# Publishable Summary for 19NRM02 RevStdLED

# Revision and extension of standards for test methods for LED lamps, luminaires and modules

**Overview**

LED-based lighting products are the most rapidly evolving light sources on the market for general lighting in urban areas or domestic dwellings. These include not only white light sources, but also coloured and multi‑coloured light sources, whose colour depends on internal or external control mechanisms. Due to spectral and geometrical peculiarities, SI traceable measurements of LED-based light sources are much more difficult than those of traditional tungsten filament lamps or fluorescent light sources. This makes it difficult for test laboratories to evaluate application-relevant properties using existing measurement methods and standards developed for incandescent light sources. Standards for traceable test methods exist but important metrological aspects for their practical application have not yet been fully considered. For example, the assessment of uncertainty, and input and output tolerances for imaging luminance measurements, intensity distributions of luminaires as well as spectral measurements and coloured sources, have yet to be resolved. This project will identify essential test parameters, develop validated procedures and good practice guidelines for test laboratories and help shape the forthcoming revisions of CIE S 025:2015, ISO/CIE 19476:2014 and EN 13032-4 standards.

**Need**

Reliability and validity of product specifications are of great importance in the general lighting market, which is unsettled by unfulfilled performance promises of cheap lighting products. Trust can only be rebuilt if test laboratories can deliver reliable SI-traceable test results of photometric quantities, which meet the demands of industry and customers, for a large range of diverse LED-based light sources. Statements on uncertainty assessment to improve the evaluation of LED products became mandatory in the first worldwide accepted standards CIE S 025:2015 and EN 13032-4 on test procedures for LED based lamps, luminaires and modules published by the International Commission on Illumination (CIE) and the European Committee for Standardization (CEN). However, these standards are incomplete, as there is still no validated procedure available to assign measurement uncertainties, at test laboratory level, for some listed measurement quantities and metrological procedures.

Requirements and boundary conditions for precise image-based luminance measurements and concepts for evaluating the uncertainty of typically correlated spectral measurement data are of high importance for test laboratories to determine the real performance of LED-based sources. Although prerequisites for the application of the standards are well established, respective guidelines are not available. Moreover, a suitable harmonised metric including associated tolerances for a target/actual performance comparison of luminous intensity distributions of LED-modules or luminaires is also missing.

Photometers, i.e. illuminance and luminance meters, are ubiquitous metrological devices in lighting, being used by a wide range of lighting professionals from designers to electricians, for testing installations on performance, compliance and utility. But these meters typically include significant errors that cannot be neglected, namely in the measurement of LED-based lamps. To estimate the spectral mismatch of the response of the photometers (in relation to standardised efficiency of the human eye) within a measurement setup, the so called *f*1’ index defined in ISO/CIE 19476:2014 can be used according to EN 13032-4. However, the metric i.e., the mathematical equation for determining *f*1’ is deemed to be not the most appropriate for LED light sources. Therefore, it must be clarified whether a new mismatch index for recently defined LED reference spectra must be developed and if it will be applicable for coloured LEDs and for the revision of ISO/CIE 19476:2014, CIE S 025:2015 and EN 13032-4.

The CIE has identified these issues as one of their research priorities.

**Objectives**

The overall goal of the project is to deliver metrics and procedures as well as guidance on metrology issues, and to make existing CIE and CEN test standards for LED-based light sources applicable to testing laboratories as a whole. The specific objectives are:

1. To develop a strategy for the evaluation, validation and traceability of spatially and angularly resolved luminance and luminous intensity distributions of LED-based lamps, luminaires, and modules. This should be based on measurements using imaging luminance measurement devices (ILMDs). Additionally, to develop guidelines on the determination of uncertainty and tolerance intervals required in the revision of CIE S 025:2015.
2. To develop guidelines on the estimation and uncertainty of i) the spectral mismatch of integral (filtered) measurements for sources emitting coloured light, and ii) integral quantities derived from spectral measurements. Additionally, to propose an extension of CIE S 025:2015 and EN 13032‑4 for an alternative spectral mismatch quality index, based on the new LED reference spectrum published in CIE 15:2018 for white LEDs.
3. To propose a harmonised metric to compare luminous intensity distributions, including the definition of the associated tolerance intervals and uncertainties, with a focus on test methods that require the declaration of measurement uncertainties.
4. To contribute to the revision of CIE S 025:2015 / EN 13032-4 through CIE Division 2, CEN/TC 169 and IEC TC 34. Outputs should be in a form that can be incorporated into the standards at the earliest opportunity and communicated through a variety of media to the standards community and to end users. Additionally, to promote the take up of the results by end users e.g. manufacturers of LED-based sources.

**Progress beyond the state of the art**

The ability to indicate light distributions, tolerances and measurement uncertainties, is a prerequisite for the comparison of different lighting products with respect to their use in different applications. The strategy developed in this project for the evaluation, validation and traceability of spatially and angularly resolved luminance and luminous intensity distributions is therefore based on the separation of requirements of different applications in order to provide generalised but application field specific solutions for traceability.

The spectral mismatch of photometers often leads to unexpected errors when measuring LED sources. Using array spectroradiometers instead of photometers is an option, but this often fails due to unknown correlations in the measurement chain, when uncertainties of a few percent are required. To make the occurrence of correlations visible to users of reference instruments, participating laboratories will for the first time start to identify correlations in their traceability chain, to provide this information to their customers with guidelines and methods for further use. This is of special importance to determine reliable colour coordinates of coloured sources and the spectral mismatch correction factor including its uncertainty. A procedure will be tested and made available to provide information about most likely impact off (hidden) correlations on the uncertainty of integral quantities derived from spectral measurements even if no correlations are explicitly declared, e.g. based on auxiliary measurements. The method is based on a Monte Carlo simulation in which orthogonal basis functions are added to the spectral distribution to be measured, weighted by the uncertainties of the spectral data. In this way, it is possible to provide correct estimates of the uncertainties of spectrally integrated quantities on the user side, even if the calibration laboratory does not provide an explicit correlation matrix.

For white light, it turns out that the idea of an alternative spectral mismatch quality index would be only of little use. Instead, the ability to use additional calibration reference spectra, e.g. based on the new LED reference spectrum L41, soon to be published by CIE in addition to Illuminant A, would extend the scope of application and will enable the user to classify the performance of photometers used for measurements of non-tungsten-filament lamps.

The ability to compare light distributions is of high importance for customers and lighting designers to choose the best suitable product for their installations.

This project has developed a generic metric from a set of defined parameters describing the symmetry, envelope and size of the light distribution created by LED lamps, modules and luminaires.

ILMDs are currently adjusted and calibrated using luminance standards that are assumed to be ideally homogeneous. This is critical for metrological traceability and can lead to large measurement errors for large fields of view. To solve this problem and as a new backbone for the characterisation/calibration of luminance standards used for the calibration of ILMDs, special ILMDs characterised via a photogrammetry procedure are therefore being developed as transfer standards.

This project has started building open-access software tools that will be available on GitHub to provide calibration laboratories with an easy entry into uncertainty assessment based on Monte Carlo methods. The latter are necessary to provide reliable and traceable measurement results for complex photometric and radiometric measurands.

**Results**

*Evaluation, validation and traceability of spatially and angularly resolved luminance and luminous intensity distributions*

A survey on the metrological requirements of luminance measurement using ILMDs was conducted amongst the partners to identify the metrological peculiarities in a variety of applications. A tabular list of more than thirty different applications was compiled, including parameters relevant for the characterisation and measurement uncertainty. In parallel and with involvement of the consortium, CIE TC 2-86 is reviewing glare evaluation reports and CIE TC 2-95 is assembling an application list regarding measurement of obtrusive light; both domains include also ILMDs. In May 2021 (M09), CIE published the technical report CIE 244:2021 “Characterization of imaging luminance measurement devices (ILMDs)” to which members of the consortium had contributed as authors. The 21 quality indices defined in this document describe the behaviour of an ILMD with respect to various measurement parameters. For each application, the most important ILMD quality indices as provided by CIE 244:2021, is now going to be elaborated by partners and will be used in the further course of the project to determine the boundary conditions for dedicated calibration procedures and the respective uncertainty assessment.

A metrology-oriented group of application was identified which is deemed to be the backbone for those user applications which require the calibration of ILMDs via uniform luminous standards for an extended field of view. This group of application is the calibration of the partial luminance distribution of large area luminance standards using specially characterised ILMDs for this purpose.

A method for investigating the pixel signal non-linearity inside different measurement ranges (namely not just by varying the integration time) of ILMDs over a very large luminance range of more than six orders of magnitude was developed and is being tested. The linearity evaluation of different ILMD models clearly indicates that the characteristic saturation (namely at low luminance and therefore long integration times) is due to the accumulation mode and dominated by the I-V curve of the pixel diode itself. The results were presented in CIE Midterm Conference 2021 and are being used to find a suitable model for the thorough pixel signal characteristic over a huge luminance range, going beyond the linear dependence on the integration time as assumed in CIE 244:2021 and CIE 237:2020. In parallel, mandatory uncertainty components are being estimated from noise analysis by statistics on the dark signal per pixel.

First investigations of the angular dependent stray-light characteristic of ILMDs using a small (pixel sized) luminance source and a positioning system based on an industrial robot demonstrate ghosts, stray-light offset and diffraction spikes with a few percent of the incident luminous flux.

A general model of evaluation for ILMDs based on the analysis of pixel counts (i.e. raw data) was developed and is currently being discussed within the consortium with respect to its use within ILMD applications.

*Guidelines on the estimation and uncertainty of the spectral mismatch and integral quantities derived from spectral measurements*

The consideration of the (often complex) correlations within spectral measurement data in the calculation of integral quantities is essential. With the aim to harmonise the different approaches used by participating NMIs, reports and internal tutorials on the treatment of measurement uncertainties using Monte Carlo simulations, as well as software code for the consideration of correlations written in Python, were developed and shared within the consortium. Python, as open-source software providing libraries and modules to deal with Monte Carlo, correlations and statistics, was chosen as the common software tool to determine measurement uncertainty. These libraries and the software tools provided by the consortium for measurement data analysis are being continuously updated during the project and made available on the GitHub development platform (https://github.com/empir19nrm02). In order to share the information with the project stakeholders, a summary report on current and future calibration strategies of the NMIs and DIs involved in the survey was published to the download area of the project website and a guideline for the development and distribution of correlation matrices is in preparation. A Good Practice guide (GPG) for calibration laboratories is currently being developed, that includes the creation of models of evaluation and the minimum requirements for test setup as the basis for a sound uncertainty budget. Work procedures required to perform trustable measurements will be provided. To setup a strong link of this project outcome to the chief stakeholder CIE, a member of the project consortium was selected to chair the new technical committee CIE TC2-97, established in May 2022, to revise the CIE standard CIE S 025. Moreover, it was achieved that the revision of CEN standards EN 13032-4, which is based on the CIE S 025, is set on halt until the revision of the CIE S 025 is close to final. This is important to ensure that both the international CIE S 025 and the European EN 13032-4 remain harmonised. In the spring of 2022, a new working group was established at the CIE Division Management level, which includes CIE Division 2 Board, Consortium members of 19NRM02 RevStdLED, and the TC Chair who was responsible for CIE S 025. This group will structure the work on the most burning questions on how to make uncertainty evaluation in CIE S 025 usable for end-users.

In order to compare the results of spectrally measured photometric quantities measured in partner laboratories taking into account correlations, an interlaboratory comparison is currently being performed with six LED-based standard lamps.

A document describing the rationale for a complementing spectral mismatch index for LED light sources, which also discusses the potential impact on existing applications and measurement uncertainty calculation, was published at the CIE midterm meeting 2021. The current status of the work on the complementing spectral mismatch index carried out in this project has been forwarded to the i) CIE reportership DR 2-89 on the "Definition of a complementary general *V*(*l*)-mismatch index", which targets the revision of standards CIE 19476:2014(E) and CIE S 025/E:2015, and to ii) Technical Committee TC 2-96, which targets the revision of ISO/CIE 19476. These two committees are chaired by members of the project’s consortium and were both established within CIE Division 2 in early 2021.

The outcome of the investigations on the mismatch index are summarised in conference proceedings and peer reviewed journals (Ferrero & Thorseth A, 2021) (Krüger et al. 2021) (Krüger et al. 2022). The most unexpected result is that there will be practically no benefit from redefining the metric of the general spectral mismatch index *f*1’, but it would make a huge difference if the calibration source, which is currently defined as Illuminant A only, will be changed to Illuminant L41. All calculations are based on a huge data set which also includes data from 15SIB07 PhotoLED (see: https://doi.org/10.11583/dtu.12783389.v1) and can be retraced using the freely accessible software and data via the EMPIR 19NRM02 GitHub project (https://github.com/empir19nrm02)). The results have been summarized in reports and publications made available by the EURAMET repository ([https://www.euramet.org/repository](http://?)) and the recommendation has been officially forwarded to CIE via reportership DR 2-89.

*Harmonised metric for luminous intensity distribution*

As a prerequisite to describe spatial distributions of light, a model for geometrical dependencies of a generic goniophotometer was developed and was presented at the NEWRAD meeting and at the CIE midterm meeting in 2021. In this model, the description of coordinate systems and relations between goniophotometer pose, source and detector are described by Denavit Hartenberg (DH) parameters. The propagation of the geometric uncertainties including correlations takes place by consecutive transformation of the coordinate systems of the source and receiver in relation to a device coordinate system.

The final results of the geometric analysis for the case of ILMD-based luminous intensity distribution (LID) measurements using Monte-Carlo simulations are submitted and published as a peer reviewed paper in the conference series of the Journal of Physics (see: https://doi.org/10.1088/1742-6596/2149/1/012015).

Based on the findings published in the article, further investigations were carried out on the influence of the centre of light on the uncertainty of the spatial luminous intensity distribution. For this purpose, the LID standards developed in the project were measured with their describable characteristic LIDs on different goniometer methods.

It turned out that all goniometers show the same expected qualitative behaviour, whereby near-field goniometers (equipped with ILMDs), on the other hand, are significantly less sensitive to shifts in the centre of gravity of light relative to the centre of the goniometer than conventional far-field goniometers with a measuring distance of several metres. However, it proved to be a challenge to determine the effective centre of light for any direction. In fact, it turned out that the quantitative behaviour can only be derived from the measurement data alone for near-field goniometers. With far-field goniometers, knowledge about the LID of the object is required in advance. This raises the problem that measurement uncertainties of the LID cannot be determined for far-field goniometers without in-depth knowledge about the LID itself.

**Impact**

To increase visibility, the project website (https://www.ptb.de/empir2020/revstdled) was created shortly after the start of the project.

As the dissemination of results to CIE as the chief stakeholder is of utmost importance, the project focused on the establishment of reporterships and technical committees in CIE under the leadership of partners and collaborators of this project. In addition, various members and collaborators of the consortium are also members of the relevant committees of the national standardising bodies and thus promote the dissemination of the project results to the corresponding bodies at ISO and CEN via national representatives.

First results were already presented at the online conference Licht2021 in March 2021 (https://www.licht2021.de). Further progress was submitted and presented at the CIE Mid-Term Conference 2021, held in September 2021 (https://malaysia2021.cie.co.at/). A total of 12 posters and oral presentations were given, including a general overview of the project and two oral presentations at a CIE workshop on the revision of ISO/CIE 19476 and CIE S 025 led by the RevStdLED project coordinator. The current status of the work in the project’s work packages was presented at the first RevStdLED stakeholder meeting, which took place on 7 October 2021 with 11 stakeholders from UK, Belgium, Italy, Austria and Germany. Due to the pandemic, all conferences and meetings were held online. In addition to these impact activities, other stakeholders important for the project, such as the chief stakeholder CIE Division 2, EURAMET TCPR, DIN and CEN/TC 169/WG 7, are also regularly informed about the status of the project through their contact persons and at their annual meetings with reports or PowerPoint presentations from the 19NRM02 RevStdLED project. In this context, the associated with the mismatch index f1’ (as described above) was discussed with stakeholder during the TC2-96 Technical Committee meeting (responsible for the revision of ISO/CIE 19476) at the Division 2 Conference in Athene in Oct. 2022.

Additionally, three open-access peer-reviewed papers have already been published and one other has been submitted and approved for publication.

*Impact on industrial and other user communities*

Since tungsten filament lamps were banned, LED based lighting products are the general lighting market's most rapidly evolving light sources. Test laboratories are therefore faced with a wide variety of different LED based light sources, for which reliable test results based on SI traceable measurements of photometric quantities are required to meet the demands of industry and have not yet been comprehensively developed. Standards CIE S 025:2015 and EN 13032-4 pave the way to improve the quality of lighting products by introducing the concepts of measurement uncertainty declarations and acceptance intervals, as mandatory requirements in test standards for LED based light sources. However, procedures to determine uncertainties especially if spectral measurements take place are missing. This project will fill the missing gap and provide the appropriate procedures and the distinctive guidance necessary for a full implementation of the standards on test laboratory level.

For testing laboratories, luminance is increasing in significance for instance in relation to glare. As the use of the LED becomes ubiquitous, considerations of luminance distribution increases in significance, for instance for arrays of bright LEDs. Traceability of luminance measurements is important to gain the confidence of the market. The developed techniques and procedures will be shared with industry and test laboratories at stakeholder meetings and workshops to be organised by this project (face to face and online)

Training activities are scheduled for i) May 23-24, 2023, at PTB, Germany, as hands-on training on characterisation and calibration of ILMDs; ii) August 22-23, 2023, at TUBITAK, Turkey, as hands-on training on spectral measurement methods for photometric quantities; and iii) on July 24, 2023, as an online training on uncertainty determination of spectrally integrated quantities. In particular, the online training on the determination of the uncertainty of spectrally integrated quantities will be open to all interested parties. Here, supported by the software modules stored on GitHub, we will present the developed guidelines.

*Impact on the metrology and scientific communities*

Since the adoption of the Guide to the Expression of Uncertainty in Measurement (GUM), the reliable determination of uncertainties is a main aspect in scientific metrology. However, in the field of testing, the use of uncertainty calculations is mostly disregarded because it is expected that any uncertainties will be covered by appropriate allowed tolerances given to the measured quantities. In many cases, this is highly justified. But in cases where the influence of details in the measurement setups on the magnitude of quantities is high, the consideration of uncertainties even in testing environments are necessary. To address this, the consortium will provide a special training course to test laboratories staff to give participants a deep insight into measurement procedures and appropriate models for the evaluation of measurement uncertainty that can be used in routine testing environments. The training is scheduled as an online course on uncertainty determination of spectrally integrated quantities on July 24, 2023.

The triumph of digital cameras used for 2D-photography also paved the way for metrological cameras, so called imaging luminance measuring devices (ILMDs), used to measure 2D-distributions of light from a source or illuminated objects. This project will provide calibration procedures that enable fully traceable measurements in selected applications, for the first time. Thus, it will enable the entry of this innovative measuring technology into precision metrology.

Recommendation CIE 198:2011 is the basic document of CIE on uncertainty analysis in photometry and radiometry. The recently published supplement CIE 198-SP2:2018 provides an analytical background for further processing of spectral data taking into account correlation. However, the analytical approach detailed here is far too complex to be useful for testing laboratories. The methods to be provided by this project, based on Monte Carlo simulation, will be more applicable and much easier to implement with the aid of the guidelines in practical metrology that take into account the handling of correlation and metadata in future digital calibration certificates. In addition, a procedure will be made available to this community to provide information about most likely impact of (hidden) correlations on the uncertainty of integral quantities derived from spectral measurements, even if no correlations are explicitly declared, e.g. based on auxiliary measurements.

*Impact on relevant standards*

In order to feed the work of this project into the relevant technical committees of CIE Division 2, the reportership DR 2-89 “Complementary mismatch index” was set up under the leadership of a partner of the consortium.

DR 2-89 will officially feed information from RevStdLED into TC2-96 “Revision of ISO/CIE 19476:2014 “Characterisation of the performance of illuminance meters and luminance meters”, which was established in CIE Division 2 after approval by ISO TC 274 in March 2021. TC2-96 is chaired by the coordinator of RevStdLED and its kick-off meeting took place in May 2021. It currently consists of 22 international members from 11 countries around the world, including 9 consortium members and 2 project collaborators. Since its establishment, in total 6 TC meetings were held.

In addition, another partner of this consortium, who is currently chair of CIE TC 2-93 on the revision of ISO 23539/CIE S 010 "Photometry- The CIE System of Physical Photometry", has also been elected as chair-designate of the new CIE TC 2-97 that will work on the revision of CIE S 025.

Members of the consortium and its collaborators are also involved in the following technical committees and reporterships of CIE, which deal at least in part with the topics of this project:

* CIE TC2-93: Standard on the “Revision of ISO 23539:2005(E) / CIE S 010/E:2004 Photometry - The CIE system of physical photometry”. This TC focuses on the basic definitions and defined distributions in photometry; it is chaired by DTU and three members of the consortium are involved.
* CIE TC2-90: Report on “LED Reference Spectrum for Photometer Calibration”. This TC defines a reference spectrum for LED light sources which is based on the output of the EMPIR Project 15SIB07 PhotoLED and is therefore strongly connected to Objective 2 of this project. Four project partners are involved in this.
* CIE TC2-95: Report on “Measurement of Obtrusive Light and Sky Glow”. This TC includes the measurement of light using ILMDs and is therefore connected to Objective 1 of this project. Two partners of the consortium are involved in this.
* CIE TC2-62: Report on “Imaging photometer-based near-field goniophotometry”. This TC deals with the boundary conditions for the use of ILMDs in goniometer systems and is connected to Objectives 1 and 3 of this project. Three project partners are involved in this.
* CIE TC2-86: Report on “Glare Measurement by Imaging Luminance Measurement Device (ILMD)” (three members and one collaborators of the consortium involved). This TC is connected to Objective 1 of this project and two project partners and one collaborator are involved in this.
* CIE DR2-90 Reference spectra and metrics for software validation (chaired by METAS, a collaborator)
* CIE TC2-89: Report on: “Measurement of Temporal Light Modulation of Light sources and Lighting Systems”, This report refers to CIE S 025 and Iso/CIE 19476 with respect to measurement conditions and quality indices. Three project partners are involved.
* CIE TC2-86: Report on Glare Measurement by Imaging Luminance Measurement Device (ILMD). This TC deals with a very important measurement application for ILMDs and is therefore connected to Objective 1 of this project. RevStdLED will provide at least the minimum requirement necessary to calibrate ILMDs for this application.

As mentioned above, the international standard CIE S 025:2015 is up for its first revision and this project aims to increase its uptake by test laboratories by proposing revisions that will aid testing in routine test environments, thereby increasing its scope, to include commonly used methods and equipment, and improved guidance for the estimation of uncertainties for laboratories. As CEN/TC 169/WG 7 will postpone the revision of the European standard EN 13032-4, until the CIE S 025 will be revised, there is a good chance that both standards will be harmonised again. Resulting from planned regular consultation and exchanges between the consortium and standards organisations CIE and CEN (via national representatives), most of the guidelines and procedures that will be developed in this project will be suitable for direct use by the respective standardisation committees. In the meantime, the CIE has formed TC2-97 to revise the CIE S 025 standard, with the 19NRM02 RevStdLED project specifically mentioned in the CIE Division 2 proposal as a stakeholder for TC2-97. The chair of TC2-97 is in turn an active member of the 19NRM02 RevStdLED consortium, and other partners in the consortium have signed up for membership in the TC. In addition, the partners continue to seek memberships in other relevant technical committees established at CIE and CEN to support the publication of revised and new standards.

As some members of the American Illuminating Engineering Society (IES), responsible for the standard IES LM-79-19, will also be members of the CIE committee on the revision of the CIE S 025 to be established. So the outcomes of this project, which will be forwarded to CIE, will also have influence on the next revision of the IES LM-79.

By improving metrological transparency and trust, the project results will support EU regulatory initiatives on lighting products, specifically the European Union's energy labelling and ecodesign requirements applied to lighting product, planned to take effect in September 2021.

*Longer-term economic, social and environmental impacts*

The confidence in the performance of lighting products relies on the reliability of test procedures provided by standards such as the CIE S 025:2015, where the standard needs to cover the full spectra of product capabilities to provide reliable test results. Appropriate standards and test procedures will provide consumers and end-users with reliable information, so that they are able to choose and purchase products which best fit to their applications. Consumers will have better characterisation on which to base purchase decisions, thus helping avoid dissatisfaction and reducing unnecessary environmental waste and increasing product satisfaction in the longer term.

Using innovative instrumentation (such as ILMDs) supported by updated standards for characterisation and testing will allow more reliable and comprehensive product specifications, so that requirements for light installations due to current and future regulations can be more easily met. In the longer term, this will improve urban lighting and reduce unnecessary light emission also known as light pollution and obtrusive light.

**List of publications**

M Kantona, K Trampert, C Schwnengel, U Krüger, C Neumann; „Geometric system analysis of ILMD-based LID measurement systems using Monte-Carlo Simulation”; Journal of Physics: Conference series 2149 (2022); <https://doi.org/10.1088/1742-6596/2149/1/012015>

Ferrero, A., & Thorseth, A. (2021). IMPACT OF THE NORMALIZATION OF THE SPECTRAL RESPONSIVITY ON THE PERFORMANCE OF THE GENERAL V() MISMATCH INDEX. In Proceedings of the Conference CIE 2021 CIE - International Commission on Illumination; doi: 10.25039/x48.2021.PO20

Krüger, U., Ferrero, A., Mantela, V., Thorseth, A., Trampert, K., Pellegrino, O., & Sperling, A. (2022). Evaluation of different general V(λ) mismatch indices of photometers for LED-based light sources in general lighting applications. *Metrologia*, *59*(6), 065003. https://doi.org/10.1088/1681-7575/ac8f4d

This list is also available here: https://www.euramet.org/repository/research-publications-repository-link/

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| Project start date and duration: | | 1 September 2020, 36 months | |
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| Chief Stakeholder Organisation: Commission Internationale de l'Eclairage (CIE) | | Chief Stakeholder Contact: Kathryn Nields, Tony Bergen | |
| Internal Funded Partners:   1. PTB, Germany 2. Aalto, Finland 3. CSIC, Spain 4. IPQ, Portugal 5. LNE, France 6. TUBITAK, Turkey | External Funded Partners:   1. DTU, Denmark 2. KIT, Germany 3. NSC-IM, Ukraine | | Unfunded Partners:   1. candelTec, Spain 2. JETI, Germany 3. NMISA, South Africa 4. TechnoTeam, Germany |
| RMG: - | | | |