Light Naturally
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Final Report

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Energy efficiency performance requirements for road lighting designs and luminaires

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1 Introduction

The aim of this study is to conduct an assessment of existing international methodologies, standards and guidelines for establishing energy efficiency requirements for streetlights, and related performance requirements for lighting installations for various classes of roads and identify options that may be suitable for application in Australia and New Zealand, particularly within the context of AS/NZS 1158. In evaluating requirements for street lighting it is important to note that consideration of options for achieving energy savings must be made within the context of requirements put in place for ensuring road safety, for example as per AS/NZS1158.3.1 for P category roads and AS/NZS1158.1.1 for V category roads.

This Report has been prepared for the South Australian Department of State Development, on behalf of the Equipment Energy Efficiency (E3) Committee.

2 Lamps and Luminaires

In the current Australian and New Zealand streetlight market, a number of lamp technologies with various performance attributes are being adopted in street lighting designs. The fairest indicator of overall energy efficiency of a luminaire, which incorporates both the lamp technology and luminaire design, is the luminaire efficacy rating (LER) metric; which is a measure of total luminaire light output divided by the total luminaire power input.

Figure 1 provides a small but indicative sampling of the LER performances of typical lamp and luminaire types used in Australia and New Zealand that have lumen outputs up to 10 klm. The lamp technologies are:

- Compact fluorescent (CFL)
- High pressure sodium (HPS)
- Light emitting diode (LED)
- Metal halide (MH)
- Mercury vapour (MV)
- Twin tube T5 linear fluorescent (T5)

While the luminaire types are:

- Semi-cutoff, which allow a small proportion of light flux above the horizontal. The additional upward light allows for increases in pole spacing but it also causes some spill light.
- Aeroscreen (aero), provides zero light flux above the horizontal. Due to the strict constraints for light output distribution for an aeroscreen type luminaire, the typical LER values will be marginally lower than for the same lamp used in a semi-cutoff fitting.

In order to have a conservative approach to traditional technology analysis, the maximum power limits applied to the lamps are derived from the Australian Energy Market Operator (AEMO) national electricity market load tables for unmetered connection points, dated 12 June 2014. The LED models shown are approved listings in this edition of the load table.

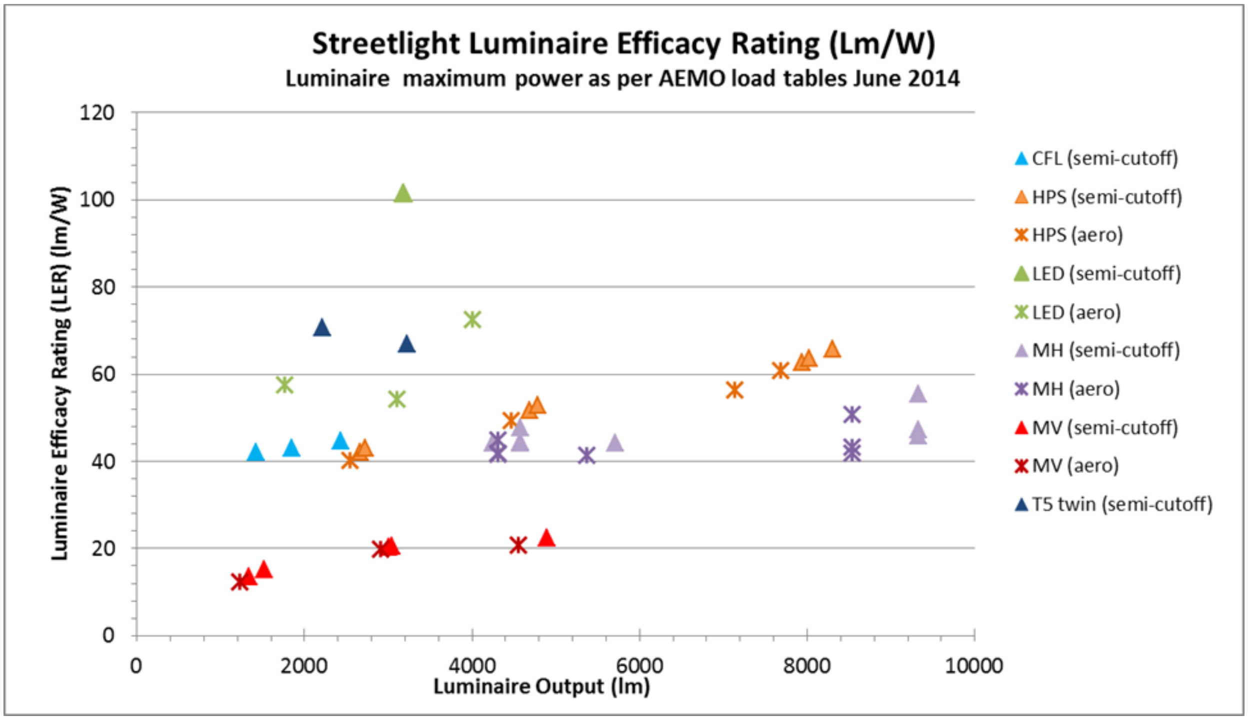


Figure 1. Performance of streetlight luminaires in Australia and New Zealand 2014 (to 10 klm output).

With LER values hovering at 15-20 lm/W, the mercury vapour luminaires are evidently the lowest performers. The rest of the market perform at or greater than 40 lm/W, with the most effective performers in the lower 1-5 klm flux range being the T5 twin linear fluorescent and LED models (60-100 lm/W). The most energy efficient in the upper 5-10 klm flux range are luminaires using HPS lamps (60-70 lm/W).

As there is not a significant variety in the performance levels that can be yielded from the gas discharge type lamps, the values shown here for any of the gas discharge lamp technologies will be fairly indicative for any brand or make of lamp on the market. LED luminaire models however, are packaged within a complete luminaire and the range of efficacies available is substantial.

Market research based on catalogue data from 26 manufacturers (6 countries of origin) was conducted during 2013-2014 into the claimed performance of LED streetlights available in Australia and New Zealand. A key finding is that the LER for LED products is not linked to the lumen rating of the light source (Figure 2). In other words, a 22 klm output LED streetlight that would provide appropriate lighting levels for a V3 lighting category level, can have the same LER as a 1.8 klm output LED streetlight that might be used in a P5 category (for Australia only) lighting installation.

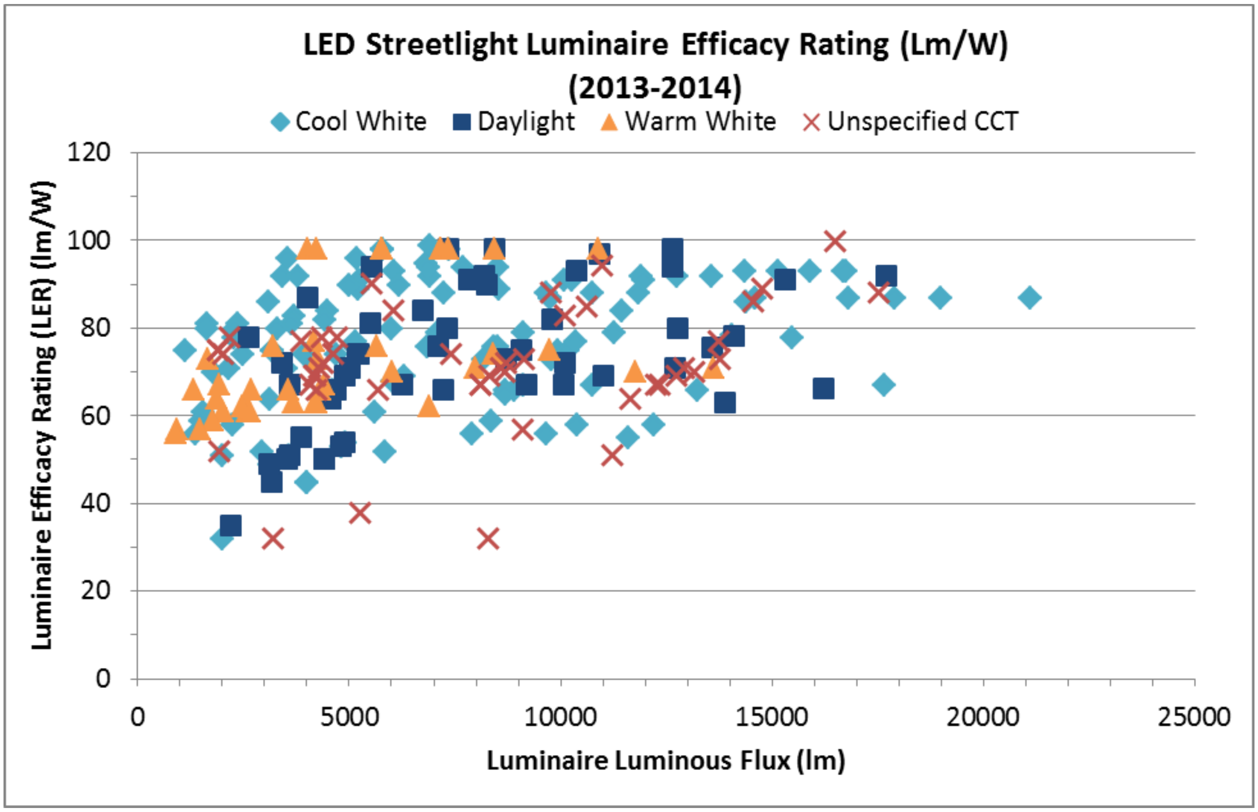


Figure 2. Performance of LED streetlight luminaires in 2013-2014 (source: Light Naturally 2014).

2.1 Typical Australian/New Zealand Road Design Solutions

The most common categories chosen for road lighting schemes in Australian/New Zealand for urban/residential streets are P4 and P5 (for Australia only) category, and for major arterial roads it is typically either V3 or V5.

As an indicative guide, traditional lighting solutions in South-East Queensland installations will often be applied using lamps shown in Table 1, as these lamp solutions have been proven to provide a good balance between meeting minimum light levels without over-lighting the given roadway area.

Table 1. Typical lamp choices for common road categories in South-East Queensland road lighting.[1]

Lighting Category	Typical Lamp	Luminaire Approx Watts	Luminaire Approx Lumens	Typical mounting height	Typical pole spacing
P5*	M50	65 W	1500 lm	6.5 m	60 m
P4	M80	95 W	3000 lm	6.5/7.5 m	60 m
V5	HPS100/HPS150	120/170 W	8000/11000 lm	9 m	45-55 m
V3	HPS250	273 W	22000 lm	10.5 m	45-55 m

* for Australia only

Obviously, lamps with different lumen outputs can be used for these road category installations and different mounting heights and pole spacings will be chosen in various circumstances; these are simply stated here to demonstrate what a typical installation will require in order to provide appropriate lighting levels.

[1] Source: Energex, 2014.

3 International MEPS regimes

Several countries have moved to establish minimum energy efficiency performance requirements (MEPS) into their road lighting standards; others have initiated voluntary programs that identify and reward energy efficient practices in road lighting. These programs and standards take a variety of forms, and pose different levels of ease for calculation of energy efficiency parameters and evaluation of compliance or comparative performance. This section provides a summary of existing international energy efficiency regimes.

Note regarding the typical application of energy efficiency in the international standards/regulations:

- Where the energy efficiency metric described by the standard includes a component of road design, such as 'Watts per metre', the energy efficiency component is contingent on the road lighting design first meeting relevant minimum illuminance/luminance requirements of the road lighting category.

This process indirectly puts the onus back onto the lighting designer to choose efficient lamp technologies that in conjunction with the luminaire optics provides a satisfactory lighting distribution in order to satisfy light technical requirements (such as minimum average light levels, uniformity and glare) for a given roadway as well as efficacy requirements – so there is a push-pull relationship driving optimal lighting design.

Likewise, the application of an energy efficiency metric/s in Australia and New Zealand would be contingent on meeting with the minimum lighting requirements as designated in AS/NZS 1158.1.1 for V category and AS/NZS 1158.3.1 for P category road lighting designs.

3.1 International Energy Agency (IEA) Energy Efficient End-Use Equipment Solid State Lighting (4E SSL) (Source: Energex, 2014)

3.1.1 Outline

The International Energy Agency, Energy Efficient End-use Equipment, Solid State Lighting Annex (IEA 4E SSL) was established in 2009 for the purpose of providing advice to its ten member countries which were seeking to implement quality assurance programs for SSL lighting. The collaboration brings together the governments of Australia, China, Denmark, France, Japan, The Netherlands, Republic of Korea, Sweden, United Kingdom and United States of America.

One of the chief collaborative tasks for IEA 4E SSL has been development of performance tiers for a number of LED product categories, which includes streetlights within the scope of outdoor lighting. The tiers (Table 2, Figure 3) have been designed to provide a limited (rationalised) set of performances that could be adopted by countries for their energy efficient lighting programs, including minimum energy performance standards (MEPS), higher energy performance standards (HEPS), endorsement labels, incentive schemes, procurement schemes and the like (IEA 4E SSL (www.ssl.iea-4e.org/task-1-quality-assurance)).

Table 2. IEA 4E SSL energy efficiency performance tiers.

	Tier 1 (MEPS)	Tier 2 (HEPS)
Minimum downward luminaire efficacy (initial)	$(0.0010 \times \phi) + 51$	$(0.0012 \times \phi) + 64$

where ϕ is initial luminous flux.

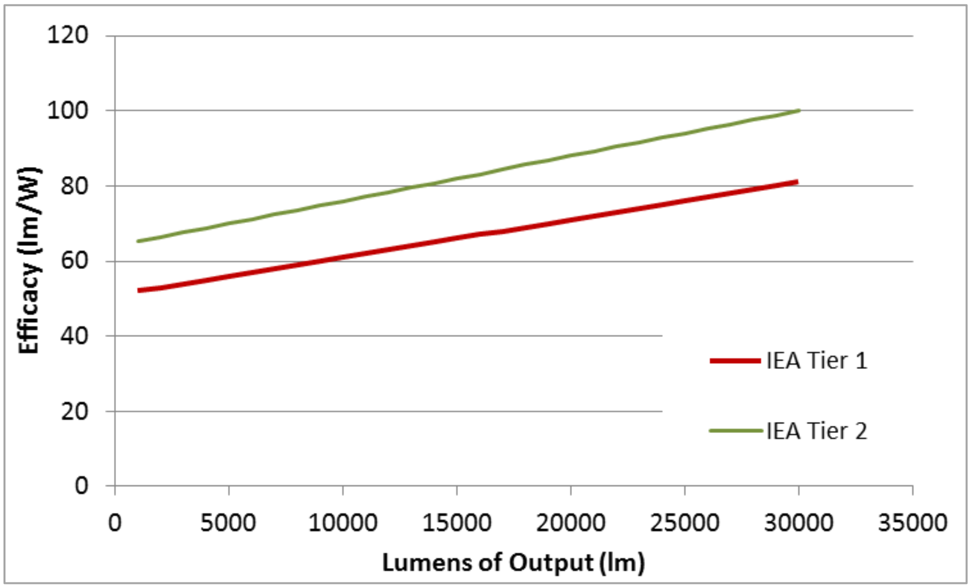


Figure 3. IEA 4E SSL energy performance tiers for LED luminaires.

Note (quoted from the IEA 4E SSL Outdoor lighting publication (www.ssl.iea-4e.org/task-1-quality-assurance)): "The efficacy requirements of LED streetlight luminaires increases with light output not because higher output products are inherently more efficient, but because the HID products they are intended to replace increase in efficacy as light output increases. This approach ensures energy savings relative to incumbent products regardless of light output levels, and allows low-output LED products – which are competitively priced in comparison to low output HID products – to qualify for these requirements at efficacies that are currently easily achieved."

The IES 4E SSL recommends adoption of the test method developed by CIE TC 2.71 for all relevant metrics.

The SSL Annex also recommends suitable accreditation frameworks for SSL testing laboratories, to ensure a structure for worldwide acceptance of SSL testing laboratories' test data. Some countries (Thailand and Armenia) have already utilised some of these recommendations in government programs.

3.1.2 Other technical parameters

Energy efficiency of an LED product does not ensure that it will be of a high quality overall; in fact high energy efficiency levels may be achieved at the expense of other quality attributes (such as lumen maintenance, flicker, colour maintenance, or colour rendering). Some of the sacrifices in quality are unique to SSL technology and/or electronic ballasts, and these parameters are not always evident early in their lifetime. Therefore, to combat the incidence of poor products being deployed additional performance parameters were included in the 4E SSL standard. These parameters are outlined in Table 3.

Table 3. IEA 4E SSL Performance Tiers – Other Technical Parameters

Parameter	IEA 4E SSL Tier 1	IEA 4E SSL Tier 2
Life		
Lumen maintenance (L70/B50)	At 35000 hours, lumen maintenance should be greater than 78% of the initial flux.	At 35000 hours, lumen maintenance should be greater than 78% of the initial flux.
Minimum rated luminaire lifetime (F50)	At least 50% shall be operative after 50,000 hours.	At least 50% shall be operative after 50,000 hours.
Colour		
Colour Rendering Index (CRI)	N/A	≥ 60
Colour maintenance (Δu',v' at 6,000h)	N/A	< 0.007
Parameter	**Common to all Tiers**	
Operation		
Operating temperature (range °C)	Minimum temperature range from -10°C to 40°C without significant change of photometric and colorimetric performance, unless regional requirements are higher or lower	
Ingress Protection (IP), Impact Protection (IK)	Must be IP65 or greater	
Light & Health		
Correlated colour temperature (K) and tolerance < 6500K	Follow ANSI C78.377, excluding flexible CCT Nominal CCT: / Target CCT ± Tolerance 2700K: 2725 ± 145 3000K: 3045 ± 175 3500K: 3465 ± 245 4000K: 3985 ± 275 5000K: 5028 ± 283 5700K: 5665 ± 355 6500K: 6530 ± 510	
Chromaticity tolerance (Du'v')	Centre points based on ANSI C78.377, excluding flexible CCT Nominal CCT: / Target Du'v' ± Tolerance 2700K: 0.000 ± 0.012 3000K: 0.000 ± 0.012 3500K: 0.000 ± 0.012 4000K: 0.001 ± 0.012 5000K: 0.002 ± 0.012 5700K: 0.002 ± 0.012 6500K: 0.003 ± 0.012	
Flicker (amplitude modulation depth)	At full power: flicker index ≤ 0.3	
Minimum displacement power factor	≥ 0.9	
Safety	Must meet regional requirements for material and electrical appliance safety laws.	
Environment		
Uplight (emissions above the horizontal	> 95% of total light output will be emitted below the horizontal (90 degrees) (Note: Local regulations may have more stringent requirements for upward light)	
RoHS compliant	Yes (Note: other regulations may apply)	
Recyclability (%)	Yes, following the principles of self- declaration found in ISO 14021	

3.1.3 Discussion

Tier 1 is intended to be the minimum acceptable performance when products are used for grid-connected applications, as such, this would be an appropriate level to consider as a MEPS regulation for a country, but only if a technology specific solution were being sought, as the performance levels are very high.

Regarding the applicability in the Australian and New Zealand market: The preference for any product performance requirement of an AS/NZS standard is to be non-technology specific. The Tier 1, as a MEPS, and Tier 2, as a HEPS, for LED streetlight products as recommended by the IEA would be too high to apply as a non-technology specific performance requirement in the current market. Even though LED streetlight products can perform at higher efficacy levels than non-SSL luminaires, other performance features not considered in this report (light distribution, capital cost, reliability etc) may provide a net benefit, and in certain situations this warrants using a non-SSL product.

In addition, other light technical parameters (as per Table 3) should be considered for inclusion in the standard, but only where relevant to the lamp and ballast/driver technology. These are detailed in the recommendations section.

3.2 European Union prEN 13201-5:2013 Road Lighting - Performance Requirements (CEN, 2013)

3.2.1 Outline

The EU is the largest jurisdiction and most extensive MEPS regime in the world. This EN pre-standard was prepared by Technical Committee 169 of CEN (European Committee for Standardisation). The pre-standard form went to public for review in September 2013 with comments closing October 2013 (no further updates currently available). Application of non-mandatory EN Standards is at the discretion of each EU member state. Mandatory EN Standards must be legislated by the parliament of each member state.

The purpose of this standard is to define energy performance indicators for road lighting installations using a calculated power density (D), and a calculated annual energy consumption indicator (ECIy). It also contains equations for calculating the installation efficacy of road lighting schemes, to be adopted as a comparative tool. This standard does not set minimum performance levels.

Its scope is lamp technology neutral. The power density demonstrates the energy need for a road lighting design, while fulfilling relevant luminance/illuminance lighting requirements for different roadways as specified in EN 13201-2 [3].

$$D = \frac{P}{\sum_{j=1}^{n} \overline{E_j}.A_j} \left(\frac{\mathrm{W}}{\mathrm{lux.m^2}}\right) \qquad (1)$$

Where

P is the total lighting system power (W)

$\overline{E_j}$ is the average illuminance of the j[th] section of the road (lux)

A_j is area of the j[th] section of the road (m^2)

n is the number of sections of the road to be lit

The energy consumption indicator indicates the total electrical energy consumed by a lighting installation day and night throughout a specific year. It is noted that light sources or their control devices may consume energy during the period when lighting is not needed, therefore the parasitic power must be included in calculations applying to the relevant period.

$$ECI_y = \frac{\sum_{i=1}^{n} \sum_{k=1}^{m_i} P_{ik} t_{ik}}{1000 \sum_{i=1}^{n} A_i} \left(\frac{kWh}{m^2}\right) \tag{2}$$

$$= \text{Summation of } \left[\frac{Lighting\ System\ Power\ (in\ i^{th} section\ of\ road) \times time\ (length\ of\ k^{th}\ period)}{1000 \times Area\ (of\ \ i^{th} section\ of\ road)}\right] \tag{3}$$

where n is the number of sections of the road to be lit

Installation efficacy of a road lighting design is defined using a minimum luminous flux that would be needed to provide the minimum lighting class for the specified areas as defined in EN 13201-2.

For illuminance based design (eg. Category P in Australia), this minimum flux can be reframed in terms of required lux levels over the area which must be illuminated, such that the minimum luminous flux on the task = Average Illuminance x Area.

$$\text{Installation efficacy} = \frac{\text{Minimum luminous flux on the task area}}{\text{total power consumption of lighting installation}} \left(\frac{lm}{W}\right) \tag{4}$$

$$= \frac{\text{Average Illuminance} \times \text{Area}}{\text{total power consumption of lighting installation}} \left(\frac{lux.m^2}{W}\right) \tag{5}$$

For luminance based design (eg. Category V), the average road surface luminance in the dry condition *L*, a corresponding value of the average illuminance is derived by Illuminance = Luminance/Road surface luminance coefficient.

$$\text{Installation efficacy} = \frac{\text{Average Luminance of the task area} \times \text{Area}}{\text{Luminance coefficient of road surface} \times \text{Power consumption}} \tag{6}$$

The average luminance coefficient of the road surface is typically set to 0.07.

Based upon the calculation principles for streetlight performance and evaluation contained in the EU standard, two EU countries have additionally introduced explicit MEPS levels for luminaires and/or road lighting designs, these being Spain and the Netherlands. Performance levels for these countries are explored in Sections 3.5 and 3.6 respectively.

3.2.2 Discussion

The EU road lighting standard outlines sound calculation principles for determining key energy efficiency parameters for the installation power density, installation efficacy, and annual energy consumption indicator. Their usefulness as a comparative tool for the full road design is evident; but this standard alone does not lay out clear indication of a minimum performance level to be achieved by the lighting design. Adoption of a road lighting design efficiency grading scale based on this standard from benchmarking of many application situations would be a powerful tool. One such system has been developed by the Netherlands.

3.3 United States Department of Energy Municipal Consortium Model specification for LED roadway luminaires

The DOE Municipal Solid-State Street Lighting Consortium shares technical information and experiences related to LED street and area lighting with the intention of providing an objective resource for evaluation of new products. Members of the consortium are cities, power distributing bodies, and investors in outdoor lighting.

The Consortium's performance specification for LED roadway lighting provides the tools for a comparative analysis of street light designs. The model specification is not intended to serve as a standard specification and does not contain an energy performance standard.

3.4 Canada C653-13 Photometric performance of roadway and street lighting luminaires (Canadian Standards Association, 2013)

3.4.1 Outline

The energy efficiency performance standard developed by the Canadian Standards Association (CSA Group) is in its fourth edition, with previous editions published in 2008, 1994, and 1992; this is a well-established program. The scope includes specifications for cobra head (in Australia, termed 'semi-cutoff') and shoe box (aeroscreen) luminaires using high pressure sodium (HPS), metal halide (MH), induction, and light emitting diode (LED) light sources. It is noted that future editions may include other light sources, such as plasma.

The standard is not a road design document in that it does not mention illuminance, luminance, uniformity, nor glare levels (these parameters are to be as stipulated in ANSI/IES RP-8-00 (R2005) Roadway Lighting), rather it is intended to establish luminaire photometric performance efficiency with establishment of maximum unit power density (UPD) values in Watts per area for typical applications. The area is defined by the multiplication of the roadway width and the luminaire spacing. This is nominally the task area to be illuminated by each luminaire.

$$UPD\ (for\ HID) = \frac{\text{nominal lamp power}}{\text{roadway width} \times \text{luminaire spacing}} \left(\frac{W}{m^2}\right) \tag{7}$$

$$UPD\ \left(for\ induction\ and\ LED\ luminaires\right) = \frac{\text{luminaire input power}}{\text{roadway width} \times \text{luminaire spacing}} \left(\frac{W}{m^2}\right) \tag{8}$$

The standard includes a series of tables containing maximum UPD levels for each light source technology, luminaire type (cobra head with zero uplight, cobra head with dropped prismatic lens, or shoe box style aeroscreen), class of roadway (Freeway Class A, Freeway Class B, Expressway, Major, Collector, Local) with subdivided levels for pedestrian conflict areas (high, medium, low), and number of lanes (1, 2, 3, 4, 5).

3.4.2 Discussion

This is a relatively simple system but requires separate tables for different lamp technologies, with various luminaire types, which then define values for each category of road, conflict level and number of lanes. These tables must accommodate the worst-case scenario in each category (UPD tables are provided in Section 9.1 Appendix A). In effect, the performance requirements for each lamp technology are significantly different, eg the UPDs for different lamp technologies in aeroscreen luminaires, on a 2 lane local road with medium pedestrian conflict in table below demonstrate a 300% technology specific variation in accepted performances (Table 4).

Table 4. Comparison of UPD levels required of different lamp technologies for a given roadway and conflict area classification by C653-13.

Lamp technology	UPD (W/m^2)
LED	0.23
Induction	0.70
MH	0.35
HPS	0.30

In summary, this is a technology specific solution, which provides advantage to certain technologies of light source without providing an explicit rationale for doing so (ie. reasons might include; typical lamp wattage groupings, luminous intensity distributions, lumen depreciation, colour rendering). In achieving a generalised and fair performance evaluation system, the Canadian strategy is not a clear, fair or appropriate model for a non-technology specific standard.

3.5 Spain
ITC-EA-01 Regulation of energy efficient lighting exterior facilities – Energy efficiency (Ministry of Industry, Tourism and Trade, 2008)

3.5.1 Outline

This performance standard has been enforced since 2009 by the Ministry of Industry, Tourism and Trade via Royal Decree 1890/2008. Energy efficiency measures are enforced by setting a minimum limit for outdoor lighting installation energy efficiency, ε, calculated by either:

$$\text{Energy efficiency} = \frac{\text{Average maintained illuminance} \times \text{roadway area}}{\text{Power (lamps and auxiliary equipment)}} \left(\frac{\text{lux.m}^2}{\text{W}}\right) \quad (9)$$

or by incorporating lamp efficiency (ie lamp lumens per lamp + auxiliaries power), maintenance factor, MF, and utilisation factor, UF:

$$\text{Energy efficiency} = \text{Lamp Efficiency} \times \ \text{MF} \times \text{UF} \left(\frac{\text{lux.m}^2}{\text{W}}\right) \quad (10)$$

Energy efficiency limits are set according to installation type; functional road lighting facilities including motorways, highways, roads and streets for moderate to high traffic speed (> 30 km/h); and 'ambient' street lighting that runs on low height (3-5 m) poles in urban areas, for pedestrian lighting, commercial streets, sidewalks, parks and gardens, historic districts, paths with limited traffic speed (≤30 km/h). The levels are also varied in a stepped manner, across the average lux levels as required by a given road installation. Minimum performance levels are shown in Table 5.

The standard also establishes a rating system for lighting installations using an energy efficiency index. The installation efficiency is calculated against a reference efficiency, ε_R, which provides a normalisation factor, and an energy efficiency label is assigned. This label characterises the power consumption of the system via a seven letter system from A (more efficient) to G (less efficient), in the same style as the European Energy Label. An example of the local Spanish version of the label is shown Figure 4, with a translated to English version beside.

$$\text{Energy efficiency index } (I_\varepsilon) = \frac{\varepsilon}{\varepsilon_R} \quad (11)$$

$$\text{Consumer energy index } (ICE) = \frac{1}{I_\varepsilon} \quad (12)$$

Table 5. Spain: Minimum requirements for energy efficiency, and reference efficiency values for given average illuminance levels in 'functional' (ie. V-Cat) and 'street/environmental' (P-Cat) lighting installations.

Functional road lighting	Street lighting and environmental 'other'

Average illuminance (lux)	Minimum energy efficiency, ε (lux.m²/W)	Reference energy efficiency, ε_R (lux.m²/W)	Average illuminance (lux)	Minimum energy efficiency, ε (lux.m²/W)	Reference energy efficiency, ε_R (lux.m²/W)
≥ 30	22	32	-	-	-
25	20	29	-	-	-
20	17.5	26	≥ 20	9	13
15	15	23	15	7.5	11
10	12	18	10	6	9
≤ 7.5	9.5	14	7.5	5	7
-	-	-	≤ 5	3.5	5

Table 6. Spain: Energy rating of a lighting installation.

Energy Rating	Consumption rate energetic	Efficiency Index Energy
A	ICE <0.91	IΣ > 1.1
B	0.91 δ ICE <1.09	1.1 IΣ > 0.92
C	1.09 δ ICE <1.35	0.92 IΣ > 0.74
D	1.35 δ ICE <1.79	0.74 IΣ > 0.56
E	1.79 δ ICE <2.63	0.56 IΣ > 0.38
F	2.63 δ ICE <5.00	0.38 IΣ > 0.20
G	ICE δ 5.00	IΣ 0.20

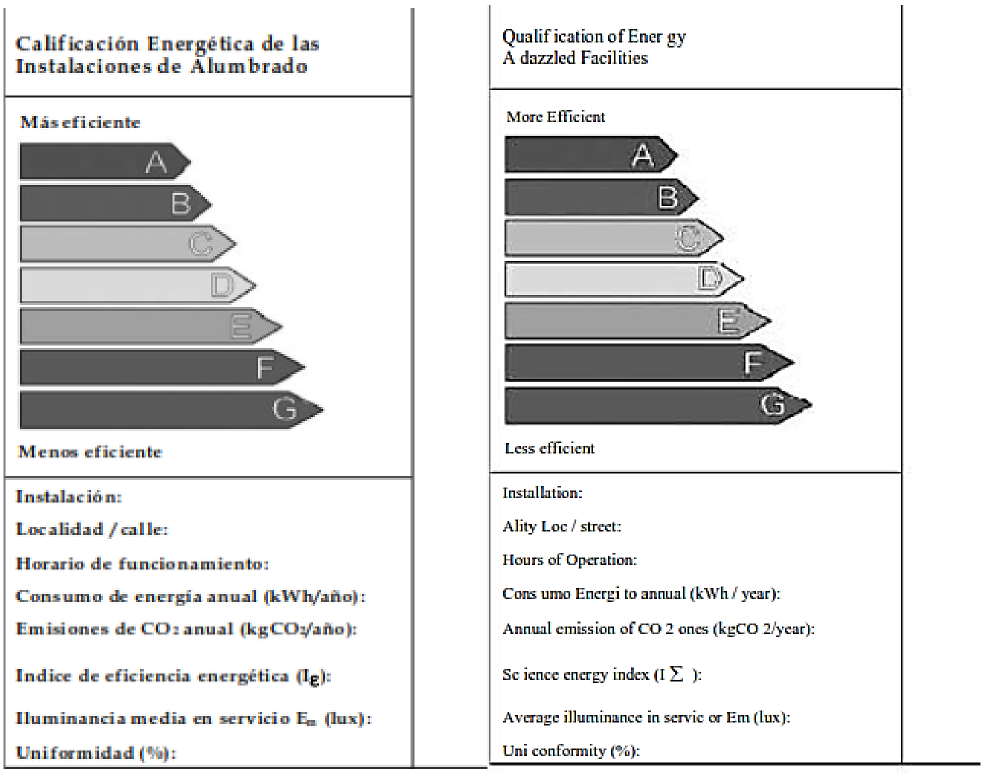


Figure 4. Spain: Energy efficiency label for a road installation. In Spanish (left), English translation (right).

3.5.2 Discussion

In the context of an application to creating an Australian and New Zealand MEPS, the energy efficiency levels required to comply with Spanish MEPS are ineffectually low (ie higher power consumption), as they are based on road illuminance levels which are significantly (an order of magnitude) higher than in Australia and New Zealand. Without a metric which is relative to the illuminance/luminance level (ie energy efficiency per lux, or energy efficiency per candela), the set of energy efficiency levels will be different for all countries which have different lighting performance levels.

3.6 Netherlands Handbook Energy Labelling for Public Lighting (Agency & Ministry of Economic Affairs, Agriculture and Innovation, 2010)

3.6.1 Outline

The Netherlands NL Agency (Ministry of Economic Affairs, Agriculture and Innovation) have developed a voluntary initiative that defines levels of energy efficiency for energy labels for public lighting installations with the intention of enabling objectives for saving energy to be specified. The minimum performance levels outlined in the handbook apply to streetlight installations, which must first be shown to comply with minimum illuminance, luminance, uniformity and glare requirements of the EU compulsory standard EN 13201-2: Road

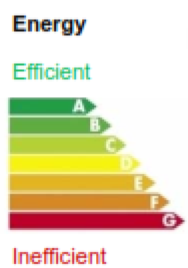
Lighting – Part 2: Performance Requirements (ie. synonymous with both AS/NZS 1158.1.1 for Vehicular Traffic and AS/NZS 1158.3.1 for Pedestrian area lighting).

The energy labelling is based on the EU standard EN13201-5; therefore the streetlight energy efficiency criterion (SLEEC) is calculated as outlined by the EU, with the formula expressed as:

$$\text{SLEEC} = \frac{\text{system power}}{\text{average horizontal illuminance} \times \text{area}} \left(\frac{W}{lux.m^2}\right) \tag{13}$$

The impetus for this label was that street lighting installations in the Netherlands were found to easily meet the minimum values stipulated in the EU standard, so the system of energy labelling was introduced to provide an opportunity to impose requirements that are more stringent, to be used as a more challenging design criterion for the procuring parties.

Practical values for the SLEEC standard were calculated for various types of road, lighting class and mounting height to simplify choice of lighting label. An upper limit was made in order to stimulate the market, set to 0.01 W/lux/m². The lower limit (less efficient than level G) is 0.07 W/lux/m² for illuminance based road lighting designs, and 10.5 W/(cd/m²)/m² for luminance based designs. The classification levels are provided in Figure 5, values in the left hand column represent illuminance design limits and the right hand column provides luminance design limits.



Label	SE W/lux/m²		SL W/(cd/m²)/m²
A	0.01	0.005-0.014	0.15
B	0.02	0.015-0.024	0.3
C	0.03	etc.	0.45
D	0.04		0.6
E	0.05		0.75
F	0.06		0.9
G	0.07		1.05

Table 4.5. Label classifications

Figure 5. Netherlands energy efficiency SLEEC classification levels.

3.6.2 Discussion

The merit of using a rating system rather than a single MEPS level is that it affords much opportunity for comparison of lighting solutions and incremental improvement. Specifiers for road design solutions would have the power to indicate the minimum energy efficiency level at which they wish a project be designed, providing impetus for faster improvement in energy efficiency of luminaires. (Note that achieving a minimum design efficacy is a secondary priority to ensuring that the roadway is in compliance with safe minimum lighting levels as per AS/NZS 1158).

Granted that there will be sections of road that have greater lighting demand such as at intersections and pedestrian crossings, it will be the case that the illuminance levels for that piece of road must first be satisfied as stipulated in AS/NZS 1158.1.1 for V-Category and AS/NZS 1158.3.1 for P-Category lighting; and then the SLEEC calculation would follow. It may be that for a given stretch of road, it might not be possible to achieve better than a 'D' rating, irrespective of lamp technology and luminaire type. What this will achieve, is a clear energy rating comparison between lighting solutions. For example, Table 7 shows the range of AS/NZS 1158 compliant solutions to a P4 Category lighting design using various lamp technologies. If the pole spacing in this instance were a minimum of 65 metres then all 4 solutions would comply with the lighting requirements but the LED solution has the best energy rating. If pole spacing were a minimum of 70 metres, only the top two solutions (MH or HPS) would be available to the lighting designer. (This table is a small excerpt from larger data analysis performed in Section 4.2).

Table 7. Netherlands performance scale applied to example calculations for a P4 Category lighting installation, on a 20 metre road reserve, using semi-cutoff type luminaires a single sided pole arrangement with a range of lamp types (LED luminaire a complete module). [Excerpt from section 4.2]

Road Details		Luminaire Details					Road Calculations		Netherlands
Road Category	Carriageway	Luminaire type	Lamp tech	Luminaire P (W)	Luminaire Φ (lm)	ER (lm/W)	Max spacing (m)	UPD per lux (W/lx/m^2)	Netherlands Energy Rating (A-G)
P4	Single sided	semi-cutoff	MH	82	4582	56	77.6	0.036	D
P4	Single sided	semi-cutoff	HPS	86	4785	56	73.1	0.051	E
P4	Single sided	semi-cutoff	LED	27	3181	120	69.9	0.018	B
P4	Single sided	semi-cutoff	MV	96	3046	32	67.2	0.069	G

3.7 Taiwan Energy Efficiency Criteria and Labelling Method for Energy Label Qualified Street Lights (Energy Label Taiwan, 2012)

3.7.1 Outline

The scope of this voluntary initiative is for any streetlight product that is applying to receive the Energy Label certification, and includes gas discharge (high/low pressure sodium, mercury vapour, metal halide, plasma, xenon, neon) and LED products.

The energy efficiency levels are luminaire specific only (Table 8 below); the Taiwanese criterion does not include a requirement for efficiency in road lighting design.

Table 8. Taiwan: MEPS levels for LED and Gas discharge luminaires.

Lamp Classification	Requirements	
Colour temperature	Initial luminous efficacy (lm/W)	
	LED	Gas discharge
> 5000 K	≧ 85.0	≧ 75.0
3500-5000 K	≧ 75.0	≧ 75.0
<3500 K	≧ 75.0	≧ 85.0

Determination of lumen maintenance values is taken at 3000 hours, and at that time must be ≥ 95% for LED lamps and ≥ 85% for gas discharge lamps.

3.7.2 Discussion

The omission of a road design efficiency component to the Taiwanese MEPS means that there is no limit to the number of streetlights that could be installed in a particular length or area of roadway, and so there is a potential to create a very inefficient lighting solution by installing an excessive number of fixtures while still achieving energy efficiency performance levels.

3.8 India Guidelines for design and implementation of street light energy efficient projects in Madhya Pradesh (Urban Administration and Development Department)

3.8.1 Outline

This guideline was introduced by Urban Administration and Development Department (UAD) of Government of Madhya Pradesh as a method of streamlining the process for design and implementation of energy efficiency street light projects. The specifications are for LED luminaires only; the scope outlines that promoting energy efficiency means to phase out other light sources and focus on LED technology only. Table 9 contains the performance specifications for LED luminaires.

Table 9. India: MEPS requirements for LED luminaires.

Lamp Classification	Lumen output (lm)	Initial luminous efficacy (lm/W)
Low output	< 9000 lm	≧ 65
Mid output	9000 to 23000 lm	≧ 80
High output	≥ 23000 lm	≧ 100

3.8.2 Discussion

The stepped approach, based on lumen output of the luminaire, is not ideal. There is anecdotal evidence to suggest that using a stepped efficacy limit rather than a smooth grade causes 'clumping' at the lower efficacy level near the boundary of the steps. A better solution is to use a formula for calculating minimum luminaire efficacy to give a smooth graded line instead of the stepped line.

The other issue with using a weighted efficacy requirement for LED luminaires is that this may not be necessary at all: Low output lamps tend to be used in P-category situations (smaller streets) and will tend to have a (relatively) small luminaire head; in contrast the high output lamps, which will tend to be used for larger V-category streets, will have a proportionately larger luminaire head (i.e. larger heat sink). Consequently, both low and high output lamps should be able to achieve the same luminous efficacy levels .

3.9 Australia
Design Energy Limits for Main Road Lighting (Mark Ellis & Associates, 2005) A report prepared for Australian Greenhouse Office (AGO) and National Appliance and Equipment Energy Efficiency Program (NAEEEP)

3.9.1 Outline

As part of the Greenlight Australia initiative in 2005, the Australian Government commissioned a review of energy efficiency of road lighting in Australia, with particular focus on category V road lighting. The objective of the report was to develop measures aimed at removing inefficient practices from category V lighting (which were seen to be lacking in optimisation due to the disaggregated nature of this market). The result was development of a 'design energy limit'.

Scope was limited to category V lighting in Australia, as defined in AS 1158.0:1997. The review included three lamp technologies, which populate the majority of Australian main road lighting installations:

- HPS
- MH
- MV

The design energy limit was characterised only by the power consumption of the luminaire and length of the carriageway over three categories of carriageway width (which provides a rough rounded value for area).

$$\text{Design energy limit}=\frac{\text{Sum of installation lamp power (at 250V)}}{\text{length of roadway}}\left(\frac{W}{m}\right) \qquad (14)$$

Table 10. Mandatory limit parameters

Road Category	Luminaire type	Carriageway arrangement	Carriageway width
V1	Non-aeroscreen	Single	CW ≤ 7m
V2	Aeroscreen	Dual	7m < CW ≤ 14m
V3			14m < CW 21m
V4			
V5			

Extensive road lighting modelling was performed in producing this report: efficiency limits were based on the most efficient technology choices in conjunction with optimised lighting design restricted to the parameters in Table 10:

- Mandatory limits were optimised using levels for metal halide lamp/luminaire/design performance plus 1 W/m

- High efficiency limits were optimised using high pressure sodium lamp/luminaire/design performance plus 0.5 W/m

An example of the performance limits for mandatory and high efficiency luminaires is shown in Figure 6. Additional performance charts were created for road categories 1-4, but have not been included in this report.

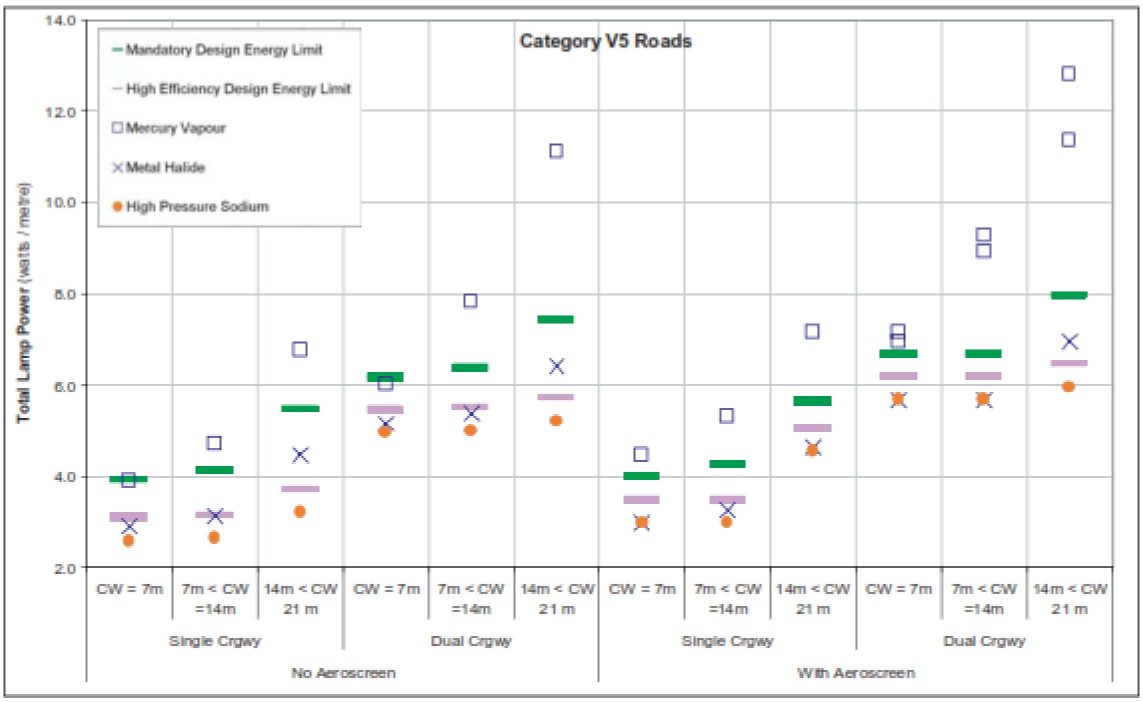


Figure 6. Design energy limits for Category V5 Roads, as proposed by Australian Government performance review 2005 (not enacted).

3.9.2 Discussion

The solution seems unnecessarily convoluted. Although this is not explicitly technology specific, the levels were determined by and provide favour to the lamp types upon which the levels were based: the MEPS level would allow MH or better, and HEPS allows HPS or better. This specificity ignores that there are quality attributes in areas OTHER than energy efficiency that may be required (ie. colour rendering, colour temperature, life time, resistance to temperature variation).

Distinct performance levels exist for every combination of the mandatory limit parameters from Table 10; for each of the five road categories, across three carriageway width groups, two carriageway arrangements (single/dual), and whether using aeroscreen or non-areoscreen luminaire type; the result is 60 differing levels for the mandatory efficiency limit, and another 60 for a high efficiency limit.

Problems may arise where the road dimensions are close to the carriageway width boundaries, leaving the standard open to 'category jumping'. There is also a question of how one would proceed if the carriageway arrangement were outside the definition of 'single' or 'dual'.

4 Impacts on installed luminaires in Australia

4.1 International luminaire MEPS

Of the international mandatory and voluntary MEPS programs that enforce luminaire efficiency performance standards, four out of five are scoped only for SSL products. Taiwan produces a separate gas discharge MEPS level, which is on parity with the SSL level for products in the colour temperature range of 3500K to 5000K. The five international luminaire efficacy levels (at the given colour temperature both Taiwanese levels are the same) have been graphed (Figure 7) with performance levels of streetlight luminaires used in Australia and New Zealand, from the market data shown Section 0.

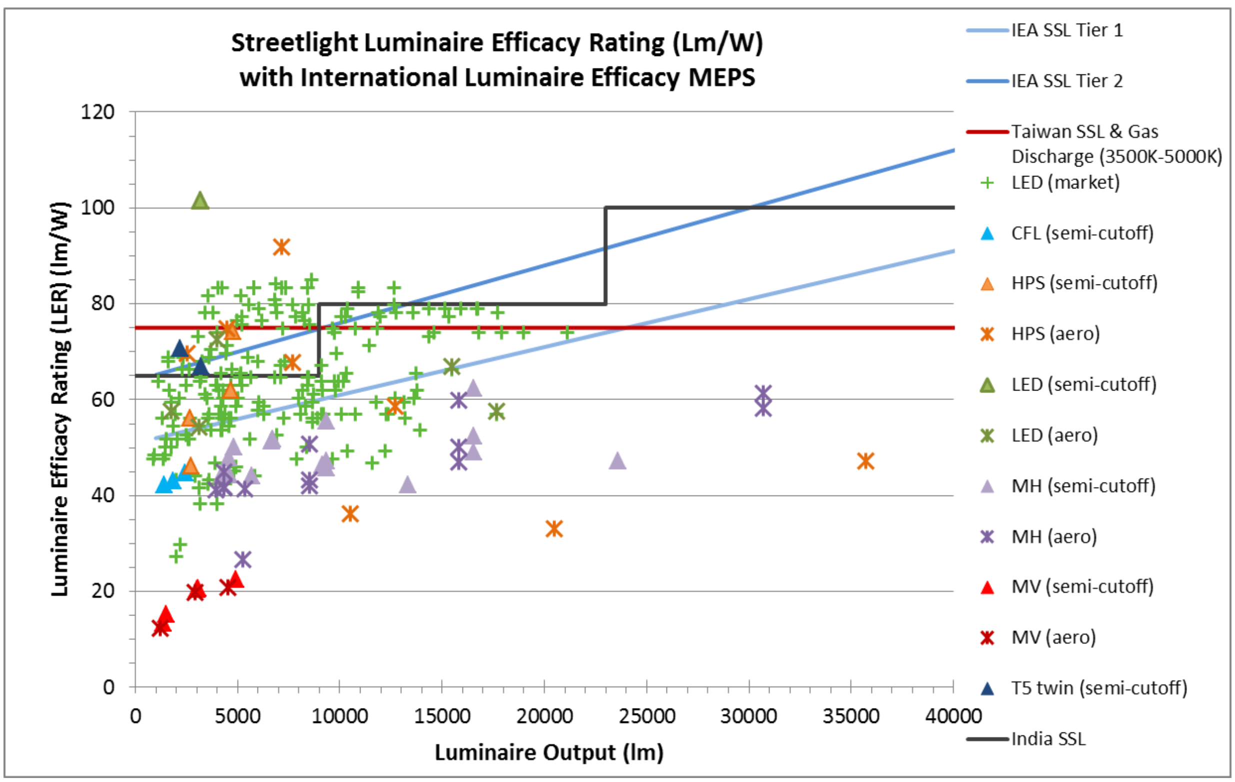


Figure 7. LER performance of Australian luminaires with international MEPS levels.

Notes:

- This graph shows luminaire performance data for only a small sampling of products actually available in the Australian/New Zealand market. In particular, more research focus was given to luminaires that provide less than 18 klm, and as such, there are few models represented in the higher lumen output category. For luminaires with greater lumen output, this graph may not provide a true representative snapshot of the market, and further research is warranted.

- The Taiwanese performance standard is more demanding of SSL products that have colour temperature greater than 5000K and gas discharge products with colour temperature less than 3500K, in both cases specifying a minimum LER of 85 lm/W. These are not included in the graph.

All reviewed performance levels for luminaire efficiency are high, and would exclude the majority of non-SSL luminaire models used in Australian and New Zealand, however overall it is evident that some technologies are competitive in the < 8 klm light output range. Recalling Table 1 in Section 2.1, this is commensurate with meeting the needs of P4 and P5 (for Australia only) category lighting; however this does not have provision for lamps other than SSL technology for V category lighting levels, ie. > 8 klm (according to the preliminary market research). It is clear that a more comprehensive survey of the streetlight market should be undertaken to confirm these results.

4.2 Luminaire and road modelling calculations

Road modelling and assessment of the international luminaire and road design efficiency standards was undertaken at a cursory level for this report to get a basic impression of potential impacts of their introduction. The road category used for assessment was P4; using single-sided/staggered/opposite pole arrangements, semi-cutoff and aeroscreen type luminaires, at a typical mounting height of 7.5 metres, and road reserve width was set to 20 metres. The required average illuminance level as per AS/NZS 1158.3.1 for P4 lighting design is 0.85 lux.

The sample of lamps used for these calculations are all approved for use in Australia on the AEMO Load tables as at 14 June 2014, including LED models.

The summary of results is shown in Table 11. Note that data is sorted by luminaire type, followed by pole spacing.

Table 11. Road calculations & international energy efficiency program compliance assessment for a typical range of lamps & luminaires used in Australian/New Zealand road lighting designs to satisfy a P4 Category lighting installation with 20 metre road reserve. Data is sorted by Luminaire type and Maximum pole spacing.

Reference	Road Details		Luminaire Details					Road Calculations				Luminaire Efficacy					Road Installation Efficiency			
												IEA	IEA	Taiwan	Taiwan	India	EU	EU	Spain	Netherlands
Row number	Road category	Carriageway	Luminaire type	Lamp tech	Luminaire P (W)	Luminaire Φ (lm)	LER (lm/W)	Max spacing (m)	UPD per lux ($W/lx/m^2$)	UPD per lux ($W/lx/m^2$)	Installation efficiency ($lux.m^2/W$)	SSL Tier 1	SSL Tier 2	LED LER (pass/fail)	Gas discharge LER (pass/fail)	LER/LER (pass/fail)	Φ min on road (lm)	Installation efficacy (lm/W)	Energy Rating (A-G)	SLEEC Energy Rating (A-G)
1	P4	opposite	aeroscreen	MH	82	4310	53	**72.5**	0.017	0.021	58.7	fail	fail	fail	fail	fail	1232.5	15.1	A	B
2	P4	opposite	aeroscreen	HPS	86	4469	52	**68.8**	0.023	0.039	44.3	fail	fail	fail	fail	fail	1169.6	13.6	A	B
3	P4	opposite	aeroscreen	MV	96	2915	30	**64.5**	0.029	0.037	34.5	fail	fail	fail	fail	fail	1096.5	11.4	A	C
4	P4	staggered	aeroscreen	MH	82	4310	53	**59.5**	0.034	0.034	29.3	fail	fail	fail	fail	fail	1011.5	12.4	A	C
5	P4	opposite	aeroscreen	LED	47	4009	85	**59.5**	0.011	0.011	94.2	pass	pass	pass	pass	pass	1011.5	21.5	A	A
6	P4	Single sided	aeroscreen	MH	82	4310	53	**56.8**	0.034	0.032	29.4	fail	fail	fail	fail	fail	965.6	11.8	A	C
7	P4	staggered	aeroscreen	HPS	86	4469	52	**53.2**	0.045	0.040	22.1	fail	fail	fail	fail	fail	904.4	10.5	A	E
8	P4	staggered	aeroscreen	LED	47	4009	85	**52.3**	0.021	0.022	46.7	pass	pass	pass	pass	pass	889.1	18.9	A	B
9	P4	staggered	aeroscreen	MV	96	2915	30	**50.9**	0.058	0.074	17.2	fail	fail	fail	fail	fail	865.3	9.0	A	F
10	P4	Single sided	aeroscreen	MV	96	2915	30	**48.7**	0.058	0.081	17.2	fail	fail	fail	fail	fail	827.9	8.6	A	F
11	P4	Single sided	aeroscreen	LED	47	4009	85	**48.7**	0.021	0.023	46.8	pass	pass	pass	pass	pass	827.9	17.6	A	B
12	P4	Single sided	aeroscreen	HPS	86	4469	52	**47.4**	0.045	0.036	22.0	fail	fail	fail	fail	fail	805.8	9.4	A	E
13	P4	opposite	semi-cutoff	CFL	46	2439	53	**115.4**	0.006	0.011	155.7	fail	fail	fail	fail	fail	1961.8	42.3	A	A
14	P4	staggered	semi-cutoff	CFL	46	2439	53	**96.4**	0.013	0.036	79.4	fail	fail	fail	fail	fail	1638.8	35.3	A	A
15	P4	Single sided	semi-cutoff	CFL	46	2439	53	**95.3**	0.013	0.016	79.7	fail	fail	fail	fail	fail	1620.1	34.9	A	A
16	P4	opposite	semi-cutoff	HPS	86	4785	56	**91.6**	0.026	0.031	39.0	fail	fail	fail	fail	fail	1557.2	18.1	A	C
17	P4	opposite	semi-cutoff	LED	27	3181	120	**87.7**	0.009	0.013	113.4	pass	pass	pass	pass	pass	1490.9	56.0	A	A
18	P4	staggered	semi-cutoff	MH	82	4582	56	**80.5**	0.036	0.039	27.5	fail	fail	fail	fail	fail	1368.5	16.8	A	D
19	P4	Single sided	semi-cutoff	MH	82	4582	56	**77.6**	0.036	0.038	27.4	fail	fail	fail	fail	fail	1319.2	16.2	A	D
20	P4	opposite	semi-cutoff	MH	82	4582	56	**77.6**	0.036	0.038	27.4	fail	fail	fail	fail	fail	1319.2	16.2	A	D
21	P4	staggered	semi-cutoff	HPS	86	4785	56	**74.5**	0.051	0.054	19.6	fail	fail	fail	fail	fail	1266.5	14.7	A	E
22	P4	Single sided	semi-cutoff	HPS	86	4785	56	**73.1**	0.051	0.062	19.6	fail	fail	fail	fail	fail	1242.7	14.5	A	E
23	P4	staggered	semi-cutoff	LED	27	3181	120	**71.1**	0.018	0.021	56.7	pass	pass	pass	pass	pass	1208.7	45.4	A	B
24	P4	Single sided	semi-cutoff	LED	27	3181	120	**69.9**	0.018	0.021	56.8	pass	pass	pass	pass	pass	1188.3	44.7	A	B
25	P4	Single sided	semi-cutoff	MV	96	3046	32	**67.2**	0.069	0.078	14.5	fail	fail	fail	fail	fail	1142.4	11.9	A	G
26	P4	staggered	semi-cutoff	MV	96	3046	32	**50.9**	0.058	0.039	17.2	fail	fail	fail	fail	fail	865.3	9.0	A	F

Conclusions that can be made from the road calculation data:

- It is predominantly LED models that comply with the luminaire standards outlined by IEA 4E SSL Tiers 1 and 2, India's LED standard, and Taiwan's LED and gas discharge standards.
- Spanish road design MEPS levels have zero impact on promoting improvements in energy efficiency (ie. all luminaires pass) and are granted an 'A' rating on the Energy Efficiency Label. The levels are not resolved at the correct efficiency range to be useful.
- The A-G rating scale used in the Netherlands shows a clear comparative resolution between these road designs, and appears to offer the best street light design energy efficiency comparison of any international standard currently being used.
- It is not possible to directly compare luminaire product performance levels (ie. IEA) to installation efficiency (ie. Netherlands). This is due to different intensity distributions of each luminaire having an impact on pole distances such that a road lighting installation will satisfy minimum lux level compliance for the P4 category as per AS/NZS 1158.3.1. For example:
- Row 14 of Table 11 shows a CFL in a luminaire with LER of 53 lm/W which fails to pass any of the 'luminaire efficacy' based MEPS levels, but in achieving an installation efficiency of 79.4 lux.m²/W the road design achieves an 'A' rating in the Netherlands SLEEC rating scheme.
- Row 23 shows the same roadway but now using an LED luminaire, which has an LER of 120 lm/W. This luminaire passes all international 'luminaire efficacy' based MEPS, but due to having a different light output distribution, at the maximum pole spacing it achieves an installation efficiency of only 56.7 lux.m²/W and the road design only achieves an 'B' rating in the Netherlands rating scheme.

So it has been shown that it is possible to have a luminaire of exceptionally high efficacy, but still not achieve the highest overall energy savings once this luminaire has been deployed into a compliant road lighting design as per the current road lighting standard, AS/NZS 1158.

5 Adaptive lighting

5.1 Dimming and switching

In general there are four reasons that justify dimming according to local conditions:

1. Changes in traffic/pedestrian density (eg. dimming of streetlights after given curfew) due to:
    - Traffic volume could be interpreted on a time-related basis, hourly throughout the night or at a single curfew time; or it could be monitored directly by using sensors. Light levels to be adapted accordingly (examples of methods, see Figure 8).
    - Increase in activity due to special events (eg street parades, night markets etc)
    - Accident recovery or crime scene investigations
2. Changes to local weather conditions. Lighting performance could be adapted depending on:
    - ambient temperatures (affecting lamp output)
    - fog conditions
    - torrential rain
    - heavy sleet/snow
3. Fine tuning luminaire light output to suit specific street arrangement (in the case of unavoidable over-lighting)
    - Necessary when the standard lamp types are only available in a limited number of power values, eg. for category V, a 70W HPS versus 100W HPS.
4. Compensating for Lamp Lumen Maintenance Factor (LLMF)
    - Useful for lamp types with known variable LLMF over lifetime (see Figure 9)

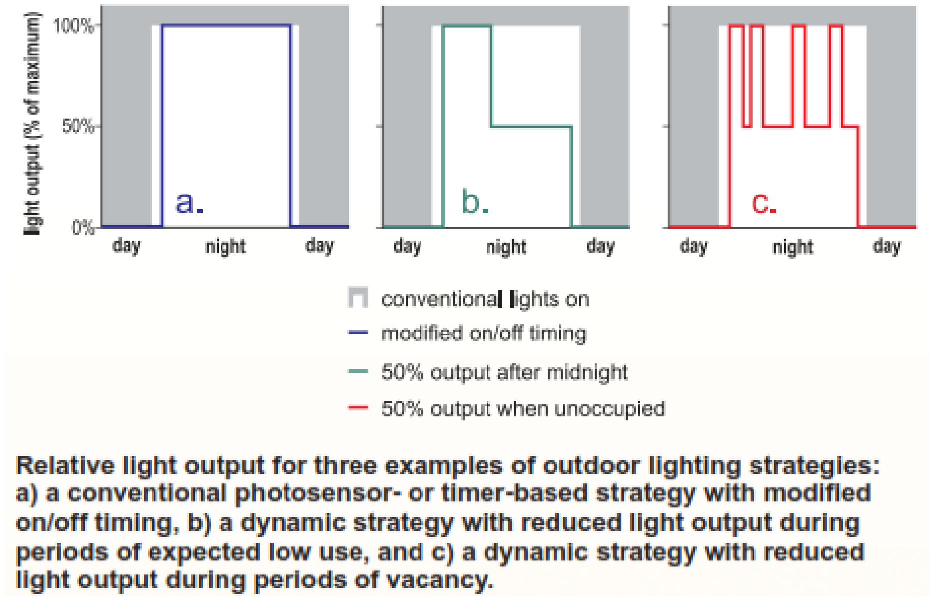


Figure 8. Dynamic outdoor lighting strategies. Source: NLPIP Lighting Research Centre (www.lrc.rpi.edu/resources/newsroom/pdf/2010/DynamicOutdoorLighting_8511.pdf)

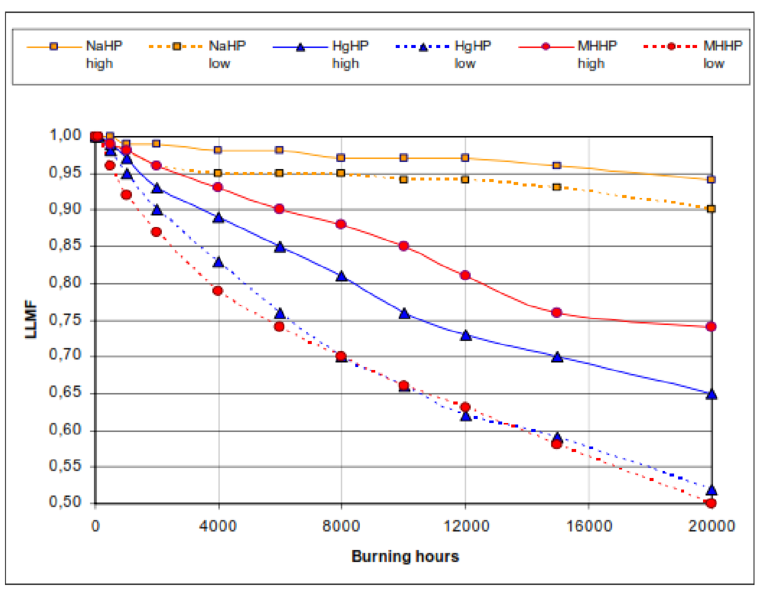


Figure 9. LLMF for various lamp types with lowest and highest values. Note: NaHP is HPS, HgHP is MV, MHHP is MH. (source: 2007 Preparatory Studies for Eco-design requirements of EuPs. Final Report. Lot 9: Public Street lighting)

Dimmability depends on the presence of a dimming system; although a lamp might have the capability to dim, if the installation does not have a dimming ballast or controls, this will not be an option.

Known issues with dimming are varied depending on the lamp technology (Issues for conventional lamp technologies are provided in Table 12). Also:

- Some light sources are not dimmable, others are only able to partially dim.
- A colour shift that may occur with particular lamp technologies, due to the method by which dimming is achieved.

LED luminaires provide a significant opportunity for incorporating sensor, switching and dimming technology to suit the usage profile of the street/park etc. But sensor systems also present potential issues. Therefore whatever sensing technology is used it must operate as required for correct performance. The critical element is the ultimate safety requirements for the outdoor spaces and this will include a need for a failsafe system.

Table 12. Issues with dimming for lamp technologies.

Lamp type	Dimmability	Dimming principle
Incandescent lamp	100%	Voltage drop; phase shift; phase cut-off; ratio P/E linear
Halogen lamp	95%	Idem with regulated voltage (dimmer) due to halogen cycle
Low-pressure sodium lamp	0%	Non-dimmable
High-pressure sodium lamp	90%	Voltage drop; phase shift (100% to 50%); dimmable EB; under development; ratio p/E non-linear
Low-pressure mercury lamp	90%	Voltage drop; phase shift (100% to 0%); dimmable EB; under development; ratio p/E non-linear
Low-pressure mercury lamp, compact	80%	Restricted by voltage drop where flicker does not occur; dimmable EB (100% - 5%; integrated: 100% - 15%); ratio P/E non-linear
Low-pressure mercury induction lamp	0%	Non-dimmable
High-pressure mercury lamp	0%	Non-dimmable
Halogen-metal lamp with quartz burner	25%	Voltage drop with conv B; phase shift with B; dimmable EB; disadvantage: dimming causes rapid deviation in colour temperature; ratio P/E non-linear
Halogen-metal lamp with ceramic burner (CDM)	25%	Voltage drop with conv B; phase shift with B; dimmable EB; disadvantage: dimming causes rapid deviation in colour temperature; Ra worse; ratio P/E non-linear
LED	50% at the moment	Current-operated; pulse width modulation (PWM); disadvantage: colour shift to red with lower output or low energy content (PWM); Ra worse; however ratio P/E is linear

Source: Laboretec

5.1.1 Netherlands

Handbook Energy Labelling for Public Lighting (Nov 2010)

Though not established at time of publishing, the handbook provided a review of possibilities for including effects of dimming in their labelling method for installations that continue to comply with the standard MEPS within the chosen dimming regime.

It is noted that the ability to dim is rewarded highly, when used in conjunction with the performance metric for calculating power density of a lighting installation.

Suggestions:

- If a public lighting installation is dimmable, a separate dimming label might be used to indicate dimmability.
- Account for adjustment in output and/or power consumption on the second label. The second label can specify how much more economical the installation would become as a result of dimming. For example, Figure 10 presents the concept of a car energy label:

Energy label	Economy compared with an average car from the same class
A	at least 20% more economical
B	10% to 20% more economical
C	a maximum of 10% more economical
D	a maximum of 10% less economical
E	10% to 20% less economical
F	20% to 30% less economical
G	at least 30% less economical

Figure 10. Example energy labelling scale (for vehicles) as proposed in the Netherlands Handbook Energy Labelling for Public Lighting.

5.1.2 France

'Grenelle I' (2009) and 'Grenelle II' (2010) laws

Introduction of these laws was to satisfy the following aims:

- Replacing old technologies with modern lamps

- Promoting LED technology
- Regulating mains quality and reducing cost impact
- Promoting power variation systems
- Promoting electronic ballasts
- Turning off lights late at night
- Enhancing preventive maintenance
- Converting traffic lights to LEDs

The legislation has resulted in a saving of 19.55 GWh spread across 2131 small French communities with a total population of 1.7 million inhabitants. With legislated impetus to save energy, dimming strategies for streetlights have been investigated.

In April 2014 Professor Georges Zissis of the Light and Matter Research Group at LaPlaCE (Laboratoire Plasma et Conversion d'Énergie) at the University of Toulouse gave a seminar series in Australia as part of the Lighting Council's seminar series on SSL (Lighting Council Australia (www.lightingcouncil.com.au/site/docs/LED/LED%20Seminar%20Series%20-%20Street%20Lighting%20Seminar%20Presentation.pdf). He discussed research into various adaptive lighting elements including the effects of mesopic vision under dimming conditions. It is well understood that the visual performance of the eye is dependent on the level of illumination. There is a gradual shift in visual perception from colour vision (photopic) to grey scale vision (scotopic) with an associated increase in short wave sensitivity (peak sensitivity shifting from 555nm to 505nm), Figure 11. Human luminous efficacy sensitivity functions, under photopic, mesopic and scotopic light levels.. This is relevant to dimming in road lighting because typical illuminance levels in Australian road lighting are not in the photopic visual range, they fall into the mesopic range category; and as dimming occurs, human spectral sensitivity changes as it moves from high to low levels in the mesopic visual range.

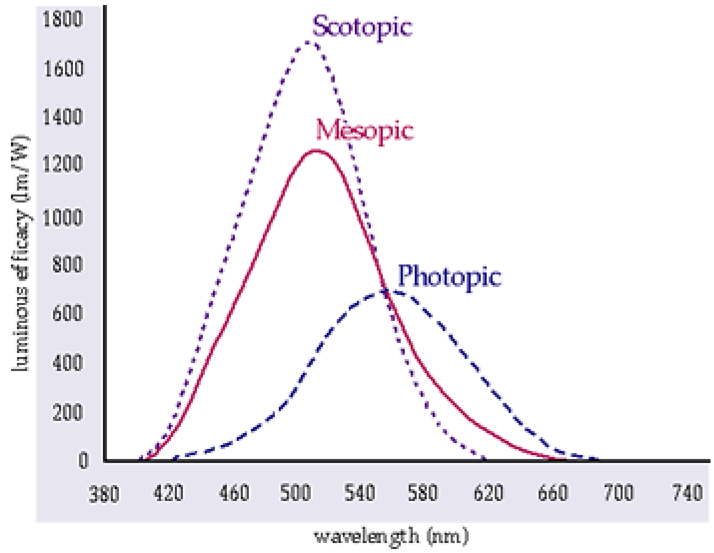


Figure 11. Human luminous efficacy sensitivity functions, under photopic, mesopic and scotopic light levels.

There are a number of points to note from this shift in wavelength sensitivity during the dimming of light levels, which could potentially assist with minimising outdoor lighting energy usage.

- For the human eye, photopic vision is completely active when illuminance levels are greater than 50 lux. Mesopic vision engages when illuminance levels are between approximately 0.5 lux and 50 lux. This corresponds to luminances in typical applications of approximately 0.001 to 3 cd/m², which encompasses the typical range for outdoor lighting design specifications.
- With LED technology can adjust the colour to suit the mesopic spectral function of the eye at lower light levels
- Therefore with better colour adaptation, can achieve a perception of equal brightness using less lumens (and by association, power).

An application of this research has been found to have success on a pedestrian bridge spanning wetlands in Portugal by replacing older technology with LEDs that contain greater proportion of short wave light spectrum.

5.1.3 UK National Physical Laboratory Mesopic Photometry for SSL (www.m4ssl.npl.co.uk/wp-content/uploads/2013/06/Teresa-Goodman-Mesopic-photometry-for-SSL-for-website.pdf)

On the topic of mesopic lighting, Teresa Goodman of the UK National Physical Laboratory gave a presentation in 2013, which included a discussion on the issues for implementation of mesopic photometry. The relevance of this presentation to current deficiencies in light technical metrics for streetlighting relates to the internationally adopted system for mesopic photometry only provides photometric values for use in the mesopic region based on visual adaptation (photopic luminance) and the scotopic/photopic S/P ratio of adaptation field. More specifically the mesopic photometry does not state:

- What is the relevant adaptation field – i.e. what is the size, shape and position of the adaptation field and are all areas within (or surrounding) the defined adaptation field equally important? CIE committee **JTC-1** is working on this for outdoor lighting
- How measurements should be made, how quantities other than luminance should be calculated or how measurement results should be expressed. CIE committee **TC2-65** is working on this
- How the system fits within the SI system. CIE committee **JTC-2 (CIE-CCPR)** is working on this
- What other considerations are important for key applications, especially road lighting CIE committee **TC4-48** is reporting on this.

6 Recommended Energy Efficiency Scheme for Australia and New Zealand

6.1 Philosophy

Minimum efficiency performance requirements for luminaires will provide a simple method for ensuring that energy is not wasted on inefficient products, when there are better alternatives on the market that would produce equal lighting outcomes.

A design energy classification scale would encourage energy efficient practice in road lighting, while allowing a degree of flexibility of designers of these installations. The most efficient lamps, control gear and luminaires as well as best case designs featuring optimum lighting distribution would be favoured.

Alignment with existing international standards to achieve these outcomes is the most favourable approach.

6.2 Recommendations

A threefold approach for achieving energy efficiency is recommended, Figure 12:

1. Minimum energy performance standard (MEPS) for luminaires. These could be placed in the current standard as a normative requirement and if desired made mandatory by reference in appropriate legislation (Such as GEMS act)
2. Normative disclosure of road design energy efficiency classification scale with neither a normative nor mandatory minimum performance limit
3. Voluntary selection (from tendered design options) of preferred solution by procuring agency

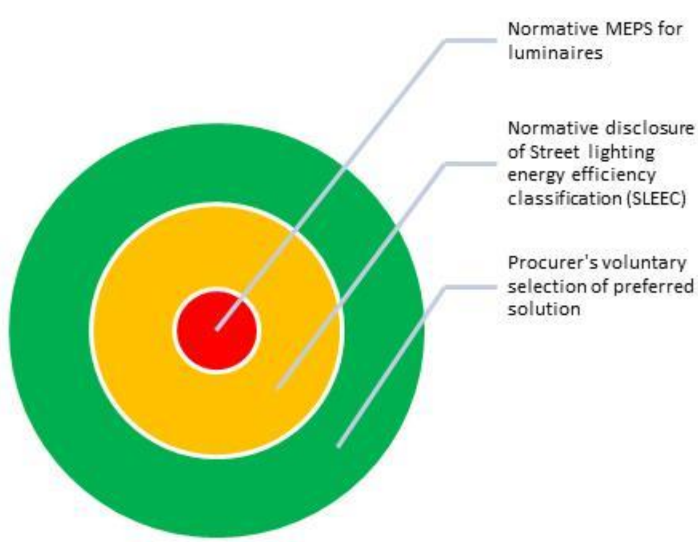


Figure 12. Structure of the energy efficient street lighting proposal

6.2.1 Minimum energy performance standard (MEPS) for luminaires

If a MEPS approach is to be endorsed for streetlight luminaires (and for inclusion into AS/NZS1158.6) is it recommended that MEPS levels remain technology-neutral. Rather than "picking a winner" technology, this provides industry with opportunity and incentive to conduct R&D on application appropriate technology solutions unencumbered by historical perspectives on technologies. It is recommended that Australia and New Zealand adopt a luminaire MEPS that follows the intent of the IEA 4E SSL Tier system, albeit with adjustment factor to allow a fair range of suitable non-SSL lighting technologies to also comply. This will ensure that a diversity of products possibly with other superior light technical parameters (other than energy efficiency, or more viable operation, maintenance and replacement (OMR) costs) remain available in the market until a greater body of evidence is available regarding the long term application of SSL based products to all road lighting situations.

The proposed MEPs would require luminaires to meet a minimum luminaire efficacy rating (LER) based on equation

$$LER \geq 40 + 0.001 \times \emptyset \tag{15}$$

Where

ϕ is the total initial luminaire luminous flux.

In order to retain the integrity of a luminaire's efficiency rating, if the light source is replaceable (eg lamp), the lamp type (ILCOS code) and lamp efficacy should be specified with the luminaire so that upon lamp changeover, the LER can be retained.

Figure 13 illustrates the implications of the proposed minimum LER level (the green line) for a range of luminaires used in Australian/New Zealand road designs, and for an addition range of SSL products available on the market (not approved by AEMO for unmetered network use).

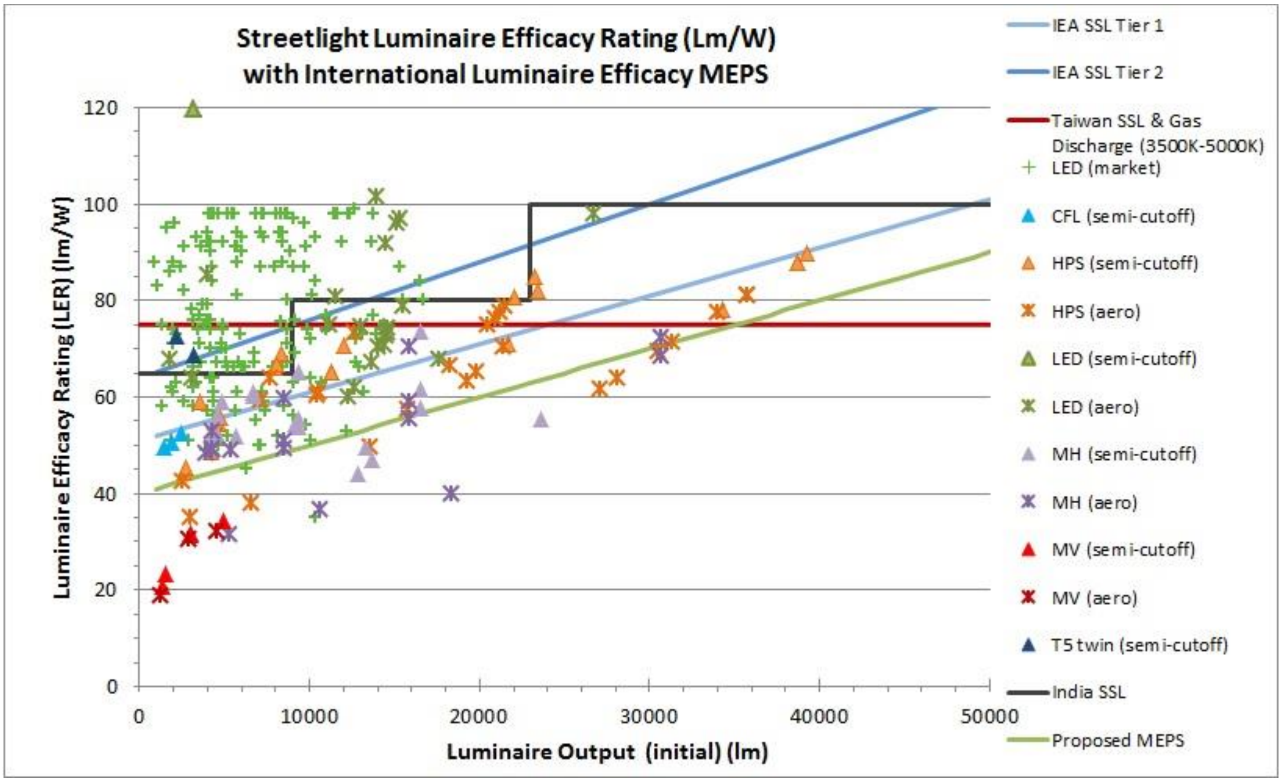


Figure 13. Streetlight luminaire efficacy, with international MEPS and proposed non-technology specific MEPS.

A major outcome for introduction of this MEPS level is the immediate phase out of luminaires using mercury vapour lamps, and there would be a small range of metal halide, LED and HPS aeroscreen models excluded. All CFL, twin T5 linear, and HPS in semi-cutoff fittings in the benchmarking analysis would be compliant; as well as the majority of metal halide, LED fittings, and HPS aeroscreen luminaires.

Test methods for determining total luminaire luminous flux and luminaire power should be as per AS/NZS1158.6 Section 6.3. This cites AS/NZS1158.1.1 and AS/NZS1158.3.1, which refers to test method CIE 121 (Note: Reference to the anticipated new test method when ratified from CIE TC2.71 for LED luminaires will be necessary).

6.2.2 High efficiency performance SSL installations

There are many funding organisations and municipalities that are exclusively supporting by granting of funds for SSL based installations. In the case where an upfront decision to use SSL rather than considering a cost benefit analysis of all technology solutions is made, it is recommended that the procurer should consider the IEA Tier 1 or possibly Tier 2 as a minimum performance level for the luminaire selection. Procurers should carefully consider the implications of this approach before locking in to a specific technology without due diligence on the overall cost benefit.

6.2.3 Other technical parameters for luminaires

Light technical parameters other than energy efficiency are critical for characterising the quality of a luminaire. It is recommended that these also be addressed, as it has been done in IEA 4E SSL standard. However not all parameters are relevant to all lighting technologies. It is therefore proposed that the following IEA parameters shown in Table 13 be applied to lamp technologies, combined with lamp performance benchmarks for gas discharge luminaires as guided in Commission Regulation EC 245-2009 Annex III – 'Ecodesign requirements for fluorescent and high intensity discharge lamps and ballasts and luminaires able to operate such lamps' and Annex VII – 'Indicative benchmarks for products meant to be installed as public street lighting'.

A number of parameters from the IEA 4E SSL recommended performance tiers are already incorporated in AS/NZS 1158 and as such, are not included in Table 13.

Table 13. Proposed additional performance parameters for luminaire MEPS.

Parameter	LED (IEA 4E SSL Tier 1)	MH, LF, CFL, HPS
Life		
Lumen maintenance (L70/B50)	At 35000 hours, lumen maintenance should be greater than 78% of the initial flux.	At 16,000 hours, lumen maintenance should be greater than 92% of initial flux (EU 245) This metric should be referenced directly to Commercial Lighting Product Profile outcomes, review 2014, which includes evaluation of EC 245 (Indicative LLMF values as per EC 245 Table 24)
Minimum rated luminaire lifetime (F50)	At least 50% shall be operative after 50,000 hours.	As per AS/NZS 1158.6 Preface
Operation		
Operating temperature (range °C)	Minimum temperature range from -10°C to 40°C without significant change of photometric and colorimetric performance, unless regional requirements are higher or lower	As per AS/NZS 1158.6 Part 1.5 (Australia: -10°C to 40°C. NZ: -10°C to 25°C)
Light & Health		
Correlated colour temperature (K) and tolerance < 6500K	Follow ANSI C78.377, excluding flexible CCT Nominal CCT: Target CCT ± Tolerance 2700K: 2725 ± 145 3000K: 3045 ± 175 3500K: 3465 ± 245 4000K: 3985 ± 275 5000K: 5028 ± 283 5700K: 5665 ± 355 6500K: 6530 ± 510	✓ (HPS exempt)
Chromaticity tolerance (Du'v')	Centre points based on ANSI C78.377, excluding flexible CCT Nominal CCT: Target Du'v' ± Tolerance 2700K: 0.000 ± 0.012 3000K: 0.000 ± 0.012 3500K: 0.000 ± 0.012 4000K: 0.001 ± 0.012 5000K: 0.002 ± 0.012 5700K: 0.002 ± 0.012 6500K: 0.003 ± 0.012	✓ (HPS exempt)
Flicker (amplitude modulation depth)	At full power: flicker index ≤ 0.3	✓
Minimum displacement power factor	≥ 0.9	✓
Environment		
Recyclability (%)	Yes, following the principles of self- declaration found in ISO 14021	✓

6.2.4 Road design classification system

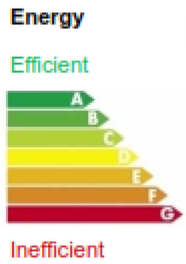
It is recommended to use the Netherlands street light energy efficiency criterion system (which uses performance metrics and calculations defined in the EU standard, prEN 13201-5:2013) as the basis for a mandatory classification scheme in Australia and New Zealand. It is recommended that the Dutch streetlight energy efficiency defined as:

$$\text{SLEEC} = \frac{\text{system power}}{\text{average horizontal illuminance} \times \text{area}} \left(\frac{W}{lux.m^2}\right) \tag{16}$$

should be redefined as the Road Lighting Efficiency parameter

$$\text{RLE} = \frac{\text{system power}}{\text{average maintained horizontal illuminance} \times \text{area}} \left(\frac{W}{lux.m^2}\right) \tag{17}$$

The classification levels used in the Netherlands standard appear, from analysis conducted for this report, to be appropriate for adoption. But, instead of using the European generic classification system for energy efficiency (A+++ to G), this should be replaced by the more familiar generic Australian/New Zealand system of a Star rating system, similar to other installation based schemes such as the House Energy Rating Scheme and the appliance energy rating label scheme, Figure 14 and Table 14.



Label	SE W/lux/m²		SL W/(cd/m²)/m²
A	0.01	0.005-0.014	0.15
B	0.02	0.015-0.024	0.3
C	0.03	etc.	0.45
D	0.04		0.6
E	0.05		0.75
F	0.06		0.9
G	0.07		1.05

Table 4.5. Label classifications

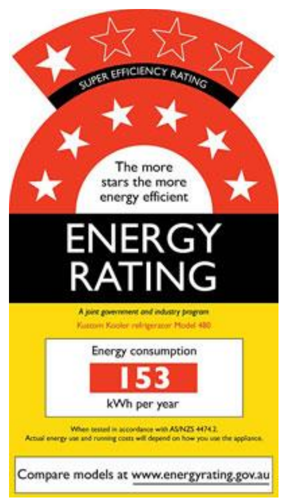


Figure 14. Netherlands energy efficiency label (top left) and label classification levels (top right); Australian housing energy rating scheme label (bottom left); Australian appliance energy rating label (bottom right).

Table 14. Proposed road design energy efficiency star rating classifications

AU/NZ Star Rating	Netherlands Label	Illuminance based designs RLE or SLEEC (W/lux/m²)		Luminance based designs RLE or SLEEC (W/(cd/m²)/m²)
★★★★★★★	A	0.01	(0.005-0.014)	0.15
★★★★★★	B	0.02	(0.015-0.024)	0.3
★★★★★	C	0.03	(0.025-0.034)	0.45
★★★★	D	0.04	(0.035-0.044)	0.6
★★★	E	0.05	(0.045-0.054)	0.75
★★	F	0.06	(0.055-0.064)	0.9
★	G	0.07	(0.065-0.074)	1.05

A star rating label could be developed, which through its familiarity in Australia and New Zealand and use on reports, would provide quick identification of energy efficient road lighting designs, Figure 15.

Figure 15. Proposed road lighting energy efficiency rating label.

Dimming systems

Another key component in the energy efficiency of the installation is through the provision of dimming. The suitability of a specific site to the application of dimming will be determined by consideration of the factors, which traditionally determine the original classification of the lighting requirement for the street. If these conditions change sufficiently, and for long enough, then dimming to a lower lighting sub-category may be warranted. To assist with quantifying the energy efficiency that may be achieved due to the dimming another parameter is proposed: the typical time weighted dimming level (Dim_{ave}) for an installation.

This is defined as

$$Dim_{ave} = \frac{\sum_{j=1}^{n}(Dim_j \times t_j)}{\sum_{j=1}^{n} t_j} \quad (18)$$

where

t_j is the time of operation during dimming period j

Dim_j is the dimming level (as a percentage) during dimming period j

A lighting design with no dimming factor associated with it will have an average dimming level of 100%.

Where there is an active response system specified to control the dimming (for example presence detection) and not just a time based system, justification of the periods for the dimming (t_j), would need to be provided. These could be in the form of actual traffic flow surveys at the site, traffic flow data from feeder roads to the site or similar roads to the actual site.

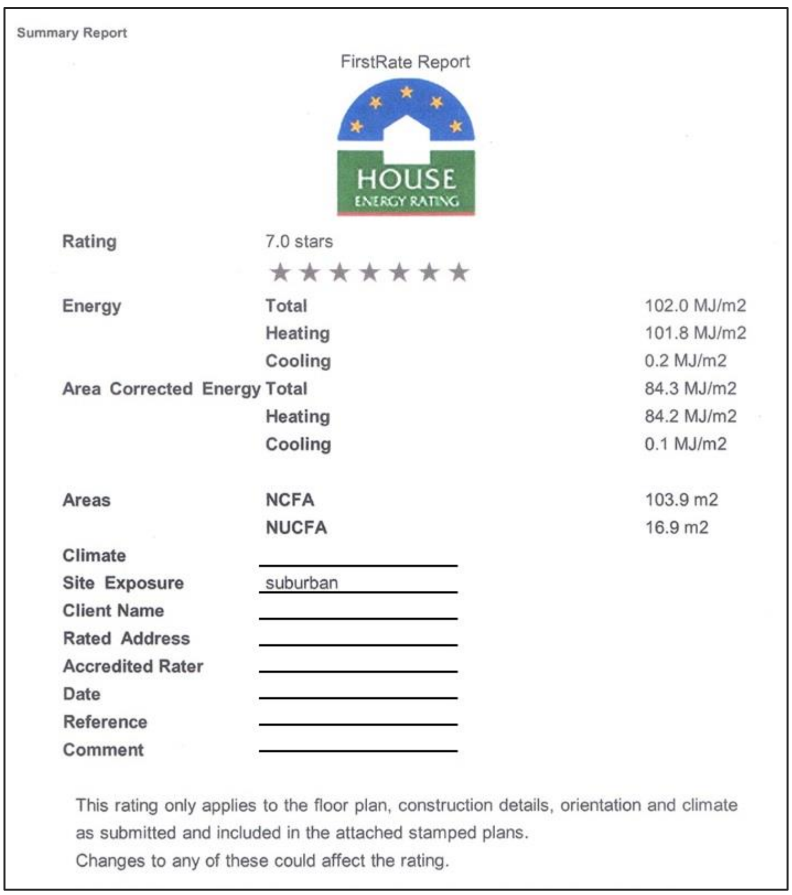
This should be reported along with the RLE Star Rating, therefore providing information about the energy efficiency of the standard operation of the installation (RLE Star Rating) and the potential for further energy savings through dimming. Conceivably, if there is confidence in the dimming strategy and the supporting evidence for re-classification of the lighting levels, the Road Lighting Efficiency Rating could be adjusted, RLE_{adj}, to include the typical time weighted dimming level (Dim_{ave}) for an installation.

$$RLE_{adj} = RLE \times Dim_{ave} \tag{19}$$

Road Lighting Energy Efficiency Report

These recommend parameters could be presented in the form of a road lighting design energy efficiency report. This could requested as part of tender and then can be used by the procurer (Council or DB) as part of their decision making process and cost benefit analysis when selecting winner of tender.

This could be similar to that currently required in the housing sector, Figure 16.



Summary Report

FirstRate Report

HOUSE ENERGY RATING

Rating	7.0 stars ★★★★★★★	
Energy	Total	102.0 MJ/m2
	Heating	101.8 MJ/m2
	Cooling	0.2 MJ/m2
Area Corrected Energy	Total	84.3 MJ/m2
	Heating	84.2 MJ/m2
	Cooling	0.1 MJ/m2
Areas	NCFA	103.9 m2
	NUCFA	16.9 m2
Climate		
Site Exposure	suburban	
Client Name		
Rated Address		
Accredited Rater		
Date		
Reference		
Comment		

This rating only applies to the floor plan, construction details, orientation and climate as submitted and included in the attached stamped plans.
Changes to any of these could affect the rating.

Figure 16. House Energy efficiency rating report example.

A one page road lighting energy efficiency report could be generated as part of the lighting design and one would expect it to be incorporated into commonly used road lighting design software relatively quickly once adopted. This one page report would provide all the energy efficiency information about the proposed lighting design as well as including key parameters required for assessing the overall cost benefit of the installation. This information is important in determining the preferred solution, as there are situations where the financial savings gained through energy efficiency are exceeded by the increase in capital and maintenance costs.

Key parameters to be reported should include:

- Unique site identifiers
- RLE Star Rating
- Dim_{ave} (default is 100%)
- Road lighting re-classification justifications and associated dimming schedule
- Lamp types (ILCOS code) and associated lamp efficacies (where lamps are replaceable in luminaires to retain LERs)
- Key design parameters (explicit clarification of design-assigned LLMF and corresponding lamp age).
- Lamp Lumen Maintenance Factor (LLMF)
- Life of lamp at assigned LLMF

7 Possible Standards Inclusions

A brief summary of the updates that would be required to the AS/NZS1158 series should these recommendations be adopted is provided here. The endeavour has been to minimise the number of changes required to the publications within the series.

7.1 AS/NZS1158.0 Introduction

7.1.1 Clause 3.2 Task area definitions

Parameters for task areas for Netherlands method refer to area definitions as outlined in EN 13201-1. The task area definitions for Australia and New Zealand should be as defined in AS/NZS1158.0. That is, the Category V and Category P calculations applicable area will be the product of carriageway widths and pole spacing.

7.1.2 Clause 3.4 Photometric and light output definitions

Definition for luminaire efficiency rating (LER)

7.1.3 Clause 3.5 Light technical parameter (LTP) definitions

7.1.3.1 Clause 3.5.2 Category V LTPs

Definition for luminance based Road Lighting Efficiency RLE_L as per Netherlands method, which defers to prEN 13201-5:

$$RLE_L = \frac{P}{\sum_{j=1}^{n}\left(\frac{\bar{L}}{Q_0}\right)_j . A_j}\left(\frac{\mathrm{W}}{(\mathrm{cd/m^2}).\mathrm{m^2}}\right) \qquad (20)$$

Where

$\left(\frac{\bar{L}}{Q_0}\right)_j$ is the derivation of average illuminance of the j^{th} section of the road, (expressed in terms of luminance)

P is the total lighting system power (W)

$\bar{L}$ is the average maintained road surface luminance in the dry condition (cd/m^2)

Q_0 is the average luminance coefficient of the road surface used for the lighting calculation. Where the average luminance coefficient Q_0 of the road surface is not known Q_0 = 0.07 should be used.

A_j is area of the j^{th} section of the road (m^2)

n is the number of sections of the road to be lit

7.1.3.2 Clause 3.5.3 Category P LTPs

Definition for illuminance based Road Lighting Efficiency RLE_E as per Netherlands method, which defers to prEN 13201-5:

$$RLE_E = \frac{P}{\sum_{j=1}^{n} \overline{E_j}.A_j} \left(\frac{\mathrm{W}}{\mathrm{lux.m^2}}\right) \qquad (21)$$

Where

P is the total lighting system power (W)

$\overline{E_j}$ is the average maintained horizontal illuminance of the j^{th} section of the road (lux)

A_j is area of the j^{th} section of the road (m^2)

n is the number of sections of the road to be lit

7.1.4 Section 4 SYMBOLS AND ABREVIATIONS

As required for the definitions above.

7.1.5 Clause 5.1 Lighting categories

Initial paragraph must include explicit statement on the opportunity to have documented assessment of reclassification of a road's subcategory throughout a 24 hour cycle based on temporal variation of the parameters currently considered for the general classification of a road. This information must also be accompanied by a review period, a duration of which should be assigned based on any foreseeable changes of the issues considered (eg traffic level, crime level etc).

There must also be a provision for the overriding (either remote or manual) of the classification to lower (energy saving) lighting levels for extra-ordinary events within these dimmed times, (eg street festival, crash scene etc).

7.1.6 Clause 5.1 (vi)

Energy efficiency rating calculations of lighting installations for Category V and Category P lighting shall be provided for new or upgraded installations as specified in AS/NZS1158.2.2 (new).

7.2 AS/NZS1158.1.1 Vehicular traffic (Category V) lighting- Performance and design requirements.

7.2.1 Clause 2.6.3 Luminaire Efficiency Rating (new)

All luminaires shall satisfy the MEPS requirements as stated in AS/NZS1158.6 Section 5.10.

7.2.2 Clause 3.6 Road Lighting Efficiency Rating (new)

All road lighting designs shall have calculated a Road Lighting Efficiency (RLE_L) and star rating. This shall be determined by methods described in AS/NZS1158.2.2.

7.2.3 Appendix D1 Mandatory Requirements

(n) Road Lighting Energy Efficiency Report (as described in AS/NZS1158.2.2)

7.3 AS/NZS1158.2.2 Lighting installation energy efficiency calculations and reporting for Category V and Category P lighting (NEW)

This new publication within the AS/NZS1158 series will define a number of new parameters and related calculations as well as describing the reporting requirements. The following sub-sections briefly discuss each of these new elements.

7.3.1 Road Lighting Efficiency Star Rating

A modified (for Australian/New Zealand terminology) description of the Netherlands streetlight energy efficiency criterion system (with explanations of the performance metrics and calculations defined in the EU standard, prEN 13201-5:2013). This will be the basis for a normative energy efficiency classification scheme for roads in Australia and New Zealand, which may be assigned a different name to the Dutch parameter (SLEEC), such as Road Lighting Efficiency (RLE) Star Rating.

The Road Lighting Efficiency defined as:

$$\text{RLE} = \frac{\text{system power}}{\text{average maintained horizontal illuminance} \times \text{area}} \left(\frac{W}{lux.m^2}\right) \tag{22}$$

An energy efficiency classification, (RLE Star Rating), for the road lighting design shall be assigned as per values given in Table 15

.

Table 15. Road lighting installation energy efficiency label classifications

RLE Star Rating Label	RLE for illuminance based designs (W/lux/m²)	RLE for luminance based designs (W/(cd/m²)/m²)
★★★★★★★	0.01 (0.005-0.014)	0.15 (0.075-0.224)
★★★★★★	0.02 (0.015-0.024)	0.3 (0.225-0.374)
★★★★★	0.03 (0.025-0.034)	0.45 (0.375-0.524)
★★★★	0.04 (0.035-0.044)	0.6 (0.525-0.674)
★★★	0.05 (0.045-0.054)	0.75 (0.675-0.824)
★★	0.06 (0.055-0.064)	0.9 (0.825-0.974)
★	0.07 (0.065-0.075)	1.05 (0.975-0.124)

7.3.2 Average Dimming

The typical time weighted dimming level (Dim_{ave}) for an installation.

This will be determined by suitability of a specific site to the application of dimming. Consideration of the variability of the factors, which traditionally determine the main classification of the lighting requirement for the street, will provide insight into the opportunity dimming to a lower lighting sub-category.

A lighting design with no dimming factor associated with it will have an average dimming level of 100%.

$$Dim_{ave} = \frac{\sum_{j=1}^{n}(Dim_j \times t_j)}{\sum_{j=1}^{n} t_j} \quad (23)$$

where

t_j is the time of operation during dimming period j

Dim_j is the dimming level (as a percentage) during dimming period j

This parameter shall be reported along with the RLE Star Rating.

Where there is an active response system specified to control the dimming (for example presence detection), justification of the periods for the dimming (t_j), shall be provided, eg traffic flow surveys etc.

7.3.3 Road Lighting Energy Efficiency Report

A road lighting energy efficiency report shall be produced as part of the road lighting design and AS/NZS 1158 compliance process to assist a procuring authority (municipality, electricity distribution business or private provider of street lighting) with selection of the preferred lighting design solution.

Key parameters to be reported shall include:

- RLE Star Rating Label
- Unique site identifiers
- RLE value
- Dim_{ave} (default is 100%)
- Road lighting re-classification justifications and associated dimming schedule
- Estimated annual energy consumption
- Luminaire efficacy (compliance with MEPS?)
- Lamp types (ILCOS code) and associated lamp efficacies (where lamps are replaceable in luminaires to retain LERs so as to retain confidence of MEPS compliance)
- Key design parameters (explicit clarification of design-assigned LLMF and corresponding lamp age).
- Lamp Lumen Maintenance Factor (LLMF)
- Life of lamp at assigned LLMF

7.4 AS/NZS1158.3.1 Pedestrian area (category P) lighting – Performance and design requirements

7.4.1 Clause 2.10.1 Compliance of design (append)

All luminaires shall satisfy the MEPS requirements as stated in AS/NZS1158.6 Section 5.10.

All road lighting designs shall have calculated a Road Lighting Efficiency (RLE_E) and star rating. This shall be determined by methods described in AS/NZS1158.2.2.

7.4.2 Appendix E1 Mandatory Requirements

(m) Road Lighting Energy Efficiency Report (as described in AS/NZS1158.2.2)

7.5 AS/NZS1158.6 Luminaires

7.5.1 Section 5 PERFORMANCE AND TESTING

Insert new 5.10 (see below). Old 5.10 becomes 5.12 Additional tests

7.5.2 Clause 5.10 Minimum Energy Performance (MEPS) for luminaire

Luminaires shall meet a minimum luminaire efficiency rating (LER) based on equation

$$LER \geq 40 + 0.001 \times \emptyset \qquad (24)$$

Where ϕ is the total initial luminaire luminous flux.

If the light source is replaceable (eg lamp), the lamp type (ILCOS code) and lamp efficacy shall be specified.

Test methods for determining total luminaire luminous flux and luminaire power shall be as per requirements of Section 6.3. (AS/NZS1158.1.1 and AS/NZS11581158.3.1 refers to Test method CIE 121. Note will need to refer to new test method when ratified from CIE TC2.71 for LED luminaires).

7.5.3 Clause 5.11 Quality performance parameters for luminaire

Luminaires shall meet the technical parameter requirements as specified in Table below.

Parameter	LED (IEA 4E SSL Tier 1)	MH, LF, CFL, HPS
Life		
Lumen maintenance (L70/B50)	At 35000 hours, lumen maintenance should be greater than 78% of the initial flux.	At 16,000 hours, lumen maintenance should be greater than 92% of initial flux (EU 245) This metric should be referenced directly to Commercial Lighting Product Profile outcomes, review 2014, which includes evaluation of EC 245 (Indicative LLMF values as per EC 245 Table 24)
Minimum rated luminaire lifetime (F50)	At least 50% shall be operative after 50,000 hours.	As per AS/NZS 1158.6 Preface
Operation		
Operating temperature (range °C)	Minimum temperature range from -10°C to 40°C without significant change of photometric and colorimetric performance, unless regional requirements are higher or lower	As per AS/NZS 1158.6 Part 1.5 (Australia: -10°C to 40°C. NZ: -10°C to 25°C)
Light & Health		
Correlated colour temperature (K) and tolerance < 6500K	Follow ANSI C78.377, excluding flexible CCT Nominal CCT: / Target CCT ± Tolerance 2700K: 2725 ± 145 3000K: 3045 ± 175 3500K: 3465 ± 245 4000K: 3985 ± 275 5000K: 5028 ± 283 5700K: 5665 ± 355 6500K: 6530 ± 510	✓ (HPS exempt)
Chromaticity tolerance (Du'v')	Centre points based on ANSI C78.377, excluding flexible CCT Nominal CCT: / Target Du'v' ± Tolerance 2700K: 0.000 ± 0.012 3000K: 0.000 ± 0.012 3500K: 0.000 ± 0.012 4000K: 0.001 ± 0.012 5000K: 0.002 ± 0.012 5700K: 0.002 ± 0.012 6500K: 0.003 ± 0.012	✓ (HPS exempt)
Flicker (amplitude modulation depth)	At full power: flicker index ≤ 0.3	✓
Minimum displacement power factor	≥ 0.9	✓
Environment		
Recyclability (%)	Yes, following the principles of self- declaration found in ISO 14021	✓

8 References & Bibliography

1. IEA_4E, *Solid State Lighting Annex: Product Quality and Performance Tiers*, in *Outdoor Lighting (Street Lighting)*. 2013.
2. CEN_(European_Committe_for_Standardization), *Road lighting*, in *Part 5 - Energy performance indicators*. 2013, BSI Group.
3. CEN_(European_Committe_for_Standardization), *Road lighting*, in *Part 2 - Performance requirements*. 2003, BSI Group.
4. Canadian_Standards_Association, *Photometric performance of roadway and street lighting luminaires*. 2013, CSA Group.
5. Ministry_of_Industry_Tourism_and_Trade, *Regulation of energy efficient lighting exterior facilities*, in *Complementary Technical Instruction - Energy efficiency*. 2008: Spain.
6. NL_Agency_&_Ministry_of_Economic_Affairs_Agriculture_and_Innovation, *Handbook Energy Labelling for Public Lighting*. 2010: Netherlands.
7. Energy_Label_Taiwan, *Energy Efficiency Criteria and Labeling Method for Energy Label Qualified Street Lights*. 2012: Taiwan.
8. Madhya_Pradesh_Urban_Administration_and_Development_Department_(UAD), *Guidelines for design and implementation of street light energy efficient projects in Madhya Pradesh*.
9. Mark_Ellis_&_Associates, *Design Energy Limits for Main Road Lighting (Report)*. 2005, Australian Greenhouse Office (AGO) and National Appliance and Equipment Energy Efficiency Program (NAEEEP).

9 Appendices

9.1 Appendix A

The following tables (Table 4A, 4B, 5A, 5B, 6, 7) from Canadian standard C653-13 outline the required maximum UPD levels for different lamp technologies in given luminaire types.

Table 4A
Maximum UPD levels for high-pressure sodium cobra-head luminaires
(See Clauses 1.4, 3, 4.7, and A.3.)

		UPD levels, W/m²									
		1 lane		2 lanes		3 lanes		4 lanes		5 lanes	
Roadway	**Pedestrian conflict area classification**	**Zero uplight**	**Other**	**Zero uplight**	**Other**	**Zero uplight**	**Other**	**Zero uplight**	**Other**	**Zero uplight**	**Other**
Freeway Class A		0.65	0.65	0.50	0.45	0.35	0.40	0.35	0.35	0.30	0.30
Freeway Class B		0.50	0.40			0.25	0.20	0.25	0.25	0.25	0.20
Expressway	High					0.45	0.55	0.50	0.45	0.55	0.45
	Medium					0.35	0.55	0.45	0.45	0.40	0.35
	Low					0.35	0.35	0.40	0.35	0.35	0.30
Major	High			0.75	0.70	0.60	0.55	0.55	0.55	0.55	0.45
	Medium			0.50	0.45	0.40	0.45	0.40	0.40	0.35	0.35
	Low			0.35	0.35	0.35	0.30	0.30	0.30	0.35	0.25
Collector	High			0.40	0.50	0.50	0.40	0.35	0.30	0.35	0.30
	Medium			0.35	0.35	0.40	0.25	0.30	0.25	0.25	0.25
	Low			0.30	0.25	0.25	0.20	0.30	0.20	0.20	0.20
Local	High	0.60	0.50	0.30	0.30	0.25	0.25				
	Medium	0.50	0.45	0.30	0.25	0.25	0.20				
	Low	0.40	0.30	0.30	0.20	0.15	0.15				

Notes:

1) Annex A provides information on how to use the values in this Table.
2) The values in this Table are not intended for lighting design.
3) Calculations are based on initial lumens (LLF = 1.0).
4) One, two and three lane designs have poles on one side.
5) Four and five lane designs have poles in opposite arrangement.
6) Photometric files are tested to IES LM-31 procedures.
7) Designed are optimized to maximum pole spacing.

Table 4B
Maximum UPD levels for high-pressure sodium shoebox luminaires
(See Clauses 1.4, 3, 4.7, and A.3.)

Roadway Classification		**UPD levels, W/m² Zero Uplight**				
Road	**Pedestrian conflict area classification**	**1 lane**	**2 lanes**	**3 lanes**	**4 lanes**	**5 lanes**
Freeway Class A		0.72	0.42	0.33	0.35	0.32
Freeway Class B		0.58		0.26	0.30	0.24
Expressway	High			0.49	0.44	0.41
	Medium			0.43	0.42	0.34
	Low			0.33	0.33	0.30
Major	High		0.53	0.49	0.41	0.39
	Medium		0.44	0.38	0.32	0.34
	Low		0.29	0.26	0.25	0.23
Collector	High		0.38	0.35	0.32	0.29
	Medium		0.33	0.30	0.21	0.24
	Low		0.31	0.21	0.18	0.22
Local	High	0.37	0.31	0.22		
	Medium	0.37	0.31	0.23		
	Low	0.37	0.25	0.11		

Notes:

1) Calculations are based on initial lumens (LLF = 1.0).
2) One, two and three lane designs have poles on one side.
3) Four and five lane designs have poles in opposite arrangement.
4) Photometric files are tested to ANSI/IES LM-63 procedures.
5) Designs are optimized to maximum pole spacing.

Table 5A
Maximum UPD levels for metal-halide cobra-head luminaires
(See Clauses 1.4, 3, 4.7, and A.3.)

		UPD levels, W/m²									
		1 lane		2 lanes		3 lanes		4 lanes		5 lanes	
Roadway	**Pedestrian conflict area classification**	**Zero uplight**	**Other**	**Zero uplight**	**Other**	**Zero uplight**	**Other**	**Zero uplight**	**Other**	**Zero uplight**	**Other**
Freeway Class A		0.98	0.82	0.64	0.43	0.49	0.37	0.44	0.31	0.33	0.28
Freeway Class B		0.68	0.56			0.40	0.27	0.32	0.25	0.34	0.22
Expressway	High					0.67	0.60	0.69	0.51	0.48	0.46
	Medium					0.57	0.49	0.54	0.43	0.48	0.39
	Low					0.44	0.37	0.47	0.35	0.38	0.30
Major	High			0.75	0.65	0.76	0.51	0.60	0.49	0.46	0.43
	Medium			0.59	0.52	0.56	0.38	0.44	0.39	0.44	0.35
	Low			0.51	0.40	0.47	0.32	0.47	0.29	0.30	0.25
Collector	High			0.53	0.48	0.70	0.38	0.58	0.41	0.41	0.33
	Medium			0.45	0.34	0.44	0.33	0.44	0.29	0.33	0.25
	Low			0.39	0.30	0.28	0.27	0.32	0.28	0.29	0.20
Local	High	0.56	0.63	0.36	0.27	0.43	0.30				
	Medium	0.48	0.48	0.35	0.27	0.39	0.22				
	Low	0.35	0.31	0.23	0.25	0.25	0.13				

Notes:

1) Calculations are based on initial lumens (LLF = 1.0).

Table 5B
Maximum UPD levels for metal-halide shoebox luminaires
(See Clauses 1.4, 3, 4.7, and A.3.)

Roadway Classification		**UPD levels, W/m² Zero Uplight**				
Road	**Pedestrian conflict area classification**	**1 lane**	**2 lanes**	**3 lanes**	**4 lanes**	**5 lanes**
Freeway Class A		1.06	0.51	0.46	0.37	0.37
Freeway Class B		0.57		0.30	0.26	0.23
Expressway	High			0.69	0.55	0.51
	Medium			0.49	0.48	0.46
	Low			0.42	0.36	0.31
Major	High		0.72	0.67	0.59	0.53
	Medium		0.68	0.57	0.46	0.44
	Low		0.49	0.39	0.32	0.28
Collector	High		0.60	0.53	0.38	0.40
	Medium		0.34	0.34	0.33	0.23
	Low		0.31	0.24	0.21	0.21
Local	High	0.57	0.33	0.34		
	Medium	0.57	0.31	0.28		
	Low	0.44	0.24	0.17		

Notes:

1) Calculations are based on initial lumens (LLF = 1.0).
2) One, two and three lane designs have poles on one side.
3) Four and five lane designs have poles in opposite arrangement.
4) Photometric files are tested to ANSI/IES LM-63 procedures.
5) Designs are optimized to maximum pole spacing.

Table 6
Maximum UPD levels for induction luminaires
(See Clauses 1.4, 3, 4.7, and A.3.)

Roadway Classification		**UPD levels, W/m² Zero Uplight**				
Road	**Pedestrian conflict area classification**	**1 lane**	**2 lanes**	**3 lanes**	**4 lanes**	**5 lanes**
Freeway Class A		1.89	1.13	0.84	0.76	0.66
Freeway Class B		1.26		0.54	0.47	0.42
Expressway	High			1.08	0.96	0.92
	Medium			0.95	0.75	0.70
	Low			0.69	0.54	0.52
Major	High		1.62	1.26	0.94	0.91
	Medium		1.26	0.94	0.71	0.65
	Low		0.76	0.58	0.50	0.41
Collector	High		0.87	0.86	0.71	0.57
	Medium		0.67	0.52	0.56	0.41
	Low		0.54	0.45	0.41	0.39
Local	High	0.93	0.62	0.47		
	Medium	0.63	0.70	0.46		
	Low	0.45	0.28	0.27		

Notes:

1) Annex A provides information on how to use the values in this Table.
2) The values in this Table are not intended for lighting design.
3) Calculations are based on initial lumens (LLF = 1.0).
4) One, two and three lane designs have poles on one side.
5) Four and five lane designs have poles in opposite arrangement.
6) Photometric files are tested to IES LM-31 procedures.
7) Designs are optimized to maximum pole spacing.

Table 7
Maximum UPD levels for LED luminaires
(See Clauses 1.4, 3, 4.7, and A.3.)

Roadway Classification		**UPD levels, W/m² Zero Uplight**				
Road	**Pedestrian conflict area classification**	**1 lane**	**2 lanes**	**3 lanes**	**4 lanes**	**5 lanes**
Freeway Class A		0.69	0.41	0.40	0.30	0.28
Freeway Class B		0.50		0.22	0.21	0.21
Expressway	High			0.43	0.39	0.38
	Medium			0.35	0.32	0.30
	Low			0.28	0.32	0.30
Major	High		0.61	0.47	0.40	0.38
	Medium		0.47	0.34	0.28	0.28
	Low		0.31	0.22	0.24	0.21
Collector	High		0.36	0.34	0.33	0.25
	Medium		0.25	0.25	0.23	0.19
	Low		0.23	0.16	0.14	0.16
Local	High	0.40	0.23	0.20		
	Medium	0.35	0.23	0.18		
	Low	0.26	0.16	0.11		

Notes:

1) Annex A provides information on how to use the values in this Table.
2) The values in this Table are not intended for lighting design.
3) Calculations are based on initial lumens (LLF = 1.0).
4) One, two and three lane designs have poles on one side.
5) Four and five lane designs have poles in opposite arrangement.
6) Photometric files are tested to IES LM791 procedures.
7) Designs are optimized to maximum pole spacing.