University Transportation Research Center - Region 2

Final Report

Evaluation of Light Emitting Surface and Light Emitting Diode Roadway Luminaires

Performing Organization: Rensselaer Polytechnic Institute (RPI)

November 2019

Sponsor:
New York State Department of Transportation (NYSDOT)

University Transportation Research Center - Region 2

The Region 2 University Transportation Research Center (UTRC) is one of ten original University Transportation Centers established in 1987 by the U.S. Congress. These Centers were established with the recognition that transportation plays a key role in the nation's economy and the quality of life of its citizens. University faculty members provide a critical link in resolving our national and regional transportation problems while training the professionals who address our transportation systems and their customers on a daily basis.

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16. Abstract

In the present study, roadway luminaires using light emitting surface (LES) technology were compared in terms of photometric performance to roadway luminaires using high pressure sodium (HPS) lamps and light emitting diode (LED) sources. Measurements of light output and electrical power use revealed that the LES luminaires performed similar to the high end of the range of LED luminaires used for comparison. Spectral metrics were similar to those of LED luminaires with the same correlated color temperature (CCT). Measurements of the intensity distribution showed close correspondence with published data for roadway luminaire distributions. In general, the photometric, energy and economic performance of the LES luminaires were among those of LED luminaires evaluated for comparison, suggesting that LES technology can be feasible for roadway lighting.

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EXECUTIVE SUMMARY

In the present study, roadway luminaires using light emitting surface (LES) technology were compared in terms of photometric performance to roadway luminaires using high pressure sodium (HPS) lamps and light emitting diode (LED) sources. Measurements of light output and electrical power use revealed that the LES luminaires performed similar to the high end of the range of LED luminaires used for comparison. Spectral metrics were similar to those of LED luminaires with the same correlated color temperature (CCT). Measurements of the intensity distribution showed close correspondence with published data for roadway luminaire distributions. In general, the photometric, energy and economic performance of the LES luminaires were among those of LED luminaires evaluated for comparison, suggesting that LES technology can be feasible for roadway lighting.

ACRONYMS AND ABBREVIATIONS

A – ampere
CCT – correlated color temperature
cd/m^2 – candelas per square meter
CRI – color rendering index
ft - foot
HPS – high pressure sodium
IES – Illuminating Engineering Society
K – kelvin
kWh – kilowatt-hour
LED – light emitting diode
LES – light emitting surface
lm – lumen
LRC – Lighting Research Center
lx – lux (approximately 0.1 footcandle)
nm – nanometer
NYSDOT – New York State Department of Transportation
PF – power factor
S/P – scotopic/photopic ratio
SPD – spectral power distribution
V – volt
W – watt
yr – year

1. INTRODUCTION

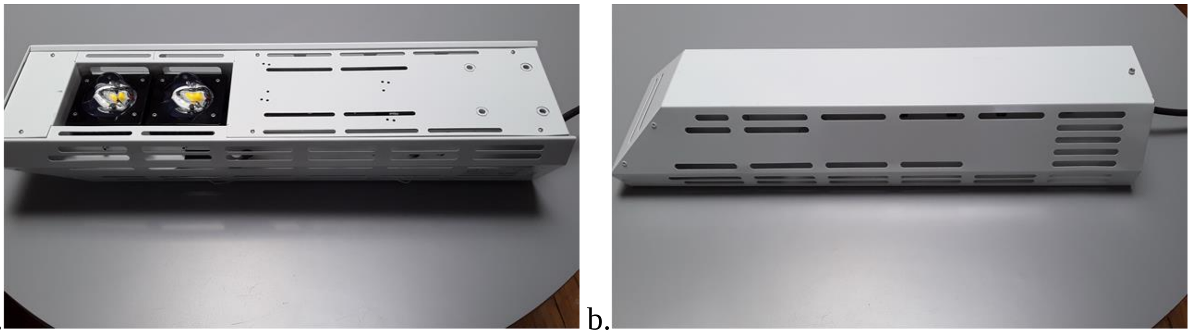
The prevalence of solid state illumination systems is growing throughout the U.S., and is likely to overtake the use of high pressure sodium (HPS) systems that are currently the most commonly used technology for roadway lighting applications (Navigant Consulting, 2012). Among the reasons for this technological transformation include higher luminous efficacy, longer operating life, and the potential for improved visual quality with light emitting diode (LED) systems compared to HPS (Radetsky, 2010, 2011; Bullough, 2012; Bullough and Radetsky, 2013, 2014). As part of a study for the New York State Department of Transportation (NYSDOT), it was found that retrofitting HPS luminaires along parkways and arterial roadways with LEDs could result in improved lighting performance and reduced energy costs (Bullough et al., 2015).

Unlike HPS roadway lighting systems where a single lamp is surrounded by a reflector and lens combination that distributes the light along the roadway, solid state lighting systems using LEDs have many possible configurations. In some solid state lighting luminaires, individual LED sources are equipped with lenses or other optical elements, each producing a portion of the overall beam pattern produced by the luminaire, and having an overall appearance of a matrix of sources. In other cases, a module of closely packed LEDs is surrounded by a lens or reflector to produce the desired intensity distribution; the individual LEDs are not visible, but rather seem to form a single bright source of light.

A number of solid state lighting products have been emerging in recent years described as light emitting surface (LES) configurations. These include chip on board (COB) module configurations where a number of chips are mounted directly to a substrate, and where the reduced size and packaging requirements can reduce the heat generation and potentially improve performance of the module compared to traditional LED configurations (Miron, 2016). In order to understand the suitability of roadway luminaires using LES configurations, the present study was carried out by the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute (RPI) to measure their performance compared to more conventional LED lighting systems. The subsequent sections of this report describe the activities undertaken to evaluate two LES roadway luminaires.

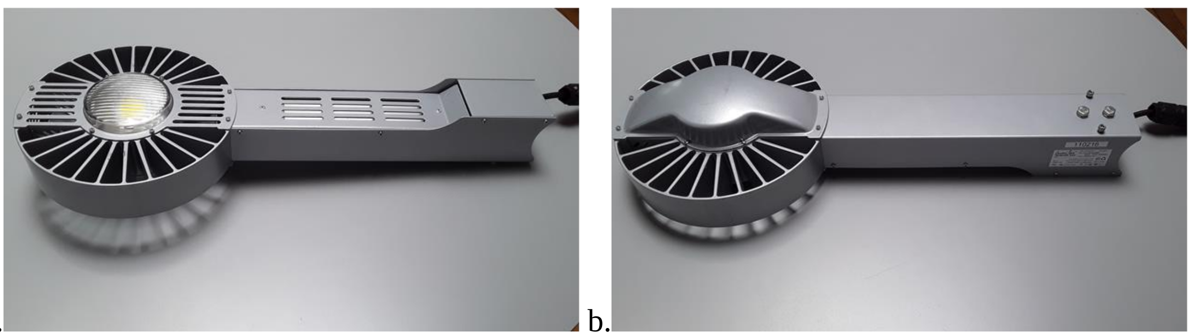
2. LIGHT OUTPUT AND COLOR CHARACTERISTICS

Two LES luminaires were provided by a manufacturer for use in the evaluation study. NYSDOT coordinated with the manufacturer to obtain luminaires that would be equivalent in performance to HPS luminaires containing 100 W and 150 W lamps. The LES luminaires received by the project team were labeled as using 32 W and 60 W, and are shown in Figures 1 and 2, respectively.



a. b.

Figure 1. 32 W LES luminaire. a: View showing light source optics; b. View showing luminaire housing.



a. b.

Figure 2. 60 W LED luminaire. a: View showing light source optics; b. View showing luminaire housing.

Light Output Measurement and Thermal Performance

The LES luminaires were checked for damage upon receiving, fitted with an end plug for use on 120 V AC power in the U.S., and mounted in an integrating sphere (Figure 3) for light output measurement (in lm). At the same time, the power (in W) and power factor (PF) were measured. The power is the active wattage used by the luminaire when operating at a stable thermal condition, and the PF is a quantity that indicates the ratio of active power (in W) to apparent power (in root-mean-square V·A) of an electrical device such as a lamp or luminaire and can range from 0 to 1.0, where 1.0 is considered ideal. Power factor is a measure of how effectively an electric load converts power into useful work.

Figure 3. Integrating sphere used to measure absolute light output at 25º C.

While the light output was being measured in the sphere, the spectral power distribution (SPD) of each LES luminaire was recorded for subsequent analysis. The calibration of the sphere was checked with a known reference source and found to be within less than 1% of the calibration value. Both luminaires were stabilized at ambient room temperature until the light output remained stable (at least 30 minutes).

To assess their performance under different thermal conditions, relative measurements of light output were made using the LRC's thermal chamber (Figure 4) at -10º, 25º and 40º C (14º, 77º and 104º F). In each case, the luminaires were acclimated to each ambient temperature while de-energized and then switched on after stabilizing at the ambient temperature. Relative light output was monitored and measurements taken once the output remained stable; the lumen values from the sphere measurements were adjusted by these relative values to estimate light output at the low and high temperatures. Luminous efficacy (lm/W) was calculated from the measured light output and power data for each luminaire.

Figure 4. Thermal chamber used to measure performance at different temperatures.

The resulting data summary for the two luminaires is as follows.

*32 W LES (38 W LES):**

- Power: 38.5 W (39.5 W at -10^{o} C; 37.8 W at 40^{o} C)
- Power factor: 0.99
- Light output: 4874 lm (5282 lm at -10^{o} C; 4744 lm at 40^{o} C)
- Luminous efficacy: 127 lm/W (134 lm/W at -10^{o} C; 125 lm/W at 40^{o} C)

(**Because this luminaire was found to use more power than its labeling implied, it is referred throughout the remainder of this report as a 38 W LES luminaire.*)

60 W LES:

- Power: 59.7 W (60.1 W at -10^{o} C; 59.4 W at 40^{o} C)
- Power factor: 0.99
- Light output: 7728 lm (8180 lm at -10^{o} C; 7485 lm at 40^{o} C)
- Luminous efficacy: 130 lm/W (136 lm/W at -10^{o} C; 126 lm/W at 40^{o} C)

For comparison, LED luminaire performance data for several common manufacturers (denoted A through E) for roadway lighting luminaires with similar wattages are provided below as well as corresponding data for 100 W and 150 W HPS roadway lighting luminaires. Ambient temperature for all of the LED and HPS systems is assumed to be 25^{o} C (these data were taken from manufacturer data sheets, not measured independently):

Table 1. Summary of power, light output and luminous efficacy for the LES, LED and HPS luminaires.

Luminaire Type	Power (W)*	Power Factor	Light Output (lm)	Efficacy (lm/W)
LED A	31	Not Stated	4,000	129
38 W LES	38.5	0.99	4,874	127
LED B	32	0.94	3,960	124
LED E	31	Not Stated	3,784	122
LED D	30	> 0.90	3,650	122
LED C	35	> 0.90	3,263	93
100 W HPS	119	Not Stated	6,320	53
60 W LES	59.7	0.99	7,728	130
LED B	58	0.94	7,200	124
LED A	58	Not Stated	7,000	121
LED E	60	Not Stated	7,194	120
LED D	58	> 0.90	6,630	114
LED C	66	> 0.90	6,473	98
150 W HPS	183	Not Stated	10,645	58

Table 1 summarizes the power, light output and efficacy data for the LES, LED and HPS luminaires, sorted by their luminous efficacy. In terms of luminous efficacy, the LES luminaires were comparable to the upper end of the range of LED luminaires used for comparison, and the efficacies of all of the LES and LED luminaires exceed the performance of HPS luminaires. In addition, it was noted that the lower-wattage LES luminaire actually used 38.5 W even though the product label stated that the luminaire used 32 W. Therefore, when it was used in photometric analyses it was compared to LED luminaires using between 35 W and 40 W, rather than to the LED luminaires listed in Table 1.

Color Characteristics

As stated previously, the spectral power distributions (SPDs) of the two LES luminaires were recorded (at an ambient temperature of 25° C) while they were being measured for light output in the integrating sphere. The SPDs show the amount of radiant power produced by the luminaire at each wavelength in the visible light spectrum (between 400 and 700 nm). Figure 5 shows the SPDs for each LES luminaire.

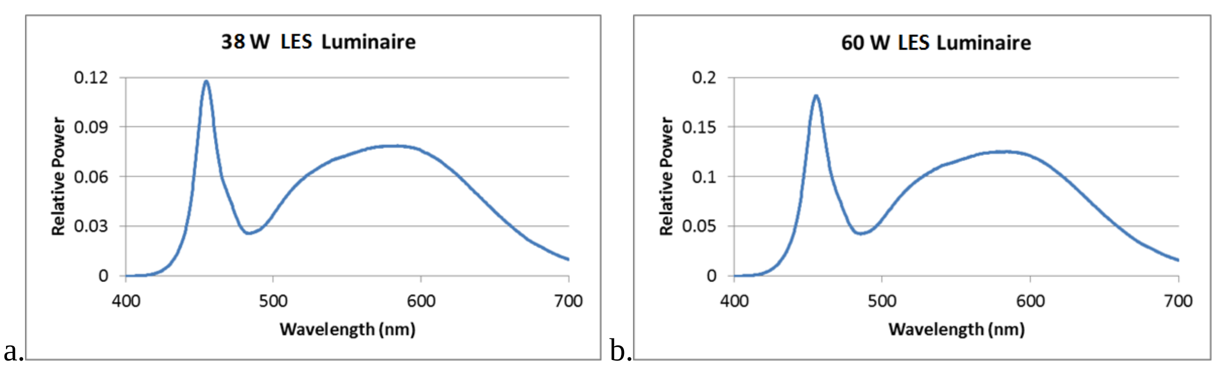


Figure 5. Spectral power distributions. a: 38 W LES luminaire. b: 60 W LES luminaire.

The two SPDs are very similar and when the SPD for the 60 W LES luminaire is scaled by a factor of 0.63 (the ratio of the two LES luminaires' lumen outputs), the two SPDs fall along nearly identical curves. Table 2 lists the correlated color temperature (CCT) and the color rendering index (CRI) of the LES luminaires, alongside the values for these metrics published by the LED luminaire manufacturers.

CCT is an indication of the relative "blueness" or "yellowness" of a light source color. It is expressed in terms of the physical temperature (in K) of a blackbody radiator (tungsten is a material that approximates a blackbody radiator when heated) that emits a color most similar to the color of the light source being measured. A CCT of 3000 K is considered "warm white" while a CCT of 4000 K is more likely to be considered "cool white." CRI is an index that gives an indication of how similarly a light source will make colored objects appear, relative to an "ideal" reference source. For sources with CCTs of 5000 K and lower, the reference source is a blackbody radiator, similar to a tungsten filament. For sources with higher CCTs the reference source is daylight. A CRI of 100 indicates that colors illuminated by a source will match the same colors when illuminated by the reference source. The CRI of an HPS lamp is 22, indicating that many colors will appear distorted under this lamp.

Table 2. Correlated color temperature and color rendering index for the LES and LED luminaires.

Luminaire Type	**CCT (K)***	**CRI***
LES (38 W)	4,502	81
LED A (31 W)	4,000	70
LED B (32 W)	4,000	70
LED C (35 W)	4,000	70
LED D (30 W)	4,000	70
LED E (31 W)	4,000	70
LES (60 W)	4,512	81
LED A (58 W)	4,000	70
LED B (58 W)	4,000	70
LED C (66 W)	4,000	70
LED D (58 W)	4,000	70
LED E (60 W)	4,000	70

**For comparison, an HPS lamp has a CCT of 2200 K and a CRI of 22.*

SPD data for the LED luminaires that were evaluated were not available through information published by their manufacturers, but Table 3 lists typical values for several spectral metrics for LED sources with CCTs of 3000, 4000 and 5000 K, along with the values for the LES luminaires based on the measured data for those luminaires. The metrics include the following:

- Scotopic/photopic (S/P) ratio: Used in assessing the relative effectiveness of the source for peripheral visual performance at nighttime light levels.
- Scene brightness spectral ratio: Used to assess the relative brightness appearance of a street scene illuminated by the source.

- Discomfort glare spectral ratio: Used to assess the relative degree to which the spectral distribution influences discomfort glare.

Table 3. Spectral metrics for the LES luminaires and for typical LED sources having CCTs of 3000, 4000 and 5000 K.

Luminaire Type	**S/P Ratio**	**Scene Brightness Ratio**	**Discomfort Glare Ratio**
LES (38 W)	1.81	1.73	1.34
LES (60 W)	1.82	1.74	1.35
LED (3000 K)	1.23	1.43	1.20
LED (4000 K)	1.67	1.63	1.30
LED (5000 K)	2.00	2.13	1.48

The values for the LES luminaires fall between the ranges of LED sources having CCTs of 4000 and 5000 K, consistent with their measured CCTs of around 4500 K. This suggests that in terms of their spectral performance, the LES luminaires are similar to LED luminaires of the same CCT.

3. LUMINOUS INTENSITY DISTRIBUTION MEASUREMENT

This section summarizes photometric intensity distribution measurements made for the 38 W LES and 60 W LES luminaires.

Measurement Procedure

The LES luminaires were mounted and adjusted for levelness on the bar photometer in the Levin Photometric Laboratory at the Lighting Research Center. An LMT photosensor was mounted on the wall 6.24 m from the luminous element of each luminaire and black matte baffles were positioned to reduce stray light from the measurement location.

The bar photometer contains a platform that allows the luminaire to be tilted and rotated about its luminous aperture so that angular measurements could be made. Measurements were made for 0° and 90° "cuts" relative to the luminaire, corresponding to directions along and across the roadway, respectively, when the luminaire would be mounted alongside a roadway. The 38 W LES luminaire's optical elements were able to be swiveled to adjust the distribution of the luminaire. For the intensity measurement, these elements were not rotated but were level with the plane of the luminaire.

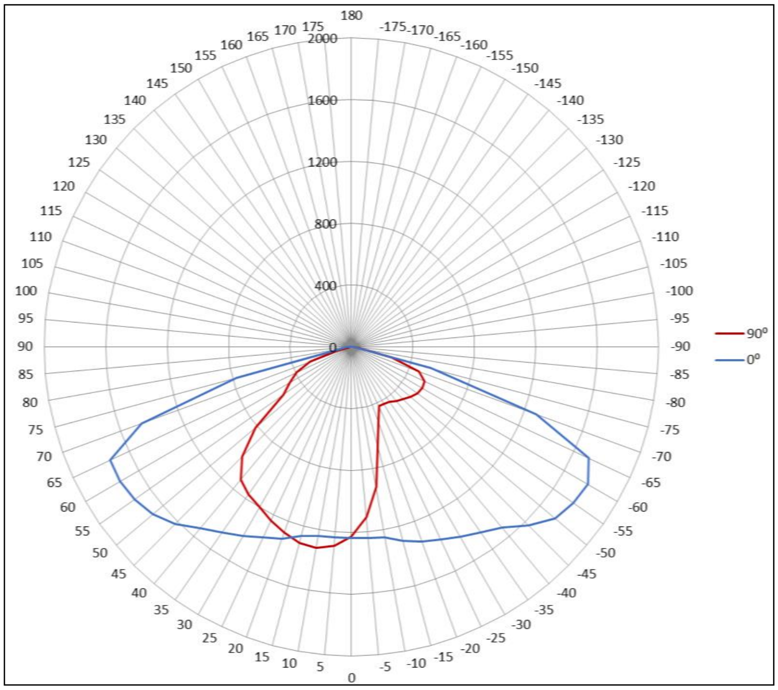
The luminous intensity distributions were also compared visually to photometric data provided by the manufacturer.

Results

The luminous intensity distribution of the 38 W LES luminaire is shown in Figure 6a. It was a very close match to all of the photometric intensity curves for the model of luminaire provided by the manufacturer. These curves differ in their absolute value because they correspond to different luminaire wattages. An example of one of the published curves is provided in Figure 6b.

The luminous intensity distribution of the 60 W LES luminaire (Figure 7) was, essentially a round pattern of light. The output from this luminaire was projected onto a wall to confirm that its distribution was largely circular and symmetrical. There were no examples of photometric data provided by the manufacturer with an intensity distribution similar to this. After consulting with the manufacturer, it was determined that this luminaire was designed for applications such as area or parking lot lighting rather than for roadway illumination.

For the subsequent section of this report on the photometric analyses, a photometric distribution with a similar pattern as the 38 W LES luminaire, but scaled to the light output of the measured 60 W LES luminaire, was used.

a.


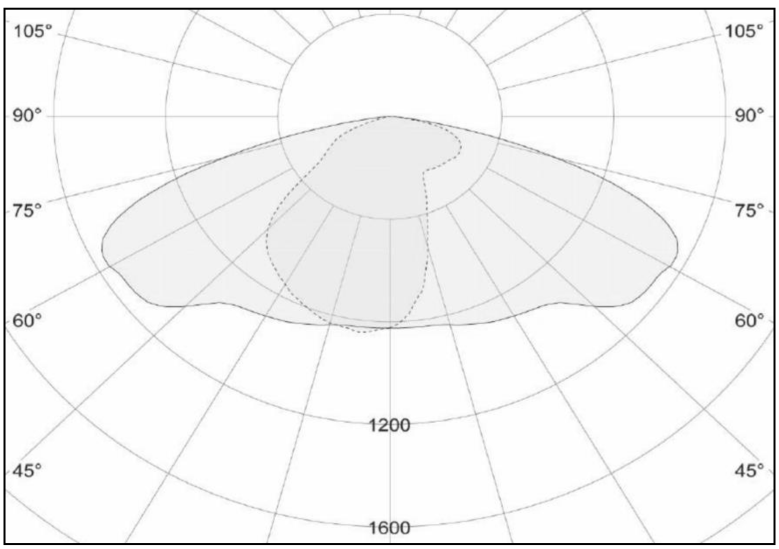
b.


Figure 6. a: Measured luminous intensity distribution curves for 0^o and 90^o cuts for the 38 W LES luminaire. b: Published luminous intensity distribution curves from the LES luminaire manufacturer.

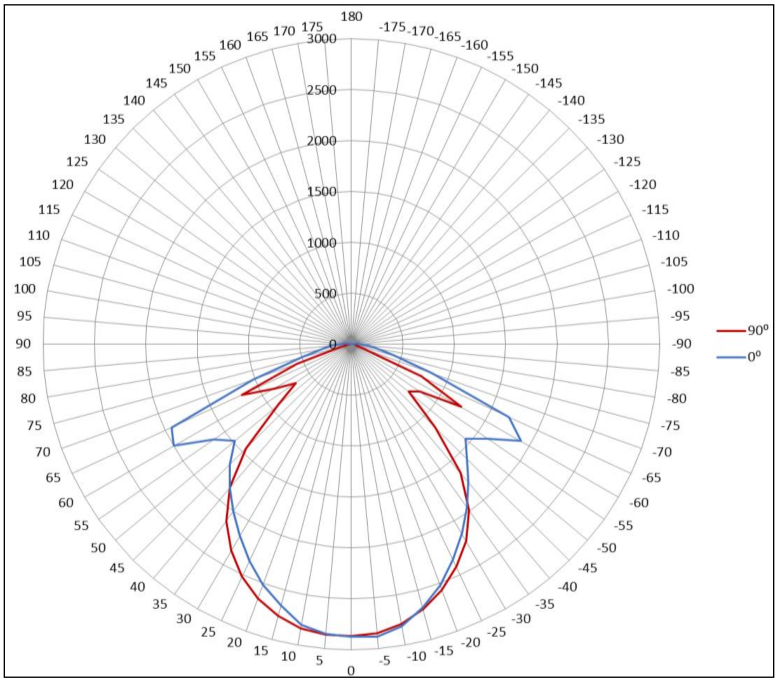


Figure 7. Measured luminous intensity distribution curves for 0º and 90º cuts for the 60 W LES luminaire.

4. PHOTOMETRIC, ENERGY AND ECONOMIC ANALYSES

In this section, roadway lighting simulations were carried out using photometric data for the LES and LED luminaires identified previously. NYSDOT provided roadway lighting inventory for two regions (Hudson Valley and Long Island), from which the project team identified two roadway environments where luminaires with 100 W and 150 W HPS lamps were used: parkways, and ramps exiting from or entering onto parkways. The geometric characteristics of these environments are summarized in Table 4. Typical pole spacings were determined by measuring the average distance between poles in Google Earth using the NYSDOT inventory data.

Table 4. Characteristics of the modeled roadway environments.

	Parkway	**Ramp**
Lanes in Each Direction	2 / 2	0 / 2
Lane Width	12 ft	12 ft
Median Width	6 ft	None
Pole Setback from Lane Edge	10 ft	10 ft
Mast Arm Length	16 ft	12 ft
Mounting Height	30 ft	30 ft
Typical Spacing of Poles	240 ft	110 ft
Layout of Poles	Staggered	One Sided
Pavement Type	R3 (Asphalt)	R3 (Asphalt)

For all lighting calculation analyses, the web-based calculator Visual Roadway Tool (Acuity Brands) was used to perform the lighting calculations. The criteria for lighting along the two roadway environments are the same, because they both are defined according to the Illuminating Engineering Society (IES, 2014) roadway lighting standard as "expressway" road types with low pedestrian conflict. The IES criteria for this type of road are as follows:

- Average roadway luminance (this criterion ensures that there is sufficient light along the roadway): At least 0.6 cd/m²
- Average:minimum luminance ratio (this criterion ensures that the lighting along the roadway is not excessively non-uniform): No greater than 3.5:1
- Maximum:minimum luminance ratio (like the average:minimum ratio, this criterion also ensures sufficient uniformity of illumination): No greater than 6:1
- Veiling luminance ratio (this criterion ensures that the brightness of the luminaires in the direction of drivers does not create excessive glare): No greater than 0.3:1

For the asphalt pavement type (R3) that is assumed, the average luminance criterion of 0.6 cd/m² corresponds approximately to an average illuminance of 9 lx (0.9 footcandles).

For the parkway road environment, the 150 W HPS, 60 W LES and LED luminaires with wattages similar to 60 W that are listed in Tables 1 and 2 were used in the analyses. For the ramp environment, the 100 W HPS, 38 W LES, and LED luminaires with wattages between 35 and 40 W and from the same manufacturers listed in Tables 1 and 2 were used.

For the 38 W LES luminaire, three configurations were used: one in which the light modules were not rotated (denoted 0^o), one in which one of the modules was rotated toward the road by 20^o and the other module was not rotated (denoted $0^o + 20^o$), and one in which both modules were rotated by 20^o (denoted 20^o). This was done to determine whether adjusting the rotation of these modules could be done to improve the lighting performance. Because the 60 W LES luminaire's light module could not be rotated, these analyses were not performed for that luminaire.

Retrofit Scenarios

Parkway Environment

Table 5 summarizes the photometric and energy characteristics for the parkway environment for each luminaire type in the retrofit scenario (maintaining the existing spacing between poles). In roadway lighting retrofit scenarios, it is not always expected that luminaires will meet all IES (2014) lighting criteria (Beckwith et al., 2011).

Table 5. Lighting performance and energy use for each luminaire, for the parkway environment. For the lighting criteria, green shaded cells indicate performance meeting IES (2014) criteria; yellow shaded cells indicate performance within 10% of IES (2014) criteria.

Luminaire Type	Average Luminance (cd/m^2)	Average: Minimum Luminance Ratio	Maximum: Minimum Luminance Ratio	Veiling Luminance Ratio	Annual Energy per Mile (kWh/year)	Annual Energy Cost per Mile ($)
LES (60 W)	0.58	3.22	6.94	0.22	11,563	$1,734
HPS (183 W)*	0.98	2.18	4.33	0.30	35,268	$5,290
LED A (58 W)	0.81	2.19	4.38	0.27	11,178	$1,677
LED B (58 W)	0.58	4.50	10.31	0.23	11,178	$1,677
LED C (66 W)	0.59	2.95	7.40	0.28	12,720	$1,908
LED D (58 W)	0.68	2.72	5.32	0.29	11,178	$1,677
LED E (60 W)	0.52	3.25	6.38	0.21	11,563	$1,734

*The 150 W HPS luminaire uses a total of 183 W including ballast power.

Because the spacing in this scenario is fixed at 240 ft between poles on each side of the road with a total of 44 poles per mile, the energy use among the LES and LED scenarios does not differ much; all of them are substantially lower than HPS. The annual energy cost per mile assumes a cost of $0.15/kWh for energy and delivery charges.

Ramp Environment

A similar procedure was used to evaluate the alternatives for the ramp environment, assuming a retrofit scenario where the pole spacing configuration is not changed. Table 6 summarizes the lighting performance and energy use characteristics for each luminaire.

Table 6. Lighting performance and energy use for each luminaire, for the ramp environment. For the lighting criteria, green shaded cells indicate performance meeting IES (2014) criteria; yellow shaded cells indicate performance within 10% of IES (2014) criteria.

Luminaire Type	Average Luminance (cd/m^2)	Average: Minimum Luminance Ratio	Maximum: Minimum Luminance Ratio	Veiling Luminance Ratio	Annual Energy per Mile (kWh/year)	Annual Energy Cost per Mile ($)
LES (38 W, 0°)	0.59	1.64	2.33	0.14	7,989	$1,198
LES (38 W, 0° + 20°)	0.53	1.47	1.89	0.14	7,989	$1,198
LES (38 W, 20°)	0.47	1.34	1.69	0.14	7,989	$1,198
HPS (119 W)*	0.99	2.20	3.20	0.19	25,019	$3,753
LED A (39 W)	0.91	1.60	2.35	0.20	8,199	$1,230
LED B (39 W)	0.59	1.74	2.59	0.15	8,199	$1,230
LED C (35 W)	0.48	1.71	2.96	0.19	7,358	$1,104
LED D (38 W)	0.78	1.53	2.06	0.18	7,989	$1,198
LED E (39 W)	0.53	2.04	3.19	0.19	8,199	$1,230

*The 100 W HPS luminaire uses a total of 119 W including ballast power.

Differences among the LES and LED luminaires in this scenario were relatively small; again, this is largely because the pole spacing (110 ft apart on one side of the road) was essentially fixed. In addition, rotating the light modules within the LES luminaire resulted in lower light levels on the roadway and slightly more uniform illumination.

New Lighting Scenarios

The Visual Roadway Tool can be used to optimize the spacing between luminaires in a given layout to meet specified IES (2014) criteria, for the design of new lighting systems. This is done to minimize the lighting system cost, because poles in a new lighting installation are a major portion of the total cost.

Parkway Environment

Using the lighting criteria and geometric characteristics summarized in Table 4 (except the pole spacing value), Table 7 shows the performance of each luminaire in terms of the number of poles per mile, the energy use per mile, and the energy use per year, for the parkway environment. The luminaires in Table 7 are sorted by annual energy use per mile, in ascending order.

Table 7. Optimized spacing and energy performance for the parkway environment.

			Per Mile					
Luminaire Type	**Power (W)**	**Spacing (ft)**	**Poles**	**Power (W)**	**Energy (kWh/yr)**	**Initial Installation Cost ($)**	**Annual Operating Cost ($)**	**Overall Annualized Cost ($)**
LED A	58	285	37	2,146	9,399	$122,100	$2,014	$14,450
LED D	58	255	41	2,378	10,416	$135,300	$2,232	$16,012
LES	60	222	47	2,820	12,352	$155,100	$2,621	$18,418
LED E	60	211	50	3,000	13,140	$165,000	$2,788	$19,593
LED C	66	224	47	3,102	13,587	$155,100	$2,806	$18,603
LED B	58	191	55	3,190	13,972	$181,500	$2,994	$21,480
HPS	183	248	43	7,869	34,466	$133,816	$5,603	$19,233

As with the retrofit scenarios, the differences among the LES and LED luminaires in terms of energy use are relatively small compared to the differences between these and the HPS luminaire. Of course, energy costs are not the only costs associated with a new lighting installation; the equipment and pole costs as well as maintenance costs are major contributors to the overall cost. To compare the alternatives, the total annualized cost of installing and operating the lighting systems over a 20-year period was calculated, using the following assumptions (Leslie, 1998):

- HPS luminaire cost: $210
- HPS lamp cost: $43 (100 W), $46 (150 W)
- LES/LED luminaire cost: $350
- Pole cost: $1300
- Labor costs: Equal to equipment costs
- Capital recovery factor: 0.10185
- Operating life: 30,000 hr (HPS), 100,000 hr (LES/LED)
- Relamping labor cost: $23
- Electricity cost: $0.15/kWh

Installation, operating (energy and maintenance) and overall costs annualized over a 20-year period are shown for each system in Table 7. The LES and most of the LED systems result in lower annualized costs than HPS, even though most of these systems had higher initial installation costs, because the LES and LED systems used substantially less energy than the HPS system. The LES luminaire was among the LED luminaires in terms of overall annualized costs.

Ramp Environment

Also using the same lighting criteria and geometric characteristics summarized in Table 4 (except the pole spacing value), Table 8 shows the performance of each luminaire in terms of the number of poles per mile, the energy use per mile, and the energy use per year, for the ramp environment. Similar to Table 7, the luminaires in Table 8 are sorted by annual energy use per mile, in ascending order.

Table 8. Optimized spacing and energy performance for the ramp environment.

			Per Mile					
Luminaire Type	**Power (W)**	**Spacing (ft)**	**Poles**	**Power (W)**	**Energy (kWh/yr)**	**Initial Installation Cost ($)**	**Annual Operating Cost ($)**	**Overall Annualized Cost ($)**
LED A	39	166	31	1,209	5,295	$102,300	$1,301	$11,720
LED D	38	143	36	1,368	5,992	$118,800	$1,487	$13,587
LES 0º	38	108	49	1,862	8,156	$161,700	$2,024	$18,493
LED B	39	110	48	1,872	8,199	$158,400	$2,014	$18,147
LES 0º + 20º	38	97	54	2,052	8,988	$178,200	$2,230	$20,380
LED C	35	88	59	2,065	9,045	$194,700	$2,321	$22,151
LED E	39	99	53	2,067	9,053	$174,900	$2,224	$20,037
LES 20º	38	87	60	2,280	9,986	$198,000	$2,478	$22,645
HPS	119	182	28	3,332	14,594	$89,968	$2,459	$11,317

With the exception of two LED luminaires for which the annual energy use per mile was less than 6000 kWh/year (LED A and LED D), the differences among the LES and LED luminaires in terms of energy use were relatively small compared to the differences between these and the HPS luminaire. The total annualized cost of installing and operating each of the lighting systems over a 20-year period (Leslie, 1998) was also calculated, using the same cost assumptions as for the parkway environment. These along with the initial installation costs and annual operating (energy and maintenance) costs are shown in Table 8.

The HPS luminaire had the lowest overall annualized cost even through it had nearly the highest annual operating (energy and maintenance) cost, compared to the LES and LED luminaires. The LES luminaire was among the LED luminaires in terms of overall annualized costs.

Similar to the retrofit scenarios for the ramp environment, rotating the light modules within the LES luminaires tended to worsen rather than improve performance (in terms of the ability to space luminaires farther apart). It is possible that for a situation when poles are mounted very far from the edge of a roadway, that rotating the distribution could have a benefit, but this situation was not evaluated.

To investigate whether the potential for longer operating life of the LES luminaire might impact economic performance, economic comparisons were made assuming an operating life of 400,000 hours for this system, rather than 100,000 hours. The overall annualized cost for the LES system was only reduced by about 3%, mainly because the largest part of this cost is related to the pole/installation costs.

5. CONCLUSIONS

Based on the limited analyses described in this report, the LES luminaires that were evaluated had the following characteristics:

- Luminous efficacy similar to that of the high end of the range of efficacies for several LED luminaires to which it was compared, and stable performance over a large temperature range (-10^{o} C to 40^{o} C).
- Color rendering characteristics (CRI > 80) slightly higher than the rated color rendering indices of the LED luminaires (CRI > 70) evaluated.
- Spectral characteristics similar to LEDs of the same CCT (for the LES luminaires that were measured, the CCT was approximately 4500 K).
- Luminous intensity distributions closely matching that of published photometric data for luminaires having a roadway distribution.
- The ability to rotate the light modules up to 20^{o} had relatively small impacts on performance (and for the scenarios in this report, tended to worsen rather than improve performance). It is possible that for a situation when poles are mounted very far from the edge of a roadway, that rotating the distribution could have a benefit, but this situation was not evaluated.
- Energy use, optimized pole spacing, and overall annualized costs for the LES system were, in general, comparable to those of LED luminaires for the scenarios investigated in this study. Energy use for the LES systems was substantially lower than for the HPS systems evaluated.

The present study did not assess the long-term performance of LES luminaires compared to LED luminaires, and for the purpose of the photometric and energy analyses, all of the solid state luminaires were assumed to have similar performance in terms of operating life and lumen maintenance. In general, the project findings suggest that roadway luminaires using LES technology are technologically feasible for roadway lighting applications. Longer term performance could be assessed through a demonstration installation where the lighting system performance could be periodically monitored over time.

Of course, the specific ranking of any specific luminaire for a given situation will depend upon the specific geometric characteristics of the application. Every road can have different lane widths, different numbers of lanes, different pole heights, different median widths, different mast arm lengths and different onsets. The photometric analysis procedure used in section 4 of this report therefore may be a useful process when NYSDOT is investigating the suitability of specific luminaires for other specific roadway conditions, regardless of the lighting technology type.

6. STATEMENT ON IMPLEMENTATION

The findings from the present project can be used by NYSDOT and other agencies to help identify energy efficient alternatives to HPS lighting on roadways in New York State. The analysis methods employed in the present project can be used to compare new and retrofit lighting options. The photometric and economic analyses described in this report can serve as a basis for a methodology for comparing different roadway lighting options in terms of lighting performance, energy use and cost impacts.

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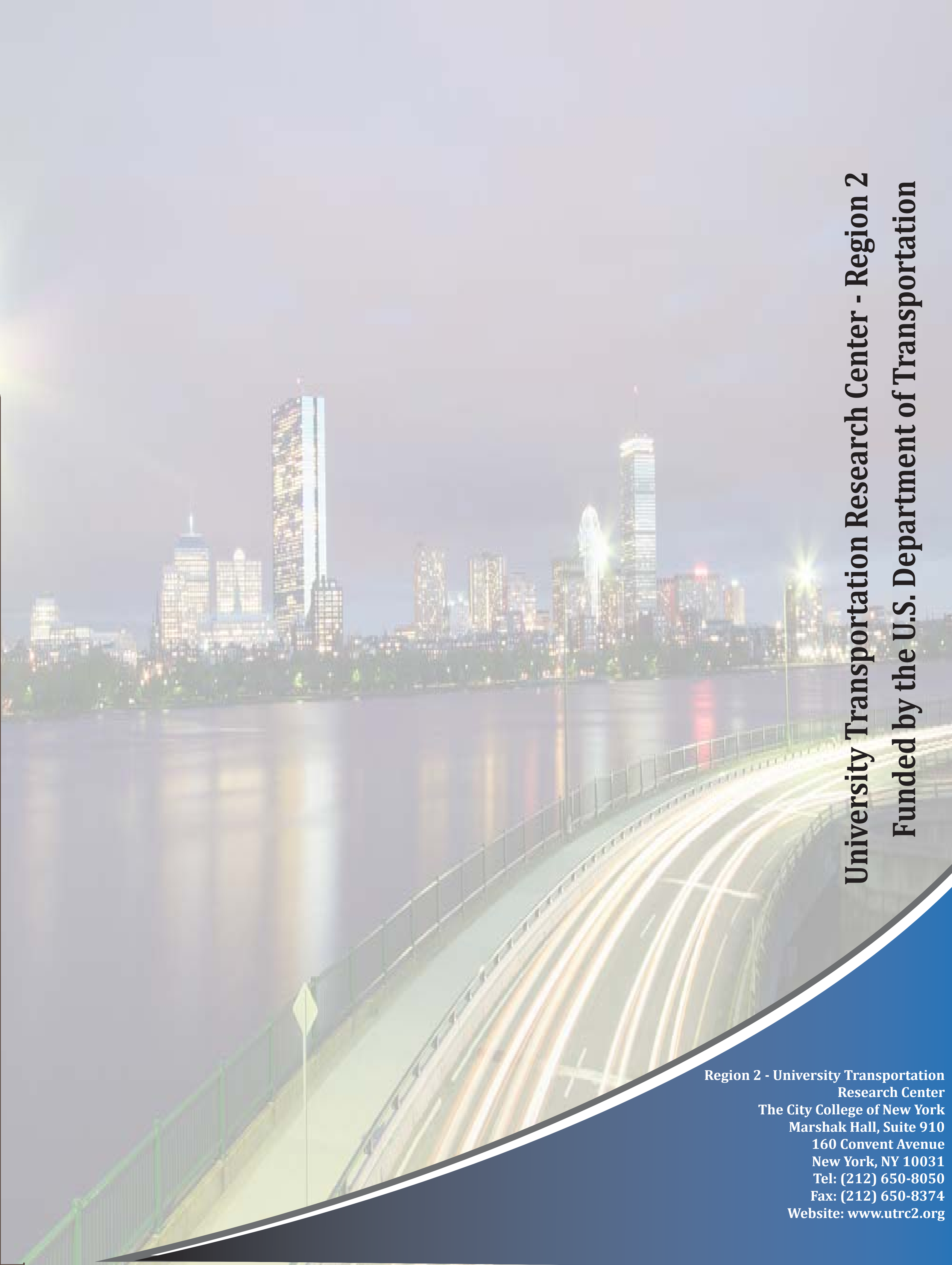

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