GUIDE FOR OPTIMIZING THE EFFECTIVENESS AND EFFICIENCY OF ROADWAY LIGHTING

Final Report

Prepared for

THE NEW YORK STATE ENERGY RESEARCH AND DEVELOPMENT AUTHORITY
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16. Abstract

The objective of the present project was to develop a simple guide for roadway lighting replacement approaches using new light source technologies to maintain visibility for safety, while reducing energy use. Several roadway types were evaluated: parkways, residential streets and rural intersections. The guide is to be suitable for a non-technical readership familiar with roadway design and safety issues, but not necessarily with lighting. A review of published literature and a survey of engineers from New York State and local transportation agencies were conducted. Based on this information as well as data on new light source technologies, a series of roadway types for inclusion in the guide was selected, and recommendations for roadway lighting system replacement were developed. Analyses of the visual efficacy produced by different lighting systems under nighttime conditions, and the performance characteristics of light emitting diode (LED) and induction fluorescent lighting systems, resulted in recommendations for replacement of high pressure sodium (HPS) lighting systems. The resulting energy savings ranged from about 7% to 50% depending upon the roadway type. Energy savings for isolated rural intersections could depend upon the level of pedestrian traffic expected. A number of new light sources that produce “whiter” light than the incumbent HPS technology used on most roadways have been developed and significantly improved in the past decade. Using these technologies in combination with recent information about driver and pedestrian vision under nighttime conditions could result in energy savings for different roadway types. A guide for replacement strategies resulting from the present project contains pointers to information about lighting policies, practices, technologies, and visual efficacy that could assist lighting decision-makers with other scenarios not discussed in the guide.

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ABSTRACT

The objective of the present project was to develop a simple guide for roadway lighting replacement approaches using new light source technologies to maintain visibility for safety, while reducing energy use. Several roadway types were evaluated: parkways, residential streets and rural intersections. The guide is to be suitable for a non-technical readership familiar with roadway design and safety issues, but not necessarily with lighting. A review of published literature and a survey of engineers from New York State and local transportation agencies were conducted. Based on this information as well as data on new light source technologies, a series of roadway types for inclusion in the guide was selected, and recommendations for roadway lighting system replacement were developed. Analyses of the visual efficacy produced by different lighting systems under nighttime conditions, and the performance characteristics of light emitting diode (LED) and induction fluorescent lighting systems, resulted in recommendations for replacement of high pressure sodium (HPS) lighting systems. The resulting energy savings ranged from about 7% to 50% depending upon the roadway type. Energy savings for isolated rural intersections could depend upon the level of pedestrian traffic expected. A number of new light sources that produce “whiter” light than the incumbent HPS technology used on most roadways have been developed and significantly improved in the past decade. Using these technologies in combination with recent information about driver and pedestrian vision under nighttime conditions could result in energy savings for different roadway types. A guide for replacement strategies resulting from the present project contains pointers to information about lighting policies, practices, technologies, and visual efficacy that could assist lighting decision-makers with other scenarios not discussed in the guide.

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SUMMARY

OBJECTIVES

The objective of the present project was to develop a simple guide for roadway lighting replacement approaches using new light source technologies to maintain visibility for safety, while reducing energy use. Several roadway types were evaluated: parkways, residential streets and rural intersections. The guide is to be suitable for a non-technical readership familiar with roadway design and safety issues, but not necessarily with lighting.

RESEARCH APPROACH

A review of published literature and a survey of engineers from New York State (NYS) and local transportation agencies were conducted. Based on this information as well as data on new light source technologies, a series of roadway types for inclusion in the guide was selected, and recommendations for roadway lighting system replacement were developed.

ANALYSES AND RESULTS

Analyses of the visual efficacy produced by different lighting systems under nighttime conditions, and the performance characteristics of light emitting diode (LED) and induction fluorescent lighting systems, resulted in recommendations for replacement of high pressure sodium (HPS) lighting systems. The resulting energy savings ranged from about 7% to 50% depending upon the roadway type. Energy savings for isolated rural intersections could depend upon the level of pedestrian traffic expected.

CONCLUSIONS AND RECOMMENDATIONS

A number of new light sources that produce “whiter” light than the incumbent HPS technology used on most roadways have been developed and significantly improved in the past decade. Using these technologies in combination with recent information about driver and pedestrian vision under nighttime conditions could result in energy savings for different roadway types. A guide for replacement strategies resulting from the present project contains pointers to information about lighting policies, practices, technologies, and visual efficacy that could assist lighting decision-makers with other scenarios not discussed in the guide.

Section 1
INTRODUCTION

Lighting along roadways and highways serves a primary purpose of safety by supporting visibility of pedestrians, vehicles and other potential hazards for drivers. In NYS, an estimated 1.1 billion kilowatt hours (kWh) of electricity per year is currently used for roadway lighting, equivalent to burning approximately 320,000 tons of coal, and corresponding to the production of about 740,000 tons of CO_2, 6200 tons of SO_2, and 2700 tons of NO_X compounds. New developments in light source technologies and in an understanding of the human visual system's response to light under nighttime conditions could result in the potential for energy savings while maintaining (or improving) driver and pedestrian visibility. In particular, because of the human eye's shifted response to light at nighttime (mesopic) light levels, light sources that produce greater short-wavelength ("blue") light are relatively more effective for vision than those with little short-wavelength light, even at the same measured light level. A system of unified photometry (Rea et al. 2004) or visual efficacy (Rea and Freyssinier 2009) has been published to account for this effect, and a similar method has been incorporated into some practices of the Illuminating Engineering Society (IES) and the Commission Internationale de l'Eclairage (CIE).

The present project was conducted to summarize these developments in a simple guide in the form of an informational brochure that could be used by traffic and roadway lighting engineers in NYS to develop replacement recommendations for existing HPS lighting systems with light sources better tuned to drivers' and pedestrians nighttime visual requirements. It is anticipated that traffic engineers will be able to use this Guide to select the light source that will best meet the needs of each application in the most efficient, and effective manner.

To develop the guide, the project team consisting of researchers from the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute reviewed published literature on roadway lighting, and surveyed transportation engineers from NYS and local agencies in order to identify applications where energy savings might be possible. Based on this information, technical analyses based on the performance characteristics of light sources and on visual efficacy of roadway lighting were performed, which served as the basis for an easy-to-understand guide describing replacement scenarios for roadway lighting systems along several roadway types.

Section 2
BACKGROUND AND REVIEW

The present document summarizes the information gathering findings for the present project. This consists of two parts: a review of light levels and lamp types used on roadways in New York State (NYS), and obtaining information directly from transportation engineers in NYS involved in lighting decision making regarding their awareness of roadway lighting issues and needs for technical information.

REVIEW OF LIGHT LEVELS AND LAMP TYPES

Light Levels and Pole Spacings

The NYSDOT Highway Design Manual (1995), Chapter 12 – "Highway Lighting," is the primary reference for roadway lighting used by NYSDOT. This document describes the source of light level recommendations, namely the American Association of State Highway and Transportation Officials (AASHTO) guide to lighting, previously published in 1976 and 1984, and of which the current edition was published in 2005 (AASHTO, 2005).

According to AASHTO (2005), which in turn is based on the recommended practice for roadway lighting published by the IES (2000), different types of roadways are to be illuminated to different levels. A sample of these types and recommended level ranges (assuming asphalt pavement; illuminances can be about 30% lower if pavement is concrete) is given below:

- Local roads: 4 to 9 lux (lx)
- Collector roads: 6 to 12 lx
- Principal arterials: 9 to 17 lx

The ranges for each roadway type allow the lighting engineer to specify the highest or lowest value, or an intermediate value, depending upon the classification of the area as having high pedestrian conflict (commercial area) which requires the highest illuminance value, medium pedestrian conflict (intermediate area) which requires the intermediate illuminance value, or low pedestrian conflict (residential area) which requires the lowest illuminance value.

The project team also reviewed a sample of local municipal and county ordinances with respect to street and roadway lighting. A number of localities had very similar language. Examples of ordinance language pertaining to street and roadway lighting follow:

Amherst. "Street lighting should be considered at all intersections, and continuous lighting should be considered in heavily built-up areas, particularly on collector streets. Determinations on lighting should be coordinated with crime protection and other community needs. Factors that should be taken into consideration in determining whether or not lighting should be provided are the ratio of night to day accidents, pedestrian and vehicular volumes, type of marginal development and previous experience at other locations having similar geometric design."

Athens. "Streetlighting facilities. Lighting facilities shall be in conformance with the lighting system of the Town. Such lighting standards and fixtures shall be installed after approval by the appropriate power company and the authorized Town Electrical Inspector."

Montgomery. "Streetlighting facilities. Where required by the Planning Board, streetlighting standards in conformance with the lighting system of the Town of a design approved by the Planning Board Engineer shall be installed by the subdivider in a manner and location approved by the Planning Board Engineer, the appropriate power company and the Highway Superintendent. In the case of a subdivision involving a county or state highway, approval shall be obtained from the County Superintendent of Highways. Where a new lighting district is to be created or an existing district expanded, the applicant shall petition the Town Board to create said district or expansion before final approval."

Oneida. "Lighting shall be provided in accordance with a plan designed by the utility company, or using as a guideline the standards set forth by the IES Lighting Handbook. Lighting for safety shall be provided at intersections, along walkways, at entryways, between buildings, and in parking areas. Spacing of standards shall be equal to approximately four times the height standard. The maximum height of standards shall not exceed the maximum building height permitted, or 25 feet, whichever is less. The height and shielding of lighting standards shall provide proper lighting without hazard to drivers or nuisance to residents, and the design of lighting standards shall be of a type appropriate to the development and the City of Oneida. Spotlights, if used, shall be placed on standards pointing toward the building and positioned so as not to blind the residents, rather than on the buildings and directed outwards which creates dark shadows adjacent to the buildings."

Rhinebeck. "Within the public frontages, the prescribed types of street trees and examples of streetlight types shall be as shown in Figures 3, 4, and 5. The spacing may be adjusted to accommodate specific site conditions, such as building entrances." (Street light types from the Rhinebeck ordinance are shown in the following images as Figure 1.)

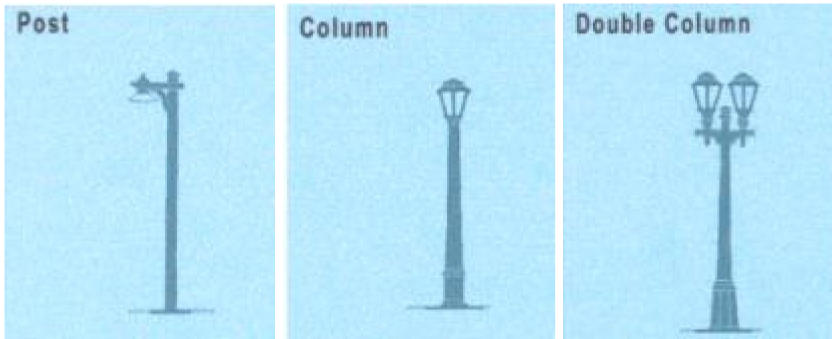

Figure 1. Streetlight types described in Rhinebeck lighting ordinance (referred to as Figures 3, 4 and 5 in the ordinance).

Suffolk County. "When purchasing new or replacement lighting, all County departments shall include a specification in a solicitation for the purchase of any permanent outdoor luminaire that requires the provider to offer for sale to the County of Suffolk only fully shielded luminaires. All outdoor lighting in all County facilities shall be replaced in accordance with this section. All new outdoor lighting shall be installed in accordance with this section."

SURVEY OF NEW YORK STATE ROADWAY LIGHTING PRACTICES

The LRC project team also contacted NYSDOT regional design engineers, and county and municipal roadway design engineers regarding the basis for their light level recommendations (see Appendix). Of the individuals who were able to respond to the LRC's request for information, 30% (all from counties in NYS) stated that their organization did not design or maintain roadway lighting. Of those whose agencies had responsibility for roadway lighting, 71% stated that Chapter 12 of the NYSDOT (1995) Highway Design Manual was a basis for light levels and pole spacing between fixtures. 43% stated that the IES (2000) recommended practice, and 14% each that the AASHTO (2005) guide, the Federal Highway Administration (FHWA, 1978) Roadway Lighting Handbook, local municipal requirements, and local electric utility recommendations were used to select light levels and pole spacings.

Lamp Types

The NYSDOT Highway Design Manual (1995), in Chapter 12, describes HPS lamps as the preferred light source for roadway lighting. In addition, as part of a previous study for NYSERDA, the LRC in conjunction with ICF Consulting surveyed municipalities in NYS regarding their choices for lamp type in street and found that more than 80% of lamps for street and roadway lighting were HPS.

This finding was reinforced by the information provided to the LRC by NYSDOT regional design engineers and by engineering staff at NYS localities. Of the individuals whose organizations had responsibility for roadway lighting, 100% stated that HPS lamps were used. In addition, 57% reported that they also used metal halide (MH) lamps for some situations. No other sources were identified by the design engineers from NYSDOT or from local municipalities in NYS.

Practices for Different Roadway Types

NYSDOT Region 1 (2008) published a document entitled "Street Lighting: An Informational Booklet" that includes specific information for various roadway types and configurations, and lighting-related issues. A summary of the guidance included in this document is as follows:

- Ornamental lighting: "Often preferred by municipalities to provide improved aesthetics within local residential or business areas."
- Pedestrian lighting: "Designers may consider the applicability of pedestrian scale lighting, and its potential benefits to the community, versus conventional roadway lighting systems."
- Bridges: It is stated that the local utility "is no longer willing to maintain lighting on bridges. This is apparently due to the additional traffic control requirements NYSDOT imposes for work on bridges as well as the difficulty maintaining the conduit to the lights."
- Roundabouts: "Past and present practice in Region 1 is to provide, maintain, and energize lighting for all roundabouts constructed in Region 1 until Department policies and designer guidance are updated."
- Light pollution: "Designers should be aware that numerous municipalities in New York State now have light trespass related ordinances. Designers need to be aware of the importance of this issue to the public as they design lighting systems and select lighting components."

Awareness of Roadway Lighting Issues and Needs for Technical Information

Awareness of Roadway Lighting Issues. Of the NYSDOT regional design engineers and design engineering staff members from NYS localities whose agencies were responsible for roadway lighting, awareness of lighting issues related to mesopic vision and other visibility related factors was mixed. Half of the individuals were not aware of any issues related to the spectrum or color of light sources for roadway lighting. Of those who expressed some awareness, all reported that they believed that colors were easier to see under "whiter" light than HPS and that "whiter" lights produced more glare. Two-thirds each reported that they believed that detection of visual hazards was easier and that appearance of the roadway was brighter under "whiter" light than produced by HPS lamps.

When asked whether there were specific roadway types and locations where they would be more likely to use light sources other than HPS, the individuals contacted from agencies that had responsibility for roadway lighting included the following types: urban and downtown locations (by 67%), roundabouts (by

50%), bridges (by 33%), and intersections/interchanges, parkways and diverging diamond interchanges included by 17% each.

Needs for Technical Information. Of the individuals contacted by the LRC project team who have responsibility for roadway lighting, they were asked what would be an appropriate format for technical information regarding the possible use of alternative light sources. The largest percentage of individuals (86%) reported that a lookup table with lamp and fixture wattages (i.e., “replace 250 W HPS with 200 W LED”) would be useful. 71% each stated that a brochure or brief descriptive guide, and an online calculator or spreadsheet would be useful. 57% stated that patterns with fixture layouts for typical situations would be useful, and 14% reported that a smartphone “app” (application) would be useful.

Among the specific topic areas that they would like information to be about, all of the individuals who were able to answer this question reported that lighting for special roadway situations such as roundabouts, singe-point urban interchanges (SPUIs), or midblock pedestrian crossings would be helpful. Most individuals (83%) also stated that information about new lamp technologies would be helpful, and (by 67%) that information on mesopic vision or “white” light issues was desired. Half of the individuals (50%) each stated that information about light pollution and about adaptive or dynamic lighting would be desired. A third of the individuals (33%) desired information about photovoltaic or solar-powered roadway lighting systems, and 17% desired guidance for locations where access to lighting was impaired, such as by trees or along traffic islands. An additional individual stated that guidelines for maintaining and replacing roadway lighting systems was desirable.

MESOPIC VISION ISSUES

The present section of this chapter summarizes research reports, case studies, analyses and other reports related to the use of unified photometry or visual efficacy as a basis for roadway lighting (or illumination of other outdoor areas). This information makes up part of the basis of the proposed guide for optimizing energy effectiveness of roadway lighting to account for nighttime visibility.

Laboratory Research Studies

Bullough et al. 2011:

- Brightness responses for scale-model outdoor scenes were well predicted by a model developed by Rea et al. (2011) regardless of whether there were colored objects such as vehicles present in the scenes, suggesting that color rendering has little to do with overall brightness perception

Bullough and Rea 2000:

- An experiment using a driving simulator at mesopic light levels (from 0.1 to 3 cd/m², corresponding to 0.3 to 10 fc on asphalt pavement) under different spectra was conducted
- Driving speeds were related only to the measured photopic light levels
- Ability to detect peripheral flashed objects was substantially stronger for spectra with greater short-wavelength energy in the range of light levels tested

Bullough and Rea 2004:

- A review of studies of visual responses under mesopic light levels in the laboratory and in the field revealed the robust effects of spectrum on performance in laboratory and field studies

Fotios and Cheal 2007:

- A series of laboratory tests of visual performance and brightness perception under different light sources suggests that "white" light sources (metal halide, fluorescent) could provide equivalent visibility under lower light levels than the yellowish illumination from high pressure sodium lamps

Goodman et al. 2007:

- A unified photometry system having the same framework as that proposed by Rea et al. (2004), based on the results of experiments of reaction times, contrast sensitivity, and threshold detection, is proposed

He et al. 1997:

- Simple reaction times were measured under high pressure sodium and metal halide spectra at mesopic luminances (from 0.003 to 10 cd/m², corresponding to 0.01 to 30 fc on asphalt pavement)
- On-axis reaction times depended upon only the measured luminance at all light levels
- Off-axis reaction times were increasingly shorter under metal halide illumination as the overall light level decreased below 1 cd/m² (corresponding to 3 fc on asphalt)

Rea and Bullough 2007:

- A comparison of a unified photometry system developed by Rea et al. (2004) and a similar system developed by Goodman et al. (2007) revealed that they produced nearly identical predictions of visual effectiveness under most conditions

Rea et al. 2004:

- A system to quantify the relative visual effectiveness of different light spectra at mesopic light levels (luminances from 0.01 to 0.6 cd/m², corresponding to illuminances of 0.03 to 2 fc on asphalt) is presented, along with look-up tables that can be used by practitioners

Rea et al. 2011:

- For the illuminance range from 0.2 to 2 fc, brightness judgments for a scale-model scene were higher for an MH light source than for an HPS light source
- The responses were well predicted by a spectral sensitivity model that estimated increased sensitivity to "blue" light near 450 nm

<u>Field Research Studies</u>

Akashi et al. 2007:

- A roadway lighting field experiment was conducted to test drivers' ability to detect and respond to moving targets while driving, under different lighting conditions providing equivalent mesopic vision
- Once equated for mesopic vision, driver response times to roadside moving objects were essentially equivalent
- Driver response times under MH illumination were shorter than under HPS even when photopic light levels were equated

Rea et al. 2009:

- In a series of roadway lighting field experiments, it was found that "white" light sources such as MH resulted in increased perceptions of brightness compared to the "yellower" illumination from HPS
- Brighter outdoor spaces were also judged as feeling safer
- Color identification, but not facial recognition, was improved under MH relative to HPS

Rea et al. 1997:

- An outdoor field experiment of visual acuity and off-axis target detection was conducted under HPS and MH illumination
- No differences in visual acuity were found once the measured (photopic) light level was equal
- Reaction times to off-axis targets were shorter under MH than under HPS illumination

<u>Demonstrations and Case Studies of Street Lighting and Other Applications</u>

Akashi et al. 2005:

- Fluorescent roadway lighting was installed along a residential street normally illuminated by HPS lighting, according to the unified system of photometry (Rea et al., 2004)
- Despite lower measured (photopic) light levels and decreased energy use, residents judged the lighting to be at least as visually effective as the sodium illumination

Belcher et al. 1999:

- A survey of residents whose streets were illuminated by HPS or by MH illumination revealed that they had subjective preferences for the MH illumination

Brons 2009:

- Along the main street of a small village downtown, twelve 40 W LED luminaires replaced eight 150 W HPS luminaires
- Residents judged the LED installation as having more visual effectiveness and brighter appearance than the sodium installation

Brons 2010:

- An installation of 79 W LED luminaires was judged to be as good or better than conventional (HPS) street lighting by 84% of observers asked to judge the lighting

Cook et al. 2008:

- Installations of several types of LED street lights were assessed for user acceptance, photometric performance, economic cost and mesopic vision
- The authors conclude that LED street lights can provide equivalent overall performance to HPS street lighting at lower energy use levels

Morante 2008:

- Fluorescent induction lamps and MH lamps were used to replace HPS lighting along roadways in Groton, CT based on the unified system of photometry (Rea et al., 2004)
- Subjective responses of residents living along the streets confirmed that perceptions of brightness and visual effectiveness were as good or better under reduced (photopic) light levels and energy use, with the induction and MH sources

Morante et al. 2007:

- A fluorescent lighting system installed along a roadway according to the unified system of photometry from Rea et al. (2004) was judged by real-world observers to be as bright and visually effective as a corresponding HPS lighting system

Economic Considerations

Bullough and Rea 2008:

- Economic analyses of roadway scenarios consisting of suburban, residential and rural roadways and intersections, and of mid-block crossings, comparing HPS, MH, induction lamps, and LED sources were developed based on unified photometry
- For locations in rural and residential areas with lower light levels, alternatives to HPS could result in lower life cycle costs, despite higher initial costs
- LED systems (in 2008) were substantially more expensive in terms of initial cost than other systems

Kostica et al. 2009:

- The authors conducted analyses of the economic cost to install road lighting systems based on mesopic vision and concluded that installations using MH lamps providing equal visibility as those using HPS lamps can have lower overall costs

Ylinen et al. 2011:

- The authors conclude that when incorporating mesopic visual efficacy of light sources into roadway lighting design, such as when considering LEDs for street lighting, the resulting system can use less energy than a system based on conventional photometry

Consensus Standards and Industry Recommendations

CIE 2010:

- A system of photometry based on visual performance at mesopic light levels is proposed, which is an intermediate system adapted from those of Rea et al. (2004) and Goodman et al. (2007)

IES 2006:

- A number of laboratory and field studies of visual performance at mesopic light levels are described and a look-up table for estimating unified luminances based on light level and spectrum is provided

Rea and Freyssinier 2009:

- A method for comparing the ability of different light sources to support visual performance at nighttime light levels is provided based on the unified system of photometry developed by Rea et al. (2004)

Section 3
SCENARIO SELECTION AND TECHNICAL ANALYSES

Based on the review of NYSDOT and local specifications pertaining to roadway lighting, and on feedback from NYSDOT and local roadway lighting engineering personnel, several scenarios have been identified. For these scenarios, baseline lighting configurations consistent with NYSDOT design and practice have been developed and alternate equipment selections based on human factors (i.e., mesopic vision) and energy considerations are presented.

SCENARIO SELECTION

Following the literature review, the review of NYSDOT and local lighting practices, and based on the needs of the NYSDOT and local lighting engineering personnel who were contacted as described in the previous chapter of this report, several roadway scenarios to be targeted in the proposed guidance were identified. These include:

- Parkways
- Rural intersections
- Residential streets

EQUIPMENT SELECTION

<u>Parkways</u>

NYS has an extensive parkway system. Many of these roads were designed to have scenic qualities integrated with the landscape along which they are located. Lighting is often an element of this design. It is not unusual for parkways to be lighted with historic luminaires mounted on wooden poles such as the fixture illustrated in Figure 2, showing a portion of the Meadowbrook State Parkway on Long Island (NYSDOT 2010). Several of these systems are relatively old and in need of replacement.

Figure 2. Example of light pole and luminaire along a parkway (Source: NYSDOT 2010).

Current NYSDOT lighting policies (NYSDOT 1979) specify the conditions under which continuous and interchange lighting should be installed along parkways. For continuous lighting to be warranted on a section of a parkway, one of the following conditions must be met:

- The ratio of night-to-day accident rates must exceed 3.0, the total accident rate must be at least twice the statewide average for similar roads, and there must have been at least 9 crashes within a 3 year period.
- Two or more successive interchanges must be located within 0.5 miles of each other (or for a sequence of more than two interchanges, the average distance between interchanges must be less than 0.5 miles).
- The average daily traffic on the section in question must exceed 75,000 vehicles/day.

For interchange lighting to be warranted along a parkway, one of the following conditions must be met:

- The ratio of night-to-day accident rates must exceed 2.5 and there must have been at least 6 crashes at the interchange within a 3 year period.
- Two opposing approaches to the interchange are continuously lighted.
- An interchange ramp connects lighted sections.
- An interchange ramp carries traffic between lighted and unlighted sections.

The NYSDOT Highway Design Manual (NYSDOT 1995) states that parkway lighting operating and maintenance costs in Regions 8 and 10 are borne by NYSDOT, and that ornamental or decorative lighting intended to replicate a historic appearance along a historic parkway can be incorporated into a special specification in order to pay for such lighting. (Ornamental or decorative lighting installation costs in other locations are borne by the municipality requesting it.) Although specific to NYSDOT Region 1, guidance for street lighting projects in that region are also available (NYSDOT 2008).

The most common luminaires used by NYSDOT (1995) are medium distribution, Type II or III, semi-cutoff luminaires using HPS lamps (typically, 150 W lamps if the mounting height will be about 9 m, 250 W lamps if the mounting height will be about 12 m, and 400 W lamps if the mounting height will exceed 12 m up to about 15 m). Treating a parkway as a principal arterial roadway located along parks or vacant land, and assuming the lowest pavement reflectance is used, the average recommended illuminance for a parkway would be approximately 9 lx. The National Lighting Product Information Program (NLPIP 2010) determined for commercially available LED luminaires available in Fall 2010, that the existing standards for lighting (AASHTO 2005), assuming a base case consisting of a 150 W HPS system with a 9 m mounting height, could be achieved with LED luminaires resulting in an average energy reduction of 7%. (Initial costs tended to be higher because of higher equipment costs.) Since a 150 W HPS system actually uses about 185 W, the corresponding average wattage of an LED luminaire to meet those requirements would be about 172 W.

Of course, every LED roadway luminaire has a very different optical distribution and design so simply recommending a single wattage in order to meet AASHTO (2005) standards is not practical at present. But this estimate provides a baseline for roadway lighting engineers in order to select LED systems that could be used to illuminate parkways to existing AASHTO (2005) requirements.

An average illuminance of 9 lx, assuming asphalt pavement, corresponds to a luminance of 0.3 cd/m^2. At this luminance, an LED system with a correlated color temperature (CCT) of 4300 K would produce a unified luminance (Rea et al. 2004) that is 38% higher than the unified luminance under HPS (Rea and Freyssinier 2009). However, current AASHTO (2005) and IES (2000) specifications do not take into account the potential visual benefits associated with unified photometry. These are primarily associated with peripheral visibility, and since parkways are generally limited-access roadways with little pedestrian traffic, peripheral visibility may not be as critical along parkways as along other types of roads.

Residential Streets

A survey of municipal and utility lighting engineers (Mara 2005) found that the most common lamp type for local roads was the 100 W HPS lamp. Based on AASHTO (2005) standards, the recommended illuminance on local roads in residential areas is 4 lx. Residential streets are most often illuminated with luminaires mounted to existing utility poles rather than dedicated lighting poles (Mara 2005) with the consequence that other than possibly meeting average illuminance criteria, most residential street lighting systems do not meet other AASHTO (2005) criteria such as uniformity. Rather luminaire placement may be based on the potential for conflicts such as at intersections or near locations where pedestrian crossings are more likely.

For this reason, since AASHTO (2005) criteria are generally not limiting factors underlying the layout of residential street lighting systems, and because pedestrians in residential areas might be more likely to require peripheral vision in order to be detected reliably while driving along a residential street, a residential street lighting retrofit of an HPS system could feasibly be deployed using a source with greater short-wavelength ("blue") spectral output and a lower photopic (light-meter-measured) light level.

Assuming an average pavement luminance of 0.14 cd/m^2 when the average illuminance is 4 lx, a 4300 K CCT LED and a 5000 K CCT fluorescent induction luminaire would both produce the same unified luminance with a (photopic) illuminance of 2 lx. The luminous efficacy of LED and induction fluorescent street light luminaires (evaluated in 2010) are similar to those of 100 W HPS luminaires (NLPIP 2011), and that the total power used by a 100 W HPS system is 127 W (NLPIP 2011). From these data it is estimated that an LED or induction street light with a power of about 65 W could replace 100 W HPS luminaires, to achieve the same average unified luminance. Higher wattages would result in lower energy savings, but increase unified luminance even more relative to the HPS system. Field evaluations of induction lighting systems by Morante et al. (2007) and Morante (2008) confirmed that residential street lighting systems using 30% to 50% less energy could produce equivalent apparent visibility (as judged by residents of the streets) as HPS systems. Figure 3 illustrates a residential street in Groton, CT (Morante 2008) originally illuminated by an HPS system that was subsequently retrofitted with an induction lamp system using about half the power.

Figure 3. HPS residential street lighting system (left) that was replaced by an induction-lamp system (right) with a 50% power reduction (Morante 2008).

Rural Intersections

A common method for illuminating rural intersections on non-access-controlled highways is to use one or two luminaires at the intersection location, where the likeliest vehicle-to-vehicle conflicts would be expected (IES 2000). Recommended light levels according to IES (2000) and AASHTO (2005) specifications stipulate that they should be equal to the sum of the recommended light levels for the intersecting roadways. Assuming a local roadway intersects with a collector roadway in a rural area, the resulting recommended illuminance would be 10 lx in the intersection conflict area. This could be achieved, for example, with two 100 W HPS luminaires, or with a single 150 W luminaire.

A recent analysis (Bullough and Rea 2011) of benefits and costs associated with rural intersection lighting (using costs associated with the state of Minnesota) identified the necessary traffic volume required to achieve the break-even point between the cost of the lighting system (i.e., poles, luminaires, lamps, energy and maintenance) and the benefits in terms of the value of avoided crashes. A daily traffic volume of nearly 1900 vehicles/day through the more major roadway of the intersection was associated with the break-even point based on present-day practices in Minnesota (MNDOT 2006). While specific costs based on NYS energy, material and labor costs, and on NYSDOT practices would differ, the method from Bullough and Rea (2011) could be applied to rural intersections as well. Many intersections with low traffic volumes might not recover the costs of lighting because the benefits are low in terms of the absolute number crashes reduced in a given time period (such as a year). In other locations, Bullough and Rea (2011) estimated that substantially higher levels (with correspondingly higher energy costs, of course) might provide greater reductions in nighttime crashes with a larger benefit-cost ratio than lower levels.

As described above (“Parkways”), LED luminaires for roadway lighting can achieve the requirements published by AASHTO (2005) and IES (2000) with an average 7% reduction (albeit with potentially higher initial and equipment costs). Using the 150 W HPS lamp system as the base case for rural intersection lighting (having a total power of 185 W), LED luminaires with a power of 172 W would be expected to provide an approximately equivalent light level to the 10 lx specified for rural intersections.

The discussion of rural intersections to this point has focused on locations where vehicle-to-vehicle crashes are the predominant type of crash experienced at rural intersections during the night. In these types of crashes, opposing vehicles are generally not found in the visual periphery but rather a driver must judge the relative speed and direction of travel of other vehicles that are generally highly visible because of the presence of headlights and other signal and marking lights (Rea et al. 2010). However, at a rural intersection where pedestrian related crashes have been found to have a much higher frequency relative to vehicle-to-vehicle crashes, it may be possible to take advantage of higher unified luminances produced by “whiter” or higher CCT lamps. For example, the unified luminance under 10 lx of HPS illumination (with an average luminance of 0.32 cd/m^2) can be achieved from a 4300 K CCT LED system or a 5000 K CCT induction lamp system with 35% lower power (Rea and Freyssinier 2009), corresponding to 120 W (compared to 185 W from the 150 W HPS system).

SUMMARY

This chapter summarizes the technical analyses performed to provide relatively simply guidance to lighting decision makers regarding selecting wattages and characteristics of lighting systems using alternative light sources in comparison with HPS, the dominant light source presently used in NYS for roadway lighting (NYSDOT 1995). Not all roadway applications are equally impacted by taking into account the changing visual response of the human eye under mesopic light levels. Nonetheless, the rapidly evolving performance of LED roadway luminaires and the introduction of other technologies is spurring the consideration of new criteria for roadway lighting in certain applications. These findings were used to develop simple, practical and defensible guidance to NYSDOT and municipal lighting decision-makers as described in the subsequent chapter.

Section 4
GUIDE DEVELOPMENT

The present chapter summarizes the development and contents of the guide as well as the plan for disseminating it widely among NYS stakeholders. Included as an Appendix to the present report is the final guide.

GUIDE CONTENTS

The title of the guide is "New Lighting Technologies and Roadway Lighting: An Informational Brochure" (see Appendix). As described in the previous chapter, the guide provides a discussion of three roadway facility types:

- Parkways
- Residential streets
- Rural intersections

Also described are newer light source technologies that have been introduced as alternatives to the incumbent lighting technology, HPS lamps. These technologies include:

- MH lamps
- Fluorescent induction lamps
- LED sources

The guide also includes a brief summary of the concept of unified (mesopic) photometry or "visual efficacy" in which the spectral power distribution (SPD) of a light source can impact the visual effectiveness of a light source used under nighttime, or mesopic lighting conditions. This is caused by the shift in spectral sensitivity of the human visual system toward short visible wavelengths as the light level is reduced. As a result, "white" light sources such as MH, induction and LEDs can provide greater visual effectiveness than the "yellowish" illumination produced by HPS even when the conventionally-measured light level is identical.

Based on this background information, several roadway lighting replacement scenarios are described that give guidance for replacement of conventional HPS roadway lighting systems with alternatives to achieve energy savings and maintain or improve visual effectiveness, while meeting published recommendations for roadway lighting, when applicable, from AASHTO (2005) and the IES (2000). Based on these guidelines, energy savings of 7% could be achievable by replacing HPS systems with LED along parkways, 30%-50% energy savings could be achievable by replacing HPS with LED or induction systems along residential streets, and up to 35%-40% by replacing HPS with LED or induction at rural intersections where peripheral visibility is critical.

The guide also contains several resources from NYSDOT, NYSERDA, IES, AASHTO and the LRC on roadway lighting practice, technologies and on visual efficacy.

DISSEMINATION PLAN

The guide has been produced as a PDF document that can be freely downloaded and readily printed (see Appendix). Links to the resources listed on the last page of the document are "clickable" and when viewed online and clicked, will call up the resource if freely available, or the appropriate web page (for IES and AASHTO publications) where the documents can be purchased.

The PDF guide can be posted on the LRC website (or if preferred, on the NYSDOT website in the same folder that will contain the published final report for the project). The guide will be publicized with links to it on the website of the LRC (www.lrc.rpi.edu). In addition, the guide and final report will be submitted to the Transportation Research Information Documentation (TRID) database maintained by the Transportation Research Board (TRB), and a notice will be submitted for inclusion in the TRB's electronic weekly newsletter.

The guide will also be distributed to design engineers in each NYSDOT Region and to the New York State Thruway, and will be made available to the New York Conference of Mayors, the New York State Association of Counties and the Association of Towns of New York State.

The availability of the guide will also be publicized to the University Transportation Research Center (UTRC) at City University of New York, the New York Metropolitan Transportation Council, and each of the Metropolitan Planning Organizations for publicizing in their newsletters or websites. News items introducing the guide will be submitted to the AASHTO and ITE Journals, Lighting Design + Application, Driving Vision News, ITS International Magazine, Roads & Bridges Magazine and other trade publications. It will also be submitted as a possible presentation topic for the New York State Association of Transportation Engineers semi-annual meetings and technical symposia.

STATEMENT ON IMPLEMENTATION

It is anticipated that the guide developed for this project (see Appendix) will be disseminated to roadway lighting practitioners and decision makers in NYS. By carrying out the dissemination plan identified above, the information herein will be able to be broadly shared. The guide is intended to be consistent with existing practices and recommendations for lighting.

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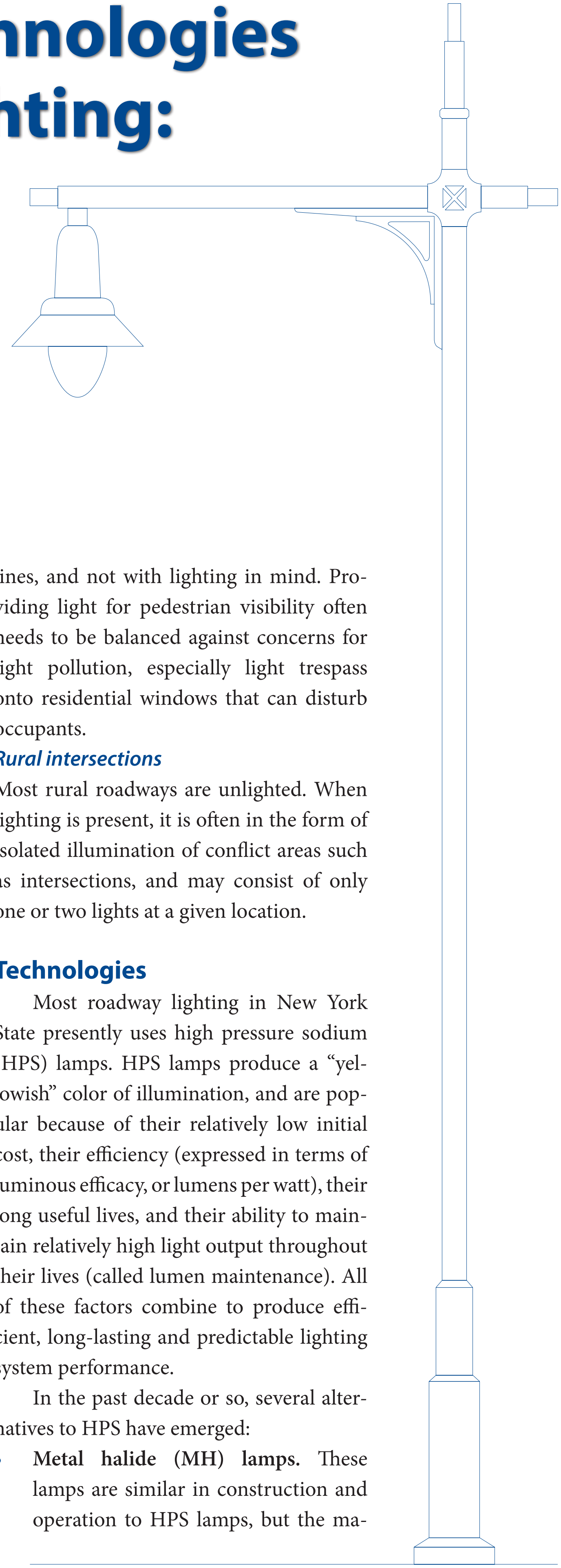
APPENDIX A

NEW LIGHTING TECHNOLOGIES AND ROADWAY LIGHTING:

AN INFORMATIONAL BROCHURE

New Lighting Technologies and Roadway Lighting:

An Informational Brochure



Developed by the **Lighting Research Center (LRC) at Rensselaer Polytechnic Institute**

Project Sponsors:
New York State Energy Research and Development Authority (NYSERDA)
New York State Department of Transportation (NYSDOT)

Lighting is an important element of roadway safety. Evidence suggests that roadway lighting is usually associated with reductions in nighttime crashes. After several decades of relatively slow and gradual change, light source technologies for roadway lighting are evolving rapidly. Many new options for roadway lighting are available, and there is more information about how light interacts with the human visual system. This informational brochure provides some information about these developments and how they might be incorporated into lighting practices for several types of roadways and locations in New York State. The focus is on replacement of older roadway lighting systems near the end of their useful lives, and on maintaining or improving visibility and safety while minimizing energy use and associated costs.

Types of Roadways Discussed

Roadways in New York State range from residential streets to freeways. This brochure focuses on three types of roadways.

Parkways

These are usually highways with designed landscaping and limited access control. They often carry traffic at fairly high speeds (greater than 40 mph) but are not built to the same standards as most freeways. Parkways may have more winding turns and changes in elevation than typical freeways; lighting might assist drivers in identifying and responding to these roadway features safely. Many parkways are considered historic or scenic in character, and maintaining this character is often an important lighting design consideration.

Residential streets

In many residential areas, the focus of lighting is more on nighttime pedestrian activity than traffic safety. Many residential street lighting systems are mounted on existing utility poles, which are located for the purpose of carrying utility lines, and not with lighting in mind. Providing light for pedestrian visibility often needs to be balanced against concerns for light pollution, especially light trespass onto residential windows that can disturb occupants.

Rural intersections

Most rural roadways are unlighted. When lighting is present, it is often in the form of isolated illumination of conflict areas such as intersections, and may consist of only one or two lights at a given location.

Technologies

Most roadway lighting in New York State presently uses high pressure sodium (HPS) lamps. HPS lamps produce a "yellowish" color of illumination, and are popular because of their relatively low initial cost, their efficiency (expressed in terms of luminous efficacy, or lumens per watt), their long useful lives, and their ability to maintain relatively high light output throughout their lives (called lumen maintenance). All of these factors combine to produce efficient, long-lasting and predictable lighting system performance.

In the past decade or so, several alternatives to HPS have emerged:

- **Metal halide (MH) lamps.** These lamps are similar in construction and operation to HPS lamps, but the ma-

Image: NYSDOT

Distinctive lighting along a parkway.

terials inside the lamp discharge produce "whiter" light. MH lamps have actually been available for several decades, but until recently their efficiency, useful lives and lumen maintenance were substantially poorer than HPS. Newer MH lamps with ceramic arc tubes and new methods of starting have much increased efficiency, life and lumen maintenance. Lighting systems using MH lamps are similar in appearance and luminaire (fixture) types to those using HPS lamps.

- **Fluorescent and induction lamps.** Fluorescent lamps are not usually thought of for roadway lighting, but a number of fluorescent roadway lighting systems are available. And more recent fluorescent lamp types known as induction lamps, which use radio frequencies to stimulate the material in the lamp to produce light (unlike conventional fluorescent lamps, which use electrodes at either end of the lamp tube), are becoming more widespread. Induction lamps have similar color as conventional fluorescent lamps and share their diffused appearance, but do not require the longer tubular shape of most fluorescent sources. Although they are somewhat more compact than conventional fluorescent lamps, induction lamps are still relatively large in size compared to HPS and MH lamps, and as a result, induction roadway lighting fixtures often need to be large to provide a uniform distribution of light on the roadway, or else they can produce light patterns with greater variations in light level.
- **Light-emitting diode (LED) sources.** Recent advances in solid-state lighting technologies have resulted in LED sources that produce white light, mainly by using short-wavelength LEDs that produce blue light in combination with phosphors that convert some of the blue light to yellow light, with the resulting mixture appearing white. LED roadway lighting systems are approaching and sometimes exceeding the efficiency of HPS systems. As solid-state devices, LED lighting systems potentially have very long rated lives–perhaps double that of HPS systems, and can exhibit good lumen maintenance, when fixtures are designed with proper heat management. Initial costs have been relatively high but are decreasing rapidly as this technology advances.

	High Pressure Sodium (HPS)	Metal Halide (MH)	Fluorescent Induction	Light Emitting Diode (LED)
Efficacy (lumens/watt)	80-120	60-110	60-90	70-120
Power (watts)	35-400	70-400	55-200	55-300
Operating Life (hours)	24,000-30,000	10,000-20,000	60,000	30,000-100,000
Correlated Color Temp. (kelvins)	2100 (yellowish)	2800-4200 (white/cool white)	2700-6500 (warm white/ bluish white)	3000-8000 (white/ bluish)

In general, each of these sources produces a "whiter" illumination color often judged superior to that of HPS illumination. The long operating lives and relatively high efficiency of these sources can make them suitable replacements or alternatives to HPS for roadway lighting.

Visual Efficacy

As lighting technologies have advanced, so has our understanding of the potential benefits, and drawbacks, of using these newer technologies for roadway lighting. One issue that stems from the use of "white" light sources like MH, induction fluorescent and LED lighting systems is the eye's sensitivity to light at nighttime light levels. Standards and recommendations for roadway lighting are given in terms of photometric quantities such as footcandles (fc) or lux (lx; 1 fc ≈ 10 lx), which are based on the eye's sensitivity to light at interior or daytime levels experienced in offices, schools and homes. The eye's sensitivity at nighttime levels actually shifts so that "blue" or "green" portions of the visible spectrum are relatively more effective than under daytime conditions, especially for seeing objects in the visual periphery.

Since "white" light contains energy in all parts of the visible spectrum while illumination from HPS lamps is concentrated in the "yellow" and "red" portions of the spectrum where the eye is relatively less sensitive under nighttime levels, visibility under "white" light sources may be under-estimated by conventional fc or lx relative to HPS. A growing number of experimental studies has shown that visibility under "white" light sources can be equivalent to HPS even if the measured


Images: LRC

A local road illuminated by high pressure sodium (left) and by fluorescent induction (right) systems.

light level is lower than under HPS, and international standards bodies are beginning to recognize these findings. The use of "visual efficacy" rather than "luminous efficacy" to quantify the usefulness of illumination for roadway lighting provides a way to maintain visual effectiveness under any light source, whether the "yellow" illumination from HPS, or the "white" illumination from MH, fluorescent induction, or LED sources.

Replacement Scenarios

Parkways

New York State has an extensive parkway system. Many of these roads were designed to have scenic qualities integrated with the landscape along which they are located and lighting is often an element of this design. It is not unusual for parkways to be lighted with historic luminaires mounted on wooden poles. Several of these systems are relatively old and in need of replacement.

In New York State, parkway lighting operating and maintenance costs are borne by NYSDOT in certain regions (NYSDOT Regions 8 and 10), and ornamental or decorative lighting intended to replicate a historic appearance along a historic parkway can be incorporated into a special specification in order to pay for such lighting. Ornamental or decorative lighting installation costs in other locations are borne by the municipality requesting it.

The most common luminaires used by NYSDOT are semi-cutoff luminaires using HPS lamps. Treating a parkway as a principal arterial roadway located along parks or vacant land, and assuming low pavement reflectance (i.e., asphalt) is used, the average recommended illuminance for a parkway would be approximately 0.9 fc based on guidelines from the American Association of State Highway and Transportation Officials (AASHTO) and the Illuminating Engineering Society (IES). The National Lighting Product Information Program (NLPIP) determined that for commercially available LED luminaires available in 2010, existing standards for lighting could be achieved with LED luminaires resulting in an average energy reduction compared to HPS lighting. (Initial costs tended to be higher because of higher equipment costs.) The average wattage of LED luminaires to meet existing standards was about 172 W(watts), or 7% lower than the wattage of a 150-W HPS lamp system (which uses 185 W once the ballast power is included).

Of course, every LED roadway luminaire has a very different optical distribution and design, so simply replacing existing HPS luminaires with LED ones may not provide sufficient uniformity of illumination. Specific luminaires should be checked in specific roadway scenarios to determine whether replacing an HPS with LED in existing mounting locations will conform to AASHTO and IES guidelines.

An average illuminance of 0.9 fc, assuming asphalt pavement, corresponds to a luminance of 0.3 candelas/square meter (cd/m^2). At this luminance, an LED system with a correlated color temperature (CCT) of 4300 kelvins (K) would produce 35%-40% higher visual effectiveness (based on visual efficacy) than HPS. In theory, equal visual effectiveness could be achieved with a lower measured light level from a "white" LED source than under the "yellow" illumination from HPS, but current AASHTO and IES guidelines for continuous roadway lighting, such as is installed along many parkways, do not take visual efficacy into account.

Roadway Application	Base Case Lighting	Measured Light Level	Replacement Alternative
Parkways	150 W HPS (185 W total)	0.9 fc (average)	172 W LED (4300 K CCT or higher)

Residential Streets

A very common lamp type for local residential roads is the 100 W HPS lamp. AASHTO and IES recommend an illuminance of 0.4 fc when designing continuous lighting on local roads in residential areas. However, most residential street lighting systems are mounted to existing utility poles rather than dedicated lighting poles. As a consequence, residential streets might meet the average illuminance criterion of 0.4 fc but are not likely to meet other criteria such as uniformity.

Therefore, AASHTO and IES criteria are generally not limiting factors underlying the layout of most residential street lighting systems. Because pedestrians might be more likely to require peripheral vision in order to be seen while driving along a residential street, a residential street lighting retrofit of an HPS system could feasibly be deployed using a source with greater short-wavelength ("blue") spectral output and a lower photopic (light meter-measured) light level.

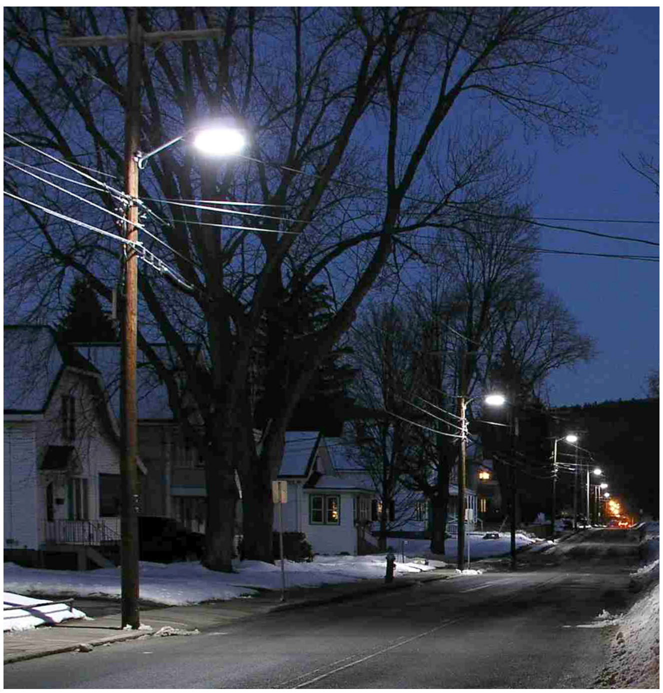


Image: LRC

Street lighting on utility poles in a residential neighborhood.

Assuming an average asphalt pavement luminance of 0.14 cd/m² when the average illuminance is 0.4 fc, a 4300 K CCT LED and a 5000 K CCT fluorescent induction luminaire would both produce the same unified luminance with a (photopic) illuminance of 0.2 fc. The efficiencies of LED and induction fluorescent street lights (evaluated by NLPIP in 2010) are similar to those of 100 W HPS luminaires. The total power used by a 100 W HPS system is 127 W (because of power required by the ballast in HPS systems). It is estimated that an LED or induction street light with a power of about 65 W could replace 100 W HPS luminaires, to achieve the same average visual effectiveness. Higher wattages would result in lower energy savings, but increase visual effectiveness even more relative to the HPS system.

Field evaluations of induction lighting systems replacing HPS luminaires on residential streets have confirmed that residential street lighting systems using 30% to 50% less energy could produce equivalent apparent visibility (as judged by residents of the streets) as HPS systems.

Roadway Application	Base Case Lighting	Measured Light Level	Replacement Alternative 1	Replacement Alternative 2
Residential streets	100 W HPS (127 W total)	0.4 fc (average)	65 W LED (4300 K CCT)*	65 W induction fluorescent (5000 K CCT)*

** - To provide equivalent visual effectiveness as the base case at the measured light level.*

Rural Intersections

A common method for illuminating rural roadway intersections is to use one or two luminaires at the intersection location, where the likeliest vehicle-to-vehicle conflicts would be expected to occur. AASHTO and IES guidelines are silent regarding illuminance recommendations for isolated intersection lighting systems. According to AASHTO and IES, illuminances at the intersections of continuously lighted roadways should be equal to the sum of the recommended light levels for the intersecting roadways. Assuming a local roadway intersects with a collector roadway in a rural area (and that both were continuously illuminated), the recommended illuminance would be 1 fc in the intersection conflict area and this is a reasonable light level for the conflict area at the intersection of two unlighted roadways. An illuminance of 1 fc could be achieved, for example, with two 100 W HPS luminaires, or with a single 150 W HPS luminaire.

A recent analysis of benefits and costs associated with rural intersection lighting in the state of Minnesota identified the necessary traffic volume required to achieve the break-even point between the cost of the lighting system (i.e., poles, luminaires, lamps, energy and maintenance) and the benefits in terms of the value of avoided nighttime crashes (in terms of avoided injury and property damage costs). A daily traffic volume of nearly 1900 vehicles/day through the busier roadway in the intersection was needed to break even, based on Minnesota data. While specific costs based on New York State costs and lighting practices would differ, such a method could be applied to rural intersections in New York State as well. Many intersections with low traffic volumes might not recover the costs of lighting because the benefits would be low in terms of the number of nighttime crashes reduced in a given time period (such as a year).

As described for parkways, LED luminaires for roadway lighting can meet AASHTO and IES recommendations with an average 7% reduction in power. Using the 150 W HPS lamp system as a base case for rural intersection lighting (having a total power of 185 W), LED luminaires with a power of 172 W would be expected to provide an illuminance of approximately 1 fc at rural intersections.

Image: Chris Phan

Rural intersection lighting.

The discussion to this point has focused on locations where vehicle-to-vehicle crashes are the predominant type of crash experienced during the night. At rural intersections where pedestrian-related crashes are of special concern and where detecting pedestrians relies on peripheral vision, it may be possible to take advantage of the higher visual effectiveness produced by "whiter" lamps producing lower conventionally measured light levels. For example, the same visual effectiveness as produced by 1 fc of HPS illumination (with an average asphalt pavement luminance of 0.32 cd/m²) could be achieved from either a 4300 K CCT LED system or a 5000 K CCT induction lamp system having 35% lower power than the equivalent to a 150 W HPS system, corresponding to 112 W for an LED system or 120 W for an induction fluorescent lamp system (compared to 185 W from the 150 W HPS system).

Roadway Application	Base Case Lighting	Measured Light Level	Replacement Alternative 1	Replacement Alternative 2
Rural intersection	150 W HPS (185 W total)	1 fc (in conflict area)	172 W LED (4300 K CCT) [112 W LED 4300 K CCT)]*	185 W induction fluorescent (5000 K CCT) [120 W induction fluorescent (5000 K CCT)]*

** - Alternatives in square brackets are to provide equivalent visual effectiveness as the base case at the measured light level if pedestrian detection through peripheral visibility rather than vehicle-to-vehicle crashes is of primary concern.*

Resources

The following resources contain helpful technical information about roadway lighting practices in New York State, lighting technologies, and visibility under nighttime conditions:

Roadway Lighting Guidelines and Recommendations

- *American National Standard Practice for Roadway Lighting,* Illuminating Engineering Society, 2000: http://www.ies.org/store/product/roadway-lighting-1028.cfm
- *Highway Design Manual: Chapter 12, Highway Lighting,* New York State Department of Transportation, 1995: http://www.dot.ny.gov/divisions/engineering/design/dqab/hdm/hdm-repository/chapt_12.pdf
- *How-to Guide to Effective Energy-Efficient Street Lighting for Municipal Elected/Appointed Officials,* New York State Energy Research and Development Authority, 2002: http://www.rpi.edu/dept/lrc/nystreet/how-to-officials.pdf
- *How-to Guide to Effective Energy-Efficient Street Lighting for Planners/Engineers,* New York State Energy Research and Development Authority, 2002: http://www.rpi.edu/dept/lrc/nystreet/how-to-planners.pdf
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