Publishable JRP Summary Report for Project ENG05 Lighting "Metrology for Solid State Lighting"

Need for the project

Solid-State Lighting (SSL) has the potential to revolutionize the efficiency, appearance and quality of lighting as we know it. SSL is the most efficient lighting technology available; although current products are still in their early stages of development, it is predicted to become twice as energy efficient as fluorescent lamps and more than ten times as efficient as incandescent lamps. As one fifth of global electricity consumption is for lighting, a considerable reduction in energy consumption could be obtained by replacing conventional lighting products by SSL technology. However, both professional users and consumers have been reluctant to embrace solid-state lighting, often due to previous unjustifiable or simply false claims about "low energy" lighting product performance.

To improve user confidence in manufacturer's claims for this technology, and to encourage its use, an extensive program is required including new research, measurement capabilities, and Standards that will allow unambiguous data on SSL to be determined. Existing conventional photometric guidelines work well for incandescent lighting sources, but when applied to SSL, do not provide unambiguous results for efficacy, light intensity distribution, lifetime and colour rendering.

Project objectives

This project supported the large-scale implementation and application of SSL through the development, validation and dissemination of adequate metrology for the unambiguous and reliable characterization of solid state lighting products.

The specific scientific objectives were to:

- develop and validate traceable measurement facilities and traceability routes aimed specifically at SSL
- develop and validate basic measurement methods for the characterisation of SSL products, including optical, electrical and thermal properties. Both single devices and complete systems to be considered
- implement metrics for the human perception of SSL
- develop and validate traceable quality metrics for the specification of SSL products in various applications.

The measurement capability developed will enable measurement laboratories to provide unambiguous information on SSL products, based on new technical guidelines and methods. This in turn will enable

- designers, producers and importers of SSL products to make reliable and verifiable product claims;
- policy makers to develop fact-based policy;
- market surveillance authorities to combat unfair trade practices based on faulty claims;
- users to select the best-fit products for their application.

The project developed essential measurement facilities and basic measurement methods, but also carried out application focused research to understand practical problems and to develop relevant quality metrics.

EMRP European Metrology Research Programme ▶ Programme of EURAMET

The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union

By combining both aspects, a measurement infrastructure was created which is both scientifically sound and corresponds to the real needs of the users. Through interaction with standardization organizations and accreditation bodies, the infrastructure is cemented into place.

Project structure

The technical work within the project, which corresponds to the four key scientific objectives, was divided into four aspects: Traceable measurement facilities; Measurement methods; Human perception and Application specific quality metrics. These aspects are further broken down as shown in the diagram below.

Traceable measurement facilities

- Electrical measurement systems
- Time-resolved measurements
- Mesopic photometers
- Spectral effects in measurement systems
- Near-field goniometry
- Environmental influences

Measurement methods

- Electrical characterisation
- Efficacy
- Goniometric measurements
- Lifetime

Human perception

- Colour quality
- Visual comfort
- Mesopic and scotopic vision

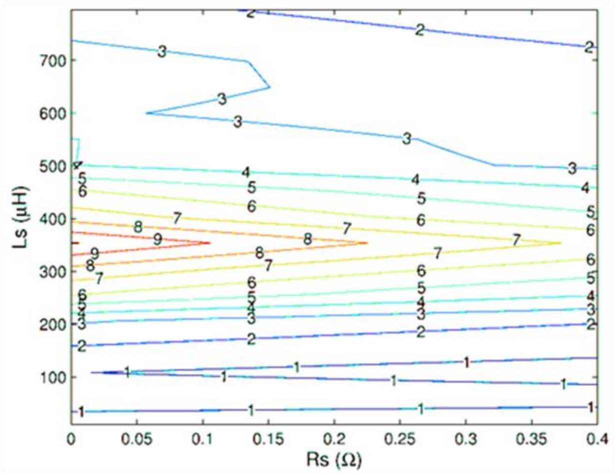
Application specific quality metrics

- Measurement equipment
- Indoor lighting
- Road lighting
- Greenhouses
- Art

Traceable Measurement Facilities and Measurement Methods

SSL light sources are not only different optically from conventional, incandescent sources, they are also different electrically, therefore the project addressed electrical and as well as optical measurements of SSLs. These measurements are necessary for effective in the design, manufacture and quality control of SSLs.

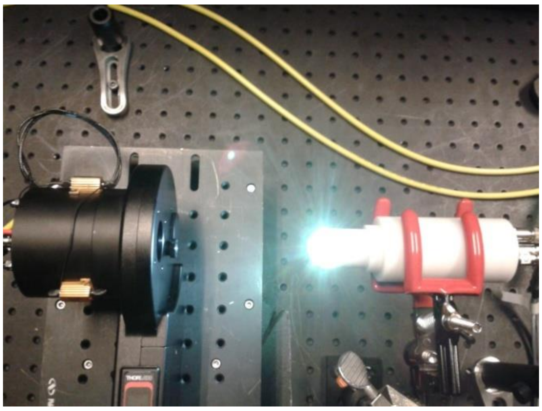
Electrical measurements

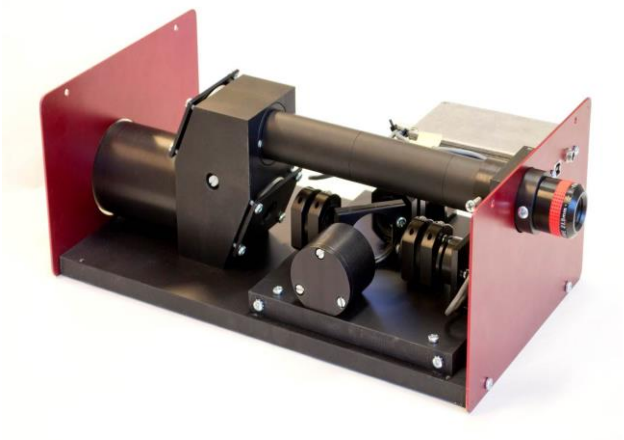


For electrical measurements traceable measurement facilities were developed at three partners to measure the electrical power and power factor of SSL products, including the impact of the source impedance on current waveform and the high frequency current emission of such sources. By using these facilities, significant deviations in electrical power compared with specifications were found, even for ‘A brand’ manufacturers, of SSL products. Depending on the complex impedance of the current source used for the measurement, errors of up to 9% were observed. A special stabilisation network was designed to reduce the effects of current source impedance to better than 0.02%, allowing electrical measurements with an unprecedented accuracy.

Time Resolved Measurements

SSL sources in pulsed mode operation, can be switched on and off at very high frequencies. A calibration facility for the dynamic behaviour of tristimulus meters (for measuring colour) up to 200 kHz was developed using monochromatic lasers of different colours, an acousto-optical modulator and fast photodiodes. Tristimulus meters calibrated on this facility were then used to study the effects of pulsed-mode operation on the colour of SSLs. The main conclusion of this work was that the use of a well-defined standard pulsed light source is an important component in performing a reliable and traceable characterization of the instruments which are intended for pulsed SSL measurements. A characterization of a commercial tristimulus meter showed that such instrument can provide erroneous results when used to measure pulsed SSL sources, if this is not properly characterized first. It is necessary that future standards take this fact into account.



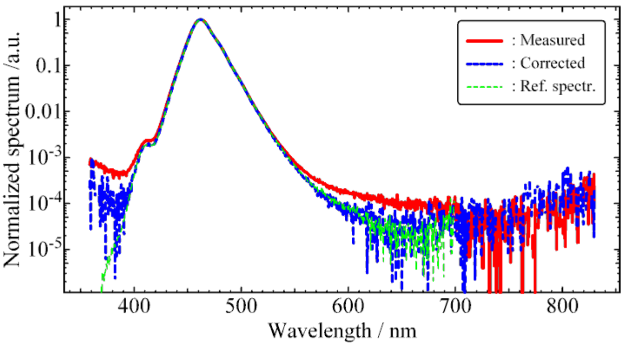


Mesopic and scotopic photometry

A major use of SSLs is for street lighting, where the light conditions are different than for photopic (daylight) vision. Traceable instruments for the measurement of light under scotopic (night-time) and mesopic (intermediate) conditions were lacking. For this reason, traceable mesopic and scotopic luminance and illuminance meters were designed and produced. Traceable calibration procedures were also developed. This work has been done in collaboration with a leading photometer manufacturer, who have developed and are marketing commercial instruments based on this work.

Spectral measurements

Due to the narrow peaks in the SSL spectrum, accurate spectral measurements are very important. A common measurement setup for SSL consists of an integrating sphere in combination with an array spectroradiometer. Development of guidelines on the calibration and use of such setups including uncertainty estimation were developed in the project. An important aspect of array spectroradiometers is the correction for band-pass and stray light. A correction method based on a calibration with tunable lasers and the calculation of a correction matrix was developed, using a new approach to ensure numerical stability.

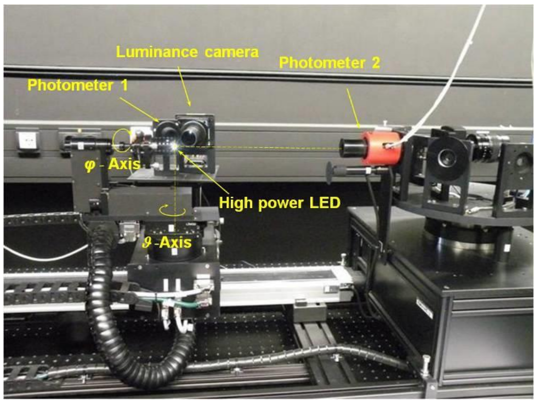


Influence of environmental conditions

Environmental conditions have a strong effect on SSL performance in general. The measurement of these effects however is difficult. A special instrument has been constructed as part of the project, which allows for the instantaneous capture of a 2D illumination profile, using multiple parallel detectors. With this, real-time investigations were made of the effect of temperature on the illumination profile of indoor and street lighting. The main outcome of the investigation showed that environmental temperature variations have insignificant effect on the shape of the spatial distribution of light from SSL products (both indoor and outdoor).

Goniometrical aspects

Lighting design depends heavily on models which take as input information in the form of 'ray files' that contain the angular and spatial distribution of light coming from a source. Traceable facilities for the determination of such ray files were developed and these were used to validate and improve models for the light distribution from high-power LEDs. An important issue is the reliability of the modelling predictions against deviations from the input ray files due to e.g. aging or temperature effects. These effects were investigated in the project and recommendations for improved procedures for using input ray files for lighting design were produced.



Life-time estimation

SSL devices are claimed to have long lifetime, most rated with 50 % - 70 % lumen maintenance (light output) after 30.000 to 50.000 hours of operation. Verifying such long lifetime claims directly is not practical and therefore alternative methods for predicting the lifetime of SSL products were needed. The approach taken in this project focussed on monitoring junction temperature in the SSL electronics and spectral changes of SSL products, as these factors are believed to be intimately connected to SSL lifetime. This work has resulted in two patent applications being made relating to junction temperature measurement, ultimately leading to better life-time prediction Also existing ageing tests capabilities were used in to evaluate current state-of-the-art in lifetime measurements. The main outcome of this work is the ability to perform accurate accelerated aging using heat. This can reduce testing time by a factor of 4.

Comparison on SSL efficacy measurements

As part of the project, the first comparison on SSL efficacy between the European national metrology institutes was organised. Ten participants measured a commercially available SSLs and a conventional incandescent lamp. The results of the comparison showed the level of agreement between the participating institutions for various parameters and lamp types.

Human perception

As human perception is key to the widespread acceptability of SSL products, this project also developed methods for assessing key qualities including: colour rendition, visual comfort, and mesopic (low light) vision. A test suite has been built resembling a normal living room where subjects were asked to perform tasks under different lighting conditions and then assess the suitability of the lighting for that task. This subjective evaluation was then compared to various proposed objective quality parameters. The results of these comparisons were presented as experimental input into the discussion on new standard methods.

Application specific quality metrics

In addition to the general quality metrics for SSL lighting, this project has also considered quality metrics that are application specific for three key areas including: greenhouses, road lighting and art expositions. For greenhouses applications, the focus is on optimising plant growth and results from this project indicate the potential for energy saving and spectral optimisation using SSL. For art exhibitions, results showed the potential for SSL to be used to protect various exhibits from frequencies that could damage artefacts. For street lighting where energy efficiency and safety are key factors SSL, the main conclusion of this activity is that the influence of the varying environmental temperatures on the spatial distribution of the illumination profiles of street-lighting luminaires is not significant.

Actual and Potential Impact

Dissemination:

The results of the project were widely disseminated to the lighting industry, standards making bodies and the scientific community.

- The project has produced 35 scholarly and technical publications and made 89 presentations at domestic and international events for both research engineering and commercial sectors. Highlights include: a successful final workshop held 24-25 April 2013 at NPL in Teddington (UK), with attendance of stakeholders from within and outside Europe.
- NPL contributed to the UK Lighting Liaison Group document "A Guide to the Specification of LED Lighting Products 2012". NPL conducted a Measurement of Commercially Available Solid State Lighting product Round Robin amongst UK Lighting Manufacturers and Testing Laboratories. This work was presented at the CIE Lighting Quality & Energy Efficiency conference in Hangzhou, China, September 2012 and Strategies in Light Europe conference in Munich, September 2012.
- During the project the consortium have provided training/education at over 40 external workshop events at European and international venues.

Standards:

The project has interacted with standards organisations. Particular highlights include:

- The consortium has documented 32 interactions with standards bodies or their members during the course of the project; 11 of these with CEN 169 (Comité Européen de Normalisation) technical committee on Light and Lighting, 15 interactions with UNI GL5 (Ente Nazionale Italiano di Unificazione); and 6 with CIE (Commission Internationale de l'Eclairage) TC2 (Physical Measurement of Light and Radiation) and Division 4 (Lighting and Signalling for Transport)
- A report on quality metrics, produced in this project, was used to review the draft standard (CEN13032). This standard will be used for LED metrology accreditation in Europe. Best practice generated throughout this project was highlighted and presented to CEN169 Committee. One of the aims of this standard is for it to become the accepted international methodology for LED measurement.
- INRIM participated in CEN 169/226 JWG12 for the revision of the European standards for road lighting (EN13201) and to CIE Div 4 Technical Committees on road lighting.
- A response to the EU Greenpaper on SSL was submitted on behalf of the consortium.

Industrial Impact:

The project has worked closely with the lighting industry. Particular highlights include:

- Collaboratively, NPL and Surrey University have applied for 2 patents on the use of electronic circuitry to enable the in-situ measurement of light intensity by LEDs and so leading to an estimation of the junction operating temperature. The technology behind this work has been used in a further EMRP research project (ENV04 METEOC) to provide for automatic calibration of solar radiation sensors.
- As part of the efficacy of SSL measurement intercomparison exercise, industrial stakeholders in the UK made parallel measurements with NPL leading to the dissemination of methods and procedures to industrial stakeholders. This has provided LUX TSI with greater confidence in their measurement capability and consequently to apply for UKAS accreditation.
- In association with Italian road authorities, highway tunnels with LED luminaires were studied and luminaires for tunnel internal, and entrance and exit zones were characterized using the INRIM goniophotometer, enabling safety critical design parameters for tunnel lighting to be determined.
- In collaboration with photometer manufacturer LMT, a commercial mesopic light level device has been developed and is currently being marketed.

Continued uptake of reliable and robust measurements of the properties and performance of SSLs will contribute to the on-going development and application SSLs as an effective and energy efficient light source.

List of Publications

The documents below can be accessed via: http://www.euramet.org/index.php?id=repository

[1] Zhao, D., Rietveld, G., Braun, J., Overney, F., Lippert, T. and Christensen, A. Guidelines for Traceable Measurements of Electrical Parameters of SSL,

[2] Zhao, D., Braun, J., Overney, F., Lippert, T. and Christensen, A. D2.1.1 Comparison Report on Measurement of Electrical Quantities of Selected SSL Lamps,

[3] Zhao, D. and Rietveld, G. The Influence of Source Impedance in Electrical Characterization of Solid State Lighting Sources, (Proceedings) CPEM 2012: Conference on Precision Electromagnetic Measurements, Washington, DC, USA, 1 - 6 July 2012,

[4] EMRP-ENG05-1.3.4: Guidelines on the calibration procedures for spectroradiometers necessary for SSL measurements

[5] Lacomussi, P., Rossi, G. and Rossi, L., A comparison between different light sources induced glare on perceived contrast, Proceedings of the 27th Session of the CIE, (Proceedings), 27th Session of the CIE, Sun City, South Africa, 9 - 16 July 2011

[6] Villamarin, A., Ferrero, A., Pons, A., Campos, J., Rabal, A., Hernanz, M., Velásquez, J. and Corrons, A., Distribución angular de la intensidad radiante espectral de LEDs blancos de alta luminosidad - Angular and spectral radiant intensity distribution of high brightness white LEDS, Optica Pura y Aplicada, 45(2), 2012, 131-136 (Article)

[7] López, M., Bredemeier, K., Rohrbeck, N., Véron, C., Schmidt, F. and Sperling, A., LED near-field goniophotometer at PTB, Metrologia, 49(2), 2012 (Article) , http://iopscience.iop.org/0026-1394/49/2/S141

[8] Nevas, S., Wübbeler, G., Sperling, A., Elster, C. and Teuber, A., Simultaneous correction of bandpass and stray light effects in array spectroradiometer data, Metrologia, 49(2), 2012 (Article), http://iopscience.iop.org/0026-1394/49/2/S43

[9] Velásquez, J., Campos, J., Pons, A., Ferrero, A. and Hernanz, M., Diseño de un medidor mesópico, Book title: Ciencia y Tecnología del Color , Editor: Esther Perales Joaquin Campos and Rafael Huertas , (Contribution to book), Publisher: Copicentro Granada S.L., 2012

[10] López, M., Lindemann, M., Linder, D., Winter, S. and Sperling, A., Tristimulus head for measuring the long-term stability of the chromaticity of high-power LEDs, Proceeedings of NEWRAD 2011 - The 11th International Conference on New Developments and Applications in Optical Radiometry, (Proceedings) , NEWRAD 2011 - The 11th International Conference on New Developments and Applications in Optical Radiometry, Hawaii, USA, 19 - 23 September 2011

[11] Rossi, L., Zegna, L., Iacomussi, P. and Rossi, G., Pupil Size under Different Lighting Sources, Proceedings of CIE 2012 'Lighting Quality and Energy Efficiency', (Proceedings), CIE 2012: 'Lighting Quality and Energy Efficiency, Hangzhou, China, 19 - 21 September 2012

[12] Villamarin, A., Velásquez, J., Pons, A., Ferrero, A., Campos, J. and Hermanz, M., Estudio de la iluminancia en función de la distancia de LEDs de alta luminosidad, Proceedings of X Reunión Nacional de Óptica, (Proceedings), X Reunión Nacional de Óptica, Zaragoza, Spain, 04 September 2012

[13] Rossi, L., Schiavi, A., Rossi, G., Astolfi, A. and Iacomussi, P., MEASURING MAN AND SOFT METROLOGY: INFLUENCE OF VISUAL AND AUDITORY DISTURBING FACTORS ON CONTRAST DETECTION

Proceedings of the 15th International Congress of Metrology, (Proceedings), 15th International Congress of Metrology, Paris, France, 3 - 6 October 2011

[14] Villamarin, A., Ferrero, A., Pons, A., Campos, J., Hernanz, M. and Corrons, A., Distribución angular de la intensidad radiante espectral de LEDs blancos de alta luminosidad - Angular distribution of spectral radiant intensity emitted by high brightness white LEDs, Proceedings of VII Reunión Española de Optoelectrónica OPTOEL 2011, (Proceedings), VII Reunión Española de Optoelectrónica OPTOEL 2011, Santander, Spain, 19 June 2011

[15] Schuster, M., Lindner, D., Eltmann, M., Ulrich, H. and Sperling, A., Characterisation of scotopic luminance meters, Proceedings Lux Junior 2011: 10. Internationales Forum des lichttechnischen Nachwuchses, (Proceedings), Lux Junior 2011 - 10. Internationales Forum des lichttechnischen Nachwuchses, Doernfeld/Ilm, Germany, 23 - 25 September 2011

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