CLEAN DEVELOPMENT MECHANISM

AMS-II.L

Small-scale Methodology

Demand-side activities for efficient outdoor and street lighting technologies

Version 02.0

Sectoral scope(s): 03

United Nations
Framework Convention on
Climate Change

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1. Introduction

1. The following table describes the key elements of the methodology:

Table 1. Methodology key elements

Typical project(s)	Adoption of energy efficient lamps and/or fixture combinations to replace less efficient lamps and/or fixture combinations in public- or utility-owned street lighting systems
Type of GHG emissions mitigation action	Energy efficiency: Displacement of less-efficient lighting by more-efficient technology

2. Scope, applicability, and entry into force

2.1. Scope

2. This category comprises activities that lead to efficient use of electricity through the adoption of energy efficient lamps and/or fixture combinations to replace less efficient lamps and/or fixture combinations in public- or utility-owned street lighting systems. Project and baseline lamps and/or fixture combinations are referred to here as luminaires, which encompasses all of the components in an individual assembly of street lighting equipment, including lamp, lens and reflector, fixture housing, wiring, and driver or ballast and individual and centralized controls components/system(s). This methodology covers projects involving multiple luminaires used to illuminate roadways.

2.2. Applicability

3. This methodology is applicable for one-for-one replacements of baseline luminaires with project luminaires or for replacing multiple baseline luminaires with multiple project luminaires.[1] This methodology is also applicable to projects that involve the implementation of lighting controls that reduce total operating hours or average wattage of the lighting system as well as for new construction installations.

4. This methodology is only applicable if failed project equipment will continuously be replaced based on local maintenance practices, during the crediting period, with equipment of equivalent or better lighting and energy performance specification.

5. The luminaires selected to replace existing equipment must be new equipment and not transferred from another project activity.

6. Controls covered by this methodology may include simple photocells and/or astronomical time clocks that provide basic streetlight scheduling control. Controls may also include advanced systems that allow for more sophisticated strategies, such as dynamically altering street lighting power (dimming or multiple levels of operation such

[1] For example, a project involving replacing a collection of street lighting luminaires with new street lighting luminaires when the number of project luminaries may be more or less numerous than the baseline luminaires, but the project luminaires in total consume less energy than the replaced luminaries.

as bi-level lighting) based on vehicle and/or pedestrian traffic sensors or schedules, time of night, ambient conditions, etc.; a practice known as adaptive lighting.[2]

7. This methodology applies to street lighting projects that provide lighting performance quality either: (a) equivalent to or better than the baseline lighting performance; or (b) equivalent to or better than the applicable street lighting standard. If adaptive controls will be used to vary light output for project luminaires, lighting performance must be proven to meet or exceed baseline performance or the applicable standard for all light output settings. The preferred standard would be the local standard if there is one, in the absence of a local standard the national standard if there is one, or the CIE standards detailed in appendix 1 of this methodology, if there is no local or national standard.

8. For retrofit projects, lighting performance quality of project luminaires shall be shown to comply with this methodology through the use of one of the following methods:

   (a) Equivalence to existing baseline luminaires: the project participant shall prove that project luminaires provide equivalent or improved total useful illumination (lx), compared to the baseline luminaires being replaced, at each representative location.[3] Either by: (i) measurements and calculations; or (ii) computer modeling of average illuminance from baseline and project luminaires at representative locations that shall be determined in accordance with CIE standard 140:2000;[4]

   (b) Compliance with applicable street lighting standard:

      (i) If a national or local lighting standard is available that prescribes lighting levels for roadway lighting classes, such shall be used to evaluate project luminaire compliance at each representative location. A standard field of calculation shall be defined to field measure or computer model illuminance per appendix 2 of this methodology. Project luminaires must meet or exceed the illuminance levels prescribed in the standard, as well as uniformity and glare criteria as applicable;

      (ii) If no national or local standard exists, the project participant shall use an approved international standard such as CIE's *Lighting of Roads for Motor and Pedestrian Traffic* (CIE 115:2010), which provides a structured model for selection of the appropriate roadway lighting class and gives recommended maintained lighting levels. Alternately, if appropriate, project participant may use the illuminance standards given in CIE's *Technical Report: Road Transport Lighting for Developing Countries* (CIE 180:2007).

[2] The International Commission on Illumination (CIE) Roadway Lighting Standard 115:2010, addresses adaptive street lighting and gives guidance on its application for temporal change in parameters such as traffic volume and composition (CIE 115:2010, section 6.2.2) that effectively alter a location's lighting class. Lighting classes are a system of differentiation amongst areas where streetlights are used based on traffic and pedestrian volume and other considerations. The lighting class for a roadway is normally determined by the most onerous conditions, while the use of adaptive lighting recognizes that roadway conditions are not static. Care must be taken however to ensure that appropriate light levels are always present.

[3] Refer to appendix 2.

[4] When a standard or technical report is referenced in this methodology, it is implied that the most current version of the reference should be utilized, or equivalent.

The illuminance, uniformity and glare requirements of both of these standards are provided in appendix 2 of this methodology;

(iii) Illuminance evaluations for comparison of project and baseline luminaires or for compliance with an applicable standard shall either be made on the basis of the photopic response curve, or using the mesopic system of photometry developed by the CIE and relying on photopic and scotopic response curve measurements;[5]

(iv) Determining lighting performance quality is a one-time activity and thus continuous monitoring and verification of lighting system performance compliance with baseline performance or applicable street lighting standards are not required during the crediting period.

9. In the case of a Greenfield (new construction) project, the existing baseline technology is assumed to be the prevailing street lighting technology used in the region for equivalent roadway types and lighting classes. If it is not common practice in the project's region to illuminate roadways with electric lighting and it cannot be shown that a less efficient street lighting system would be installed in lieu of project activities, this methodology is not applicable.

10. For Greenfield baseline determination, project participant must be able to document representative locations, as described in paragraph 7, where baseline luminaires are already installed in the same region as the project. The same region is defined as either: (a) within 200 km of the project's boundary; or (b) within the same city or town jurisdiction. The project participant must document the type, wattage, and operating schedule of the baseline luminaires at the comparable location and assume this as the baseline for the project representative location. In selecting the baseline technologies to consider, the project participant shall follow the "General guidelines for SSC CDM methodologies" under the section 'Type II and III Greenfield projects'.

11. Steps for defining a Greenfield project's baseline are:

(a) Determine representative locations and construct fields of calculation for all roadway and intersection lighting classes within the project boundary. For large street lighting projects there will likely be various roadway types with different dimensions, uses and lighting classes. Representative locations for each roadway and intersection lighting class and any major variations in roadway dimensions within the project boundary should be documented and labeled in the Project Design Document (PDD) in a consistent way. Representative locations should include any major variations within the project boundary in type of location (urban, semi-urban, rural);

(b) For each representative location within the project boundary, choose a comparable location outside of the project boundary, but within the project's region where the baseline lighting technology is installed and assume this as the baseline lighting system for the representative location. Baseline compliance with a lighting standard is not required;

[5] Refer to appendix 3.

(c) Extrapolating from the selected baseline system for each representative locations to the entire area within project boundaries, project participant shall inventory the entire hypothetical baseline lighting system that would be installed in lieu of project activities, including total counts for all luminaires by wattage and schedule of operation, documenting all assumptions clearly in the PDD.

12. The aggregate electricity savings by a single project activity may not exceed the equivalent of 60 GWh per year.

13. The PDD shall include and/or explain:

(a) Design specifications of project lamps and/or luminaires such as:[6]

(i) Equipment power (in Watts) and output (in lumens);

(ii) Type of controls installed (astronomical time clock, photocell, wireless RF controller, etc.);

(iii) Equipment warranty;

(b) How project procedures eliminate double counting of emission reductions, for example due to project luminaire manufacturers, wholesale providers or others possibly claiming credit for emission reductions for the project luminaires;

(c) How the project design utilizes professional lighting design practices to ensure adequate roadway lighting levels are delivered by project equipment according to accepted practice or local or national roadway lighting standard if one exists;

(d) How the maintenance and replacement practices for the street lighting system will ensure that failed equipment is replaced by equipment of the same or better specification to that of any failed project equipment to assure that lighting and energy performance of the project system is maintained.

2.3. Entry into force

14. The date of entry into force is the date of the publication of the EB 75 meeting report on 4 October 2013.

3. Normative references

15. Project participants shall apply the “General guidelines for SSC CDM methodologies”, information on additionality (attachment A to appendix B) provided at: <http://cdm.unfccc.int/methodologies/SSCmethodologies/approved.html> mutatis mutandis.

16. Relevant reports, procedures and specifications for the methodology include:

(a) “Guidelines for sampling and surveys for CDM project activities and programme of activities”;

[6] If the project participant at a later date chooses different equipment or a different equipment/system supplier, the performance, lifetime, and warranty specifications for the new equipment/systems/supplier(s) should be at least equivalent to those of the originally indicated equipment/systems/supplier(s).

(b) Standard for “Sampling and surveys for CDM project activities and programme of activities”;

(c) “General guidelines for SSC CDM methodologies;

(d) “AMS-I.D: Renewable electricity generation for a grid”;

(e) The methodological tool “Assessment of the validity of the original/current baseline and update of the baseline at the renewal of the crediting period”;

(f) CIE 140:2000. International Commission on Illumination Technical Report: Road Lighting Calculations. ISBN 3 901 906 54 1. This report includes guidance for the calculation of luminance, illuminance, and their associated measures of lighting uniformity, as well as disability glare. The conventions adopted for luminance and illuminance grids are also included; these form the basis for appendix 1 of this methodology;

(g) CIE 115:2010. 2nd Edition. International Commission on Illumination Technical Report: Lighting of Roads for Motor and Pedestrian Traffic. ISBN 978 3 901906 86 2. This report presents a structured model for the selection of the appropriate lighting classes based on the luminance or illuminance concept, taking into account the different parameters relevant for the given visual tasks. The use of adaptive lighting systems that apply time-dependant variables like traffic volume or weather conditions to luminance or illuminance requirements is described. This report also gives recommended maintained lighting levels and lighting quality requirements for roadway classes;

(h) CIE 180:2007. International Commission on Illumination (CIE) Technical Report. Road Transport Lighting for Developing Countries. ISBN 978 3 901 906 61 9. This report deals with the part that better lighting and visibility can play in reducing the toll of death and injury from nighttime road accidents; it is addressed to those involved in road safety work, not to lighting specialists… [the] chapter on fixed roadway lighting deals with the basic design of simple installations and explains the many different factors that need to be considered;

(i) CIE 191:2010. International Commission on Illumination Technical Report: Recommended System for Mesopic Photometry Based on Visual Performance. ISBN 978 3 901906 88 6. This report deals with visual task performance based approaches to mesopic photometry, with a major aim to establish appropriate mesopic spectral sensitivity functions to serve as a foundation of a system of mesopic photometry. A review of the most important visual tasks and the range of visual conditions typically encountered in night-time driving is given. The report summarizes the justification for the recommended system and gives general guidance for its use and application. The system of mesopic photometry is complex and cannot be reproduced in this methodology. For the purposes of this methodology it is acceptable to use the system of mesopic photometry described in CIE 191:2010 to establish equivalent or improved lighting performance of a measure lighting technology as compared to the performance of a baseline lighting technology or to demonstrate compliance with illuminance requirements in an applicable street lighting standard[7];

[7] Refer appendix 3.

(j) IESNA RP-8-00 (2005). Illumination Engineering Society of North America (IESNA) Roadway Lighting. American National Standard Practice for Roadway Lighting. Standard Practice Subcommittee of the IESNA Roadway Lighting Committee. ISBN 0 87995 160 5. This standard serves as the North American basis for design of fixed lighting for roadways, adjacent bikeways, and pedestrian ways;

(k) IESNA LM-50-99. Illumination Engineering Society of North America (IESNA) Guide for Photometric Measurement of Roadway Lighting Installations;

(l) Gordon McKinlay. Light Up the World Report Lighting for the Developing World. Dec. 2006;

(m) Stevens, Cook, Shackelford, and Pang. Street Lighting Network Controls Market Assessment Report. Application Assessment Report #0914. PG&E Emerging Technologies Program. January, 2010. P. 55.

4. Definitions

17. The definitions contained in the Glossary of CDM terms shall apply.

18. For the purpose of this methodology, the following definitions apply:

(a) **Annual failure rate** - fraction or per cent of equipment of a given type within a system that fail annually;

(b) **Lighting classes (roadway and intersection)** - system of differentiation between areas where streetlights are used, based on traffic and pedestrian volume and other considerations. In the methodology’s use of representative locations, lighting classes are the primary means of differentiation between locations. Applying CIE 115:2010 standards also requires the use of lighting class to determine the applicable lighting criteria;

(c) **Outage factor** - the average time, in hours, elapsed between failure of equipment and replacement of equipment, divided by annual operating hours. This shall be determined by documented maintenance practice and records of maintenance turn-around time from failure to replacement;

(d) **Representative location** - representative locations are defined here as sample locations selected during project design for each roadway and intersection lighting class-found within the project boundaries, and including multiple locations within a lighting class if any significant variation in streetlight pole spacing and mounting height, and street dimensions occur. Fields of calculation for average illuminance shall be laid out for each representative location according to the standard provided in appendix 2 of this methodology. Representative locations are used only for comparing baseline and measure lighting performance and are not intended to constitute the sampling plan for ex post power and operating hours monitoring;

(e) **System outage factor** - the product of the equipment outage factor and the equipment annual failure rate, as defined here; used to de-rate total annual electricity for baseline and project street lighting systems due to equipment outages within the systems;

(f) **Luminance** - luminance a measure of the intensity of reflected light per unit area of an illuminated surface, in candela (cd)/m^2, is common metric for evaluating street lighting performance. Luminance can be measured in the field or calculated as well and is acceptable metric for compliance with applicable street lighting standards or comparison of baseline and measure technology performance;

(g) **Total useful illuminance** - the average maintained illuminance on the target task plane (i.e. roadway surface), from the baseline and project street lighting equipment. Maintained illuminance takes into account the depreciation in luminous flux over time, and is defined as illuminance delivered when a product has reached the end of its maintenance cycle. Appropriate depreciation factors should be applied to modeled or measured illuminance values, based on the lighting technology used.

5. Baseline methodology

5.1. Project boundary

19. The project boundary is the physical, geographical location of all project luminaires installed.

5.2. Emission reductions

20. Ex ante calculations are done as per the following steps:

(a) Estimate the nameplate/rated power (Watts) of the baseline and project luminaires, or the time-integrated average power if adaptive street lighting controls will decrease lighting power at periods of lower demand; nightly, weekly, seasonally or otherwise. If patterns of variation in parameters such as traffic volume are well known, such as from records of traffic counts, such records shall be used to estimate time-integrated average power based on controls settings;

(b) Default value for daily hours of operation of luminaires is assumed to be equal to:

(i) For luminaires controlled with a standard timer, use the number of hours that the timer will be set during the crediting period for operating hours during an average day; or

(ii) For luminaires controlled by ambient light sensors or astronomical time clock, use the average number of hours between sunset and sunrise; or

(iii) For luminaires controlled by motion sensors, use the average number of hours between sunset and sunrise divided by ten unless documentation of occupancy patterns can be given to justify another value; or

(iv) For luminaires controlled by advanced controls that allow scheduling options other than light sensing or time clock, use the operating hours that will be programmed into the controls system; or

(v) Scheduling and controls strategies may lead to different default value for daily hours of operation for baseline luminaires and project luminaires;

(c) Calculate the gross electricity savings by comparing the total average power of the project luminaires multiplied by project annual hours of operation, with the average power of the baseline luminaires multiplied by baseline annual hours of operation (daily hours times 365 or other number equal to the number of days per year that the lights are expected to be operated);

(d) Calculate the net electricity saving (NES) by correcting the gross electricity savings for any leakage and transmission & distribution losses.

21. Once the project is installed, the electricity saved by the project activity in year *y* is calculated as follows:

$$NES_y = \sum_{i=1}^{n} ES_{i,y} \times \frac{1}{(1 - TD_y)}$$ Equation (1)

Where:

$$ES_{i,y} = \left(Q_{i,BL} \times P_{i,BL} \times O_{i,BL} \times (1 - SOF_{i,BL})\right) - \left(Q_{i,P} \times P_{i,P,y} \times O_{i,y} \times (1 - SOF_{i,y})\right)$$ Equation (2)

$$SOF_{i,BL} = AFR_{i,BL} \times OF_{i,BL}$$ Equation (3)

$$SOF_{i,y} = AFR_{i,y} \times OF_{i,y}$$ Equation (4)

Where:

NES_y	=	Net electricity saved in year *y* (kWh)
$ES_{i,y}$	=	Estimated annual electricity savings for equipment of type *i*, for the relevant type of project equipment in year *y* (kWh)
y	=	Crediting year counter
i	=	Counter for luminaire type
n	=	Number of luminaires

TD_y	=	Average annual technical grid losses (transmission and distribution) during year *y* for the grid serving the locations where the luminaires are installed, expressed as a fraction. This value shall not include non-technical losses such as commercial losses (e.g. theft/pilferage). The average annual technical grid losses shall be determined using recent, accurate and reliable data available for the host country. This value can be determined from recent data published either by a national utility or an official governmental body. Reliability of the data used (e.g. appropriateness, accuracy/uncertainty, especially exclusion of non technical grid losses) shall be established and documented by the project participant. A default value of 10 per cent shall be used for average annual technical grid losses, if no recent data are available or the data cannot be regarded accurate and reliable
Q_i ($Q_{i,BL}$ and $Q_{i,Py}$)	=	Quantity of baseline (*BL*) or project (*P*) luminaires of type *i* distributed and installed under the project activity (units). Once all of the project luminaires are distributed or installed, $Q_{i,P}$ is normally a constant value independent from *y* unless size of operating luminaire inventory decreases during crediting period, in which case only operating project luminaires shall be credited. Note that $Q_{i\ BL}$ and $Q_{i\ P}$ may represent a different number of luminaries (e.g. a larger number of LEDs with less output), but they must represent the same illuminated area
$P_{i,BL}$	=	Rated power of the baseline luminaires of the group of *i* lighting devices (kW), or time-integrated average power if equipment operates at various power settings, constant value independent from *y*. For retrofit projects, project proponents shall maintain records to demonstrate what type of luminaire are replaced
$P_{i,P,y}$	=	Rated power of the project luminaires of the group of *i* lighting devices (kW), or time-integrated average power if equipment operates at various power settings, normally constant value independent from *y* unless operating schedule or parameters changes during crediting period. Time-integrated average power takes into account controls savings such as dimming or bi-level operation that reduce lighting power for periods of time. For example, if on average, project equipment operates at full power 50 per cent of annual operating hours, and half power 50 per cent of annual operating hours, $P_{i,\ P}$ will be de-rated from full value to 75 per cent of full value ((1 x 50%)+(0.5 x 50%))

O_i ($O_{i,BL}$ and $O_{i,y}$)	=	Annual operating hours for the baseline and project luminaires in year *y*. May differ from *BL* to *P*. This value is based on continuous measurement of daily average usage hours of luminaires for a minimum of 90 days at monitoring survey sample locations (sampling determined by minimum 90 per cent confidence interval and 10 per cent maximum error margin) corrected for seasonal variation of lighting hours and multiplied by 365 days. The method used to extrapolate the 90 days of data to annual values must be documented. For projects involving the following control strategies, the monitoring for determination of annual operating hours shall be continuous for 365 days per year: (i) Luminaires controlled by motion sensors; (ii) Luminaires controlled by advanced controls that allow scheduling options other than light sensing or time clock. The measurements shall be repeated at the monitoring survey sample locations at the time of ex post monitoring as indicated in paragraph 24. In no case can a value greater than the daily average annual number of hours between sunset and sunrise hours, per 24 hour period, be used under this methodology to calculate annual operating hours
SOF_i ($SOF_{i,BL}$ and $SOF_{i,y}$)	=	System Outage Factor (*SOF*) for equipment type *i* in year *y*. *SOF* is calculated as the product of the equipment Outage Factor and the equipment Annual Failure Rate. The value for *BL* is assumed to be the same as monitored for *P* and may vary from year to year
OF_i ($OF_{i,BL}$ and $OF_{i,y}$)	=	Outage Factor is the average time, in hours, elapsed between failure of luminaires type *i* and their replacement, divided by $O_{i,y}$, annual operating hours. This shall be determined by documented maintenance practice and records of maintenance turn-around time from failure to replacement. The outage factor value during the baseline (*BL*) is assumed to be the same as determined for each year of the crediting period (*y*) and may vary from year to year
AFR_i ($AFR_{i,BL}$ and $AFR_{i,y}$)	=	Annual Failure Rate of luminaires calculated as a fraction of *Q*. The value for failure rate during the baseline (*BL*) is assumed to be the same as determined for each year of the crediting period *y* and may vary from year to year. Failure rates during the crediting period should be determined ex post from maintenance records that indicate the actual fraction of system-wide equipment of type *i* that fail annually. For ex ante calculations, failure rate in year *y* could be assumed to equal to $O_{i,y}$ divided by the rated average life for project equipment type *i*

22. Emissions reduction is the net electricity savings (*NES*) times an emission factor (*EF*).

$$ER_y = NES_y \times EF_{CO2,ELEC,y} \quad \text{Equation (5)}$$

Where:

$EF_{CO2,ELEC,y}$	=	Emission factor in year *y* calculated in accordance with the provisions in AMS-I.D (t CO_2/MWh)
ER_y	=	Emission reductions in year *y* (t CO_2e)

23. The electricity savings from the project equipment installed by the project activity shall be considered from the date of completion of installation of all the project equipment.

6. Monitoring methodology

24. Ex post monitoring and adjustment of net electricity savings:

(a) First ex post monitoring survey, carried out within the first year after installation of all project luminaires shall provide a value for:

(i) Outage factor (OF_i);

(ii) Annual failure rate (AFR_i);

(iii) Average annual operating hours (O_i);

(iv) Average project equipment power (P_i);

(v) Number of project luminaires placed in service and operating under the project activity ($Q_{P,i}$). While project luminaires replaced as part of a regular maintenance or warranty program can be counted as operating, project luminaires cannot be replaced as part of the CDM monitoring survey process and counted as operating;

(b) Subsequent ex post monitoring surveys are carried out at least every other year after the first year of the crediting period (for example years 3, 5, 7, 9 and onward for projects that have selected renewal of crediting period in years 11, 13, 15, 17, 19 and 21) to determine ex post OF_i, AFR_i, O_i, and $P_{i,\ P}$ for use in ex post emission reduction calculations until such time as CERs are no longer being requested;

(c) For each ex post monitoring survey, the project monitoring plan shall include continuous monitoring of equipment run-time for at least 90 continuous days to determine average daily operating hours for extrapolation to annual operating hours (O_i). For projects involving the following control strategies the monitoring must for determination of annual operating hours (O_i) and average project equipment power ($P_{i,\ P}$) shall be continuous for 365 days per year:

(i) Luminaires controlled by motion sensors;

(ii) Luminaires controlled by advanced controls that allow scheduling options other than light sensing or time clock;

(d) For monitoring survey, individual project luminaires or groups of project luminaires if applicable (i.e. a continuous string of project luminaires on a dedicated electric circuit that can be monitored) shall constitute the population constituents when determining sample size and distribution;

(e) If multiple systems of scheduling and/or controls are installed within the project boundaries, the luminaires under each system of schedules and/or controls shall represent unique population sets for sample sizing and sample location selection;

(f) For measurement of average annual operating hours (O_i), a simple recorder of on/off time or direct monitoring over time of power or even light intensity may be used.

25. Monitoring includes recording of luminaire distribution data and ex post monitoring surveys as defined in paragraph 24:

(a) During project activity implementation, the following data are to be recorded:

(i) Number of project luminaries distributed and installed under the project activity, identified by the type of luminaires, operating schedule and adaptive controls strategy, if any, and the date of installation;

(ii) The number, power, and operating schedules of the replaced devices;

(iii) Information on baseline and project lighting controls indicate:

a. Use of photocell and type if so;

b. Use of time clock and type if so;

c. Dimming or multi-level operation, and type if so;

d. Sensor controls – traffic volume, light sensors, etc. and type if so;

e. Networked controls with central scheduling, monitoring, and/or reporting features;

(b) The emission reductions are calculated ex ante and adjusted ex post following the monitoring surveys, as described under the paragraphs above.

6.1. Project activity under a Programme of Activities

26. The methodology is applicable to a programme of activities, no additional considerations required.

Appendix 1. Roadway lighting requirements in lieu of national or local standard

1. The following tables present illuminance, luminance, glare, and uniformity criteria for roadways and intersections from standards that should be referenced in the absence of a prevailing national or local standard for street lighting. The lighting criteria here are adapted from CIE 115:2010, *Lighting of Roads for Motor and Pedestrian Traffic* and CIE 180:2007, *Road Transport Lighting for Developing Countries*. Please refer to the actual standards for detailed information on the criteria, definitions, and specific considerations.

2. Roadway and intersection lighting classes are an important designation to differentiate between types of areas where streetlights are necessary, based on traffic and pedestrian volume and other considerations. In the methodology's use of representative locations to characterize street lighting installations in project boundaries, lighting classes are the primary means of differentiation. Applying CIE 115:2010 requires the use of lighting class to determine the applicable lighting criteria.

Table 1. Lighting Classes for Roadways (adapted from CIE 115:2010 Table 1)

Parameter	**Options**	**Value**	**Selected Value**
Traffic Speed	Very High	1	
	High	0.5	
	Moderate	0	
Traffic Volume	Very High	1	
	High	0.5	
	Moderate	0	
	Low	-0.5	
	Very Low	-1	
Traffic Composition	Mixed with high % non-motorized	2	
	Mixed	1	
	Motorized Only	0	
Separation of Roadways	Yes	1	
	No	0	
Intersection Density	High	1	
	Moderate	0	
Parked Vehicles	Present	0.5	
	Not Present	0	
Ambient Luminance	High	1	
	Moderate	0	
	Low	-1	
Visual Guidance/Traffic Control	Poor	0.5	
	Moderate/Good	0	
		Sum	
	Roadway Lighting Class M (6 - Sum):		

Table 2. Roadway luminance requirements (adapted from CIE 115:2010 Table 2)

Lighting class	Road surface				Threshold increment	Surround ratio
	Dry			Wet		
	Luminance (cd/m^2)	U_o	U_1	U_o	%	R_s
M1	2.0	0.4	0.7	0.15	10	0.5
M2	1.5	0.4	0.7	0.15	10	0.5
M3	1.0	0.4	0.6	0.15	15	0.5
M4	.75	0.4	0.6	0.15	15	0.5
M5	0.5	0.35	0.4	0.15	15	0.5
M6	0.3	0.35	0.4	0.15	20	0.5

3. CIE 115:2010 only lists luminance requirements for roadway lighting classes. Luminance, a measure of the intensity of reflected light per unit area of an illuminated surface, in candela (cd/m^2), is a common criterion used in street lighting standards. Equivalent illuminance values for given luminance values can be determined from the average luminance coefficient, qo, in $cd/m^2/lx$, if reflective properties of the surface are given qo relates illuminance to luminance by the following relationship: Luminance (cd/m^2) = Illuminance (lx) * qo ($cd/m^2/lx$). A qo default value of 0.07 is often given for typical roadway surfaces; see CIE 115:2010. Such surfaces are typically asphalt roads with aggregate composed of a minimum of 60 per cent gravel, greater than 10mm in size, with a mode of reflectance that is “mixed” (diffuse and specular). The value of 0.07 can also characterize an asphalt road surface with 10–15 per cent artificial brightener in aggregate mix.

4. Roughly equivalent average illuminance requirements can be listed for three common roadway surface classes:

Table 3. Illuminance requirements for roadways (adapted from CIE 115:2010 Table 4)

Lighting class	Average illuminance (lx); q_o = .05	Average illuminance (lx); q_o = .07	Average illuminance (lx); q_o = .09
M1	50	30	20
M2	30	20	15
M3	20	15	10
M4	15	10	7.5
M5	10	7.5	7.5
M6	7.5	7.5	7.5

Table 4. Lighting classes for conflict areas, intersections (adapted from CIE 115:2010 Table 3)

Parameter	Options	Value	Selected Value
Traffic Speed	Very High	3	
	High	2	
	Moderate	1	
	Low	0	
Traffic Volume	Very High	1	
	High	0.5	
	Moderate	0	
	Low	-0.5	
	Very Low	-1	
Traffic Composition	Mixed with high % non-motorized	2	
	Mixed	1	
	Motorized Only	0	
Separation of Roadways	Yes	1	
	No	0	
Ambient Luminance	High	1	
	Moderate	0	
	Low	-1	
Visual Guidance/Traffic Control	Poor	0.5	
	Moderate / Good	0	
		Sum	
	Conflict Lighting Class C (6 - Sum):		

Table 5. Requirements for conflict areas (adapted from CIE 115:2010 Table 5)

Lighting class	Average illuminance	Uniformity	Threshold increment %	
	lx	U_o	High, mod. speed	Low speed
C0	50	0.4	10	15
C1	30	0.4	10	15
C2	20	0.4	10	15
C3	15	0.4	15	20
C4	10	0.4	15	20
C5	7.5	0.4	15	25

5. Considering vehicle types found in less developed countries, the following values are suggested by CIE 180:2007. For areas where the traffic consists mostly of pedestrians and non-motorized vehicles (the first two rows in the table) the figures are for illuminance only. For recognized traffic routes (the remaining rows in the table) the figures are for luminance, but roughly equivalent values for illuminance, for moderately dark road surfaces, are given as well.

Table 6. Suggested lighting standard for developing countries (adapted from CIE 180:2007)

Category	**Average Lighting Level**	**Uniformity (U_o)**	**Uniformity (U_1)**	**Threshold Increment %**
Roadways in residential areas, with pedestrians and many non-motorized vehicles	1 – 2 lx	0.2	n/a	n/a
Largely residential, some motorized vehicles	4 – 5 lx	0.2	n/a	n/a
Major access roads, distributors, and minor main roads	0.5 cd/m^2 8 lx	0.4	0.5	n/a
Important rural and urban traffic routes	1.0 cd/m^2 15 lx	0.4	0.6	20
High speed roads, dual carriageways	1.5 cd/m^2 25lx	0.4	0.7	15

Appendix 2. Method for measuring and calculating average illuminance

1. Evaluating roadway illuminance, a measure of the amount of luminous flux falling per unit area – lumens/m^2, or lux (lx), is a simple comparative basis for roadway lighting systems (McKinlay. Dec. 2006) used in this methodology, though luminance evaluations are common and are also acceptable.[8] Total Useful Illuminance is defined here as the average maintained illuminance on the target task plane (i.e. roadway surface), from the baseline and project luminaires. *Maintained* illuminance takes into account the depreciation in luminous flux over time, which varies from one light source to another, and is defined as illuminance delivered when a product has reached the end of its maintenance cycle. Appropriate depreciation factors should be applied to modeled or measured illuminance values, based on the light source used.

2. Because roadway uses, dimensions, and lighting systems layout vary from location to location, it is not practical to measure or model lighting performance for an entire street lighting system. It shall be sufficient for this methodology's lighting performance requirements to show compliance at Representative locations within the project boundaries. Representative locations are defined here as sample locations selected during project design for each roadway and intersection lighting class (defined in appendix 1 of this methodology) found within the project boundaries, and including multiple locations within a lighting class if any significant variation in streetlight pole spacing and mounting height, and street dimensions occur. Representative locations are used only for comparing baseline and measure lighting performance and are not intended to constitute the sampling plan for ex post monitoring of project equipment power and operating hours. Lighting performance and compliance shall be established at the commencement of project activities by competent lighting design professionals.

3. Quantifying illuminance can either be done through computer modelling of illuminance or actual field measurements. Measurement and calculation of average illuminance from baseline and project luminaires at representative locations shall be determined in accordance with standard practices, such as CIE 140:2000. CIE 140:2000 provides the basis for determining fields of calculation, the location of measurement or simulation points for lighting calculations, and calculation methods for average illuminance values, as well as uniformity and glare values across the field of calculation.

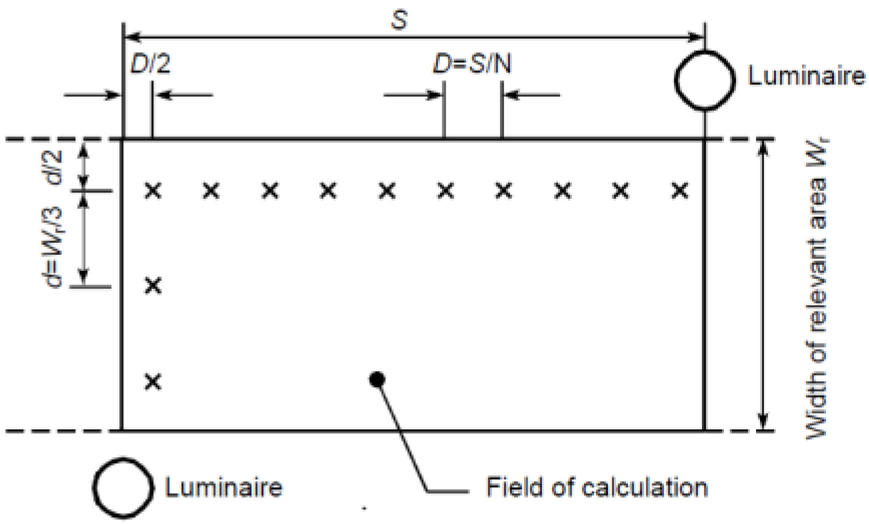
4. Illuminance comparisons must be made for fields of calculation within each representative location addressed by project activities, based on roadway and intersection lighting class as well as variations in mounting height, distance between luminaires, and roadway dimensions, as described in paragraph 2.

5. Illuminance equivalence shall be determined following the guidance provided here for illuminance measurements and modeling, based on CIE 140:2000, which provides detailed guidance on the layout of fields of calculation for measuring or simulating illuminance points in a given area. Please refer to CIE 140:2000 for details:

[8] Refer to appendix 1.

(a) The field of calculation should be typical of the area of the road or intersection which is of interest to the driver and pedestrian, and may include the footways, cycleways, and verges. As shown in the figure below, adapted from CIE 140:2000. it should be bounded by the edges of the roadway and by transverse lines through two consecutive luminaires;

Figure 1. CIE 140:2000 Illustration of illuminance field of calculation



(b) For staggered installations, consecutive luminaires will be on opposite sides of the road;

(c) The calculation points should be evenly spaced in the field of calculation (see figure above) and their number should be chosen as follows:

(d) In the longitudinal direction, the spacing in the longitudinal direction should be determined from the equation:

$$D = S/N \qquad \text{Equation (1)}$$

Where:

D	=	Space between points in the longitudinal direction (m)
S	=	Space between luminaires (m)
N	=	Number of calculation points in the longitudinal direction with the following values: S ≤ 30 m, N = 10; S > 30 m, N = the smallest integer giving D ≤ 3 m

(i) The first row of calculation points is spaced at a distance D/2 beyond the first luminaire (m);

(e) In the transverse direction:

$$d = W_r/3 \quad \text{Equation (2)}$$

Where:

d	=	Space between points in the transverse direction (m)
W_r	=	The width of the roadway or intersection (m)

(i) The spacing of points from the edges of the relevant area is *D*/2 in the longitudinal direction, and *d*/2 in the transverse direction, as indicated in the figure above;

(f) Number of luminaires included in calculation:

(i) Luminaires which are situated within five times the mounting height from the calculation point should be included in the calculation.

Appendix 3. Guidance on use of mesopic photometry for lighting performance evaluation

1. “The photopic response curve is a function that weights the visual effectiveness of wavelengths in the electromagnetic spectrum according to the human eye’s response in levels of adaption over 3 cd/m^2 (e.g. daylight conditions), which are dominated by the eye’s cone photoreceptors. Commercial photometry traditionally measures light levels based on this function. However, under the lowest light conditions (adaption less than 0.001 cd/m^2), when the eye’s rods are the active photoreceptors, human perception of light follows the scotopic luminous efficiency function. At intermediate levels between daylight and darkness (ambient photopic luminance in the 0.001 to 3 cd/m^2 range) typical of nighttime roadway lighting levels, rods and cones both provide levels of spectral sensitivity, with rods’ importance diminishing and cones’ increasing as light levels increase. In these intermediate levels, the photopic response curve and the scotopic response curve are both important. This is known as the mesopic range.”

   Stevens, Cook, Shackelford, and Pang. *Street Lighting Network Controls Market Assessment Report*. Application Assessment Report #0914. PG&E Emerging Technologies Program. January, 2010. P. 55.

2. Mesopic photometry characterizes the performance of the human visual system under low light levels typical of nighttime roadway conditions. Broad spectrum light sources excite multiple types of photoreceptors in the human eye (rods and cones), and often provide higher performance in the mesopic range than narrow spectrum sources such as Sodium Vapor lamps. Mesopic photometry may better quantify the benefits of efficient broad spectrum light sources such as LED luminaires and induction lamps that may be selected as project luminaires under this methodology.

3. If mesopic photometry is to be used in the lighting performance evaluation, project participant shall refer to CIE 191:2010 methods to calculate mesopic luminance (and to estimate mesopic illuminance) based on photopic and scotopic luminance levels (field measured or computer modeled) or using photopic luminance and the ratio of light source photopic:scotopic luminous output. The mesopic model will require many calculation steps that should be documented in the Project Design Document.

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Document information

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