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Demonstration Assessment of LED Post-Top Lighting

Host Site: Central Park, New York City

September 2012

Prepared for:

Solid-State Lighting Program
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Prepared by:

Pacific Northwest National Laboratory

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Demonstration Assessment of Light-Emitting Diode Post-Top Lighting at Central Park in New York City

Final Report prepared in support of the
U.S. Department of Energy GATEWAY Solid-State Lighting Technology Demonstration Program

Study Participants:
U.S. Department of Energy
Pacific Northwest National Laboratory
The Climate Group
New York City Department of Transportation

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September 2012

Prepared for
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under Contract DE-AC05-76RL01830

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Preface

This document reports observations and results obtained from a lighting demonstration project conducted under the U.S. Department of Energy (DOE) GATEWAY Solid-State Lighting (SSL) Technology Demonstration Program (GATEWAY). The program supports demonstrations of high-performance SSL products in order to develop empirical data and gain experience with in-the-field applications of this advanced lighting technology. The GATEWAY Program focuses on providing a source of independent, third-party data for use in decision making by lighting users and professionals; the data contained herein should be considered in combination with other information relevant to the walkway and post-top luminaires and application under examination. Some GATEWAY demonstrations compare one SSL product against the incumbent technology used in that location; however, in this demonstration five SSL products were installed and subsequently compared with the incumbent technology. Depending on available information and circumstances, each SSL product may also be compared to alternative lighting technologies.

Products demonstrated in the GATEWAY Program may or may not have been prescreened and/or tested to verify their actual performance. DOE does not endorse any commercial product or in any way guarantee that users will achieve the same results through use of these products.

Electronic copies of this report are available from DOE's SSL website at http://www1.eere.energy.gov/buildings/ssl/gatewaydemos.html.

Executive Summary

This report describes the process and results of a demonstration of solid-state lighting (SSL) technology in a pedestrian walkway lighting application, conducted under the U.S. Department of Energy (DOE) GATEWAY Solid-State Lighting Technology Demonstration Program in collaboration with The Climate Group and the New York City Department of Transportation (NYCDOT). The goals of the GATEWAY Program are to develop real-world experience with SSL products, reduce energy use, match or improve lighting quality, and meet the cost-effectiveness criteria defined by the user. Pacific Northwest National Laboratory (PNNL), which manages the GATEWAY Program for DOE and conducts evaluations on DOE's behalf, provided lighting measurement and documentation in this report.

Pathway lighting along paved walking trails in New York City's Central Park is evaluated in this report. Post-top-mounted luminaires (post tops) light the walkway and adjacent grass areas. Fixtures are mounted on post tops 9 feet above finished grade and are spaced roughly 80 feet on center along the walkway.

Quantifying the lighting performance for this application is complicated. Unlike parking lot lighting where luminaires tend to be evenly spaced across a large, typically flat area, the walkway lighting here is located along one side of the path with spacing that varies depending on vegetation and surroundings. Furthermore, the path itself meanders around the various landscaping features and does not present a uniform standard for measurement; values measured along a curving path vary greatly as a function of their position relative to the light source, which makes accurate comparisons among light sources located at different points on the path difficult.

For walkways in general, both horizontal and vertical illuminance values are important. Horizontal measurements confirm the amount of light available for navigating the path and establish roughly how much light is distributed into the adjacent grass. Vertical measurements are necessary for safety purposes, revealing whether there is adequate illumination to identify the face of an approaching person. Current Illuminating Engineering Society (IES) guidance on appropriate measurement procedures is limited for this application; thus, a polar measurement system employing both horizontal and vertical measurements was devised to enable consistent comparison of luminaire performance regardless of location.

NYCDOT selected a total of five different light-emitting diode (LED) products representing a variety of energy use and lumen packages for evaluation against the metal halide baseline luminaire. Four of the LED products were complete new luminaires installed on top of the poles and the other LED product was a retrofit insert kit installed in an existing housing unit (the Sentry Electric Central Park globe).

A summary of the comparative energy performance and costs for the products evaluated in this study are provided in Table ES-1. Energy savings of the different LED systems evaluated ranged from 50% to 83% relative to the incumbent metal halide luminaire.

The life-cycle costs included in Table ES-1 are based on an 18.3-year analysis period, or 75,000 operating hours, which corresponds to the longest claimed lifetime among the products evaluated. Four of the LED products offer lower life-cycle costs than the incumbent metal halide luminaire–ranging from about $2,258 for the OSRAM SYLVANIA to $4,688 for the Sentry Electric replacement product.

Table ES-1. Annual Energy Use, Percent Savings, and Life-Cycle Cost

Luminaire	Luminaire Power (W)	Annual Energy Use (kWh)	Energy Savings (%)	Life-Cycle Costs ($)
Metal Halide Baseline	200.3	820	–	4,606
Spring City	66.4	271	66.9	4,193
King Luminaire	98.5	406	50.9	3,814
Philips Lumec	84.5	349	57.8	3,656
Sentry Electric	89.8	369	55.2	4,688
OSRAM SYLVANIA	33.5	139	83.3	2,258

Qualitative lighting results were mixed, however, so that not all energy and cost savings reported in the table represent necessarily comparable or "suitable" replacement conditions. Table ES-2 provides illuminance performance relative to the baseline, along with some limited color quality data (correlated color temperature and color rendering index). A positive value of compared illuminance indicates that the LED luminaires delivered greater values on average than the metal halide baseline, whereas negative values indicate lower average values. Illuminance measurement variations within ±10% of the baseline are considered negligible.[ES-1]

All of the LED products provide a larger percentage of their output as downlight, due to the directional nature of LEDs and the better optical control offered by the smaller emitters, with the result that their corresponding backlight, uplight, and glare (BUG) ratings (for products that provided photometry) show a reduced uplight rating. All LED products similarly had lower ratings for glare. Glare varies with distance and height of the observer relative to the source; lower "G" values in the BUG ratings will generally translate into lower perceived glare from a given luminaire when viewed from a distance.

Table ES-2. Comparison of Color Quality and Illuminance

Luminaire	Distribution	CCT (kelvin)	CRI	Average Horizontal Illuminance Compared to Baseline (%)	Average Vertical Illuminance Compared to Baseline (%)	BUG Rating
Metal Halide Baseline	Type V	3700	70	–	–	B3-U5-G4
Spring City	Type II	3000	85	25	11	B1-U2-G1
King Luminaire	Type V	5000	72	-4	26	B2-U3-G1
Philips Lumec	Type III	6000	70	62	59	B3-U2-G1
Sentry Electric	Type V	4700	N/A[(a)]	-36	-47	N/A[(a)]
OSRAM SYLVANIA	Type V	4900	80	-50	-58	B2-U2-G2[(b)]

CCT = correlated color temperature; CRI = color rendering index.
(a) A photometric report for this product was not available.
(b) Value is for retrofit kit **NOT** installed in existing luminaire. Manufacturer claims the actual light output value is much lower than its photometric report would suggest when it is installed base up, as it is here.

[ES-1] Levin, R. 1982. "The Photometric Connection – Part 3." Lighting Design & Application. New York, New York. Illuminating Engineering Society of North America, New York, NY

Because NYCDOT desired to focus illuminance on the pathway versus the surrounding grassy areas, it opted to evaluate both symmetric and asymmetric distributions. A strictly asymmetric approach would not necessarily work in all sites; in fact, a symmetrical distribution might prove the most appropriate in locations in Central Park where pathways intersect. Ultimately, the Spring City and Philips Lumec luminaires, both asymmetric, and the symmetric King Luminaire all cost effectively reduced energy use and met or exceeded measured illuminance values relative to the metal halide baseline.

Note, however, that no subjective survey of park users was undertaken regarding the acceptability of the fixtures. Of the three LED fixtures that were cost effective and saved energy, only Spring City had a correlated color temperature (CCT) roughly comparable to the traditional metal halide luminaire, whereas the other two had notably higher CCT, which could prove objectionable to some users. Note also that newer products and distributions could alter these results significantly.

Since the original evaluation was conducted, NYCDOT has proceeded (Summer 2012) with replacing Central Park Lighting with an updated Spring City LED product, that is approximately 15% more efficacious (new installed fixture draws same amount of power, but produces more lumens) than the one used in the field study and offers other generational improvements over the incumbent luminaire. The new product has an asymmetrical distribution similar to the one evaluated in this study.

Acknowledgments

Pacific Northwest National Laboratory (PNNL) would like to thank Dasha Rettew at The Climate Group, Ghanshyam Patel and Alex Volfson at the New York City Department of Transportation, and The Central Park Conservancy.

In addition, PNNL would like to thank Chris Rosfelder at Spring City, Sean Yacoub at Stresscrete/King Luminaire, Joe Hayden at Continental Lighting, Robert Murphy at Philips Lumec, Shepard Kay at Sentry Electric, and Jeff TeRoller at OSRAM SYLVANIA for providing additional information on the luminaires installed and evaluated in this study.

Acronyms and Abbreviations

BUG	backlight, uplight, and glare
CCT	correlated color temperature
CRI	color rendering index
DOE	U.S. Department of Energy
IES	Illuminating Engineering Society (of North America)
IP	Ingress Protection
LCC	life-cycle cost
LED	light-emitting diode
lm/W	lumen(s) per watt
NYCDOT	New York City Department of Transportation
PF	power factor
PNNL	Pacific Northwest National Laboratory
SSL	solid-state lighting

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1.0 Introduction

This report describes the process and results of a demonstration of solid-state lighting (SSL) technology along pedestrian walkways conducted by Pacific Northwest National Laboratory (PNNL) in New York City's Central Park during April 2010. The project was supported under the U.S. Department of Energy (DOE) GATEWAY Solid-State Lighting Technology Demonstration Program. Other participants in the demonstration project included The Climate Group[1] and the New York City Department of Transportation (NYCDOT).[2] NYCDOT selected the equipment to be evaluated while PNNL conducted the measurements and analysis of the results for this report. The Climate Group collected monthly data for a report of its own. PNNL manages several related demonstrations for DOE and represents DOE's perspective in the conduct of the work.

DOE supports such demonstration projects to develop real-world experience and data with SSL products in general illumination applications. DOE's approach is to carefully match applications with suitable products and form teams to carry out the needed project work. Other project reports and related information are available on DOE's SSL website.[3]

This demonstration was planned as part of the LightSavers Pilot project by The Climate Group, to investigate the feasibility of replacing the luminaires throughout Central Park in New York City. Central Park contains an estimated 1,600 luminaires, so total energy savings for a park-wide retrofit could be substantial if cost effective for NYCDOT. This project offered an opportunity to evaluate several competing luminaires side by side and compare their performance as suitable replacements for the existing metal halide luminaires.

[1] http://www.theclimategroup.org/
[2] http://www.nyc.gov/html/dot/html/home/home.shtml
[3] http://www1.eere.energy.gov/buildings/ssl/gatewaydemos.html

2.0 Methodology

2.1 Site Description

The site for the demonstration was on the east side of Central Park near 5th Avenue between 67th and 72nd Streets. Despite its urban location, the site has many large trees that block light from surrounding streets and buildings, as shown in Figure 2.1. The contrast is especially stark with the high ambient light levels on city streets. The northern end (near 72nd Street) of the site is generally flat but the site slopes down significantly in the southern end (approaching 67th Street) of the installation, between 10 feet and 15 feet lower than the northern end.

Figure 2.1. Central Park aerial view (Source: Google Earth)

Five products were selected for testing by NYCDOT. They include products from Spring City Electrical (Spring City),[1] Philips Lumec,[2] Stresscrete/King Luminaire,[3] Sentry Electric[4], OSRAM SYLVANIA,[5] and the existing Sentry Electric luminaire. The luminaires were grouped by manufacturer in clusters of two or three along pedestrian paths in the park as shown in Figure 2.2.

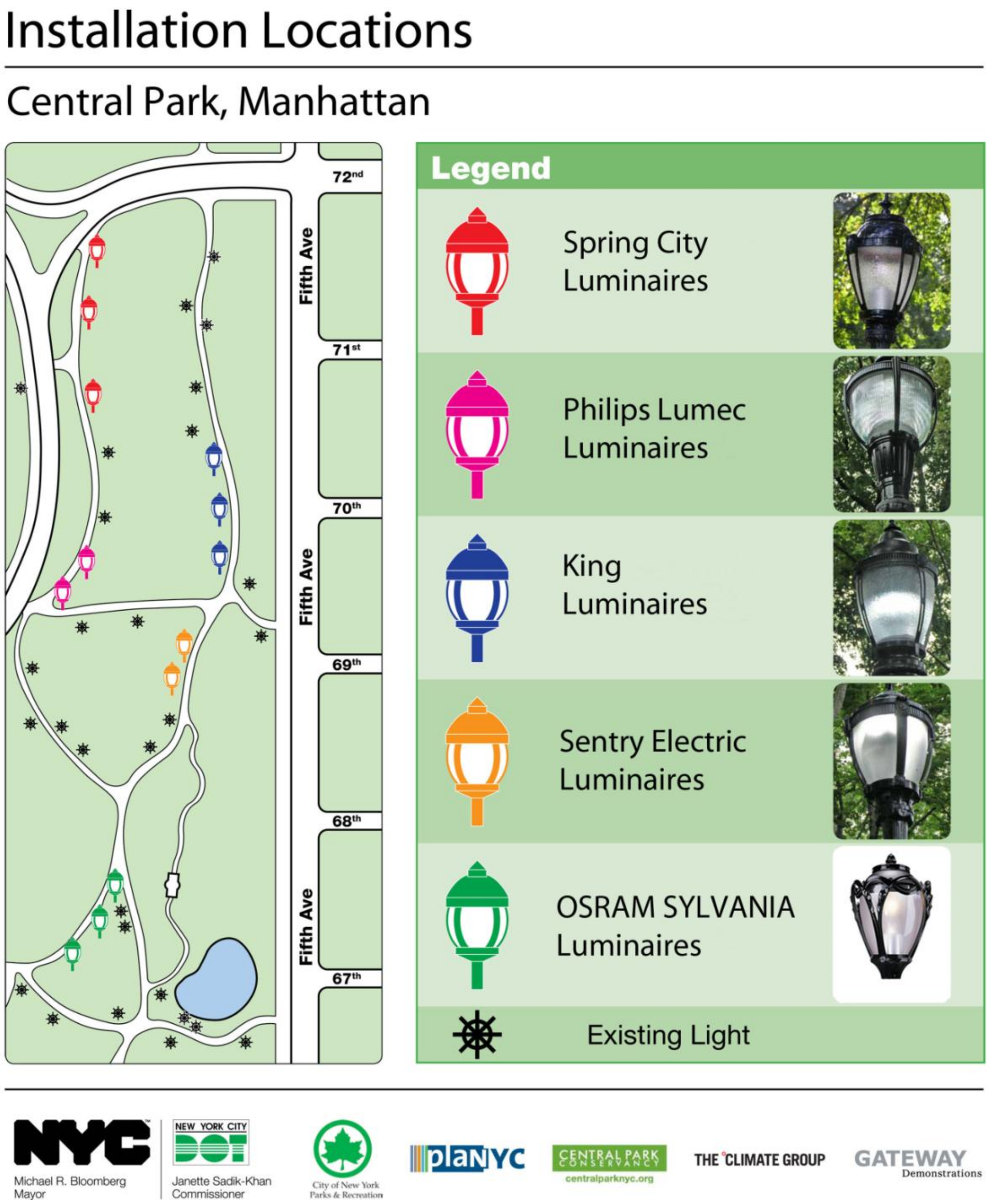


Figure 2.2. Site map (courtesy of The Climate Group)

[1] http://www.springcity.com/
[2] http://www.lumec.com/index.html
[3] http://kingluminaire.com/
[4] http://www.sentrylighting.com/
[5] http://www.sylvania.com/

2.2 Luminaires in the Demonstration

The existing luminaires are of the Sentry Electric "Central Park" style, which was designed to complement the original poles while modernizing the luminaires. The approximately 1,600 existing luminaires all use a polycarbonate prismatic globe to direct light and control direct glare. The luminaires are mounted atop 9-foot poles spaced approximately 80 feet apart, with significant variation due to site geometry. Two existing luminaires were cleaned and relamped for measurements and benchmarking purposes. It should be noted that polycarbonate yellows and becomes diffuse over time. It appears that one of the baseline luminaires might have had an "aged/yellowed" lens.

2.2.1 Comparison of Luminaire Photometric Characteristics

Because of their better optical control, size of the light-emitting diodes (LED), and design of the LED luminaires, all of the LED products provide a larger percentage of their output as downlight. This meant that the "backlight, uplight, glare" (i.e., BUG) ratings for the LED products that had available photometry showed a reduction in uplight compared to the baseline luminaire (see Appendix A for more information about BUG and the lighting classification system).[6] All of the products with photometry had a lower rating for glare (G) as well. Most initial luminaire efficacies were comparable or slightly better than the baseline metal halide product.

The Sentry Electric LED product did not have photometry available at the time of selection and installation; however, Sentry is the manufacturer of the baseline "Central Park" luminaire and its optics and housings are usually interchangeable, so the product represents a simple SSL upgrade to the existing unit.

Photometry was available for the OSRAM SYLVANIA retrofit unit, but only for the unit itself outside of a luminaire. This retrofit was not photometered inside an existing fixture, so assumptions about its corresponding luminaire performance were required. Based on a comparison of manufacturer photometry of the retrofit alone and manufacturer photometry of the retrofit installed in a post top, the efficacy of the retrofit is expected to be reduced by approximately 35% when installed.

2.2.2 Comparison of Luminaire Photometric Characteristics

Table 2.1 compares photometric data of the conventional and LED luminaires along with input power and luminaire efficacy. The baseline luminaire used a universal orientation probe-start metal halide lamp (14,490 initial lumens) rated at 175 W and a nominal power draw of the ballast of 210 W. All of the LED luminaires drew less power than the conventional product.

The conventional baseline fixture was 59% efficient, so that the corresponding total initial luminaire output was 8,500 lumens. All the LED luminaires emitted fewer lumens than the baseline luminaire, but

[6] Uplight refers to light emitted above the horizontal plane (see Appendix A). Uplight can be an important criterion in many areas. In New York City, the "U" ratings for a pedestrian path light may get less attention because the uplight may light building facades and tree canopies that contribute to a sense of place and safety, and because there are so many other contributors to skyglow. Also in this application, the tree canopy is extensive above the luminaires, blocking some uplight from the luminaires going into the sky.

the absolute lumen output was not the only relevant metric of comparison. Only 80% of the light emitted by the existing luminaire was directed downward, translating to 6,800 lumens that provided useful illumination (the remainder being directed skyward). Virtually all of the LEDs produced 95% or more downward lumens (with the precise values of the OSRAM SYLVANIA and Sentry being undetermined); the highest three LED total light output values were one-third less than the initial baseline value.

The LED luminaires all exceeded the luminaire efficacy of the conventional luminaire except for the Spring City luminaire. However, if only the portion of light directed downwards is examined, the baseline luminaire efficacy drops to 32.3 lumens per watt, virtually matching that of the Spring City LED luminaire.

Table 2.1. Comparison of Manufacturer Photometric Data

	Manufacturer Power Data (W)	Luminaire Output (lumens)	Luminaire Efficacy (lm/W)	BUG Values	Uplight (%)	Downlight (%)
Metal Halide Baseline	210	8,499	40.5	B3-U5-G4	20.1	79.9
Spring City	75	2,416	32.2	B1-U2-G1	2.3	97.7
King Luminaire	100	4,905	49.1	B2-U3-G1	4.4	95.6
Philips Lumec	82	4,238	51.7	B3-U2-G1	2.9	97.1
Sentry Electric	83	4,584	55.2	N/A	N/A	N/A
OSRAM SYLVANIA (retrofit only)	40	3,200	80.0	B2-U2-G2	0.6	99.4
OSRAM SYLVANIA in Housing Estimate	40	2,080	52.0	N/A	N/A	N/A

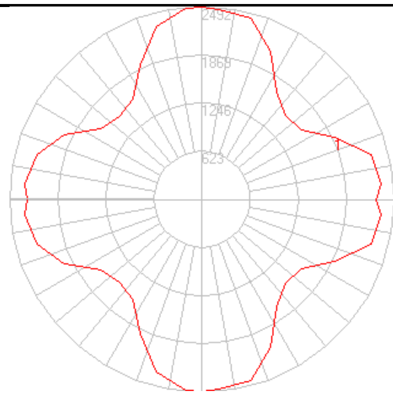
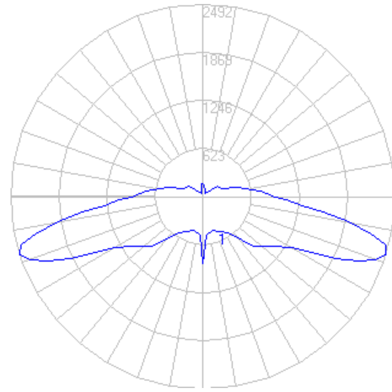
NA = not applicable.

2.2.3 Comparison of Photometric Distributions

Three of the five LED luminaires match the Type V (symmetrical) distribution of the baseline luminaire, whereas the Spring City luminaire has a Type II and the Philips Lumec luminaire has a Type III (both asymmetrical) distribution. NYCDOT installed the Type II and Type III to compare the performance with the Type V, because the asymmetrical distribution can be better directed towards the walkway than a symmetrical distribution and might prove a preferred choice in some areas of the pathway lighting.

Table 2.2 shows the horizontal and vertical distributions of the products installed in this demonstration.

Table 2.2. Comparison of Photometric Distributions

<table>
<tr><th></th><th>Horizontal</th><th>Vertical</th></tr>
<tr><td>Sentry (conventional)
Type V</td><td>
SCP-WB-175MH-120V-PG</td><td></td></tr>
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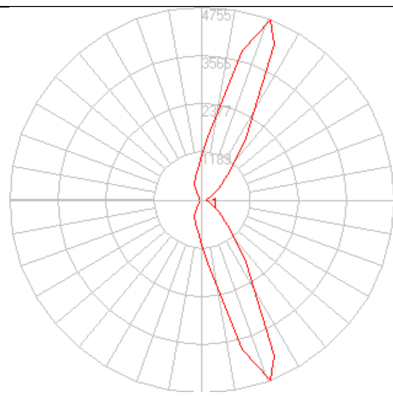
Type II</td><td>
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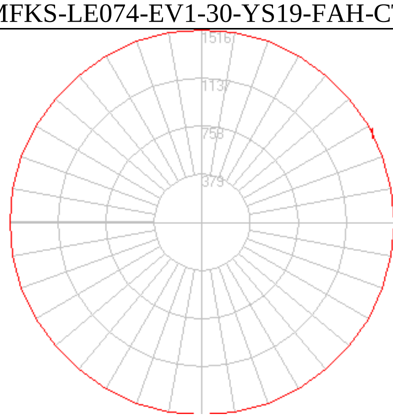
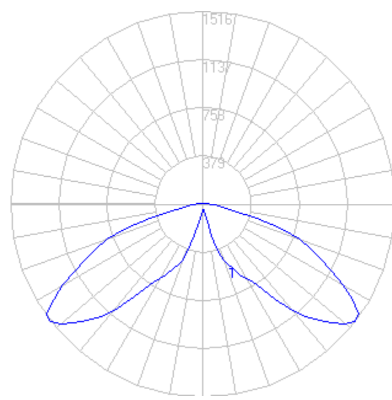
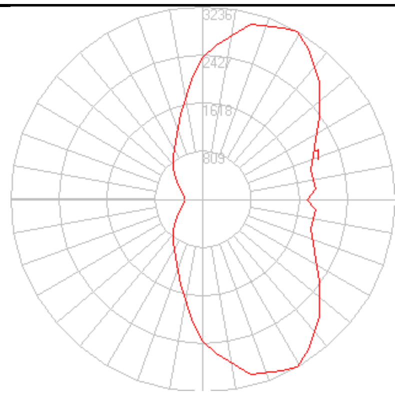
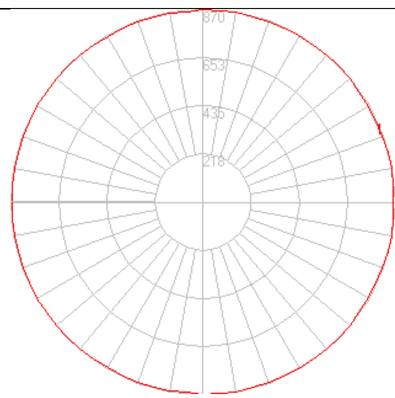
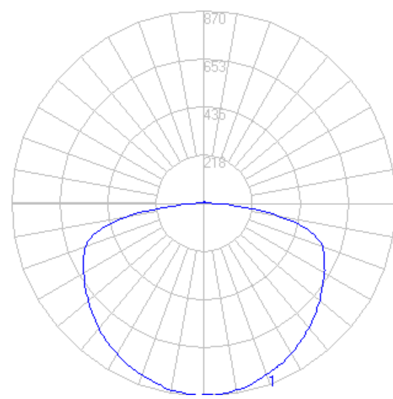
Type V</td><td>
K132R-BAPR-V-6-(SSL)-5000-120(MT)-K37-SST-GRS</td><td></td></tr>
</table>

Table 2.2 (continued). Comparison of Photometric Distributions

	Horizontal	Vertical
Lumec Type III	 S55C1-82LED63L6K-ACDR-LE3-120-SFX-BKTX	 Lumec Photometric Distribution
Sentry (LED)	Photometry not available	Photometry not available
OSRAM SYLVANIA Type V[(a)]	 LED40POST/850/T5S/D11/1G	

(a) Note: Photometry shown is for the LED retrofit module only and not from the module installed within the existing luminaire.

2.2.4 Comparison of Luminaire Color Characteristics

The correlated color temperatures (CCT) of the LED luminaires in this demonstration ranged from 3000 K to 6000 K. NYCDOT's target range was for 4000−4500 K to roughly approximate the cooler CCT of the metal halide lamps, which typically run between 3700−4500 K. Table 2.3 compares the CCT and color rendering index values of the products installed in this demonstration.

Table 2.3. Comparison of Manufacturer Color Quality Data

	CCT (K)	Color Rendering Index
Metal Halide Baseline	3700	70
Spring City	3000	70
King Luminaire	5000	70
Philips Lumec	6000	70
Sentry Electric	4700	70
OSRAM SYLVANIA (retrofit only)	4900	80
OSRAM SYLVANIA in Housing Estimate	N/A	N/A

2.2.5 Comparison of Luminaire Life Characteristics

At the time this evaluation began, the estimated period for an LED product to reach a lumen depreciation value of 70% of initial lumen output (L_{70}) was commonly used as a proxy for product lifetime. Although still commonly used, a greater acknowledgement now exists that other factors may more realistically determine the end of life, particularly as present L_{70} estimates regularly exceed 100,000 hours of operation. Table 2.4 reports the manufacturers' stated product lifetimes, where they were available.

Table 2.4. Comparison of Manufacturer Lifetime Data

	Rated Life (hours)	End-of-Life Value
Metal Halide Baseline (lamp)	10,000	B_{50} [(a)]
Metal Halide Baseline (ballast)	50,000	N/A
Spring City	50,000	L_{70}
King Luminaire	75,000	L_{70}
Philips Lumec	70,000	L_{70}
Sentry Electric	50,000	L_{70}
OSRAM SYLVANIA (retrofit only)	50,000	L_{70}
OSRAM SYLVANIA in Housing Estimate [(b)]	N/A	–

(a) B_{50} – when 50% of the sample population is no longer working.
(b) OSRAM SYLVANIA in housing might increase the ambient temperature and thus negatively affect the product life.

2.3 Installation

Two luminaires were relamped and cleaned for benchmarking purposes so that initial light levels could be measured for both existing and new luminaires. Existing luminaires were relamped and operated for over 100 hours before illumination and power measurements were taken (IESNA 1999).[7] New luminaires were installed over several months as they arrived. Figure 2.3 through Figure 2.5 show various luminaires installed in Central Park.

[7] IESNA LM-54-99, *IESNA Guide to Lamp Seasoning*, recommends operating discharge lamps for 100 hours so that measurements can establish initial or rated lumens. The output of high-intensity discharge lamps in the 0-to-10-hour range is between 8% and 10% lower than rated.

Figure 2.3. Example of asymmetric product (Spring City) (courtesy of The Climate Group and Ryan Pyle [#103])

Figure 2.4. Example of symmetric distribution product (Sentry Electric) (courtesy of The Climate Group and Ryan Pyle [#70])

Figure 2.5. Lighting the pathway presents a variety of distribution challenges (OSRAM SYLVANIA) (courtesy of The Climate Group and Ryan Pyle [#81])

2.4 Power and Energy

Multiplying measured power by the reported operating hours gives an estimated annual energy usage of the different lighting systems. Unfortunately, much of the wiring inside the poles is the original wiring from the time the electric fixtures were installed in the park approximately 100 years ago. The antiquated wiring prevented staff from placing the power meter clamps on the wires for fear of breaking them, and therefore only voltage and current measurements were taken via the wire nuts. Manufacturer data had to be relied on for providing power factor and thus the estimated real power used by each luminaire.

2.4.1 Power Measurements

NYCDOT measured at least two operating luminaires from each manufacturer. Power (watts (W)) is calculated by multiplying the measured voltage (V) by the measured current (A) and multiplying by power factor (PF) as shown in Equation 2.1.

$$W = VA \times PF \tag{2.1}$$

The resulting calculated power draw for each product differed slightly from the manufacturer-reported power draw. These two values for each product are provided in Table 2.5. Individual measurements can be found in Appendix B.

Table 2.5. Comparison of Manufacturer Data and Calculated Power

	Manufacturer Data (W)	Average Measured Power (VA)	Power Factor [(a)]	Calculated Power (W)	Difference Between Manufacturer-Reported and Measured Power (W)	(%)
Metal Halide Baseline	210	222.6	0.90	200	-10	-5
Spring City	75	73.8	0.90	66	-9	-12
King Luminaire	100	99.5	0.99	99	-1	-1
Philips Lumec	82	85.4	0.99	85	3	4
Sentry Electric	83	97.6	0.92	90	7	8
OSRAM SYLVANIA	40	37.2	0.90	34	-6	-15

(a) Supplied in manufacturer's literature.

2.4.2 Operating Schedule

The luminaires in Central Park operate from dusk to dawn via an astronomical time clock. NYCDOT estimates annual operation of 4,100 hours, which translates to an average of 11.25 hours per night, 365 nights a year.

2.4.3 Energy Use of System

Table 2.6 shows annual energy use on a per-luminaire basis and the percentage savings relative to the baseline.

Table 2.6. Annual Energy Use and Percent Savings per Luminaire

Luminaire	Luminaire Power (W)	Annual Operation (hours)	Annual Energy Use (kWh)	Percent Energy Savings Relative to Baseline
Metal Halide Baseline	200	4,100	820	–
Spring City	66	4,100	271	67
King Luminaire	99	4,100	406	51
Philips Lumec	85	4,100	349	58
Sentry Electric	90	4,100	369	55
OSRAM SYLVANIA	34	4,100	139	83

2.5 Illuminance

The measurement system used in this demonstration was developed based on the horizontal and vertical illuminance recommendations for pedestrian walkways in IESNA DG-5-1994 and IESNA RP-33-1999 (IESNA 1994, IESNA 1999). Both of these documents provide illuminance recommendations of 0.5 footcandles average horizontal on the walkway and 0.5 fc average vertical. However, they do not prescribe a measurement process, unlike other documents that define it, for example roadway or parking lot lighting. Both documents do note that horizontal illuminance should be measured on the pavement, and vertical measurements should be at 6 feet above the walkway for pedestrian identification.

Table 2.7. IESNA RP-33-99 Recommended Maintained Illuminance Levels for Pedestrian Ways

Walkways Distant from Roadways and Type B Bikeways	Minimum Average Horizontal Illuminance Levels on Pavement [(a)] (lux/fc)	Average Vertical Illuminance Levels for Special Pedestrian Security [(b)] (lux/fc)
Walkways and Bikeways	5/0.5	5/0.5
Pedestrian Stairways	5/0.5	10/1
Pedestrian Tunnels	20/2	5/0.5

(a) Uniformity ratios should not be greater than 10:1 maximum to minimum
(b) For pedestrian identification at a distance. Values are specified at 1.8 meters (6 feet) above the walkway.

From RP-33-99:

> Walkways not adjoining roadways, and having minimal non-pedestrian traffic, need not be lighted continuously.
>
> Walkways located in the middle of a park or large landscaped area need not be lighted continuously. Here a unique blend of lighting is required that covers key landscape features, selected buildings or shelters, resting points and any walkway hazards (e.g., stairs, abrupt changes in elevation, bridges, and curves). When the entire park scene is lighted, pedestrians can adequately see potential hazards in plenty of time. Careful design is needed to minimize disability glare from luminaires to avoid lighting objects so they are seen only in silhouette.
>
> Specific design recommendations for walkway and bikeway lighting are found in IES DG-5 *Recommended Lighting for Walkways and Class I Bikeways.* It is important to consider the adjacent surroundings for walkways and bikeways.

2.5.1 Measurement Protocol

Measurements were taken around two luminaires from each manufacturer, in four polar directions from each: two parallel and two perpendicular to the adjacent walking path. Horizontal measurements on the ground were taken at 10-, 15-, 20-, 25-, and 30-foot distances from the center of the base. At each horizontal point, vertical measurements facing the luminaire were also taken at 2-, 4-, and 6-foot heights above finished grade facing the luminaire. More information explaining the measurements is included in Appendix C.

2.5.1.1 Measurement Comparison

The measurement protocol in this field study required measuring the illuminance in both horizontal and vertical planes at different distances from the pole where the fixtures were mounted.

Due to scheduling conflicts, baseline measurements could not be taken before the LED products were installed, so measures of the baseline Central Park metal halide luminaires were taken from two other existing luminaires nearby and similarly averaged. The luminaires were cleaned and relamped for the measurements. However, polycarbonate can yellow and it appears that one of the measured luminaires was either not relamped or the lens had yellowed and reduced the output of the luminaire. Appendix D lists the measured values.

In brief, there were marked contrasts between the measurements of luminaires from the same manufacturer, including the baseline metal halide luminaires, for three out of the five manufacturers. Various underlying reasons can contribute to such results, such as geographic contours, individual adjustments performed inconsistently during installation, and spacing and proximity of adjacent fixtures.

In the following diagrams, the LED-specific measurements are presented side by side with the baseline luminaires for comparison. Two of each product were measured and averaged to produce the values shown. The upper values represent the prototypical baseline, and the bottom values are from the corresponding LED luminaire. In all cases the “north” axis is towards the top of the page and represents measurements parallel to the general direction of the walkway. All original measurements can be found in Appendix C. Compiled comparisons of performance across products begin in Section 2.5.2, following the individual product performance tables.

2.5.1.2 Spring City Luminaire

In general the Spring City luminaire performed better than the baseline, as evident in Figure 2.6. The Type II distribution provided comparable or slightly higher horizontal illuminances at greater distances from the pole (located at center of figure below) in the three directions targeted by this distribution pattern. Horizontal illuminances were lower than the baseline closer to the luminaire.

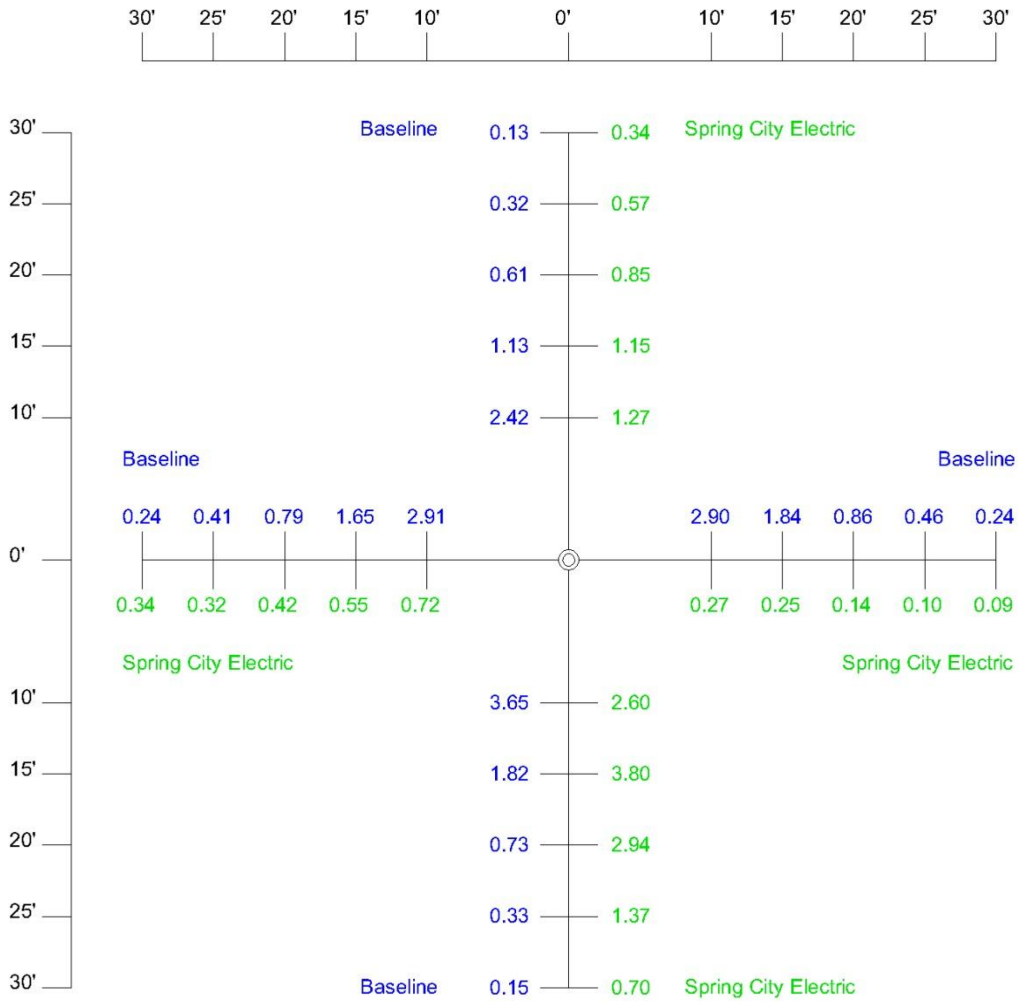


Figure 2.6. Spring City average horizontal measured illuminance in footcandles

2.5.1.3 King Luminaire

Overall, the measured illuminance values of the King Luminaire were comparable to the baseline. Many of the horizontal points measured were within 10%; measurements tended to more closely match the baseline at greater distances from the luminaire, as shown in Figure 2.7.

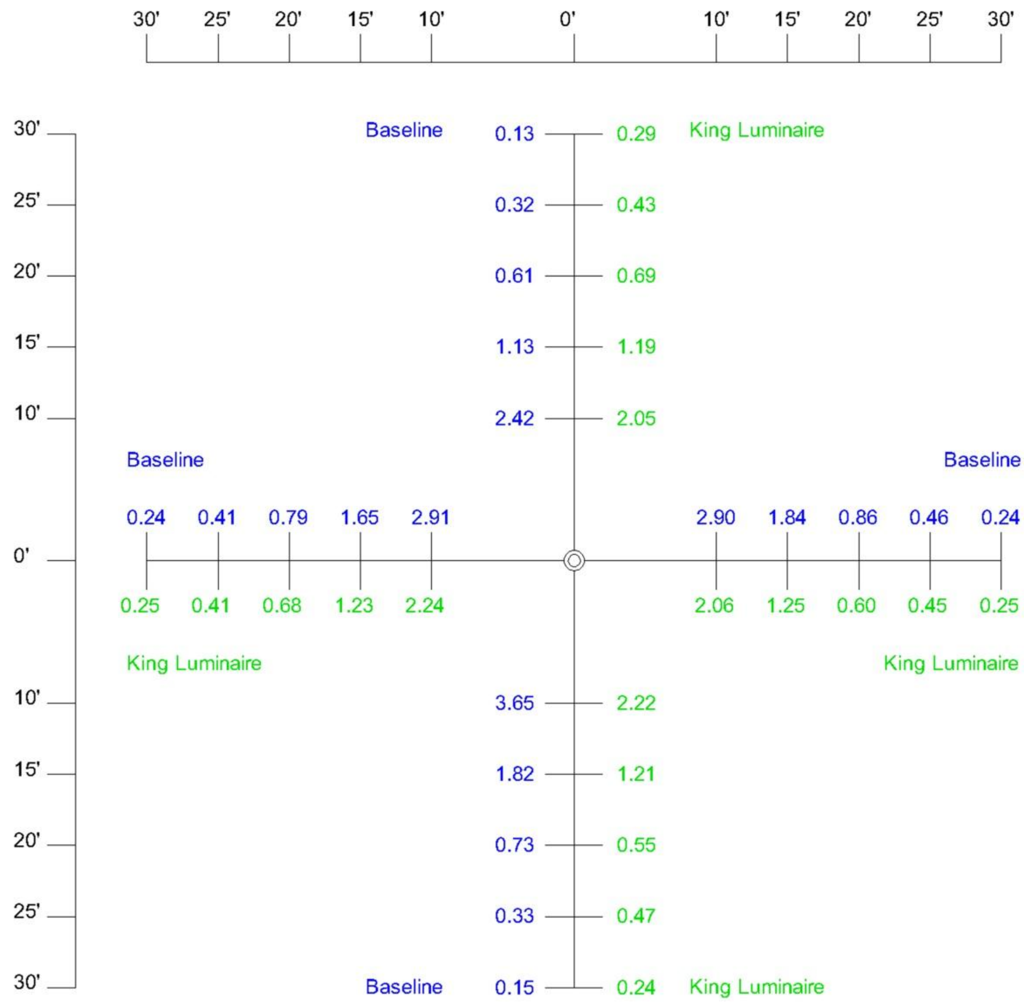


Figure 2.7. King Luminaire average horizontal measured illuminance in footcandles

2.5.1.4 Philips Lumec Luminaire

Measured illuminance values were similar to the baseline in many cases, with many values hovering within 10%. This luminaire provided higher horizontal illuminance at greater distances from the pole except behind the luminaire ("east" or right-hand side of Figure 2.8) because the luminaire has an asymmetric distribution and is oriented towards the walkway ("west" or left-hand side of Figure 2.8).

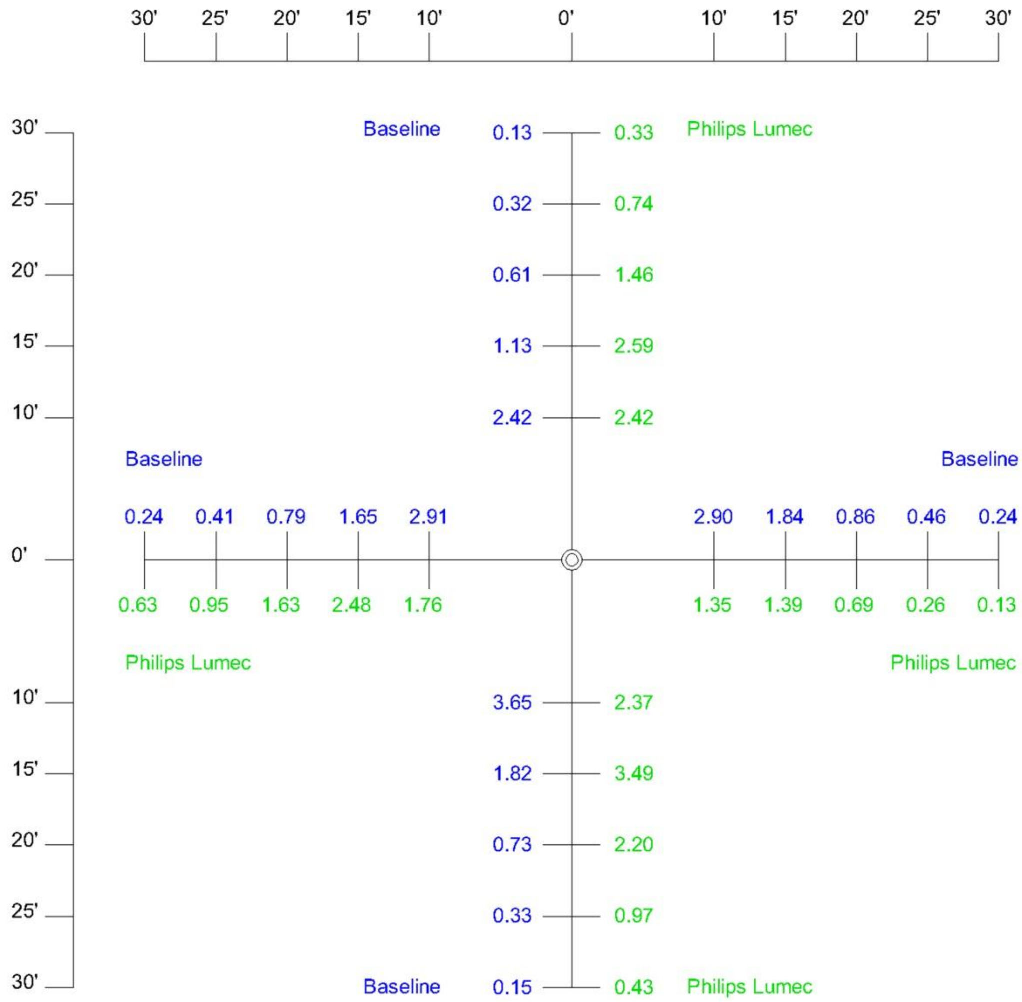


Figure 2.8. Philips Lumec average horizontal measured illuminance in footcandles

2.5.1.5 Sentry Electric Luminaire

The Sentry Electric product provided lower illuminance levels than the baseline for virtually all horizontal measurements. Horizontally, only two measured points showed slightly higher illuminance levels than the baseline; many were significantly lower (Figure 2.9).

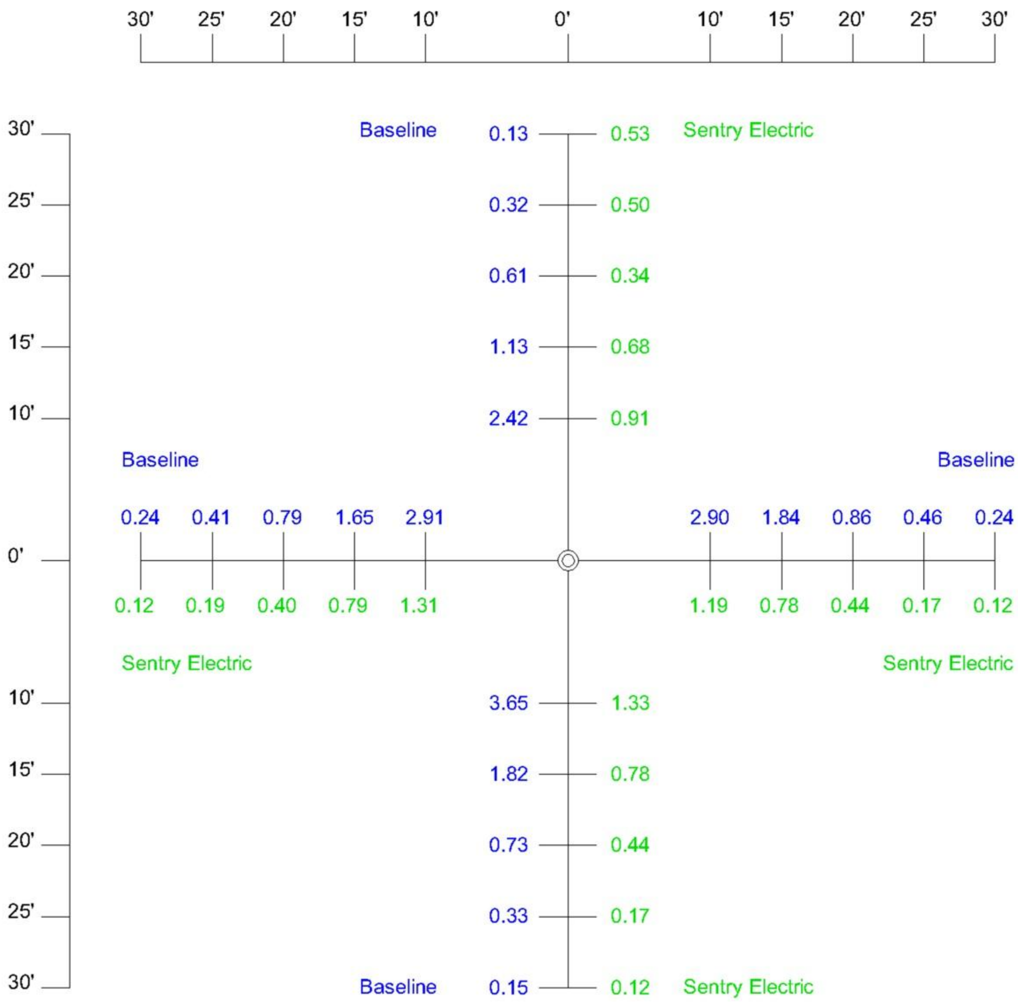


Figure 2.9. Sentry Electric average horizontal measured illuminance in footcandles

2.5.1.6 OSRAM SYLVANIA Luminaire

This product provided a very even horizontal distribution, with a gradual decrease (similar in values to the baseline at 25 feet and beyond from the pole) in light levels at measurement points further from the luminaire, as shown in Figure 2.10.

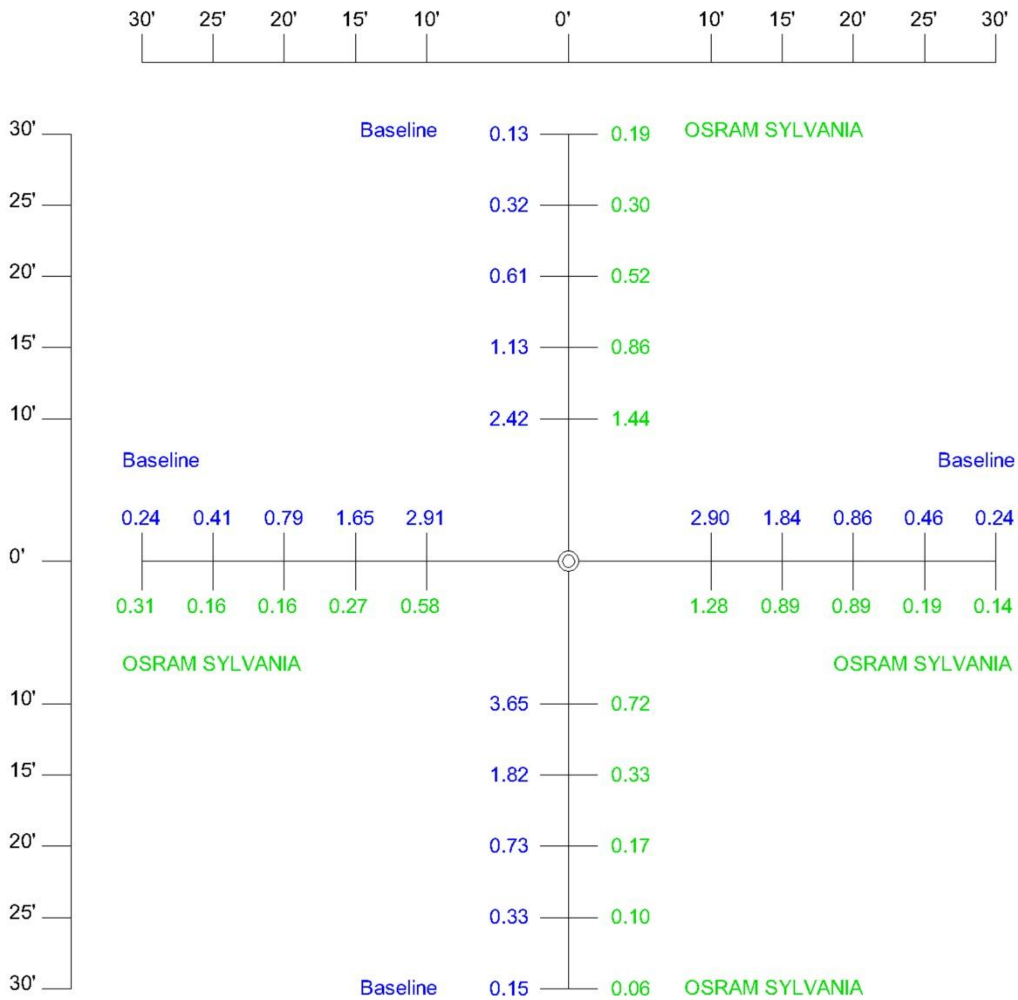


Figure 2.10. OSRAM SYLVANIA average horizontal measured illuminance in footcandles

2.5.2 Horizontal Illuminance Comparison

The different LED products performed at varying levels compared to the baseline luminaire, ranging between about 50% less to about 60% greater average horizontal illumination. Table 2.8 compares the differences between each averaged value at various horizontal distances from the pole: a positive value indicates that the LED product increased the illuminance at that point and a negative value means that the illuminance at that point was reduced. For example, the average of the four values at 10 ft for the Spring City was 1.21 fc and the average for the four values at 10 ft for the baseline was 2.97 fc. Spring City represented a 60 percent reduction and this is indicated by a value of -59.26% in Table 2.8. A sample calculation of a positive value would be the average of the four values at 15 ft for the Philips Lumec was

2.49 fc and the average of the four values for the baseline was 1.61 fc. Philips Lumec increased illumination at this horizontal distance and is indicated by a value of 54.66% in Table 2.8.

In general, the LED luminaires tend to have higher light levels at greater horizontal distances, corresponding to a wider distribution. The Spring City (Type II) and Philips Lumec (Type III) luminaires in particular provide greater horizontal illuminance values than the incumbent baseline luminaire, whereas the King Luminaire, Sentry Electric, and OSRAM SYLVANIA luminaires overall provided less.

Table 2.8. Comparison of Horizontal Measurement Differences Between LED Luminaires and the Baseline

Distance	Spring City Type II (%)[a]	King Luminaire Type V (%)	Philips Lumec Type III (%)	Sentry Electric Type V (%)	OSRAM SYLVANIA Type V (%)
10 ft	-59.26	-27.95	-33.67	-60.27	-66.33
15 ft	-11.18	-24.22	54.66	-53.42	-63.35
20 ft	45.33	-16.00	98.67	-48.00	-58.67
25 ft	55.26	15.79	92.11	-31.58	-50.00
30 ft	94.74	31.58	100.00	15.79	-10.53
Average	24.98	-4.16	62.35	-35.49	-49.78

(a) A positive value indicates that the LED product increased the illuminance at that point and a negative value means that the illuminance at that point was reduced.

2.5.3 Vertical Illuminance Comparison

Spring City, King Luminaire, and Philips Lumec luminaires provide comparable vertical illuminance to the baseline, while Sentry and OSRAM SYLVANIA provide lower vertical illuminance values. Tables 2.9 – 2.11 provide a comparison of the vertical measurements.

Table 2.9. Comparison of Vertical Measurement Differences Between Spring City and King Luminaire LED Luminaires and the Baseline

Horizontal distance from pole	Spring City Luminaire Type II (% difference at height above grade)			King Luminaire Type V (% difference at height above grade)		
	2 ft	**4 ft**	**6 ft**	**2 ft**	**4 ft**	**6 ft**
10 ft	-39.56	12.21	42.50	-29.67	-24.60	-0.19
15 ft	29.68	45.19	17.75	-21.55	4.18	59.17
20 ft	43.17	34.91	-20.00	5.76	49.06	64.44
25 ft	41.10	4.76	-28.07	41.10	58.73	49.12
30 ft	21.28	-13.64	-32.50	55.32	50.00	35.00
Average	19.13	16.69	-4.06	10.19	27.47	41.51

Table 2.10. Comparison of Vertical Measurement Differences Between Philips Lumec and Sentry Electric LED Luminaires and the Baseline

Horizontal	Philips Lumec Luminaire	Sentry Electric Luminaire

	Type III (% difference at height above grade)			Type V (% difference at height above grade)		
	2 ft	4 ft	6 ft	2 ft	4 ft	6 ft
10 ft	-7.03	45.96	104.23	-57.58	-53.86	-46.54
15 ft	66.43	103.35	95.27	-53.00	-46.03	-41.42
20 ft	102.16	100.00	36.67	-44.60	-39.62	-48.33
25 ft	98.63	55.56	7.02	-39.73	-44.44	-52.63
30 ft	65.96	15.91	-5.00	-38.30	-47.73	-52.50
Average	65.23	64.15	47.64	-46.64	-46.34	-48.28

Table 2.11. Comparison of Vertical Measurement Differences Between OSRAM SYLVANIA LED Luminaires and the Baseline

Horizontal distance from pole	OSRAM SYLVANIA Luminaire Type V (% difference at vertical ht above grade)		
	2 ft	4 ft	6 ft
10 ft	-67.69	-66.07	-57.12
15 ft	-63.60	-55.65	-51.48
20 ft	-55.40	-50.94	-57.78
25 ft	-47.95	-53.97	-61.40
30 ft	-53.19	-59.09	-62.50
Average	-57.57	-57.14	-58.06

The Sentry Electric and OSRAM SYLVANIA luminaires reduce measured light levels compared to the benchmark. The Philips Lumec and King luminaires provide the most similar distributions, actually providing higher vertical light levels in some cases, which indicates a wider distribution, but also more potential for disability and discomfort glare to nearby pedestrians. The Spring City also produces higher illuminance values, but has a very narrow Type II distribution, resulting in uneven illuminance values on the walkways and skewing the average illuminance values.

2.6 Energy Savings and Illuminance

All of the products tested reduce energy use; however some significantly reduce the corresponding light levels as well. Taking both energy savings and illuminance into account allows a comparison akin to application efficacy among products.

Table 2.12 compares energy savings and illuminance levels relative to the baselines. A positive value indicates that the corresponding LED luminaire delivered greater values *on average* relative to the metal halide baseline. A negative value indicates that the LED luminaire delivered less *on average*. Illuminance measurements within ±10% of the baseline can be considered essentially equivalent (Levin 1982).

The averages were developed taking all measured points into consideration. The Philips Lumec and Spring City both reduced energy use while increasing measured illuminance values. The King Luminaire reduced energy use with a slight decrease in average horizontal illuminance and increase in average vertical illuminance. Sentry Electric and OSRAM SYLVANIA reduced energy use and average horizontal and vertical illuminance.

Table 2.12. Comparison of Illuminance and Energy Savings Relative to Baseline

Luminaire	Distribution	Energy Savings (%)	Average Horizontal Illuminance (%)	Average Vertical Illuminance (%)
Spring City	Type II	67	24.98	10.59
King Luminaire	Type V	51	-4.16	26.39
Philips Lumec	Type III	58	62.35	59.01
Sentry Electric	Type V	55	-35.49	-47.09
OSRAM SYLVANIA	Type V	83	-49.78	-57.59

3.0 Economics

LED luminaires typically require higher initial investment than conventional luminaires. In some cases the cost increment may be sufficient to prevent the investment from being economically viable if only the value of the energy saved is taken into account. However, the expected longer lifetimes of LED products translate into significant additional savings in maintenance costs that can also help justify the investment. Life-cycle costing is thus often used in rationalizing an LED retrofit.

3.1 Cost Inputs

Representatives of each manufacturer provided luminaire pricing used in the analysis, whereas energy costs were calculated from data provided by NYCDOT and The Climate Group. NYCDOT also provided maintenance costs for relamping and luminaire cleaning.

3.1.1 Electricity Tariff

According to NYCDOT, the total annual energy cost for the pedestrian luminaires in Central Park is $172,200. Dividing this by an estimated annual park lighting usage of 1,148,000 kilowatt-hours yields a melded rate of $0.15 per kilowatt-hour, including both the electrical rate and any applicable demand charges.

3.1.2 Luminaire Prices

Representatives of the five manufacturers in this demonstration provided pricing based on single-unit purchases, rather than for a park-wide replacement of 1,600 units. The initial cost of the Spring City luminaire was $1,500; the King Luminaire was $1,500; the Philips/Lumec was $1,400; Sentry was $1,650; and the OSRAM SYLVANIA retrofit kit was $450. The luminaire prices are dated, based on single unit, regionally priced, and affected by other factors.

3.1.3 Maintenance

Total estimated maintenance costs for the approximately 1,600 luminaires in Central Park are reported to be $178,560 per year, or about $111.60 per luminaire per year. According to NYCDOT, this value breaks down into roughly $65.60 for pole/fixture/ballast maintenance and $46.00 for lamp replacement. Significant savings are expected from the longer lifetimes of the LED products, but this impacts only the latter of these cost components. Other sources of costs besides lamp burnout include pole knock-downs, corrosion, and wire or equipment failure and are largely independent of source type. This report estimates the maintenance savings for scenarios for both "deferred lamp maintenance only" and for "deferred lamp and luminaire/pole maintenance combined." Because further cost details are not available in the second category (i.e., ballast vs. globe vs. pole replacement), it is difficult to accurately pin down the total dollar savings achieved through an LED retrofit. Realistically, the expected maintenance savings falls somewhere between these two values (i.e., between $46 and $111.60 per pole per year), to be conservative, the lower value was used in this analysis.

3.1.4 Light Source Life

The manufacturer's claimed lifetimes for the LEDs correspond to their respective projected operating hours to reach L_{70} (Table 2.4) and are used as the assumed luminaire lifetimes in the economic analysis. The life of other components, such as the ballasts and LED power supplies, are not addressed in this analysis.

3.2 Cost Effectiveness

The substitution of LED light sources for the incumbent metal halide significantly reduces energy use and associated costs for Central Park, but resulting maintenance savings will also play a large role in the cost effectiveness of the new lighting system.

3.2.1 Simple Payback

In the following examples, the simple payback is calculated for three scenarios: (1) energy savings only; (2) energy savings and deferred lamp maintenance; and (3) energy savings, deferred lamp maintenance, and deferred luminaire/pole maintenance combined.

3.2.1.1 Simple Payback–Energy Savings Only

Saving energy is a primary goal for many municipalities. However, based on energy savings alone, the payback period for these luminaires appears quite long despite the relatively high electricity rate. Table 3.1 shows a range estimated payback periods for these products from 4.4 to 24.1 years. Note that there is no accompanying judgment of lighting quality or suitability of the product in the table, and so the results only reflect the basic costs and savings arithmetic.

Table 3.1. Estimated Simple Payback of LED Luminaires from Electricity Savings

Luminaire	Luminaire Power (W)	Annual Operation (hours)	Energy Use (kWh)	Energy Cost ($/kWh)	Annual Energy Cost ($)	Energy Savings ($)[a]	Maintenance Savings ($)	Payback (years)
Baseline	200	4,100	820	0.15	123.00	–	–	–
Spring City	66	4,100	271	0.15	40.65	82.35	–	18.2[b]
King Luminaire	99	4,100	406	0.15	60.90	62.10	–	24.1[b]
Philips Lumec	85	4,100	349	0.15	52.35	70.65	–	19.8[b]
Sentry Electric	90	4,100	369	0.15	55.35	67.65	–	24.4[b]
OSRAM SYLVANIA	34	4,100	139	0.15	20.85	102.15	–	4.4

(a) The simple payback uses the current electricity price and does not modify future prices of electricity.
(b) Exceeds rated life from Table 2.4 (Rated life hours / 4,100 operating hours)

3.2.1.2 Simple Payback–Energy and Deferred Lamp Maintenance Savings

The higher initial costs of the LED products continue to produce payback periods that would be an obstacle for many users. The only product with a payback less than five years is the OSRAM SYLVANIA retrofit kit, which does not include the cost of the luminaire. Table 3.2 depicts the simple payback for electricity and lamp replacement savings ranges from 3.0 to 14.5 years. Note again there is no indication here of suitability of the replacement luminaire in terms of performance.

Table 3.2. Estimated Simple Payback of LED Luminaires from Electricity Savings and Deferred Lamp Maintenance

Luminaire	Luminaire Power (W)	Annual Operation (hours)	Annual Energy Use (kWh)	Energy Cost ($/kWh)[a]	Annual Energy Cost ($)	Annual Energy Savings ($)	Annual Maintenance Savings ($)	Payback (years)
Baseline	200	4,100	820	0.15	123.00	–	–	–
Spring City	66	4,100	271	0.15	40.65	82.35	46.00	11.7
King Luminaire	99	4,100	406	0.15	60.90	62.10	46.00	13.9
Philips Lumec	85	4,100	349	0.15	52.35	70.65	46.00	12.0
Sentry Electric	90	4,100	369	0.15	55.35	67.65	46.00	14.5[b]
OSRAM SYLVANIA	34	4,100	139	0.15	20.85	102.15	46.00	3.0

(a) The simple payback uses the current electricity price and does not modify future prices of electricity.
(b) Exceeds rated life from Table 2.4 (Rated life hours / 4,100 operating hours)

3.2.1.3 Simple Payback–Energy and Deferred Lamp and Luminaire/Pole Maintenance Savings

This scenario represents the quickest imaginable simple payback, if substitution of the LED product eliminated all maintenance of the poles and wiring and any other type of maintenance related to the lights/poles. While not a realistic scenario, it illustrates the absolute limit for the products evaluated in this study, given the pricing and other inputs that applied at the time. Table 3.3 shows simple payback ranging from 2.1 to 7.7 years.

Table 3.3. Estimated Simple Payback of LED Luminaires from Maximum Maintenance Savings

Luminaire	Luminaire Power (W)	Annual Operation (hours)	Annual Energy Use (kWh)	Energy Cost ($/kWh)[a]	Annual Energy Cost ($)	Energy Savings ($)	Annual Maintenance Savings[b] ($)	Payback (years)
Baseline	200	4,100	820	0.15	123.00	–	–	–
Spring City	66	4,100	271	0.15	40.65	82.35	111.60	7.7
King Luminaire	99	4,100	406	0.15	60.90	62.10	111.60	8.6
Philips Lumec	85	4,100	349	0.15	52.35	70.65	111.60	7.7
Sentry Electric	90	4,100	369	0.15	55.35	67.65	111.60	9.2
OSRAM	34	4,100	139	0.15	20.85	102.15	111.60	2.1

SYLVANIA					

(a) The simple payback uses the current electricity price and does not modify future prices of electricity.
(b) Assumes all maintenance discussed in section 3.1.3 is deferred for all LED luminaires.

3.2.2 Life-Cycle Cost

A weakness in the simple payback metric when results extend beyond a few years is that it ignores the time value of money—the fact that a dollar today is worth more than a dollar in the future. A more accurate comparison for longer-term investments is the life-cycle cost (LCC).

An analysis period of 18.3 years was used to assess the LCC of each luminaire in this demonstration. This period was determined by taking the light source with the longest claimed life (75,000 hours for the King Luminaire) and dividing it by 4,100 annual operating hours. Results are displayed in Table 3.4.

Table 3.4. Life-Cycle Costs

Luminaire	Annual Energy Use (kWh)	Energy Cost ($/kWh)	Annual Energy Cost[(a)] ($)	Annual Maintenance Cost[(b)] ($)	Analysis Period (years)	Life-Cycle Costs ($)
Baseline	820	0.15	123.18	111.60	18.3	4,609
Spring City	271	0.15	40.84	65.60	18.3	4,193
King Luminaire	406	0.15	60.58	65.60	18.3	3,814
Philips Lumec	349	0.15	51.96	65.60	18.3	3,656
Sentry Electric	369	0.15	55.22	65.60	18.3	4,688
OSRAM SYLVANIA	139	0.15	20.60	65.60	18.3	2,258

(a) Life-cycle cost analysis factors in future price changes to electricity prices based on Department of Energy's Energy Information Administration price projections.
(b) For the baseline assumes all maintenance in section 3.1.3. For the LED luminaires, only lamp servicing is deferred. Does not estimate costs in the future for replacing the LED luminaire when it reaches the projected end of life.

The LCC analysis factors in both the initial and any replacement costs (needed for products with shorter claimed lifetimes) of the LED integrated luminaires. The metal halide luminaire and the OSRAM SYLVANIA LED retrofit kit avoid the fixture cost because that component is already in place. The metal halide must also account for periodic lamp and ballast replacement.

The metal halide luminaire has the third highest LCC in the table despite its initial cost advantages. Reasons for this include the frequent lamp replacement schedule that incurs both material and labor costs, and the significantly higher annual electricity costs. In contrast, despite having to replace the entire luminaire at the end of life, both the Spring City and Philips Lumec luminaires offer lower LCC than the installed metal halide baseline. The OSRAM SYLVANIA retrofit likewise offers a considerable reduction in annual costs relative to the baseline, but its accompanying poor illumination performance in this case must also be considered (see Table 5.1 for a comparison of energy savings, payback, and life-cycle costs for all of the luminaires).

4.0 Discussion

The Central Park demonstration offered an opportunity to compare several products side by side against the existing baseline. Although the various luminaires evaluated were not necessarily directly comparable, they provided a representative snapshot of what was currently available on the market at the time the study was undertaken (early 2010).

4.1 User Feedback

Central Park Conservancy placed plaques on the luminaire poles describing the demonstration and requesting public feedback through email. However, NYCDOT did not receive any comments on the demonstrated lighting during the time it was in place.

Direct user feedback was not further pursued as it did not seem practical at the time. NYCDOT may yet want to organize some form of lighting survey to gather the opinions of both park users and lighting professionals.

One issue that may be evident from photographs taken at the time is the potential for discomfort and disability glare. Note the high level of contrast evident between the two sides of the seated woman's face in Figure 4.1 and Figure 4.2. Regardless of light source (high-intensity discharge or LED), glare is a possible concern because of the geometries associated with the pedestrian-scale fixture and the multiple viewing angles possible. Fixture selection should be evaluated accordingly on an individual site basis.

Figure 4.1. People walking along a path in Central Park (courtesy of The Climate Group and Ryan Pyle [#89])

Figure 4.2. Detail showing high illumination contrast (courtesy of The Climate Group and Ryan Pyle [#89])

Note further in Figure 4.3 that many park patrons appear to have selected sitting areas along the outside ring of illumination.[1] Various explanations could underlie this situation, not the least likely of which could be a desire to take advantage of the lighting while minimizing their perception of glare and possibly a desire to not be in the spotlight. Observed behavior like this suggests that a feedback survey might be worthwhile.

[1] An issue apparently contributing to this situation is that the asymmetric luminaire has been oriented incorrectly with respect to the path. The photo reveals that most of the illumination is being distributed in the grassy area rather than on the path, counter to the design intent. As a result the illumination in the grassy area is much higher than seated users probably prefer.

Figure 4.3. People sitting on grass outside ring of illumination in Central Park (courtesy of The Climate Group and Ryan Pyle [#95])

4.2 Energy Savings and Illuminance

All of the products evaluated provided significant energy reductions relative to the metal halide baseline, ranging from 50% to 83%, although the effects on light output and illuminance varied. Specifically:

- The Type II and Type III distribution products greatly increased illuminance along the pathway, though, as expected, they reduced the corresponding illuminance on the off-path (i.e., house side) grassy areas. However, when reviewing overall averages produced using the polar method employed here, at first glance it may appear that the average levels have increased everywhere. In reality, the Type V distribution products generally produced higher illuminance levels on the house (grass) side and lower levels on the street (path) side of the luminaire than did the asymmetric products. This underscores why asymmetric distributions, while increasing the overall *average* illuminance, would not necessarily be suitable replacements in every location. Locations with two meeting path ways or areas were general area lighting (e.g., a plaza) is needed and there is no defined pathway may not be ideal for asymmetric distributions. Also the asymmetric distributions are needed to light the pathway, but still need some backlight to provide some light to the off path areas to allow pedestrians traversing the pathway to see the surrounds.

- Two of the Type V products reduced light levels quite significantly. The first of these was challenged from the outset by being a retrofit kit. The IES file for this retrofit product was generated outside of a luminaire globe and thereby does not account for fixture loss, which can be significant depending on both the original characteristics and present condition of the polycarbonate globe; location of metal structure and decorative elements; and other factors. The second product was a customized version built by the manufacturer of the original Central Park fixtures. Not being a commercially available unit, it had never been photometered up to the time of the demonstration and thus this evaluation has insufficient information to determine the exact reasons underlying its relatively low measured performance.

4.3 Cost Effectiveness

The products evaluated in this study were purchased in late 2009 and reflect the prices and performance available at that time. Though the estimated simple paybacks would be considered long by many potential users, they have undoubtedly improved in the time since. Taking a more comprehensive perspective, the two products that offered superior performance also offered estimated LCCs that were lower than the baseline, even given the earlier stage of products noted above. Again, the number of such products can be expected to have increased in the time since these were evaluated.

Maintenance savings continue to play a significant role in justifying the investment, and yet are largely based on assumptions. Central Park and NYCDOT should monitor actual maintenance costs as the luminaires age to check the accuracy of the maintenance cost assumptions.

5.0 Conclusions

The demonstration evaluated four different LED luminaires and one LED retrofit kit against the metal halide baseline. All products reduced energy use as well as raw lumen output, but individual results varied. Two provided higher illuminance levels than the baseline; one provided approximately equivalent illuminance, and the remaining two reduced illuminance levels.

Reducing uplight (i.e., above 90 degrees from the plane of the luminaire) was not a particular focus of the installation given its interurban location, all of the LED luminaires produced considerably less uplight than the baseline. Specifically, the LED products ranged between 0.6% and 4.4% uplight while the much older baseline fixture yielded 20.1% uplight. This difference partially explains how some of the LEDs produced higher measured illuminance values even with lower overall output.

Due to the combination of greatly reduced energy use and low first cost associated with being a retrofit kit rather than a full luminaire replacement, the OSRAM SYLVANIA product was the only one that achieved a simple payback in less than 10 years in the deferred lamp maintenance scenario. However, the much lower light output of this product means it is not equal to the baseline light source and does not constitute a suitable comparison.

Table 5.1 summarizes product comparisons across the various performance criteria of energy savings, improved horizontal and vertical illuminance, LCC, and simple payback. Note that the Spring City and Philips Lumec luminaires have different distributions from the baseline (Type V) and therefore may not be suitable for all locations in the park.

Table 5.1. Luminaire Comparison

Luminaire	Type Distribution	Energy Savings?	Improved Horizontal Illuminance?	Improved Vertical Illuminance?	Reduced Life-Cycle Cost?	Short Payback [b]?
Spring City	II	Yes	Yes	Yes	Yes	No
King Luminaire	V	Yes	No	Yes	Yes	No
Philips Lumec	III	Yes	Yes	Yes	Yes	No
Sentry Electric[a]	–	Yes	No	No	No	No
OSRAM SYLVANIA	V	Yes	No	No	Yes	Yes

(a) Photometry not available, but believed to be a Type V.
(b) Short payback is defined as 10 years or less when factoring savings from electricity and deferred maintenance from lamp replacements (see Table 3.2).

Despite the challenge presented by the longer simple payback periods, NYCDOT may have other motivations such as reducing energy use, maintenance costs, or greenhouse gas emissions that may favor LED options. In addition, from a longer-term perspective, the LCCs for the Spring City and Philips Lumec are lower than the baseline and could provide justification on that basis. Physically, the LED products appear similar enough to the baseline that they will not alter the aesthetic of Central Park, although some slight change in color temperature might be noticeable to some users. NYCDOT and the

Central Park Conservancy may wish to pursue feedback from park users to determine whether this is the case, and to investigate whether other issues like glare have surfaced with the replacement lighting.

In terms of lessons learned, proper orientation of directional luminaires (regardless of the technology) can be a challenge. For example, some of the asymmetric luminaires had not been properly oriented with respect to the target area they were intended to illuminate (see Figure 4.3). It is not always obvious to the electrician how to align asymmetrical luminaires during the day, and the crew may not revisit the site at night to confirm proper orientation. Manufacturers should ensure that aiming instructions are clearly marked on the optical system.

The polar measurement methodology used in this analysis, if imperfect, does provide a means for comparing luminaires across multiple metrics for illuminating public spaces like parks. Lighting authorities may want to investigate the development of a more formal approach that takes a broader set of potential park activities into account than do current methods.

6.0 References

IESNA DG-5-1994. *Recommended Lighting for Walkways and Class 1 Bikeways*. Illuminating Engineering Society of North America, New York, NY.

IESNA RP-33-1999. *Lighting for Exterior Environments*. Illuminating Engineering Society of North America, New York, NY.

IESNA RP-54-1999. *IESNA Guide to Lamp Seasoning*. Illuminating Engineering Society of North America, New York, NY.

Levin R. 1982. "The Photometric Connection–Part3." *Lighting Design & Application*. New York, NY.

Appendix A

Luminaire Classification Values

Appendix A – Luminaire Classification Values

The role of the “B” value in the backlight, uplight, and glare (BUG) rating is to characterize backlight. Backlight is more of a concern with luminaires that do not have a symmetric distribution (e.g., Type V) because symmetrical distributions are intended to light the same amount in front and behind the luminaire. The backlight zone is comprised of three secondary solid angles (low, medium, and high, abbreviated as BL, BM, and BH respectively). Figure A.1 graphically depicts the backlight distribution and secondary solid angles. For each secondary solid angle there is an absolute amount of lumens that can be emitted in that zone to be rated at that specific B value. Table A.1 lists the lumen output for each backlight value per secondary angle.

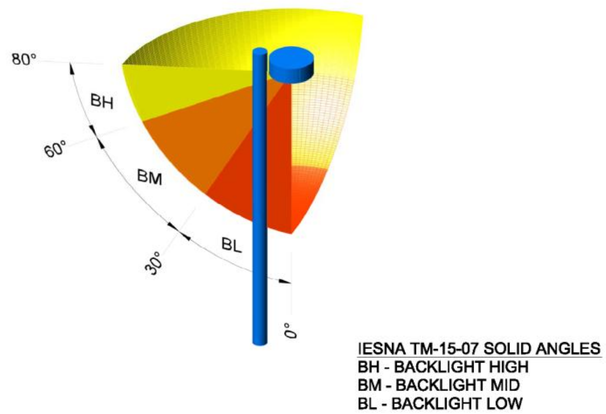


Figure A.1. BUG zones–B (backlight) (courtesy of Clanton & Associates)

Table A.1. Backlight Rating (Backlight/Trespass)

Secondary Solid Angle	B0	B1	B2	B3	B4	B5
BH	110	500	1,000	2,500	5,000	>5,000
BM	220	1,000	2,500	5,000	8,500	>8,500
BL	110	500	1,000	2,500	5,000	>5,000

The role of the “U” value in the BUG rating is to characterize uplight. Uplight characterizes skyglow and many traditional post tops have high U values. The U zone is comprised of three secondary solid angles (front/back very high, uplight low, and uplight high, abbreviated as FVH/BVH, UL, and UH). Figure A.2 graphically depicts the uplight distribution and secondary solid angles. For each secondary solid angle there is an absolute amount of lumens that can be emitted in that zone to be rated at that specific U value. Table A.2 lists the lumen output for each uplight value per secondary angle.

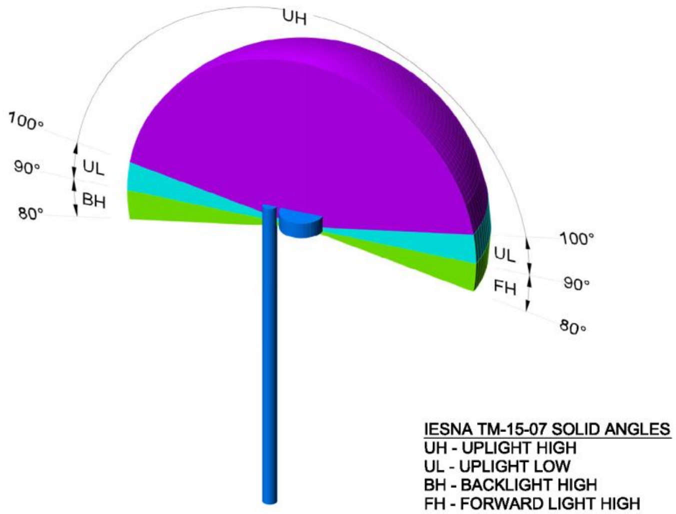


Figure A.2. BUG zones–U (uplight) (courtesy of Clanton & Associates)

Table A.2. Uplight Rating (Skyglow)

Secondary Solid Angle	U0	U1	U2	U3	U4	U5
UH	0	10	100	500	1,000	>1,000
UL	0	10	100	500	1,000	>1,000
FVH	10	75	150	>150	–	–
BVH	10	75	150	>150	–	–

The role of the “G” value in the BUG rating is to characterize glare. Glare can be disabling or discomforting. Due to the moderately low mounting height of post-top luminaires, the glare value may not be representational for post tops. The lumen rating (see Table A.3 for glare values for asymmetrical distributions and Table A.4 for symmetrical distributions) for Glare in the Luminaire Classification System is the same for a post top, a roadway fixture, a bollard, and a wallpack. A post-top luminaire and a roadway luminaire with the same G value may not appear the same because the post top is closer to the person’s line of sight. The G zone is comprised of four secondary solid angles (front/back high, front/back very high, abbreviated as FH, BH, FVH, and BVH). Figure A.3 graphically depicts the glare distribution and secondary solid angles. For each secondary solid angle there is an absolute amount of lumens that can be emitted in that zone to be rated at that specific G value.

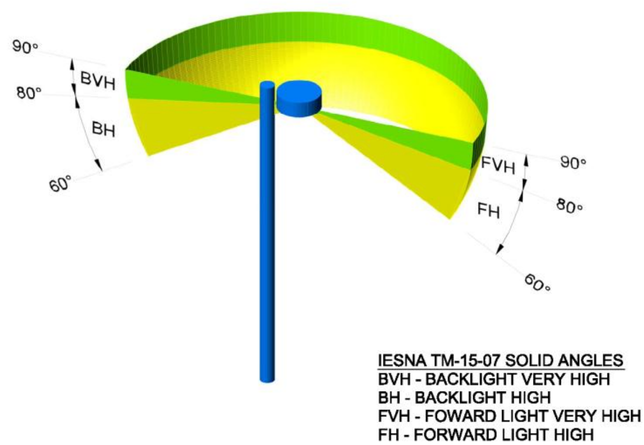


Figure A.3. BUG zones–G (glare) (courtesy of Clanton & Associates)

Table A.3. Glare Rating for Asymmetrical Distribution (Type I/II/III/IV)

Secondary Solid Angle	G0	G1	G2	G3	G4	G5
FVH	10	250	375	500	750	>750
BVH	10	250	375	500	750	>750
FH	660	1,800	5,000	7,500	12,000	>12,000
BH	110	500	1,000	2,500	5,000	>5,000

Table A.4. Glare Rating for Symmetrical Distribution (Type V)

Secondary Solid Angle	G0	G1	G2	G3	G4	G5
FVH	10	250	375	500	750	>750
BVH	10	250	375	500	750	>750
FH	660	1,800	5,000	7,500	12,000	>12,000
BH	660	1,800	5,000	7,500	12,000	>12,000

Appendix B

Power Measurements

Appendix B – Power Measurements

Voltage and current were measured at a minimum of two luminaires of each manufacturer.[1]

Table B.1. Electrical Measurement for Metal Halide Baseline

	Voltage	Current	Apparent Power
	(V)	(A)	(VA)
Luminaire 1	123.0	1.8	221.4
Luminaire 2	124.0	1.8	223.2
Average	–	–	222.6
Standard of Deviation	–	–	1.0

Table B.2. Electric Measurement for LED Luminaire from Spring City

	Voltage	Current	Apparent Power
	(V)	(A)	(VA)
Luminaire 1	123.0	0.6	73.8
Luminaire 2	121.0	0.6	72.6
Luminaire 3	125.0	0.6	75.0
Average	–	–	73.8
Standard of Deviation	–	–	1.2

Table B.3. Electrical Measurements for LED Luminaire from King Luminaire

	Voltage	Current	Apparent Power
	(V)	(A)	(VA)
Luminaire 1	123.0	0.8	98.4
Luminaire 2	125.0	0.8	100.0
Luminaire 3	125.0	0.8	100.0
Average	–	–	99.5
Standard of Deviation	–	–	0.9

Table B.4. Electric Measurements for LED Luminaire from Philips Lumec

	Current	Voltage	Apparent Power
	(V)	(A)	(VA)
Luminaire 1	123.0	0.7	86.1
Luminaire 2	121.0	0.7	84.7
Average	–	–	85.4
Standard of Deviation	–	–	0.9

[1] Frailty of the aged wiring in the park prevented direct measurement of power and power factor onsite, due to the necessary connections of the power meter used. Voltage and amperage were instead measured, and later combined with the respective power factors supplied by the manufacturers to estimate "real" power for each unit.

Table B.5. Electrical Measurements for LED Luminaire from Sentry Electric

	Voltage	Current	Apparent Power
	(V)	(A)	(VA)
Luminaire 1	124.0	0.8	99.2
Luminaire 2	120.0	0.8	96.0
Average	–	–	97.6
Standard of Deviation	–	–	2.3

Table B.6. Electrical Measurements for LED Retrofit Kit from OSRAM SYLVANIA

	Voltage	Current	Power
	(V)	(A)	(VA)
Luminaire 1	124.0	0.3	37.2
Luminaire 2	125.0	0.3	37.5
Luminaire 3	125.0	0.3	37.5
Average	–	–	37.4
Standard of Deviation	–	–	0.2

Appendix C

Measurement Setup and Procedure

Appendix C – Measurement Setup and Procedure

In order to measure the illuminance values produced by luminaires along at the walkway, measurements were taken parallel and perpendicular to the path. The locations of horizontal measurements are noted in the Figure C.1.

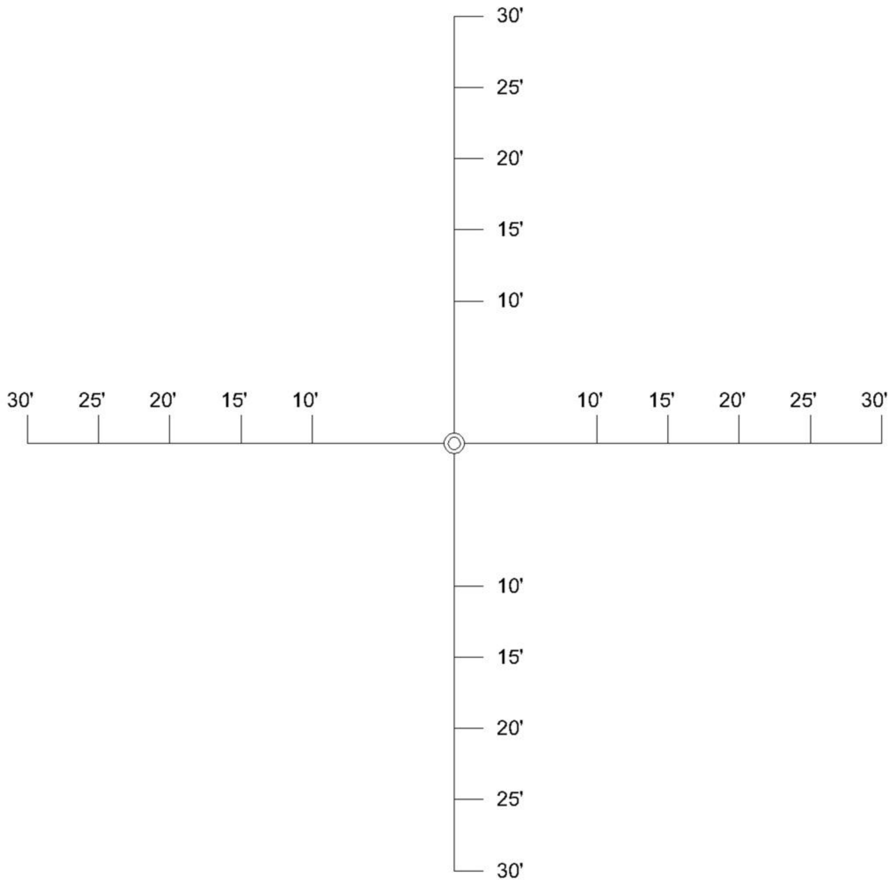


Figure C.1. Horizontal measurement plan

At each horizontal measurement point vertical measurements were also taken. Vertical measurements were taken at 2, 4, and 6-feet above finished grade. All vertical measurements were taken with the meter facing the pole where the luminaire was mounted. The locations of measurements are noted in the Figure C.2.

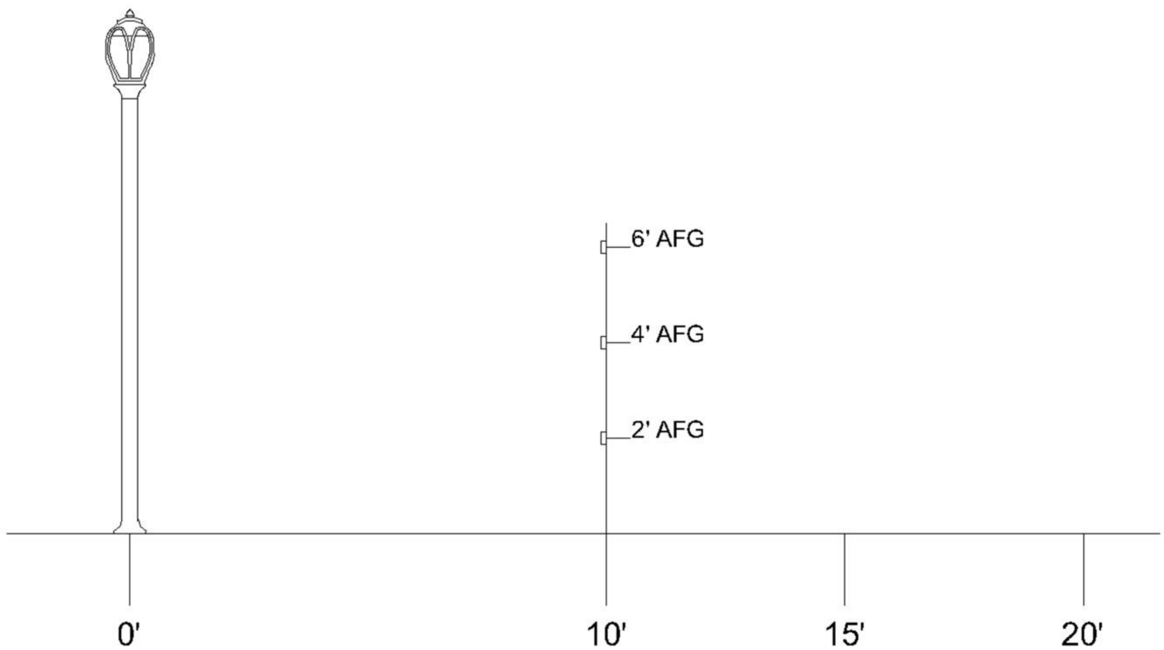


Figure C.2. Vertical measurement diagram

Appendix D

Illuminance Measurements

Appendix D – Illuminance Measurements

D.1 Metal Halide Baseline Luminaire

Table D.1. All Measurements (Horizontal and Vertical) for Both Luminaires

Luminaire 1 [(a)]					Luminaire 2				
			Vertical Illuminance (fc)					Vertical Illuminance (fc)	
Distance	**Horizontal Illuminance (fc)**	**2 ft**	**4 ft**	**6 ft**	Distance	**Horizontal Illuminance (fc)**	**2 ft**	**4 ft**	**6 ft**
				North [(b)]					
10 ft	0.70	1.18	1.70	2.28	10 ft	4.14	6.08	7.86	5.36
15 ft	0.36	0.87	1.16	1.39	15 ft	1.89	3.60	2.50	1.20
20 ft	0.26	0.70	0.80	0.83	20 ft	0.96	1.51	0.81	0.59
25 ft	0.23	0.56	0.59	0.56	25 ft	0.41	0.63	0.44	0.37
30 ft	0.12	0.41	0.41	0.40	30 ft	0.13	0.36	0.28	0.25
				South					
10 ft	1.94	3.18	3.77	3.92	10 ft	5.35	6.94	8.55	7.70
15 ft	1.08	1.73	1.70	1.54	15 ft	2.56	4.35	3.21	1.56
20 ft	0.49	0.94	0.91	0.80	20 ft	0.96	1.79	1.01	0.71
25 ft	0.24	0.56	0.52	0.48	25 ft	0.42	0.70	0.50	0.42
30 ft	0.13	0.36	0.34	0.32	30 ft	0.17	0.37	0.32	0.27
				East					
10 ft	1.35	2.73	3.28	4.61	10 ft	4.45	6.85	8.18	7.53
15 ft	1.16	2.17	2.52	2.68	15 ft	2.52	4.15	3.26	1.48
20 ft	0.70	1.52	1.71	1.59	20 ft	1.05	1.86	0.98	0.68
25 ft	0.47	1.08	1.10	1.03	25 ft	0.45	0.70	0.50	0.42
30 ft	0.31	0.81	0.79	0.72	30 ft	0.17	0.38	0.35	0.31
				West					
10 ft	1.14	1.90	2.52	3.53	10 ft	4.68	7.52	8.71	6.63
15 ft	0.77	1.55	2.07	2.26	15 ft	2.52	4.25	2.70	1.43
20 ft	0.46	1.30	1.32	1.26	20 ft	1.11	1.53	0.92	0.70
25 ft	0.34	0.96	0.89	0.84	25 ft	0.48	0.65	0.51	0.42
30 ft	0.32	0.70	0.67	0.62	30 ft	0.15	0.37	0.33	0.30

(a) Throughout this section, a number of corresponding points between the two samples show marked differences in the values measured onsite. See Section 2.5.1.1. for discussion of the likely causes underlying these results.
(b) North of luminaire, facing the fixture pole.

D.2 Spring City Luminaire

Table D.2. All Measurements (Horizontal and Vertical) for Both Luminaires

Luminaire 1 [(a)]					Luminaire 2				
		Vertical Illuminance (fc)					Vertical Illuminance (fc)		
Distance	**Horizontal Illuminance (fc)**	**2 ft**	**4 ft**	**6 ft**	Distance	**Horizontal Illuminance (fc)**	**2 ft**	**4 ft**	**6 ft**
				North [(b)]					
10 ft	1.45	2.78	5.12	7.68	10 ft	1.09	2.33	3.75	5.52
15 ft	1.32	2.82	3.67	2.62	15 ft	0.97	2.08	2.69	2.16
20 ft	0.99	2.14	1.96	0.95	20 ft	0.71	1.64	1.53	0.98
25 ft	0.68	1.41	0.96	0.57	25 ft	0.46	1.10	0.82	0.51
30 ft	0.42	0.83	0.58	0.36	30 ft	0.26	0.67	0.49	0.33
				South					
10 ft	2.31	5.35	13.52	18.26	10 ft	2.88	8.37	22.9	21.7
15 ft	3.19	8.29	8.54	4.04	15 ft	4.40	13.62	9.77	4.20
20 ft	2.85	5.01	2.97	1.19	20 ft	3.03	5.20	3.15	1.14
25 ft	1.39	2.16	1.20	0.58	25 ft	1.34	2.25	1.15	0.52
30 ft	0.61	1.16	0.61	0.34	30 ft	0.79	1.00	0.58	0.34
				East					
10 ft	0.27	0.55	0.73	1.10	10 ft	0.26	0.53	0.61	0.85
15 ft	0.30	0.25	0.62	0.77	15 ft	0.19	0.46	0.51	0.67
20 ft	0.15	0.37	0.50	0.48	20 ft	0.12	0.36	0.41	0.36
25 ft	0.11	0.36	0.37	0.33	25 ft	0.09	0.29	0.30	0.31
30 ft	0.10	0.26	0.24	0.22	30 ft	0.08	0.25	0.23	0.23
				West					
10 ft	0.69	0.99	1.57	1.94	10 ft	0.74	1.13	1.80	2.20
15 ft	0.56	0.88	0.94	0.71	15 ft	0.54	0.96	1.04	0.72
20 ft	0.48	0.56	0.44	0.33	20 ft	0.36	0.61	0.47	0.34
25 ft	0.37	0.32	0.26	0.21	25 ft	0.26	0.31	0.25	0.21
30 ft	0.41	0.21	0.17	0.15	30 ft	0.26	0.21	0.17	0.16

(a) Throughout this section, a number of corresponding points between the two samples show marked differences in the values measured onsite. See Section 2.5.1.1. for discussion of the likely causes underlying these results.

(b) North of luminaire, facing the fixture pole.

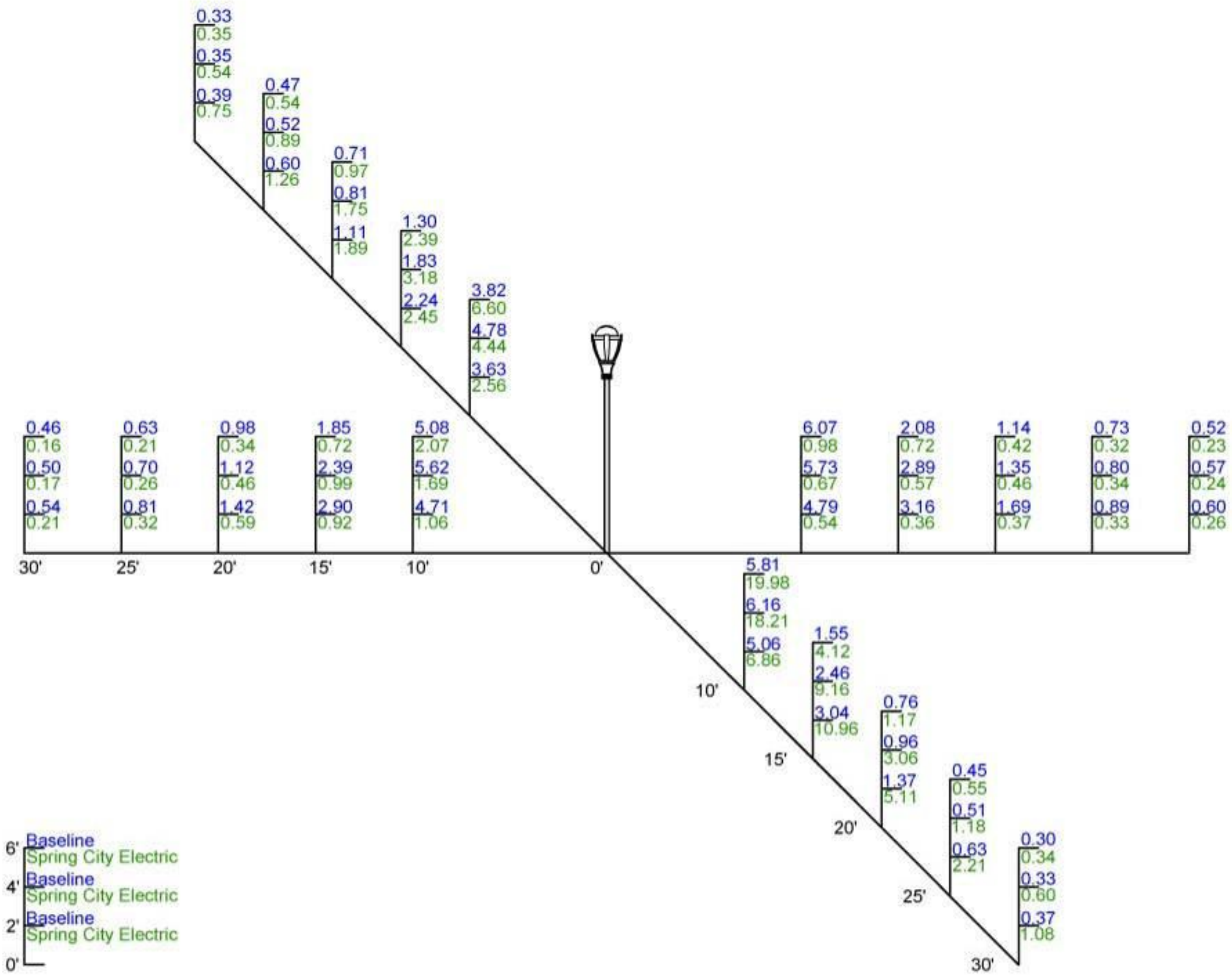


Figure D.1. Spring City average vertical measured illuminance in footcandles

D.3 King Luminaire

Table D.3. All Measurements (Horizontal and Vertical) for Both Luminaires

Luminaire 1 [(a)]					**Luminaire 2**				
		Vertical Illuminance (fc)					**Vertical Illuminance (fc)**		
Distance	**Horizontal Illuminance (fc)**	**2 ft**	**4 ft**	**6 ft**	Distance	**Horizontal Illuminance (fc)**	**2 ft**	**4 ft**	**6 ft**
				North [(b)]					
10 ft	1.99	2.98	4.15	4.97	10 ft	2.10	3.23	4.19	4.90
15 ft	1.22	2.23	2.51	2.52	15 ft	1.15	2.13	2.32	2.52
20 ft	0.77	1.51	1.55	1.32	20 ft	0.61	1.42	1.46	1.38
25 ft	0.50	1.04	0.96	0.80	25 ft	0.36	0.98	0.99	0.78
30 ft	0.28	0.72	0.65	0.51	30 ft	0.29	0.66	0.62	0.50
				South					
10 ft	2.17	3.54	4.41	5.83	10 ft	2.26	3.19	4.24	4.94
15 ft	1.30	2.41	2.76	2.87	15 ft	1.11	2.27	2.47	2.69
20 ft	0.50	1.56	1.72	1.41	20 ft	0.59	1.45	1.48	1.49
25 ft	0.58	1.14	1.02	0.73	25 ft	0.36	0.99	0.99	0.92
30 ft	0.27	0.81	0.56	0.42	30 ft	0.22	0.74	0.72	0.60
				East					
10 ft	1.97	3.14	4.23	5.21	10 ft	2.15	3.24	4.23	5.16
15 ft	1.18	2.19	2.50	2.88	15 ft	1.31	2.12	2.48	2.67
20 ft	0.67	1.50	1.67	1.63	20 ft	0.53	1.42	1.58	1.59
25 ft	0.46	1.11	1.08	0.98	25 ft	0.43	1.01	1.07	1.12
30 ft	0.25	0.79	0.77	0.60	30 ft	0.23	0.75	0.76	0.80
				West					
10 ft	1.98	2.84	4.08	5.14	10 ft	2.50	3.44	4.09	5.34
15 ft	1.13	2.11	2.42	2.59	15 ft	1.32	2.26	2.45	2.74
20 ft	0.67	1.38	1.53	1.43	20 ft	0.69	1.50	1.62	1.33
25 ft	0.44	1.01	1.01	0.87	25 ft	0.38	0.98	0.87	0.61
30 ft	0.24	0.71	0.68	0.52	30 ft	0.25	0.68	0.49	0.40

(a) Throughout this section, a number of corresponding points between the two samples show marked differences in the values measured onsite. See Section 2.5.1.1. for discussion of the likely causes underlying these results.
(b) North of luminaire, facing the fixture pole.

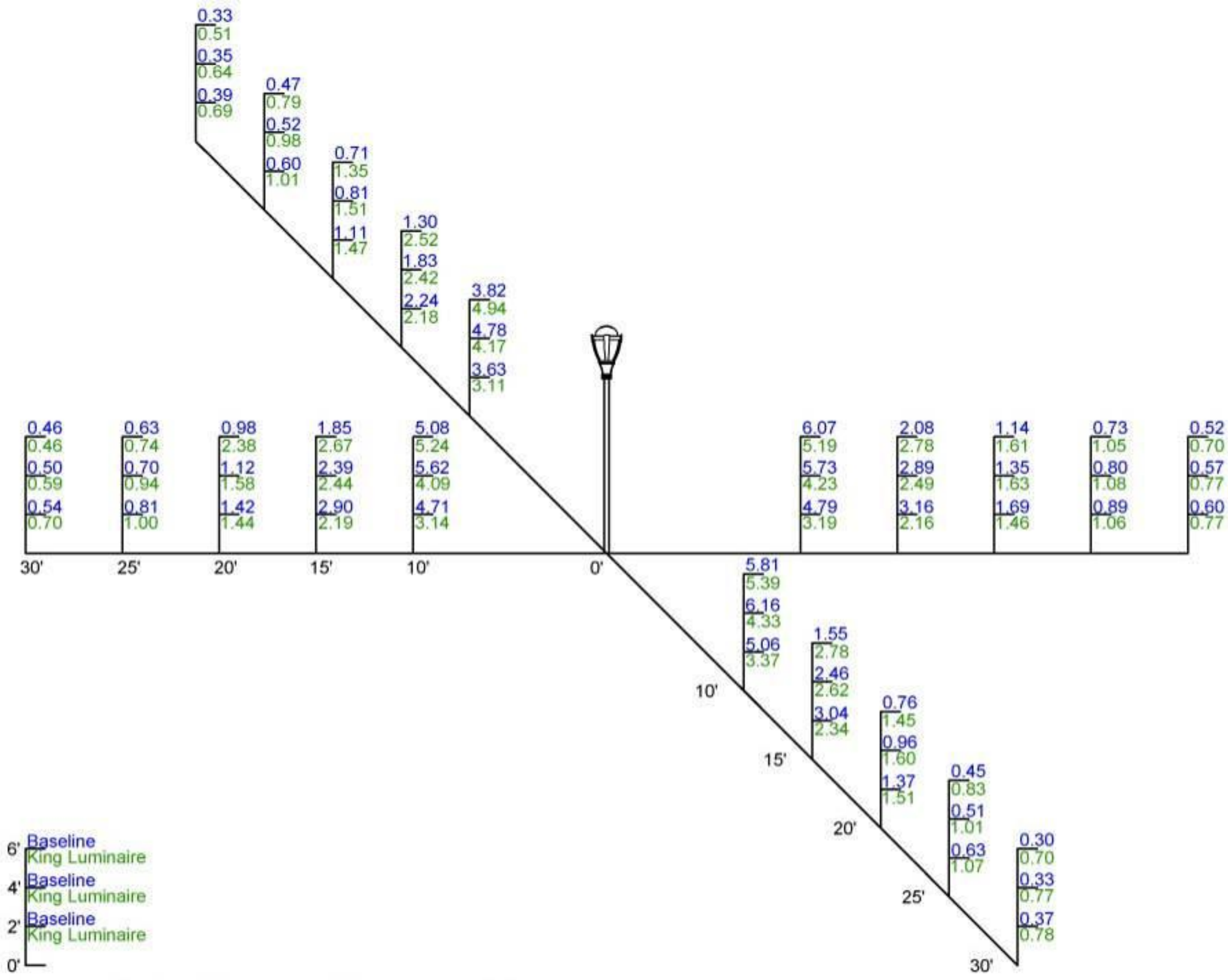


Figure D.2. King Luminaire average vertical measured illuminance in footcandles

D.4 Philips Lumec Luminaire

Table D.4. All Measurements (Horizontal and Vertical) for Both Luminaires

Luminaire 1 [(a)]					Luminaire 2				
		Vertical Illuminance (fc)					Vertical Illuminance (fc)		
Distance	**Horizontal Illuminance (fc)**	**2 ft**	**4 ft**	**6 ft**	Distance	**Horizontal Illuminance (fc)**	**2 ft**	**4 ft**	**6 ft**
North [(b)]									
10 ft	1.12	2.05	3.42	2.69	10 ft	3.72	8.26	15.02	17.6
15 ft	0.95	1.65	1.33	1.09	15 ft	4.23	8.76	8.39	4.73
20 ft	0.46	0.73	0.68	0.64	20 ft	2.45	4.95	3.23	1.43
25 ft	0.21	0.46	0.46	0.43	25 ft	1.26	2.28	1.34	0.70
30 ft	0.12	0.31	0.34	0.33	30 ft	0.53	1.11	0.63	0.44
South									
10 ft	1.91	4.14	9.14	15.52	10 ft	2.83	6.54	13.05	17.16
15 ft	2.89	5.60	6.21	3.81	15 ft	4.09	7.82	7.76	4.04
20 ft	1.91	3.63	2.61	1.34	20 ft	2.48	4.38	2.71	1.13
25 ft	0.98	1.83	1.10	0.64	25 ft	0.95	1.91	0.99	0.56
30 ft	0.46	0.91	0.60	0.41	30 ft	0.39	0.83	0.47	0.38
East									
10 ft	1.42	2.40	4.72	4.99	10 ft	1.28	2.51	4.39	2.93
15 ft	1.37	2.53	2.18	0.97	15 ft	1.40	2.07	1.56	1.05
20 ft	0.77	1.12	0.67	0.63	20 ft	0.61	0.89	0.67	0.57
25 ft	0.30	0.42	0.38	0.38	25 ft	0.21	0.47	0.42	0.42
30 ft	0.13	0.31	0.22	0.20	30 ft	0.12	0.31	0.30	0.31
West									
10 ft	2.40	5.84	11.6	20.83	10 ft	1.11	2.15	3.70	3.22
15 ft	3.86	7.27	10.02	9.72	15 ft	1.10	1.99	1.45	1.02
20 ft	2.72	5.98	5.79	3.52	20 ft	0.53	0.87	0.61	0.57
25 ft	1.66	3.81	2.73	1.36	25 ft	0.24	0.43	0.40	0.38
30 ft	1.10	2.12	1.26	0.69	30 ft	0.16	0.31	0.28	0.29

(a) Throughout this section, a number of corresponding points between the two samples show marked differences in the values measured onsite. See Section 2.5.1.1. for discussion of the likely causes underlying these results.
(b) North of luminaire, facing the fixture pole.

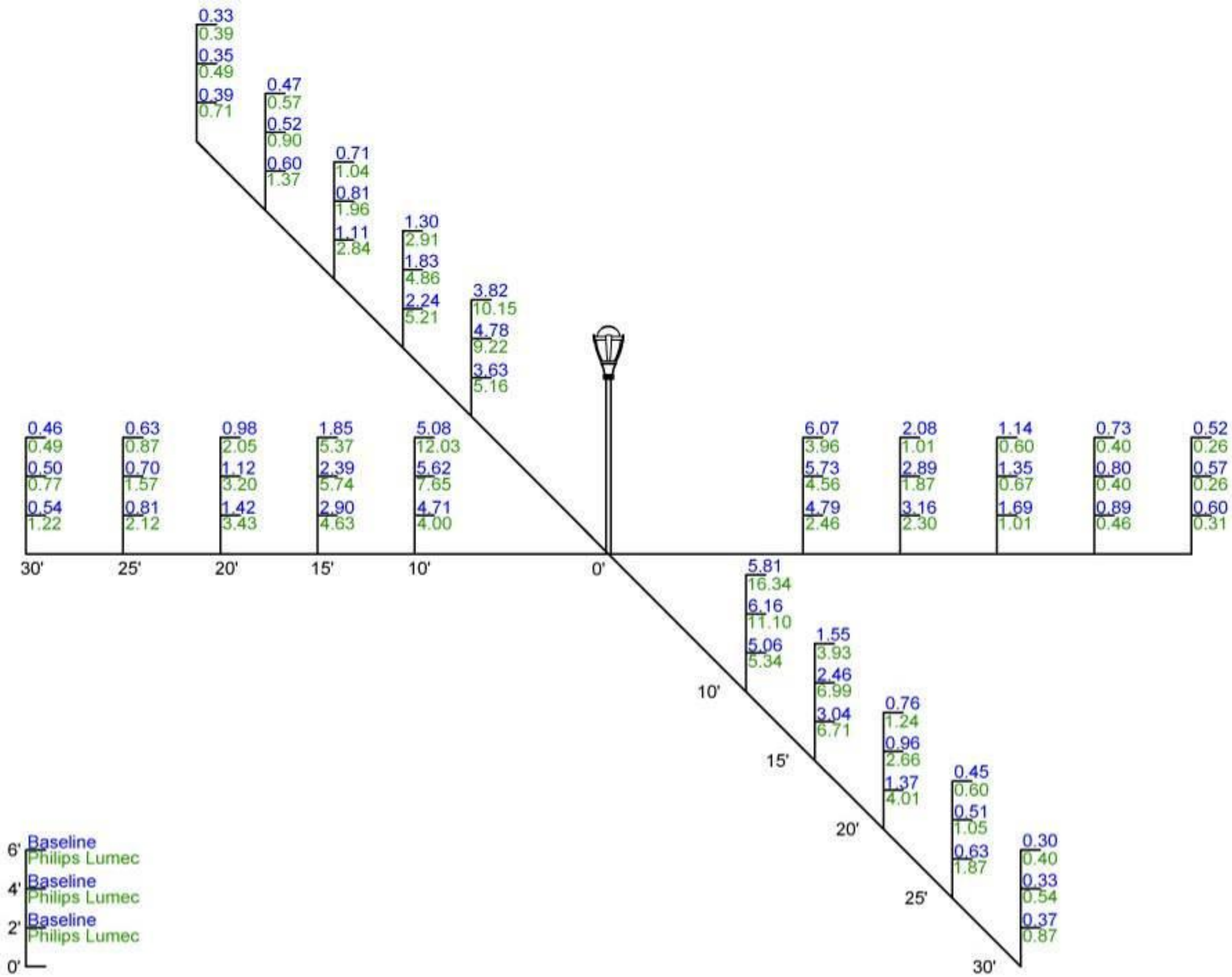


Figure D.3. Philips Lumec average vertical measured illuminance in footcandles

D.5 Sentry Electric Luminaire

Table D.5. All Measurements (Horizontal and Vertical) for Both Luminaires

Luminaire 1 [(a)]					Luminaire 2				
Distance	**Horizontal Illuminance (fc)**	**Vertical Illuminance (fc) 2 ft**	**4 ft**	**6 ft**	Distance	**Horizontal Illuminance (fc)**	**Vertical Illuminance (fc) 2 ft**	**4 ft**	**6 ft**
North [(b)]									
10 ft	1.48	2.08	2.65	2.45	10 ft	0.34	1.64	2.33	
15 ft	0.97	1.27	1.10	0.70	15 ft	0.38	1.19	1.22	
20 ft	0.34	0.66	0.50	0.37	20 ft	0.34	0.71	0.59	
25 ft	0.82	0.37	0.30	0.23	25 ft	0.17	0.41	0.32	
30 ft	0.95	0.24	0.19	0.16	30 ft	0.11	0.25	0.19	
South									
10 ft	1.41	2.3	2.77	2.92	10 ft	1.24	1.74	2.47	
15 ft	0.85	1.54	1.47	1.09	15 ft	0.66	1.28	1.36	
20 ft	0.40	0.93	0.76	0.54	20 ft	0.36	0.77	0.69	
25 ft	0.20	0.55	0.45	0.35	25 ft	0.19	0.48	0.39	
30 ft	0.12	0.38	0.31	0.26	30 ft	0.13	0.30	0.24	
East									
10 ft	1.30	2.14	2.55	3.34	10 ft	1.07	1.70	2.50	
15 ft	0.73	1.52	1.37	1.20	15 ft	0.82	1.31	1.41	
20 ft	0.43	0.94	0.85	0.62	20 ft	0.45	0.82	0.72	
25 ft	0.14	0.45	0.42	0.36	25 ft	0.20	0.49	0.38	
30 ft	0.11	0.34	0.27	0.21	30 ft	0.12	0.31	0.23	
West									
10 ft	1.50	2.13	2.83	2.56	10 ft	1.11	1.71	2.43	
15 ft	0.83	1.30	1.13	0.85	15 ft	0.74	1.20	1.22	
20 ft	0.48	0.66	0.50	0.41	20 ft	0.32	0.68	0.54	
25 ft	0.18	0.36	0.26	0.20	25 ft	0.20	0.39	0.29	
30 ft	0.14	0.28	0.20	0.20	30 ft	0.10	0.24	0.18	

(a) Throughout this section, a number of corresponding points between the two samples show marked differences in the values measured onsite. See Section 2.5.1.1. for discussion of the likely causes underlying these results.
(b) North of luminaire, facing the fixture pole.

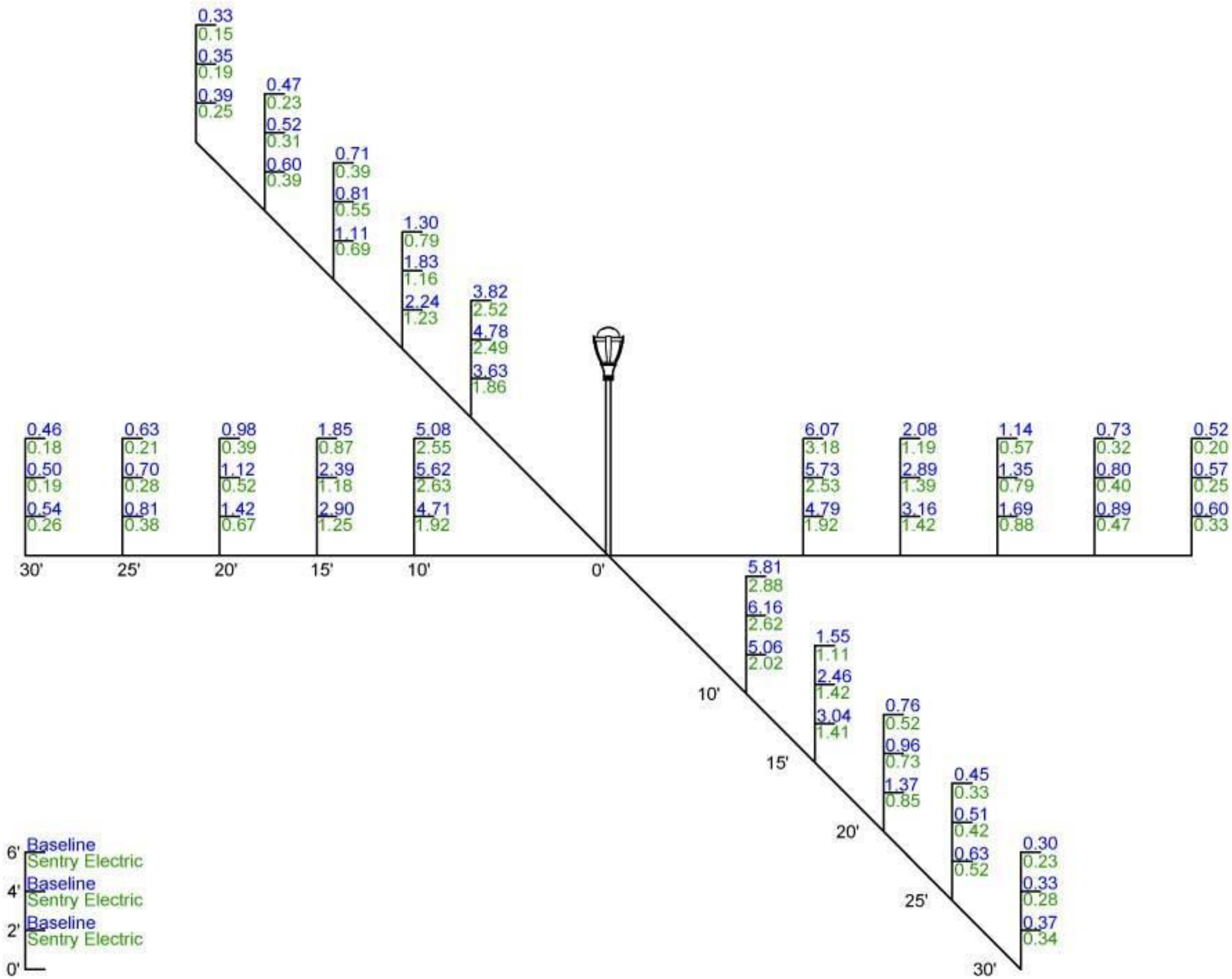


Figure D.4. Sentry Electric average vertical measured illuminance in footcandles

D.6 OSRAM SYLVANIA Retrofit

Table D.6. All Measurements (Horizontal and Vertical) for Both Luminaires

Luminaire 1 [(a)]					Luminaire 2				
		Vertical Illuminance (fc)					Vertical Illuminance (fc)		
Distance	**Horizontal Illuminance (fc)**	**2 ft**	**4 ft**	**6 ft**	Distance	**Horizontal Illuminance (fc)**	**2 ft**	**4 ft**	**6 ft**
					North [(b)]				
10 ft	1.84	2.71	3.64	5.27	10 ft	1.03	1.72	2.31	2.34
15 ft	1.11	2.11	2.64	2.13	15 ft	0.61	1.23	1.14	0.81
20 ft	0.68	1.58	1.34	0.89	20 ft	0.36	0.68	0.52	0.36
25 ft	0.41	0.97	0.71	0.48	25 ft	0.18	0.46	0.32	0.22
30 ft	0.25	0.57	0.43	0.32	30 ft	0.12	0.23	0.18	0.15
					South				
10 ft	0.93	1.23	1.43	1.43	10 ft	0.51	0.66	0.76	0.81
15 ft	0.41	0.64	0.65	0.54	15 ft	0.24	0.43	0.41	0.35
20 ft	0.20	0.38	0.34	0.27	20 ft	0.14	0.23	0.24	0.20
25 ft	0.11	0.24	0.21	0.17	25 ft	0.08	0.22	0.16	0.15
30 ft	0.07	0.15	0.13	0.11	30 ft	0.04	0.09	0.08	0.11
					East				
10 ft	1.55	2.29	3.00	3.39	10 ft	1.00	1.66	2.18	2.55
15 ft	1.05	1.57	1.49	1.02	15 ft	0.73	1.32	1.18	0.80
20 ft	0.44	0.81	0.61	0.41	20 ft	0.33	0.69	0.51	0.36
25 ft	0.18	0.41	0.31	0.22	25 ft	0.20	0.37	0.28	0.21
30 ft	0.12	0.24	0.19	0.15	30 ft	0.16	0.23	0.18	0.15
					West				
10 ft	0.72	0.92	1.15	1.30	10 ft	0.44	0.56	0.67	0.75
15 ft	0.30	0.58	0.62	0.60	15 ft	0.24	0.38	0.35	0.34
20 ft	0.14	0.32	0.35	0.31	20 ft	0.17	0.24	0.21	0.20
25 ft	0.11	0.22	0.21	0.19	25 ft	0.21	0.15	0.13	0.12
30 ft	0.06	0.15	0.14	0.13	30 ft	0.56	0.12	0.10	0.09

(a) Throughout this section, a number of corresponding points between the two samples show marked differences in the values measured onsite. See Section 2.5.1.1. for discussion of the likely causes underlying these results.
(b) North of luminaire, facing the fixture pole.

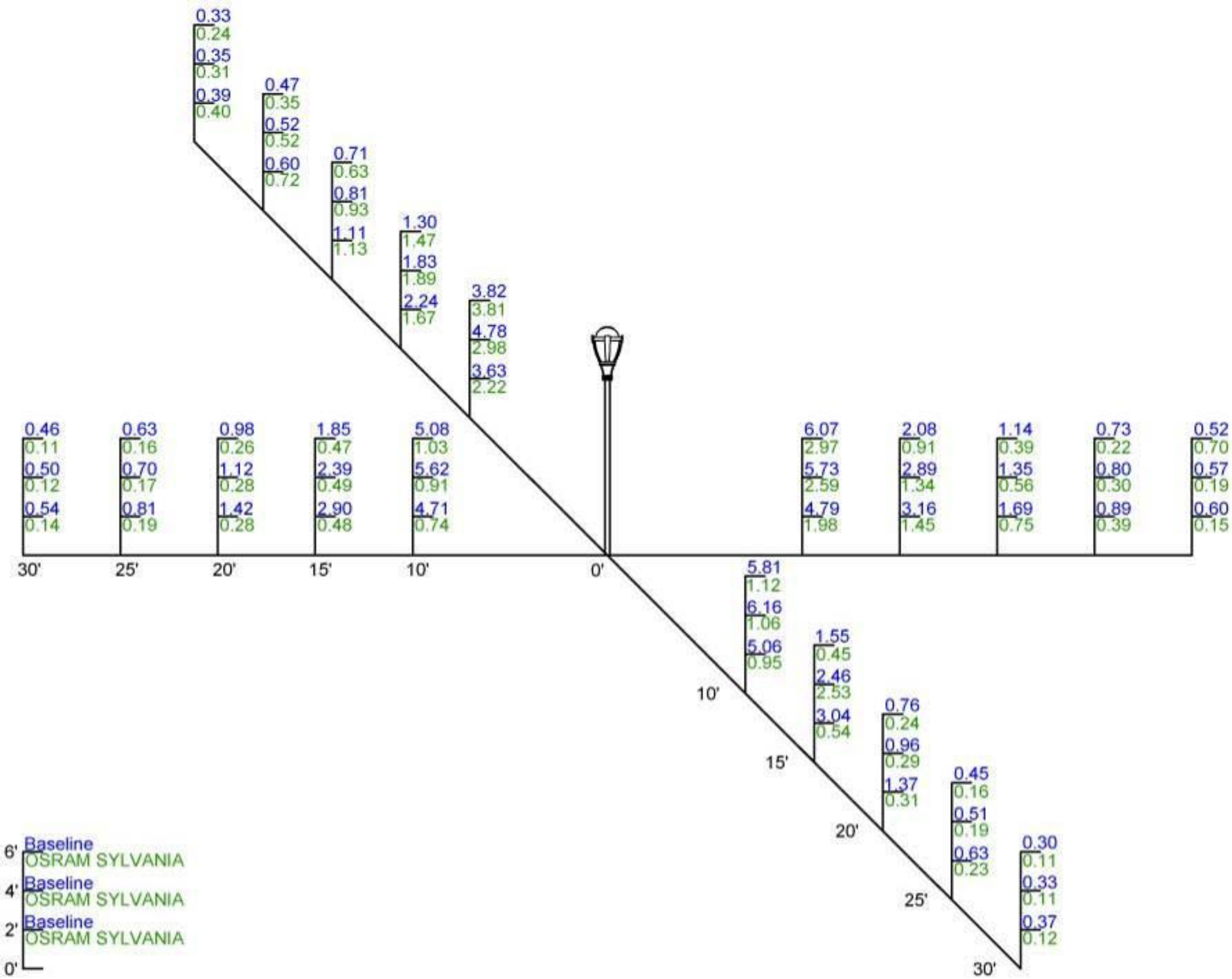


Figure D.5. OSRAM SYLVANIA average vertical measured illuminance in footcandles

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