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

TECHNICAL REPORT

GUIDELINES FOR MINIMIZING SKY GLOW

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THE INTERNATIONAL COMMISSION ON ILLUMINATION

The International Commission on Illumination (CIE) is an organisation devoted to international co-operation and exchange of information among its member countries on all matters relating to the art and science of lighting. Its membership consists of the National Committees in 40 countries and one geographical area and of 13 individual members.

The objectives of the CIE are :

1. To provide an international forum for the discussion of all matters relating to the science, technology and art in the fields of light and lighting and for the interchange of information in these fields between countries.
2. To develop basic standards and procedures of metrology in the fields of light and lighting.
3. To provide guidance in the application of principles and procedures in the development of international and national standards in the fields of light and lighting.
4. To prepare and publish standards, reports and other publications concerned with all matters relating to the science, technology and art in the fields of light and lighting.
5. To maintain liaison and technical interaction with other international organisations concerned with matters related to the science, technology, standardisation and art in the fields of light and lighting.

The work of the CIE is carried on by seven Divisions each with about 20 Technical Committees. This work covers subjects ranging from fundamental matters to all types of lighting applications. The standards and technical reports developed by these international Divisions of the CIE are accepted throughout the world.

A plenary session is held every four years at which the work of the Divisions and Technical Committees is reviewed, reported and plans are made for the future. The CIE is recognised as the authority on all aspects of light and lighting. As such it occupies an important position among international organisations.

LA COMMISSION INTERNATIONALE DE L'ÉCLAIRAGE

La Commission Internationale de l'Éclairage (CIE) est une organisation qui se donne pour but la coopération internationale et l'échange d'informations entre les Pays membres sur toutes les questions relatives à l'art et à la science de l'éclairage. Elle est composée de Comités Nationaux représentant 40 pays plus un territoire géographique, et de 13 membres individuels.

Les objectifs de la CIE sont :

1. De constituer un centre d'étude international pour toute matière relevant de la science, de la technologie et de l'art de la lumière et de l'éclairage et pour l'échange entre pays d'informations dans ces domaines.
2. D'élaborer des normes et des méthodes de base pour la métrologie dans les domaines de la lumière et de l'éclairage.
3. De donner des directives pour l'application des principes et des méthodes d'élaboration de normes internationales et nationales dans les domaines de la lumière et de l'éclairage.
4. De préparer et publier des normes, rapports et autres textes, concernant toutes matières relatives à la science, la technologie et l'art dans les domaines de la lumière et de l'éclairage.
5. De maintenir une liaison et une collaboration technique avec les autres organisations internationales concernées par des sujets relatifs à la science, la technologie, la normalisation et l'art dans les domaines de la lumière et de l'éclairage.

Les travaux de la CIE sont effectués par 7 Divisions, ayant chacune environ 20 Comités Techniques. Les sujets d'études s'étendent des questions fondamentales, à tous les types d'applications de l'éclairage. Les normes et les rapports techniques élaborés par ces Divisions Internationales de la CIE sont reconnus dans le monde entier.

Tous les quatre ans, une Session plénière passe en revue le travail des Divisions et des Comités Techniques, en fait rapport et établit les projets de travaux pour l'avenir. La CIE est reconnue comme la plus haute autorité en ce qui concerne tous les aspects de la lumière et de l'éclairage. Elle occupe comme telle une position importante parmi les organisations internationales.

DIE INTERNATIONALE BELEUCHTUNGSKOMMISSION

Die Internationale Beleuchtungskommission (CIE) ist eine Organisation, die sich der internationalen Zusammenarbeit und dem Austausch von Informationen zwischen ihren Mitgliedsländern bezüglich der Kunst und Wissenschaft der Lichttechnik widmet. Die Mitgliedschaft besteht aus den Nationalen Komitees in 40 Ländern und einem geographischen Gebiet und aus 13 persönlichen Mitgliedern.

Die Ziele der CIE sind :

1. Ein internationaler Mittelpunkt für Diskussionen aller Fragen auf dem Gebiet der Wissenschaft, Technik und Kunst der Lichttechnik und für den Informationsaustausch auf diesen Gebieten zwischen den einzelnen Ländern zu sein.
2. Grundnormen und Verfahren der Meßtechnik auf dem Gebiet der Lichttechnik zu entwickeln.
3. Richtlinien für die Anwendung von Prinzipien und Vorgängen in der Entwicklung internationaler und nationaler Normen auf dem Gebiet der Lichttechnik zu erstellen.
4. Normen, Berichte und andere Publikationen zu erstellen und zu veröffentlichen, die alle Fragen auf dem Gebiet der Wissenschaft, Technik und Kunst der Lichttechnik betreffen.
5. Liaison und technische Zusammenarbeit mit anderen internationalen Organisationen zu unterhalten, die mit Fragen der Wissenschaft, Technik, Normung und Kunst auf dem Gebiet der Lichttechnik zu tun haben.

Die Arbeit der CIE wird in 7 Divisionen, jede mit etwa 20 Technischen Komitees, geleistet. Diese Arbeit betrifft Gebiete mit grundlegendem Inhalt bis zu allen Arten der Lichtanwendung. Die Normen und Technischen Berichte, die von diesen international zusammengesetzten Divisionen ausgearbeitet werden, sind von der ganzen Welt anerkannt.

Tagungen werden alle vier Jahre abgehalten, in der die Arbeiten der Divisionen überprüft und 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 4-21 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. The latest CIE Proceedings or CIE NEWS should be consulted regarding possible subsequent amendments.

Ce rapport technique a été préparé par le Comité Technique CIE 4-21 de la Division 4 "Eclairage et signalisation pour les transports" et a été approuvé par le Bureau d'Administration de la Commission Internationale de l'Eclairage, pour étude et application. Le document traite des connaissances courantes et de l'expérience dans le domaine spécifique indiqué de la lumière et de l'éclairage, et il est établi pour l'usage des membres de la CIE et autres groupements intéressés. Il faut cependant noter que ce document est indicatif et non obligatoire. Pour connaître d'éventuels amendements, consulter les plus récents comptes rendus de la CIE ou le CIE NEWS.

Dieser Technische Bericht ist vom CIE Technischen Komitee 4-21 der Division 4 "Beleuchtung und Signale für den Verkehr" ausgearbeitet und vom Vorstand der Commission Internationale de l'Eclairage gebilligt worden. Das Dokument berichtet über den derzeitigen Stand des Wissens und Erfahrung in dem behandelten Gebiet von Licht und Beleuchtung; es ist zur Verwendung durch CIE-Mitglieder und durch andere Interessierte bestimmt. Es sollte jedoch beachtet werden, daß das Dokument eine Empfehlung und keine Vorschrift ist. Die neuesten CIE-Tagungsberichte oder das CIE NEWS sollten im Hinblick auf mögliche spätere Änderungen zu Rate gezogen werden.

Any mention of organisations or products does not imply endorsement by the CIE. Whilst every care has been taken in the compilation of any lists, up to the time of going to press, these may not be comprehensive.

Toute mention d'organisme ou de produit n'implique pas une préférence de la CIE. Malgré le soin apporté à la compilation de tous les documents jusqu'à la mise sous presse, ce travail ne saurait être exhaustif.

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Foreword

At its 20th Session in Amsterdam in 1989, the Commission Internationale de l'Eclairage CIE established, within Division 4 Lighting and Signalling for Transport, a Technical Committee TC 4-21 on "*Interference by Light of Astronomical Observations*". After participating in several international conferences, the TC prepared a document "*Guidelines for minimizing sky glow; a CIE Technical Report*". The preparation of an ISO-standard is considered. The earlier CIE Document "Statement concerning protection of sites for astronomical observatories" (CIE, 1978) and the joint IAU/CIE publication "Guide lines for minimizing urban sky glow near astronomical observatories" (IAU/CIE, 1984) are not withdrawn with the publication of this Guide.

Terms of reference

The Terms of Reference of this Technical Committee are

1. Maintain liaison with the International Astronomical Union IAU Commission 50.
2. Study the interference by light of astronomical observation.
3. Prepare recommendations for the reduction of the interference.

Membership

The Membership of CIE TC 4-21 is at 6 June 1997

Dr. Alec Fisher	Australia
Dr. V.D.P. Sastri	India
Dr. Syuzo Isobe	Japan
Dr. K. Narisada	Japan
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Guidelines for minimizing sky-glow; a CIE Technical Report**CONTENTS**

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Guidelines for minimizing sky glow; a CIE Technical Report*Summary*

In most countries of the world, astronomical observations are disturbed by the light from outdoor lighting installations. Part of the light is scattered in the atmosphere and forms a luminous halo. The phenomenon is called 'sky glow'. The Technical Report gives general guidance for lighting designers and policy makers on the reduction of the sky glow. The report discusses briefly the theoretical aspects of sky glow and it gives recommendations about maximum permissible values for lighting installations in relation to the needs of astronomical observations - casual sky viewing included. These values must be regarded as limiting values. Lighting designers should do all possible to meet the lowest specifications for the design unless the specific installation requires relaxation. Other uses of the open air areas at night will usually result in less stringent sky-glow requirements. Practical implementation of the general guidance is left to National Regulations. Other aspects of light obtrusion are covered in detail by CIE TC 5-12 "Obtrusive light".

Guide pour minimiser la lueur du ciel*Sommaire*

Dans la plupart des pays du monde les observations astronomiques sont perturbées par la lumière émanant d'installations extérieures d'éclairage. Une partie de la lumière est dispersée dans l'atmosphère et forme un halo lumineux. Ce phénomène s'appelle 'sky glow'. Le Rapport Technique fournit des directives générales concernant les effets nuisibles de la lumière sur les observations astronomiques. Ces directives sont destinées aux ingénieurs de l'éclairage et aux politiciens. Le rapport traite brièvement des aspects théoriques du 'sky glow' et fournit des recommandations sur les valeurs maximales permises à appliquer lors de la construction d'installations d'éclairage. Le but de ces recommandations est de diminuer la nuisance de la lumière tant pour les observateurs professionnels que pour les amateurs. Les ingénieurs de l'éclairage devront s'efforcer de se conformer aux normes les plus strictes, à moins qu'il ne s'agisse d'un projet demandant une application moins sévère. D'autres usages, la nuit, d'espaces non-couverts exigeront le plus souvent des normes moins strictes. L'application pratique des recommandations générales devra être laissée aux réglementations nationales. D'autres aspects de la lumière perturbante sont traités en détail par le rapport de la CIE TC 5-12 "Obtrusive light".

Richtlinien zur Minimierung des Himmels Lichtschleier*Zusammenfassung*

In den meisten Ländern der Welt werden die astronomischen Beobachtungen gestört von der Lichtausstrahlung von Aussenbeleuchtungsanlagen. Ein Teil des Lichtes wird in der Atmosphäre verstreut und bildet einen Lichtschleier, 'sky glow' genannt. Dieser Technische Bericht gibt allgemeine Richtlinien für Beleuchtungsingenieure und für Politiker über die Bekämpfung der Lichtstörung von astronomische Wahrnehmungen. Die theoretische Grundlagen sind kurz besprochen. Empfehlungen über die zulässigen Grenzwerten sind gegeben für den Entwurf von Beleuchtungsanlagen in Zusammenhang mit astronomische Wahrnehmungen, oberflächliche Himmelsbeobachtung damit einbegriffen. Die angegebenen Werten sind als maximal zu betrachten. Der Entwurf der Beleuchtungsanlage soll so weit wie möglich die niedrigsten Werten einhalten, es sei denn daß der Entwurf höhere Werte benötigt. Andere Benutzungsweisen der Aussenraum ergeben gewöhnlich schwächere Bedingungen für die Begrenzung des Streulichtes. Praktische Ausarbeitungen sind die nationale Regelgebung überlassen. Andere Störlichtaspekten werden von CIE TC 5-12 "Obtrusive light" behandelt.

1. The scope of the report

The report gives general guidance for lighting designers and also policy makers about the ways the interference by light of astronomical observations can be reduced or even avoided. The report gives guidance for the design of lighting installations and lighting equipment. Practical implementation of the general guidance is left to National Regulations.

The Guide focuses on sky-glow, the general diffuse sheen that is visible in the direction of large cities, airports, and industrial complexes. Other aspects of light obtrusion are covered in detail by CIE TC 5-12 "Obtrusive light" in the Draft Report 'Guide on the limitation of the effects of obtrusive light from outdoor lighting installations' (CIE, 1995). It is envisaged that in the future the two CIE-documents will be amalgamated. It has been suggested that a separate Technical Report concerning road and outdoor lighting aimed at the special interest of astronomers should be prepared.

The report gives suggestions that will result in a reduction of the sky-glow. It should be noted that sky-glow does not depend exclusively on the lighting design. It also depends on the atmospheric conditions (humidity, aerosols, clouds, haze, atmospheric pollution, etc.). The recommendations given in the report are expressed in photometric terms, where the amount of light emitted above the horizontal plane is given as a proportion of the lamp lumens according to the design of the luminaire (Upward Light Output Ratio ULOR) or of the luminaire luminous flux in practical situations (Upward Light Output Ratio - installed: $ULOR_{inst}$). It should be realised that essentially the ULOR is related to the luminaire and $ULOR_{inst}$ to the lighting installation. In other publications, the more subjective description Upward Waste Light Ratio (UWLR) is sometimes used. The terminology used in this report is given in Section 3.

The report gives recommendations about maximum sky-glow values to be applied when designing lighting installations in relation to astronomical observations - casual sky viewing included. The values of the Upward Light Output Ratio - installed ($ULOR_{inst}$) quoted in the report must be regarded as **limiting** values. Lighting designers should do all possible to meet the lowest specifications for all designs unless the specific installation requires relaxation.

Other uses of the open air areas at night will usually result in less stringent sky-glow requirements. It should be noted that the maximum admissible sky-glow values recommended in this report apply to a clear and dry atmosphere; humidity, aerosols, clouds and haze may result in sky-glow values well in excess of the recommended values of this report.

2. Introduction

Most of the interference - for astronomers and for others - results from poor lighting design, both in equipment and installations. The result is that a part (and often a major part) of the lamp light flux ends up where it should not be. People may suffer from glare, obtrusive light and loss of darkness, but also plants and animals may suffer from excessive light. This intrusion of light represents 'obtrusive light'. It should be realised that all these effects represent economic losses that have negative monetary and environmental effects.

Better 'quality' is obviously the answer, not only to enhance the benefits for the environment but also to reduce the wastage. A description of what is to be understood by 'quality lighting' is given by Crawford (1991), see p. 10.

The fact that almost all people benefit from lighting, but are also affected in some way by obtrusive light makes it practically impossible to try to avoid it completely. This leads to the concept of zoning: different requirements for the restriction of obtrusive light are set up for different zones, depending on the activities that take place (or are planned) in these zones.

Several nations, states or regions that have important astronomical observatories within their boundaries, have set up regulations to restrict light pollution. It has been argued that in agreement with juridical principles, light may be considered a possible 'pollutant' because:

- it is a hazard to safety (i.e. for motorists);
- it produces ecological disturbances;
- it may produce environmental and visual nuisance;
- it represents waste of energy.

The same arguments are used to define noise as a 'pollutant' (Gray, 1993). At the UNESCO-conference it has been suggested to classify the most important observational sites as "Objects of World Cultural Heritage" (See Anon., 1992).

3. Terminology

In line with the current ISO-code, all units are SI-units - as far as applicable - and the decimal sign is the comma and not the full stop. The terminology is in line with other CIE publications, more in particular with the International Lighting Vocabulary, 4th edition, Publication No. 17.4 (CIE, 1987), the 'Guide on the limitation of the effects of obtrusive light from outdoor lighting installations' (CIE, 1995) and with the workshop held at the CIE Session in 1991 (CIE, 1991).

For the purpose of this Technical Report, the following terminology is used:

contrast: The contrast C between a relatively small object with sharp contours and its (immediate) background is defined as:

$$C = \frac{L_o - L_b}{L_b}$$

with L_o the luminance of the object and L_b the luminance of the background. The contrast is an important determining factor in the visibility of objects. For objects with fuzzy borders, sometimes an alternative definition may be used, based on a grid with alternate light and dark bands with sinusoidal luminance variations:

$$C = \frac{L_1 - L_2}{L_1 + L_2}$$

with L_1 the highest luminance in the bright bands and L_2 the minimal luminance in the dark bands.

curfew: The time after which stricter requirements (for the control of obtrusive light) will apply; often a condition of use of lighting applied by a government controlling authority, usually the local government.

light pollution: A generic term indicating the sum-total of all adverse effects of artificial light.

obtrusive light: Spill light which, because of the quantitative, directional or spectral attributes in a given context, gives rise to annoyance, discomfort, distraction or a reduction in the ability to see essential information.

reference location (reference point): The location (in a designated zone of a certain zone rating) for which the light pollution (the sky-glow) is assessed.

sky-glow: The brightening of the night sky that results from the reflection of radiation (visible and non-visible), scattered from the constituents of the atmosphere (gas molecules, aerosols and particulate matter) in the direction of observation. It comprises of two separate components as follows: