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COMMISSION INTERNATIONALE DE L'ECLAIRAGE
INTERNATIONAL COMMISSION ON ILLUMINATION
INTERNATIONALE BELEUCHTUNGSKOMMISSION

TECHNICAL REPORT

ON SITE MEASUREMENT OF THE PHOTOMETRIC PROPERTIES OF ROAD AND TUNNEL LIGHTING

CIE 194:2011

UDC: 628.971.6
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Descriptor: Street lighting (fixed)
Lighting of tunnels

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3. Richtlinien für die Anwendung von Prinzipien und Vorgängen in der Entwicklung internationaler und nationaler Normen auf dem Gebiet der Lichttechnik zu erstellen.
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Alle vier Jahre findet eine Session statt, in der die Arbeiten der Divisionen überprüft, berichtet und neue Pläne für die Zukunft ausgearbeitet werden. Die CIE wird als höchste Autorität für alle Aspekte des Lichtes und der Beleuchtung angesehen. Auf diese Weise unterhält sie eine bedeutende Stellung unter den internationalen Organisationen.

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This Technical Report has been prepared by CIE Technical Committee 4-26 of Division 4 "Lighting and Signalling for Transport" and has been approved by the Board of Administration of the Commission Internationale de l'Eclairage for study and application. The document reports on current knowledge and experience within the specific field of light and lighting described, and is intended to be used by the CIE membership and other interested parties. It should be noted, however, that the status of this document is advisory and not mandatory.

Ce rapport technique a été élaboré par le Comité Technique CIE 4-26 de la Division 4 "Eclairage et signalisation pour les transports" et a été approuvé par le Bureau de la Commission Internationale de l'Eclairage, pour étude et emploi. Le document expose les connaissances et l'expérience actuelles dans le domaine particulier de la lumière et de l'éclairage décrit ici. Il est destiné à être utilisé par les membres de la CIE et par tous les intéressés. Il faut cependant noter que ce document est indicatif et non obligatoire.

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ON SITE MEASUREMENT OF THE PHOTOMETRIC PROPERTIES OF ROAD AND TUNNEL LIGHTING

SUMMARY

This Technical Report gives the information which designers and users of automatic systems intended to measure the photometric properties of road and tunnel lighting systems need in order to understand the performance of such systems. The main aim of this guide is to clearly define and describe the technical limitations and characteristics of these measurement systems. In this way the advantages and disadvantages of the technical solutions adopted in different systems can be assessed. Their measurement uncertainty can be evaluated and discrepancies understood when the measurement results are compared with those obtained by manual systems or by theoretical evaluations from mathematical algorithms and/or computer simulations. The guide concentrates on systems that measure horizontal illuminance and luminance on road surfaces, but much of the guidance is relevant to other quantities and measurement conditions, too. The guide is divided into two parts:

- Review of essential photometric quantities where differences between their physical or normative definition, their mathematical evaluation and their measurable approximation are highlighted (Clause 2 and Clause 3);
- Review of the types and characteristics of instruments, the conditions and methodologies of measurements, the evaluation of uncertainty in measurement results and data elaboration (Clause 5, Clause 6 and Clause 7).

SYSTEMES DE MESURES SUR SITE DES PROPRIETES PHOTOMETRIQUES DES INSTALLATIONS D'ECLAIRAGE DES ROUTES ET TUNNELS

RESUME

Ce rapport technique apporte l'information nécessaire aux concepteurs et utilisateurs des outils de métrologie dynamique pour la mesure des propriétés photométriques des installations d'éclairage des routes et tunnels. Le principal objectif de ce guide est de définir précisément et de décrire les limites techniques et les caractéristiques de ces outils de mesures. Ainsi, les avantages et inconvénients des solutions techniques adoptées par les différents systèmes de mesures peuvent être évalués. Leur(s) incertitudes sur les mesures peut(vent) être évaluées; les écarts avec les mesures statiques ou les évaluations théoriques issues des algorithmes mathématiques et/ou les outils de simulation sur ordinateur peuvent également être comprises. Le guide se limite aux instruments de mesures des éclairagements horizontaux et des luminances sur la chaussée, mais une grande partie des informations peut s'appliquer aussi à d'autres grandeurs et conditions expérimentales. Le guide est composé de deux parties:

- Recensement des grandeurs photométriques principales pour lesquelles les différences entre leur définition physique ou normative, leur évaluation mathématique et leur détermination au moyen de mesures sont mises en évidence (sections 2 et 3);
- Recensement des types et caractéristiques des instruments, des conditions et méthodologies expérimentales, des évaluations des incertitudes sur les mesures et sur les détermination des paramètres qui en découlent (sections 5, 6 et 7).

SYSTEME ZUR VORORTMESSUNG DER PHOTOMETRISCHEN EIGENSCHAFTEN VON STRASSEN- UND TUNNELBELEUCHTUNG

ZUSAMMENFASSUNG

Dieser Technische Bericht liefert Informationen, die Planer und Nutzer automatischer Systeme zur Messung photometrischer Eigenschaften von Straßen- und Tunnelbeleuchtungsanlagen benötigen, um die Leistungsmerkmale solcher Systeme zu verstehen. Hauptsächliches Ziel dieses Leitfadens ist die Definition und Beschreibung der technischen Grenzen und Eigenschaften dieser Messsysteme. Auf diese Weise können Vor- und Nachteile der in verschiedenen Systemen eingesetzten technischen Lösungen abgeschätzt werden. Ihre Messunsicherheit kann bewertet werden, und Abweichungen können nachvollzogen werden, wenn die Messergebnisse mit denen von manuellen Systemen oder theoretischen Berechnungsergebnissen über mathematische Algorithmen und/oder Computersimulationen verglichen werden. Der Leitfaden konzentriert sich auf Systeme, die horizontale Beleuchtungsstärken und Leuchtdichten auf Straßenoberflächen messen, ein Großteil der Anleitung bezieht sich aber auch auf andere Größen und Messbedingungen. Der Leitfaden ist in zwei Abschnitte unterteilt:

- Überblick über grundlegende photometrische Größen, wobei Unterschiede zwischen ihrer physikalischen und normativen Definition, ihrer mathematischen Bewertung und ihrer messbaren Approximation herausgestellt werden (Kapitel 2 und Kapitel 3);
- Überblick über Typen und Eigenschaften von Instrumenten, Messbedingungen und -methodiken, Bewertung der Ergebnisunsicherheit und Datenauswertung (Kapitel 5, Kapitel 6 und Kapitel 7).

1 INTRODUCTION

1.1 Preamble

The TC 4-26 "Systems for Measurement of Photometric Quantities of Road Lighting Installations" was activated in 1991 with the following terms of reference:

"To produce a guide to automatic measurement systems for the metrological characteristics of road and tunnel lighting"

and the following working programme:

- To review the automatic measurement systems currently being used or developed.
- To review the essential photometric quantities required from an automatic measurement system to adequately describe or specify a lighting system.
- To produce a "Guide" to enable automatic measurement systems to be specified.

The TC was formed in response to the growing need to describe the technical limitations and/or improvements in specially designed automatic static and mobile measurement systems for the on site photometric measurement of road and tunnel lighting .

The formation of this TC was justified by several reasons. The most important is that today automatic measurement systems are able to carry out the analysis of the performance of a lighting system with a large number of measurement points or directions of observation.

In contrast, the parameters or photometric quantities normally used to characterise a road lighting installation are defined with regard to the limitations of manual measurement systems and thus with a limited number of measurement points. Therefore these parameters should be reviewed, and specifications and procedures should be provided to evaluate the uncertainty of the measurements obtained with automatic systems.

The TC was not involved in the definition of the necessary parameters or techniques to characterise a particular photo-detector from the photometric point of view. However, the TC was interested in the measurement problems arising when that detector is used to characterise a lighting system, i.e. the acceptable accuracy, the geometrical measurement conditions, the elaboration algorithm of the measured data, etc.

At the beginning of its activity the TC tried to consider in this guide all the types of measurement and characterisation for lighting engineering that a particular automatic system can carry out in a road, from illuminance on the road surface to glare or road markings. However, during the period of activity of the TC, many of international and national standards were in a process of change, and due to the desire to complete the guide within a reasonable time, it was decided that the report should only consider systems for measuring road surface and tunnel wall illuminance and luminance.

The systems not considered here will eventually be dealt with in another report, but some of the general information in the first part of this guide is relevant for these systems.

1.2 The Need for On Site Photometric Measurements of Road Lighting

The need to perform on site photometric measurements of road lighting systems has increased through the years with the simultaneous development of standards and the increase in the level of technical sophistication of lighting systems.

One or more of the following measurements are often carried out:

- a) in the final testing phase, to verify the correlation between the system performance and the design values, and for its formal approval;
- b) at pre-determined intervals during the system lifetime, to quantify the degradation of the lighting performance and to define the need for maintenance action;
- c) continually, in systems capable of regulating the illumination conditions as a function of measurable photometric parameters of interest (e.g. internal level of illumination as a function of outside luminance in tunnel entrance);

- d) for the purpose of research, essentially to investigate the actual visual conditions under a particular lighting system or as a comparison between different design approaches or visibility models.

Normally the photometric parameters of interest are defined by international [1], [2], [3], [4] or national (e.g. [5]) standard-setting bodies and by CIE itself [6], [7], [8], [9], [10], sometimes together with generic description of usable measurement systems and with the geometric conditions that have to be met. In fact, these procedures are defined with a very limited number of measurement points, assuming manual data collection and elaboration techniques.

In cases a) and b), the following parameters must be measured:

- the vertical and/or horizontal illuminance at ground level and at different heights on the carriageway;
- the vertical illuminance on the walls (if there are any);
- the luminance of the road surface and of any walls that may be present, in accordance with the usual vision angles (often specified by standards);
- the luminance of light sources and/or the illuminance on the observer's eye to evaluate glare;

and the following parameters must be evaluated:

- the average value of these quantities in pre-defined areas;
- the transverse and longitudinal uniformity seen as ratios between the minimum or maximum values and the average value;

with the intention of providing a small number of evaluation parameters, and at the limit a single overall parameter (quality parameter) of the system condition and photometric performance.

For the sake of completeness, in the same circumstances the on site photometric measurement of the lighted environment could be extended; in particular it could include signage devices such as retroreflectors and traffic signs, horizontal road markings and the road surface. The measured quantities in these cases are essentially reflection factors or luminance coefficients, acquired with particular geometries of the incident and reflected light.

In case c), a continuous recording is carried out of one or more photometric parameters, either directly measurable or one that can be calculated from measurable quantities, through a defined algorithm. The values obtained, acting on a control feedback loop, directly influence the feed parameters and the functioning conditions of the light sources installed in the lighting system. The purpose is to vary the performance of the system as a function of pre-determined external conditions (outside luminance, traffic conditions, etc.) so as to maintain constant the conditions of vision or safety while saving energy, maintenance and upkeep costs. These measured photometric parameters can also be communicated in units different from those in SI (International System) [11] acquired following non-standard geometries and procedures, as only their correlation with the controlled parameters needs to be known. Thus instrument calibration and traceability is not essential, but stability, repeatability and a real evaluation of the transfer function between the measured signal, the controlled parameter of the plant (i.e. the emitted luminous flux) and its performance are key factors.

Case d) is not subject to generic formulations and will not be directly covered in this guide. However, the information provided may be useful to researchers wishing to better formulate the metrological requirements on the system, the research methodology or the limits of the results obtained.

The measurement uncertainties, accuracies and methodologies have to be appropriate to the particular measurement situations:

- in the final testing phase, measurements have to be carried in full compliance with the requirements of standards or following design constraints, and with adequate uncertainty

levels [12], as otherwise they could cause seriously incorrect evaluation of lighting system performance, and the results may be challenged;

- at pre-determined intervals through the lifetime of the system, the measurements may be carried out using non-standard measurement positions or with different steps, as long as they are repeatable, and with uncertainty levels adequate to the needs (i.e. correct alignment of luminaires, maintenance actions, etc.). These results could be compared with the results obtained, in the same measurement conditions, when the lighting system was new or in the final testing phase, to obtain a realistic and accurate evaluation of system performance at low measurement cost;
- to regulate the lighting system behaviour, absolute accuracy in the instrumentation is of little importance, compared with the need for repeatability, consistency over time, and most importantly actual correlation of the measured parameter with the regulated parameter.

Devices in the lighted environment or the road surface can also be photometrically measured on site with specially developed instrumentation, but generally a complete set of measurements of signs and other retro-reflective or signalling devices, both active or passive, according to standards and with a high level of accuracy, is only possible in controlled laboratory situations and with adequate instrumentation. Although this situation is changing with the introduction of new devices, currently on site measurement activity consists only of:

- relatively low accuracy measurements, compared to typical laboratory measurements carried out with geometries similar to the standard ones but with greater tolerances;
- the evaluation of the actual behaviour of the system, considering non-standard on site measurements that could be correlated with some values measured in the laboratory (e.g. illumination/luminance ratio for a particular point of the road surface and direction of vision);
- measurements with geometries similar to the standard ones, but limited in some parameters, such as measurement distance, measurable angles, source dimension, etc. (These results could be compared with measurements carried out in the same conditions with new or reference devices).

The main purposes of these measurements are, for example, for assessing the deterioration of devices during the installation phase, or verifying their correct alignment with respect to the road surface and axes, or assessing their ageing over time to evaluate the need for or effectiveness of maintenance actions.

1.3 Automatic Measurement Systems

This guide only considers automatic systems able to perform on site photometric measurements. A number of classifications of measurement systems could be proposed, according to their technical characteristics, types of sensors used, quantities measured or conditions of use.

The classification system shown in Figure 1.1 is proposed: it was suggested by considerations both of application and of technology. While the choice between one system and another is made essentially by application considerations and measurement accuracy, at the current state of the art each system type requires substantially different technologies and has different costs.

The definitions of the categories in Figure 1.1 are explained in Clause 2.

An automatic system can measure quantities following strictly a standard or with ad hoc geometries and constraints. When a single photometric parameter is derived from a number of measurements (i.e. mean value, uniformity, etc.), standards usually suggest a limited number of measurement points or directions. Automatic systems can carry out a deeper investigation considering a great number of measurements acquired simultaneously (see 3.3). For these reasons, to avoid ambiguity, and to achieve the greatest benefit from automatic systems, a clear definition of the relevant quantities and parameters is given in Clause 2.

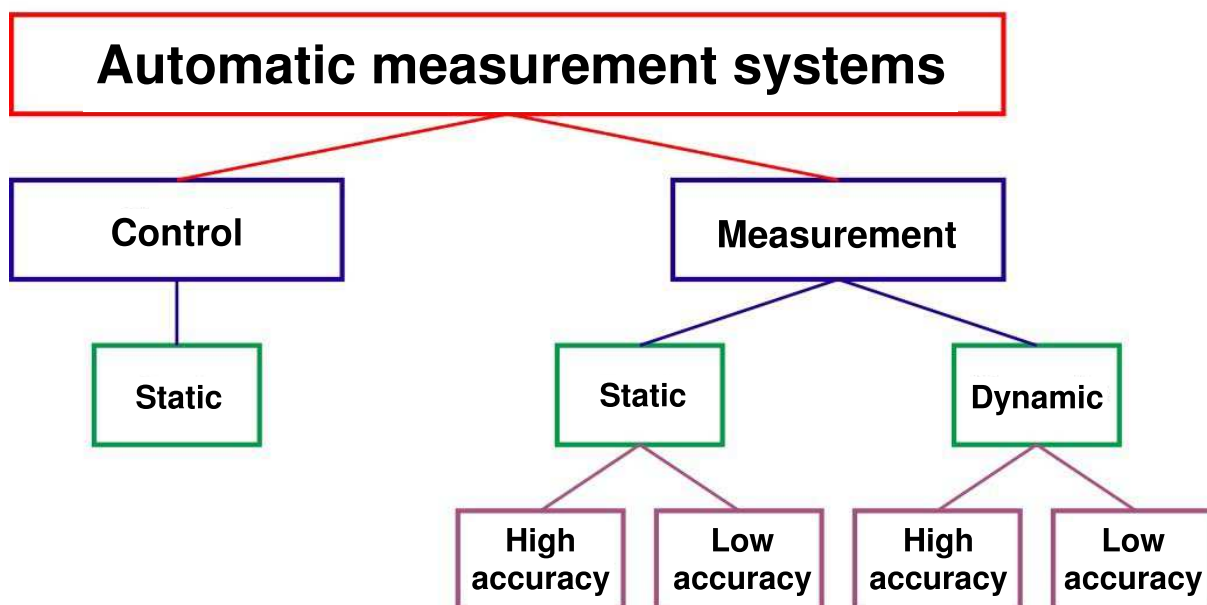


Figure 1.1. Classification of automatic measurement systems.

1.4 Organisation of the Guide

The aims of this guide are:

- 1) to provide a detailed description of the metrological characteristics of automatic measurement systems that are important for on site measurement and are particular to this type of measurement;
- 2) to make a survey of measurement methods, of measured quantities and of geometric measurement conditions envisioned by the relevant CIE publications;
- 3) to define measurement conditions that are suitable when using automatic dynamic measurement systems;
- 4) to qualify the sources of uncertainty of the different methods and measurement technologies, providing detailed indications of the causes and identifying the maximum limits of current technology and photometric instrumentation when applied to road measurements;
- 5) to provide information on the necessary minimum accuracy and the acceptable levels of uncertainty in various measurement situations.

The guide does not consider the parameters or techniques necessary for describing a particular photo-detector from the photometric point of view. This matter is dealt in other CIE publications [13], [14].

The guide deals with the measurement problems arising when that detector or measuring system is used for measuring the photometric properties of a lighting system, i.e. the acceptable accuracy, the geometrical measurement conditions, the elaboration algorithm of the measured data, etc.

2 DEFINITIONS

The following definitions are given in this document. Other important definitions can be found in [15] (concerning photometry and radiometry) and in [16] (concerning metrology).

A parameter could be measured strictly in accordance with a standard (i.e. the average luminance at the calculation points of a standard grid) or it could be measured following other specified or custom conditions (i.e. particular situations like the average luminance over the whole road surface in a defined zone of a carriageway).

In the first case the adjective “normative” is added in the parameter’s name; in the second case the adjective “particular” is added. The quantities defined as “normative” are obtained from the CIE documents [6], [7], [8], [9] and [10]. Strictly speaking these documents are not standards, but this adjective is justified because their conclusions or recommendations are adopted in many national and international standards.

Sometimes a parameter cannot be measured strictly in accordance with the normative definition (e.g. the standard requires the luminance at an element of a surface – a point – but the measurement is carried out on a finite area, see 3.1). In this case the person responsible for the measurement should also evaluate if the value obtained could be considered of “normative” or “particular” type for a given accuracy or if it is possible to introduce a correcting factor.

For all normative parameters defined in this clause, one or more particular parameters are also defined. To avoid the introduction of too many symbols, the normative and the particular parameters have the same symbol. If necessary at the particular parameter symbol one or more suffixes, separated by commas, are added; otherwise the context where the parameter is used should clearly indicate the meaning of the parameter itself. Any possibility of confusion between parameters should be avoided because they could have a very different physical meaning.

The rules adopted to specify the suffixes used to obtain the complete symbol of a given particular parameter are specified in 3.3.5. In the definitions the generic suffix q is used.

If not otherwise specified, when a measurement is related to a road surface the horizontal plane is the plane tangent to the road surface at the given point, and the vertical plane is the plane perpendicular to that horizontal plane and with its normal oriented in a given direction, for example parallel to the road longitudinal axis.

As explained in 1.1 only the quantities involved in the measurement of road illuminance and luminance are considered here.

automatic system

a measurement system able to carry out measurements without a) the presence of an operator; or b) when the operator presence is necessary only at the beginning of the measurement procedure (i.e. to start it or to select the measurement zone; or c) when the operator presence is necessary only for the elaboration of measurement results and evaluation of the quality parameters; or d) when the operator presence is necessary for other purposes, not directly associated with the measurement procedure (i.e. to drive the vehicle where the automatic system is in operation)

automatic system for control purpose

an automatic system used to generate a control signal, correlated to one or more photometric parameters that can influence the operating conditions of a lighting system

NOTE Metrological parameters, such as measurement repeatability and stability, could be the main characteristic of the system.

automatic system for measurement

an automatic system used to measure photometric quantities following standard or well-defined non-standard geometrical and optical conditions and procedures

NOTE The system can measure quantities as absolute values (in this case the instrument should be calibrated in SI units) or as relative values (to a given reference).

dynamic measurement system

a measurement system that moves along the road surface to carry out the measurement

static measurement system

a measurement system that does not move when in service

system for high accuracy measurements

a system able to obtain, for a given parameter, a measurement uncertainty equal or better to that required by the applicable standard or by the particular technical specification

system for low accuracy measurements

a system where a) the measurement uncertainty is not completely defined, or b) the measurement uncertainty is higher than that permitted by the applicable standard or technical specification, or c) the measured parameters or conditions are not defined according to the applicable standard or technical specification and the influence of these discrepancies on the results are not adequately estimated

reference standard

a standard or convention used as a reference document to define the measurement conditions

NOTE 1 Normally these documents specify a grid of points on the road surface, and on the walls in tunnels, where the photometric parameters must be evaluated.

NOTE 2 For the measurement conditions described in this guide the reference standards are [6], [7], [8], [9] and [10].

(normative) parameter

a parameter defined in a reference standard which can be: a) evaluated using an appropriate algorithm (based on a physical model of light propagation in the environment), often specified by the standard itself; b) measured following the instructions given by the standard itself and verifying the influence of the metrological characteristics of the measuring instrument in the physical definition of the parameter

NOTE 1 A typical example of a quantity that could be different when evaluated and measured is luminance: the discrepancy arises between the physical definition of luminance (point a) that involves an elementary surface and the measured luminance carried out on a surface with a real extended area (point b).

NOTE 2 A standard or a technical document could specify the optical and photometric characteristics of the instrument used in order to reduce discrepancies between the two conditions (i.e. [17], page 20).

(particular) parameter

a parameter measured according to given and well-defined conditions q , but different to those specified in a standard

extended parameter

a particular parameter evaluated as described in 3.3.3, the symbol of which is the same as that of the corresponding particular parameter but with the subscript $e(a\%)$ added at the end. For the meaning of the symbol a see 3.3.3.

NOTE 1 Not all particular parameters can be evaluated in the extended form.

(normative) luminance L_p

luminance of an elementary surface or of a finite but specified area centred at point p specified, together with the evaluation conditions, by the reference standard

Unit: $\text{cd}\cdot\text{m}^{-2}$

(particular) luminance $L_{p,q}$

luminance of a surface centred at a given point p and obtained in given conditions q

Unit: $\text{cd}\cdot\text{m}^{-2}$

(normative) average luminance L_{ave}

arithmetic mean of the set of (normative) luminance values L_p ($p = 1, \dots, K$) obtained at K points of the grid as specified by the reference standard

$$L_{\text{ave}} = \frac{1}{K} \sum_{p=1}^K L_p \quad (2.1)$$

NOTE For this parameter the symbol $\bar{L}$ is used in [6].

Unit: $\text{cd}\cdot\text{m}^{-2}$

(particular) average luminance $L_{\text{ave},q}$

arithmetic mean of the set of (particular) luminance values $L_{p,q}$ ($p = 1, \dots, K$) obtained at K given points of a particular grid

$$L_{\text{ave},q} = \frac{1}{K} \sum_{p=1}^K L_{p,q} \quad (2.1)$$

Unit: $\text{cd}\cdot\text{m}^{-2}$

(particular) highest luminance $L_{\text{max},q}$

highest value in the set of (particular) luminance values $L_{p,q}$ ($p = 1, \dots, K$) obtained at K given points of a particular grid

Unit: $\text{cd}\cdot\text{m}^{-2}$

(normative) lowest luminance L_{min}

lowest value in the set of (normative) luminance values L_p ($p = 1, \dots, K$) obtained at K points of the grid as specified by the reference standard

Unit: $\text{cd}\cdot\text{m}^{-2}$

(particular) lowest luminance $L_{\text{min},q}$

lowest value in the set of (particular) luminance values $L_{p,q}$ ($p = 1, \dots, K$) obtained at K given points of a particular grid

Unit: $\text{cd}\cdot\text{m}^{-2}$

(particular) average luminance along a longitudinal line $L_{\text{ave},j,q}$

arithmetic mean of the set of (particular) luminance values $L_{p,q}$ ($p = 1, \dots, K$) obtained at K given points on a given longitudinal line j along a given driving lane

$$L_{\text{ave},j,q} = \frac{1}{K} \sum_{p=1}^K L_{p,q} \quad (2.2)$$

Unit: $\text{cd}\cdot\text{m}^{-2}$

(normative) highest luminance along the centre line $L_{\text{max},c}$

highest value in the set of (normative) luminance values L_p ($p = 1, \dots, K$) obtained, as specified by the reference standard, at K points on the longitudinal line along the centre of a given driving lane

Unit: $\text{cd}\cdot\text{m}^{-2}$

(particular) highest luminance along the centre line $L_{\max,c,q}$

highest value in the set of (particular) luminance values $L_{p,q}$ ($p = 1, \dots, K$) obtained at K given points on the longitudinal line along the centre of a given driving lane

Unit: $\text{cd}\cdot\text{m}^{-2}$

(particular) highest luminance along a longitudinal line $L_{\max,j,q}$

highest value in the set of (particular) luminance values $L_{p,q}$ ($p = 1, \dots, K$) obtained at K given points on a given longitudinal line j along a given driving lane

Unit: $\text{cd}\cdot\text{m}^{-2}$

(normative) lowest luminance along the centre line $L_{\min,c}$

lowest value in the set of (normative) luminance values L_p ($p = 1, \dots, K$) obtained, as specified by the reference standard, at K points on the longitudinal line along the centre of a given driving lane

Unit: $\text{cd}\cdot\text{m}^{-2}$

(particular) lowest luminance along the centre line $L_{\min,c,q}$

lowest value in the set of (particular) luminance values $L_{p,q}$ ($p = 1, \dots, K$) obtained at K given points on the longitudinal line along the centre of a given driving lane

Unit: $\text{cd}\cdot\text{m}^{-2}$

(particular) lowest luminance along a longitudinal line $L_{\min,j,q}$

lowest value in the set of (particular) luminance values $L_{p,q}$ ($p = 1, \dots, K$) obtained at K given points on a given longitudinal line j along a given driving lane

Unit: $\text{cd}\cdot\text{m}^{-2}$

(normative) luminance overall uniformity $U_o(L)$

(normative) lowest luminance divided by the (normative) average luminance:

$$U_o(L) = \frac{L_{\min}}{L_{\text{ave}}} \quad (2.3)$$

Unit: 1

NOTE U_o is the usual symbol for this parameter, $U_o(L)$ is the unambiguous symbol used in this guide to make it clear that this uniformity is the ratio between two luminances.

(particular) luminance overall uniformity $U_{o,q}(L)$

(particular) lowest luminance divided by the (particular) average luminance obtained in a specified condition q :

$$U_{o,q}(L) = \frac{L_{\min,q}}{L_{\text{ave},q}} \quad (2.4)$$

Unit: 1

(particular) luminance linear overall uniformity along a longitudinal line $U_{o,j,q}(L)$

(particular) lowest luminance along the longitudinal line j divided by the (particular) average luminance along the same line and obtained in a specified condition q :

$$U_{o,j,q}(L) = \frac{L_{\min,j,q}}{L_{\text{ave},j,q}} \quad (2.5)$$

Unit: 1

(normative) luminance longitudinal uniformity $U_l(L)$

(normative) lowest luminance along the centre-line divided by the (normative) highest luminance along the same centre line of a given driving lane:

$$U_l(L) = \frac{L_{\min,c}}{L_{\max,c}} \quad (2.6)$$

Unit: 1

NOTE U_l is the usual symbol for this parameter, $U_l(L)$ is the unambiguous symbol used in this guide to make it clear that this uniformity is the ratio between two luminances.

(particular) luminance longitudinal uniformity $U_{l,q}(L)$

(particular) lowest luminance along the centre-line divided by the (particular) highest luminance along the same line of a given driving lane:

$$U_{l,q}(L) = \frac{L_{\min,c,q}}{L_{\max,c,q}} \quad (2.7)$$

Unit: 1

(particular) luminance longitudinal uniformity in a given longitudinal line $U_{l,j,q}(L)$

(particular) lowest luminance along a given longitudinal line j divided by the (particular) highest luminance along the same line of a given driving lane:

$$U_{l,j,q}(L) = \frac{L_{\min,j,q}}{L_{\max,j,q}} \quad (2.8)$$

Unit: 1

(normative) horizontal illuminance $E_{h,p}$

horizontal illuminance at point p specified, together with the evaluation conditions, by the reference standard

Unit: lx

(particular) horizontal illuminance $E_{h,p,q}$

horizontal illuminance at a given point p and obtained in given conditions q

Unit: lx

(normative) average horizontal illuminance $E_{h,\text{ave}}$

arithmetic mean of the set of (normative) horizontal illuminance values $E_{h,p}$ ($p = 1, \dots, K$) obtained at K points of the grid as specified by the reference standard:

$$E_{h,\text{ave}} = \frac{1}{K} \sum_{p=1}^K E_{h,p} \quad (2.9)$$

Unit: lx

NOTE For this parameter the symbol $\overline{E}$ is used in [6] and E_{av} in [9].

(particular) average horizontal illuminance $E_{h,ave,q}$

arithmetic mean of the set of (particular) horizontal illuminance values $E_{h,p,q}$ ($p = 1, \dots, K$) obtained at K given points of a particular grid:

$$E_{h,ave,q} = \frac{1}{K} \sum_{p=1}^K E_{h,p,q} \quad (2.10)$$

Unit: lx

(particular) highest horizontal illuminance $E_{h,max,q}$

highest value in the set of (particular) horizontal illuminance values $E_{h,p,q}$ ($p = 1, \dots, K$) obtained at K given points of a particular grid

Unit: lx

(normative) lowest horizontal illuminance $E_{h,min}$

lowest value in the set of (normative) horizontal illuminance values $E_{h,p}$ ($p = 1, \dots, K$) obtained at K points of the grid as specified by the reference standard

Unit: lx

(particular) lowest horizontal illuminance $E_{h,min,q}$

lowest value in the set of (particular) horizontal illuminance values $E_{h,p,q}$ ($p = 1, \dots, K$) obtained at K given points of a particular grid

Unit: lx

(particular) average horizontal illuminance along a longitudinal line $E_{h,ave,j,q}$

arithmetic mean of the set of (particular) horizontal illuminance values $E_{h,p,q}$ ($p = 1, \dots, K$) obtained at K given points on a given longitudinal line j along a given driving lane:

$$E_{h,ave,j,q} = \frac{1}{K} \sum_{p=1}^K E_{h,p,q} \quad (2.11)$$

Unit: lx

(normative) highest horizontal illuminance along the centre line $E_{h,max,c}$

highest value in the set of (normative) horizontal illuminance values $E_{h,p}$ ($p = 1, \dots, K$) obtained, as specified by the reference standard, at K points on the longitudinal line along the centre of a given driving lane

Unit: lx

(particular) highest horizontal illuminance along the centre line $E_{h,max,c,q}$

highest value in the set of (particular) horizontal illuminance values $E_{h,p,q}$ ($p = 1, \dots, K$) obtained at K given points on the longitudinal line along the centre of a given driving lane

Unit: lx

(particular) highest horizontal illuminance along a longitudinal line $E_{h,max,j,q}$

highest value in the set of (particular) horizontal illuminance values $E_{h,p,q}$ ($p = 1, \dots, K$) obtained at K given points on a given longitudinal line j along a given driving lane

Unit: lx

(normative) lowest horizontal illuminance along the centre line $E_{h,min,c}$

lowest value in the set of (normative) horizontal illuminance values $E_{h,p}$ ($p = 1, \dots, K$) obtained, as specified by the reference standard, at K points on the longitudinal line along the centre of a given driving lane

Unit: lx

(particular) lowest horizontal illuminance along the centre line $E_{h,min,c,q}$

lowest value in the set of (particular) horizontal illuminance values $E_{h,p,q}$ ($p = 1, \dots, K$) obtained at K given points on the longitudinal line along the centre of a given driving lane

Unit: lx

(particular) lowest horizontal illuminance along a longitudinal line $E_{h,min,j,q}$

lowest value in the set of (particular) horizontal illuminance values $E_{h,p,q}$ ($p = 1, \dots, K$) obtained at K given points on a given longitudinal line j along a given driving lane

Unit: lx

(normative) horizontal illuminance overall uniformity $U_o(E_h)$

(normative) lowest horizontal illuminance divided by the (normative) average horizontal illuminance:

$$U_o(E_h) = \frac{E_{h,min}}{E_{h,ave}} \quad (2.12)$$

Unit: 1

NOTE $U_o(E)$ is the usual symbol for this parameter, $U_o(E_h)$ is the unambiguous symbol used in this guide to make it clear that this uniformity is the ratio between two horizontal illuminance values.

(particular) horizontal illuminance overall uniformity $U_{o,q}(E_h)$

(particular) lowest horizontal illuminance divided by the (particular) average horizontal illuminance:

$$U_{o,q}(E_h) = \frac{E_{h,min,q}}{E_{h,ave,q}} \quad (2.13)$$

Unit: 1

(particular) horizontal illuminance linear overall uniformity along a longitudinal line $U_{o,j,q}(E_h)$

(particular) lowest horizontal illuminance along the longitudinal line j divided by the (particular) average horizontal illuminance along the same line and obtained in a specified condition q :

$$U_{o,j,q}(E_h) = \frac{E_{h,min,j,q}}{E_{h,ave,j,q}} \quad (2.14)$$

Unit: 1

(normative) horizontal illuminance longitudinal uniformity $U_l(E_h)$

(normative) lowest horizontal illuminance along the centre line divided by the (normative) highest horizontal illuminance along the same centre line of a given driving lane:

$$U_l(E_h) = \frac{E_{h,\min,c}}{E_{h,\max,c}} \quad (2.15)$$

Unit: 1

NOTE $U_l(E)$ is the usual symbol for this parameter, $U_l(E_h)$ is the unambiguous symbol used in this guide to make it clear that this uniformity is the ratio between two horizontal illuminance values.

(particular) horizontal illuminance longitudinal uniformity $U_{l,q}(E_h)$

(particular) lowest horizontal illuminance along the centre line to the (particular) highest horizontal illuminance along the same line of a given driving lane:

$$U_{l,q}(E_h) = \frac{E_{h,\min,c,q}}{E_{h,\max,c,q}} \quad (2.16)$$

Unit: 1

(particular) horizontal illuminance uniformity in a given longitudinal line $U_{l,j,q}(E_h)$

(particular) lowest horizontal illuminance along a given longitudinal line j divided by the (particular) highest horizontal illuminance along the same line of a given driving lane:

$$U_{l,j,q}(E_h) = \frac{E_{h,\min,j,q}}{E_{h,\max,j,q}} \quad (2.17)$$

Unit: 1

(normative) hemispherical illuminance $E_{hs,p}$

hemispherical illuminance at point p specified, together with the evaluation conditions, by the reference standard

Unit: lx

(particular) hemispherical illuminance $E_{hs,p,q}$

hemispherical illuminance at a given point p and obtained in given conditions q

Unit: lx

(normative) average hemispherical illuminance $E_{hs,ave}$

arithmetic mean of the set of (normative) hemispherical illuminance values $E_{hs,p}$ ($p = 1, \dots, K$) obtained at K points of the grid as specified by the reference standard:

$$E_{hs,ave} = \frac{1}{K} \sum_{p=1}^K E_{hs,p} \quad (2.18)$$

Unit: lx

(particular) average hemispherical illuminance $E_{hs,ave,q}$

arithmetic mean of the set of (particular) hemispherical illuminance values $E_{hs,p,q}$ ($p = 1, \dots, K$) obtained at K given points of a grid:

$$E_{hs,ave,q} = \frac{1}{K} \sum_{p=1}^K E_{hs,p,q} \quad (2.19)$$

Unit: lx

(particular) highest hemispherical illuminance $E_{\text{hs,max},q}$

highest value in the set of (particular) hemispherical illuminance values $E_{\text{hs},p,q}$ ($p = 1, \dots, K$) obtained at K given points of a grid

Unit: lx

(normative) lowest hemispherical illuminance $E_{\text{hs,min}}$

lowest value in the set of (normative) hemispherical illuminance values $E_{\text{hs},p}$ ($p = 1, \dots, K$) obtained at K points of the grid as specified by the reference standard

Unit: lx

(particular) lowest hemispherical illuminance $E_{\text{hs,min},q}$

lowest value in the set of (particular) hemispherical illuminance values $E_{\text{hs},p,q}$ ($p = 1, \dots, K$) obtained at K given points of a particular grid

Unit: lx

(particular) average hemispherical illuminance along a longitudinal line $E_{\text{hs,ave},j,q}$

arithmetic mean of the set of (particular) hemispherical illuminance values $E_{\text{hs},p,q}$ ($p = 1, \dots, K$) obtained at K given points on a given longitudinal line j along a given driving lane:

$$E_{\text{hs,ave},j,q} = \frac{1}{K} \sum_{p=1}^K E_{\text{hs},p,q} \quad (2.20)$$

Unit: lx

(normative) highest hemispherical illuminance along the centre line $E_{\text{hs,max,c}}$

highest value in the set of (normative) hemispherical illuminance values $E_{\text{hs},p}$ ($p = 1, \dots, K$) obtained, as specified by the reference standard, at K points on the longitudinal line along the centre a given driving lane

Unit: lx

(particular) highest hemispherical illuminance along the centre line $E_{\text{hs,max,c},q}$

highest value in the set of (particular) horizontal illuminance values $E_{\text{hs},p,q}$ ($p = 1, \dots, K$) obtained at K given points on the longitudinal line along the centre of a given driving lane

Unit: lx

(particular) highest hemispherical illuminance along a longitudinal line $E_{\text{hs,max},j,q}$

highest value in the set of (particular) hemispherical illuminance values $E_{\text{hs},p,q}$ ($p = 1, \dots, K$) obtained at K given points on a given longitudinal line j along a given driving lane

Unit: lx

(normative) lowest hemispherical illuminance along the centre line $E_{\text{hs,min,c}}$

lowest value in the set of (normative) hemispherical illuminance values $E_{\text{hs},p}$ ($p = 1, \dots, K$) obtained, as specified by the reference standard, at K points on the longitudinal line along the centre of a given driving lane

Unit: lx

(particular) lowest hemispherical illuminance along the centre line $E_{\text{hs,min,c},q}$

lowest value in the set of (particular) hemispherical illuminance values $E_{\text{hs},p,q}$ ($p = 1, \dots, K$) obtained at K given points on the longitudinal line along the centre of a given driving lane

Unit: lx

(particular) lowest hemispherical illuminance along a longitudinal line $E_{\text{hs,min},j,q}$

lowest value in the set of (particular) hemispherical illuminance values $E_{\text{hs},p,q}$ ($p = 1, \dots, K$) obtained at K given points on a given longitudinal line j along a given driving lane

Unit: lx

(normative) hemispherical illuminance overall uniformity $U_o(E_{\text{hs}})$

(normative) lowest hemispherical illuminance divided by the (normative) average hemispherical illuminance:

$$U_o(E_{\text{hs}}) = \frac{E_{\text{hs,min}}}{E_{\text{hs,ave}}} \quad (2.21)$$

Unit: 1

(particular) hemispherical illuminance overall uniformity $U_{o,q}(E_{\text{hs}})$

(particular) lowest hemispherical illuminance divided by the (particular) average hemispherical illuminance:

$$U_{o,q}(E_{\text{hs}}) = \frac{E_{\text{hs,min},q}}{E_{\text{hs,ave},q}} \quad (2.22)$$

Unit: 1

(particular) hemispherical illuminance linear overall uniformity along a longitudinal line $U_{o,j,q}(E_{\text{hs}})$

(particular) lowest hemispherical illuminance along the longitudinal line j divided by the (particular) average hemispherical illuminance along the same line and obtained in a specified condition q :

$$U_{o,j,q}(E_{\text{hs}}) = \frac{E_{\text{hs,min},j,q}}{E_{\text{hs,ave},j,q}} \quad (2.23)$$

Unit: 1

(normative) hemispherical illuminance longitudinal uniformity $U_l(E_{\text{hs}})$

(normative) lowest hemispherical illuminance along the centre line divided by the (normative) highest hemispherical illuminance along the same line of a given driving lane:

$$U_l(E_{\text{hs}}) = \frac{E_{\text{hs,min},c}}{E_{\text{hs,max},c}} \quad (2.24)$$

Unit: 1

(particular) hemispherical illuminance longitudinal uniformity $U_{l,q}(E_{\text{hs}})$

(particular) lowest hemispherical illuminance along the centre line divided by the (particular) highest hemispherical illuminance along the same line of a given driving lane:

$$U_{l,q}(E_{\text{hs}}) = \frac{E_{\text{hs,min},c,q}}{E_{\text{hs,max},c,q}} \quad (2.25)$$

Unit: 1

(particular) hemispherical illuminance longitudinal uniformity in a given line $U_{l,j,q}(E_{\text{hs}})$

(particular) lowest hemispherical illuminance along a given longitudinal line j divided by the (particular) highest hemispherical illuminance along the same line of a given driving lane:

$$U_{l,j,q}(E_{\text{hs}}) = \frac{E_{\text{hs,min},j,q}}{E_{\text{hs,max},j,q}} \quad (2.26)$$

Unit: 1

(normative) semi-cylindrical illuminance $E_{\text{sc},p}$

semi-cylindrical illuminance at point p specified, together with the evaluation conditions, by the reference standard

Unit: lx

(particular) semi-cylindrical illuminance $E_{\text{sc},p,q}$

semi-cylindrical illuminance at a given point p and obtained in given conditions q

Unit: lx

(normative) average semi-cylindrical illuminance $E_{\text{sc,ave}}$

arithmetic mean of the set of (normative) semi-cylindrical illuminance values $E_{\text{sc},p}$ ($p = 1, \dots, K$) obtained at K points of the grid as specified by the reference standard:

$$E_{\text{sc,ave}} = \frac{1}{K} \sum_{p=1}^K E_{\text{sc},p} \quad (2.27)$$

Unit: lx

(particular) average semi-cylindrical illuminance $E_{\text{sc,ave},q}$

arithmetic mean of the set of (particular) semi-cylindrical illuminance values $E_{\text{sc},p,q}$ ($p = 1, \dots, K$) obtained at K given points of a particular grid:

$$E_{\text{sc,ave},q} = \frac{1}{K} \sum_{p=1}^K E_{\text{sc},p,q} \quad (2.28)$$

Unit: lx

(particular) highest semi-cylindrical illuminance $E_{\text{sc,max},q}$

highest value in the set of (particular) semi-cylindrical illuminance values $E_{\text{sc},p,q}$ ($p = 1, \dots, K$) obtained at K given points of a particular grid

Unit: lx

(normative) lowest semi-cylindrical illuminance $E_{\text{sc,min}}$

lowest value in the set of (normative) semi-cylindrical illuminance values $E_{\text{sc},p}$ ($p = 1, \dots, K$) obtained at K points of the grid as specified by the reference standard

Unit: lx

(particular) lowest semi-cylindrical illuminance $E_{\text{sc,min},q}$

lowest value in the set of (particular) semi-cylindrical illuminance values $E_{\text{sc},p,q}$ ($p = 1, \dots, K$) obtained at K given points of a grid

Unit: lx

(particular) average semi-cylindrical illuminance along a longitudinal line $E_{\text{sc,ave},j,q}$

arithmetic mean of the set of (particular) semi-cylindrical illuminance values $E_{\text{sc},p,q}$ ($p = 1, \dots, K$) obtained at K given points on a given longitudinal line j along a given driving lane:

$$E_{\text{sc,ave},j,q} = \frac{1}{K} \sum_{p=1}^K E_{\text{sc},p,q} \quad (2.29)$$

Unit: lx

(normative) highest semi-cylindrical illuminance along the centre line $E_{\text{sc,max,c}}$

highest value in the set of (normative) semi-cylindrical illuminance values $E_{\text{sc},p}$ ($p = 1, \dots, K$) obtained, as specified by the reference standard, at K points on the longitudinal line along the centre of a given driving lane

Unit: lx

(particular) highest semi-cylindrical illuminance along the centre line $E_{\text{sc,max,c},q}$

highest value in the set of (particular) semi-cylindrical illuminance values $E_{\text{sc},p,q}$ ($p = 1, \dots, K$) obtained at K given points on the longitudinal line along the centre of a given driving lane

Unit: lx

(particular) highest semi-cylindrical illuminance along a longitudinal line $E_{\text{sc,max},j,q}$

highest value in the set of (particular) semi-cylindrical illuminance values $E_{\text{sc},p,q}$ ($p = 1, \dots, K$) obtained at K given points on a given longitudinal line j along a given driving lane

Unit: lx

(normative) lowest semi-cylindrical illuminance along the centre line $E_{\text{sc,min,c}}$

lowest value in the set of (normative) semi-cylindrical illuminance values $E_{\text{sc},p}$ ($p = 1, \dots, K$) obtained, as specified by the reference standard, at K points on the longitudinal line along the centre of a given driving lane

Unit: lx

(particular) lowest semi-cylindrical illuminance along the centre line $E_{\text{sc,min,c},q}$

lowest value in the set of (particular) semi-cylindrical illuminance values $E_{\text{sc},p,q}$ ($p = 1, \dots, K$) obtained at K given points on the longitudinal line along the centre of a given driving lane

Unit: lx

(particular) lowest semi-cylindrical illuminance along a longitudinal line $E_{\text{sc,min},j,q}$

lowest value in the set of (particular) semi-cylindrical illuminance values $E_{\text{sc},p,q}$ ($p = 1, \dots, K$) obtained at K given points on a given longitudinal line j along a given driving lane

Unit: lx

(normative) semi-cylindrical illuminance overall uniformity $U_o(E_{\text{sc}})$

(normative) lowest semi-cylindrical illuminance divided by the (normative) average semi-cylindrical illuminance:

$$U_o(E_{\text{sc}}) = \frac{E_{\text{sc,min}}}{E_{\text{sc,ave}}} \quad (2.30)$$

Unit: 1

(particular) semi-cylindrical illuminance overall uniformity $U_{o,q}(E_{\text{sc}})$

(particular) lowest semi-cylindrical illuminance divided by the (particular) average horizontal illuminance:

$$U_{o,q}(E_{sc}) = \frac{E_{sc,min,q}}{E_{sc,ave,q}} \quad (2.31)$$

Unit: 1

(particular) semi-cylindrical illuminance linear overall uniformity along a longitudinal line $U_{o,q}(E_{sc})$

(particular) lowest semi-cylindrical illuminance along the longitudinal line j divided by the (particular) average semi-cylindrical illuminance along the same line and obtained in a specified condition q :

$$U_{o,j,q}(E_{sc}) = \frac{E_{sc,min,j,q}}{E_{sc,ave,j,q}} \quad (2.32)$$

Unit: 1

(normative) semi-cylindrical illuminance longitudinal uniformity $U_l(E_{sc})$

(normative) lowest semi-cylindrical illuminance along the centre line divided by the (normative) highest semi-cylindrical illuminance along the same line of a given driving lane:

$$U_l(E_{sc}) = \frac{E_{sc,min,c}}{E_{sc,max,c}} \quad (2.33)$$

Unit: 1

(particular) semi-cylindrical illuminance longitudinal uniformity $U_{l,q}(E_{sc})$

(particular) lowest semi-cylindrical illuminance along the centre line divided by the (particular) highest semi-cylindrical illuminance along the same line of a given driving lane:

$$U_{l,q}(E_{sc}) = \frac{E_{sc,min,c,q}}{E_{sc,max,c,q}} \quad (2.34)$$

Unit: 1

(particular) semi-cylindrical illuminance longitudinal uniformity in a given line $U_{l,j,q}(E_{sc})$

(particular) lowest semi-cylindrical illuminance along a given longitudinal line j divided by the (particular) highest semi-cylindrical illuminance along the same line of a given driving lane:

$$U_{l,j,q}(E_{sc}) = \frac{E_{sc,min,j,q}}{E_{sc,max,j,q}} \quad (2.35)$$

Unit: 1

(normative) vertical plane illuminance $E_{v,p}$

illuminance on a vertical plane at point p specified, together with the evaluation conditions, by the reference standard

Unit: lx

(particular) vertical plane illuminance $E_{v,p,q}$

illuminance on a vertical plane at a given point p and obtained in given conditions q

Unit: lx

(normative) average vertical plane illuminance $E_{v,ave}$

arithmetic mean of the set of (normative) vertical plane illuminance values $E_{v,p}$ ($p = 1, \dots, K$) obtained at K points of the grid as specified by the reference standard.

$$E_{v,ave} = \frac{1}{K} \sum_{p=1}^K E_{v,p} \quad (2.36)$$

Unit: lx

(particular) average vertical plane illuminance $E_{v,ave,q}$

arithmetic mean of the set of (particular) vertical plane illuminance values $E_{v,p,q}$ ($p = 1, \dots, K$) obtained at K given points of a particular grid:

$$E_{v,ave,q} = \frac{1}{K} \sum_{p=1}^K E_{v,p,q} \quad (2.37)$$

Unit: lx

(particular) highest vertical plane illuminance $E_{v,max,q}$

highest value in the set of (particular) vertical plane illuminance values $E_{v,p,q}$ ($p = 1, \dots, K$) obtained at K given points

Unit: lx

(normative) lowest vertical plane illuminance $E_{v,min}$

lowest value in the set of (normative) vertical plane illuminance values $E_{v,p}$ ($p = 1, \dots, K$) obtained at K points of the grid as specified by the reference standard

Unit: lx

(particular) lowest vertical plane illuminance $E_{v,min,q}$

lowest value in the set of (particular) vertical plane illuminance values $E_{v,p,q}$ ($p = 1, \dots, K$) obtained at K given points of a particular grid

Unit: lx

(particular) average vertical plane illuminance along a longitudinal line $E_{v,ave,j,q}$

arithmetic mean of the set of (particular) vertical plane illuminance values $E_{v,p,q}$ ($p = 1, \dots, K$) obtained at K given points on a given longitudinal line j along a given driving lane:

$$E_{v,ave,j,q} = \frac{1}{K} \sum_{p=1}^K E_{v,p,q} \quad (2.38)$$

Unit: lx

(normative) highest vertical plane illuminance along the centre line $E_{v,max,c}$

highest value in the set of (normative) vertical plane illuminance values $E_{v,p}$ ($p = 1, \dots, K$) obtained, as specified by the reference standard, at K points on the longitudinal line along the centre of a given driving lane

Unit: lx

(particular) highest vertical plane illuminance along the centre line $E_{v,max,c,q}$

highest value in the set of (particular) vertical plane illuminance values $E_{v,p,q}$ ($p = 1, \dots, K$) obtained at K given points on the longitudinal line along the centre of a given driving lane

Unit: lx