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NEW YORK CITY CENTRAL PARK LED TRIAL: FINAL REPORT

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THE CLEAN REVOLUTION

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ACKNOWLEDGEMENTS

The LightSavers global LED trials ran from October 2009 to January 2012 and aimed to provide greater certainty about the state of LED technology. During the trials, lighting managers from nine of the cities independently tested the performance of more than 500 luminaires representing 27 different commercially available LED products, using the same measurement protocol. Key findings of the trials were:

- LEDs achieve the expected 50-to-70 percent energy savings and reach up to 80 percent savings when coupled with smart controls;
- Even with these energy savings, the vast majority of tested products exceeded local lighting standards;
- Many commercial LED products tested show behavior indicative of lifespans of 50,000 hours, though the results from the trials should not be used for predictive purposes;
- LED products generally show very little change in color;
- The 'catastrophic' failure rate of LED products over 6,000 hours is around one percent, compared, for example, up to 10 percent for metal halide fixtures over a similar time period;
- In cities where surveys were conducted, the public prefers LED illumination, with about 90 percent of survey respondents supporting a full rollout of LEDs across city street lights.

It should be noted that the LED luminaire product tested in this trial was designed and manufactured several years ago. It would be expected that recent generations of products should exhibit even better performance. The Climate Group's LightSavers trial concludes that LEDs are now mature enough for scale-up in most outdoor applications, and that LEDs combined with smart controls promise greater savings.

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EXECUTIVE SUMMARY

The Central Park LED trial, which was conducted by the New York City Department of Transportation (NYCDOT) October 2009 - January 2011, yielded valuable data that has enabled a useful evaluation of the performance of the five LED products. Here is a summary:

1. **Illuminance**. Results are provided from both the NYCDOT and the US Department of Energy (US DOE) measurement methodologies. While these results provide complementary insights, they are not directly comparable, since each agency used a different sampling grid with different goals. The NYCDOT results indicate performance that emphasizes light falling on the pedestrian pathway. NYC-1(a) stood out for its performance. The US DOE results compare illuminance produced radially, thus avoiding the methodological challenges posed by the variable distances between the light poles at the site. Two luminaires stood out—NYC-1(a) and NYC-1(b). Two LED luminaires provided significantly less illumination than the baseline MH according to both methodologies—NYC-1(d) and NYC-1(e). Hot weather in the months of July and August 2010 did not appear to affect LED illuminance.

2. **Color temperature (CCT)**. All five LED products showed less than one percent color shift on average over the 13-month period, an excellent result. By comparison, the metal halide (MH) luminaire's color temperature shifted eight percent.

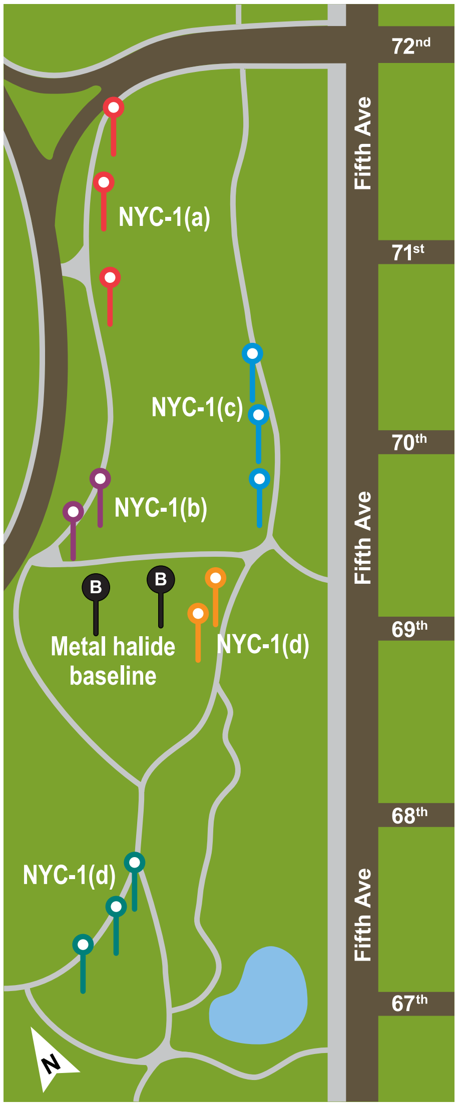
3. **Energy**. All of the LED products achieved significant energy savings compared with the baseline metal halide lamp, ranging from 55% to 83%. In the case particularly of NYC-1(d) and NYC-2(e), these savings were largely due to significantly less illumination that they provided compared with the baseline MH.

4. **Lumen maintenance**. Three of the five products maintained relatively stable light output over the first year—one LED product's light output even increased. These results indicate that after an initial period of volatility of the LED light source due to various factors, lumen output appears to stabilize. A trial lasting three years would be needed to yield data that could be used for predictive purposes.

5. **Economic payback**. A full-scale LED replacement program in Central Park should have simple economic payback below five years, should the capital cost per LED fixture eventually fall into the $800 - $1,200 range. Over 12 years, NYC-1(a), for example, would save $2.3 million in energy costs and 6,000 tonne tones of CO_2.

In conclusion, the trial increased our confidence that LED technology has matured enough to produce some products that provide excellent performance compared with the incumbent metal halide technology. Three products, NYC-1(a), NYC-1(b), and NYC-C all exhibited very good lumen maintenance and color stability over their first year of operation.

Background



With 38 million visitors annually, Central Park, a US National Historic Landmark designed by Frederick Olmsted and Calvert Vaux, is the second most popular tourist destination in the world, according to Travel + Leisure Magazine. Its appearance over the years in many movies and television shows has bestowed iconic status on Central Park. Its 843 acres of grassy fields, woodlands, lakes and ponds, a reservoir, stone bridges, and recreational facilities are estimated to have a real estate value of $530 billion!

The Central Park Conservancy, a private charitable organization, manages Central Park under a contract with the City of New York Department of Parks and Recreation. The Conservancy has raised more than $300 million to restore Central Park to its original 19th century splendor and to transform it into a model for urban parks worldwide. Today, the Conservancy provides more than 85% of Central Park's annual $20 million operating budget and takes care of the Park.

Miles of winding pedestrian paths are a key feature of Central Park. They are lit at night by post-top antique-style luminaires. The Department of Parks and Recreation has an agreement with the NYCDOT, to maintain these metal halide lamps. The NYCDOT plans to upgrade to LED luminaires to improve the aesthetic quality of the park at night and reduce operation and maintenance costs.

The LightSavers LED Trial

The primary aim of the LightSavers trials is to assess the quality and performance of LED illumination over time—12-to-18 months—in outdoor lighting applications, compared with the products they would eventually replace. From February - July 2009, the NYCDOT installed five sets of LED luminaires, a total of 13 luminaires, along adjacent pedestrian walkways in the eastern side of Central Park Park near Fifth Avenue at East 79th Street. The LED luminaires replaced metal halide post-top luminaires of heritage design with similarly designed post-top LED luminaires. Table 1 below summarizes the manufacturers' data on the baseline and LED luminaires.

TABLE 1: Summary of Manufacturers' Data

Product Reference	Nominal Rating (Watts)	Luminaire Output (lumens)	Luminaire Efficacy (lumens/watt)	Distribution Type
Metal halide baseline (MH)	210	8,499	40.5	v
NYC-1(a)	75	2,416	32.2	II
NYC-1(b)	82	4,238	51.7	v
NYC-1(c)	100	4,905	49.1	v
NYC-1(d)	83	4,584	55.2	v
NYC-1(e)	40	3,200	80.0	v

Note that the baseline metal halide lamp and four of the five LED products are of Type V distribution, which illuminates in a 360° circular symmetry, glowing at all lateral angles around the luminaire (like an antique gas lamp). However, one LED product, NYC-1(a), is of Type II distribution, which produces a narrow, longitudinal symmetry, primarily illuminating the pedestrian walkway in front of the lamp post.

Here is an overall summary of the trial:

- Central Park has 1,600 post-top luminaires, of antique style design, sitting atop nine-foot tall poles that are typically spaced 80 feet apart, but with considerable variability in distance between them due to the curvilinear character of the pedestrian walkways and the uneven terrain.

- Existing lamps are high intensity discharge (HID) lamps of the metal halide (MH) type , Philips Switch Start MH Std 175W/640 Mog ED28 rated at 175 watts, which uses a M57/E type ballast that draws 35 watts, for a total nominal rating of 210 watts.

- In Central Park NYCDOT adheres to IESNA RP-8-00 (Table 6: Recommended Values for Medium Pedestrian Conflict Areas), which is based on IESNA DG-5 *Recommended Lighting for Walkways and Class I Bikeways* and also described in IESNA RP-33-99, *Lighting for Exterior Environments*. The recommended value for average horizontal illuminance on pavement is 5 lux (~0.5 footcandles).

- Central Park's heritage luminaires operate 4,100 hours annually, leading to electricity use of 1,312,000 kWh, which costs $196,800 and emits 681 tonnes of carbon dioxide (CO_2) annually.

- Total annual maintenance costs for the Park's lighting are $134 per luminaire/pole, for a total of approximately $214,160 annually.

Ambient lighting conditions for the trial were excellent. There was minimal trespass light coming from 5th Avenue directly east of the study area, which might have confounded light meter readings. Although some trespass light may have entered the study area from East Drive directly west of the pedestrian walkways, this was judged not to be a factor in the light readings taken for LED luminaire products designated *NYC-1(a)* and *NYC-1(b)* located closest to that roadway.

The selected study area, however, presented significant challenges. Central Park's walkways are heavily traveled, winding, and characterized by elevation changes, making it difficult to isolate a section of walkway that might be ideal for testing. Also, distances between poles vary, making it difficult to achieve consistency in the measurement grid from one product group to another.

Field testing of LED luminaires involves compromises that seldom meet the exacting scientific demands and precision of measurement possible in a laboratory setting. However, testing in the field exposes the product to actual weather and environmental conditions over time, and can yield valuable performance insights specific to the products and site, enabling lighting asset managers to better judge what products will work best for them in a specific application.

The Monitoring Protocol and Methodology

The objective of the trial was to conduct a product evaluation of five LED luminaires in realistic field conditions **over time**. The trial aimed to determine the effects of environment—weather, seasonal changes, dust, grime, etc.—over a period of a year or more on the selected LED luminaire products in real-world conditions, in comparison to the incumbent MH luminaires now in use on Central Park's pedestrian walkways. In addition, the trial sought to quantify energy savings replacement for the Park's 1,600 luminaires with LED luminaires, as well as calculate financial metrics associated with investment such a program. NYCDOT staff adopted the following protocol in implementing the trial.

1. **Installation**. An existing group of post-top luminaires designated as the baseline was cleaned and relamped with new Philips MH lamps as per normal maintenance procedures. Meanwhile, new post-top LED luminaires were installed by NYCDOT staff on the site over a period of several months, July - September 2009, as product was received from manufacturers.

2. **Burn in period and measurements**. The baseline lamps and LED luminaires were "burned in" for periods ranging from 1,300 - 3,000 hours. For the purpose of

this report, the first set of measurements were recorded in November 2009 after the burn in period. The following initial set of measurements were taken for each group of luminaires, baseline and LED:

a) Voltage and amperage,
b) Photopic illuminance,
c) Scotopic illuminance,
d) Scotopic/photopic ratio,
e) Correlated color temperature (CCT),
f) Ambient temperature.

The monitoring team noted date, time, weather, and site conditions when they took measurements.

3. **Power measurements**. Spot voltage and amperage measurements of the baseline group and the LED luminaire group(s) luminaires were taken, from which apparent power was calculated. Power factor was not measured.

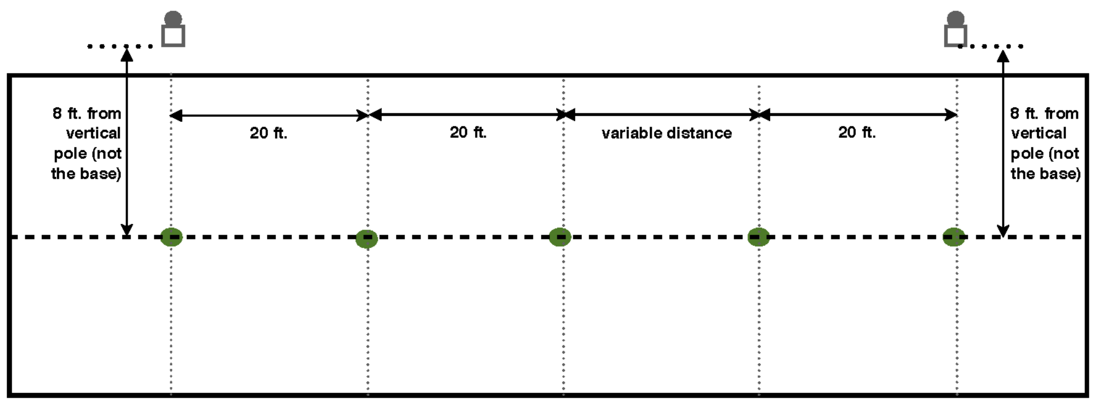
4. **Illuminance measurements**. Both photopic and scotopic illuminance readings were taken using the Solar Light SL-3101 radiometer, equipped with photopic and scotopic detectors that adhere to CIE spectral luminous efficiency curves. The equipment was calibrated to the National Institute of Standards and Technology (NIST) and has an accuracy of ±5 percent according to the manufacturer. The illuminance and CCT measurements were taken with the equipment placed on the pavement surface, facing the light source. Vertical illuminance measurements were not taken by the NYCDOT team.

5. **Correlated color temperature (CCT)**. CCT was measured using the Konica Minolta CL-200 Chroma Meter and were taken twice, a baseline measurement in October 2009 and final measurement in January 2011, 15 months later. The meter has an accuracy of ±2 percent according to the manufacturer.

6. **Ambient temperature**. Ambient temperature measurements were taken using a NYCDOT's staff person's Blackberry.

7. **Periodic testing**. IES RP-8 does not specify a measurement grid for pedestrian pathways, so the following grid was improvised to address the varying distances found between poles in the study area. Illuminance measurements were taken and recorded accordingly at random monthly intervals over 13 months, November 2009 - November 2010. Over the course of this period, a total of 65 illuminance measurements were recorded for each luminaire product group, excepting NYC-1(d), for which 52 measurements were taken. Measurements for NYC-1(d) did not include a sampling point in front of the right pole—no reason was given by NYCDOT staff.

FIGURE 1: NYCDOT Central Park trial illuminance sampling grid



8. **Dirt depreciation test**. In order to assess the impact of luminaire dirt depreciation (LDD) on lumen maintenance, the LightSavers trial protocol recommended washing of all luminaires in the trial area at the end of the trial[1]. Two complete set of illuminance readings were to be taken before and after washing the luminaires. The difference in average values for each group of luminaires before and after washing would have yielded an approximate LDD for each group. Due to lack of resources, however, NYCDOT was unable to undertake this procedure.

9. **Lumen maintenance**. LED streetlight luminaire manufacturers claim their products will typically maintain lumen output at 70 percent or above (L_{70}) their original output for 50,000 hours or more. Indeed, the five LED luminaire manufacturers in this trial claimed lifetimes ranging from 50,000 - 75,000 hours for their products. It is challenging to evaluate such claims in a real world trial. The IESNA TM-21 Working Group, during the recent course of its evaluation of 40 sets of laboratory data on LED light source lumen maintenance over 6,000 hours or more, concluded that lumen depreciation can change in various ways that is difficult to model or predict, especially during the first 1,000 hours of operation when rapid variations have been observed.[2] Ideally, in order to have predictive value, a field trial should be 10,000 hours or more, i.e., three years, with the last 5,000 hours yielding the most consistent and reliable information. While ideal, such a trial is not practicable in a municipal context given limited resources, as well as the need to make procurement decisions in a shorter time frame. In this trial, data was collected approximately monthly over a period of 13 months, or 4,441 hours. The lumen maintenance results from the trial provide a useful snapshot of how the five LED products performed relative to each other during this period in terms

[1] The Climate Group, *LightSavers Technology Monitoring Protocol*, Version 1.2, November 12, 2009

[2] IESNA, *Projecting Long Term Lumen Maintenance of LED Light Sources*, TM-21-11, August 2011

of light loss. However, the results should not be used to predict how these products will perform in the future.

Results

Illuminance comparisons—NYCDOT measurements

The main aims of monthly illuminance measurements as recorded on the pedestrian walkway are to:

- Compare over time the performance LED products with each other and with the baseline metal halide lamp, averaging a high volume of data to reduce uncertainty;

- Create a longitudinal set of data that tracks lumen maintenance over time; and

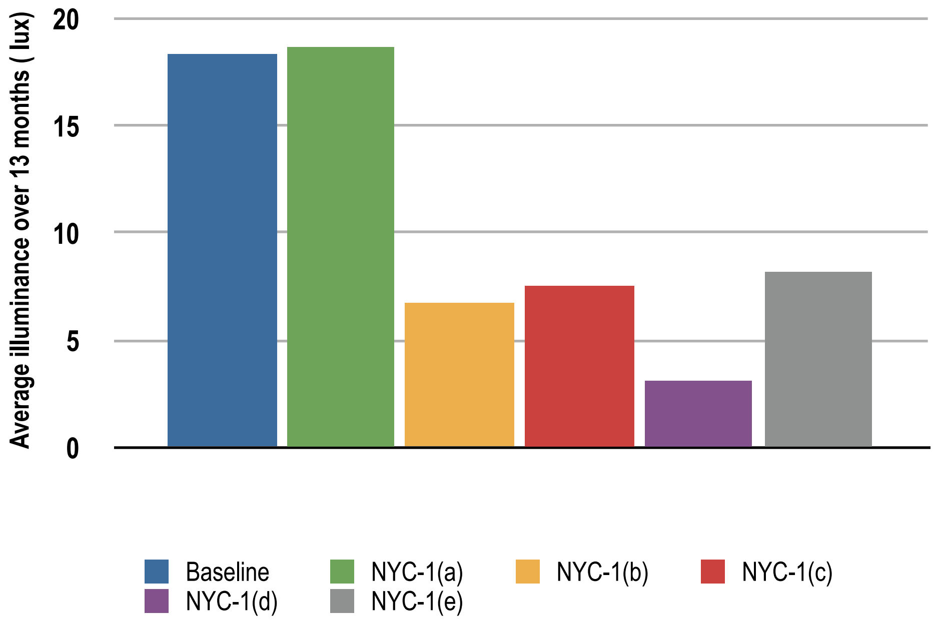
- Investigate how well the luminaires directed light to the surface of the walkway[3].

Graph 1 below shows that one LED luminaire, NYC-1(a), matched the illuminance values on the surface of the pedestrian walkway average performance of the baseline metal halide luminaire over the trial period. The other LED luminaires produced half or less the illuminance on the pedestrian walkway, largely due to their Type V radial distribution pattern, hence not as much light fell on the pathway as a result. As noted above, measurements for NYC-1(d) omitted a sampling point in front of the right pole and so should be discounted or disregarded for the purposes of this comparison.

Since NYC-1(a) incorporates optics that offer Type II distribution that directs more light in a narrow band across the pavement and less in the area surrounding the luminaire, this result is not unexpected. The US DOE report provides complementary information based on a radial or circular measurement grid that is more appropriate for Type V distribution, and its results are summarized below.

[3] Note that LED luminaire NYC-1(a), due to its Type II distribution, held an inherent advantage over the other four LED luminaires in the trial in directing light to the pavement surface.

GRAPH 1: Central Park illuminance (NYCDOT measurements)



Illuminance comparisons—US DOE measurements

The US DOE utilized an illuminance measurement system based on recommendations for pedestrian walkways prescribed by IES DG-5[4] and RP-33[5]. The Central Park measurements were taken around two luminaires from each manufacturer, in four directions from each luminaire: two parallel and two perpendicular to the adjacent walking path. The two values measured for each sampling point for each product were averaged to produce the values shown in Graph 2 below, which shows, as one example, the averaged measured results side by side for LED product NYC-1(b) and the MH baseline.

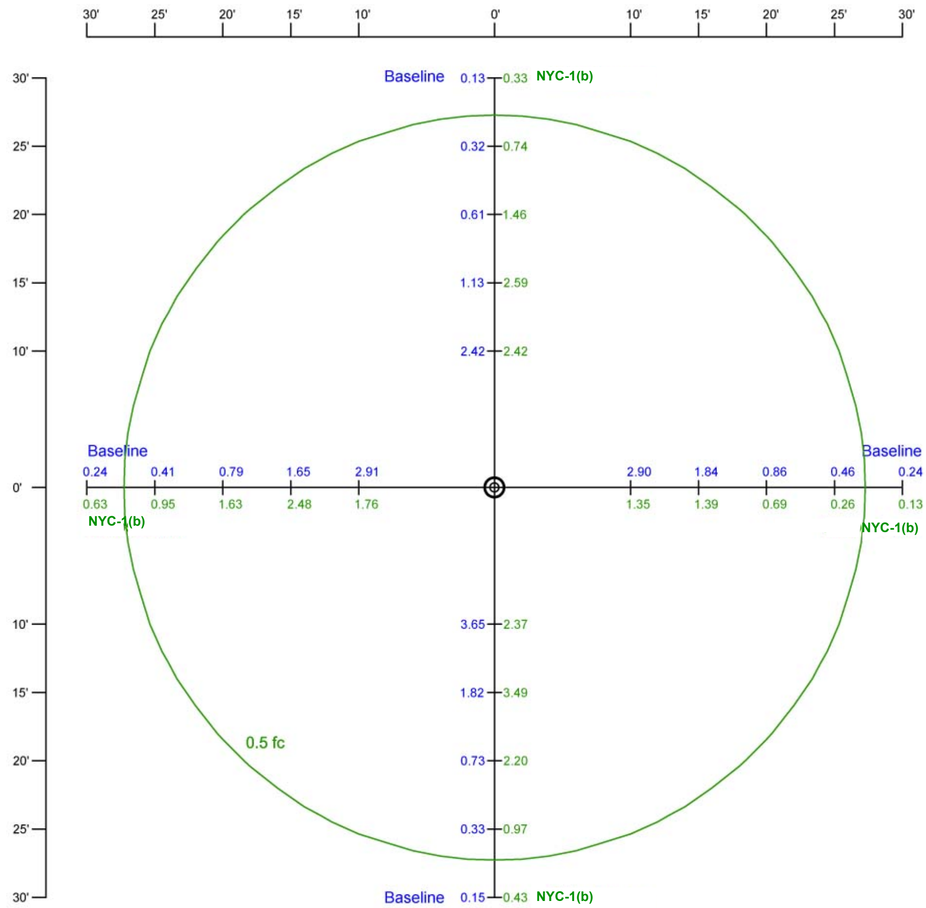
The average horizontal illuminance levels for each of the LED luminaires was compared with those levels for the baseline MH luminaire. The percentage differences between each LED luminaire and the baseline are summarized in Table 2 below. The percentage differences ranged from about 50% less for NYC-1(e) to about 62% more for NYC-1(b). NYC-1(a) and NYC-1(b) in particular provided greater horizontal illuminance values than the baseline MH luminaire. The remaining three luminaires provided less horizontal illuminance overall than the existing baseline MH product. The US DOE report notes that

[4] IESNA DG-5-1994 Recommended Lighting for Walkways and Class 1 Bikeways

[5] IESNA RP-33-1999 Lighting for Exterior Environments

the LED luminaires tended to have higher light levels at greater horizontal distances, indicating to a wider distribution of light than the baseline MH luminaire.[6]

GRAPH 2: Central Park radial illuminance (US DOE measurements)



Source: R. T. Goettel and M. Myer, *Demonstration of Light-Emitting Diode Post-top Lighting at Central Park in New York City*, unpublished US DOE report, May 2011

[6] R. T. Goettel and M. Myer, *Demonstration of Light-Emitting Diode Post-top Lighting at Central Park in New York City*, unpublished US DOE report, May 2011

Table 2: Comparison of horizontal illuminance differences (US DOE measurements)

Product Reference	NYC-1(a)	NYC-1(b)	NYC-1(c)	NYC-1(d)	NYC-1(e)
Distribution	Type II	Type V	Type V	Type V	Type V
10' from pole	-59.26%	-33.67%	-27.95%	-60.27%	-66.33%
15' from pole	-11.18%	54.66%	-24.22%	-53.42%	-63.35%
20' from pole	45.33%	98.67%	-16.00%	-48.00%	-58.67%
25' from pole	55.26%	92.11%	15.79%	-31.58%	-50.00%
30' from pole	94.74	100.00%	31.58%	15.79%	-10.53%
Average	**24.98%**	**62.35%**	**-4.16%**	**-35.49%**	**-49.78%**

Source: R. T. Goettel and M. Myer, *Demonstration of Light-Emitting Diode Post-top Lighting at Central Park in New York City*, unpublished US DOE report, May 2011

The illuminance results from the NYCDOT and US DOE measurements are not directly comparable, since each agency used a different sampling grid pursuing different objectives, but the results do provide complementary insights into the relative performance of the LED products. The results from the NYCDOT measurements are indicative of performance that emphasizes light falling on the pedestrian pathway. The results from the US DOE measurements compare average illuminance produced radially by the LED luminaires, using consistent distances between sampling points and thus avoiding the methodological challenges posed by the variable distance between the light poles along the pathway.

In the case of both the NYCDOT and US DOE measurement approaches, however, three of the LED products fell short of matching the light output of the baseline MH luminaire, which accounted for the significant energy savings observed in the case of those LED products.

Correlated color temperature (CCT)

Changes in color temperature of the illumination produced by LED luminaires over time may indicate a number of problems stemming from degradation of the components of the LED device, especially the materials that encapsulate and cover the LED diode.

As the following Table 3 indicates, there was very little change in CCT over the period, October 2009 - January 2011, in all five of the Central Park LED luminaires, an excellent result. The metal halide luminaire's color shifted, however, by eight percent.

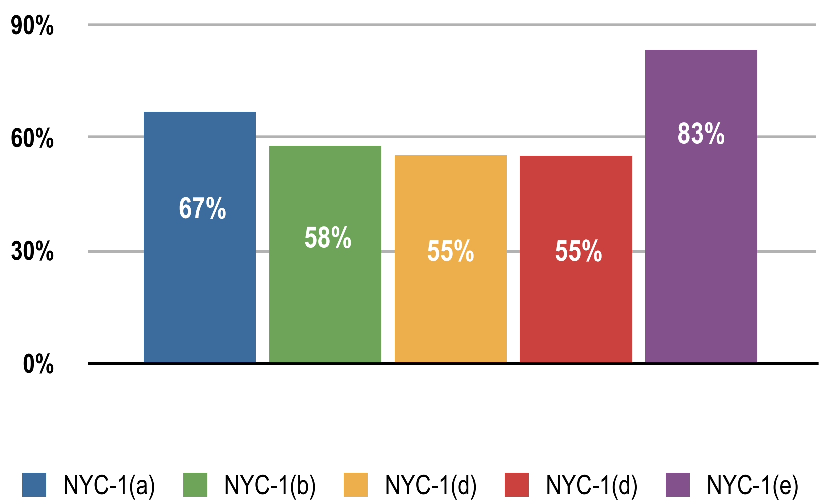
TABLE 3: Change in color temperature (CCT)

Product Reference	Manufacturer's Nominal CCT (°Kelvin)	Measured CCT Oct-2009 (°Kelvin)	Measured on Oct-2009 vs. Nominal	Measured CCT Jan-2011 (°Kelvin)	% Change
Baseline	3700	n.a.	n.a.	4001	8.14%
NYC-1(a)	3000	2922	-2.6%	2938	0.55%
NYC-1(b)	6000	4565	-23.9%	4523	-0.92%
NYC-1(c)	5000	5523	10.5%	5496	-0.49%
NYC-1(d)	4700	4419	-6.0%	4412	-0.16%
NYC-1(e)	4900	4289	-12.5%	4305	0.37%

Energy savings

As seen in Graph 3 below, all of the LED luminaires saved significant amounts of energy, ranging from 55% to 83%, with NYC-1(e) reducing electricity consumption from the baseline by the largest amount. However, the illumination provided by both NYC-1(d)

GRAPH 3: LED energy savings from baseline MH



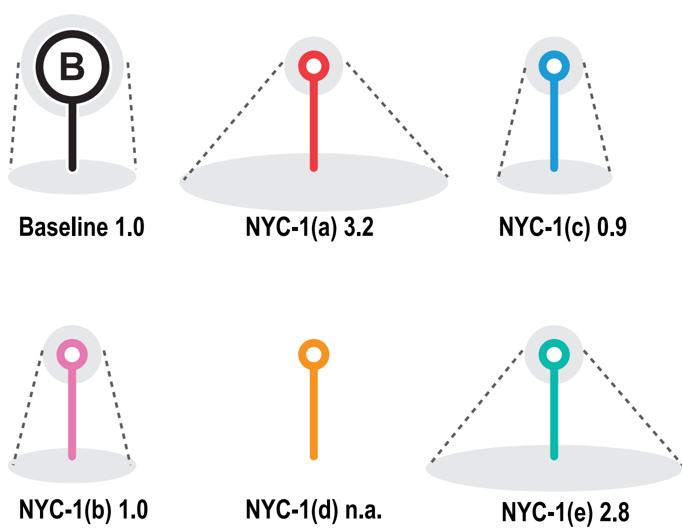
and NYC-1(e) was significantly below the baseline MH in both the NYCDOT and the UDS DOE measurements, accounting for the significant energy saved in these two cases.

Luminaire site-specific system effectiveness

A key advantage that LED luminaires hold over conventional HID luminaires is that the light they produce is more directional. Thus, more of the light produced by the LED luminaire reaches the surface where it is needed. However, there does not currently exist a standard lighting metric for measuring how effective luminaires are projecting light on a specific surface in a trial like this one.

We propose a "site-specific system effectiveness" metric that is calculated for each LED luminaire simply by dividing its average photopic illuminance measured on a sampling grid by its apparent power value. The calculated value of lumens per watt is then indexed to the comparable baseline value, which is normalized to the value 1.0. This metric does not take into account uniformity.

GRAPH 4: Site-specific system effectiveness indexed to the baseline metal halide lamp (value = 1.0)



Graph 4 above shows that LED luminaire NYC-1(a) is 3.2 times as efficient as the baseline MH luminaire at directing light to the surface of the pedestrian walkway. However, this is likely due to the fact that its Type II distribution delivers more light to the pavement surface than either the MH luminaire or the other LED luminaires, which instead illuminate radially instead of in a longitudinal manner. LED luminaire NYC-1(e) is about 2.8 times more efficient that the baseline. LED luminaires NYC-1(b) and NYC-1(c) are roughly comparable to the baseline luminaire in on-site system effectiveness. There was not enough data to make a determination for NYC-1(d)—measurements at one sampling point were not taken over the course of the trial.

Ascertaining how much apparent power it takes for a luminaire to deliver its light to a surface grid can assist lighting asset managers in understanding the directional effectiveness of different LED luminaire products at illuminating a surface, compared with conventional lamps such that rely more on luminaire lens optics to direct and shape their output.

Lumen maintenance

For the purposes of this study, lumen maintenance factors affecting LED luminaires can be divided into two groups:

- Factors that can be reversed or recovered through maintenance, such as luminaire cleaning to remove dust and grime from its lens;

- Factors that cannot be reversed or recovered, such as the gradual fading of the LED device's lumen output or dramatic changes in its correlated color temperature (CCT).

In the first category, luminaire dirt depreciation (LDD) is the most significant factor. It results from the accumulation of dust and grime on the luminaire lens over time. This varies significantly from one locale, climate, or season to another. Air pollution is obviously an important variable. Also, an electrostatic charge on the plastic lens of a LED luminaire attracts particles floating in the air. The dryer the environment, the higher the charge and attraction of particles to the lens. Conversely, higher humidity reduces the static charge and particle attraction. Finally, design of the LED luminaire affects dust buildup. Some manufacturers incorporate self-washing features into their luminaire design, so that precipitation removes dust that has adhered to the luminaire lens. The effectiveness of such designs is highly variable.

Note that LDD is not linear. Dust buildup on a newly installed luminaire may be rapid at the start, depending on humidity and temperature, and then decline in rate as the amount of dirt on the luminaire lens reaches a level that dampens its static charge.

NYCDOT washed the luminaires being tested in accordance with the LightSavers trial testing protocol, so they were relatively dust free at the start of the trial. The LightSavers trial protocol also specifies washing the luminaires just before and after the last measurement session, in order to determine locale-specific values for each product in the trial. As already noted, NYCDOT was unable to implement this provision.

The Municipal Solid-State Street Lighting Consortium's *Model Specification for LED Roadway Luminaires* recommends using a LDD value of 0.9 or 10 percent depreciation over four years and assumes the luminaires are washed at 4 year intervals.[7] This LDD factor when annualized is 0.975 or 2.5 percent depreciation annually. This annualized LDD value—2.5 percent—is used as the default in this study.

In the second category of lumen maintenance factors, LED devices, unlike HPS lamps, do not typically burn out. Instead, the light they produce gradually fades over a long period of time in a non-linear fashion. As noted above, the end of lifetime of a LED device occurs when its light output declines to 70 percent of its original output. Since the luminaires in Central Park operate 4,100 hours annually, a LED luminaire rated at 50,000 hours of operation would reach L_{70} at 12 years and two months after its initial start of operation, implying a calculated rate of approximately three percent depreciation *per annum* simply averaged over the lifetime of the product. Note that the manufacturers' claimed lifetime of LED products in this trial range from 50,000 to 75,000 hours, or a maximum of 18.2 years.

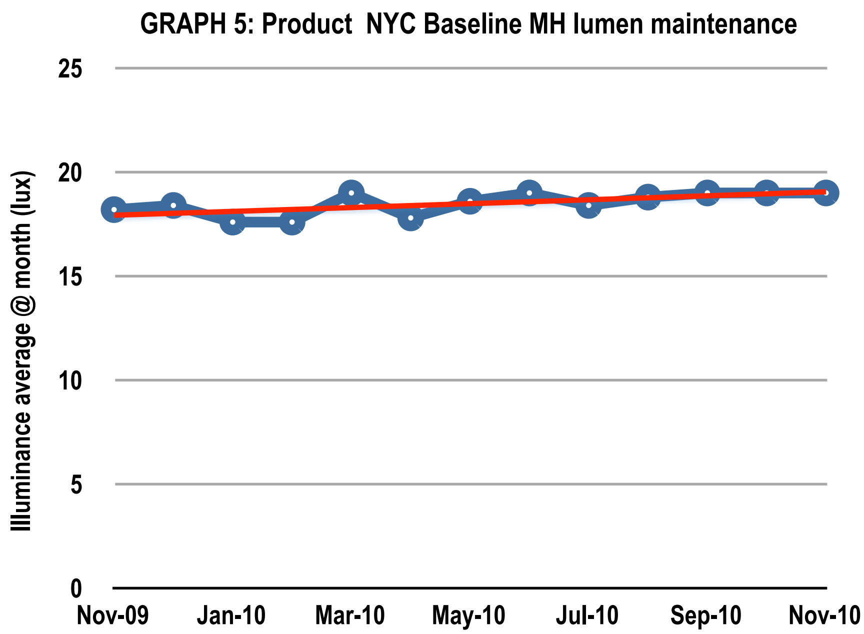
For the purposes of easy product comparison in this trial and study, we assume a lifetime of 50,000 hours for all the LED products, notwithstanding manufacturer claims. Thus, lumen depreciation significantly exceeding three percent in the first year of the trial, *net of LDD,* would be less desirable than a value in the range of three percent or less.

It should be noted again, in respect of the IESNA's TM-21 Working Group's recent findings, that the lumen depreciation metric for the first year has no predictive value. However, comparing first-year lumen output performance of multiple products in a trial can offer insights that enable lighting asset managers in a practical way to better differentiate products from one another.

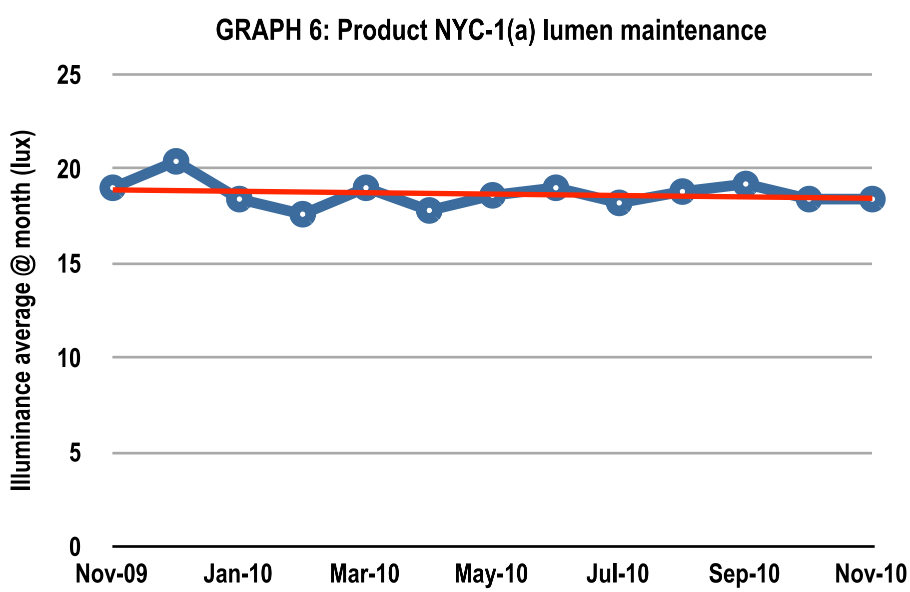
The graphs below show the monthly averaged photopic illuminance values (lux) for each luminaire over a period of 13 months (blue line) subjected to Excel's exponential trendline function (red line), which uses the LOGEST function to generate an exponential least squares fit of the individual observed values to a curved line. (This is the equivalent of performing an Excel LINEST linear least squares fit on the logarithms of the observed values, the slope of the generated straight line equalling the logarithm of the depreciation rate of the exponential fit.) <u>The graphs do not take into account LDD</u>, which is, however, discussed in the text.

As shown by Graph 5 below, the illuminance produced by the baseline MH lamps increased by 6.3% over the first year, or 8.8% net of LDD.

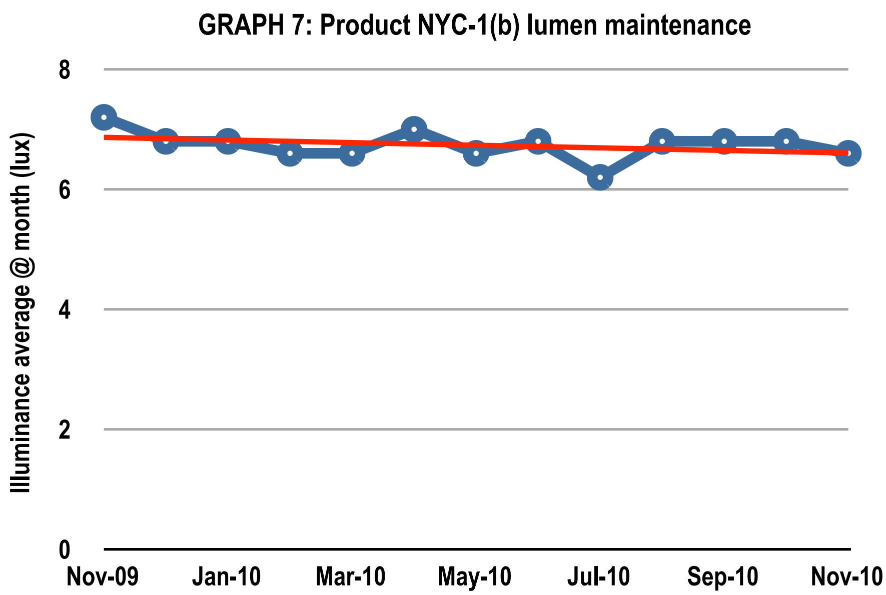
[7] US DOE Municipal Solid-State Streetlighting Consortium, *Model Specification for LED Roadway Luminaires*, Version 1.0, October 2011.

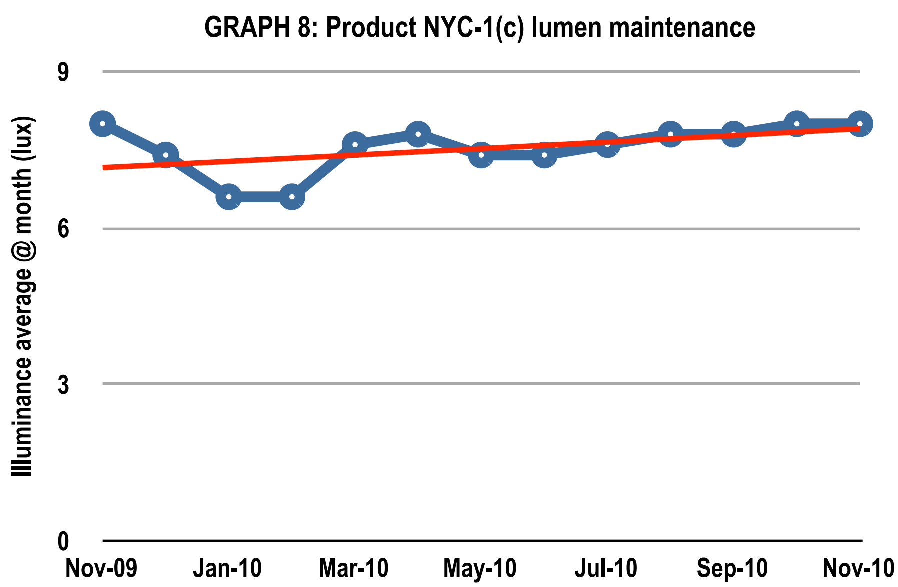


As shown by Graph 6 below, the illuminance produced by product NYC-1(a) declined by 2.4%, or increased by 0.1% net of LDD. Choppy illuminance values were exhibited in the first four months of the measurement period, settling into a stable pattern in the last six months. During the hot months of July and August, no noticeable declines in measured values were observed.



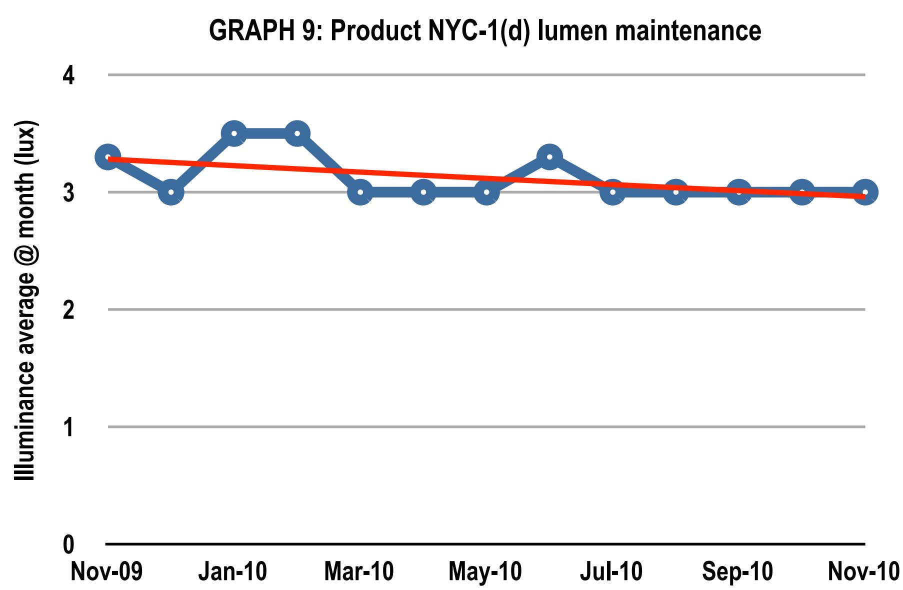
As shown by Graph 7 below, the illuminance produced by product NYC-1(b) declined by 3.8%, or 1.3% net of LDD. Measured values were relatively stable over the measurement period, except for a dip in July, when temperatures were hot. A corresponding dip did not occur in August, however, when temperatures were comparably hot.



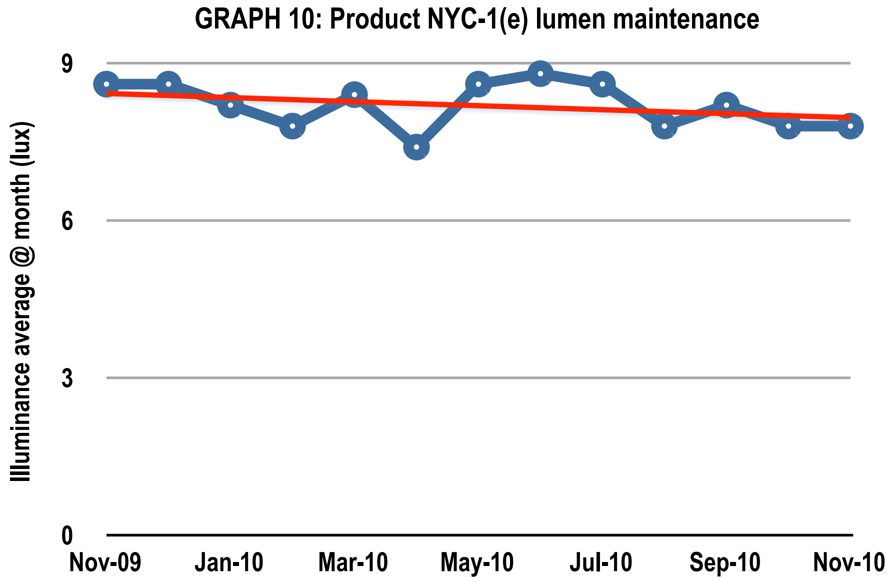


As shown by Graph 8 above, the illuminance produced by product NYC-1(c) increased by 10.4%, or 6.8% net of LDD. There was significant variability from November 2010 to February 2011—illuminance declined by 18% in this period. However, measured values stabilized in the last six months, increasing gradually during the period. The measured value in November 2010 was 4.4% higher than on November 2010. Measured values did not decline when temperatures were hot in July and August.

As shown by the Graph 9 below, the illuminance produced by product NYC-1(d) declined by 9.3% or 11.8% net of LDD, with significant volatility exhibited during the first four months of the measurement period. Measured values stabilized in the last five months of the period. Indeed, if the measurement for this product had commenced in December 2011, lumen depreciation would have been negligible over the remaining year. Measured values did not decline when temperatures were hot in July and August.



Finally, as shown by the Graph 10 below, the illuminance produced by product NYC-1(e) declined by 5.5% or 3.0% net of LDD, however, this LED luminaire exhibited significant volatility over the course of the measurement period. Measured values did not decline when temperatures were hot in July and August.



Ambient temperature measurements were taken in the Central Park study by the NYC-DOT monitoring team at the same time that they made illuminance measurements in the trial. The intent was to ascertain whether changes in illuminance recorded might correlate with changes in ambient temperature. Since LED devices are very sensitive to

TABLE 4: Summary of Lumen Maintenance Results (pro rated annually)

Trial Reference	Exponential Trendline (Excel)	Lamp Lumen Depreciation (LLD)	Coefficient of Variation (CV)	Luminaire Dirt Depreciation Factor (LDD)	Net LLD at One Year
Baseline	+6.3%	1.063	0.023	0.975	1.090
NYC-1(a)	-2.4%	0.976	0.039	0.975	1.001
NYC-1(b)	-3.8%	0.962	0.034	0.975	0.987
NYC-1(c)	+10.4%	1.104	0.057	0.975	1.132
NYC-1(d)	-9.3%	0.907	0.055	0.975	0.930
NYC-1(e)	-5.5%	0.945	0.053	0.975	0.969

temperature, some depreciation on hot summer days might be expected. Also, if a LED luminaire's lumen output were to vary with ambient temperature, this might indicate that the thermal management system in the luminaire is not well designed to dissipate heat and protect the LED devices. As noted above, there was little evidence that measured illuminance values declined during the hot months of July and August for any of the LED products, except for NYC-1(b), when a small dip was observed.

Table 4 above summarizes the information displayed in the above lumen maintenance graphs.

Summary product evaluation

Table 5 below summarizes the results of the product evaluation. Three products, NYC-1(a), NYC-1(b), and NYC-1(c), exhibited very good performance with respect to lumen maintenance and color temperature stability over the initial the 13 months of the trial. NYC-1(c) measured illuminance values actually increased over the period.

Product NYC-1(a) exhibited very good performance with respect to illuminance by matching that of the baselines MH on the pavement (NYCDOT measurement). However, NYC-1(a) is the only luminaire in the trial with Type II classification. Since it was designed to direct lumen output in a narrow longitudinal band across the pavement, it is expected that it would perform the best in this regard.

TABLE 5: Summary Product Evaluation

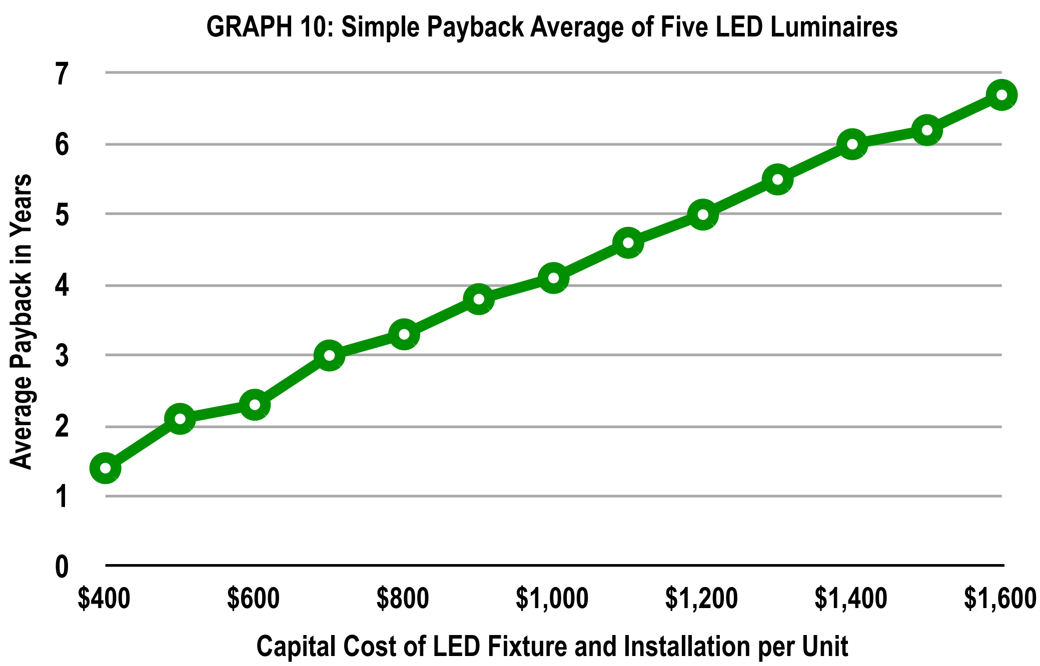
Trial Ref.	Illuminance Relative to Baseline (NYCDOT)	Illuminance Relative to Baseline (US DOE)	Energy Savings vs. Baseline	Luminaire Site-specific System Effectiveness	Lumen Maintenance After 1 Year (net of LDD)	Color Temp Change After One Year	Total Stars (18 max)
NYC-1(a)	***	***	***	***	***	***	18
NYC-1(b)	*	***	***	*	***	***	14
NYC-1(c)	*	**	***	*	***	***	13
NYC-1(d)	n.a.	*	***	*	*	***	n.a.
NYC-1(e)	*	*	***	***	*	***	12

Economic Payback

The graph below shows the average simple payback for all five LED luminaire products up to seven years and a $1,600 capital expenditure. The analysis indicates that at a capital expenditure of approximately $800, for example, a LED replacement program in Central Park would pay back in under five years. The assumptions underlying the graph are as follows:

- Total annual electricity costs of $196,800 for 1,600 luminaires,
- Electricity cost of $0.15/kWh, with an annual inflation rate of 3%,
- Energy savings as indicated by Graph 3,
- Annual maintenance costs of $214,160 or $134/luminaire, no annual inflation.

The possible cost of replacing the LED device driver is not factored into the analysis. Some manufacturers claim their drivers will last 50,000 hours, while others do not. Further, the analysis does not include potential borrowing costs.



The replacement of 1,600 Central Park's metal halide post-top luminaires with NYC-1(b), which performed best in the NYCDOT using the agency's measurement methodology, would save the following:

- Total annual electricity consumption of 976,128 kWh, and 11,713,536 kWh over a 12-year period,

- Total cumulative electricity costs of $2,286,832 over 12 years,
- Total cumulative carbon dioxide emissions of 6,080 tonnes over 12 years.

Summary

For the period November 2009 - November 2010 (October 2009 - January 2011 for CCT measurements), the Central Park LED trial has yielded valuable data that has enabled a useful evaluation of the performance of the five LED products. Here is a summary:

1. **Illuminance**. Results are provided from both the NYCDOT and the US DOE measurement methodologies. While these results provide complementary insights, they are not directly comparable, since each agency used a different sampling grid pursuing different objectives. The results from the NYCDOT measurements indicate performance that emphasizes light falling on the pedestrian pathway. NYC-1(a) stood out for its performance. The results from the US DOE measurements compare illuminance produced radially in total by the LED luminaires, thus avoiding the methodological challenges posed by the variable distances between the light poles ate the site. Two luminaires stood out—NYC-1(a) and NYC-1(b). Two LED luminaires provided significantly less illumination than the baseline MH according to both methodologies—NYC-1(d) and NYC-1(e). Hot weather in the months of July and August 2010 did not appear to affect LED illuminance.

2. **Color temperature (CCT)**. All five LED products showed less than one percent color shift over the 13-month period, an excellent result. By comparison, the metal halide baseline luminaire's color temperature shifted eight percent.

3. **Energy**. All of the LED products achieved significant energy savings compared with the baseline metal halide lamp, ranging from 55% to 83%. In the case particularly of NYC-1(d) and NYC-2(e), these savings were largely due to significantly less illumination that they provided compared with the baseline MH. In other words, they were significantly underpowered.

4. **Lumen maintenance**. Three of the five products maintained relatively stable light output over the first year—one LED product's light output even increased. These results indicate that after an initial period of volatility of the LED light source due to various factors, lumen output appears to stabilize. A trial lasting three years or 10,000 hours would be needed to yield data that could be used for predictive purposes, in accordance with IES TM-21.

5. **Economic payback**. A full-scale LED replacement program in Central Park should have reasonable simple economic payback, below five years, should the capital cost per LED fixture eventually fall into the $800 - $1,200 range. Note that payback calculations do not include possible interest charges were the project to be fi-

nanced. Over 12 years, NYC-1(a), for example, would save $2.3 million in energy costs and 6,000 tonne tones of CO_2.

In conclusion, the trial increased our confidence that LED technology has matured enough to produce some products that provide excellent performance compared with the incumbent metal halide technology. Three products, NYC-1(a), NYC-1(b), and NYC-1(c) exhibited very good lumen maintenance and color stability over their first year of operation.