating outages,
    - Maintenance can respond in a more efficient manner reducing the number of system wide outages and down times, improving customer service,
    - Outage patrols can be reduced, and
    - Trend analysis can be conducted from information received from the field.

There are many new light control systems on the market today. Just as with LED luminaires, care needs to be taken to select the correct system to meet agency needs. There are many different items that need to be considered both for the control system itself and the infrastructure needs to support that system. Further evaluation of lighting control systems and their potential benefits for Seattle City Light is recommended.

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End Notes

[1] Light pole spacing is an important factor since the general practice on residential streets is to place light poles on every third property line giving typically 150 foot spacing between light poles. Mounting heights of luminaires were simulated at 30 feet. It was assumed this would provide the worst case illuminance values.

[2] The RP-8-00 standards for a residential street with low pedestrian volumes are an average maintained illuminance level of 0.4fc and uniformity ratio of 6:1. Seattle's average illuminance requirement is 0.7fc.