Publishable Summary for 16NRM02 SURFACE
Pavement surface characterisation for smart and efficient road lighting

Overview

The knowledge of the so-called luminance coefficient q (ratio between the luminance of the road surface and the illuminance on it for given directions of illumination and observation) is an unavoidable requirement for designing road lighting installations able to ensure that road luminance is adequate for visual conditions, energy consumption and traffic safety according to standard requirements. SURFACE will provide the necessary metrological support to the European standardisation process with validated, optimised and reliable geometrical conditions for the measurement of q as well as reference data representative of current road pavements, useful for smart and efficient road lighting system design.

Need

Presently in Europe about 40 % of the 5.5 million kilometres of roads have lighting. Current EU standards on road lighting (i.e. EN 13201 series) seek to establish road luminance values able to satisfy quantitative and qualitative performances in terms of safety, visual appearance and energy consumption. Thus, the weighting and spacing of a road lighting system (i.e. luminous flux installed per kilometre) is calculated accordingly and ensures compliance with the suggested luminance values of the assigned road class. Usually the design of such lighting systems (e.g. the definition of installation layout, luminous intensity, distribution of luminaires, and luminous flux installed per kilometre or power density indicator) considers reference weighted *q* data (*r*-tables) of the road surface.

In the EN 13201 Road lighting Standard series, r-tables provide values only for the necessary incident and view directions for traditional lighting installation (i.e. installation luminaires height greater then 10 m and columns inter-distance of about 30 m) and the *q* data for those directions are missing. A lighting engineer adopts as de facto standard values, the *r*-table or the equivalent *q* values published in CIE documents. However, these data are based on measurements performed on concrete samples more than 40 years ago without traceability and uncertainty evaluation. Recent studies have shown that the use of CIE data as reference leads to large errors (on average over 30 %, but up to 50 % in worst case) on expected road luminance. Moreover, the photometric properties of road materials have changed over time considering new material components and laying techniques as well as the road lighting systems (i.e. LED sources, adaptive systems and smart lighting systems, and luminaires installed at lower heights). Such an evolving situation requires the definition of new values of q and an upgrade of the reference directions for its measurement. To ensure EU targets on Energy Saving and Road Safety are met it is now time to improve *q* reference data and reference geometries through a large metrological research review of basic concepts and a measurement campaign.

Objectives

The goal of this project is to address the current deficiencies in European Standards regarding (i) the definition and characterisation of the road surface photometry, (ii) traceable measurement and characterisation methods for road surface characteristics and (iii) traceable reference data for photometric tables useful in the design process of road lighting installations. The results will be used by CEN TC169/WG12 in the next revision of EN 13201 series, and by CIE TC4-50 in the revision of pertinent CIE publications.

The specific objectives are:

1. To develop optimised measurement geometries for the characterisation of photometric quantities for road surface materials to support EN 13201 ‘Road Lighting’ and its future revisions.

2. To produce technical and metrological specifications for instruments used to measure luminance and reduced luminance coefficients of road surfaces in laboratories or on-site, including methodologies for calibration, establishing traceability and evaluating the measurement uncertainty.
3. To develop pre-normative guidelines for measurement methods and procedures, for the future evolution of European standards to include aspects such as mesopic visual conditions (CIE191:2010), reduced obtrusive light and reduced light pollution of road lighting installations.
4. To develop pre-normative guidelines for photometric characterisation of road and pavement surfaces, including factors such as aging of road surfaces, wet conditions, spectral properties, diffusion of adaptive lighting systems (smart lighting), luminaire luminous intensity distribution and effects of measurement uncertainty in tolerance calculations.
5. To contribute to the standards development works of the technical committees CEN TC169/WG12 and CIE TC4-50 through the provision of data, methods, guidelines and recommendations. In particular traceable data related to new geometries and materials for inclusion in updated photometric tables of pavements in the international CIE database shall be provided. To ensure that the outputs of the project are aligned with their needs, results will be communicated quickly to those developing the standards and to those who will use them (e.g. lighting engineers, road designers), and in a form that can be incorporated into the standards at the earliest opportunity.

Progress beyond the state of the art

Although the luminance coefficient, *q,* is a quantity for characterising the spatial reflectance behaviour of a material, the measurement of *q* of a road surface for all possible directions of illumination and view is not necessary for a Road Lighting Standard, but a sub-set of useful directions for current and future smart lighting systems shall be clearly established. Actually, the available reference directions were established at the time of measurement of the reference data, based on the luminaire, traffic conditions and design approaches of that age. Therefore, this project tackles the need for the new directions of illumination and view that are most significant and useful in the design of road lighting systems with Solid State Lighting (SSL), in adaptive lighting, for improved glare evaluation, as well as considering new vision models, the complexity of traffic conditions and obtrusive lighting. Moreover, the prescribed direction of observation is 1°, the corresponding observation distance is around 85 m in front of the driver: an obviously unrealistic visual condition in urban environment both for driver and pedestrian.

Available commercial measurement devices for measuring luminance lack a clear assessment of photometric and geometrical performance. In addition, measurement guidelines are not available; the reliability of measurements is unknown and the uncertainty difficult to evaluate. The development of reference materials will establish traceability and provide an opportunity to verify measurement procedures and uncertainty calculations. These reference materials will allow the performance of the first comparison on measurement of luminance coefficient in the last 20 years and to ensure the traceability of the road characterisation metrology infrastructure in the EU.

New revisions and future editions of the EN road lighting standard series need to enlarge the scenario of aspects to be included in road lighting in order to achieve higher Energy Saving and Road Safety and to reduce the Environmental Impact of road lighting systems. The project will provide research results and guidelines about the influence of road surface ageing (installation over dimensioning), spectral properties (mesopic vision), and wet/dry conditions (adaptive systems). The CIE Expert Symposium on Road Surface Photometry and CIE TC4-50 stated that no guidelines on traceable measurement methods and sample management and alignment are currently available. Without standard measurement guidelines the reliability of measurements is unknown and their measurement uncertainty difficult to evaluate. *SURFACE* guidelines will also describe measurement methods and handling as well as specifications for new vision models, tolerance analysis and quality parameters.

An analysis of current NMIs involvement on road surface characterisation was carried out via the BIPM (Bureau International des Poids et Mesures) website on the KCDB database devoted to intercomparisons (Key Comparison Database) and gave no results about road surface intercomparison. In KCDB only eleven Key Comparisons are ascribed to materials properties, nine of them belong to regular transmittance and two to diffuse reflectance, none of which are of use for road surface characterisation.

The planned intercomparison will stress and improve the measuring capabilities of NMI goniometers to materials very different from usual metrology applications (e.g. ceramic tiles or lambertian surfaces).

Results

The joint research project *SURFACE* is developing the necessary metrological research and infrastructure, i.e. measurement methodologies, reference data, new geometries and reference materials for instrument calibration to enable European Standardisation organisations to achieve more efficient, more sustainable and safer road lighting design by the new edition or revision of EN standards that will be used by EU night-time road users.

The results will be mainly used:

- by CEN TC169/WG12 in the next revision of EN 13201 series (mainly part 3) or as an addendum;
- by CIE TC4-50 and TC4-51, for improving reference tables and guidelines;
- by National Standards Organisations, like the Italian UNI GL5 for standard UNI 11248, AFNOR for France, EVS for Estonia, SIS for Sweden and SNV for Switzerland.
- by Laboratory Accreditation System

This project will select a new set of geometries (objective no. 1) able to represent the directions of illumination and view that are most useful and significant for Solid State Lighting (SSL) and adaptive lighting design, in glare evaluation and for new vision models (objective no. 4). These advanced situations require spectral investigation on the photometric properties of asphalts: in the first part of the project, the impact of different lighting source spectrum on available *q* data have been evaluated. To be more effective future investigations will include also the spectrum of the new CIE LED Reference Illuminant, as soon as it will be available for testing. Currently CIE Div.2 is working on its definition.

The project will also provide specific guidelines on: metrological requirements (objective no. 2) for instruments, measurement procedures (including sampling and handling), calibration and uncertainty evaluation, and methods (objective no.3) for evaluating the influence of ageing, of spectral properties and of wet conditions. At the end of the three years *SURFACE* will provide to Standardisation Organisations and to CIE, new reference data for *q* of actual road surface, with an uncertainty statement, for current EN 13201 *q* reference geometries and for future reference geometries.

To achieve objectives 1, 2 and 3, , the consortium launched two different calls for contributions among the stakeholders and CIE Division 4. The first call was to catalogue existing measurement devices (for in laboratory and on-site measurements), and review their performances for setting up the intercomparison protocol and future guidelines on instrument specifications and performance (objective no.2) as well as for an initial version of the proposed portable measuring device. Twenty-two different measuring devices from across Europe have been classified; fifteen of them are laboratory instruments. All portable instruments belong to consortium partners or to those within the stakeholder group. Indeed, road lighting and road surface characterisation is a worldwide need, so ten additional devices from outside Europe have also been classified, most of them are the same instruments developed in Europe and installed abroad, with the exception of goniometers developed in USA and China.

The second call was to establish the actual distribution of road surfaces typologies across Europe to start with the identification of the typologies most relevant in Europe to reach objective no.1. In the call for information, also qualitative and descriptive data are requested in order to classify the performance from the ageing point of view. The call for information has been spread extensively through the stakeholder community, at international road lighting congresses (CIE mid term session and Lux Europa congress), symposium (CIE New advance on road Visibility) and events (CIE division 4 and TC meetings, national congress). Currently the database of available road surfaces includes about 250 different road surfaces. Data have been classified in clusters, and a champion for each cluster was used as reference for road lighting calculations. The results highlight the differences among current road surfaces and published road data, especially in terms of LED road lighting systems. A first draft proposal on new geometry has been prepared and discussed among consortium members and then presented to stakeholders at the first stakeholder meeting in Berlin (May 2018), and was well accepted. The proposal contains three different observation angles, representative of the different needs of road users in different situations like: urban environment (vehicle drivers and pedestrians), extra-urban environment (vehicle drivers), and road surface boundary reflectance diffusing-specular behaviour.

Collaboration between the NMIs and the planned intercomparison, the first one ever carried out on luminance coefficient, will ensure the necessary traceability and uncertainty of the European Metrology Infrastructure and instrument manufacturers. A dedicated Creative Commons (CC) open source software for uncertainty calculations will also be tested and provided to the community. The measurement intercomparison will be based on Reference Materials (RM) fabricated by means of 3D printing, representative of asphalt photometric performances. Several 3D printable materials have been characterised for their photometric performances, while two different RM have been designed to be used during the intercomparison based on given photometric performances and given artefact attributes. After prototyping and deep metrological characterization of photometric performances, the consortium has chosen to produce RM of given artefact attributes. Two different sets of 3D printed RM will be used during the intercomparison: one set is based on flat materials of given reflectance with matte and glossy behaviour, the other set is based on artefacts with attributes similar to a road surface with matte and glossy behaviour. Different measuring challenges related to geometrical attributes have been identified. Both sets will be used during the planned intercomparison.

At the end of the project the EU market will have the benefit of Certified Reference Material (CRM) for calibrating road surface measuring instruments.

Impact

Impact on Industrial and other user communities

The initial version of a portable instrument, the development of Certified Reference Material as well as software for uncertainty evaluation will push forward the market for developing new and adequate laboratory and portable measuring instruments for the characterisation of road surface as requested in EN 13201 standard series and never implemented due to an actual lack in metrological infrastructure.

The file format of luminance coefficient data as well as the data itself will be assimilated by the lighting engineering community and designers by using Creative Commons policy for the dissemination of relevant material and results and by the involvement of an IT company in the consortium.

The interest in the production of CRMs has grown up and the idea of CRMs for a luminance coefficient has been shared on several occasions, and promoted by ACCREDIA, the Italian Body for accreditation, including at the largest Energy Saving event in Italy, Ecomondo 2017 and the exposition A&T in Torino in April 2018.

In December 2018 a delegation of the stakeholder Panasonic visited INRIM and Cerema for a technical meeting focused on portable instruments development and their introduction to Japan.

Impact on the metrology and scientific communities

The guidelines on measurement uncertainty and measurement methodologies, and the planned comparison will improve the measuring capabilities of NMI goniophotometers for road surfaces and the European metrological services on road lighting and material characterisation.

The scientific community will receive new contributions via CIE TC4-50 and TC4-51.

The first of two planned workshops on road surface characterisation were held at the CIE Mid Term Session in Korea, allowing the project to enlarge the stakeholder committee and to raise awareness of the EMPIR programme and the project to eastern countries communities. A second workshop is planned near the end of the project to disseminate the results under the aegis of CIE. Several papers on the results of the project will also be published in target end user journals and presented at scientific conferences. The ongoing activities in the project are reported on the project website: www.surface-nrm02.eu. The website was set up in July 2017 and is continually updated as new public information becomes available. It also contains a member's area with restricted access for project partners and collaborators.

The project and its results are constantly shared with the road lighting and lighting design communities giving presentations and publishing at international and national conferences. Indeed, these two communities are deeply rooted to communications through conferences instead of publication on journals. Therefore, consortium partners gave several presentations and published papers at the main lighting conferences: LuxEuropa 2017, CIE 2017 mid-term congresses, a CIE road visibility workshop, and the National lighting engineering congress of Italy.

Impact on relevant standards

The project supports EN 13201 'Road Lighting' and its future revisions, and contributes to the standards development works of the technical committees CEN TC169/WG12 and CIE TC4-50.

The *SURFACE* reference data of actual (and upcoming) road materials will allow lighting designers to meet the normative energy savings and quality parameters as per the EU's commitment to cut energy consumption by 20 % by 2020. It will also strengthen the turnover of old lighting luminaires into new SSL luminaires and the introduction of adaptive and smart lighting systems allowing energy savings up to 70 %. The *q* reference data of actual road surface are an unavoidable need for the design of safer roads and the implementation of EU Road Safety Action trough the improvement of EU road Infrastructures.

The project has been introduced to CIE TCs TC4.50, TC4.15,TC 4.51 at the CIE-meeting in October 2017 and the TCs members strongly supported the TCs involvement. At SDO the project was presented to CEN TC 169, and several other TC and WG at National and International meetings.

During the CIE Div4 meeting in Berlin, May 2018, the project results so far have been discussed within CIE Div4 members, while during the CIE TC4-50 project actions have been planned and integrated with the CIE TC4-50 document revision. On May 25 2018, at Berlin TU University, after the CIE Workshop "A new Vision of Visibility in Roadway Lighting" the consortium organised the first stakeholder meeting. About 20 different stakeholders attended the event. Stakeholders acknowledged the main results presented by the consortium: new geometry for road surface characterisation based on three different observation angles (instead of only one as in the current reference documents), new reference source for spectral calculations of road surface behaviour (available reference documents do not consider spectral peculiarities) and RM for the planned intercomparison.

List of publications

The project plan to produce pre-normative guidelines:

- for photometric characterisation of road and pavement surfaces including measurement methods and procedures, aging of road surfaces, wet conditions, spectral properties
- for applications in road lighting, including effects of measurement uncertainty in tolerance calculations, contribution to obtrusive light and light pollution of road lighting installations considering the road reflectance, mesopic visual conditions, and adaptive lighting systems (smart lighting).

The project plan includes the publication of at least three papers in open access peer review journals describing the intercomparison results, metrological characteristics of instruments for road surface measurements and the new database of road surface characteristics. Training materials in the form of a brochure on measurement difficulties when applying EN 13201 in real life situations will be also disseminated in different EU languages to stakeholders and road authorities, under CC policies.

The following publications have been published on open access peer review journals:

G. Rossi, P. Iacomussi, M. Zinzi, *Lighting implications of urban mitigation strategies through cool pavements: energy savings and visual comfort* Climate journal DOI: 10.3390/cli6020026

A special issue of *Coatings Journal* dedicated to Road Characterisation, is planned and the consortium is going to submit a paper.

Project start date and duration:	1 July 2017, 36 Months	
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