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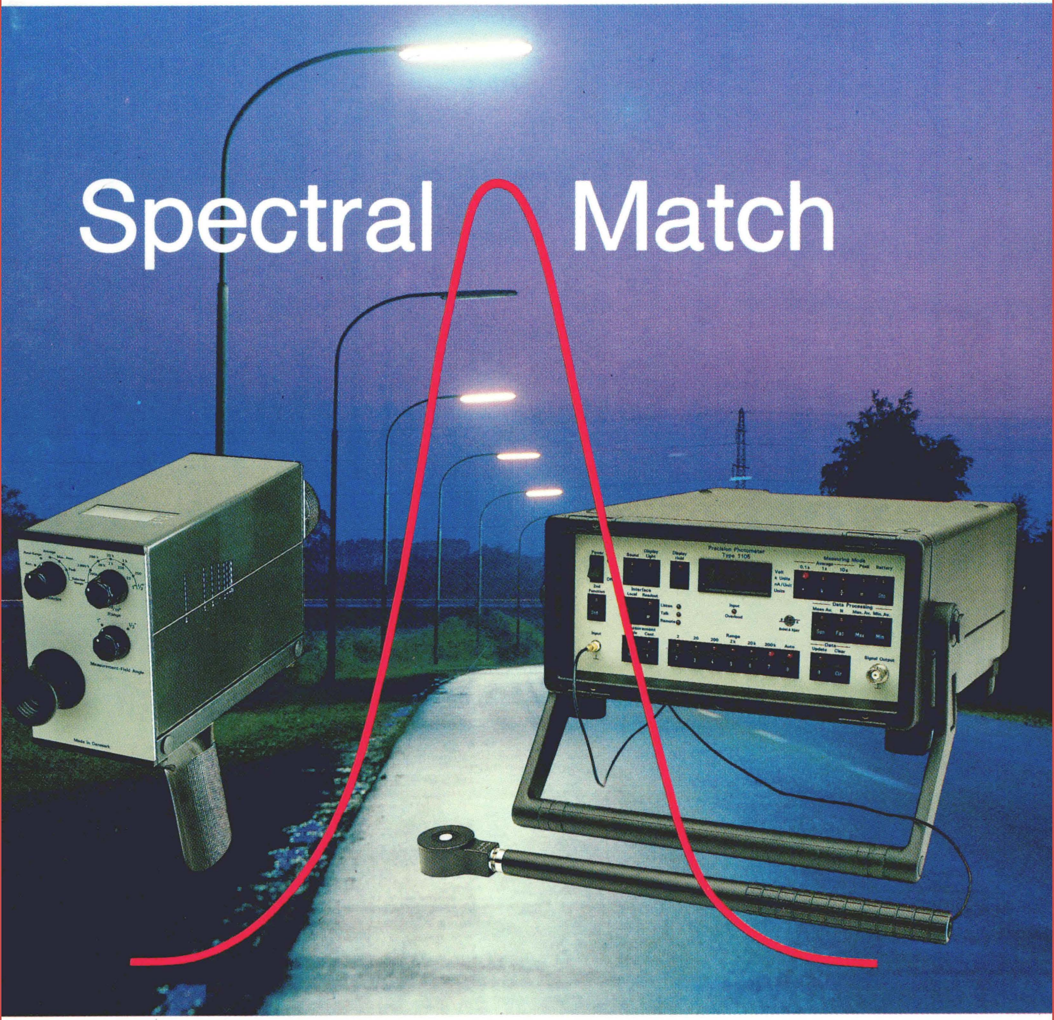

Brüel & Kjær

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(Continued on cover page 3)

TECHNICAL REVIEW

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Contents

QUALITY IN SPECTRAL MATCH OF PHOTOMETRIC TRANSDUCERS

by

O. Nielsen

ABSTRACT
The article reviews some methods for obtaining spectral match, and calculations of measurement errors are made for some transducers of differing match, exposed to different types of light sources. The new CIE method for defining the error in spectral match is explained and compared to other error definitions used in USA and Japan.

SOMMAIRE
Cet article passe en revue quelques méthodes pour obtenir des comparaisons spectrales, et des calculs d'erreurs de mesure sont établis pour quelques capteurs comparant différemment et exposés à différents types de sources lumineuses. La nouvelle méthode CIE pour déterminer les erreurs dans la comparaison spectrale est expliquée et comparée aux autres définitions d'erreurs utilisées aux USA et au Japon.

ZUSAMMENFASSUNG
In diesem Artikel werden einige Methoden zur spektralen Anpassung gegeben. Es werden die Fehler für verschiedene, fehlangepaßte Meßzellen berechnet, die bei der Beleuchtung mit verschiedenen Lichtquellen entstehen. Die neue CIE-Methode zur Beschreibung der Güte der spektralen Anpassung wird beschrieben und mit anderen, in den USA und Japan gebräuchlichen Methoden verglichen.

1. Introduction

The primary aim of photometry is to measure visible radiation or light so that the results correlate as closely as possible to the relevant visual sensation of a normal human observer exposed to such radiation or light. In order to achieve this aim both the light stimulus and the characteristics of vision must be taken into account. The light stimulus is the radiation entering the eye and the characteristics are those of the visual organ which produce the relevant sensation of light.

Until about 1940 photometry predominantly used visual measurement techniques. Typically an observer was required to match the brightness of two visual fields to the object being viewed either sumultaneously or sequentially.

Although the direct involvement of the visual organ in every measurement had the advantage of ensuring a close relevance with the primary aim of photometry, visual photometry eventually disappeared almost completely from normal practice because of its inconvenience, low precision, and poor reproducibility, and because of the differences which occur even between normal observers.

In modern photometric practice, almost all measurements are made with physical detectors of radiation, such as silicon cells. The quantities measured are defined in objective terms. They differ from the corresponding radiometric quantities by incorporating factors that take into account, though only approximately, the response characteristic of the visual organ or photo-biological effects.

This physical photometry has been much more successful than visual photometry in being reasonably convenient, precise and reproducible.

In physical photometry, the most important element is the match of the response of the transducer to the standardized curve for photopic vision. In this article the response of some commercially available transducers exposed to light of different spectral composition is shown.

2. Spectral response of the human eye

The eye is a complex sensory organ which maintains the spatial and temporal relationships of objects in visual space and converts the light power it receives into electrical signals to be processed by the brain.

The human eye contains two types of retinal receptors, rods and cones. The former is responsible for low level vision and the latter for high level vision.

Neither the rod nor the cone system is sensitive to radiations of wavelengths larger than about 780 nm under ordinary levels of retinal illuminance. Accordingly, radiation at these wavelengths are not perceived, even though there is a retinal irradiance as far as 1400 nanometers. Wavelengths shorter than 380 nm are absorbed by the pre-retinal media and are therefore not received by the retina. The term light is

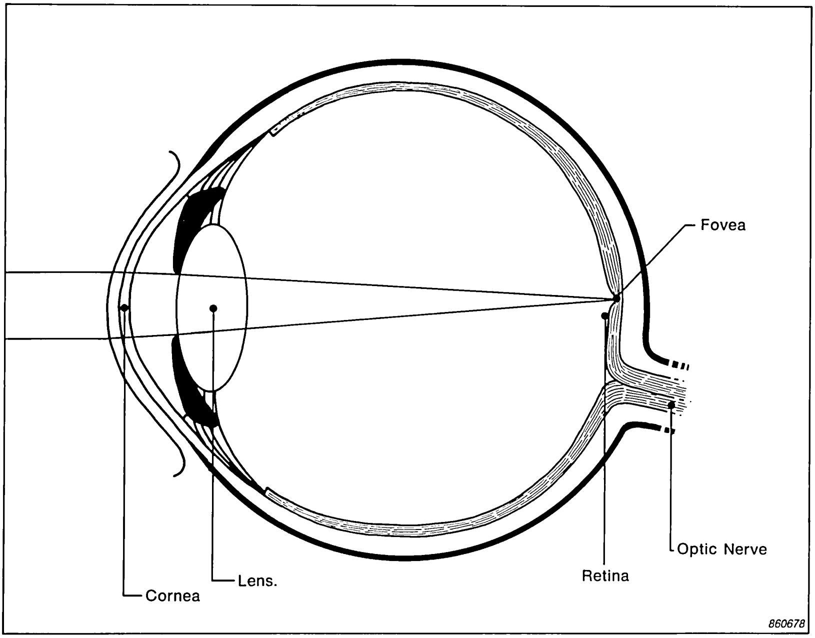


Fig. 1. Sectional diagram of the human eye

applied only to the radiation which reaches the retina and stimulates vision. Therefore light is restricted to wavelengths between 380 and 780 nanometers.

Scotopic eye response, or rod vision, is the response of the rods in the retina (Fig. 1). It occurs after the eye has adapted to field luminances equal to, or less than, about $3 \times 10^{-5}\, cd/m^2$. The rods are scarce near the central field of the retina, the fovea centralis and increase in number towards the periphery. Unlike the cones, all rods contain the same photopigment and cannot therefore distinguish between colours. Once it has adapted to the light, the eye requires considerable time to adapt to the dark when the luminance is lowered (Fig. 2).

The response of the cones in the retina is known as photopic eye response. It occurs after the eye has adapted to a field luminance equal to or greater than $3\, cd/m^2$. Once it has adapted to the dark, the eye requires about two or three minutes to adapt to the light when the luminance is raised.

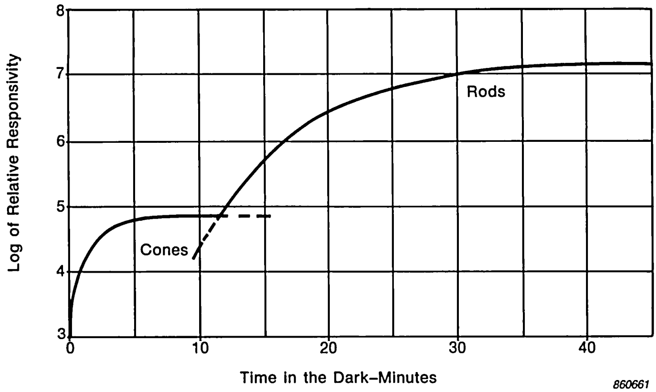


Fig. 2. Adaptation of the eye to complete darkness after exposure to a bright field

Between the dark-adapted state and the light-adapted state of the human eye, the luminous efficacy curve changes progressively from scotopic vision to photopic vision (Fig. 3). The spectral responsivity of the eye in the light-adapted state differs considerably from the dark-adapted state. For definition of luminous efficacy and luminous efficiency, see Appendix.

There are three classes of cones. Their primary difference lies in the pigment contained in their outer segments. The three types are responsible for the ability to differentiate one colour from another.

At low light levels, the rod system determines the sensitivity. The spectral luminous efficacy function has been adopted by the CIE (Commission Internationale de l'Eclairage) 1951 for scotopic vision. At higher levels, the cone system determines the relative sensitivity. The spectral luminous efficacy functions were standardized by CIE in 1924 (Fig. 3) for photopic vision.

When light is measured, it is common practice to have a spectral responsivity which follows the standardized curve for photopic vision $V(\lambda)$. Even when the luminous level is at the mesopic or scotopic state, the photopic curve still applies.

Tabulated values of the spectral responsivity of the human eye can be found in Reference [2].

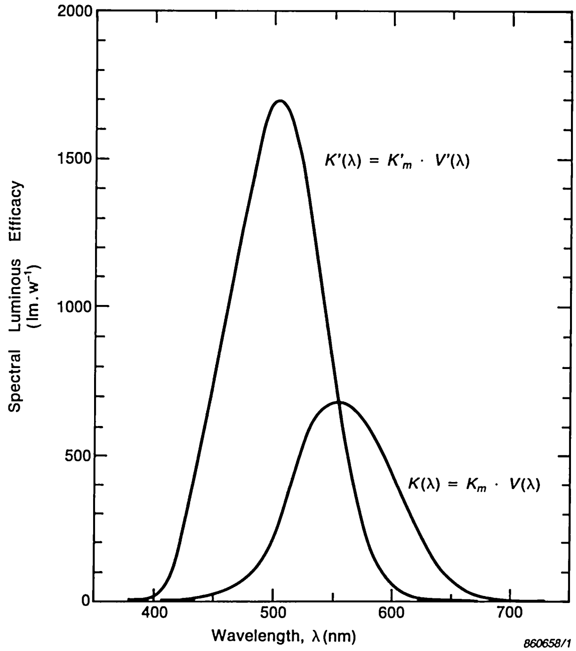


Fig. 3. Spectral luminous efficacies of monochromatic radiation, $K(\lambda)$ for photopic vision, $K'(\lambda)$ for scotopic vision. Spectral luminous efficiency function is $V(\lambda) = K(\lambda)/K_m$

In future, there may be a call for measurements performed with other spectral responsivities matched to the spectral sensitivity of the eye for low level photometry.

At 555 nm wavelength, the eye has its maximum sensitivity which decreases above and below this wavelength. The photometric quantity is then calculated from the integral given below, as

$$X_v = K_m \cdot \int_{380\,nm}^{780\,nm} X_{e,\lambda} \cdot V(\lambda) \cdot d\lambda \qquad (1)$$

where

X_v = Any photometric quantity for day vision
K_m = 683 lm/W, maximum luminous efficacy of photopic vision
$X_{e,\lambda}$ = Radiometric quantity per wavelength unit, corresponding to the photometric quantity X_v
$V(\lambda)$ = Spectral luminous efficiency of photopic vision, between 0 and 1.

For different types of light sources, X_v will vary accordingly. For a hypothetical monochromatic light source at 555 nm wavelength, the luminous efficacy will be

$$\frac{X_v}{X_e} = 683\ lm/W \tag{2}$$

which is much higher than for normal light sources which yields 40–100 *lm / W.*

The $V(\lambda)$ function can also be considered as a weighting curve for the spectral responsivity which emphasizes the yellow-green part of the spectrum of a broadband light source and neglects the blue and the red part of the spectrum.

3. Spectral Match

Photometric quantities are normally defined as in equation (1) shown in section 2. For any transducer measuring photometric units, the radiation received is spectrally weighted according to:

$$I_{ph} = k \cdot \int_{380\,nm}^{780\,nm} X_{e,\lambda} \cdot s(\lambda)_{\mathrm{rel}} \cdot d\lambda \tag{3}$$

where

I_{ph} = photometric current
$s(\lambda)_{rel}$ = relative spectral responsivity of the transducer
$X_{e,\lambda}$ = radiometric quantity per wavelength unit corresponding to the photometric quantity X_v

In order to obtain a photometric quantity which is as correct as possible, it follows that $s(\lambda)_{rel} \approx V(\lambda)$ for any wavelength. The $V(\lambda)$ function is normally defined in the range from 380 nm to 780 nm. Beyond these limits, the value decreases towards zero, (Fig. 3). This implies that the transducer sensitivity should also decrease towards zero in the ultraviolet part and the infrared part of the spectrum. Otherwise an error signal will occur in case of spectral radiation in these ranges. Incandescent lamps, for instance, have a high content of IR radiation (Fig. 4) and consequently special precautions should be taken to prevent this radiation from reaching the silicon diode of the transducer, as silicon diodes are sensitive up to 1100 nm in wavelength.

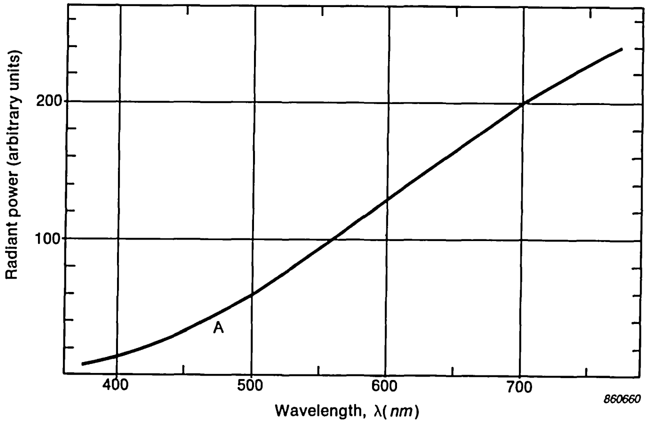


Fig. 4. Power spectral distribution of a CIE standard illuminant source. Temperature 2856 K

During calibration the transducer is illuminated by a standard illuminant A source (Fig. 4) which has a well-known power spectral distribution. If all photometric measurements were made in light of this type, the spectral match would be less important.

However, we are faced with several types of sources, some of which are natural, others artificial. Among the artificial sources the discharge types play an important role and require good spectral match. These sources have typical spectral lines which contain most of the radiated energy.

If the spectral responsivity of the transducer at these wavelengths deviates too much from the $V(\lambda)$ curve, unacceptable errors will occur. A low pressure sodium arc lamp, for instance, has one single band of energy at 590 nm wavelength (Fig. 5). If the transducer deviates by 20% at this wavelength from the $V(\lambda)$ function, a corresponding measurement error will result (Ref. [9]).

If the spectrum of the light to be measured is known, a correction factor will compensate for a lack in spectral match. Light is often composed of several different sources where it is difficult to predict the final spectrum. It is therefore more practical and valuable to rely on quality in match rather than give calibration factors depending on the type of light source.

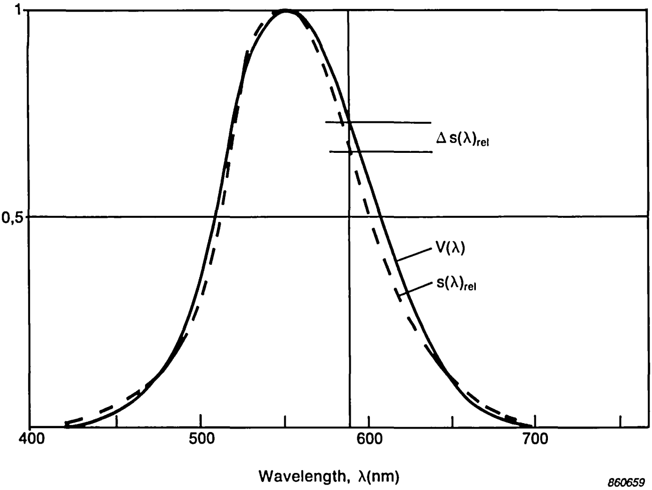


Fig. 5. Example of a bad spectral match. Notice the error of 7% at the sodium line at 590 nm. The relative spectral error is defined as $\Delta s(\lambda)/V(\lambda)$. At other wavelengths higher errors are possible

4. Possibility of Spectral Matching

No transducer sensitive to light will have a perfect match to the $V(\lambda)$ function. At certain wavelengths deviation will occur. To obtain a spectral match of, for example, a silicon diode, different methods are available.

Partial Filtering

Here the sensitive device is covered with a mosaic of coloured glasses where each glass has a certain colour. Both the area and the thickness of the filter glasses are adjusted to give the combination its total response. Although calibration is time-consuming, it yields a fairly good accuracy.

Full Filtering

When the filter combination is sandwiched together and placed on top of the detector, the method is called full-filtering. All the light passes through multiple layers of optical filters. Absorption type glasses are applied because they have a fairly smooth spectral response.

Interference filters can also be applied, especially for matching to narrow bandwidth responses.

The Luminance Meter Type 1101 and the Illuminance Transducer Type 8600 both have full filtering and are individually calibrated.

There are other spectral responses in the fields of biology and agriculture and it is possible to match transducers to follow these functions.

5. Variation in sensitivity for different types of light sources

5.1. Relative Sensitivity (Actinity)

If the spectral response of the transducer is not ideal, the sensitivity to different kinds of light sources of equal luminosity may deviate.

This deviation in sensitivity is expressed by $a(Z)$. The value $a(Z)$ of a transducer exposed to a certain type of light source Z is the ratio of sensitivity for that source to the sensitivity when exposed to a reference light source Type A (Ref. [1, 8]).

$$a(Z) = \frac{\int S_\lambda(Z) \cdot s(\lambda)_{\mathrm{rel}} \cdot d\lambda}{\int S_\lambda(Z) \cdot V(\lambda) \cdot d\lambda} \cdot \frac{\int S_\lambda(A) \cdot V(\lambda) \cdot d\lambda}{\int S_\lambda(A) \cdot s(\lambda)_{\mathrm{rel}} \cdot d\lambda} \tag{4}$$

where $S_\lambda(A)$: Power spectral distribution for the calibration source A
and $S_\lambda(Z)$: Power spectral distribution for the source Z.

The corrected response of a transducer of a given relative spectral responsivity $s(\lambda)_{rel}$ exposed to light from source Z is then given by

$$x(Z) = \frac{1}{a(Z)} \cdot x(Z)_{\mathrm{measured}} \tag{5}$$

The measurement error is calculated as

$$f(Z) = \big(a(Z) - 1\big) \cdot 100\% \tag{6}$$

The relative sensitivity $a(Z)$ must be regarded as a correction factor for a measurement with a given light source type Z, provided the calibration is performed with the source type A.

5.2. Measurement errors for different light sources

To illustrate the need for good spectral match of transducers for light measurements, an investigation was made in which different light sources illuminated transducers of different makes. Often transducers are said to be matched to the $V(\lambda)$ function. However, the quality in match is seldom specified.

Five light sources, recommended by CIE as standards for testing spectral match (Ref.[1]) and a D 65 light source were selected. The power spectral distribution is shown in Fig. 6.

The measurement error $f(Z)$ according to equation (6) was then calculated for three different transducers commercially available. Each transducer was illuminated by the six light sources mentioned above.

The calculation is based on the data of relative spectral response given by the manufacturer.

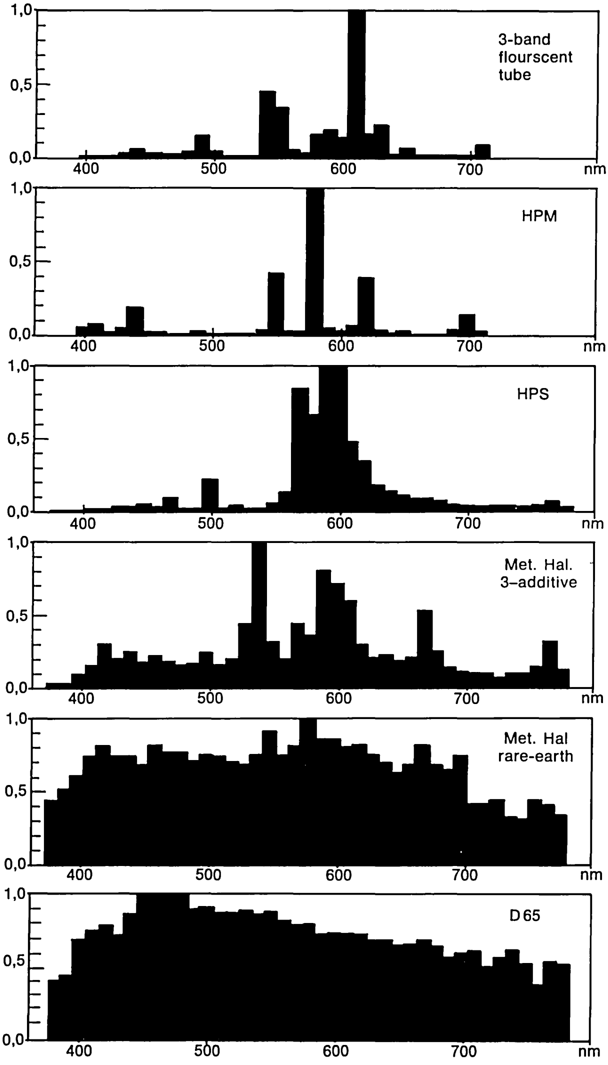
The resulting errors $f(Z)$ are shown in Fig. 6. It can be seen that the higher the degree of dispersion in error, the more pronounced is the deviation in match (Fig. 7). It is therefore not possible to come to a conclusion about accuracy for measurement of a randomly selected lamp based on the $f(Z)$ errors read from the table in Fig. 6.

6. CIE error definition

The main concern in all measurements is accuracy. One method of defining the spectral error in photometry is to use the maximum value of $f(Z)$ when testing the transducer with the five standard lamps mentioned in section 5. $f(Z)$ is a direct measure of the error that will occur if a lamp with a relative spectral distribution $S_\lambda(Z)$ is measured. The method of $f(Z)_{max}$ is in fact proposed by CIE (see Ref.[1, 8]) as one solution for checking the $V(\lambda)$ match. $f(Z)_{max}$ is designated f_1.

The method is less suited for a general description of instrument performance, as it is – at least theoretically – always possible to minimize $f(Z)$ for a selection of lamp spectral distributions, even if $s(\lambda)_{rel}$ differs considerably from $V(\lambda)$. This may lead to large $f(Z)$ values for some further $S_\lambda(Z)$ sources.

An improved CIE method is therefore recommended where the spectral responsivity is normalized with respect to the spectral distribution of the CIE standard source illuminant A, and no target source illuminant Z is considered.



T1	T2	T3
f(Z) %	f(Z) %	f(Z) %
−0,71	−5,0	−2,7
−0,45	−0,75	−2,7
−0,46	−2,4	−2,5
−0,29	−2,5	−7,5
−0,62	−0,04	−9,3
−0,78	+0,5	−12,1

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Fig. 6. Power spectral distribution of 5 CIE recommended sources and a D65 daylight source. The calculated measurement errors f(Z)% for 3 different transducers T1 – T3 is shown for each of the illuminants Z1 – Z6. Transducer T1 is a B & K Type 8600

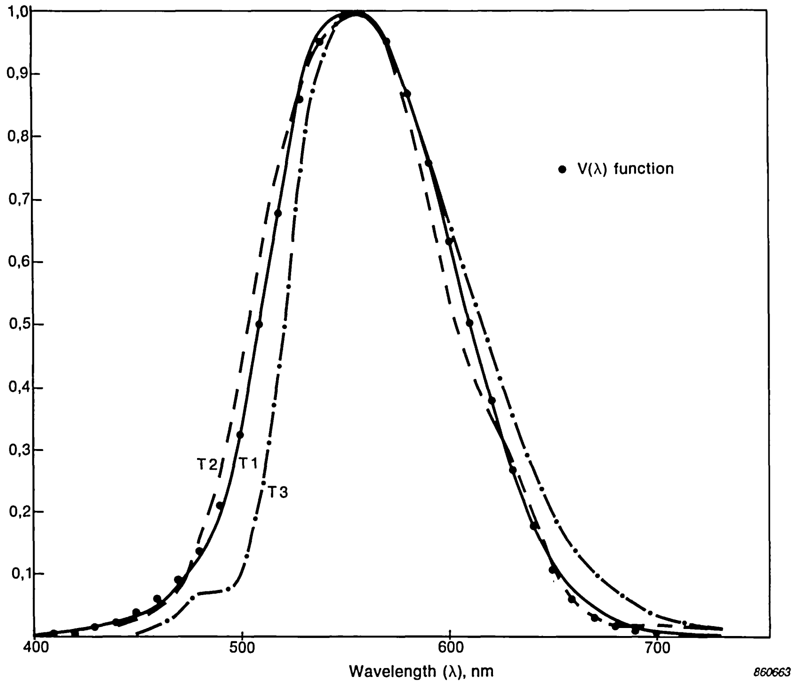

Fig. 7. Relative spectral distribution of the transducers in the investigation compared to the V(λ) function. Transducer T1 is a B & K Type 8600

The error is defined as

$$f'_1 = \frac{\int \left| s^*(\lambda)_{rel} - V(\lambda) \right| d\lambda}{\int V(\lambda) \cdot d\lambda} \cdot 100\% \qquad (7)$$

where $$s^*(\lambda)_{rel} = \frac{\int S_\lambda(A) \cdot V(\lambda) \cdot d\lambda}{\int S_\lambda(A) \cdot s(\lambda)_{rel} \cdot d\lambda} \cdot s(\lambda)_{rel} \qquad (8)$$

The error in match for this improved method is designated f'_1 and should not be confused with the designation f_1 used with the five

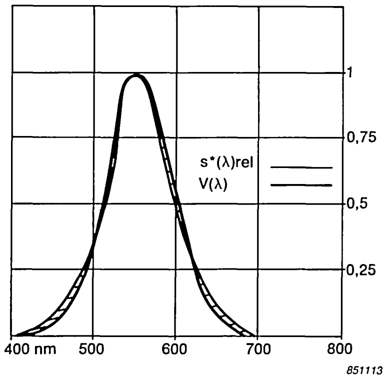

Fig. 8. A graphical interpretation of error designation f'_1 means that the area parts between the curves for $s^*(\lambda)_{rel}$ and $V(\lambda)$ are added numerically and compared to the area under the $V(\lambda)$ curve. Positive and negative deviations are not allowed to cancel out

standard lamps. The disadvantage is that f'_1 cannot be applied as a correction factor, as can the f_1 for a particular light source and transducer (Ref. [1]).

For the Illuminance Transducer Type 8600 the f'_1 error is typically 1,5% and the Luminance Meter Type 1101 has an f'_1 error of typically 2%.

7. Other error definitions

An example of the most common way of expressing the accuracy of the spectral match of a transducer is to say "within ± 2%, integrated, of the CIE photopic curve". In fact this has nothing to do with spectral match. Rather it provides information on the accuracy of response to the standard illuminant A used for the calibration. Any form of spectral responsivity of a transducer can be calibrated to give the desired ± 2% accuracy of the CIE curve on an area basis.

Mathematically this way of defining the error is:

$$f = \left(\frac{k \cdot \int S_\lambda(A) \cdot s(\lambda)_{rel} \cdot d\lambda}{\int S_\lambda(A) \cdot V(\lambda) \cdot d\lambda} - 1 \right) \cdot 100\% \qquad (9)$$

where k may be adjusted in the calibration to any value which makes $f = 0$. This is also the reason why the error f in this definition may assume either a positive or negative value. This method of definition is widely used both in the US and in Europe although it is not a generally agreed method. The drawbacks with this method are that no information on the real spectral responsivity is given and that the error by no means gives an indication of the measurement accuracy obtained for a randomly selected light source.

The only fact which can be deduced from the definition is the accuracy when measuring on light sources of the same spectral distribution as that of the lamp used for the calibration.

Normally this is a standard illuminant A source. Therefore measurements of incandescent light in general will not lead to considerable errors, whereas measurements on fluorescent types or discharge types may lead to unpredictable errors. Furthermore, the spectral distribution of daylight differs considerably from that of incandescent light and can lead to a considerable error in case of a bad match of the transducer.

In Japan a similar method of defining accuracy is referred to in a national Japanese standard for photometers (see Ref.[10]). In abbreviated form the error is calculated as:

$$f_{jap} = \left(\frac{k \cdot \int s(\lambda)_{rel} \cdot d\lambda}{\int S_\lambda(A) \cdot s(\lambda)_{rel} \cdot d\lambda} - 1 \right) \cdot 100\% \qquad (10)$$

Also here the factor k may be adjusted in the calibration to minimize the error f_{jap}. The definition of f_{jap} does not in itself clarify the shape of the spectral response of the transducer.

Therefore the spectral band from 400 – 760 nm is subdivided into bands of smaller bandwidth. For each band the accuracy is then specified with greater relative deviation tolerated at both ends of the spectrum, (Table. 1). The error figure normally given by the manufacturer is the one covering the overall bandwidth of tolerance 1 ± 0,02.

Other error definitions have in the past been proposed, see Ref.[8].

Wave length zone (λ_1 to λ_2) (nm)	Class AA	Class A	Class B
400 to 760	1 ± 0,02	1 ± 0,04	1 ± 0,06
450 to 500	1 ± 0,40	—	—
500 to 550	1 ± 0,10	—	—
550 to 600	1 ± 0,10	—	—
600 to 650	1 ± 0,20	—	—
650 to 700	1 ± 0,50	—	—

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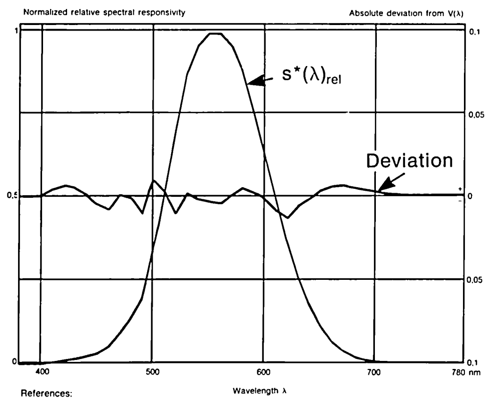
Table 1. Tolerances for the deviation from the $V(\lambda)$ function at different wavelength bands. Class AA is the finest in Japan

Calibration Chart for Illuminance Transducer Type 8600

Brüel & Kjær

Serial no 1143114
Date 28.11.1984
Signature JLS



BC0169-11

References:
CIE Publication No. 53, 1982
DIN 5032 (Draft), Part 6 and 7

(a)

Normalized relative spectral responsivity
$s^*(\lambda)_{rel}$ at 25°C

λ / nm	$s^*(\lambda)_{rel}$	λ / nm	$s^*(\lambda)_{rel}$
380	0.0000	580	0.8746
390	0.0001	590	0.7590
400	0.0013	600	0.6293
410	0.0053	610	0.4947
420	0.0101	620	0.3676
430	0.0163	630	0.2593
440	0.0236	640	0.1734
450	0.0326	650	0.1102
460	0.0517	660	0.0667
470	0.0916	670	0.0385
480	0.1379	680	0.0214
490	0.1974	690	0.0114
500	0.3326	700	0.0059
510	0.5053	710	0.0030
520	0.6997	720	0.0015
530	0.8632	730	0.0008
540	0.9521	740	0.0004
550	0.9914	750	0.0002
560	0.9906	760	0.0001
570	0.9527	770	0.0001
		780	0.0000

Match to V(λ), f_1' ..1.32 .. %

Absolute sensitivity at 25°C ......1.52 . nA / lux

860665

Fig. 9. Calibration chart for transducer type 8600, showing the normalized spectral responsivity

8. Conclusion

From the various definitions of accuracy, it can be seen that the new method defined by CIE, see Ref.[1] is the most accurate compared to the others mentioned here. This is primarily because negative and positive deviations are not allowed to cancel out. In the future this CIE method will probably be more commonly used by the manufacturers of light measurement equipment to define the spectral match.

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APPENDIX

1. New definition of the candela

The unit of luminous intensity, now called the candela, is regarded as the base unit for photometry. This tradition persists in the present SI system of units although there is a widely held view that the unit of luminous flux, the lumen, would now be more appropriate.

The first standards of luminous intensity were candles but in the second half of the nineteenth century these were superseded by several types of lamps that used hydrocarbon liquids as fuel. With the development of filament lamps it was thought that an incandescent surface might provide the basis of a more stable standard, and the surface of platinum at its freezing point was proposed. This was found unsatisfactory because of variations in the surface emissivity and the freezing point caused by contamination (Ref. [3]).

Early in the twentieth century proposals were being put forward to use a blackbody radiator as the primary standard at some reproducible temperature. However, the experimental procedures involved were complex and the first successful realization of this standard was not reported until 1931. The temperature used was again that of freezing platinum. After several national laboratories had realized this blackbody standard and found that their results agreed adequately, it became recognized universally in 1948 as the primary standard of light. In that year the ninth CGPM ratified a new definition of the unit of luminous intensity in terms of the blackbody, and adopted the Latin name "candela" for the unit. In 1967 the thirteenth CGPM improved the wording of this definition by adopting the following form:

> "The candela is the luminous intensity, in the perpendicular direction, of a surface of 1/600 000 square metre of a blackbody at the temperature of freezing platinum under a pressure of 101 325 newtons per square metre."

The surface area of 1/600 000 m^2 was chosen to give acceptable continuity with the units in use in different countries before 1948.

The blackbody definition of the candela remained in force through the period 1948–79, and the corresponding standard proved significantly more reproducible than its predecessors. Moreover, the spectral power distribution of the blackbody radiation was calculable from Planck's law and the thermodynamic temperature of freezing platinum. From this distribution, the definition of the candela, and the values of the $V(\lambda)$ functions, it was possible to evaluate approximately the relationship between photometric and radiometric quantities for monochromatic radiation of any wavelength, both for photopic and scotopic vision.

However, realization of the candela by the blackbody method remained a difficult undertaking and it was performed infrequently even at the larger national standards laboratories. A major improvement in the accuracy attainable by this approach seemed unlikely. A rapid increase in the application of radiometric techniques to photometry, and in the accuracy achievable by these methods, led to proposals that the photometric base unit be redefined in a way that would give it a numerical relationship with the watt which was precisely known. After lengthy consideration of the issues involved by the CIPM and its appropriate consultative committees, the sixteenth CGPM in 1979 adopted the following definition of the candela:

> "The candela is the luminous intensity in a given direction of a source that emits monochromatic radiation of frequency 540×10^{12} Hertz and that has a radiant intensity in that direction of (1/683) watt per steradian."

The frequency 540×10^{12} Hz corresponds to a wavelength of 555 nm

The candela so defined is the present SI base unit applicable to photopic quantities and to quantities yet to be defined in the mesopic domain. In this definition the values of frequency and radiant intensity used are the rounded values judged to give the best continuity with the previous definition. Within the limits of uncertainty the new definition has not changed the magnitude of the candela for photopic vision, but for scotopic vision it has increased the magnitude by about 3 percent.

2. Spectral Luminous Efficacy and Spectral Luminous Efficiency

Spectral Luminous Efficacy (Photopic Vision) of radiant flux $K(\lambda)$ is the quotient of the luminous flux at a given wavelength by the radiant flux at that wavelength. Hence,

$$K(\lambda)\,[\,lm/W\,] = \Phi_{v,\lambda} / \Phi_{e,\lambda} \tag{A.1}$$

The maximum value of the $K(\lambda)$ function occurs at a wavelength of about 555 nm and has a value of 683 *lm*/ *W*.

Spectral Luminous Efficiency (Photopic Vision) of radiant flux $V(\lambda)$ is the ratio of the luminous efficacy at a given wavelength to the value of the luminous efficacy (683 *lm*/ *W*) at the wavelength of maximum luminous efficacy. Accordingly,

$$V(\lambda) = K(\lambda)/683 \tag{A.2}$$

GUIDE TO LIGHTING OF URBAN AREAS *

ABSTRACT

At its meeting in Kyoto in August 1979 the CIE committee on Road lighting TC–4–6 decided to appoint a committee to investigate and draw up recommendations for lighting of all public routes – motor vehicles, cycle and pedestrian – not covered in recommendations and technical reports already published by CIE.
This has now resulted in a third draft of a report, "Guide to lighting of urban areas" which is a joint document from other committees on the subject. What follows is an excerpt from the report with emphasis on the recommendation.
In addition to proposing levels of luminance and illuminance the recommendations consider aspects such as the modelling of people and structures within the environment and the effects of glare, the effect of the lighting on the environment and the general aesthetics of the lighting equipment used.

SOMMAIRE

Lors de la réunion d'août 1979 à Kyoto, le commité CIE s'occupant de l'éclairage routier, le TC–4–6, décida de nommer un comité chargé d'étudier et de rédiger des recommandations concernant l'éclairage de tous les chemins publics – pour véhicules à moteur, bicyclettes et piétons – non couverts par les recommandations et les rapports techniques déjà publiés par le CIE.
Il en a déjà résulté la troisième rédaction provisoire du rapport "Guide de l'éclairage des zones urbaines", qui est un document commun sur le sujet provenant d'autres comités. Ce qui suit est un extrait du rapport mettant l'accent sur les recommandations.
En plus de proposer des niveaux de luminance et d'éclairement, les recommandations considèrent des aspects tels que les modélisations de personnes et de structures dans leur environnement, les effets de l'éblouissement, l'effet de l'éclairage sur l'environnement et les aspects esthétiques généraux des équipements d'éclairage utilisés.

* Excerpt from CIE report by O. Nielsen

ZUSAMMENFASSUNG
Das CIE-Kommitee für Straßenbeleuchtung TC-4-6 beschloß auf der Tagung in Kyoto im August 1979 ein Kommitee einzusetzen. Es sollte die Beleuchtung von allen Verkehrswegen — für Kfz, Fahrräder und Fußgänger — die noch nicht in existierenden Richtlinien und technischen Berichten vom CIE behandelt werden, untersuchen und Richtlinien ausarbeiten.
Jetzt ist der dritte Entwurf des Berichts „Guide to lighting of urban areas" als gemeinsames Dokument mit anderen Kommitees erschienen. Der Inhalt des Berichts wird kurz mit Betonung auf die Richtlinien beschrieben.
Neben Richtwerten für Beleuchtungsstärke und Leuchtdichte gehen Aspekte wie die Erkennbarkeit von Personen und Gegenständen ein. daneben werden Blendeffekte, der Einfluß der Beleuchtung auf die Umgebung sowie allgemeine ästethische Merkmale der Beleuchtungssysteme berücksichtigt.

1. Introduction

Traditionally in many countries residential and industrial areas of a town were designed on a grid system where roads were generally straight, intersections with other roads were at right angles to each other and all roads were designed to cater for all types of traffic. Later, through the introduction of features such as schools and shopping centres, some of these roads developed into arterial routes or link roads between centres.

The intention of this guide is to evaluate the visual requirements of each of the road users and make recommendations for their safe and easy progress along roads and paths in old and new types of urban areas. In addition, as one of the main purposes of urban lighting is the improvement of the night-time appearance and character of the area, recommendations are given on how such effects can be aimed at and how lighting equipment should be aesthetically incorporated into the total visual scene.

In the guide, traditional units of luminance and illuminance are those recommended for use. However, the more recent introduction of the concepts of hemispherical and semicylindrical illuminance are considered to be appropriate alternatives for the identification of obstacles and persons in pedestrian areas and recommended values are given where appropriate. In the same way, a new approach to the assessment of glare leading to discomfort has been introduced in certain residential and pedestrian areas.

As some urban areas will require special artistic treatment of the lighting to provide variety and points of interest to attract and hold pedestrians, the values given in this guide should be used with discretion and artistic freedom permitted in these areas. In many places, the recommended values will be considerably exceeded but they should nevertheless be regarded as minimum for security of persons and property. The pleasantness of an installation will often be gauged by the amount of modelling achieved by the lighting on human features and decorative components in the area.

2. Benefits of Urban Lighting

2.1. Safety of Persons and Property

Public lighting was originally introduced into urban areas as a means of reducing crime, directed at both people and property. Today, crime and vandalism are still major problems in many public areas and surrounding properties. Many investigations have been carried out into the contribution lighting can make to reduce these undesirable aspects of community living. The majority of these investigations have unfortunately been limited in area and/or detail of the lighting standards and are therefore inconclusive. Furthermore, "crime" can take many forms, for example:

a) Mugging i.e., assault and robbery with violence
b) Theft of and from vehicles in the streets
c) Thefts from vendors and stalls in the streets
d) Vandalism of public and private property
e) Theft from gardens and other private property adjoining the street.
f) Misuse of thoroughfares usually lanes and isolated roads as toilets and for sex acts
g) Shop and housebreaking
h) Acts of sabotage and terrorism

It would be a very long and difficult exercise to obtain any reliable data on the effect of lighting on any or all of the above. In many cases these acts are not reported to the police as many members of the public believe that lesser crimes would not receive effective investigation. There is, however, a very definite public conviction that areas of poor or no lighting do attract criminal acts. This is amply demonstrated by the fact that requests for the installation of new or improved lighting from members of the public and the police are fare more frequently based on crime prevention than road traffic accident reduction. In view of this the question of crime and lighting is very high on the priority list of any public authority and attention must be given to the subject in any consideration of public lighting.

The benefits derived from the installation of lighting can be summarized as follows:

a. There is a strong indication that darkness is an ally of the criminal and terrorist.

b. Urban lighting does discourage vandalism, minor crimes, fouling and misuse of public thoroughfares, particularly in lanes.

c. Urban lighting improves reaction time and distance of visibility. It assists law enforcement officers in the identification of criminals and vagrants, anticipating criminal tendencies and in enabling the police to keep an eye on the safety of their colleagues.

d. Urban lighting provides a sense of security to residents and all road users, particularly pedestrians, at night.

The continued provision of funds for urban lighting projects, other than for reduction in road accidents, must therefore be encouraged as it plays a vital part in the safety and pleasantness of an area at night.

2.2. Reduction in Road Accidents

It is well known that the provision of lighting on roads to recognised standards will reduce the number and severity of accidents at night. This is well covered in CIE publication No.8/2 "Road Lighting as an Accident Countermeasure".

Much of the data collected refers to accidents on motorways and arterial routes but little information is available on the contribution lighting can make to reducing accidents on local and residential roads. Accidents involving pedestrians constitute a high percentage of all road accidents, especially during dark or twilight hours. Many of these occur at entrances to railway stations and at bus stops. However, a substantial number of accidents do occur in residential areas. These take place near schools and recreation centres as well as in purely residential streets where children play either on sidewalks or in the street itself.

It is possible that the generally lower speeds of traffic on residential roads give a false sense of security to pedestrians. Whatever the cause the relatively high incidence of accidents on these streets cannot be ignored. Adequate and appropriate standards of lighting must be provided if the number of accidents occurring at night are to be reduced.

2.3. Contribution of Lighting to Community Character and Vitality

There are a number of people who will strongly resist the installation of street lighting in a town, and particularly in the area in which they live. The chief claim is that street lights destroy the natural environment by driving away birds and small animals. This has never been proven.

Opposed to this is the strong feeling amongst other people that lighting at night in the streets and other public areas can contribute considerably to the character and vitality of a city. This can generate a sense of civic pride and provide an attraction for tourists.

The provision of lighting in an urban area will also be helpful to visitors to the town or strangers in a particular area. It provides proper orientation within the area and allows quick and accurate identification of streets and houses. Good lighting will always be an asset to ambulances, fire fighting crews, police cars and rescue teams in an emergency.

For guidance on the decorative aspects of urban lighting readers are referred to CIE Publication No.37 “Exterior Lighting in the Environment”.

3. Recommendations

In this section recommendations are given for the following application fields:

- Residential areas;
- Industrial areas;
- Commercial areas;
- Miscellaneous areas: pedestrian and cycle bridges, pedestrian underpasses, crosswalks, pedestrian walkways and cycle paths.

The recommendations for each application are divided into three sections viz “Design Objectives”, “Installation Design” and “Environmental Factors”. For most applications one table is given for the drivers' requirements and one table for the pedestrian requirements.

For the pedestrian requirements lighting recommendations are given in two forms, firstly in the traditional and well-known parameter of horizontal illuminance and secondly as a new suggested design guide using the parameter **semicylindrical** and **hemispherical** illuminance. The recent introduction of the concept of semicylindrical illuminance at 1,5 m above ground level is considered to be more appropriate for identification of persons in pedestrian areas. The hemispherical illuminance is considered to be a good measure for visibility of ramps, kerbs, steps or road edges and obstacles on the ground. Details of the method of calculation of **semicylindrical illuminance** and **hemispherical illuminance** are given in the Appendix. In the same way, a new approach to the assessement of glare leading to discomfort glare assessment has been introduced for low mounted luminaires, up to approximately 7 m, where the risk exists of pedestrians having to look straight into the luminaires. This is based on the luminance of the light emitting area of individual luminaires and details of calculation methods are given in the Appendix. Designers must decide which parameters best suit their requirements and calculate accordingly.

The following abbreviations are used in the lighting requirements tables:

$L_{(ave)}$: average road surface luminance (CIE 12/2)
U_O : overall luminance uniformity (CIE 12/2)
U_L : longitudinal luminance uniformity (CIE 12/2)
G : glare control mark (CIE 12/2)
TI : threshold increment for glare (CIE 12/2)

$E_{H(ave)}$: average horizontal illuminance at ground level
$E_{SC(min)}$: local minimum semicylindrical illuminance at a height of 1,5 m (see Appendix)
$E_{V(ave)}$: average vertical illuminance
$E_{HS(ave)}$: local average hemispherical illuminance at ground level (see Appendix)
$L \cdot A^{0,25}$: glare value for mounting heights lower than 7 m (see Fig. 1)

3.1. Residential Areas

Residential areas may be defined as areas of a village, town or city which are suitable for or are occupied by private dwellings.

It is difficult to provide an accurate definition of residential areas for lighting recommendations. Where the residences are located on an arterial route of whatever importance, the lighting design must be dictated primarily by the road traffic requirements such as laid down in Tables I and II of the CIE document 12/2. However, considerable thought should be given to other street users such as pedestrians and particular attention be paid to Section 4.4.2 of the above document which deals with the lighting of the surroundings to the road.

Modern thinking regarding residential areas is to keep separated domestic buildings from any form of arterial route and, with the slight exception of roads catering for that area, restrict access to residents, visitors and delivery vehicles. Restrictions can take many different forms – extremely narrow roads, roads with frequent curves, construction of speed humps and chicanes in the roadway, culs-de-sac and loops or crescents. Even older grid-type suburbs are being re-assessed from the point of view of traffic and many of the roads in these areas are being altered to restrict access in manners similar to new town areas.

For these reasons this section of the recommendations is restricted to collector and local roads as described above for strictly local residents' collectoraccess. In addition the needs of other road users such as cyclists and pedestrians will be considered and recommendations made regarding the provision of lighting for their needs.

3.1.1. Collector Roads

Design Objectives
These roads can be defined as principal roads in a residential area which link all local roads to an arterial route. Fundamentally these are the Class E roads of CIE publication 12/2 but as they will be roads through residential complexes the additional requirements of residents must be included in the lighting design.

Lighting Requirements (maintained values)

Driver Requirements	L *ave*	U_0	U_l	G	TI
Roadway	0,5 – 1 cd/m^2	0,4 min:ave	0,5 min:ave	4 – 5	14 – 20

T01129GB0

An average horizontal illuminance must be provided on the footways of not less than 50% of that on the adjacent 5 m of roadway.

Pedestrian Requirements	E_H *ave*	E_H *max:min*	E_{SC} *min*	E_{HS} *ave*
Footway	4 lux	20:1	0,8 lux	2,5 lux
Roadway	7 lux	20:1	–	5 lux

T01130GB0

The semicylindrical illuminance values (E_{SC}) will apply in both longitudinal directions parallel to the run of the road.

Installation Design
As the lighting must cater for the vehicle users on the carriageway and pedestrians on footways it is recommended that lights be installed where necessary on both sides of the road in either opposite or staggered formation.

Environmental Aspects
The aesthetic appearance of all street lighting equipment both by day and night must receive careful consideration. In residential areas the environment may contribute considerably to the quality of life in the area and the street lighting, like any other street fittings, must be related to that environment. This will entail consideration of the mounting height of the luminaire, the overhang or outreach of any bracket employed, the shape and proportions of the luminaire and pole both individually and in relationship to each other and their surrounds.

3.1.2. Local Roads

Design Objectives
The standard for visibility on these roads can no longer be solely the luminance of the road surface. By design, the roads will restrict the speed of vehicles and therefore the time available for a vehicle driver to see an obstacle is greatly increased.

Lighting Requirements (maintained values)

Driver Requirements	L *ave*	U_0	U_l	G	TI
Roadway	0,5 cd/m^2	0,4 min:ave	0,5 min:ave	4	20

T01131GB0

An average illuminance of not less than 50% of that on the adjacent 5 m of roadway should be provided on the footway.

Pedestrian Requirements	E_H *ave*	E_H max:min	E_{SC} min	E_{HS} *ave*	$L \cdot A^{0,25}$
Footway	4 lux	20:1	0,8 lux	2,5 lux	(a) 3 000 (b) 4 000
Roadway	7 lux	20:1	1 lux	5 lux	(c) 5 000

T01132GB0

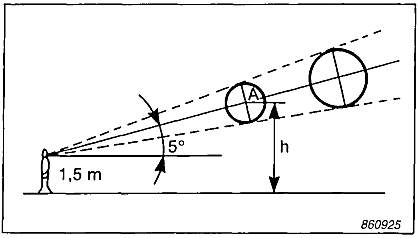

Fig. 1. Relation between light emitting area, viewing direction and mounting height of luminaires

The semicylindrical illuminance values will apply in both longitudinal directions to the run of the road. In the table L equals the luminance (in cd/m^2) of the luminaire in a direction between 0° and 5° from the horizontal and A equals the area (in m^2) of the light limiting surface in the horizontal direction (see Fig. 1).

The $L \cdot A^{0,25}$ values are maximum values for limitation in discomfort glare for mounting heights h of:

a) up to 4,5 m
b) 4,5 m to 6 m
c) above 6 m

Installation Design
The arrangements of luminaires will be dependent on the width of the street between property boundaries. Generally a single row of luminaires should be adequate, but where the transverse distance between a luminaire and the property line on the opposite side of the street exceeds twice the mounting height of the luminaire, an additional row will be required on the opposite walkway. The actual light distribution of the luminaire may however dictate other arrangements.

Environmental Factors
It is important at all times to ensure that the appearance of the street is attractive both by day and by night. Luminaires and poles should be selected or designed to ensure that they appear as an integral unit. Where appropriate, multi-lamp units may be used. Care should be taken to ensure that the choice of luminaire, pole, paint finishes and related equipment is suited to with the general architecture of the buildings in the vicinity and the design of other street fittings.

3.1.3. Residential, Townhouse

Design Objectives

A comparatively new development in residential town area design is the building of new or the conversion of existing residential areas into complexes in which access is restricted. The purpose is to provide living entities of comparatively high density where the people residing in these areas share the amenities of the common property between and surrounding the residential units. The movement of motor vehicles within the area is severely curtailed and right of way is accorded to the pedestrian.

Lighting Requirements (maintained values)

	E_H ave	E_H max:min	E_{SC} min	E_{HS} ave	$L \cdot A^{0,25}$
High usage areas	10–15 lux	15:1	–	7–10 lux	
Medium usage areas	5 lux	20:1	1 lux	3 lux	a) 3 000 b) 4 000 c) 5 000
Low usage areas	3 lux	20:1	0,5 lux	2 lux	

T01133GB0

The $L \cdot A^{0,25}$ values are maximum values for limitation in glare leading to discomfort for mounting heights of

a) up to 4,5 m
b) 4,5 to 6 m
c) above 6 m.

The lighting levels need not, in fact preferably not, be uniform throughout the area. Changes in levels can add to the visual attraction of the complex at night. Travel and play areas will require appropriately high levels. Areas where people congregate will require intermediate levels with greater emphasis on semicylindrical illuminance and areas of landscaping and parking of vehicles will require minimum standards.

Installation Design

As the design of poles, standards and luminaires must be in keeping with the architectural characteristics of the complex, considerable importance must be paid to the choice, use and positioning of equipment. This applies not only to the relationship of lighting components to the surroundings but also to other inter-related features e.g. luminaire to pole.

Environmental Aspects
In view of the importance of making these areas as attractive as possible to encourage residents to utilize the facilities offered to the maximum extent it is important that the total environment be considered in the lighting design. Lighting equipment and methods should be diverse within the complex to provide variety and interest and areas of brightness and comparative darkness be deliberately arranged to provide modelling of buildings, ornaments, flora and people.

Where wall-mounted luminaires are used they should not, for aesthetic reasons protrude more than 1,5 m from the wall.

3.2. Industrial Areas

As with residential suburbs, the design of industrial areas has undergone considerable changes over recent years. Although large industries have tended to congregate in specific regions, small industries have been allowed to develop in a fairly haphazard fashion in commercial and in some cases, even in residential suburbs. Many local authorities have recognised the need to control small industries and as a result there is a growing tendency to create industrial complexes or estates.

Design Objectives
Where industrial areas are part of an existing town the premises are likely to be located on arterial or collector roads, and the standard of lighting should be as laid down in CIE Document 12/2.

Lighting Requirements (maintained values)

Driver Requirements	L ave	U_0	U_l	G	TI
Peak Periods	1 cd/m^2	0,4	0,5	5	20
Valley Periods	0,5 cd/m^2	0,4	0,5	4	20

T01134GB0

An average illuminance of not less than 50% of that on the adjacent 5 m roadway should be provided on the footway.

Pedestrian Requirements	E_H *ave*	E_H max:min	E_{SC} min	E_{HS} *ave*	*G*
Peak Periods	5 lux	20:1	2 lux	3 lux	5
Valley Periods	0,5 lux	20:1	0,8 lux	0,5 lux	4

T01135GB0

The semicylindrical illuminance values will apply in both longitudinal directions parallel to the run of the road. As standard road lighting poles and luminaires are likely to be used in these areas the CIE G mark is recommended.

Installation Design
As one of the principle purposes of the lighting is security of the area at night, mounting heights under 8 m are not recommended. The luminaires and the electrical installation should be designed to withstand vandalism or direct intent to break or disrupt the electrical supply.

Environmental Aspects
Generally the aesthetics of the installation in industrial areas will not assume any significant proportions. in some of the special industrial town areas consideration of the appearance of the lighting installation may be needed although this will be essentially a daylight consideration. Restrictions on positioning and luminance levels may be imposed.

3.3. Commercial Areas

In the early days of development of the majority of villages and towns, the commercial area, i.e. shops, places of entertainment and restaurants, were located at the centre of the area. As development proceeded the streets within this area grew progressively busier as more and more pedestrians filled the sidewalks and vehicles the roadway. This created a dangerous situation particularly for pedestrians; parking too became a problem as car owners wanted to park their cars in close proximity to their main shopping points.

This section of the guide covers three aspects:

1. The older type of town centre with main streets and shopping centres.
2. Streets with a high density of shopping and roadways limited to bus traffic and/or lower volume vehicle access.
3. Outdoor shopping malls exclusively for pedestrian use.

Design Objectives
The lighting requirements of vehicle drivers will be very much as laid down in CIE Document 12/2 for each classification of road except that in areas with high pedestrian usage it is essential that lighting standards on the roadway be increased by not less than 100% and the spill of light onto walkways be increased proportionally. This will ensure that drivers can more readily see pedestrians on the roadway or those about to step off the walkway to cross the road.

Lighting Requirements (maintained values), see Tables Page 34.

An average illuminance of not less than 50% of that on the adjacent 5 m of roadway shall be provided on the footway.

The semicylindrical illuminance values will apply in both longitudinal directions parallel to the run of the road. The $L \cdot A^{0,25}$ values are maximum values for limitation in glare leading to discomfort for mounting heights of:

a) up to 4,5 m
b) 4,5 to 6 m
c) above 6 m

Installation Design
For general traffic route lighting the performance of a road lighting luminaire is measured by its ability to illuminate the horizontal plane of the road surface so as to give it a high luminance by which objects on it can be viewed in silhouette. Within commercial areas much more visual information is required from surfaces other than the horizontal. In particular the vertical plane is important as this covers not only pedestrians but door entrances, signs and indeed most other "objects" of note within an urban environment.

Luminaires therefore need to be selected to give light as much on the vertical as on the horizontal planes but with care not to produce too much glare. It should be noted that glare is in itself a product of ambient lighting levels and therefore in an environment of relatively bright vertical surroundings (i.e. background luminances) higher actual luminaire intensities can be permitted than is usual on more general traffic routes.

a) Driver Requirements on Roadway	City or Town Centres				Suburban Shopping Streets				Village Centres			
	L_{ave}	U_0	U_1	G	L_{ave}	U_0	U_l	G	L_{ave}	U_0	U_l	G
Mixed vehicle & pedestrian	2 cd/m^2	0,4	0,7	6	1,5 cd/m^2	0,4	0,7	5	1 cd/m^2	0,4	0,5	4
Primarily pedes-trian	1,5 cd/m^2	0,4	0,6	5	1 cd/m^2	0,4	0,5	4	0,5 cd/m^2	0,4	0,5	4

T01136GB0

b) Pedestrian Requirements on Walkways	City or Town Centres					Suburban Shopping Streets					Village Centres				
	E_H *ave*	E_H max:min	E_{SC} min	E_{HS} *ave*	$L \cdot A^{0,25}$ max	E_H *ave*	U_0 max:min	E_{SC} min	E_{HS} *ave*	$L \cdot A^{0,25}$ max	E_H *ave*	U_0 max:min	E_{SC} min	E_{HS} *ave*	$L \cdot A^{0,25}$ max
Mixed vehicle & pedestrian	20 lux	20:1	2 lux	15 lux		10 lux	20:1	1,5 lux	7 lux		5 lux	30:1	1 lux	4 lux	
Primarily pedestrian	15 lux	20:1	2 lux	10 lux	(a) 5 000 (b) 6 000 (c) 8 000	5 lux	20:1	1,5 lux	4 lux	(a) 5 000 (b) 6 000 (c) 8 000	2 lux	40:1	0,8 lux	1,5 lux	(a) 4 000 (b) 5 000 (c) 6 000
Wholly pedestrian	10 lux	25:1	2 lux	7 lux		10 lux	25:1	1,5 lux	7 lux		10 lux	10:1	0,8 lux	7 lux	

T01138GB0

3.4. Miscellaneous Areas

In all urban areas there will be a call to light miscellaneous areas such as pedestrian bridges and underpasses, cycle paths and road crossings. The latter has been covered in CIE Publication No.32 "Lighting in Situations Requiring Special Treatment" and should be read in conjunction with these recommendations.

3.4.1. Pedestrian and Cycle Bridges

Design Objectives

The chief requirements for these areas will be:

a) to allow for the safe interaction of pedestrian and cyclists particularly where the bridge is shared
b) to allow pedestrians and/or cyclists to see any obstacles and/or irregularities in the bridge surface, and
c) to allow pedestrians and/or cyclists to recognize fellow users of the facility and to determine their friendly or hostile intentions.

Lighting Requirements (maintained values)

	E_H ave	E_H max:min	E_{SC} min	E_{HS} ave	Glare
Shared with residential collector road	As CIE 12/2 Class D	As CIE 12/2	1 lux	5 lux	G = 4
Shared with residential local road	5 lux	20:1	1 lux	3 lux	$L \cdot A^{0,25}$ = 3000 max
Separate from other traffic	5 lux	20:1	1 lux	3 lux	$L \cdot A^{0,25}$ = 3000 max

T01140GB0

Where the bridge is shared with a road a minimum illuminance of 50% of that on the adjacent 5 m of roadway must be provided on the footway. Semicylindrical values will apply in both horizontal directions parallel to the run of the road.

Where bridges are lighted decoratively, care should be taken to ensure that the lighting equipment for that purpose does not interfere with the pedestrians or cyclists, either as a result of glare or excessive shadows on the pavement.

3.4.2. Pedestrian and Cycle Underpasses

Pedestrian and cycle underpasses or tunnels are likely to be a part of any urban transportation system and adequate lighting must be provided for them due to the potential special safety and security needs.

Lighting Requirements (maintained values)

	E_H ave	E_H max:min	E_{SC} min	E_{HS} ave	Glare
Pedestrians & cycles only	Day: 150 lux Night: 40 lux	10:1	8 lux	25 lux	$L \cdot A^{0.25}$ 3000 max

T01141GB0

Where underpasses are shared with residential industrial or commercial roads the recommendations as laid down in CIE publication No.26 should apply where applicable.

Installation Design

Short underpasses (such as those encountered where a roadway or pedestrian walkway or cycle path goes beneath a roadway or other structure) can generally be lighted satisfactorily with standard luminaires if they are positioned properly. They should be positioned so that there are no large discontinuities in the pavement lighting. Care must be taken that the uniformity does not fall below that specified. These luminaires should also provide suitable vertical illumination on the supporting structures as an aid to avoid accidents.

3.4.3. Pedestrian Road Crossings

Design Objectives

The chief requirements for these areas will be:

a) to allow for the safe passage of pedestrians across the roadway, and
b) to allow pedestrians to see any obstacles and/or irregularities in the road surface.

Lighting Requirements (maintained values)

	E_H ave	E_V ave	Uniformity max:min	E_{HS} ave
Commercial and Industrial Areas	20 lux	20 lux	5:1	12,5 lux
Residential Areas	6 lux	5 lux	10:1	4 lux

T01142GB0

The average vertical illuminance must apply over an area between 0,5 m and 1,6 m above road level across the road.

The average horizontal illuminance should never be less than twice the illuminance of the roadway on each side of the crossing.

Installation Design
Adequate lighting for safety at crosswalks requires additional equipment at that location. This may take the form of an increased number of the luminaires used in lighting the entire route such as using two at each corner of an intersection with pedestrian crosswalks or two fixtures at each mid-block crossing. Alternatively, special fixtures with narrow and/or directional beams may be suspended or mounted above the crosswalks to provide the increased illumination.

3.4.4. Pedestrian Walkways and Paths

In many new urban areas, paths are specifically provided to allow pedestrian access from parking lots to shopping and recreation areas, paths which link residential complexes to areas of communical gatherings and paths through parks. Some guidance for the lighting of such paths is given below:

Design Objectives
The chief requirements for the lighting of these areas will be:

a) to allow pedestrians to see obstacles and/or irregularities in the paved surface on which he is walking.
b) to enable pedestrians to recognise fellow users of the area in sufficient time to determine the intent of these persons (friendly or hostile) and to take the necessary evasive action when required.
c) to provide an attractive area which will draw people and allow them to enjoy facilities provided in comfort and safety.

Lighting Requirements (maintained values)

	E_H min	E_H max:min	E_{SC} min	E_{HS} *ave*	$L \cdot A^{0,25}$
In parks and residential areas	2 lux	20:1	0,8 lux	1,5 lux	
In city centre	5 lux	20:1	1 lux	3 lux	a) max 4000 b) max 5000
In arcades and passageways	15 lux	20:1	5 lux	10 lux	

T01143GB0

The semicylindrical illuminance values will apply in both longitudinal directions parallel to the path. The glare values relate to the luminaire mounting heights of

a) up to 4,5 m
b) above 4,5 m.

Installation Design
The major problem associated with footway lighting is the need for all lighting equipment to be manufactured of strong and durable materials to resist vandalism. For this reason no luminaires should be mounted less than 4 m above the pathway except possibly bollards manufactured from concrete or other vandal-resistant materials. Poles should be smooth finish without any protusions which can be used for foot or hand holds.

3.4.5. Cycle Paths

In many countries where the terrain is mainly flat there is a demand for the provision of lighting for the safe passage of cyclist at night. Surveys conducted in the Netherlands indicated that a very large number of cyclists feel unsafe and ill at ease at dusk or during the night and that the lack of lighting is considered by many to be a factor which contributes towards accidents. This is particularly important where cycle tracks cross roads.

Lighting Requirements (maintained values)

As the main requirement of visibility will be determination of changes to or the presence of objects on the pathway the concept of path surface luminance is recommended as the standard. As speeds of cycling will vary from 10 – 20 km/h for pedal cycles and up to 40 km/h for mopeds the lighting requirements will not be as stringent as that laid down for other motorised traffic as time of perception will generally be longer. Based on this the following recommendations are made:

	L_{ave}	Uniformity max:min	G
Straight stretches	0,1 cd/m^2	5:1	3
Paths with side roads	0,2 cd/m^2	3:1	4
Junctions with traffic routes	0,5 cd/m^2	3:1	4

T01144GB0

4. APPENDIX

Definition and Calculation

a) Semicylindrical Illuminance

In areas dominated or used by pedestrians the most important lighting requirement at night is to be able to recognise other people approaching or in the vicinity at a reasonable distance away. To provide the very necessary sense of security it must be possible to recognise if the other person is likely to be friendly, indifferent or aggressive in sufficient time to make any appropriate response. The minimum distance required to recognise any sign of hostility and take evasive or defensive action is, according to research, 4 m in front of the observer. Vertical illuminance of a sufficiently high level at the average height of a human face – approximately 1,5 m above pavement level – will provide the requirements of adequate visibility. For a number of reasons pure vertical illuminance from whatever direction is not the optimum parameter. The comparatively recent introduction of the concept of semicylindrical illuminance has therefore been used in this guide. Research has indicated that the minimum semicylindrical illuminance necessary to recognise and gauge a person's intention at 4 m is 0,8 lux at 1,5 m above ground level. At 10 m distances, which would give greater time for any necessary avoiding action the recommended level is 2,7 lux.

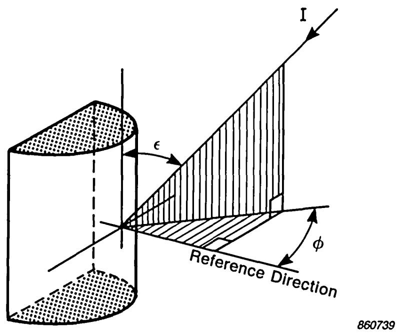

Fig. 2. Definition of angles of incidence for semicylindrical illuminance

Fig. 2 illustrates the concept of semicylindrical illuminance from which the following formula can be deduced.

$$E_{SC} = I \cdot \frac{(1 + \cos \phi) \sin \epsilon}{\pi \cdot d^2} \text{ (lux)} \tag{1}$$

where

I = luminous intensity in candelas in the shown direction
d = distance between light source and measurement point
ϕ = angle between direction of light incidence and direction of observation projected onto a horizontal plane
ϵ = angle between direction of light incidence and the vertical

b) Hemispherical Illuminance

On urban streets the pedestrian and, to a certain extent, the vehicle driver is concerned with observing not only the horizontal surface of the sidewalk or roadway but also vertical surfaces such as kerbs, street boundaries and steps as well as inclined surfaces such as ramps. Reasonable levels of hemispherical illuminance at footway level will generally also provide adequate illuminance of people at shoulder and head heights and so give sufficient lighting for recognition purposes.

Hemispherical illuminance is the luminous flux on a small half-sphere divided by the area of that half-sphere. This half-sphere is placed base downwards on the footway or road surface when taking measurements.

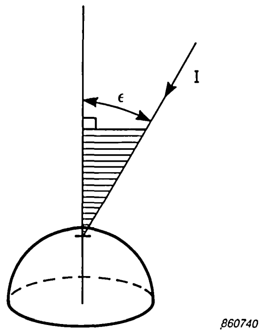

Fig. 3. Definition of angle of incidence for hemispherical illuminance

Average hemispherical illuminance is the average of a number of measured points in the area and the uniformity ratio is the lowest value obtained divided by the average value. For all levels of hemispherical illuminance this uniformity should not be less than 0,15.

Fig. 3 illustrates the concept of hemispherical illuminance from which the following formula can be deduced.

$$E_{HS} = \frac{I}{d^2} \cdot \frac{1}{4}\left(1 + \cos \epsilon\right) \text{ (lux)} \qquad (2)$$

where

I = luminous intensity in candelas in the shown direction
d = distance between light source and measurement point
ϵ = angle of incidence

c) Luminaire Glare Restriction Formula
In residential and pedestrian areas the sensation of discomfort glare to a pedestrian or slow moving cycle or vehicle driver is likely to be caused by the brightness of an individual luminaire near to the direct line of sight of the observer. This would be particularly applicable in those areas where lower luminaire mounting heights are used.

To provide guidance to users of this code it was decided that the standard CIE road lighting glare mark of 5 (just admissible) would be recommended throughout for pedestrian traffic.

For each mounting height, the following relationships between L and A are recommended:

for a mounting height of up to 4,5 m	$L \cdot A^{0,25}$ should not exceed 3000
for a mounting height of 4,5 to 6 m	$L \cdot A^{0,25}$ should not exceed 4000
for a mounting height of above 6 m	$L \cdot A^{0,25}$ should not exceed 5000

Here L equals the luminaire's greatest (average) luminance in cd/m^2 in the direction between 0° and 5° from the horizontal and A the flashed area of the luminaire in m^2 in the horizontal direction (see Fig. 1). For a description of the determining procedure for A see CIE publication No.31/1976.

d) Modelling

The pleasantness and acceptance of an installation with people will be judged on the "naturalness" of the appearance of these people. This is a measure of the modelling of their features (see Fig. 4). They will have neither excessive nor inadequate contrast, both of which can cause distortions. Studies have shown that the ratio between the vertical (E_v) and the semicylindrical (E_{SC}) illuminances will give good guidance regarding modelling. It is recommended therefore that

$$\frac{E_v}{E_{SC}} \quad \text{should be between 0,8 and 1,3} \qquad (3)$$

Fig. 4. Illustration of the effects of light direction on visibility and modelling of people's faces

This aspect of lighting design can be incorporated into the overall design concept of special pedestrian areas where, for aesthetic reasons, the appearance of the users and the fitting in the area must receive special consideration.

5. Literature

[1] "Recommendations for the lighting of public thoroughfares", CIE Publication 12.2

[2] "Road lighting in situations requiring special treatment", CIE publication 32 (1977)

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[6] "Government circular on road lighting", September 1979 (In Danish)

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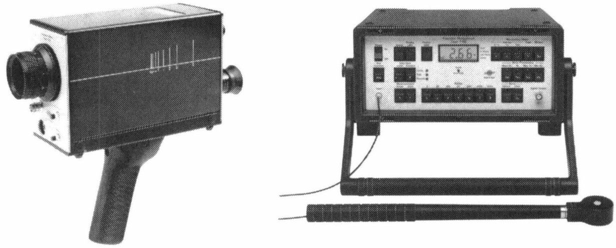
[8] "Lighting of Pedestrian Crossings", Technical Report No.12, Institution of Public Lighting Engineers

News from the Factory

Luminance Meter Type 1101 and
Precision Photometer Type 1105



Brüel & Kjær has released two new instruments for measurements in the lighting environment:

The Luminance Meter Type 1101 and
The Precision Photometer Type 1105

Together with the existing Luminance Constrast Meter Type 1100 these instruments cover a wide range of light measuring applications.

The Luminance Meter features Average, Max. Average and Peak measuring modes in a well-defined $^{1}/_{3}°$ or 1° measurement-field angle, with excellent spectral matching and a high degree of suppression of stray light.

The Precision Photometer is combined with illuminance Transducer Type 8600 to provide a highly versatile luxmeter, with a range of measurement storage and processing facilities. Two spatial adaptors are provided with the transducer – one hemispherical and one semicylindrical – in addition to a wide-angle luminance adapter. The Precision Photometer's IEEE 488 interface provides remote control of all primary functions and allows measurements to be transmitted to a range of compatible devices for further processing, storage, and/or output.

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(Continued from cover page 2)

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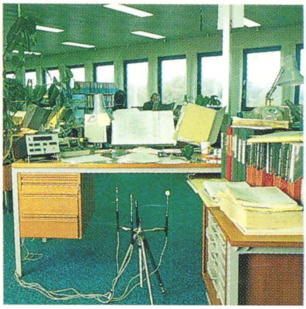

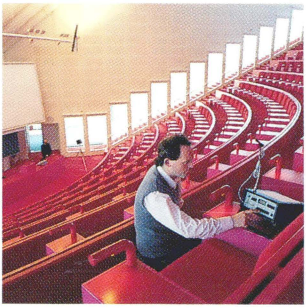
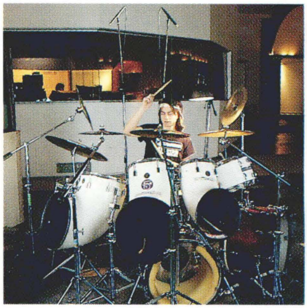

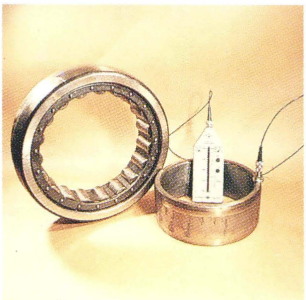


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