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Standard method of assessing the spectral quality of daylight simulators for visual appraisal and measurement of colour

Méthode normalisée d'évaluation de la qualité spectrale des simulateurs de lumière du jour pour le jugement visuel et la mesure des couleurs

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by the International Commission on Illumination (CIE) in cooperation with Technical Committee ISO/TC 274, *Light and lighting*.

This first edition of ISO/CIE 23603 cancels and replaces ISO 23603:2005, which has been technically revised.

The main changes are as follows:

— prior reference numbers of the document (CIE S 012:2004, ISO 23603:2005) replaced by ISO/CIE 23603;

— normative references updated;

— terms and definitions updated;

— minor editorial changes.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The purpose of the assessment method described in this document is to quantify the suitability of the spectral irradiance distribution of a practical daylight simulator of CIE daylight illuminant D55, D75 or CIE standard daylight illuminants D50 and D65 for the visual appraisal and measurement of colours of fluorescent or non-fluorescent specimens.

The basis for the assessment is the special metamerism index for change in illuminant, using pairs of virtual (rather than real) specimens specified by their reflecting and fluorescing properties. The pairs of specimens are metameric matches under the CIE daylight illuminant, when evaluated with the CIE 1964 standard colorimetric observer. The method described in this document quantifies the mismatch when the pairs of virtual specimens are illuminated by the daylight simulator under test and evaluated by the same standard colorimetric observer.

A visible range metamerism index is derived to quantify the suitability of the simulator for the visible wavelength range.

An ultraviolet range metamerism index is derived using a different set of virtual metameric pairs, each pair having a fluorescent and a non-fluorescent specimen which spectrally match for the CIE daylight illuminant and CIE standard colorimetric observer. The non-fluorescent specimen in each pair is specified by its spectral radiance factor. The fluorescent specimen in each pair is specified by its spectral reflected radiance factor, relative spectral distribution of radiance due to fluorescence and spectral external radiant efficiency of the fluorescent specimen. The ultraviolet range metamerism index quantifies the mismatch due to fluorescence that results from the use of the daylight simulator and the CIE 1964 standard colorimetric observer.

Standard method of assessing the spectral quality of daylight simulators for visual appraisal and measurement of colour

1 Scope

This document specifies a method of assessing the spectral quality of the irradiance provided by a daylight simulator to be used for visual appraisal of colours or for colour measurements and a method of assigning a quality grade to the simulator. It specifies the maximum permissible deviation of the chromaticity of the simulator from the chromaticity of the CIE standard daylight illuminant or CIE daylight illuminant being simulated for a daylight simulator to be graded by this method.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/CIE 11664-1, *Colorimetry — Part 1: CIE standard colorimetric observers*

ISO/CIE 11664-2, *Colorimetry — Part 2: CIE standard illuminants*

ISO/CIE 11664-4, *Colorimetry — Part 4: CIE 1976 L*a*b* colour space*

ISO/CIE 11664-5, *Colorimetry — Part 5: CIE 1976 L*u*v* Colour Space and u′, v′ Uniform Chromaticity Scale Diagram*

CIE 051.2-1999, *A Method for Assessing the Quality of Daylight Simulators for Colorimetry*

CIE 250:2022, *Spectroradiometric measurement of optical radiation sources*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

CIE maintains a terminology database for use in standardization at the following address:

— CIE e-ILV: available at https://cie.co.at/e-ilv

3.1
daylight simulator
device for the visual appraisal or measurement of the colour of materials or surfaces that provides spectral irradiance approximating a CIE standard illuminant representing a phase of daylight

[SOURCE: CIE S 017:2020, Entry 17-23-025]

3.2
quality grade
<illuminant simulator> class of quality of simulation of the spectral irradiance of a CIE illuminant by a simulator, expressed as a letter symbol A, B, C, D or E, with class A representing the highest quality

[SOURCE: CIE S 017:2020, Entry 17-23-024]

3.3
reflectance factor
R
quotient of the flux reflected in the directions delimited by a given cone with apex at a surface element, Φ_n, and the flux reflected in the same directions by a perfect reflecting diffuser identically irradiated or illuminated, Φ_d

$$R = \frac{\Phi_n}{\Phi_d}$$

Note 1 to entry: The definition holds for a surface element, for the part of the reflected radiation contained in a given cone with apex at the surface element, and for incident radiation of given spectral composition, polarization and geometric distribution.

Note 2 to entry: The reflectance factor is also defined spectrally and is called spectral reflectance factor, $R(\lambda)$.

Note 3 to entry: The ideal isotropic (Lambertian) diffuser with reflectance or transmittance equal to 1 is called a perfect diffuser.

Note 4 to entry: For regularly reflecting surfaces that are irradiated or illuminated by a beam of small solid angle, the reflectance factor can be much larger than 1 if the cone includes the mirror image of the source.

Note 5 to entry: If the solid angle of the cone approaches 2π sr, the reflectance factor approaches the reflectance for the same conditions of irradiation.

Note 6 to entry: If the solid angle of the cone approaches 0 sr, the reflectance factor approaches the radiance factor or luminance factor for the same conditions of irradiation.

Note 7 to entry: The reflectance factor has unit one.

[SOURCE: CIE S 017:2020, Entry 17-24-070, modified — Notes 8 and 9 to entry omitted.]

3.4
radiance factor
β_e
quotient of the radiance of a surface element in a specified direction, $L_{e,n}$ and the radiance of the perfect reflecting diffuser or perfect transmitting diffuser identically irradiated and viewed, $L_{e,d}$

$$\beta_e = \frac{L_{e,n}}{L_{e,d}}$$

Note 1 to entry: The definition holds for a surface element of a non-self-radiating medium, in a specified direction and under specified conditions of irradiation.

Note 2 to entry: Radiance factor is equivalent to reflectance factor or luminance factor when the cone angle is infinitely small, and is equivalent to reflectance when the cone angle is 2π sr. These quantities are also defined spectrally and called spectral radiance factor, $\beta(\lambda)$, and spectral reflectance factor, $R(\lambda)$.

Note 3 to entry: The ideal isotropic (Lambertian) diffuser with reflectance or transmittance equal to 1 is called a perfect diffuser.

Note 4 to entry: For photoluminescent media, the radiance factor contains two components, the reflected radiance factor, β_R, and the luminescent radiance factor, β_L. The sum of reflected radiance factor and luminescent radiance factor is the total radiance factor, β_T: $\beta_T = \beta_R + \beta_L$.

The subscript R is used here for the reflected radiance factor because it is more intuitive than the traditional S and avoids confusion with the use of S to denote a state of polarization.

Note 5 to entry: The radiance factor has unit one.

[SOURCE: CIE S 017:2020, Entry 17-24-075, modified — symbol β deleted; Notes 6 and 7 to entry omitted.]

3.5
reflected radiance factor
β_R
quotient of the reflected radiance at a point on a surface of a non-self-radiating medium in a given direction and that of the perfect reflecting diffuser identically irradiated and viewed

Note 1 to entry: In general, the reflected radiance factor from a surface does not depend upon the relative spectral distribution of the irradiation. This is not the case for a photoluminescent surface, where it is necessary to specify this quantity.

Note 2 to entry: The reflected radiance factor has unit one.

[SOURCE: CIE S 017:2020, Entry 17-21-104, modified — Note 3 to entry omitted.]

3.6
fluorescent radiance factor
β_F
<surface element of a non-self-radiating medium, in a given direction, under specified conditions of irradiation> ratio of the radiance due to fluorescence of the specimen to the radiance of the perfect reflecting diffuser identically irradiated and viewed

3.7
fluorescent radiant efficiency
quotient of the integrated value of the radiant flux of all wavelengths emitted by fluorescence (fluorescence band) and the radiant excitation power irradiating the fluorescent material for a given excitation wavelength

Note 1 to entry: The fluorescent radiant efficiency is a measure of the external radiant efficiency of the fluorescent material; the internal radiant efficiency is obtained by taking a quotient of the emitted radiation and the radiant excitation power that is absorbed by the fluorescent material.

Note 2 to entry: In this definition the excitation wavelength is considered to be monochromatic. However, in practice, the excitation radiation will have a wavelength range and distribution.

Note 3 to entry: Fluorescence is understood to include both fluorescent and phosphorescent phenomena with time constants short enough to be ignored for the application.

Note 4 to entry: The fluorescent radiant efficiency has unit one.

[SOURCE: CIE S 017:2020, Entry 17-24-042]

3.8
spectral external radiant efficiency of the fluorescent specimen
$Q(\lambda')$
quotient of the total radiant flux of all wavelengths emitted by the fluorescent process for an excitation wavelength and the *total radiant excitation* (3.9) power irradiating the fluorescent material

Note 1 to entry: This quantity is also measured in relative terms by comparison to the radiant flux reflected from the perfect reflecting diffuser identically irradiated and viewed for a given excitation wavelength.

Note 2 to entry: Fluorescence is understood to include both fluorescent and phosphorescent phenomena with time constants short enough to be ignored for the application.

Note 3 to entry: The spectral external radiant efficiency of the fluorescent specimen has unit one.

[SOURCE: CIE S 017:2020, Entry 17-21-088]

3.9
total radiant excitation
N
total radiant power irradiating the specimen that is capable of exciting fluorescence

3.10
relative spectral distribution of radiance due to fluorescence
$F(\lambda)$
ratio of the spectral distribution of radiance due to fluorescence to the sum of the tabulated values of this distribution, i.e. $\Sigma_\lambda F(\lambda) = 1{,}0$

4 Requirements

4.1 Chromaticity tolerance

The first requirement of a daylight simulator is that the light it provides be nearly the same chromaticity as the light of the CIE daylight illuminant. For a daylight simulator to qualify for classification by this document, the CIE 1976 u'_{10} v'_{10} chromaticity difference in accordance with ISO/CIE 11664-5 between the light of the daylight simulator and that of the CIE daylight illuminant shall not exceed 0,015 in accordance with CIE 051.2-1999.

4.2 Quality grade

The chromaticity requirement described in 4.1 having been met, and a metamerism index having been determined by the method of this document, the spectral quality of simulation shall be classified, using a letter symbol indicating a quality grade, according to Table 1.

The quality of spectral simulation is evaluated for the visible spectrum and for the ultraviolet spectrum and separate quality grades are assigned for those two spectral regions. The quality grades are reported as a two-letter symbol, the quality grade for the visible region being stated first. For example, the symbol BC means the daylight simulator has a quality grade of B for the visible spectrum and C for the ultraviolet spectrum. (Daylight simulators having the BC grade have been found useful for many applications.)

5 Test methods

5.1 Spectroradiometry

The relative spectral irradiance (the relative spectral power distribution of the flux incident on the specimen) of the daylight simulator shall be measured by spectroradiometry for the near ultraviolet and visible spectrum, in the wavelength range from 300 nm to 780 nm. The radiometric quantity required is the relative spectral irradiance at the surface to be observed or measured. This procedure takes into account not only the relative spectral radiance of the source but also the spectral effect of any lenses, reflectors, diffusers or filters that affect the relative spectral irradiance.

Devices providing significant spectral irradiance at wavelengths less than 300 nm are not suitable as daylight simulators. Radiant power at wavelengths of less than 300 nm, coming from the sun, is absorbed in the earth's atmosphere, and is insignificant at ground level in natural daylight.

The relative spectral irradiance shall be measured at 5 nm intervals and over 5 nm bands, at wavelengths from 300 nm to 780 nm. This may be accomplished by direct measurement or a combination of measurement and interpolation, depending on the nature of the spectroradiometer and whether the relative spectral irradiance includes some component of a line spectrum. When the spectral power distribution of the daylight simulator includes spectral lines, as is the case when fluorescent lamps are used, the spectral data shall be treated by the method in CIE 250:2022.

5.2 Computations

5.2.1 Normalization

The spectral irradiance of the daylight simulator is normalized so the assessment is independent of the absolute value of irradiance. The normalized irradiance shall be computed by Formula (1):

$$S_{\mathrm{n}}(\lambda)=\frac{100\cdot S(\lambda)}{\sum_{300}^{780} S(\lambda)\cdot\bar{y}_{10}(\lambda)\cdot\Delta\lambda} \tag{1}$$

where

$S(\lambda)$ is the measured irradiance, the subscript n denotes the normalized quantity,

$\bar{y}_{10}(\lambda)$ is one of the colour-matching functions of the CIE 1964 standard colorimetric observer in accordance with ISO/CIE 11664-1,

$\Delta\lambda$ is the wavelength interval used for the summation, and the summation is over the wavelength range from 300 nm to 780 nm; $\Delta\lambda$ shall be 5 nm.

NOTE Although $\bar{y}_{10}(\lambda)$ is not defined below 380 nm, the wavelength range is given as 300 nm to 780 nm in order not to give the impression that only the wavelength range 380 nm to 780 nm is needed.

5.2.2 Chromaticity deviation

The CIE 1976 $u'_{10}\ v'_{10}$ chromaticity difference between the light from the daylight simulator and that of the simulated CIE standard daylight illuminant in accordance with ISO/CIE 11664-2 or CIE daylight illuminant shall not exceed 0,015. To facilitate this computation, the chromaticity coordinates of the four respective CIE daylight illuminants as given in CIE 015:2018 are listed in Table 2.

5.2.3 Virtual metameric pairs

5.2.3.1 Pairs for visible-range assessment

Sets of virtual metameric pairs of specimens for visible-range assessment are specified by their spectral radiance factors in Tables 3 and 4 to 7. Each pair has a "standard" spectrum and a "comparison" spectrum, representing virtual specimens that match for the CIE 1964 standard colorimetric observer. The five standard spectra are listed in Table 3 and the same set of five is used for all four CIE daylight illuminants. Five comparison spectra are listed for each of the four CIE daylight illuminants in Tables 4 to 7.

5.2.3.2 Pairs for ultraviolet-range assessment

Three virtual metameric pairs of specimens for ultraviolet-range assessment are specified in Tables 8 to 12.

Three virtual fluorescent specimens are listed in Table 8. Their reflection and fluorescence properties are specified by tabulated values of the spectral reflected radiance factor $\beta_{\mathrm{R}}(\lambda)$, the relative spectral distribution of radiance due to fluorescence $F(\lambda)$ and the spectral external radiant efficiency of the fluorescent specimen $Q(\lambda')$.

Three virtual non-fluorescent specimens are listed in Tables 9 to 12. Their reflection properties are specified by their spectral reflectance factors for each of the CIE daylight illuminants.

5.2.4 Computing metamerism indices

5.2.4.1 General

Tristimulus values shall be computed by integrating the product of the colour-matching functions of the CIE 1964 standard colorimetric observer, the normalized relative spectral irradiance of the daylight simulator and the tabulated properties of the virtual specimens over the wavelength range and intervals specified in Tables 4 to 7 (visible-range assessment) and Tables 8 to 12 (ultraviolet-range assessment). (See also CIE 015:2018.)

5.2.4.2 Indices for visible-range assessment

Using the normalized spectral irradiance of the daylight simulator, tristimulus values shall be computed for the appropriate five metameric pairs in Tables 3 and 4 to 7. Using the CIE 1976 $L^*a^*b^*$ colour-difference formula in accordance with ISO/CIE 11664-4, the colour difference between the standard specimen and the corresponding comparison specimen, $\Delta E^*_{ab,10}$, shall be computed to at least three decimal places for each of the five pairs. The visible range metamerism index M_v is the average of the five colour differences. (See also CIE 015:2018.)

5.2.4.3 Indices for ultraviolet-range assessment

The virtual fluorescent specimens absorb radiant power in the ultraviolet region of the spectrum and emit light in the visible region of the spectrum. The emitted light affects the colour of the specimen. The three virtual specimens absorb radiant power in three different parts of the ultraviolet spectrum. Their ultraviolet excitation properties are typical of those in commonly used whitening agents.

When a daylight simulator having both ultraviolet and visible spectral components illuminates a fluorescent specimen, the specimen reflects some light and emits light due to fluorescence. The light emanating from the specimen is the sum of these two components. The amount of light emitted due to fluorescence depends on the fluorescent radiant efficiency of the virtual specimens and the amount of excitation, which depends on the ultraviolet spectral distribution of irradiance provided by the daylight simulator.

The total radiant excitation, N, of the fluorescent standard specimen in Table 8 is computed by Formula (2):

$$N = \sum_{300}^{460} S_n(\lambda') \cdot Q(\lambda') \cdot \Delta\lambda' \quad (2)$$

where

$S_n(\lambda')$ is the normalized spectral irradiance of the simulator in the spectral region from 300 nm to 460 nm,

$Q(\lambda')$ is the spectral external radiant efficiency of the fluorescent specimen over the same spectral range, as shown in Table 8, and

$\Delta\lambda'$ is the wavelength interval of 5 nm.

The spectral fluorescent radiance factor $\beta_F(\lambda)$ is computed by Formula (3):

$$\beta_F(\lambda) = \frac{N \cdot F(\lambda)}{S_n(\lambda)} \quad (3)$$

where

N is the total radiant excitation computed by Formula (2),

$F(\lambda)$ is the relative spectral distribution of radiance due to fluorescence as shown in Table 8, and

$S_n(\lambda)$ is the normalized spectral irradiance distribution of the simulator.

The total spectral radiance factor, $\beta_T(\lambda)$, is computed by Formula (4):

$$\beta_T(\lambda) = \beta_R(\lambda) + \beta_F(\lambda) \quad (4)$$

where

$\beta_R(\lambda)$ is the spectral reflected radiance factor listed for the fluorescent specimen in Table 8, and

$\beta_F(\lambda)$ is the spectral fluorescent radiance factor computed by Formula (3).

The tristimulus values for each pair of specimens shall be computed using the normalized spectral irradiance distribution of the simulator, $S_n(\lambda)$, the spectral radiance factor for the standard specimen, $\beta_T(\lambda)$, and the tabulated values in Tables 9 to 12 for the comparison specimen. The colour difference between the specimens in each pair shall be computed to at least three decimal places by the CIE 1976 $L^*a^*b^*$ colour-difference formula in accordance with ISO/CIE 11664-4.

The ultraviolet-range metamerism index M_u is the average colour difference for the three metameric pairs.

6 Tables

Table 1 — Quality classification of daylight simulators

Quality grade	Metamerism index M_v or M_u
A	≤ 0,25
B	>0,25 to 0,50
C	>0,50 to 1,00
D	>1,00 to 2,00
E	> 2,00

Table 2 — CIE 1976 $u'_{10}v'_{10}$ chromaticity coordinates of CIE standard daylight illuminants/ CIE daylight illuminants

CIE daylight	u'_{10}	v'_{10}
D50	0,210 2	0,488 9
D55	0,205 1	0,481 6
D65	0,197 9	0,469 5
D75	0,193 0	0,460 1

Table 3 — Spectral radiance factors of standard specimens for visible range assessment

Wave-length nm	Specimen					Wave-length nm	Specimen				
	1	2	3	4	5		1	2	3	4	5
380	0,056	0,054	0,052	0,318	0,120	585	0,369	0,035	0,093	0,206	0,135
385	0,054	0,062	0,050	0,314	0,115	590	0,401	0,037	0,090	0,204	0,156
390	0,052	0,069	0,048	0,301	0,111	595	0,431	0,041	0,089	0,202	0,183
395	0,050	0,075	0,046	0,299	0,108	600	0,459	0,046	0,089	0,203	0,214
400	0,048	0,080	0,044	0,298	0,106	605	0,482	0,053	0,089	0,209	0,250
405	0,045	0,084	0,042	0,298	0,106	610	0,501	0,061	0,090	0,220	0,285
410	0,043	0,087	0,040	0,300	0,109	615	0,516	0,071	0,091	0,236	0,313
415	0,041	0,089	0,038	0,305	0,114	620	0,528	0,082	0,092	0,256	0,333
420	0,040	0,089	0,037	0,311	0,120	625	0,537	0,095	0,092	0,277	0,340
425	0,038	0,088	0,036	0,318	0,127	630	0,544	0,109	0,092	0,298	0,342
430	0,037	0,085	0,035	0,326	0,136	635	0,551	0,121	0,093	0,317	0,341
435	0,036	0,082	0,034	0,335	0,146	640	0,557	0,133	0,096	0,337	0,345

Table 3 *(continued)*

Wavelength nm	Specimen					Wavelength nm	Specimen				
	1	2	3	4	5		1	2	3	4	5
440	0,035	0,078	0,033	0,346	0,156	645	0,562	0,145	0,101	0,361	0,362
445	0,034	0,074	0,032	0,357	0,166	650	0,567	0,156	0,109	0,391	0,391
450	0,034	0,070	0,032	0,369	0,176	655	0,573	0,166	0,120	0,430	0,434
455	0,035	0,066	0,032	0,381	0,184	660	0,579	0,177	0,134	0,476	0,487
460	0,036	0,063	0,032	0,391	0,191	665	0,585	0,188	0,154	0,531	0,547
465	0,037	0,060	0,033	0,398	0,195	670	0,592	0,201	0,177	0,589	0,609
470	0,039	0,057	0,034	0,401	0,197	675	0,598	0,217	0,202	0,647	0,667
475	0,041	0,054	0,036	0,400	0,195	680	0,605	0,236	0,228	0,702	0,721
480	0,045	0,052	0,038	0,396	0,191	685	0,613	0,257	0,252	0,749	0,766
485	0,051	0,050	0,041	0,387	0,183	690	0,621	0,279	0,275	0,787	0,803
490	0,058	0,048	0,045	0,376	0,174	695	0,629	0,302	0,296	0,816	0,830
495	0,067	0,046	0,049	0,363	0,165	700	0,637	0,326	0,316	0,835	0,849
500	0,077	0,044	0,055	0,348	0,155	705	0,645	0,350	0,336	0,847	0,859
505	0,089	0,042	0,062	0,331	0,146	710	0,653	0,374	0,355	0,855	0,866
510	0,102	0,041	0,070	0,313	0,137	715	0,661	0,398	0,373	0,861	0,871
515	0,115	0,039	0,078	0,297	0,129	720	0,669	0,422	0,390	0,865	0,875
520	0,127	0,038	0,086	0,283	0,122	725	0,677	0,446	0,406	0,867	0,878
525	0,139	0,037	0,092	0,272	0,115	730	0,685	0,470	0,421	0,868	0,880
530	0,151	0,036	0,097	0,262	0,110	735	0,693	0,494	0,435	0,868	0,881
535	0,162	0,035	0,101	0,251	0,107	740	0,701	0,518	0,448	0,868	0,881
540	0,174	0,034	0,104	0,241	0,105	745	0,709	0,542	0,460	0,868	0,881
545	0,185	0,033	0,106	0,230	0,105	750	0,717	0,566	0,471	0,868	0,881
550	0,198	0,032	0,107	0,220	0,105	755	0,725	0,590	0,481	0,868	0,881
555	0,213	0,031	0,107	0,213	0,105	760	0,733	0,614	0,490	0,868	0,881
560	0,230	0,031	0,106	0,208	0,105	765	0,741	0,638	0,498	0,868	0,881
565	0,251	0,031	0,104	0,207	0,105	770	0,749	0,662	0,505	0,868	0,881
570	0,276	0,031	0,101	0,208	0,107	775	0,757	0,686	0,511	0,868	0,881
575	0,305	0,032	0,099	0,208	0,111	780	0,765	0,710	0,516	0,868	0,881
580	0,336	0,033	0,096	0,208	0,120						

Table 4 — Spectral radiance factors of comparison specimens for visible range assessment of D50 simulators

Wavelength nm	Specimen					Wavelength nm	Specimen				
	1	2	3	4	5		1	2	3	4	5
380	0,050	0,069	0,033	0,401	0,173	585	0,309	0,049	0,097	0,234	0,131
385	0,049	0,068	0,032	0,401	0,174	590	0,345	0,055	0,097	0,234	0,149
390	0,045	0,066	0,032	0,401	0,175	595	0,384	0,063	0,100	0,235	0,174
395	0,042	0,064	0,030	0,401	0,176	600	0,427	0,072	0,102	0,238	0,200
400	0,035	0,059	0,028	0,401	0,177	605	0,473	0,077	0,103	0,240	0,228
405	0,029	0,059	0,028	0,401	0,178	610	0,515	0,083	0,104	0,241	0,258
410	0,027	0,063	0,027	0,401	0,179	615	0,552	0,085	0,104	0,240	0,286
415	0,026	0,074	0,027	0,401	0,180	620	0,582	0,086	0,104	0,237	0,316

Table 4 *(continued)*

Wave-length nm	Specimen					Wave-length nm	Specimen				
	1	2	3	4	5		1	2	3	4	5
420	0,024	0,081	0,027	0,401	0,184	625	0,608	0,087	0,103	0,234	0,342
425	0,024	0,088	0,026	0,400	0,187	630	0,630	0,087	0,103	0,229	0,366
430	0,024	0,089	0,026	0,398	0,187	635	0,646	0,087	0,104	0,228	0,387
435	0,025	0,088	0,024	0,393	0,186	640	0,659	0,087	0,104	0,228	0,405
440	0,025	0,083	0,025	0,387	0,181	645	0,671	0,088	0,106	0,236	0,424
445	0,026	0,081	0,026	0,375	0,178	650	0,683	0,088	0,108	0,245	0,440
450	0,027	0,076	0,027	0,372	0,174	655	0,695	0,088	0,113	0,264	0,454
455	0,028	0,071	0,029	0,366	0,170	660	0,708	0,088	0,119	0,287	0,469
460	0,031	0,066	0,031	0,360	0,165	665	0,723	0,088	0,128	0,320	0,485
465	0,035	0,059	0,034	0,353	0,160	670	0,736	0,088	0,141	0,358	0,506
470	0,043	0,052	0,037	0,345	0,156	675	0,750	0,088	0,158	0,403	0,526
475	0,054	0,048	0,045	0,336	0,151	680	0,755	0,088	0,174	0,455	0,548
480	0,068	0,045	0,056	0,327	0,148	685	0,762	0,088	0,195	0,505	0,567
485	0,085	0,042	0,067	0,319	0,144	690	0,770	0,088	0,213	0,560	0,591
490	0,103	0,038	0,077	0,311	0,141	695	0,778	0,088	0,234	0,610	0,616
495	0,121	0,037	0,086	0,304	0,139	700	0,782	0,088	0,257	0,660	0,641
500	0,136	0,034	0,092	0,296	0,137	705	0,785	0,089	0,281	0,710	0,659
505	0,148	0,035	0,095	0,289	0,135	710	0,787	0,089	0,308	0,755	0,676
510	0,156	0,033	0,097	0,281	0,135	715	0,788	0,089	0,332	0,795	0,692
515	0,160	0,032	0,095	0,276	0,132	720	0,789	0,089	0,354	0,825	0,705
520	0,160	0,032	0,092	0,271	0,129	725	0,790	0,089	0,374	0,850	0,715
525	0,162	0,032	0,090	0,265	0,125	730	0,791	0,089	0,389	0,870	0,725
530	0,164	0,032	0,089	0,260	0,122	735	0,791	0,089	0,400	0,885	0,734
535	0,167	0,032	0,088	0,255	0,121	740	0,791	0,089	0,410	0,895	0,744
540	0,172	0,033	0,086	0,250	0,121	745	0,792	0,089	0,417	0,900	0,754
545	0,177	0,033	0,084	0,248	0,121	750	0,792	0,089	0,424	0,900	0,764
550	0,182	0,033	0,084	0,246	0,121	755	0,792	0,089	0,429	0,900	0,774
555	0,189	0,032	0,085	0,245	0,119	760	0,792	0,089	0,431	0,900	0,784
560	0,196	0,030	0,087	0,244	0,116	765	0,792	0,089	0,432	0,900	0,794
565	0,209	0,032	0,088	0,243	0,110	770	0,792	0,089	0,432	0,900	0,804
570	0,226	0,036	0,091	0,241	0,109	775	0,792	0,089	0,432	0,900	0,814
575	0,248	0,041	0,094	0,239	0,113	780	0,792	0,089	0,432	0,900	0,824
580	0,275	0,045	0,096	0,236	0,119						

Table 5 — Spectral radiance factors of comparison specimens for visible range assessment of D55 simulators

Wave-length nm	Specimen					Wave-length nm	Specimen				
	1	2	3	4	5		1	2	3	4	5
380	0,037	0,025	0,040	0,408	0,145	585	0,309	0,050	0,097	0,233	0,131
385	0,035	0,033	0,036	0,407	0,153	590	0,346	0,055	0,098	0,232	0,149
390	0,033	0,041	0,035	0,406	0,160	595	0,386	0,063	0,101	0,233	0,173
395	0,030	0,046	0,031	0,400	0,164	600	0,430	0,071	0,103	0,235	0,199
400	0,029	0,054	0,030	0,399	0,169	605	0,476	0,075	0,104	0,237	0,227
405	0,028	0,060	0,028	0,399	0,173	610	0,518	0,082	0,104	0,239	0,258
410	0,027	0,067	0,028	0,399	0,177	615	0,555	0,084	0,104	0,237	0,286
415	0,026	0,074	0,027	0,398	0,181	620	0,586	0,086	0,104	0,234	0,315
420	0,026	0,081	0,027	0,398	0,183	625	0,611	0,086	0,103	0,230	0,341
425	0,025	0,088	0,026	0,398	0,185	630	0,633	0,086	0,103	0,225	0,365
430	0,025	0,088	0,026	0,395	0,185	635	0,649	0,086	0,104	0,223	0,386
435	0,025	0,088	0,025	0,390	0,184	640	0,662	0,086	0,105	0,225	0,405
440	0,025	0,083	0,026	0,382	0,180	645	0,674	0,086	0,107	0,231	0,422
445	0,026	0,081	0,027	0,376	0,177	650	0,686	0,087	0,110	0,243	0,437
450	0,028	0,076	0,027	0,370	0,173	655	0,698	0,087	0,115	0,260	0,452
455	0,029	0,071	0,029	0,364	0,169	660	0,711	0,087	0,121	0,285	0,468
460	0,032	0,066	0,031	0,358	0,164	665	0,725	0,087	0,130	0,317	0,484
465	0,036	0,059	0,034	0,351	0,159	670	0,739	0,087	0,141	0,353	0,504
470	0,044	0,052	0,038	0,343	0,155	675	0,753	0,088	0,155	0,402	0,524
475	0,054	0,048	0,046	0,335	0,150	680	0,770	0,088	0,171	0,450	0,547
480	0,068	0,045	0,056	0,327	0,147	685	0,785	0,088	0,190	0,504	0,570
485	0,085	0,042	0,067	0,319	0,143	690	0,800	0,089	0,210	0,556	0,593
490	0,103	0,039	0,077	0,312	0,141	695	0,812	0,089	0,231	0,605	0,616
495	0,121	0,037	0,086	0,304	0,139	700	0,823	0,089	0,257	0,652	0,635
500	0,136	0,034	0,092	0,297	0,137	705	0,834	0,090	0,283	0,697	0,661
505	0,147	0,035	0,095	0,290	0,135	710	0,843	0,090	0,314	0,734	0,681
510	0,155	0,033	0,096	0,283	0,135	715	0,851	0,090	0,344	0,771	0,698
515	0,158	0,033	0,094	0,278	0,133	720	0,859	0,090	0,374	0,803	0,711
520	0,159	0,033	0,091	0,273	0,130	725	0,865	0,090	0,404	0,832	0,724
525	0,161	0,033	0,089	0,267	0,126	730	0,870	0,090	0,434	0,855	0,736
530	0,163	0,033	0,088	0,262	0,123	735	0,875	0,090	0,464	0,873	0,747
535	0,166	0,033	0,087	0,257	0,122	740	0,879	0,090	0,524	0,887	0,757
540	0,170	0,033	0,086	0,253	0,122	745	0,880	0,090	0,554	0,894	0,766
545	0,175	0,033	0,084	0,250	0,122	750	0,880	0,090	0,581	0,896	0,774
550	0,180	0,033	0,084	0,248	0,122	755	0,880	0,090	0,612	0,896	0,781
555	0,187	0,032	0,085	0,246	0,119	760	0,880	0,090	0,641	0,896	0,785
560	0,195	0,030	0,086	0,245	0,116	765	0,880	0,090	0,670	0,896	0,780
565	0,208	0,032	0,088	0,244	0,111	770	0,880	0,090	0,699	0,896	0,794
570	0,225	0,036	0,091	0,242	0,109	775	0,880	0,090	0,728	0,896	0,797
575	0,247	0,040	0,094	0,239	0,113	780	0,880	0,090	0,757	0,896	0,799
580	0,275	0,045	0,096	0,235	0,119						

Table 6 — Spectral radiance factors of comparison specimens for visible range assessment of D65 simulators

Wave-length nm	Specimen					Wave-length nm	Specimen				
	1	2	3	4	5		1	2	3	4	5
380	0,036	0,051	0,043	0,389	0,075	585	0,309	0,049	0,098	0,231	0,131
385	0,035	0,052	0,042	0,389	0,094	590	0,347	0,054	0,100	0,229	0,149
390	0,034	0,054	0,040	0,389	0,111	595	0,389	0,062	0,102	0,229	0,172
395	0,034	0,056	0,037	0,389	0,128	600	0,434	0,069	0,104	0,230	0,198
400	0,033	0,055	0,031	0,391	0,150	605	0,480	0,074	0,105	0,232	0,226
405	0,030	0,057	0,028	0,393	0,169	610	0,523	0,081	0,104	0,234	0,256
410	0,028	0,063	0,028	0,394	0,176	615	0,560	0,083	0,105	0,232	0,285
415	0,026	0,073	0,027	0,395	0,180	620	0,593	0,085	0,105	0,228	0,313
420	0,026	0,080	0,027	0,396	0,182	625	0,619	0,085	0,104	0,224	0,339
425	0,026	0,088	0,026	0,395	0,183	630	0,641	0,085	0,104	0,220	0,363
430	0,026	0,089	0,026	0,392	0,183	635	0,657	0,085	0,105	0,218	0,384
435	0,026	0,088	0,026	0,387	0,182	640	0,669	0,085	0,106	0,221	0,402
440	0,026	0,083	0,027	0,379	0,179	645	0,681	0,085	0,108	0,227	0,419
445	0,027	0,081	0,028	0,373	0,175	650	0,691	0,085	0,111	0,238	0,435
450	0,029	0,076	0,028	0,367	0,171	655	0,703	0,084	0,116	0,254	0,451
455	0,030	0,071	0,029	0,361	0,167	660	0,712	0,084	0,124	0,278	0,464
460	0,033	0,066	0,031	0,355	0,162	665	0,727	0,085	0,135	0,309	0,485
465	0,037	0,059	0,034	0,348	0,157	670	0,742	0,084	0,147	0,347	0,504
470	0,044	0,052	0,039	0,340	0,153	675	0,756	0,084	0,162	0,391	0,524
475	0,054	0,048	0,047	0,333	0,149	680	0,769	0,084	0,179	0,446	0,545
480	0,068	0,045	0,057	0,326	0,146	685	0,781	0,084	0,198	0,496	0,566
485	0,085	0,043	0,067	0,319	0,143	690	0,792	0,084	0,218	0,547	0,585
490	0,104	0,040	0,077	0,312	0,141	695	0,802	0,084	0,240	0,601	0,601
495	0,121	0,037	0,086	0,305	0,139	700	0,811	0,084	0,263	0,647	0,615
500	0,136	0,034	0,092	0,300	0,138	705	0,818	0,083	0,270	0,693	0,631
505	0,146	0,035	0,095	0,292	0,137	710	0,825	0,082	0,270	0,733	0,647
510	0,153	0,033	0,095	0,286	0,136	715	0,831	0,082	0,271	0,773	0,662
515	0,156	0,033	0,093	0,281	0,134	720	0,836	0,082	0,271	0,807	0,676
520	0,157	0,034	0,090	0,276	0,131	725	0,840	0,082	0,271	0,837	0,686
525	0,159	0,034	0,088	0,270	0,127	730	0,844	0,081	0,272	0,880	0,701
530	0,161	0,034	0,087	0,265	0,124	735	0,846	0,081	0,272	0,888	0,710
535	0,164	0,034	0,086	0,260	0,123	740	0,847	0,081	0,273	0,893	0,720
540	0,167	0,034	0,085	0,257	0,123	745	0,847	0,081	0,273	0,893	0,729
545	0,172	0,033	0,083	0,253	0,122	750	0,847	0,081	0,273	0,894	0,738
550	0,177	0,033	0,083	0,251	0,122	755	0,847	0,081	0,273	0,894	0,744
555	0,184	0,031	0,083	0,249	0,120	760	0,847	0,081	0,273	0,894	0,747
560	0,193	0,031	0,084	0,248	0,117	765	0,847	0,081	0,273	0,894	0,751
565	0,206	0,033	0,088	0,246	0,113	770	0,847	0,081	0,273	0,894	0,754
570	0,223	0,036	0,091	0,243	0,111	775	0,847	0,081	0,273	0,894	0,756
575	0,246	0,041	0,094	0,238	0,113	780	0,847	0,081	0,273	0,894	0,757
580	0,275	0,045	0,096	0,234	0,119						

Table 7 — Spectral radiance factors of comparison specimens for visible range assessment of D75 simulators

Wave-length nm	Specimen					Wave-length nm	Specimen				
	1	2	3	4	5		1	2	3	4	5
380	0,038	0,008	0,037	0,422	0,158	585	0,309	0,049	0,098	0,229	0,131
385	0,036	0,018	0,034	0,419	0,161	590	0,348	0,055	0,100	0,228	0,149
390	0,035	0,028	0,032	0,415	0,163	595	0,391	0,060	0,103	0,226	0,171
395	0,034	0,038	0,032	0,409	0,167	600	0,437	0,069	0,105	0,226	0,197
400	0,031	0,047	0,030	0,400	0,168	605	0,483	0,073	0,106	0,228	0,225
405	0,030	0,058	0,030	0,396	0,170	610	0,527	0,079	0,106	0,230	0,255
410	0,029	0,065	0,028	0,393	0,174	615	0,564	0,081	0,106	0,228	0,284
415	0,027	0,073	0,027	0,393	0,177	620	0,596	0,083	0,106	0,225	0,311
420	0,027	0,080	0,027	0,393	0,179	625	0,622	0,084	0,105	0,221	0,337
425	0,026	0,088	0,026	0,393	0,180	630	0,645	0,084	0,105	0,217	0,361
430	0,026	0,089	0,026	0,390	0,181	635	0,661	0,084	0,106	0,215	0,382
435	0,026	0,088	0,027	0,385	0,180	640	0,674	0,084	0,107	0,217	0,400
440	0,026	0,083	0,027	0,378	0,178	645	0,686	0,084	0,109	0,222	0,417
445	0,027	0,081	0,028	0,371	0,174	650	0,698	0,085	0,112	0,232	0,430
450	0,029	0,076	0,028	0,365	0,170	655	0,711	0,085	0,117	0,249	0,446
455	0,031	0,071	0,029	0,359	0,166	660	0,723	0,086	0,124	0,272	0,464
460	0,034	0,066	0,032	0,353	0,161	665	0,736	0,087	0,133	0,303	0,484
465	0,038	0,059	0,035	0,346	0,156	670	0,749	0,087	0,144	0,339	0,505
470	0,045	0,052	0,040	0,338	0,152	675	0,764	0,088	0,158	0,380	0,527
475	0,055	0,048	0,048	0,331	0,148	680	0,777	0,089	0,175	0,425	0,547
480	0,069	0,046	0,057	0,324	0,145	685	0,792	0,089	0,196	0,475	0,568
485	0,086	0,042	0,067	0,318	0,143	690	0,804	0,089	0,218	0,525	0,588
490	0,104	0,039	0,077	0,311	0,141	695	0,814	0,089	0,239	0,570	0,608
495	0,121	0,037	0,086	0,305	0,139	700	0,822	0,089	0,261	0,615	0,627
500	0,136	0,034	0,092	0,299	0,138	705	0,826	0,089	0,278	0,655	0,648
505	0,145	0,035	0,094	0,294	0,137	710	0,833	0,089	0,299	0,690	0,668
510	0,152	0,033	0,094	0,288	0,137	715	0,838	0,089	0,318	0,722	0,688
515	0,154	0,034	0,092	0,284	0,135	720	0,842	0,089	0,362	0,757	0,709
520	0,155	0,035	0,089	0,279	0,132	725	0,843	0,089	0,383	0,784	0,729
525	0,157	0,035	0,087	0,273	0,128	730	0,844	0,089	0,406	0,804	0,749
530	0,159	0,035	0,086	0,268	0,125	735	0,845	0,089	0,427	0,825	0,769
535	0,162	0,035	0,085	0,263	0,124	740	0,846	0,089	0,448	0,850	0,787
540	0,166	0,034	0,084	0,259	0,124	745	0,847	0,089	0,468	0,860	0,803
545	0,170	0,033	0,083	0,256	0,123	750	0,848	0,089	0,488	0,865	0,817
550	0,175	0,033	0,083	0,254	0,123	755	0,849	0,089	0,508	0,875	0,829
555	0,182	0,032	0,083	0,252	0,121	760	0,850	0,089	0,528	0,885	0,839
560	0,191	0,031	0,084	0,250	0,118	765	0,851	0,089	0,548	0,887	0,849
565	0,204	0,032	0,087	0,247	0,113	770	0,852	0,089	0,568	0,891	0,853
570	0,221	0,036	0,090	0,244	0,111	775	0,853	0,089	0,588	0,894	0,857
575	0,245	0,041	0,093	0,238	0,113	780	0,854	0,089	0,608	0,897	0,859
580	0,275	0,045	0,096	0,233	0,119						

Table 8 — Spectral properties of fluorescent standard specimens for ultraviolet range assessment of daylight simulators

Wave-length nm	Specimen 1			Specimen 2			Specimen 3		
	$Q(\lambda')\Delta\lambda'$	$\beta_R(\lambda)$	$F(\lambda)$	$Q(\lambda')\Delta\lambda'$	$\beta_R(\lambda)$	$F(\lambda)$	$Q(\lambda')\Delta\lambda'$	$\beta_R(\lambda)$	$F(\lambda)$
300	0,182								
305	0,194								
310	0,205			0,001					
315	0,214			0,001					
320	0,220			0,006					
325	0,226			0,023					
330	0,230			0,050			0,001		
335	0,232			0,075			0,001		
340	0,232			0,102			0,002		
345	0,230			0,137			0,025		
350	0,224			0,174			0,055		
355	0,216			0,204			0,082		
360	0,204			0,218			0,111		
365	0,177			0,227			0,152		
370	0,145			0,229			0,191		
375	0,117			0,228			0,218		
380	0,088			0,220			0,235		
385	0,056			0,196			0,244		
390	0,028			0,164			0,245		
395	0,016			0,134			0,245		
400	0,011	0,638	0,008	0,104	0,490	0,008	0,237	0,194	0,008
405	0,009	0,661	0,011	0,068	0,570	0,011	0,213	0,270	0,011
410	0,006	0,683	0,022	0,038	0,640	0,022	0,182	0,357	0,022
415	0,002	0,704	0,036	0,023	0,678	0,036	0,153	0,437	0,036
420		0,722	0,051	0,016	0,701	0,051	0,120	0,517	0,051
425		0,734	0,070	0,011	0,718	0,070	0,082	0,603	0,070
430		0,742	0,085	0,007	0,730	0,085	0,046	0,676	0,085
435		0,750	0,092	0,004	0,744	0,092	0,028	0,712	0,092
440		0,756	0,090	0,001	0,755	0,090	0,019	0,731	0,090
445		0,761	0,081		0,762	0,081	0,013	0,744	0,081
450		0,766	0,071		0,766	0,071	0,009	0,753	0,071
455		0,770	0,064		0,770	0,064	0,005	0,764	0,064
460		0,774	0,056		0,774	0,056	0,001	0,773	0,056
465		0,778	0,048		0,778	0,048		0,778	0,048
470		0,782	0,039		0,782	0,039		0,782	0,039
475		0,788	0,033		0,788	0,033		0,788	0,033
480		0,794	0,028		0,794	0,028		0,794	0,028
485		0,799	0,022		0,799	0,022		0,799	0,022
490		0,804	0,018		0,804	0,018		0,804	0,018
495		0,808	0,014		0,808	0,014		0,808	0,014
500		0,812	0,011		0,812	0,011		0,812	0,011
505		0,817	0,009		0,817	0,009		0,817	0,009

Table 8 *(continued)*

Wavelength nm	Specimen 1			Specimen 2			Specimen 3		
	$Q(\lambda')\Delta\lambda'$	$\beta_R(\lambda)$	$F(\lambda)$	$Q(\lambda')\Delta\lambda'$	$\beta_R(\lambda)$	$F(\lambda)$	$Q(\lambda')\Delta\lambda'$	$\beta_R(\lambda)$	$F(\lambda)$
510		0,822	0,008		0,822	0,008		0,822	0,008
515		0,827	0,006		0,827	0,006		0,827	0,006
520		0,830	0,005		0,830	0,005		0,830	0,005
525		0,831	0,004		0,831	0,004		0,831	0,004
530		0,831	0,004		0,831	0,004		0,831	0,004
535		0,831	0,003		0,831	0,003		0,831	0,003
540		0,832	0,003		0,832	0,003		0,832	0,003
545		0,832	0,003		0,832	0,003		0,832	0,003
550		0,833	0,001		0,833	0,001		0,833	0,001
555		0,833	0,001		0,833	0,001		0,833	0,001
560		0,834	0,001		0,834	0,001		0,834	0,001
565		0,834	0,001		0,834	0,001		0,834	0,001
570		0,835	0,001		0,835	0,001		0,835	0,001
575		0,835			0,835			0,835	
580		0,836			0,836			0,836	
585		0,837			0,837			0,837	
590		0,837			0,837			0,837	
595		0,837			0,837			0,837	
600		0,838			0,838			0,838	
605		0,839			0,839			0,839	
610		0,840			0,840			0,840	
615		0,842			0,842			0,842	
620		0,844			0,844			0,844	
625		0,846			0,846			0,846	
630		0,848			0,848			0,848	
635		0,850			0,850			0,850	
640		0,852			0,852			0,852	
645		0,854			0,854			0,854	
650		0,856			0,856			0,856	
655		0,857			0,857			0,857	
660		0,857			0,857			0,857	
665		0,857			0,857			0,857	
670		0,858			0,858			0,858	
675		0,859			0,859			0,859	
680		0,860			0,860			0,860	
685		0,861			0,861			0,861	
690		0,862			0,862			0,862	
695		0,863			0,863			0,863	
700		0,864			0,864			0,864	