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

TECHNICAL REPORT

A METHOD FOR ASSESSING THE QUALITY OF DAYLIGHT SIMULATORS FOR COLORIMETRY

CIE 51.2 - 1999

UDC: 535.65
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Descriptor: Colorimetry
Colour vision

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A METHOD FOR ASSESSING THE QUALITY OF DAYLIGHT SIMULATORS FOR COLORIMETRY

CIE 51.2 - 1999

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CIE 51 - 1981 a été préparé par le Comité Technique CIE 1.3 Colorimétrie et a été approuvé par le Bureau d'Administration de la Commission Internationale de l'Eclairage, pour étude et application. Le supplément 1-1999 a été préparé par le Comité Technique 1-45 de la CIE "Révision de la publication CIE 51, incluant des simulateurs D50". La première partie de ce document contient la publication originale CIE 51-1981, la deuxième partie le supplément. 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.

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PART I. TECHNICAL REPORT CIE 51 - 1981

FOREWORD

This report has been prepared by CIE Technical Committee TC-1.3, Colorimetry, it being largely the work of the Sub Committee on Standard Sources¹.

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¹ At the time of the publication of the original report CIE 51 - 1981 the CIE illuminants A, B, C, D55, D65 and D75 were considered as standard illuminants. According to a later decision of CIE, only two illuminants are called "CIE standard illuminants": A and D65. All other illuminants defined by CIE are now called "CIE illuminants".

A METHOD FOR ASSESSING THE QUALITY OF DAYLIGHT SIMULATORS FOR COLORIMETRY

SUMMARY

A method is provided for evaluating the suitability of a test source as a simulator of CIE Standard Illuminant D55, D65, or D75. For each of these three Standard Illuminants, spectral radiance factor data are supplied for five pairs of non-fluorescent samples that are metameric matches. The colorimetric differences of the five pairs are computed for the test illuminant; the average of these differences is taken as the Visible Range Metamerism Index, and this is used as a measure of the quality of the test illuminant as a simulator for non-fluorescent samples. For fluorescent samples, the quality is further assessed in terms of an Ultraviolet Range Metamerism Index; this consists of the average of the colorimetric differences computed with the test illuminant for three further pairs of samples, each pair consisting of a fluorescent and a non-fluorescent sample which are metameric under the Standard Illuminant.

UNE MÉTHODE D'ÉVALUATION DE LA QUALITÉ DES SIMULATEURS DE LUMIÈRE DU JOUR POUR LA COLORIMÉTRIE

RÉSUMÉ

Une méthode pour apprécier la validité d'une source d'essai comme simulateur des Illuminants Normalisés CIE, D55, D65 ou D75 est indiquée. Pour chacun de ces trois Illuminants Normalisés, les facteurs spectraux de luminance énergétique sont donnés pour cinq paires d'échantillons, non fluorescents, capables de mettre en évidence le métamérisme. Les différences colorimétriques entre les cinq paires sont calculées pour l'illuminant d'essai; la moyenne de ces différences représente l'Indice de Métamérisme pour le Domaine Visible. Cet Indice est utilisé comme mesure de la qualité de l'illuminant d'essai en tant que simulateur pour les échantillons non fluorescents. Pour les échantillons fluorescents on évalue de plus cette qualité au moyen de l'Indice de Métamérisme pour le Domaine Ultraviolet. Celui-ci est représenté par la moyenne des différences colorimétriques calculées pour l'illuminant d'essai, pour trois paires supplémentaires d'échantillons, chacune étant composée d'un échantillon fluorescent et non fluorescent capables de mettre en évidence le métamérisme pour l'Illuminant Normalisé.

EINE METHODE ZUR GÜTEBEWERTUNG VON KÜNSTLICHEM TAGESLICHT FÜR DIE FARBMESSUNG

ZUSAMMENFASSUNG

Es wird eine Methode zur Bestimmung der Brauchbarkeit von künstlichen Strahlungsquellen zur Darstellung der Normlichtarten D55, D65 und D75 angegeben. Für jede dieser drei Normlichtarten werden die Werte der spektralen Strahldichtefaktoren für fünf metamere nicht-fluoreszierende Probenpaare mitgeteilt. Die Farbabstände dieser fünf Probenpaare werden für das zu beurteilende künstliche Tageslicht berechnet und der Mittelwert dieser Farbabstände als Metamerie-Index für den sichtbaren Strahlungsbereich genommen. Dieser Metamerie-Index wird als Maß für die Güte der künstlichen Tageslichtart zur Farbmessung nicht-fluoreszierender Proben benutzt. Für fluoreszierende Proben wird die Güte zusätzlich noch über den Metamerie-Index für den UV-Strahlungsbereich bewertet. Dieser ist der Mittelwert der Farbabstände von je drei weiteren metameren Probenpaaren für die zu beurteilende künstliche Tageslichtart, wobei jedes unter der Normlichtart farbgleiche Probenpaar aus einer fluoreszierenden und metameren Probe besteht.

1. PREFACE

In 1966 the CIE recommended that the new Standard Illuminants D55, D65 and D75 supplement the CIE Standard Illuminants A, B and C. At a joint meeting of CIE Committees E-1.3.1 (now TC-1.3, Colorimetry) and E-1.3.2 (now TC-3.2, Colour Rendering) in Washington (1967), it was recognised that daylight simulators were urgently required that would serve as CIE Standard Sources to represent the new CIE Standard Illuminants.

As a first step, several spectral irradiance distributions of daylight simulators that resembled those of D55, D65 or D75 were collected with the cooperation of the CIE National Committees. None of the daylight simulators collected provided a relative spectral irradiance distribution in an exact agreement with the illuminants. The goodness-of-fit of these spectral distributions to those of either D55, D65, or D75 was tested by several methods for evaluating the deviations between each of the daylight simulators and its target standard illuminant; this work was reported by Wyszecki (1970).

This report stimulated further studies on assessment of the discrepancies between the spectral distributions, in terms of suitable colorimetric parameters, particularly those that employ metameric pairs. Various workers have used the spectral irradiance distributions of these collected daylight simulators in succeeding studies on the assessment.

At a joint meeting of E-1.3.1 and E-1.3.2 in Barcelona (1971), it was agreed that all members and consultants of the two committees should study Wyszecki's report with a view to developing a working program for the next phase of the project. In addition, a Sub-Committee of TC-1.3, on Standard Sources, was formed with G. Wyszecki as chairman from 1971 to 1975, and Y. Nayatani thereafter. By 1973, there were several studies on visible (Berger and Strocka 1973, Nayatani and Takahama 1972, Richter 1972) and ultraviolet (Berger and Strocka 1973) range evaluations. The visible range evaluation in all the studies was made by using specific metameric sample pairs of non-fluorescent colours. The ultraviolet range evaluation was made by quantifying the fluorescence emission of a fluorescent sample excited by daylight simulators.

At a meeting of CIE TC-1.3 (Colorimetry) in London (1973), the proposal by Berger and Strocka (1973) was studied and discussed. With regard to their use of a single fluorescent sample for the ultraviolet range evaluation, many of the members expressed the opinion that more than one sample should be used. Later, Berger and Strocka (1975) reported a method for the ultraviolet evaluation involving assessment of the effective excitation of three fluorescent samples with different absorption peaks in the ultraviolet range. Based on these studies (Berger and Strocka 1973, 1975), a German Standard (DIN 1975) was specified. As a result of discussion at a meeting of TC-1.3 in London (1975), it was suggested that this German Standard be tested by theoretical methods and methods that involve physical measurement combined with visual assessment. In particular, it was suggested that the effective excitation method used for the ultraviolet assessment be examined to see whether alternative methods employing metamers, at least one of which must be a fluorescent sample, could be used to advantage. It was further suggested that the 10 metameric pairs in the German Standard for assessing the visible spectrum be examined to see whether other metameric pairs would be more appropriate.

Already an alternative method for the ultraviolet range evaluation had been reported (Richter 1975): this method used metameric pairs, each of which consisted of fluorescent samples. The characteristics of this method were further studied and a modification of it was reported (Nayatani et al. 1977). In succeeding discussions by the Standard Sources Subcommittee, it was recognised that this method gave, in principle, the same ultraviolet range evaluation as that given by the German Standard (DIN 6173).

Ganz (1977) also proposed an alternative method for ultraviolet range evaluation, based on the colorimetric error of a fluorescent sample resulting when the daylight simulator to be tested was used as an irradiating source on the samples instead of the appropriate standard illuminant. The proposal was also interpreted as a method using a metameric pair, consisting of a fluorescent and a non-fluorescent sample that are a spectrally identical match

for the daylight simulator (the term metamerism is used for convenience, but is not strictly correct for spectrally identical matches). At the meeting of TC-1.3 in Troy (1977), the discussions were mainly on the proposed methods of ultraviolet range evaluation and a modification of the Ganz proposal was adopted. The method used three metamerism pairs for each standard illuminant. Each metamerism pair consisted of a fluorescent and a non-fluorescent sample.

The reasons for the adoption of this method are:

- (a) it uses the same form for the visible and the ultraviolet range evaluations;
- (b) it is based on the evaluation of colorimetric errors of fluorescent samples; and
- (c) it gives similar evaluations for daylight simulators to those by the German Standard (DIN 6173).

At the Troy meeting, the chromaticity tolerance limits for daylight simulators were also specified, and the adjustment and the selection of metamerism pairs for visible range evaluation were decided, but the principle of the visible range evaluation was unchanged. The daylight simulators assessed to be good by the present method are expected to be used for visual colour matching and for physical colorimetry or spectrophotometry of fluorescent samples.

2. INTRODUCTION

The purpose of this assessment is to quantify the suitability of a test source as a practical reproduction of CIE Standard Illuminant D55, D65, or D75 for colorimetric tasks (1) *.

The basis for the assessment is the special metamerism index (2) for change in illuminant, employing specified samples that are metamerism matches for the standard daylight illuminant and the CIE 1964 Supplementary Standard Colorimetric Observer. The method quantifies the mismatch resulting when samples that are a match under the standard daylight illuminant are viewed under the illumination of the test source, the CIE 1964 Supplementary Standard Colorimetric Observer being used throughout.

A visible range metamerism index is employed to evaluate the colorimetric suitability of the test source for the visible wavelength range. The metamerism samples for this assessment are defined by tables of spectral reflection radiance factors.

An ultraviolet range metamerism index is employed with a second set of metamerism samples to evaluate the suitability of the test source in relation to ultraviolet-excited fluorescent colours. The metamerism sample pairs for this assessment are comprised of a fluorescent and a non-fluorescent sample that are a spectrally identical match for the standard daylight illuminant. The non-fluorescent sample in each metamerism pair is specified by values of spectral reflection radiance factor for each standard daylight illuminant (D55, D65, and D75).

The fluorescent sample in each metamerism pair is specified by values of spectral reflection radiance factor, relative spectral distribution of radiance emitted by fluorescence, and spectral external radiant efficiency.

The ultraviolet range metamerism index quantifies the failure of the spectrally identical match between the fluorescent and the non-fluorescent sample pairs resulting from changing the illuminating source from a standard daylight illuminant to a test source.

A glossary of terms used is given in Section 4

3. PROCEDURE

3.1 Spectroradiometry

The spectral power distribution of the test source is determined by spectroradiometry for the near ultraviolet and visible wavelength ranges.

* Numbers refer to Explanatory Comments given in Section 5.

Notes :

- (i) The radiometric quantity measured should be the spectral irradiance at the sample surface. Thus the effects of all wavelength selective modulators such as lenses, mirrors, diffusers, filters and booth walls are included in the measurement.
- (ii) Sources producing significant spectral irradiance at the sample surface for wavelengths less than 300 nm are not suitable as daylight simulators.
- (iii) Regardless of how the test source spectroradiometry is performed the data must be presented in the form of the spectral concentration of irradiance at 5 nm intervals and over 5 nm bands from 300 nm to 700 nm. Depending on the nature of the measurement and the nature of the spectrum of the test source (i.e. continuous or mixed continuous and line emission) this may be accomplished by measurement or by a combination of measurement and interpolation (3).

3.2 Normalisation

The spectral power distribution of the test source is normalised so that the assessment is independent of the absolute level of illumination.

The normalisation is:

$$S_n(\lambda) = 100 S(\lambda) / \sum_{400}^{700} S(\lambda) \bar{y}_{10}(\lambda) \Delta\lambda \quad (1)$$

where $\bar{y}_{10}$ is the CIE 1964 Supplementary Standard Colorimetric Observer Y_{10} function, S is the irradiance, the subscript n denotes the normalised quantity, and λ indicates wavelength.

3.3 Chromaticity specification

As a preliminary requirement, the chromaticity coordinates of the test source must be within a specified range from the chromaticity coordinates of the standard daylight illuminant in the CIE 1976 Uniform Chromaticity Scale diagram, u'_{10}, v'_{10} (4). The allowable range in this diagram is defined by a circle of radius 0,015 centred on the point representing the standard illuminant concerned (5). Figure 1 shows the allowable gamuts of chromaticity for CIE Standard Illuminants D55, D65 and D75 in the x_{10}, y_{10} chromaticity diagram.

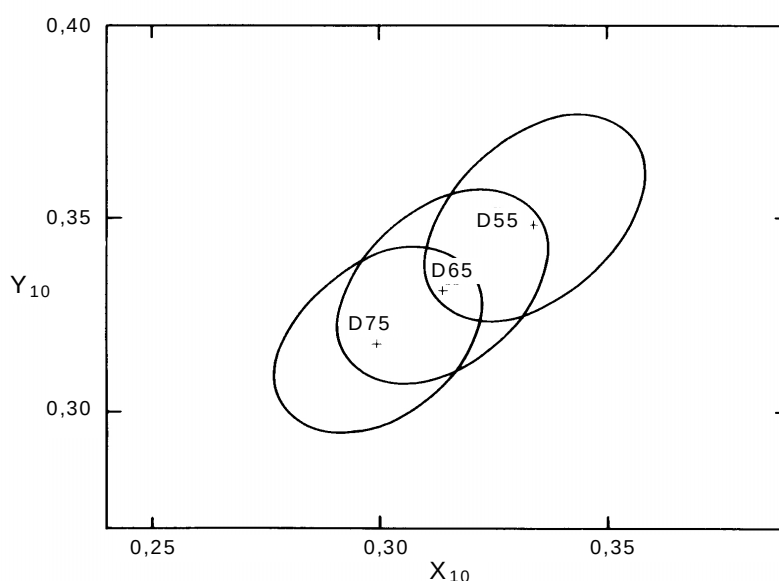


Figure 1. - Allowable range of chromaticity of daylight simulator for colorimetry of D55, D65 and D75. (These ellipses are circles on the CIE 1976 Uniform Chromaticity Scale diagram, u'_{10}, v'_{10} .)

3.4 Specification of the sample data

3.4.1 Visible range evaluation

Five sets of metameric data (6) are provided in Table 1. Each set includes the spectral reflection radiance factor of a standard and three metamers to the standard. Each of the metameric samples is metameric to the standard for the CIE 1964 Supplementary Standard Colorimetric Observer and one of the standard daylight illuminant (D55, D65 or D75). Thus each set contains one metameric pair for each of the three standard illuminants.

3.4.2 Ultraviolet range evaluation (7)

Three pairs of metameric samples are specified by the data given in Tables 2 and 3. The fluorescent sample in each metameric pair is defined by the tabulated values of the spectral reflection radiance factor, the relative spectral distribution of radiance emitted by fluorescence and the spectral external radiant efficiency given in Table 2. The non-fluorescent sample in each metameric pair is defined by tabulated values of spectral reflection radiance factor given in Table 3.

The definition of the spectral reflection radiance factor of the non-fluorescent sample varies depending on which of the daylight illuminants is the standard illuminant in order to maintain the spectrally identical match condition.

3.5 Calculation of visible and ultraviolet range metamerism indices

All tristimulus integrations must employ the CIE 1964 Supplementary Standard Colorimetric Observer data and the normalised spectral power distribution of the test source. The tristimulus integrations must be performed for wavelengths from 400 nm to 700 nm at 5 nm intervals (10).

3.5.1 Visible range evaluation

Tristimulus values are calculated for the five metameric pairs in Table 1 (each pair consists of the standard and the metameric sample for the appropriate standard illuminant) using the normalised spectral power distribution of the test source. The colour differences between the five sets of tristimulus values are calculated using the CIE 1976 $L^*u^*v^*$ or $L^*a^*b^*$ formula. The visible range metamerism index (MI_{vis}) is calculated from the individual colour differences by

$$MI_{vis} = \sum_{i=1}^5 \Delta E_i / 5 \quad (2)$$

where ΔE_i is the CIE 1976 $L^*u^*v^*$ or $L^*a^*b^*$ colour difference between the i^{th} pair of metamers.

3.5.2 Ultraviolet range evaluation

The spectral total radiance factor for the fluorescent sample part of each metameric pair is calculated by equation (3) using the normalised spectral power distribution of the test source and the fluorescent sample characteristic data in Table 2.

$$\beta_T(\lambda) = \beta_S(\lambda) + N \cdot F(\lambda) / S_n(\lambda) \quad (3)$$

$$\text{since } \beta_T(\lambda) = \beta_S(\lambda) + \beta_L(\lambda)$$

$$\text{and } \beta_L(\lambda) = N \cdot F(\lambda) / S_n(\lambda)$$

$$\text{where } N = \sum_{300}^{460} S_n(\lambda') Q(\lambda') \Delta \lambda'$$

and $S_n(\lambda')$ are the values of $S_n(\lambda)$ over the range 300 nm to 460 nm

and

- $\beta_T(\lambda)$ is the spectral total radiance factor;
- $\beta_S(\lambda)$ is the spectral reflection radiance factor;
- $F(\lambda)$ is the relative spectral distribution of radiance emitted by fluorescence;
- $Q(\lambda)$ is the spectral external radiant efficiency;
- N is the effective excitation;
- $S_n(\lambda)$ is the normalised spectral power distribution of the test source;
- λ indicates wavelengths of reflection and emission;
- λ' indicates wavelengths of excitation.

Depending on which standard illuminant is referred to, the spectral reflection radiance factor of the non-fluorescent sample part of each metameric pair is selected from the data in Table 3.

The tristimulus values of the metameric pairs are then calculated using the spectral radiance factor data and the normalised spectral power distribution of the test source. The colour difference between each pair of tristimulus values is calculated using the CIE 1976 $L^*u^*v^*$ or $L^*a^*b^*$ Colour Difference Formula. The ultraviolet range metamerism index (MI_{uv}) is then calculated by:

$$MI_{uv} = \sum_{j=1}^3 \Delta E_j / 3 \quad (4)$$

where ΔE_j is the CIE 1976 $L^*u^*v^*$ or $L^*a^*b^*$ colour difference between the j^{th} pair of metameric samples.

3.6 Interpretation of the metamerism indices

Test sources may be categorised as follows, depending upon the colour difference formula used.

<i>CIELAB</i>	<i>CIELUV</i>	<i>Category</i>
< 0,25	< 0,32	A
0,25 to 0,5	0,32 to 0,65	B
0,5 to 1,0	0,65 to 1,3	C
1,0 to 2,0	1,3 to 2,6	D
> 2,0	> 2,6	E

The MI_{vis} category must be given first and the MI_{uv} category second. For example, a test source having MI_{vis} equal to 0,3 in CIELAB and MI_{uv} , equal 0,6 in CIELAB has the category BC (CIELAB). The colour difference formula used (CIELUV or CIELAB) is an essential part of the rating and must always be indicated. The correlation of these categories with the requirements for various practical applications must be determined by experience (11). At the present time, daylight simulators of category BC (CIELAB) are found to be useful for many applications.

The Appendix contains the assessment of a number of daylight simulators, using the procedures set out in this report.

4. GLOSSARY OF TERMS

Radiance factor (at a representative element on the surface of a non-self-radiating medium, in a given direction, under specified conditions of irradiation).

Ratio of the radiance of the medium to that of a perfect reflecting or transmitting diffuser identically irradiated.

Symbol : β

Note: In the case of fluorescent media the radiance factor is the sum of two portions, the reflected radiance factor β_S and the fluorescent radiance factor β_L .