

Strategic Lighting Partners Ltd

Review of Road Lighting Design Classification System

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Submission to:

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1 Introduction

1.1 Background

In Q2 2011 the Department of State Development of the State of South Australia on behalf of the Equipment Energy Efficiency (E3) Committee commissioned a report on the energy efficiency of road lighting by Light Naturally consultants, published in August 2014 entitled “Energy efficiency performance requirements for road lighting designs and luminaires”. The report was commissioned in the context of the review of AS/NZS1158 Lighting for roads and public spaces currently underway.

The report assessed a range 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 to identify options that may be suitable for application in Australia and New Zealand (within the context of AS/NZS 1158). One of the approaches recommended by the report was the use of a road design energy efficiency classification system based on one in the Netherlands, with adjustments made for Australian and New Zealand road lighting conditions.

Strategic Lighting Partners Ltd has been commissioned by the Department of State Development to evaluate this aspect of the Light Naturally recommendations with the following objectives:

- a) Determine whether the proposed lighting design rating methodology provides a useful comparative metric;
- b) Determine the cost impacts of applying the metric as a normative disclosure requirement for AS/NZS1158 Part 1 and Part 3 road lighting compliance (excluding car parks, precincts etc);
- c) Recommendations for refinements to meet the objective of providing an evaluation method for road lighting design energy performance.

1.2 Assessment of completed road lighting designs

As part of the assessment, SLP was commissioned to use the Road Lighting Design Classification system methodology proposed in the Light Naturally Report to assess and rate a representative sample of Australia and New Zealand road lighting designs. In order to obtain a representative sample, the following requirements were used:

- 1) One Cat P and one Cat V design for each Australian jurisdiction and for New Zealand (9 States, Territories, Regions for a total of 18 scenarios).
- 1) To be a mixed selection of scenarios across the more commonly used P and V lighting subcategories.
- 2) Designs to be selected from actual projects constructed within the last ten years
- 3) Designs to be obtained from members of AS/NZS committee LG-002 as far as possible.

During the process of gathering data it became evident that 18 designs would not be sufficiently representative of each type of design and sub-category so a much larger sampling base was targeted and undertaken. Project data donor prospects beyond the LG-002 committee were approached, with contact prospecting based on SLP industry experience. In total 89 designs were gathered from 9

data donors covering 7 territorial regions. After filtering out designs that did not fit the project brief 8 lighting schemes were captured and assessed.

1.3 Report Organisation

This report is organised into ten sections:

1. Introduction
2. Executive Summary
3. Evaluation of proposed Design Energy Rating Methodology
4. Review of Latest Standards and Guidelines
5. Review of the New EN Standard - o Energy Performance Indicators
6. Assessment of AU/NZ Representative Design Solutions
7. Recommended Refinements to Design Rating Methodology
8. Cost Impacts of Design Rating Methodology
9. Conclusions and Recommendations
10. References and Bibliography

Appendix 1 – Data Donor Notes

Appendix 2 – Data Capture Matrix

Appendix 3 – Design Data Analysis

2 Executive Summary

Strategic Lighting Partners Ltd was commissioned by the Department of State Development of the State of South Australia on behalf of the Equipment Energy Efficiency (E3) Committee to evaluate the recommendations of the Light Naturally “*Energy efficiency performance requirements for road lighting designs and luminaires*” report, undertake analysis of actual lighting schemes, make recommendations for refinements and inclusion in AS/NZS 1158 standard series, and to analyse cost implications of normative implementation.

Light Naturally recommended the use energy performance indicator methodologies from the 2013 draft standard *EN 13201-5 Energy Performance Indicators* supported by the slightly modified implementing measures used by the Netherlands as a basis for the adoption in Australia and New Zealand.

This is strongly endorsed by SLP as long as this is aligned with key updates from the new 2015 version of the proposed EN standard expected to published in 2015, and the Netherlands Star Rating scale is informed and updated by recent AU/NZ market research on the efficacy of LED luminaires and the use of adaptive control systems.

A important part of the project was to gather real design data from nine “data donors” that provided comprehensive data for a total of 83 separate lighting schemes. These designs were not selected on a statistically random basis as this was beyond the project scope. SLP analysis shows a very wide spread of energy performance outcomes. The highest rated V Category design exhibits 10 times the energy performance of the lowest. In P Category designs the spread is even wider with the highest being 27 times the lowest.

Only 21% of the designs achieve the top tier of 6 or Stars with 49% of the designs achieving 3, 4, or Stars and 30% achieving the lowest ratings of zero, and stars. SLP also analysed the performance of the NZ designs against the NZ Transport Agency (NZTA) “M30” funding eligibility specification. If the M30 requirements were applied to the NZ designs 73% of V Category and 44% of the P Category designs would meet NZTA energy performance criteria.

Almost all of the very low-performing schemes have been designed and installed within the last five years. LED technology is dominant at the higher performance levels but it is also clear that LED designs are also capable of delivering low performance outcomes. Designs with CFL and T5 fluorescent luminaires achieve only mediocre performance levels and the use of overhead power line electrical reticulation appears to be a limitation on the ability of lighting designers to deliver higher performing outcomes with these light sources.

Another factor that will improve rated energy performance is the design application of scotopic/photopic (S/P) ratios that favour high CRI white light. If AS/NZS standards are updated to follow international trends, designs relevant for the application of S/P ratios will achieve higher energy performance ratings than those analysed in this report. The Star Rating scale may need periodic re-calibration to accommodate such upward rating creep.

Finally, the additional cost of adopting the requirements for energy performance calculations and reporting during the design process is considered to be very minor. The design task will be slightly increased but with appropriate software and/or spreadsheet use the additional time and cost for this should be negligible.

3 Evaluation of Proposed Design Rating Methodology

In August 2014 the Department of State Development, Government of South Australia released a report by Light Naturally Consultants (LN) “*Energy efficiency performance requirements for road lighting designs and luminaires*”. This report is a comprehensive evaluation of international practices covering a wide scope in considerable depth. The report makes recommendation for Australian New Zealand adoptions and makes further recommendations for AS/NZS standards inclusions.

The following is SLP’s review of the main observations and recommendations from this report. Direct excerpts from this report are listed below in italicised text. SLP’s response follow each topic.

Note that since the release of the Light Naturally report, there have been further updates of relevant international standards and this is reflected in the analysis below.

3.1 Recommended Energy Efficiency Scheme for Australia and New Zealand

design energy classification scale would encourage energy efficient practice in road lighting, while allowing 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.

SLP agrees: Selection of efficient equipment alone is not sufficient to ensure an efficient outcome. A holistic approach is required that employs high efficacy luminaires within an effective design so that an efficient outcome is delivered. Measures to calculate efficient outcomes and a scale that clearly identifies and ranks energy performance outcomes would encourage energy efficient practice in road lighting.

3.2 International alignment

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

SLP agrees: Alignment of terminology, metrics and calculation methodologies with international and/or influential regional standards is highly desirable for a variety of technical, political, economic and trade reasons.

3.3 Recommended approach

threefold approach for achieving energy efficiency is recommended:

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*

SLP agrees: The absence of mandatory minimum performance limits allows flexibility for different regions and/or different procuring agencies to apply implementing measures appropriate to local conditions.

3.4 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 metric SLEEC ... should be redefined as the Road Lighting Efficiency parameter RLE.

SLP agrees in principle: see SLP recommended refinements (Section 7) to update this approach to harmonise with EN 201 criteria.

3.5 Netherlands classification system

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 Star Rating system, similar to other installation based schemes such as the House Energy Rating Scheme and the appliance energy rating label scheme.

SLP agrees in principle: The adoption of a Star Rating rather than the system used in the Netherlands is desirable. Calculated results are appropriate for providing technical basis for determining energy performance. However there are significant psychological and marketing benefits associated with well-conceived Star Rating system including the fact that it is already used for appliances and other items in Australia and New Zealand. This is an important factor in the implementation of such a scheme. Consideration should be given to means of providing future accommodation for very high performance lighting schemes (such as with the adoption of smart control systems and adaptive lighting techniques). This could also be a Star Rating scale re-calibration of levels within a 7-Star system.

| Recommended 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 |

Table 1 Correlation between Netherlands and recommended Australian & NZ star ratings

3.6 Star Rating Labels

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

SLP Comment: Clarification is needed on the nature of the term “label”. Does this mean a “Brand” or physical “Sticker” or both?

a) Label as Brand

SLP agrees: that an electronic version of a graphic logo would be very useful for lighting designers and/or project managers to use on reports and in business case submissions promote the program and the particular performance level targeted or attained.

b) Label as a Sticker

SLP disagrees that a “physical label” is necessary. A sticker would have clear advantages of recognition and branding for a consumer product efficiency scheme where the sticker is affixed to a product in a showroom selection situation or similar. But in the professional sector lighting application scheme there are no commonly visible chattels (as opposed to the retail sector) to affix a physical label to so this would be of limited value for the extra cost imposed.

In either circumstance it will be important to control or limit promotional use of the RLE “Brand” to lighting schemes that are rated above a certain Star Rating threshold. In addition electronic graphics file need to be provided with a selection of Star Rating logos that identified the particular Star Rating level attained.

3.7 Control Systems

To assist with quantifying the energy efficiency that may be achieved due to dimming another parameter is proposed: the typical time weighted dimming level (Dim_{ave}) for an installation.

SLP agrees in principle: Calculation methods should allow for adapting light levels both up and down. The time-weighted average should be calculated to cover a range of planned and scheduled scenarios over the course of an annual operating cycle to yield an annual average adaptive level (EN 201 terminology calls this a Light Reduction Coefficient, LRC). This would accommodate the changes to traffic flow patterns and user visual needs caused by the variation in weekday/weekend traffic patterns as well as summer/winter patterns caused by daylight saving time adjustments and seasonal weather changes. Such measures are incorporated in the New EN¹ Standard on Energy Performance Indicators (FprEN13201-5:2015).

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 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.

¹ EN denotes a “European Normative” standard – which is mandatory as opposed to informative

SLP agrees: This could be part of risk analysis process undertaken at the project feasibility stage. The traffic flow surveys would need to be carried out on the basis of at least hourly or more frequent counts rather than the traditional methods.

The control system 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.

SLP agrees: The existence of control system in lighting scheme is not necessarily a guarantee of improved energy performance. An extended and recommended approach is to quantify the energy performance gains planned by such by switching/dimming/brightening activities. Such measures are incorporated in the New EN Standard on Energy Performance Indicators.

3.8 Road Lighting Energy Efficiency Report

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

SLP agrees: This facility is incorporated in the New EN Standard on Energy Performance Indicators, but with more advanced performance parameters and metrics.

3.9 Road Lighting Energy Efficiency Report

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.

SLP agrees: Well-known AS/NZS region software such as AGI32 and Perfect Lite are very likely to accommodate this as default report. Other international software products such as DIALux and Relux are sometimes used in Australia and New Zealand, but these Northern Hemisphere aligned software companies may be less inclined to adapt the software to AS/NZS needs. In SLP's view it is much more important that an MS Word or MS Excel formatted template be developed to ensure full transparency and easy verification that software applications do not provide.

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.

SLP disagrees: Balancing the many and complex financial factors is beyond the scope of an energy efficiency report. Financial analysis of road lighting project is a separate subject and recent developments now generally require much more sophisticated analysis than was typically the case in the recent past. Historically, a simple payback calculation was often sufficient but now most asset owners require more sophisticated discounted cash flow analysis calculated over whole of life as part of a business case based investment proposal. It is nevertheless very important that the energy performance report provides the required energy performance based parameters in a format suitable for input into financial analysis.

Key parameters to be reported should include:

- *Unique site identifiers*

- *RLE Star Rating*
- *Dim_{ave} (default is 100%)*
- *Roa lighting re-classification justifications and associated dimming schedule*
- *Lamp types (ILCOS code² and associated lamp efficacies (where lamps are replaceable)*
- *Key design parameters (clarification of design-assigned LLMF and corresponding lamp age).*
- *Lamp Lumen Maintenance Factor (LLMF)*
- *Life of lamp at assigned LLMF*

SLP agrees in principle: We think that consideration should be given to adding additional attributes from the New EN Standard on Energy Performance Indicators report that accommodates more sophisticated multi-power adaptive lighting profiles. We believe that it is important that the RLE Energy Efficiency Report is calculated and produced separate to the lighting design calculations to ensure it capture all appropriate luminaire identification and setup parameters as well as the road classifications, geometry and dimensions.

3.10 Power Density

The power density demonstrates the energy need for road lighting design, while fulfilling relevant luminance/illuminance lighting requirements for different roadways as specified in EN 13201-2.

SLP agrees in principle: European design standard such as a European Norm (EN) is an excellent foundation for a new AS/NZS design standard. It is also highly desirable to harmonise with international terminology especially that now used in the EN standards including the term “energy performance” as opposed to the term “energy efficiency” (commonly used in Australia and New Zealand), this is in keeping with latest EN¹ IEC³ ISO⁴ ANSI⁵ IESNA⁶ developments in terminology. This phraseology should be considered for AS/NZS application as it appears likely to be in increasing use as the accepted term in European, US and international standards. Note also that the phrase above “*The power density demonstrates the energy need ...*” is an incorrect use of the terms “power” and “energy”⁷.

3.11 The Energy Consumption Indicator (ECI)

The energy consumption indicator indicates the total electrical energy consumed by 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.

SLP agrees: Note that the ECI descriptor has changed from the 2013 to 2015 version of the New EN Standard on Energy Performance Indicators. The new term is “Annual Energy Consumption Indicator (AECI)”.

² ILCOS stands for International Lamp Coding System, published by the IEC in 1993 as IEC TS 6123

³ IEC stands for International Electrotechnical Commission

⁴ ISO stands for International Organisation for Standardisation

⁵ ANSI stands for American National Standards Institute

⁶ IESNA stands for Illuminating Engineering Society of North America

⁷ Power is the rate of energy use in Watts or Joules per second, whereas energy is in Joules.

Quantification of the impacts of parasitic power is essential given the growing international, and emerging Australia and New Zealand use of Central Management System (CMS) controls. This covers the power demands of conventional PE cells and CMS controls which may have both daytime and night-time power consumption.

3.12 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 minimum performance level to be achieved by the lighting design. Adoption of 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.

SLP agrees: In addition, we suggest consideration of methods for the periodic future modification of the star rating system to re-calibrate the scale at the upper levels to better identify and accommodate very high performance lighting schemes based on constantly improving technologies such as constant lumen control and/or adaptive control techniques, and possibly white light designs using S/P ratios.

3.13 Netherlands Handbook Energy Labelling for Public Lighting

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).

SLP agrees: This is a good platform for Australia New Zealand adoption.

3.14 Label Impetus

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 more challenging design criterion for the procuring parties.

Practical values for the SLEEC⁸ 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 (sic - typo 1.05, as per below) W/(cd/m²)/m² for luminance based designs. The classification levels are provided in Figure 5, values in the left hand

⁸ SLEEC stands for Street Lighting Energy Efficiency Criterion

column represent illuminance design limits and the right hand column provides luminance design limits.

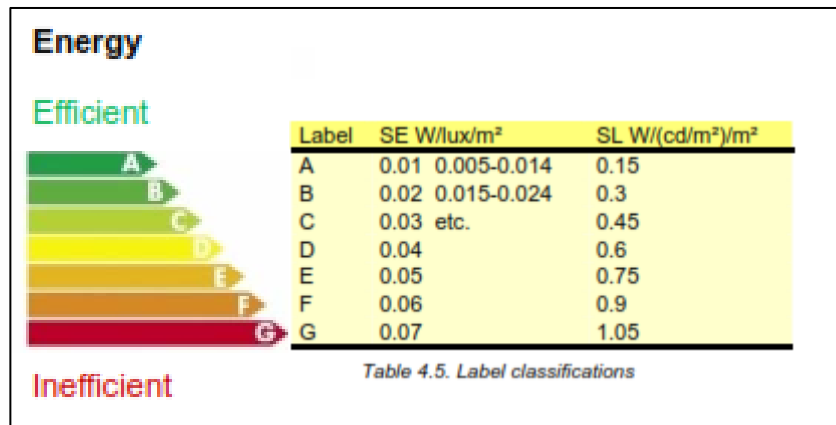


Figure 1 Netherlands energy efficiency SLEEC classification levels

The merit of using rating system rather than 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.

SLP agrees: This is highly suitable platform for Australia New Zealand adoption.

3.15 Rationale

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.

SLP agrees: This is a good platform for Australia New Zealand adoption. A clear system for the comparative evaluation of different designs or technologies under given conditions is the significant issue.

3.16 Impacts on installed luminaires in ANZ

It is clear that a more comprehensive survey of the streetlight market should be undertaken to confirm these results.

SLP agrees: Further market research is warranted to develop more current and more representative information on the LED luminaire population being deployed in Australia and New Zealand. This will assist to determine current luminaire efficacy figures as a basis for developing relevant normative disclosure requirements.

3.17 Netherlands ranking scale

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.

SLP agrees: We also agree that modification using a Star Rating scale for Australia New Zealand use will assist with communication and understanding of energy performance measures.

3.18 Best fit photometrics

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 compliant road lighting design as per the current road lighting standard, AS/NZS 1158.

SLP agrees: This is a very tangible example of why an application-based energy performance metric and calculation methodology is required. It is too often thought that the use of a high efficacy luminaire is all that is required, but the design of the scheme is a critically important factor for good energy performance.

3.19 Dimming and switching

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

1. Changes in traffic/pedestrian density

SLP agrees: But it should be noted that the term “dimming” has been superseded. “Dimming” infers that light levels are only capable of being reduced, whereas there are instances where light levels may be raised (brightened) temporarily over the nightly cycle to address issues of safety and/or public amenity. The term “adaptive lighting” is a descriptor that better communicates the current position.

2. Changes to local weather conditions. Lighting performance could be adapted depending on:

- *ambient temperatures*
- *fog conditions*
- *torrential rain*
- *heavy sleet/snow*

SLP agrees.

3. Fine tuning luminaire light output to suit specific street arrangement (in the case of unavoidable over-lighting)

SLP agrees: This is selecting exactly the luminous flux required, and no more and sometimes called Virtual Light Output (VLO),.

4. Compensating for Lamp Lumen Maintenance Factor (LLMF)

SLP agrees: This is power compensation for luminous flux depreciation over life and sometimes called Constant Light Output (CLO).

3.20 LED luminaire Controls

LED luminaires provide significant opportunity for incorporating sensor, switching and dimming technology to suit the usage profile of the street/park etc.

SLP agrees: Adaptive lighting has been used in UK and EU for the last fifteen years with HID (mainly HPS) light sources with variety of HID light source barriers and limitations. In recent times the focus has been on LED based adaptive lighting which allows real-time light level adjustment down to very low levels without discernable colour shift issues and with negligible internal energy losses.

3.21 Netherlands Handbook Energy Labelling for Public Lighting

..... 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 lighting installation. Suggestions:

If a 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.

SLP disagrees: We disagree with the need for a separate - and relatively costly to administer - dimming rating and label. If a control system has been procured, installed, commissioned and maintained appropriately to the needs of the market, then the designed adaptive lighting performance is likely to be delivered. Thus a single performance rating is justified. Such an approach is incorporated in the 2015 version of the New EN Standard on Energy Performance Indicators.

3.22 Summary and Conclusion

SLP endorses the Light Naturally report recommendation to use prEN13201-5:2015 supported by the implementing measures of the Netherlands as a basis for the adoption of energy performance indicators in Australia and New Zealand. But this should be updated to accommodate certain aspects of prEN13201-5:2015 as indicated elsewhere in this report. SLP's support is also conditional on the setting of Star Rating performance limits based on the latest available information on the performance potential of LED luminaires with adaptive controls.

The Department of State Development brief was to evaluate the Light Naturally recommendations to:

"Determine whether the proposed lighting design rating methodology provides a useful comparative metric"

SLP's answer is strong "yes" with conditions and relatively minor modifications described above.

4 Review of Latest Standards and Guidelines

4.1 International Lighting Standards - Current developments

There are a great number of new developments currently occurring internationally in the lighting standards arena and there is strong impetus within Australia and New Zealand standards development work towards internationalisation and on harmonisation of AS/NZS standards with IEC and ISO standards, where relevant and practical.

4.1.1 International Standards Organisation (ISO)

The newly formed ISO Technical Committee *TC 27 - Light and lighting* is undertaking an overarching standards initiative to draw together lighting safety, lighting performance and energy performance. Currently the project scope only includes building related lighting applications, rather than road and public lighting. This international committee is still in its early stages but it is worth noting that the term “Energy Efficiency” is to be replaced with the term “Energy Performance” to address the considerable confusion in lighting energy concepts.

It is uncertain if this change will permeate to all relevant ISO or IEC standards, but the new EN standard for road lighting energy *EN 13201-5:2015* (CEN 2015) has adopted this term. The authors have therefore used “energy performance” in this report. Consideration of the adoption of updated terminology in future will be required across a range of AS, NZS and AS/NZS energy related standards.

4.1.2 International Electrotechnical Commission (IEC)

The IEC Technical Committee for lighting *TC-34 Lamps and Related Equipment* has (November 2014) created a new Subcommittee *IEC SC-34E Lighting Systems*. This group will work on standards for the application, integration and interoperability of the elements that comprise a lighting system as well as energy performance metrics and methodologies. The group responsibilities include ICT and data communication protocols for smart homes, smart commercial buildings and smart cities. Lighting control systems and road lighting Central Management Systems (CMS) and related infrastructure will be included, thus assisting the practical application of more sophisticated energy management techniques.

4.1.3 American National Standards Institute (ANSI)

The American National Standards Institute is active in the form of Committee *ANSI ASC C137 Lighting Systems* and is currently formulating lighting energy standards under two Working Groups:

- Energy Measurement for Lighting Systems
- Energy Performance Prediction for Lighting Systems

Currently the extent of integration that will be achieved between ANSI and IEC standards is unclear.

4.2 Australia New Zealand: Luminaire Standard AS/NZS 60598.2.3:2015

The AS/NZS road lighting luminaire standard is currently under review and publication of a new standard is imminent. The proposed new standard, *AS/NZS 60598.2.3:2015, Luminaires-Part 2.3: Particular requirements—Luminaires for road and street lighting* has been developed by Standards

Australia committee *EL-041 Lamps and Related Equipment* and was issued for Public Comment as a Modified Text Adoption (of the IEC standard) on 18 March 2015. This standard is likely to be published in September 2015. This will replace the historic standard *AS/NZS1158.6:2010 Lighting for Roads and Public Spaces Part 6: Luminaires* which does not permit the use of LED luminaires. This new standard is normative and is a minimally modified text adoption of IEC 60598-2-3, Ed.3.1 (2011)⁹.

This IEC standard is an outcome-based safety standard and, unlike the standard it replaced, does not prescribe methods of technical construction. This standard is intended to be used in conjunction with the foundation luminaire safety standard *AS/NZS 60598.1: Luminaires - General requirements and tests*. There are no specific energy efficiency aspects to the new road lighting luminaire standard. The removal of prescriptive requirements and regional orientation from the previous AS/NZS luminaire standard is likely to allow greater international competition for the supply of luminaires in Australia and New Zealand including those which were “not permitted” under AS/NZS1158.6.

4.2.1 Luminaire Technical Specification SA/SNZ TS 1158.6:2015

The Technical Specification *SA/SNZ TS 1158.6:2015 Luminaires—Performance* has been prepared by the Joint Standards Australia/Standards New Zealand Committee LG-002, *Lighting for Roads and Public Spaces* to supplement *AS/NZS 60598.2.3 Luminaires, Part 2.3: Particular requirements—Luminaires for road and street lighting*. Note that the term “SA/SNZ TS” differentiates this “Technical Specification” from a normative Standard. *SA/SNZ TS 1158.6:2015* is likely to be published in September 2015.

Energy performance criteria are now included, in the form of a Luminaire Efficacy Rating (LER). This is based on the recommendations in the Light Naturally Report: “*Energy efficiency performance requirements for road lighting designs and luminaires*” released in August 2014.

The LER criteria excerpted from the January 2015 version of the draft Technical Specification (*SA/SNZ TS 1158.6:2015*) are provided below:

5.9 MINIMUM LUMINAIRE EFFICACY RATING

5.9.1 Luminaire efficacy rating (LER)

Luminaires shall have a $LER \geq 40 + (0.001 \times \Phi)$, where Φ is the total initial luminaire luminous flux.

To calculate the LER for a specific luminaire the total initial luminaire luminous flux is divided by the total luminaire power input.

5.9.2 HID Example calculation

For example an HID luminaire with light source lumen output of 10,000 lumens, a light output ratio of 0.70 has total initial luminaire luminous flux of 7000 lm (i.e. $10,000 \times 0.70$). The total luminaire power input is 18 W, and the LER is calculated as follows:

$$LER = 10,000 \times 0.70 / 180 = 3 \text{ lm/W}$$

⁹ Refer Standards Australia Public Statement 19 March 2015

Based on the above example the minimum allowed LER for this HID luminaire, is calculated as follows:

$$4 \quad (0.001 \times 10,000 \times 0.70) \quad 4 \text{ lm/W}$$

Taking into account this example, the above luminaire would not meet the minimum energy performance requirement.

5.9.3 SSL Example calculation

For example an SSL luminaire with a luminaire output of 2,000 lumens, and total wattage 22W, has a calculated LER as follows:

$$\text{LER} = 2,000/22 = 91 \text{ lm/W}$$

Based on the above example the minimum LER for this SSL luminaire is calculated as follows:

$$4 \quad (0.001 \times 2,000) \quad 4 \text{ lm/W}$$

Taking into account this example, the above luminaire would comply with the minimum energy performance requirement.

Note: The LER shall be rounded to be a whole number.

The Technical Specification was signed-off by the LG-002 committee for publication on Feb 5 2015 and has been circulated for Public Comment by Standards Australia. The LER provisions in the Technical Specification provide the initial input to the Design Classification approach.

4.2.2 AS/NZS Lighting Design Standards

The seven part series of standards AS/NZS1158 incorporates lighting design standards AS/NZS 1158.1.1:2005 Part1.1 Vehicular traffic (Category V) lighting-Performance and design requirements that is based on luminance (reflected light from the road surface), and AS/NZS 1158.3.1:2005 Part3.1:Pedestrian area (Category P) lighting- Performance and design requirements that are based on illuminance (delivered light to the road/path surface and relevant vertical planes). These two standards have recently been through an update process to correct some anomalies and to align with the updated (IEC based) luminaire standard. More significantly there are Luminaire Efficacy Rating (LER) additions from the recommendations of the Light Naturally Report - "Energy efficiency performance requirements for road lighting designs and luminaires"- Final Report August 2014. These LER requirements mirror the approach as identified above in the Luminaire Technical Specification SA/SNZ T 1158.6:2015. The Public Comment period for the two Standards AS/NZS 1158 Parts 1.1 and 3.1 closed on 2 February 2015 and they are expected to be published in September 2015.

The current update is a precursor to a more fundamental design and application review of both standards currently underway that will include the evaluation of the impacts of LED lighting and adaptive lighting techniques. The photometric characteristics of LED optics are very different to those of traditional light sources and previous assumptions and expectations regarding light distribution (ie beam cut-off, beam irregularities etc) are no longer necessarily valid. Adaptation of the design standards to better accommodate and exploit the characteristics including energy performance potential of LED optics is necessary.

The standard AS/NZS 1158.2:2005 Computer procedures for the calculation of light technical parameters of Category V and Category P lighting is also under review to better align with international norms. In future it is likely that this part of the standard series may incorporate calculation methods and software data formats for energy performance parameters

4.2.3 The New EN Standard on Energy Performance Indicators (FprEN13201-5:2015) – Updates and Advancements

The 201 version of draft European Standard prEN13201-5 is discussed and analysed extensively in the Light Naturally (LN) consultants report (August 2014) and recommended as platform for Australia and New Zealand adoption in conjunction with an adapted version of the Netherlands implementation approach. The principles and most of the details of the LN recommendations are very much endorsed by SLP as suitable approach for Australia and New Zealand.

However, the 2013 draft was not approved for publication by the Technical Committee CEN/TC 169 and has been superseded by a March 2015 Final Draft *FprEN2015-5:2015 Energy Performance Indicators* which modifies key metrics and calculation methodologies and extends the scope and detail of control system application and performance quantification. The 2015 version is assessed in detail Section 5 of this report.

4.3 NZTA M30 Specification and Guidelines for Road Lighting Design

In August 201 The New Zealand Transport Agency (NZTA) introduced specification for road lighting design and application for New Zealand, *NZTA M30 Specification and Guidelines for Road Lighting Design*. This provides guidance and requirements to councils and related parties on the design and application of lighting schemes using advanced technology LED luminaires and control systems. This specification includes energy performance criteria for Category V and Category P roads in the form of maximum power density limits for Category V and minimum column spacing requirements for Category P. The use of column spacing tables to communicate the requirements are to maintain alignment with the previous NZ Energy Efficiency and Conservation Authority (EECA) “Rightlight” road lighting energy programme.

These two guidelines are very significant for New Zealand councils as approximately 50% of all road lighting funding comes from central government sources in the form of subsidies from the NZTA National Land Transport Fund, thus rendering NZTA M30 specification criteria effectively mandatory requirements for council funding eligibility.

The energy performance requirements use static lighting power density metrics and methodologies. For reference and benchmarking purposes the sample lighting schemes in this report have been assessed for compliance with the NZTA M30 energy performance requirements the analysis shows that a proposed AS/NZS Star Rating approach would interact appropriately with the New Zealand NZTA M30 specification energy performance limits discussed in Section 6.

5 Review of EN Standard - Energy Performance Indicators

5.1 Introduction

Technical Committee CEN/TC 16 of the European Committee for Normalisation (CEN) has been working since before 2006 on a standard covering road lighting energy performance. This has been through a series of iterations with a final draft version circulated for committee vote as at March 2015. Consecutive draft versions have contained notable differences in the terminology of the title. These are listed below:

- prEN 13201-5:2007 Energy Efficiency Requirements
- prEN 13201-5:2013 Energy Performance Indicators
- Final FprEN 13201-5:2015 Energy Performance Indicators

Note that the “pr” prefix indicates that the standard is a provisional draft for consultation, the “F” prefix indicates this is the final draft for consultation and when no prefixes exist, the name will refer to the published standard. The published standard will therefore become “EN 13201-5:2015 Energy Performance Indicators”

As at July 2015 new European road lighting energy performance standard “*EN13201-5 Road lighting - Part 5: Energy performance indicators*” is under the final stages of development and is likely to have a significant impact on the AS/NZS1158 series of standards in future. The expected publication date of this EN standard is mid to late 2015 and has the following parts:

- Part 1: Guidelines on the selection of lighting classes (Not a standard. Informative only)
- Part 2: Performance requirements
- Part 3: Calculation of performance
- Part 4: Methods of measuring lighting performance
- Part 5: Energy performance indicators

The Light Naturally Report of August 2015 reviewed the 2015 version. As previously mentioned this report extends the review to encompass the 2015 final draft version.

5.2 Summary

The purpose of EN13201-5 is to define energy performance indicators for road lighting schemes. The standard designates two output based performance metrics:

- Power Density Indicator (PDI) in $W/lx/m^2$
- Annual Energy Consumption Indicator (AECI) in $kWh/m^2/yr$

To determine potential savings from improved energy performance it is essential to calculate both the PDI and the AECI. The PDI calculates the basic power density of the scheme at full operational profile and the AECI then assesses the outcomes of operational variations of light levels and time schedules.

AECI can be used for comparing the energy performance values of alternative road lighting schemes. The 2015 FprEN13201-5 version proposed, incorporates more advanced assessment methodologies

than its previous versions for the quantification of the energy performance of different approaches to adaptive lighting techniques with control systems. Such controls can deliver the following functionality:

- Elimination of excessive luminous flux and consequent excessive energy use over life by the application of gradual power compensation for light source age degradation;
- Elimination of excessive luminous flux and consequent excessive energy use over life by the selection of the exact luminous flux values required;
- Selection of variable lighting levels on a nightly or seasonal cycle basis to reflect the lighting requirements of varying pedestrian or vehicle usage patterns;

The proposed EN13201-5 standard also defines limits on specifying excessive lighting levels. This states that the calculated lighting level for a scheme should not exceed the required lighting level of the next higher lighting sub-category, or not exceed the required lighting level by more than 50% in the case of the highest sub-category. This is a very useful method of limiting the selection of excessive light levels by a lighting designer. This is a tendency sometimes exhibited by less experienced lighting designers as a means of ensuring compliance, but this approach results in a needless waste of energy over the whole life of the lighting scheme.

5.3 Terms and Definitions

The AS/NZS1158 standards series uses different terminology to that used in the final proposed European EN13201 series. Where such differences occur, This SLP report replaces the EN terminology with accepted AS/NZS terminology unless directly referencing the EN documents. The two main terms that are different are:

- Lighting class (EN) = Lighting subcategory (AS/NZS)
- Lighting installation (EN) = Lighting scheme (AS/NZS)

In addition to energy performance indicators PDI and AECl, the EN standard introduces new adaptive lighting control concepts:

- Constant Light Output (CLO)
- Detection Probability (DP)
- Lighting Reduction Coefficient (LRC)

With the emergence of outdoor lighting control systems over the last 10-15 years a range of new concepts, terms and definitions have arisen. Many of these terms have been proprietary in origin or have been unique to particular organisation and/or country. The historically poor harmonisation of terminology has created significant confusion and misunderstanding in the market. The final provisional version of EN13201-5:2015 provides an influential focal point for the harmonisation of adaptive lighting and control system terminology and usage for Australia and New Zealand.

5.4 Power Density Indicator (PDI)

This is the system power divided by the product of the surface area to be lit and the calculated maintained average illuminance on this area in $W/lx/m^2$.

To calculate the PDI for a significant road area the total area is divided into sub-areas for each given state of operation. If the required lighting subcategory changes during the nightly or seasonal cycle the PDI should be calculated separately for each of the subcategories. Alternatively, where multiple lighting subcategories are used the PDI may be calculated as an average over this period. The calculation documentation must state the input assumptions used.

5.4.1 Average horizontal illuminance for the calculation of PDI

For Category roads that are illuminance based, the calculated maintained average horizontal illuminance for the selected sub-category is used for the PDI calculation.

In the case of designing lighting for Category V roads that are predominantly for vehicular traffic, the reflectance of light off the surface of the road is the critical factor. This is luminance, which is determined by the luminaire photometrics and luminous flux, column and road geometry and road surface reflectivity. Road lighting standards worldwide specify luminance as the required metric for vehicular road lighting but as this is not useful for establishing energy performance, conversion back to illuminance is required to determine energy performance. In order to do that practically, a conversion factor is used called the Installation Lighting factor (ILF) which is described in Section 5.4.4 below.

5.4.2 System Power for the calculation of PDI

This is the total power of the road lighting scheme including control equipment (unit: W). The System Power is the sum of the power of equipment directly associated with the lighting scheme and includes:

- Light sources
- Control gear
- Light point control units
- Photoelectric cells

Plus an apportionment of the power of any centralised equipment indirectly associated with the lighting scheme such as:

- Remote photoelectric cells
- Centralised luminous flux controllers
- Centralised management systems

The PDI can be single value for full-time constant power operation or, with lighting schemes that have control systems, it can have different values for each different state of operation.

Constant Light Output (CLO) functionality is the programmed increase of power over time to a luminaire in order to compensate for the light loss from the ageing of the light source so that a constant light level is delivered over lifetime. To calculate PDI for lighting schemes with CLO controls, the average system power associated with these variations is used.

5.4.3 Area for the calculation of PDI

The area used for the calculation of PDI is the same as the area that the lighting designer used in the lighting design calculation (i.e. the product of roadway design width and luminaire spacing). For AS/NZS1158 Category P application this is the Road Reserve Width (ie LHS property boundary to RHS property boundary including roadway, paths berms etc) and for Category V application this is the road carriageway lighting design width (ie the roadway only).

5.4.4 Installation Lighting Factor (ILF)

ILF is a normalising factor (dimensionless) relating the calculated average maintained luminance of the road surface over the calculated average maintained horizontal illuminance on this surface and the average luminance coefficient of the r-table adopted in the luminance calculation. ILF characterises the energy performances of road lighting schemes independently of the lighting equipment used for its actual delivery and permits an easy comparison of the efficiency of different types of lighting schemes. Note that Australian and New Zealand r-table values for the average luminous coefficient Q are different. The luminous coefficient Q value for Australia is 0.07 and for New Zealand is 0.09. The New Zealand value is currently under review following Jackett and Frith 200 research findings (published by the NZTA as Research Report 383).

5.5 Annual Energy Consumption Indicator (AECI)

AECI is the total electrical energy consumed by a lighting scheme (day and night) over a specific year divided by the total area to be illuminated by the lighting scheme (unit: kWh/m²/yr).

The annual electricity consumption of a road lighting scheme therefore depends on the:

- period of time that lighting is provided;
- lighting sub-category for each lighting period ;
- efficiency of the lighting scheme; way the lighting management system adapts to changing needs; parasitic energy consumption of lighting or control equipment;

Actual lighting needs may vary during the year for the following reasons:

- seasonal variations of daylight/night time hours;
- changing weather conditions and perceived visual performance;
- changing traffic density during the nightly or annual cycle;
- changing functional requirements of the road area;

For lighting schemes with Constant Light Output (CLO) controls, the average power consumption over the planned lifetime is included in the AECI calculation. Calculation documentation should clearly indicate the assumptions used for determining the average power consumption. Lighting control operational profile(s) applied to the lighting scheme need to take into account the factors above for each of the operational states as well the probability of presence sensor actuation where applicable.

The AECI metric and methodology is similar in principle to the well-known European commercial building interior lighting metric and methodology LENI, the Lighting Energy Numeric Indicator. This is defined in the European standard *EN 15193: 200 Energy performance of buildings — Energy*

requirements for lighting and specifies the calculation methodology for lighting energy performance for formal European certification purposes for commercial buildings. Its underlying premise is for the designer to use adaptive control technology to provide - “the right light, at the right place, at the right time”. EN15193 incorporates dynamic measures in the form of occupancy factors, constant illuminance factors and “algorithmic lighting control” where illumination is controlled by computer software according to a variety of inputs.

5.5.1 Australia

With most street lighting in Australia being owned and maintained by the regulated monopoly electricity utilities (known as Distribution Network Service Providers, or DNSPs) a relevant issue is how the AECI metric relates to the framework for road lighting electricity consumption, measurement and billing.

Unmetered Road Lighting

The Australian Energy Market Operator (AEMO) manages metering rules through a highly structured electrical and financial methodology for unmetered electricity billing. Currently most road lighting is unmetered but that may change as control systems are progressively introduced. In order to ensure unmetered road lighting is fairly billed, AEMO maintains a table of currently used road luminaires and ancillary equipment that have independently verified energy use characteristics. Both Councils and DNSPs then multiply their inventory of lights by the energy use (in kW) according to AEMO product tables and also by the time switched on (hrs), and finally by the tariff (\$/kWhr) to come up with a cost (\$) invoiced for electricity used.

Thus for unmetered road lighting the AECI calculations should simply use the official AEMO product load table wattage figures so that AEMO product energy loads and energy use will be in harmony with the AECI metric. It will be important to ensure that the AEMO tables are current and contain the many new luminaire products coming on the market. For example, currently AEMO has accepted only one CLO control technology product onto the unmetered load tables.

Metered Road Lighting

With increasing use of control systems able to control and monitor individual luminaires, these systems allow the electricity used for road lighting to be fully metered. AEMO, like its counterparts worldwide, are considering the consequences of these developments. SLP understand that suppliers are in discussion with AEMO under their “innovation” rules about accepting control systems that have a metering chip within in a smart luminaire controller which can act as a meter allowing each luminaire to be recognised as a metered account and hence get proper credit for all dynamic loads and the consequent energy use abatement.

5.5.2 New Zealand

In New Zealand virtually all road lighting is owned by Councils or the NZ transport Agency. The NZ equivalent organisation of the AEMO is the Electricity Authority (EA) that similarly has responsibility for electricity billing but does not publish tables of lighting products with power specifications because road lighting is virtually unregulated in NZ. Road lighting energy use is left to the owners to manage. Therefore the calculation of AECI will benefit New Zealand without any regulatory consequences.

5.6 Operational Profiles

5.6.1 General

Operational profiles depicted in the scenarios below have large impact on the energy consumption of a lighting scheme. Control systems that dim and brighten have can deliver substantial energy savings. For the calculation of AECI it is necessary to sum the daily operating hours for each of the lighting levels through an annual (i.e. seasonal) cycle.

The relationship between lighting levels and luminaire power levels is equipment specific. In the case of HID and FL luminaires there is usually a significant gap of about 20-30% between programmed dimmed lighting level and the corresponding luminaire power. For example, reducing illumination by 50% might only save 30% in power. On the other hand, LED luminaires do not behave this way and the proportion reduced in lighting levels virtually correspond to the same power reduction (NEMA 2015). In both cases it is desirable that this relationship be verified by an initial one-off calibration of the system by means of light level vs power level tests for the combination of the particular luminaire and control equipment components concerned.

5.6.2 Full-power operation profile

This 100% power profile applies to lighting schemes with simple on-off switching devices such as photocells. Luminaires operate continuously at full power throughout the nightly cycle.

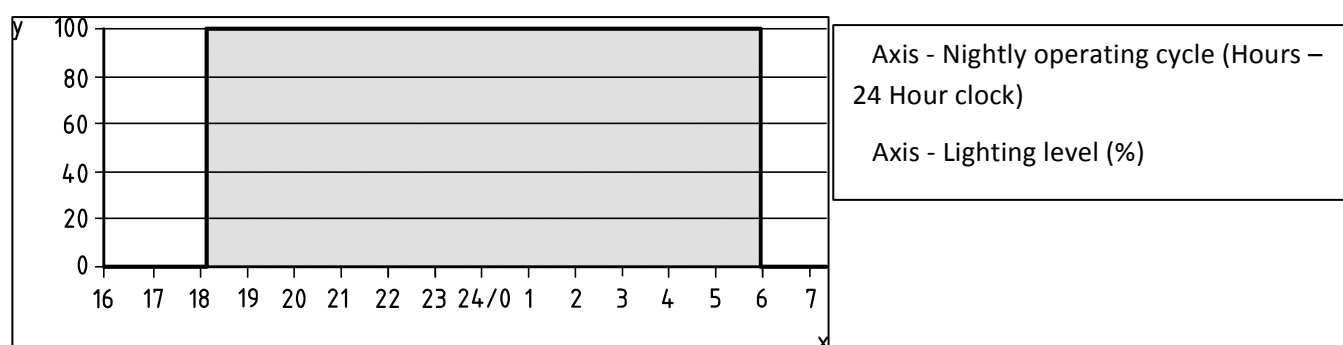


Figure 2 Full Power Operational profile

5.6.3 Multi-power operation profile

This multi-power (or in the case of Figure 3 below, “bi-power”) profile consists of two or more time periods during the nightly cycle where luminaires are operated at the different power levels associated with the different lighting levels delivered through the use of control system. Each of the lighting levels should be as per lighting design standard subcategory.

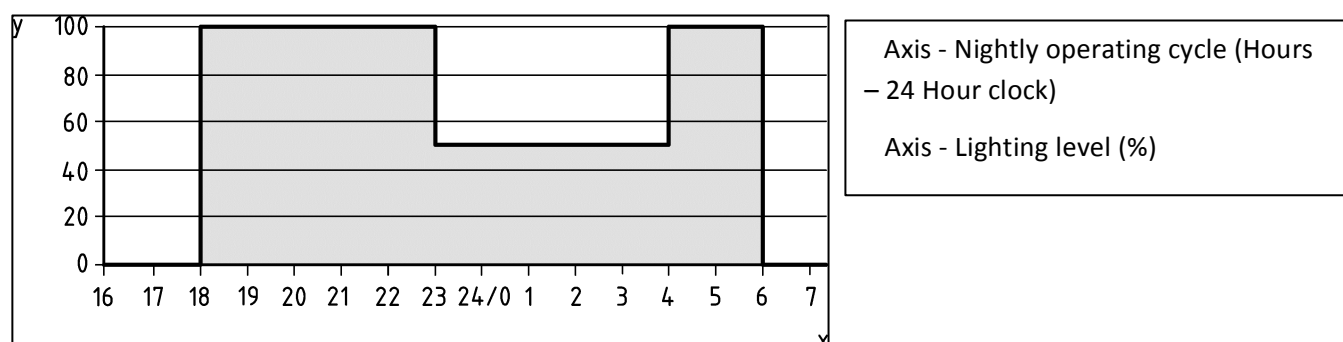


Figure 3 Multi-power operation profile

5.6.4 Presence sensor operation profile

When pedestrian or vehicular presence sensors are used as part of a lighting control system, the operational profile is minimised during the time periods when no activity is sensed and the luminaires operate at reduced lighting and power levels. The example in Figure 4 below shows a three-level profile (Tri-power) for lighting control with sensors where a minimum lighting level is maintained throughout the nightly cycle but the lighting level is raised by sensor actuation. The timing and duration of the peaks are dependent on actually occurring site usage activity. For the calculation of AECI it is necessary to define Detection Probability (DP) for each of the lighting levels. DP is a subjective probability (percent) of the likelihood of detection occurring during that phase, and the light level rising to the upper light level limit for the period in question.

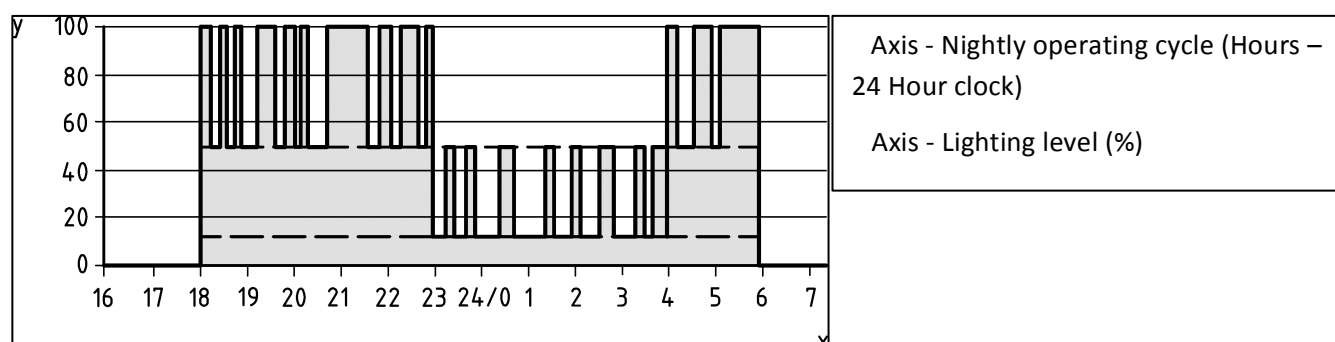


Figure 4 Presence sensor operation profile

5.7 Values of Energy Performance Indicators

5.7.1 General

The lower the value of PDI and AECI, the better the energy performance. The values of PDI and AECI will depend on many factors e.g. selected lighting subcategory, lighting column arrangement, road width, type of light source, luminaire optical performance etc. For AECI, the nature of the switching and control operational profiles will have significant influence.

possible negative factor to consider is the potential for misuse of Star Rating system by the manipulation of control system programming to generate high initial rating. This could occur in several ways –

- a) By the use of overly aggressive adaptive control profiles that reduce light levels either too deeply or for too long or a combination of both of these factors. This could cause citizen displeasure and/or expose a council to risk of liability issues resulting from abandonment of their duty of care. Or;
- b) The relaxation of adaptive control programmable parameters by operational staff after the design and installation of the lighting scheme (and the star rating applied) has occurred. Once “over the hurdle” of achieving a star rating it is easy to reduce the stringency of the operational profile and degrade the energy performance achieved. If Star Rating target was a requirement of a subsidy/funding/incentive scheme, or similar, then a periodic performance review or audit would be required. This could be readily and remotely carried out at very low cost by means of the inherent data-logging and reporting capabilities of CMS control software.

5.7.2 Values of AECI and the Lighting Reduction Coefficient (LRC)

The basic AECI calculation applies to a full power operational profile (i.e. 100% power) with annual operation time at all hours of darkness. To consider different operational profiles, it is necessary to combine the annual operation times of individual lighting levels with the related system power and the Detection Probability factor (in schemes with sensors) into a single Lighting Reduction Coefficient (LRC). This is a percentage (i.e. less than 100%) that represents the power use (reduced) under the designated combined operational states. The LRC can be used to multiply the full-power AECI value to obtain the reduced value of AECI for the actual operational profile concerned.

5.8 Presentation of Energy Performance Indicators

The two energy performance indicators – Power Density Indicator (PDI) and Annual Energy Consumption Indicator (AECI) are complementary parameters and they should be always presented together to properly describe “energy performance”. All assumptions used in the calculation of energy performance indicators should also be displayed clearly alongside the indicators. For more sophisticated control approaches graphical depiction of the operational profiles can be an effective means of presentation. The parameters below depicts suggested information to be presented (spread sheet format) together with the Energy Performance Indicators:

System Power – For each luminaire used

- Operational Power (OP) (W)
- Additional Power (AP) (W)

Illuminated Area – For each designated sub-area

- Area lit (m^2)
- Calculated illuminance (lx) (luminance based designs included)

Operational Profile – For each period

- Annual operating hours (h)
- Lighting Reduction Coefficient (LRC) (%)
- Detection Probability (DP) (%)

Energy Performance Indicators

- Power Density Indicator (PDI) (W/lx/m^2) For each period
- Annual Energy Consumption Indicator (AECI) ($\text{kWh/m}^2/\text{yr}$) For total lighting scheme

5.9 Implications for Australia and New Zealand

The 2011 version of this standard introduces the new descriptors and metrics PDI and AECI. These accommodate calculation processes for more sophisticated control techniques than earlier versions and quantify the energy performance outcomes of the use of controls. These updates should be incorporated into forthcoming AS/NZS standards updates as per the recommendations in the Light Naturally 2014 Report.

6 Assessment of Representative Design Solutions

6.1 Lighting Design Data

SLP has undertaken a road lighting design data harvesting process across various States and Territories of Australia and in New Zealand. A range of public and private sector organisations that undertake road lighting design were approached with a request to act as a data donor for this project. Relevant members of Standards Australia LG-002 Committee *Lighting for Roads and Public Spaces* who have access to design data were approached in the first instance to act as data donors, with other parties known to be active in road lighting design approached as additional sources. Nine data donor organisations were secured resulting in total of 83 eligible designs

For details of the request, see Appendix 1 - *Data Donor Notes* and Appendix - *DSD - Road Lighting Design Classification System - Data Capture Matrix*. This spread sheet lists the various factors required to undertake a road lighting energy performance assessment. Some factors are essential, and others are ancillary supportive information used to clarify some key points that may affect the energy performance outcomes.

The objective was to capture representative sample of actual lighting designs for projects that have been installed within the last ten years. These have been assessed within the framework of the European Union standard prEN 13201-5:2013 as implemented by the Netherlands and the energy performance of the actual Australia New Zealand designs have been rated by the Road Lighting Efficiency (RLE) Star Rating scheme as proposed in the Light Naturally report. Additionally, calculation of the PDI and AECI metrics has been undertaken for reference in accordance with the 2011 Final Draft prEN 13201-5:2015.

After filtering out submitted projects that were technically unsuitable for this study total of 83 road lighting designs have been captured from nine different data donor organisations. The designs cover the states and territories of NSW, VIC, QLD, SA, NT, WA, and NZ.

The donors are -

- Main Roads Western Australia - WA
- Queensland Department of Transport and Main Roads - QLD
- Odyssey Energy Ltd - NZ
- Gerard Professional Solutions Pty Ltd - NSW, VIC, QLD, NT
- AECOM - Citelum Australia - QLD
- Advanced Lighting Technologies NZ Ltd - NZ
- Betacom Ltd - NZ
- SA Power Networks - South Australia
- Ausgrid - NSW

Some data gaps are evident as some states are under-represented and some AS/NZS1158 lighting sub-categories are sparsely populated. The most commonly used sub-categories of V3 and P4 are very well represented and provide a strong basis for drawing conclusions. For the purposes of this

study this is a practical data set that is reasonable and representative sample of the actual design characteristics of common applications in the Australia New Zealand region, with the exception of sub-category P5. The scarcity of data on sub-category P5 is cause for concern as this is the commonly used sub-category for low traffic flow residential road lighting mounted on existing overhead lines power poles. It may therefore be useful to revisit the data capture process with a focus on additional data donors who are more active on sub-category P5 applications.

This study is a practical data capture and data analysis project intended as input to expert group debate. It does not purport to have the data capture sampling spread or rigour of statistical analysis that would normally be expected of (for example) an academic study.

6.2 Lighting Design Data Analysis

The following description of the parameters and calculations apply to Appendix 3 Spread sheet - *DSD - Design Data Analysis*.

This spread sheet takes the raw data as provided by the data donors and sorts this into AS/NZS1158 lighting sub-categories for ease of comparative evaluation. Columns 14-23 have been added to the original data capture spread sheet to enable various energy related calculations to be undertaken. Their function is explained below -

a) Column 14 - P Cell Parasitical Losses

This accommodates the calculation of parasitic energy losses from the photocell if incorporated in the luminaire. The figure of 0.25W is nominally inserted as a holding wattage. Most modern P cells are less than 0.25W, but this figure is a suitable proxy unless the exact PE cell specification is known. The methodology allows for Watts losses during the hours of luminaire operation. Note that this factor could also accommodate the parasitical power impacts of a CMS control system, if applicable.

Column 15 - Control Gear Losses

This allows for the inclusion of control gear Watts losses. In the case of LED luminaires this is already included in the luminaire wattage, but is usually not for traditional HID or FL luminaires. The Watt losses may be taken from AEMO load tables or from control gear manufacturer's data. The data in this report is from a combination of both of these sources, according to data availability, in order to cover the various options.

Column 16 - Total Luminaire Wattage including Control Gear and PE Cell

This is the combination of light source wattage, control gear wattage and PE cell wattage, if applicable.

Column 17 - Lighting Power Density W/m^2

This is the traditional non-dynamic energy performance metric. Total luminaire wattage divided by the lit area under assessment. This is now considered to be very limited metric in that it does not incorporate quantification of any of the performance contributions of smart controls or adaptive lighting techniques. It is included here for reference only, as part of the calculation pathway to more sophisticated performance indicators.

Column 18 - AS/NZS1158 Subcategory light level requirement, lx or cd/m^2

This column simply excerpts the average light level value (lx or cd/m² depending on lighting application) from AS/NZS1158.3.1 and AS/NZS1158.1.1 for a given lighting category to allow the RLE numerical metric to be calculated based on the requirements of that lighting category.

Column 19 - Road Lighting Efficiency Parameter (Luminance based schemes)

The Road Lighting Efficiency Parameter is the calculated result in W/(cd/m²)/m² of the proposed ANZ adapted Netherlands model. The lower the RLE number the better the energy performance.

Column 20 – Road Lighting Efficiency Parameter (illuminance based schemes)

The Road Lighting Efficiency Parameter is the calculated result in W/lx/m² of the proposed ANZ adapted Netherlands model. The lower the RLE number the better the energy performance.

Column 21 - RLE Star Rating

The Road Lighting Efficiency Star Rating is allocated (manually in this spread sheet) based on the RLE number achieved and allocated to the performance level bracket as per the Netherlands model. The higher the Star Rating (0 to 7 Stars) the better the energy performance.

Column 22 – Power Density Indicator (PDI) W/lx/m²

The Power Density Indicator (PDI) as described in the New EN Standard on Energy Performance Indicators quantifies lighting scheme power density for a given state of operation. The basic methodology is the same as that of the Road Lighting Efficiency (RLE) parameter (columns 19 and 20). The lower the PDI figure the better the energy performance. This metric only accommodates illuminance based calculation inputs. For luminance based application, the lighting designer separately needs to calculate the average illuminance level that would be achieved when delivering the criteria required for luminance compliance. Applying this calculation to the 83 designs is outside the scope of this report as it would require the input of additional design parameters and design from the original lighting designers. This column is noted as Not Applicable (N/A) for Category V schemes No. 1-48.

Column 23 – Annual Energy Consumption Indicator (AECI) kWh/m²/yr

The Annual Energy Consumption Indicator (AECI) as described in the new proposed EN Standard on Energy Performance Indicators quantifies the total energy performance attributes of a lighting scheme including the use of various types of adaptive lighting control systems. The methodology was updated in 2015 (over 2013) to accommodate the various advanced control techniques now possible. The lower the AECI figure the better the energy performance.

6.3 Performance Outcomes

Appendix 3 Spreadsheet - *DSD - Design Data Analysis* contains the eighty-three design scenario inputs, the Road Lighting Energy Performance (RLE) calculations and RLE Star Rating conversions. The Star Ratings have been established via the cut-off limits (for both illuminance and luminance designs) as per the Netherlands application criteria.

For ease of interpretation the spread sheet in Appendix shows Star Ratings that are colour coded into three performance tiers as illustrated in the pie graph in :

- Green – 1, 2 and 3 Stars (21% of sample population)
- Yellow – 4, 5, 6 and 7 Stars (49% of sample population)

- Red – 2, and Stars (30% of sample population)

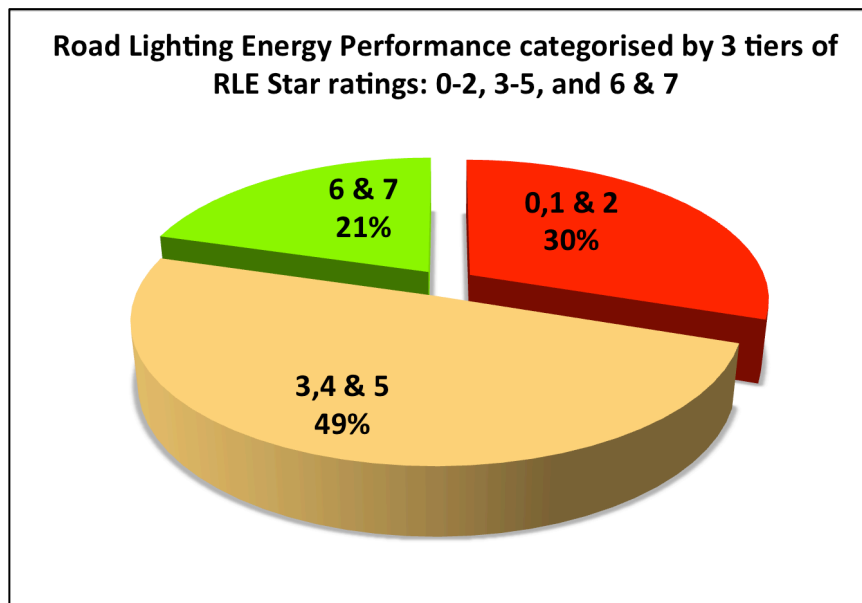


Figure 5 RLE Performance of designs categorised in three tiers

Analysis of the energy performances for the eighty-three designs are shown below in Table 2.

| Technology ↓ | RLE Star rating | | | | | | | |
|-----------------|-----------------|--------|---------|---------|---------|---------|---------|---------|
| | 0 Stars | 1 Star | 2 Stars | 3 Stars | 4 Stars | 5 Stars | 6 Stars | 7 Stars |
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| MV | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| HPS | 5 | 1 | 7 | 2 | 10 | 3 | 1 | 0 |
| T5 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| MH | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 |
| MHQ | 3 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| CFL | 1 | 1 | 2 | 3 | 0 | 0 | 0 | 0 |
| LED | 0 | 0 | 2 | 4 | 5 | 9 | 13 | 3 |
| Total | 11 | 2 | 12 | 10 | 18 | 13 | 14 | 3 |

Table 2 RLE Star Ratings by Technology

Figure 6 below shows the distribution of all 8 (7 plus zero) RLE star ratings across all 8 designs and is the same pie graph as above, but provides the full breakdown.

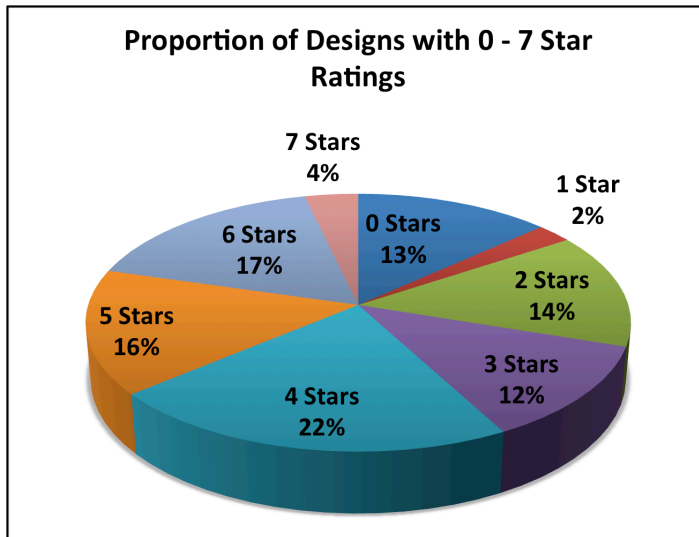


Figure 6 Proportion of 83 designs with Zero to 7 RLE Stars

The following graphs interpret Table 2 and the spread sheet in Appendix 3. Further graphs provide other useful interpretations from this wealth of information and can be seen in Appendix 4.

Figure 7 below shows the proportion of the 83 designs that use one of the technologies used by the 83 designs.

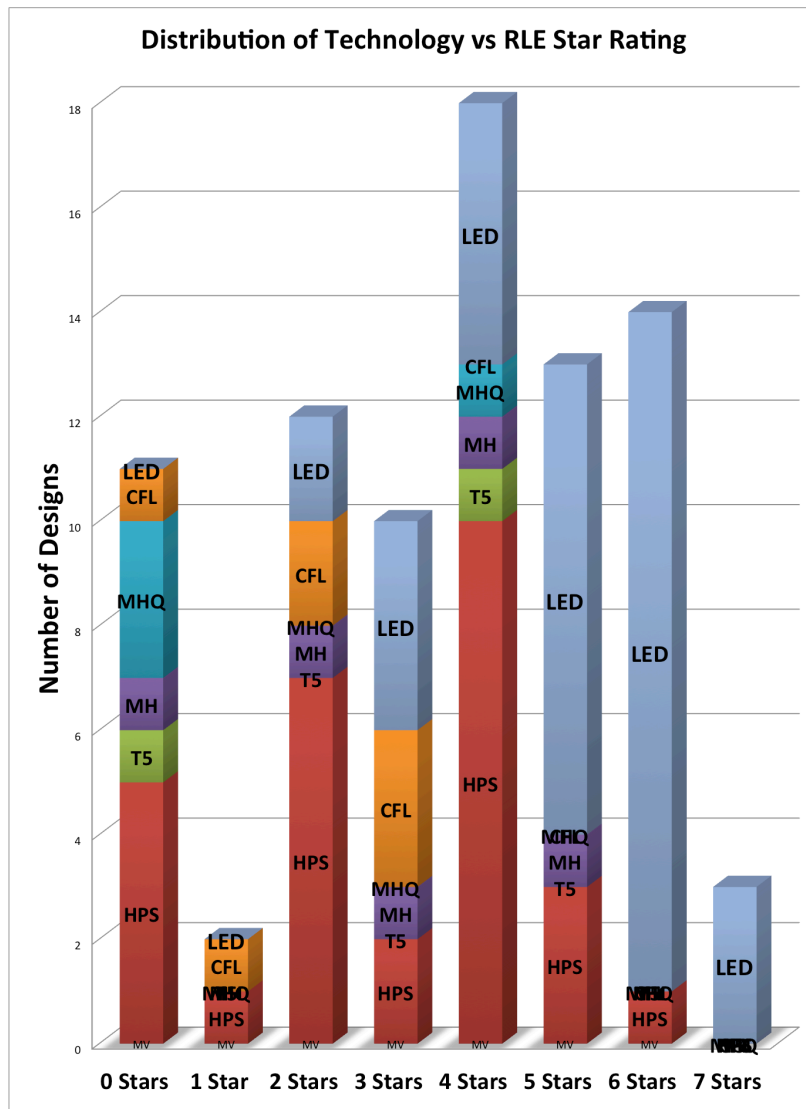


Figure 7 Technologies used in the 83 designs by Star Rating

Figure 8 below shows the distribution of the seven different technology types across each of the three tier groupings covered in the discussion section below.

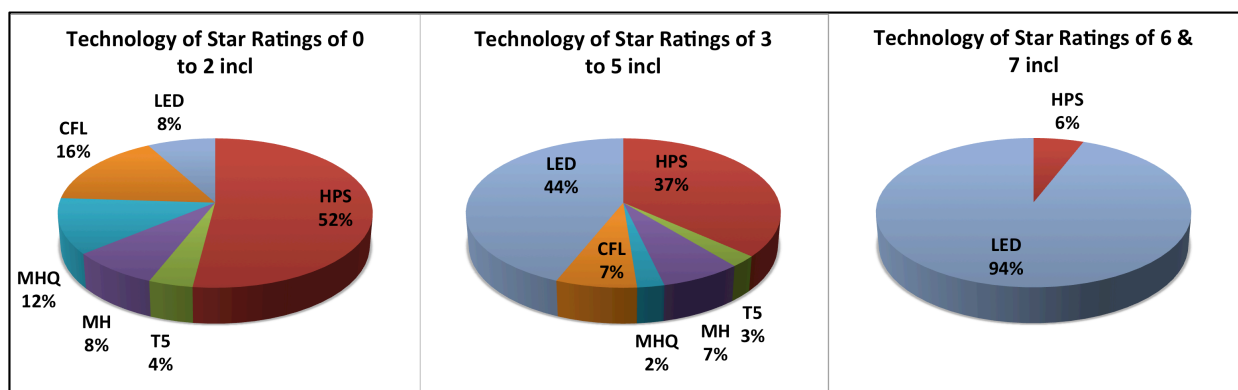


Figure 8 Technologies used in each of the 3 tier star groupings shown in Figure 6

6.4 Discussion

6.4.1 Performance Spread

Analysis of the results shows a very wide spread of performance outcomes with significant weighting towards the lower end of the Netherlands scale. As shown in Figure 5 the upper tier of 6 and 5 Stars is 21% of sample schemes, designs with 3, 4 and 5 Stars make up 49% of sample schemes and designs with zero, 1 or 2 stars make 30% of the sample schemes.

The range of performance for V Category lighting is:

- Best result – Scheme No.13, RLE = $0.1299 \text{ W}/(\text{cd}/\text{m}^2)/\text{m}^2$ 7 Star
- Worst result – Scheme No. 34, RLE = $1.3155 \text{ W}/(\text{cd}/\text{m}^2)/\text{m}^2$ 1 Star

Thus, for V Category the best performance result is 1 times better than the worst.

The range of performance for P Category lighting is:

- Best result – Scheme No. 49, RLE = $0.0093 \text{ W}/\text{lx}/\text{m}^2$, 7 Star
- Worst result – Scheme No. 82, RLE = $0.2561 \text{ W}/\text{lx}/\text{m}^2$, 0 Star

Thus, for P Category the best performance result is 2 times better than the worst.

The scheme design data does not provide any reason why there is such a broad spread of results. However, it is apparent that the combination of the best technology applied with the best design practice is delivering superior results and that the converse is also the case. LED is clearly a standout technology in the upper tiers, but it is also evident that the use of LED technology alone does not ensure high-level results.

Overall there is a significantly large percentage of low performing schemes. Of the eighty-three sample schemes, only ten (12%) are over five years old, so the overall result is from relatively current decision-making processes showing that in recent times a significant number of lower-performing schemes are being designed and installed in Australia and New Zealand.

6.4.2 Lighting Technology Mix

Analysis of the lighting energy performance shows distinct patterns of what the various technologies are achieving in the field. Figure 6, Figure 7 and Figure 8 show that unsurprisingly LED is the dominant light source in this high performance and 5 star rating tier, with a minor appearance of HPS mainly in Category 3 applications.

LED technology is a strong player at the higher levels but it is also clear that LED technology is capable of achieving low two star outcomes as seen in Figure 7. Whether this is because of inferior luminaire attributes or because of inappropriate design cannot be determined from the nature of the data captured.

HPS is the most common technology represented in the 3 and 4 star middle levels but also the most represented in zero stars.

Fluorescent technology (CFL and T5) is mostly represented in 3 star ratings with a highest rating of 4 Star for T5 and 3 Star for CFL.

Metal halide is capable of 3 and 4 Star performance mostly with ceramic metal halide technology. The metal halide lighting schemes evident in the zero star performance rating is mostly due to older quartz technology.

6.4.3 Effects of Overhead (OH) or Underground (UG) Power Supply

Figure 9 shows the distribution of the eighty-three sample schemes differentiated by whether the lighting was supplied by underground, overhead lines or a combination of both. Nineteen designs (23%) are serviced by overhead or a combination of overhead and underground) power supply lines. These schemes delivered notably lower performance levels in this evaluation process than those schemes with underground supply. Of the 19 overhead lines schemes one was a 6 star, 8 reached middle tier (3,4, and 5 stars) and 1 attained lower tier ranking with six of those 10 being zero star rated. Of the overhead schemes that attained middle tier or above all were LED.

significant constraint on overhead supply schemes is that line pole spacings are fixed and height and outreach arm dimensions have limited design flexibility. This combined with the fixed-step luminous flux output (ie 70W/150W/250W steps) and typically fixed light distribution of traditional light sources, allows little opportunity for the designer to vary parameters to optimise scheme energy performance.

The increase in LED applications are likely to reduce this performance gap between OH and UG schemes as LED luminaires generally have optical distribution options as well as a wide choice of luminous flux outputs, plus the ability to optimise drive currents to tailor the delivery of luminous flux, and thus energy use.

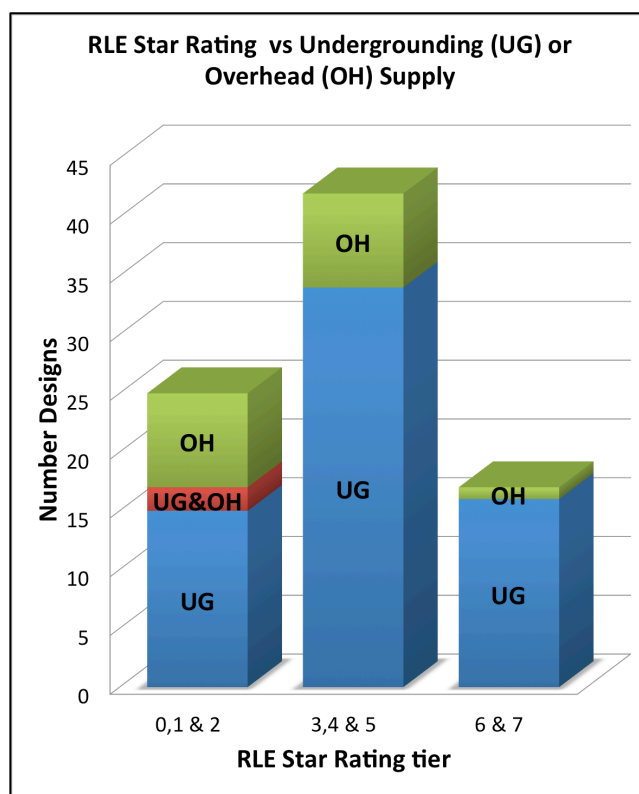


Figure 9 RLE Star Rating vs Overhead/Underground supply

6.4.4 Effects of Geographic Regions

Analysis by geographic region shows some distinct energy performance patterns.

For the regions that have provided reasonable sample sizes the results are:

- NSW: & star: 6%; 3,4 & star: 59%; 0, & star: 35%.

- QLD: & star: 14%; 3,4 & star: 64%; 0, 1 & 2 star: 22%.
- WA: & star: 0%; 3,4 & star: 60%; 0, & star: 40% (NB limited sample size).
- SA: & star: 0%; 3,4 & star: 45%; 0, & star: 55%.
- NZ: & star: 44%; 3,4 & star: 36%; 0, & star: 20%.

Noteworthy is the high performance of the NZ schemes. Whether this is representative of the region or not is unproven as the sample size and polling methods were not statistically intended for that purpose. Eighty percent of the NZ schemes submitted for this study were LED applications. It is evident that this technology can be applied under Australia and New Zealand conditions to deliver results that are significantly improved over previous technologies.

6.4.5 Effects of Lighting Categories

Analysis of the 83 designs according to AS/NZS1158 lighting categories is illustrated in Figure 10 and Figure 11 which show that category V schemes have higher performance:

- Category V: & star: 21%; 3,4 & star: 54%, 0, & star: 25%.
- Category P: & star: 19%; 3,4 & star: 44%, 0, & star: 36%.

possible explanation is the use of fluorescent technology exclusively in the lower luminous flux Category P sector.

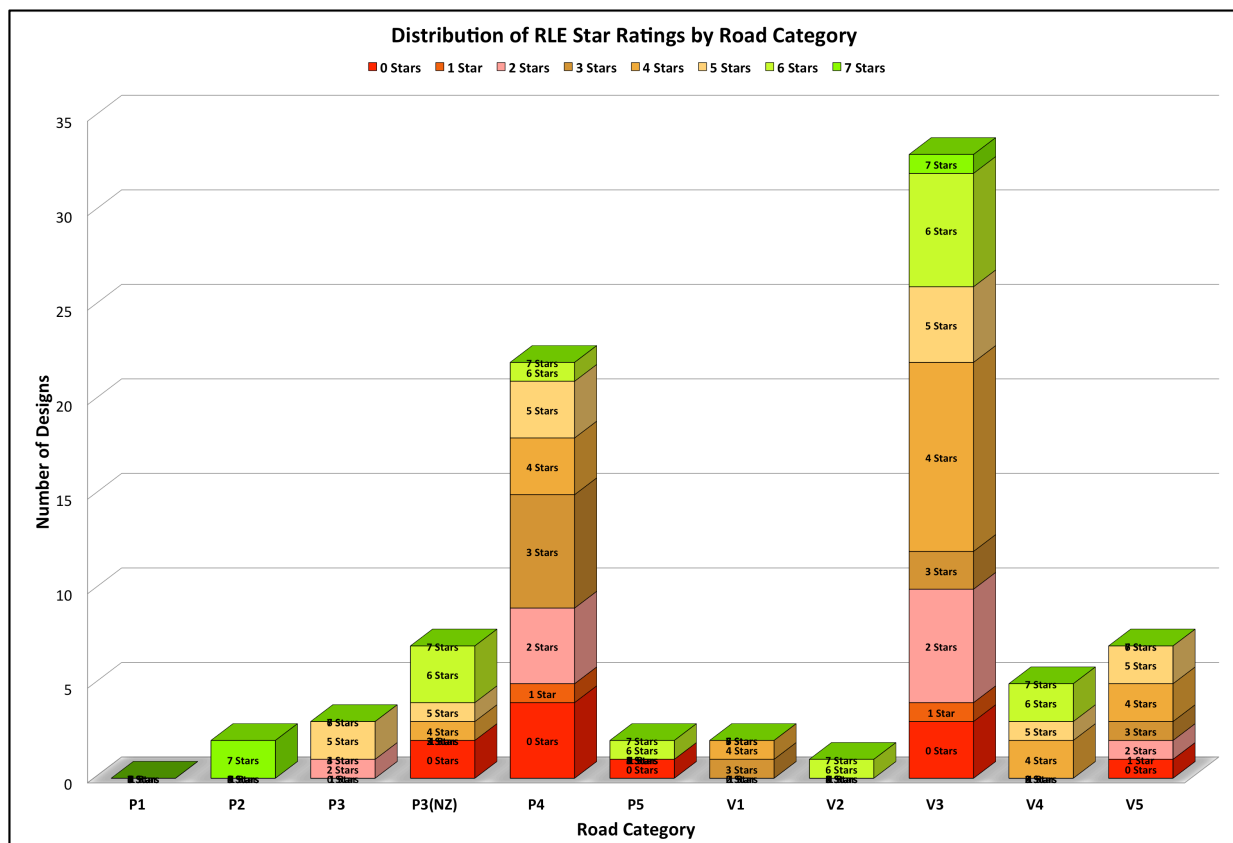


Figure 10 Distribution of RLE Star Ratings by Road Category

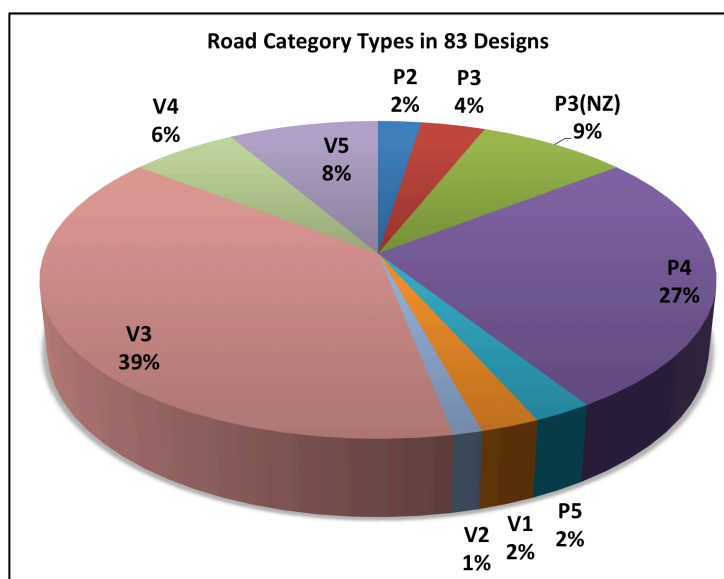


Figure 11 Road Categories % of 83 designs

6.4.6 Effects of NZTA M30 Specification Requirements

As discussed in Section 4.3 New Zealand's Transport Agency funds approximately 50% of all road lighting capital and operating costs. In 2014 they issued an important "M30 Specification" document¹⁰ which effectively mandated minimum energy performance to obtain that 50% funding. It is therefore important to ascertain how the M30 energy performance requirements compare with performance requirements proposed in Europe and recommended by Lighting Naturally and in this report by SLP.

To do this SLP have applied the NZTA M30 thresholds to the 31 eligible NZ designs (V1-V4 and P1-P4) and determined that 11 of the 15 Category V designs meet the M30 requirement, **73% achievement rate**. Seven of the 1 Category P designs meet the M30 requirements, **a 44% achievement rate**.

Compliance with M30 corresponds to between a 4 and 5 Star RLE performance rating, so if a design achieves a 4 Star rating or above it will meet NZTA's M30 guidelines.

Note that subcategory V5 or P5 lighting schemes were included in this calculation as the NZTA M30 specification does not accommodate these subcategories as they are not permitted in New Zealand under AS/NZS1158 Parts 1.1 and 3.1.

It is noteworthy to add that all of the 31 NZ designs assessed for NZTA M30 compliance were less than 5 years old. Whilst this study is not statistically rigorous it appears evident that a high proportion of low performing lighting schemes have implemented in very recent times.

NZTA's stated intention for the M30 guidelines is to eliminate lower performing technologies for new and refurbished lighting schemes, a goal it appears to effectively achieve. The analysis shows that a proposed AS/NZS Star rating approach would work well with the New Zealand NZTA M30 specification energy performance limits.

¹⁰ M30 Specification and Guidelines for Road Lighting Design

7 Recommended Refinements to Design Rating Methodology

7.1 Introduction

The South Australia DSD client brief requested evaluation of the Light Naturally recommendations with the following objective – “Recommendations for refinements to meet the objective of providing an evaluation method for road lighting design energy performance”. This section addresses that part of the brief by quoting from the LN report in *blue italics* and responding with SLPs comments and recommendations.

7.2 Market Research

Light Naturally market research (Refer Section 2, Page 3 of LN report) based on catalogue data from 2 manufacturers (6 countries of origin) was conducted during 2013-2014 into the claimed performance of LED road light luminaires available in Australia and New Zealand.

SLP recommendation: With a rapidly evolving LED lighting market this 2013/14 research has become largely obsolete and thus SLP recommends this market research be updated in order to accurately inform the energy performance standards debate process.

1.3 LN Recommendations for Possible Standards Inclusions

7.2.1 AS/NZS1158.0 Introduction - Clause 3.5 Light Technical Parameter (LTP) definitions

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. 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.

SLP recommendation: We recommend that any documentation or standards recognise that luminance coefficients for the road surfaces for New Zealand are under review. Research conducted in 2009 has indicated that the coefficients used in AS/ANZ 1158 calculations do not match the actual road surface properties encountered in New Zealand.

Note also that the 201 requirements of the new EN Standard on Energy Performance Indicators have changed from 2013. Luminance based metrics for PDI and AECI calculation inputs for V Category have been replaced by an illuminance calculation methodology.

1.3.2 Clause 5.1 Lighting categories

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.

SLP agrees: However in addition to 2 hour cycle **we recommend** the inclusion of a weekly cycle for weekday/weekend factors and an annual cycle for summer/winter weather condition factors (ie rain, fog, snow etc)

7.2.2 Adaptive Conditions Review Period

This information must also be accompanied by review period, duration of which should be assigned based on any foreseeable changes of the issues considered (eg traffic level, crime level etc).

SLP agrees in principle: How such a review period would be monitored or policed is unclear but this approach gives a strong signal that the light level and time duration judgement is a circumstantial decision based on known facts at the time about prevailing activity and traffic flows. As Central Management Systems (CMS) that provide adaptive lighting are programmable, any adjustments required to maintain appropriate and safe service levels can be readily implemented.

We recommend for new AS/NZS1158 standards updates that the text should include for a voluntary review to be carried out one year from the date of installation of light levels and where star ratings are high (say above say 3 stars) and include timings of adaptive lighting profiles. Where star ratings are lower, there is less need for this effort.

7.2.3 Dimming Override Provision

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).

SLP Agrees: Note that this provision requires the use of programmable CMS technology and precludes the use of stand-alone embedded adaptive control software within the luminaire.

7.2.4 Energy Efficiency Calculations

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 (new).

SLP agrees: Refer SLP comment in section 5 on the 2015 version of FprEN 13201-5:2015 alignments and extensions.

7.2.5 Clause 3.6 Road Lighting Efficiency Rating (new)

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

SLP agrees: Refer SLP comment in section 5 on the 2015 version of FprEN 13201-5:2015 alignments and extensions.

7.2.6 Appendix D1 Mandatory Requirements

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

SLP agrees: Refer SLP comment in section 5 on the 2015 version of FprEN 13201-5:2015 alignments and extensions.

7.3 Changes to AS/NZS1158.2 covering computer procedures

Light Naturally recommends changes to AS/NZS1158.2 *Computer procedures for the calculation of light technical parameters for Category V and Category P lighting* to include the requirements for energy efficiency calculations installations and reporting for Category V and P lighting.

As shown below SLP is in agreement with the LN recommendations but our recommendation covered in detail in section 7.4 is that European practice is followed and these energy performance requirements are allocated a new and separate part 7.

7.3.1 Road Lighting Efficiency Star Rating

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.

SLP agrees: Refer SLP comment in section 5 on the 2015 version of FprEN 13201-5:2015 alignments and extensions.

7.3.2 RLE Star Rating

*An energy efficiency classification, (RLE Star Rating), for the road lighting design shall be assigned as per values given in **Table 15. “Road lighting installation energy efficiency label classifications”***

SLP agrees: We recommend that further measures be incorporated to “future proof” the standards by periodic re-calibration of the 7-Star scale to accommodate the higher level performance outcomes that are likely to result from implementing combination of improved luminaire technologies, application of advanced controls or the adoption of S/P ratios in AS/NZS lighting design. The pace of LED and control systems technology development is significantly greater than the technologies they have replaced.

7.3.3 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. lighting design with n dimming factor associated with it will have a average dimming level of 100%. This parameter shall be reported along with the RLE Star Rating.

SLP agrees in principle: Align details with FprEN 13201-5:2015 including the descriptor Lighting Reduction Coefficient (LRC).

7.3.4 Active Response System

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

SLP agrees: Active response systems are covered in detail in FprEN 13201-5:2015, refer SLP comment in Section 5 of this report.

7.3.5 Road Lighting Energy Efficiency Report

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 with selection of the preferred lighting design solution. Key parameters to be reported shall include: (as listed).

SLP agrees in principle: Road Lighting Energy Efficiency Reporting is covered in detail in FprEN 13201-5:2015, refer SLP comment in Section of this report.

7.4 SLP Recommendations on Standards Inclusions

Since the release of the Light Naturally report August 2014 there have been considerable changes, additions and updates to the AS/NZS1158 series of standards. As at July 2015, reviews of some parts of the suite of standards are currently in progress, most notably AS/NZS1158.1.1 and AS/NZS1158.3.1.

The potential for improved visibility conditions delivered by high CRI white light is high on the agenda of the relevant AS/NZS standards Working Groups. New research and application evidence is available which shows that significant energy savings can be made. These are implemented through the use of S/P ratios in lighting design. Recent major advancements in the performance and economics of LED road lighting luminaires has raised the importance of this factor as a practical and affordable pathway to improved design energy outcomes. Another significant technology development is the use of advanced control strategies and techniques which will also need to be accommodated in the AS/NZS standards.

7.4.1 Scotopic/Photopic Ratios

The human eye is much more sensitive to blue-green light at mesopic (low) lighting levels and substantial research has confirmed that designs using high CRI white light require lower luminous flux to achieve the same outcome as yellow HPS.

While AS/NZS 1158 has some recognition of this, the European and British standards have embraced the research and formally recognised the improved effectiveness of white light by establishing a method of de-rating non-white lighting through the use of “scotopic/photopic” (S/P) ratios. The UK has a recently updated standard called *BS5489-1:2013 Code of Practice for the design of road lighting-Part 1: Lighting for roads and public amenity areas*.

This BS standard allows adjustment of lighting design lumens for high CRI ($R_a > 60$) white light under mesopic conditions. This only applies to the light levels for residential and minor roads in the UK. Note however, that UK residential lighting levels are considerably higher than those in Australia and New Zealand. The independently established S/P ratio of the light source can be used with an adjustment factor in lighting design. The S/P ratio needs to have a credible, audit trail for the lightsource under consideration determined from the measured lightsource performance data in the supplied photometric lab reports.

Use of these S/P ratios will have a significant improving effect on white lighting design energy efficiency when compared with low CRI light (eg HPS) sources. With high CRI white light sources compliant designs undertaken to this standard will require fewer lumens and will also lower the lighting power density and annual energy use.

The Institution of Lighting Professionals UK have also provided a 2012 guide called “*PLG03 Lighting for Subsidiary Roads - Using white light sources to balance energy efficiency to balance energy efficiency and visual amenity*” which is aimed at applying high CRI white light to deliver improved energy performance outcomes for residential roads. It is clear that for some applications there are very attractive opportunities to improve the energy performance of lighting installations beyond that afforded by the more cost-effective legacy technologies (particularly HPS).

It remains to be seen to what extent the LG-002 committee adopts such approaches in the reviews of Parts 1.1 and 3.1 of AS/NZS1158.

In UK, Europe, and USA the S/P ratio only favours white lighting in residential and related roads. On this basis the research evidence suggests that the Part 1 of the standard (applying to Category P) is likely to include the use of S/P lumen modification factors.

However, for Part 1 (applying to Category V roads) the picture is less clear. The international view is that under foveal visual conditions (ie on-axis or straight-ahead vision) on arterial roads and highways at EU/UK/US light levels the use of S/P based lumen modification is not appropriate (Gibbons, Terry 2011).

However, in Australia (V3, V4, V5) and New Zealand (V3, V4) the required lighting levels are well within the mesopic zone and so there is a strong case to consider the application of S/P lumen multipliers. The decisions of the LG-002 committee Part 1 and Part 2 reviews will likely have substantial effects on lighting design calculation methods and energy performance outcomes of advanced lighting schemes in the future. Conversely, the energy performance metrics and/or regulatory measures recommended in this and the Light Naturally report will also have significant impacts on the market.

SLP has previously recommended periodic review/re-calibration of the Star Rating scale to take account of the new *technologies* but another important reason for this is to appropriately accommodate the potential realised by the use of new *techniques* over time.

7.4.2 Adaptive Lighting Control

As equipment capital costs rapidly decrease and functionality increases road lighting designs will increasingly incorporate adaptive lighting techniques illustrated in this section. AS/NZS Standards and Technical Specification documents will need to be updated to accommodate suitable metrics and calculation methodologies for such techniques. If applied appropriately, these can have significant positive impacts on the energy use of road lighting schemes. The following diagrams illustrate the three aspects of adaptive lighting control opportunities: programmed dimming also called scheduled control in Figure 12, dynamic real time control in Figure 13, and constant light output (CLO) in Figure 14.

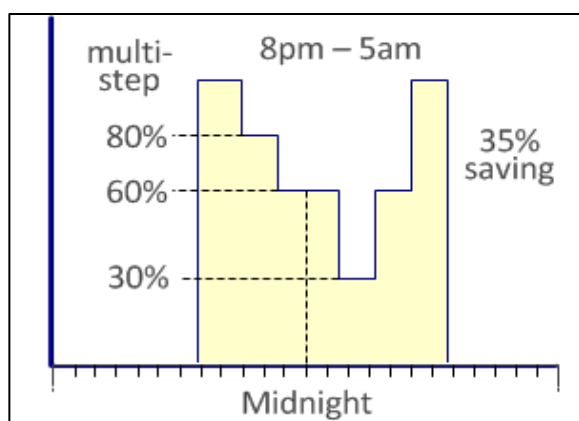


Figure 12 Programmed dimming/scheduled control scenarios to reduce light levels when road activity is historically low (Source: Telensa)

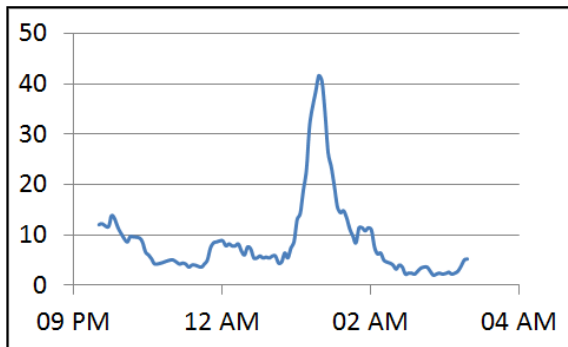


Figure 13 Localised and immediate dynamic real-time control in response to sensor actuated road/pathway activity (Source: Telensa)

Figure 13 above shows actual traffic/pedestrian count activity during the nightly cycle with the CMS controls programmed to respond with pre-set upper and lower light levels according to the demand at any particular time.

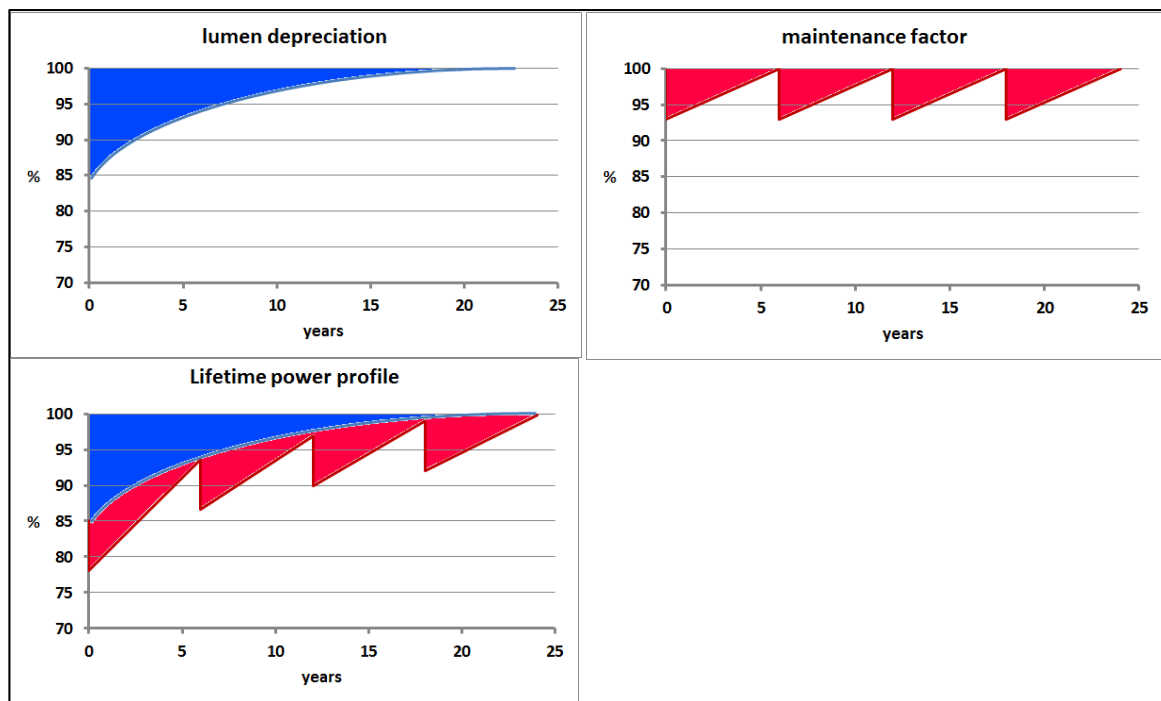


Figure 14 Constant Light Output (CLO) compensation for lightsource lumen depreciation (LLD) and luminaire dirt depreciation (LDD) (Source: Telensa)

The programmed control system illustrated in Figure 14 above raises luminaire power over its lifetime to deliver constant light output. The graphics depict the separate power curves over lifetime for LLD (blue), LDD (red) and the combination (blue and red) to give the total system power curve. The coloured portions are proportional representations of power saved by CLO implementation.

There are useful guidance documents available covering this area including:

- British Standards Institute - BS 5489-1:2013
- Institution of Lighting Professionals UK - PLG01 Central Management Systems

- Institution of Lighting Professionals UK - TR27 Code of Practice for Variable Lighting Levels for Highways

Section 5 of this report reviews the 2011 version of draft EN standard *EN13201-5:2015 Road lighting - Part 5: Energy performance indicators*. This version introduces the new metrics Power Density Indicator (PDI) and Annual Energy Consumption Indicator (AECI). These accommodate more sophisticated adaptive control techniques than the earlier draft versions of EN13201 and quantify the energy performance outcomes of the use of these controls. As recommended elsewhere these 2011 updates should be incorporated into AS/NZS 1158 standards as per the general provisions of the recommendations in the Light Naturally 2014 Report.

The New EN Standard on Energy Performance Indicators has been under development for at least eight years and has experienced several draft iterations that have had significant changes over previous versions. SLP recommends that changes to AS/NZS1158 should ensure that the published EN standard is used as the base reference document.

7.4.3 Positioning of Energy Performance Information in the AS/NZS 1158 Standard Series

The Light Naturally 2011 report recommends inserting the new energy performance criteria in Part 2 of the AS/NZS1158 series as a new section called Part 2.2. The existing *AS/NZS1158.2 Computer procedures for the calculation of light technical parameters for Category V and Category P lighting* would then become Part 2.1. Thus the LN proposed form would be called “*AS/NZS1158.2.2 Lighting installation energy efficiency calculations and reporting for Category V and Category P lighting (NEW)*”.

SLP disagrees: While this approach is workable, there is a real risk that important (normative) aspects of standards compliance could be overlooked by the market due to the difficulty of access in the detail of convoluted standards numbering and nomenclature. **SLP recommends** that “Part 7” be added to the AS/NZS1158 standards series (ie AS/NZS1158.7), in harmony with how Europe EN13201 series standards are structured. This would confer greater importance to energy performance factors both normative and informative. In the same vein **SLP recommends** the adoption of the simple title descriptor “Energy Performance Indicators” as per EN practice to assist ease of communication.

7.4.4 Star Rating Scale

The eighty-three designs evaluated in this report are all for installed lighting schemes without adaptive lighting controls or without the application of lighting designs incorporating Scotopic/Photopic (S/P) ratios (apart from the minor S/P incorporation as per AS/NZS1158.3.1 Amendment 2008). If these designs had incorporated controls and the S/P adjustments, they would be significantly higher performing. It is therefore highly likely that future designs with these features will deliver higher energy performance than those in this historic data sample and the 6 or 7 star rating as currently defined will be too easy to achieve and become “over-crowded”.

Thus **SLP recommends** that the effects of the S/P ratio and adaptive control be modelled to establish “headroom” in the Star Rating scale to anticipate and “future proof” the 7 star rating scale. This periodic review of the 7-star scale is also necessary to incorporate *continuing* technological progress.

For example, SLP has undertaken an additional trial calculation based on the only 7-Star rated (P-Category) scheme (No. 49, Connett Rd shown in Appendix 3 Spreadsheet). This scheme achieved a

RLE figure of 0.0093 (W/lx/m²) to surpass the 0.01 Netherlands threshold requirement and achieve 7-Star rating. If the luminaire wattage was halved as result of S/P adjustment and application of adaptive controls, the RLE figure would also be improved by 50% (to 0.0048) but there would be no positive discrimination to indicate that the energy performance of this scheme was substantially improved (and now 53 times the lowest P Category value!). This limitation should be allowed for with the introduction of any AS/NZS scheme in order that exceptionally good performance can be adequately recognised.

7.4.5 Light Level Overdesign

The new EN Standard on Energy Performance Indicators also defines limits on the “overdesign” of lighting levels. Note that SLP prefers the term “over-dimensioning” which is what the European standard is trying to avoid. It does this by stating that the calculated lighting level for a scheme should not exceed the required lighting level of the next higher lighting sub-category, or not exceed the required lighting level by more than 50% in the case of the highest sub-category. This is a very useful method of limiting the selection of excessive light levels by a lighting designer in order to be sure of achieving the minimum compliance figures. Inexperienced lighting designers often over-compensate on lighting levels and **SLP recommends** that this European restriction should also be included in future updates to AS/NZS1158.1.1 and AS/NZS1158.3.1

7.4.6 Lighting Practitioner Qualifications

Lighting design to AS/NZS 1158 standards has always been demanding and the addition of the energy performance requirements suggests that it is appropriate to consider means of ensuring practitioner competency. **SLP recommends** that AS/NZS 1158 updates should give serious consideration to the appropriate qualifications, training and experience of lighting practitioners in order to adequately conduct the energy performance assessments and calculations as required by the EN and Netherlands methodologies.

This recommendation is consistent with recent legislation (25 June 2015) passed at the Australian federal level as part of the Emissions Reduction Fund (ERF) legislation (*Carbon Credits (Carbon Farming Initiative-Commercial and Public Lighting) Methodology Determination 2015*). This legislation specifically defined the meaning of “qualified person” for sign-off of commercial and public lighting projects to be:

- *Member, Fellow or Registered Lighting Practitioner of the Illuminating Engineering Society of Australia and New Zealand; or*
- *Professional Member, Fellow or Certified Lighting Designer of the International Association of Lighting Designers* similar requirement with a similar definition of “qualified person” should be considered for inclusion as part of energy performance measures for road lighting design standards compliance and the implementation of AS/NZS normative design.

Further practitioner credentials relevant to road lighting should be added to the above ERF list:

- Member or Fellow of the Illuminating Engineering Society of North America; or
- Member or Fellow of the Institution of Lighting Professionals UK;

Road lighting design is a specialist discipline distinct from other sectors of lighting design and with the impending rapid increase in uptake of LED luminaires, and (more modest increase in) CMS

controls and adaptive lighting techniques the use of partially qualified or generalist practitioners should be discouraged. Any normative energy performance calculation and reporting processes sufficiently advanced to accommodate current technologies will need to be implemented by appropriately qualified and experienced professionals. SLP does not view this requirement as an additional cost of implementation as this level of expertise is already now fundamentally required to effectively deploy best practice modern technologies. On the contrary, without such safeguards, the risks of underqualified people mis-handling the additional complexity of the new technologies could introduce safety related risks.

8 Cost Impacts of a Design Rating Methodology

8.1 Introduction

This section covers the client request to:

“Determine the cost impacts of applying the metric as a normative disclosure requirement for AS/NZS1158 Part 1 and Part 3 road lighting compliance (excluding car parks, precincts etc)”

The cost implications are mainly those generated by the additional tasks by lighting designers to add energy performance calculations and reporting at the end of a design process. For simple lighting schemes without any adaptive lighting the additional calculation time for this should be negligible.

For more complex schemes with CMS controls or Constant Light Output, the time to execute these tasks will depend on the familiarity and experience of the designer with the systems and whether the calculation tasks are fragmented or aggregated. Given also that the energy saving calculations will generally be an important part of the design for the client, SLP estimates that an experienced designer might take an additional 15-20 mins per project sector to execute spreadsheet based calculation sub-routines for CLO, multi-power and presence detection operational profiles and the formatted reporting of these aspects.

In the early years of implementation of a normative reporting initiative it is likely that the majority of schemes will have no control system or will have a simpler CMS with scheduled lighting profiles so the reporting tasks will be very straightforward. More advanced real-time CMS controls will initially be only required for a small number of projects and as already mentioned will anyway require more sophisticated performance calculations as part of the business case for the client as well as for control system commissioning activities.

8.2 Design Time Impact from software

Once software is available and it has been mastered, it removes a substantial calculation load from designers. The extra time to provide energy performance calculations and verification reports will therefore also be negligible. There are four main software packages used by designers: AGi32; Perfect Lite; DIALux; and Relux Pro.

8.2.1 AGi32 Lighting Design Software

The lighting design payware software AGi32 already has an energy performance module included as part of the core product. This module is for the calculation of Lighting Power Density (LPD) (lm/W) for indoor or outdoor applications. Discussion with the Australian representatives of the US software developers of AGi32 (Lighting Analysts Inc, Colorado, USA) have indicated a willingness in principle to modify the software for the calculation and reporting of normative requirements for road lighting extended energy performance and ratings. The cost implications to software purchasers (if any) of this modification have not been explored but once the software has been updated, the extra time to have this reported will be negligible after the initial learning period.

8.2.2 Perfect Lite Lighting Design Software

Perfect Lite is Australian developed payware software for road lighting design and is the AS/NZS1158 designated software for use to undertake AS/NZS1158 Category V luminance based lighting design calculations. At present this software has no energy performance functionality. The Perfect Lite software developer (Wadello Pty Ltd, Queensland) has stated that the cost implications to the software customer of adding an integrated energy performance calculation and reporting annex to the lighting design software would be negligible. It was indicated that this may possibly be at no extra cost as part of the support service, delivered as part of a routine upgrade.

8.2.3 DIALux Lighting Design Software

DIALux is lighting design freeware software from DIAL GmbH Germany. DIALux is frequently used for illuminance based road lighting design calculations in Australia and New Zealand. This software calculates commercial *interior* energy performance in compliance with *EN 15193: Energy performance of buildings-Energy requirements for lighting*. The interior lighting energy software includes full dynamic assessment of sensor based controls techniques and calculates annual energy use and the EN normative disclosure metric the Lighting Energy Numerical Indicator (LENI). Such software is not yet available for road lighting application as there is no published EN energy performance standard to comply with, but with the impending release of the new EN Standard on Energy Performance Indicators it is likely that a similar tool will become available for road lighting.

Discussion has not been undertaken but it is unlikely that European freeware suppliers would be willing to add specific Australia New Zealand calculation and reporting modifications without some payment. If any new AS/NZS1158 energy performance normative requirements are forthcoming it would be advantageous from a software harmonisation perspective if these were in alignment with the terminology, metrics and methodologies of the new EN Standard on Energy Performance Indicators. As DIALux is freeware, therefore **SLP recommends** that the sponsoring organisations for the Lighting Naturally and SLP projects, consider commissioning modifications to DIALux for the Australian and NZ markets.

8.2.4 Relux Pro Lighting Design Software

Relux Pro is lighting design freeware software from Relux Informatik AG of Switzerland. Relux Pro is sometimes used for illuminance based road lighting design calculations in Australia and New Zealand. It does not include energy performance functionality, but additional payware software "Relux Energy CH" is available. This is an energy calculation and reporting tool aligned with the Swiss Standard *SIA 380/4 Electrical Energy in Buildings*. This performs lighting energy calculations for commercial buildings with full dynamic assessment of sensor based controls applications, calculates the Lighting Energy Numerical Indicator (LENI) and produces tailored SIA energy performance reporting certificates. Such software is not yet available for road lighting application as there is no published EN energy performance standard, but with the release of the new EN Standard on Energy Performance Indicators it is possible that a similar tool may become available for road lighting. The software harmonisation comment in the DIALux section above also applies to Relux Pro.

8.3 Spread sheet based calculation

Another approach to energy performance reporting is to use an Excel spread sheet template with manually inserted input parameters. A significant advantage of a spread sheet based calculation and

reporting format, compared to it being embedded in proprietary lighting design software, is the greater transparency and auditability of the calculations. This may be a significant factor if such processes are part of a procurement process or publicly funded incentive program (such as the ERF¹¹)

Spread sheet calculations will require a different approach depending on whether the scheme is new or existing. In each case a formatted one-page reporting summary could be readily configured from a spread sheet to meet normative requirements, in keeping with the LN reporting recommendations and/or the new EN Standard on Energy Performance Indicators requirements.

8.3.1 New Lighting Schemes

New schemes first require the designer to establish the Light Technical Parameters – generally provided by existing design software - to provide a compliant design. The spread sheet template for energy performance calculation will use these parameters and the other relevant factors together with the equations discussed in this report (and also used in the Excel spread sheet in Appendix 3) to provide an auditable record of the RLE performance indicator and star rating.

8.3.2 Existing Lighting Schemes

An existing scheme known to be compliant to AS/NZS1158 will not require the lighting design phase, and will simply calculate the RLE performance Indicators and RLE star rating as described in the previous section

8.4 Further Cost Implications

The above review of the cost impacts of the implementation of a Design Energy Rating methodology only considers the impacts of calculation and reporting requirements. Any additional infrastructure capital costs for asset owners that may arise from lifting of performance levels under a normative regime are not considered as these are outside the scope of this project.

¹¹ Australian Emissions Reduction Fund as discussed in section 7.4.6.

9 Conclusions and Recommendations

Strategic Lighting Partners Ltd has reviewed Light Naturally's August 2014 recommendations for a design rating methodology and has undertaken an extensive analysis of the energy performance of eighty-three road lighting schemes from around Australia and New Zealand using the recommended RLE metric and the RLE Star Rating System.

9.1 SLP endorses Light Naturally's recommendation on Minimum Energy Performance Standards (MEPS)

Light Naturally recommends that: *"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). We note that this has already occurred and is included in the forthcoming SA/SNZ T 1158.6:2015 Technical Specification.*

9.2 SLP strongly endorses Light Naturally's 2015 recommendations that "Normative disclosure of road design energy efficiency classification scale with neither a normative nor mandatory minimum performance limits", with the following additional requirements:

- 1) Light Naturally's detailed recommendations are modified with key updates from the new 2015 version of the proposed EN standard expected to be published in 2015 as recommended by SLP in section 7.4;
- 2) The Star Energy Performance Rating system scale used by Netherlands is modified where necessary to accommodate recent products available on the market in 2015 with particular emphasis on current LED luminaires, adaptive lighting and road lighting Central Management Systems (CMS); as recommended by SLP in section 7.2
- 3) The term "overdesign" is replaced by "over-dimensioning" as recommended in section 7.4.5;
- 4) Rather than place the energy performance requirements in a new subsection of Part 2 of AS/NZS 1158 ("Computer procedures for the calculation of light technical parameters ...") they be given "home" in new Part 7, as they are in the European standard (Part 5) to ensure these changes are clearly visible and accessible by the market as recommended in section 7.4.3;
- 5) The term "energy efficiency" be replaced by the term "energy performance" as it is used in Europe and other parts of the world in policy and standards areas and as recommended in section 7.1;
- 6) That a "physical label" attached to luminaires is not justified as discussed in section 3.6. In a road lighting application there are no readily visible chattels to affix a physical label to (unlike a point-of-sale retail electrical appliance for example) so this would be of limited value for the extra program cost imposed;
- 7) As discussed in section 3.21, we disagree with the need for a separate, and relatively costly to administer, dimming rating and label;
- 8) As discussed in section 7.4.3 we recommend the adoption of the simple title descriptor in the updated AS/NZS 1158 "Energy Performance Indicators" as per EN 13201 practice. This will assist with ease of communication and promotion.

9.3 SLP endorses Light Naturally's recommendation on voluntary selection

SLP agrees that procuring agency voluntary selection of preferred solutions is a good approach. This assumes that the procuring agency decision makers are appropriately trained and experienced in road lighting issues.

9.4 SLP conclusions from analysis of the recommended approach

- 1) The proposed lighting design rating methodology provides very useful comparative metric;
- 2) The cost impacts of applying the metric as normative disclosure requirement are minimal as discussed in section 8;
- 3) In addition to the refinements covered above in our conclusions in section 9.2 (1-5), SLP strongly recommends that normative standards incorporate lighting design S/P ratios for Category P as they do elsewhere, and consider using them also for Category V roads where their light levels are similar to those in residential road categories elsewhere, as discussed in section 7.4.1;
- 4) SLP also strongly recommends that normative energy performance standards incorporate adaptive control assessment and calculation techniques as discussed in section 7.4.2.

9.5 From the study of 83 field designs SLP concludes:

That the calculated energy performances for the designs provide significant practical insights into the resultant performance of contemporary Australian and New Zealand road lighting design practice. Key observations on the lighting applications are:

- 1) There are extremely wide variations in the energy performance outcomes with the best Category P design performing 27 times the worst design, with Category V designs exhibiting a factor of 10 times the best to worst identified in section 6.4.1;
- 2) Low performance designs are still being designed and implemented within the last five years;
- 3) LED luminaires deliver the top performing outcomes as shown in Figure 7;
- 4) The use of LED luminaires alone does not guarantee high performance outcomes as shown in Figure 7 and Figure 8;
- 5) CFL and T5 Fluorescent luminaires deliver mediocre performance outcomes as shown in Figure 7;
- 6) Applying NZTA M30 funding thresholds to the 31 eligible NZ designs (V1-V4 and P1-P4) results in 73% achievement rate for V Category designs and 44% achievement rate as discussed in section 6.4.6.

9.6 SLP further recommends that:

- 1) Serious consideration be given to the need for adequate qualifications and training of lighting design practitioners in order to competently conduct the energy performance assessments and calculations as required by the recommendations for normative disclosure discussed in section 7.4.6.
- 2) Any energy performance documentation or standards updates recognise that luminance coefficients for the road surfaces for New Zealand are under review as discussed in section 7.2.1;

- 3) In addition to an explicit statement on documented assessment of the reclassification of a road's subcategory throughout a 24 hour cycle, a weekly cycle to incorporate weekday/weekend factors and an annual cycle for summer/winter weather condition factors should also be included. This is discussed in section 1.3.2;
- 4) The text in AS/NZS1158 standards updates should request voluntary safety review of adapted light levels to be carried out one year from the date of installation of light and where Star Ratings are high (above say 5 Stars) and include timings of adaptive lighting profiles. Where Star Ratings are lower, there is less need for this effort. This is discussed in section 7.2.2;
- 5) The effects of the application of S/P ratio and adaptive controls be modeled to establish the level of "headroom" in the Star Rating scale to anticipate and "future proof" the 7 Star rating scale. A periodic review of the 7 Star scale is also necessary to incorporate continuing technological progress discussed in section 7.4.4;
- 6) The European final draft normative standard FprEN13201-5:2015 includes a clause on the restriction of light level over-specification. This should also be considered for inclusion in future updates to AS/NZS1158.1.1 and AS/NZS1158.3.1 as discussed in Section 7.4.5;
- 7) That the E sponsoring organisations for the Lighting Naturally and SLP projects consider commissioning modifications to DIALux and Relux for the Australian and NZ markets section 8.2.3;

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Appendix 1 Data Donor Notes

The following notes were provided to potential data donors as part of the process for the energy performance assessment of a sample of real road lighting design solutions from Australia and New Zealand. Refer Section for full details.

Department of State Development

Review of Road Lighting Design Classification System

Data Capture Matrix - General Information

On behalf of the South Australia Government, Department of State Development (DSD) - Energy Markets and Programs division we are seeking your input for an advisory report "Review of Road Lighting Design Classification System".

Strategic Lighting Partners Ltd, has been the successful tenderer for this consultancy project and is working on compiling an Australasian database of actual designed road lighting design parameters.

It is anticipated that this information may be used to provide input to the Standards Australia, Standards NZ AS/NZS LG-002 Committee with view to future incorporation in some form in the AS/NZS1158 suite of standards as systemic design energy performance calculation and/or classification system.

We seek lighting design parameter information on roadway designs that are -

- AS/NZS1158 compliant
- Representative of "typical" commonly used design configurations
- Are straight linear roadway sections (no intersections, curves, or unusual features).

Refer to Spreadsheet form *"DSD - Road Lighting Design Classification System - Data Capture Matrix"*.

We wish to capture lighting design data from experienced road lighting design practitioners and organisations that undertake or commission standards compliant road lighting designs.

Explanations of the various required data items are below -

1) Project Name

State a brief Project Name or Project Code Name.

The project needs to be named to be identified as real and legitimate for practical purposes and to allow for process auditing if required. If it is inappropriate to disclose the real project name (eg a commercially or politically sensitive project) a code name should be used. Use the data donor's name initials (2 letters, of first name and surname) and a sequential number eg. BW1, BW2 etc. The data donor should keep a record of the corresponding real project name if a third party audit of this DSD project is required.

8) Project Location

State project location by broad region, ie by State or Territory.

This is to be able to assess if there are any trends or differences in design energy performance between regions.

9) Project Age

State if design is less than 5 years old, or if design is greater than 5 years old (but less than a maximum of 10 yrs old).

This is to be able to assess if there are any trends or differences in design energy performance with the age of the design.

10) AS/NZS1158 Lighting Subcategories

State if illuminance based designs are (Cat P), and lighting subcategory (eg P1-P5)

State if luminance based designs are (Cat V), and lighting subcategory (eg V1-V5)

This is to differentiate between the two calculation methodologies.

11) Luminaire Spacing

State luminaire (ie column/pole) spacing distance, metres.

This is prime input to the power density calculations.

12) Wattage - Lamp or Luminaire

For traditional luminaire - State nominal lamp wattage

For LED luminaire - State LED luminaire gross wattage (module and driver combined)

13) Design Width - Roadway

State Carriageway Width - Cat V - Kerb to kerb, m.

State Road Reserve Width - Cat V - Boundary to boundary, m.

This is to establish road lighting application areas as in input to power density calculations

14) Power Lines - Underground (UG) or Overhead (OH)

State if luminaires are mounted on -

- DNSP Power Poles (OH, overhead lines), or
- Dedicated lighting columns (UG, underground lines)

15) Light Technology Type

State the lamp/luminaire technology used e.g. LED/HPS/MHC/MHQ/MV/CFL/T5/IND

MHQ = Metal Halide Quartz, MHC = Metal Halide Ceramic, IND = Induction

This is to be able to assess if there are any trends or differences in design energy performance by technology type.

16) Control Gear Type

State if luminaire uses Magnetic Control Gear (MCG) or Electronic Control Gear (ECG)

This is to be able to assess if there are any trends or differences in design energy performance by control gear technology type.

17) Luminaire Optic Type

State if luminaire has full cut-off optic (aeroscreen flat optic or visor - F)

State if luminaire has semi-cut-off optic (drop optic or visor - D)

This is to be able to assess if there are any trends or differences in design energy performance by optic type.

18) Colour Temperature

For LED light sources - State nominal colour temperature eg 3000K, 4000K, 5000K,

This is to be able to assess any trends or differences in design energy performance by LED white light colour temperature.

19) Photo Electric Cell

State presence or otherwise of luminaire mounted P Cell - Yes/ No

This is to be able to assess for any parasitic power impacts on design energy performance.

Thank you for your assistance. We will ensure that you are informed of progress with this project.

Bryan King

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Appendix 2 Data Capture Matrix

The following Data Donor Excel Spreadsheet was provided to potential data donors as part of the process for the energy performance assessment of a sample of real road lighting design solutions from Australia and New Zealand. Refer Section 6 for full details.

| DSD - Road Lighting Design Classification System - Data Capture Matrix | | | | | | | | | | | | | |
|--|-------------------------|------------|-------------|-----------|-----------|-------------|---------|----------|-------|--------------|--------|--------|---------|
| Organisation - | | | | | | | | | | | | | |
| Name - | | | | | | | | | | | | | |
| Position - | | | | | | | | | | | | | |
| Date - | | | | | | | | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | |
| No. | Project Name | Location | Age | Subcat | Luminaire | Wattage | Design | Lines | Light | Control Gear | Optic | LED | PE Cell |
| | Real Name or Coded Name | State/Terr | <5 or >5 yr | ASNZS1158 | Spacing m | Lamp or Lum | Width m | UG or OH | Type | MCG or ECG | F or D | Kelvin | Y or N |
| 1 | | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | |
| 5 | | | | | | | | | | | | | |
| 6 | | | | | | | | | | | | | |
| 7 | | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | | |
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Appendix 3 Design Data Analysis

The spreadsheet below *Design Data Analysis* is the collated lighting design data from seven data donor organisations. This comprises eighty-three real lighting schemes built within the last ten years in Australia and New Zealand. Refer Section 4 for full description.

| DSD - Design Data Analysis | | | | | | | | | | | | | | | | | | | | | | | | | | |
|----------------------------|---------|-------------------------------|------------|------|--------|-----------|-----------|----------|---------|----------|------|---------|--------|---------|---------|------|--------|-------------|-------------|-------------|-----------|---------|-------|---------|-----------|--|
| No. | Sub-cat | Project Name | Location | Age | Subcat | Luminaire | Wattage | Design | Lines | Light | Gear | Optic | LED | PE Cell | PE Cell | Gear | Tot W | LPD | 1158 Subcat | RLE Lum | RLE Illum | RLE | PDI | AECI | | |
| | | Real Name or Coded Name | State/Terr | <5yr | >5yr | 1158 | Spacing m | Lamp/Lum | Width m | UG or OH | Type | MCG/ECG | F or D | Kelvin | Y/N | W | W | inc Gear+PE | W/m2 | lx or cd/m2 | W/ld/m2 | W/ld/m2 | Stars | W/ld/m2 | kWh/m2/yr | |
| 1 | V1 | N2331 | NSW | >5 | V1 | 22 | 250 | 12 | UG | HPS | MCG | ECG | F | | Y | 0.25 | 26 | 276.25 | 1.046 | 1.50 | 0.6976 | N/A | 3 | N/A | 4.39 | |
| 2 | V1 | Flinders Street Central | QLD | <5 | V1 | 25 | 250 | 14 | UG | MHC | ECG | F | | N | 0 | 26 | 276 | 0.789 | 1.50 | 0.5257 | N/A | 4 | N/A | 3.31 | | |
| 3 | V2 | Project 3 | NZ | <5 | V2 | 40 | 139 | 13 | UG | LED | ECG | F | 4000 | Y | 0.25 | 0 | 139.25 | 0.268 | 1.00 | 0.2678 | N/A | 6 | N/A | 1.12 | | |
| 4 | V3 | V1868 | VIC | <5 | V3 | 43 | 150 | 12 | UG | MH | MCG | D | | Y | 0.25 | 18 | 168.25 | 0.326 | 0.75 | 0.4348 | N/A | 5 | N/A | 1.37 | | |
| 5 | V3 | 1413689 | NSW | <5 | V3 | 27 | 250 | 13 | OH | HPS | MCG | D | | Y | 0.25 | 26 | 276.25 | 0.787 | 0.75 | 1.0494 | N/A | 1 | N/A | 3.31 | | |
| 6 | V3 | 1413819 | NSW | <5 | V3 | 43 | 250 | 10 | OH | HPS | MCG | F | | Y | 0.25 | 26 | 276.25 | 0.642 | 0.75 | 0.8566 | N/A | 2 | N/A | 2.70 | | |
| 7 | V3 | Roberts Line Infill | NZ | <5 | V3 | 69 | 122 | 12 | UG | LED | ECG | F | 4000 | N | 0 | 0 | 122 | 0.147 | 0.75 | 0.1965 | N/A | 6 | N/A | 0.62 | | |
| 8 | V3 | 4th Avenue | NZ | <5 | V3 | 34 | 86 | 7 | UG | LED | ECG | F | 4000 | N | 0 | 0 | 86 | 0.361 | 0.75 | 0.4818 | N/A | 4 | N/A | 1.52 | | |
| 9 | V3 | Elles Road | NZ | <5 | V3 | 62 | 86 | 7 | UG | LED | ECG | F | 4000 | N | 0 | 0 | 86 | 0.198 | 0.75 | 0.2642 | N/A | 6 | N/A | 0.83 | | |
| 10 | V3 | Sandhurst | NZ | <5 | V3 | 53 | 150 | 10 | OH | HPS | MCG | D | | N | 0 | 18 | 168 | 0.317 | 0.75 | 0.4226 | N/A | 5 | N/A | 1.33 | | |
| 11 | V3 | DR2 | NZ | <5 | V3 | 36 | 170 | 30 | UG | LED | ECG | F | 4000 | N | 0 | 0 | 170 | 0.157 | 0.75 | 0.2099 | N/A | 6 | N/A | 0.66 | | |
| 12 | V3 | Project 1 | NZ | <5 | V3 | 35 | 139 | 16 | UG | LED | ECG | F | 4000 | N | 0 | 0 | 139 | 0.248 | 0.75 | 0.3310 | N/A | 5 | N/A | 1.04 | | |
| 13 | V3 | Project 4 | NZ | <5 | V3 | 61 | 101 | 17 | UG | LED | ECG | F | 4000 | N | 0 | 0 | 101 | 0.097 | 0.75 | 0.1299 | N/A | 7 | N/A | 0.41 | | |
| 14 | V3 | Project 5 | NZ | <5 | V3 | 30 | 101 | 15 | UG | LED | ECG | F | 4000 | N | 0 | 0 | 101 | 0.224 | 0.75 | 0.2993 | N/A | 6 | N/A | 0.94 | | |
| 15 | V3 | Project 6 | NZ | <5 | V3 | 35 | 133 | 8 | UG | LED | ECG | F | 4000 | Y | 0.25 | 0 | 133.25 | 0.476 | 0.75 | 0.6345 | N/A | 3 | N/A | 2.00 | | |
| 16 | V3 | Gateway Upgrade North | QLD | <5 | V3 | 75 | 400 | 14 | UG | HPS | MCG | F | | Y | 0.25 | 38 | 438.25 | 0.417 | 0.75 | 0.5565 | N/A | 4 | N/A | 1.75 | | |
| 17 | V3 | Lakes Creek Road | QLD | <5 | V3 | 55 | 250 | 8 | UG | HPS | MCG | D | | Y | 0.25 | 26 | 276.25 | 0.628 | 0.75 | 0.8371 | N/A | 2 | N/A | 2.64 | | |
| 18 | V3 | Steve Irwin Way | QLD | <5 | V3 | 50 | 250 | 9 | UG | HPS | MCG | D | | Y | 0.25 | 26 | 276.25 | 0.614 | 0.75 | 0.8185 | N/A | 2 | N/A | 2.58 | | |
| 19 | V3 | Kangaroo Gully Road | QLD | <5 | V3 | 35 | 150 | 8 | UG | HPS | MCG | F | | Y | 0.25 | 18 | 168.25 | 0.601 | 0.75 | 0.8012 | N/A | 2 | N/A | 2.52 | | |
| 20 | V3 | Moreton Bay Road | QLD | <5 | V3 | 60 | 250 | 23 | UG | HPS | MCG | F | | Y | 0.25 | 26 | 276.25 | 0.200 | 0.75 | 0.2669 | N/A | 6 | N/A | 0.84 | | |
| 21 | V3 | Southern Cross Way (trial) | QLD | <5 | V3 | 65 | 158 | 11 | UG | LED | ECG | F | 4000 | Y | 0.25 | 0 | 158.25 | 0.221 | 0.75 | 0.2951 | N/A | 6 | N/A | 0.93 | | |
| 22 | V3 | Southern Cross Way | QLD | <5 | V3 | 68 | 250 | 11 | UG | HPS | MCG | F | | Y | 0.25 | 26 | 276.25 | 0.369 | 0.75 | 0.4924 | N/A | 4 | N/A | 1.55 | | |
| 23 | V3 | Pacific Motorway, Springwood | QLD | <5 | V3 | 68 | 400 | 16 | UG | HPS | MCG | F | | Y | 0.25 | 38 | 438.25 | 0.403 | 0.75 | 0.5371 | N/A | 4 | N/A | 1.69 | | |
| 24 | V3 | Gateway Motorway | QLD | <5 | V3 | 65 | 400 | 16 | UG | HPS | MCG | F | | Y | 0.25 | 38 | 438.25 | 0.421 | 0.75 | 0.5619 | N/A | 4 | N/A | 1.77 | | |
| 25 | V3 | Ipswich Motorway | QLD | <5 | V3 | 65 | 400 | 21 | UG | HPS | MCG | F | | Y | 0.25 | 38 | 438.25 | 0.321 | 0.75 | 0.4281 | N/A | 5 | N/A | 1.35 | | |
| 26 | V3 | Bruce Highway, Mackay | QLD | >5 | V3 | 65 | 250 | 11 | UG | HPS | MCG | F | | Y | 0.25 | 26 | 276.25 | 0.386 | 0.75 | 0.5152 | N/A | 4 | N/A | 1.62 | | |
| 27 | V3 | Caloundra Road | QLD | <5 | V3 | 77 | 250 | 11 | UG | HPS | MCG | D | | Y | 0.25 | 26 | 276.25 | 0.326 | 0.75 | 0.4349 | N/A | 4 | N/A | 1.37 | | |
| 28 | V3 | Townsville Ring Road | QLD | >5 | V3 | 66 | 250 | 12 | UG | HPS | MCG | F | | Y | 0.25 | 26 | 276.25 | 0.349 | 0.75 | 0.4651 | N/A | 4 | N/A | 1.46 | | |
| 29 | V3 | Gateway-Roadway lighting-HP5 | WA | <5 | V3 | 50 | 250 | 10 | UG | HPS | MCG | D | | Y | 0.25 | 26 | 276.25 | 0.553 | 0.75 | 0.7367 | N/A | 3 | N/A | 2.32 | | |
| 30 | V3 | Kwinmana Hwy-Metro | WA | >5 | V3 | 70 | 250 | 10 | UG | HPS | MCG | D | | Y | 0.25 | 26 | 276.25 | 0.395 | 0.75 | 0.5262 | N/A | 4 | N/A | 1.66 | | |
| 31 | V3 | Mitchel Freeway-Metro | WA | >5 | V3 | 70 | 250 | 10 | UG | HPS | MCG | D | | Y | 0.25 | 26 | 276.25 | 0.395 | 0.75 | 0.5262 | N/A | 4 | N/A | 1.66 | | |
| 32 | V3 | Albany Hwy/Leach Hwy-80 km/h | WA | >5 | V3 | 50 | 250 | 9 | UG&OH | HPS | MCG | F&D | | Y | 0.25 | 26 | 276.25 | 0.614 | 0.75 | 0.8185 | N/A | 2 | N/A | 2.58 | | |
| 33 | V3 | Albany Hwy/Leach Hwy-60 km/h | WA | >5 | V3 | 48 | 250 | 9 | UG&OH | HPS | MCG | F&D | | Y | 0.25 | 26 | 276.25 | 0.639 | 0.75 | 0.8526 | N/A | 2 | N/A | 2.69 | | |
| 34 | V3 | Shepherds Hill Rd, Eden Hills | SA | <5 | V3 | 35 | 250 | 8 | UG | HPS | MCG | D | | Y | 0.25 | 26 | 276.25 | 0.987 | 0.75 | 1.3155 | N/A | 0 | N/A | 4.14 | | |
| 35 | V3 | North East Rd, Klemzig | SA | <5 | V3 | 37 | 150 | 7.5 | OH | HPS | MCG | D | | Y | 0.25 | 18 | 168.25 | 0.606 | 0.75 | 0.8084 | N/A | 0 | N/A | 2.55 | | |
| 36 | V3 | Churchill Rd, Regency Park | SA | <5 | V3 | 24 | 150 | 8 | OH | HPS | MCG | D | | Y | 0.25 | 18 | 168.25 | 0.876 | 0.75 | 1.1684 | N/A | 0 | N/A | 3.68 | | |
| 37 | V4 | SH83 | NZ | <5 | V4 | 59 | 87 | 7 | OH | LED | ECG | F | 4000 | N | 0 | 0 | 87 | 0.211 | 0.50 | 0.4213 | N/A | 5 | N/A | 0.88 | | |
| 38 | V4 | Browns Road | NZ | <5 | V4 | 53 | 86 | 12 | UG | LED | ECG | F | 4000 | N | 0 | 0 | 86 | 0.135 | 0.50 | 0.2704 | N/A | 6 | N/A | 0.57 | | |
| 39 | V4 | Pharazyn | NZ | <5 | V4 | 61 | 100 | 7 | OH | HPS | MCG | D | | N | 0 | 14 | 114 | 0.267 | 0.50 | 0.5340 | N/A | 4 | N/A | 1.12 | | |
| 40 | V4 | DR1 | NZ | <5 | V4 | 58 | 101 | 20 | UG | LED | ECG | F | 4000 | N | 0 | 0 | 101 | 0.087 | 0.50 | 0.1741 | N/A | 6 | N/A | 0.37 | | |
| 41 | V4 | Project 2 | NZ | <5 | V4 | 31 | 53 | 6 | UG | LED | ECG | F | 4000 | Y | 0.25 | 0 | 53.25 | 0.286 | 0.50 | 0.5726 | N/A | 4 | N/A | 1.20 | | |
| 42 | V5 | N2405 | NSW | >5 | V5 | 54 | 150 | 16 | UG | MH | MCG | D | | Y | 0.25 | 18 | 168.25 | 0.195 | 0.35 | 0.5564 | N/A | 4 | N/A | 0.82 | | |
| 43 | V5 | Q0740 | QLD | <5 | V5 | 66 | 150 | 17 | UG | HPS | MCG | F | | Y | 0.25 | 18 | 168.25 | 0.150 | 0.35 | 0.4284 | N/A | 5 | N/A | 0.63 | | |
| 44 | V5 | N4113 | NSW | <5 | V5 | 33 | 150 | 13 | UG | MH | MCG | D | | Y | 0.25 | 18 | 168.25 | 0.392 | 0.35 | 1.1205 | N/A | 0 | N/A | 1.65 | | |
| 45 | V5 | N4132 | NSW | <5 | V5 | 54 | 150 | 14 | UG | MH | MCG | D | | Y | 0.25 | 18 | 168.25 | 0.223 | 0.35 | 0.6359 | N/A | 3 | N/A | 0.93 | | |
| 46 | V5 | N3087 | NSW | <5 | V5 | 53 | 150 | 11 | UG | MH | MCG | D | | Y | 0.25 | 18 | 168.25 | 0.289 | 0.35 | 0.8246 | N/A | 2 | N/A | 1.21 | | |
| 47 | V5 | Evens Road | NZ | <5 | V5 | 63 | 65 | 8 | UG | LED | ECG | F | 4000 | Y | 0.25 | 0 | 65.25 | 0.129 | 0.35 | 0.3699 | N/A | 5 | N/A | 0.54 | | |
| 48 | V5 | Evans St | QLD | <5 | V5 | 32 | 150 | 32 | UG | MHQ | MCG | D | | Y | 0.25 | 18 | 168.25 | 0.164 | 0.35 | 0.4694 | N/A | 4 | N/A | 0.69 | | |
| 49 | P2 | Connett Road | NZ | <5 | P2 | 63 | 43 | 21 | UG | LED | ECG | F | 4000 | N | 0 | 0 | 43 | 0.033 | 3.50 | N/A | 0.0093 | 7 | 0.01 | 0.14 | | |
| 50 | P3 | NT4008584 | NT | <5 | P3 | 95 | 250 | 30 | UG | HPS | MCG | F | | Y | 0.25 | 26 | 276.25 | 0.097 | 1.75 | N/A | 0.0554 | 2 | 0.06 | 0.41 | | |
| 51 | P3 | Project 9 | NZ | <5 | P3 | 47 | 37 | 18.2 | UG | LED | ECG | F | 4300 | Y | 0.25 | 0 | 37.25 | 0.044 | 1.75 | N/A | 0.0249 | 5 | 0.02 | 0.18 | | |
| 52 | P3 | Croydon Rd, Keswick | SA | <5 | P3 | 43 | 27 | 15 | OH | LED | ECG | F | 4000 | N | 0 | 0 | 27 | 0.042 | 1.75 | N/A | 0.0239 | 5 | 0.02 | 0.18 | | |
| 53 | P3(NZ) | Rautawhiri Rd | NZ | <5 | P3(NZ) | 51 | 27 | 20 | UG | LED | ECG | D | 4000 | Y | 0.25 | 0 | 27.25 | 0.027 | 1.30 | N/A | 0.0206 | 6 | 0.02 | 0.11 | | |
| 54 | P3(NZ) | Puhaka Rd | NZ | <5 | P3(NZ) | 55 | 27 | 20 | OH | LED | ECG | D | 4000 | N | 0 | 0 | 27 | 0.025 | 1.30 | N/A | 0.0189 | 6 | 0.02 | 0.10 | | |
| 55 | P3(NZ) | Mangawhero | NZ | <5 | P3(NZ) | 53 | 100 | 10 | UG | HPS | MCG | D | | N | 0 | 14 | 114 | 0.215 | 1.30 | N/A | 0.1655 | 0 | | | | |