

TECHNICAL SPECIFICATION



**Multimedia systems and equipment – Colour measurement and management –
Part 13: Measurement method of display colour properties depending on
observers**



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MULTIMEDIA SYSTEMS AND EQUIPMENT – COLOUR MEASUREMENT AND MANAGEMENT –

Part 13: Measurement method of display colour properties depending on observers

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The text of this Technical Specification is based on the following documents:

Draft	Report on voting
100/3928/DTS	100/4023/RVDTS

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Specification is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 61966 series, published under the general title *Multimedia systems and equipment – Colour measurement and management*, can be found on the IEC website.

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INTRODUCTION

In colorimetry, metamerism or metameric failure is defined as a perceived matching of two colours with different spectral power distributions (SPDs). Illuminant metamerism occurs when two objects match in colour under a specific illuminant, but mismatch under another illuminant with a different SPD. Likewise, observer metamerism (OM) is defined by two stimuli with different SPDs that match in colour for a specific observer. However, the stimuli might not match for another observer. OM is caused by the normal variations in the spectral responsivities of various observers. In other words, observers do not have identical colour-matching functions (CMFs). An observer model that takes into consideration the age and the field size of observers with respect to a standard observer standard observer has already been standardised in the CIE (CIE Pub. 170-1:2006).

Meanwhile, display manufacturers and users have required measurement methods of the OM which occurs in display uses. For example, with the development of display technology and grafting of display technology to various application fields and mass distribution, it has become a common situation for users to use multiple displays at the same time. When using multiple displays at the same time, a user can display the same colour through the calibration process. However, this is only valid for certain observers because of OM. Also, when users watch a single display, there could be observer dependency in colour perception even though the display is calibrated.

Based on the CIE standards and research results of OM, a new Technical Specification is suggested to measure the difference in display colour properties according to the observer in an objective way, excluding subjective effects of evaluators.

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MULTIMEDIA SYSTEMS AND EQUIPMENT – COLOUR MEASUREMENT AND MANAGEMENT –

Part 13: Measurement method of display colour properties depending on observers

1 Scope

This document defines an objective colour difference metric and a measurement method for observer metamerism caused by displays with different spectral power distributions. This document also specifies the measuring equipment, conditions and methods that are necessary to obtain the metric. This document applies to light-emitting or backlit transmitting colour displays measured under dark-room conditions.

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 11664-4, *Colorimetry – Part 4: CIE 1976 $L^*a^*b^*$ colour space*

ISO/CIE 11664-6, *Colorimetry – Part 6: CIEDE2000 colour-difference formula*

CIE 170-1:2006, *Fundamental chromaticity diagram with physiological axes – Part 1*

CIE 170-2:2015, *Fundamental chromaticity diagram with physiological axes – Part 2*

3 Terms and definitions

3.1 Terms and definitions

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

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

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1.1

observer metamerism

differences in metameric matches when made by different observers

Note 1 to entry: Identical spectral pairs will be identified as the same colour for all observers with their individual CMFs. However, when the spectral power distributions of the two stimuli differ, and only metameric matching is possible, a match made by one observer will typically not match for other observers. This is also called metameric failure. See entry [1] of the Bibliography.

3.1.2

observer metamerism index

value of colour difference due to observer metamerism characteristics of a display

Note 1 to entry: Metamerism indices exist for illuminant metamerism but not for observer metamerism.

3.1.3

ORU

optical radiant unit

unit in a display from which light of a distinct spectral power distribution is radiated

Note 1 to entry: Unit can be present in direct-view and projection displays with temporally and/or spatially fused colour. In the case of projection, spectral irradiance is measured.

3.1.4

multi-ORU

multi optical-radiant-unit display

display with more than three optical radiant units with different spectral power distributions

3.2 Abbreviations

ABC	automatic brightness control
CCT	correlated colour temperature
CIE	Commission Internationale de L'Éclairage (International Commission on Illumination)
CIELAB	CIE 1976 (L*a*b*) colour space
CMFs	colour-matching functions
DUT	device under test
FS	field size
LMD	light-measuring device
OM	observer metamerism
ORU	optical radiant unit
SPD	spectral power distribution

4 Measuring equipment

4.1 Light-measuring devices

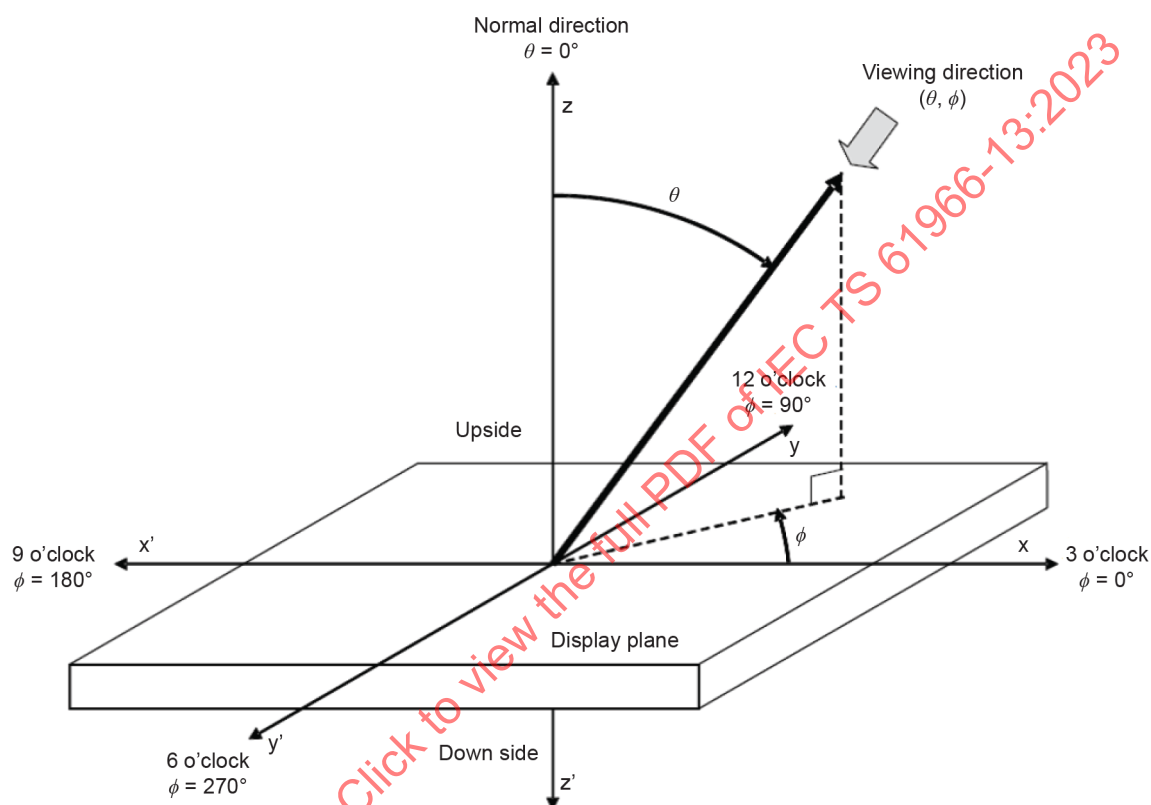
The system configurations and/or operating conditions of the measuring equipment shall comply with the structure specified in each item.

To ensure reliable measurements, the spectroradiometer shall have a wavelength range of at least from 380 nm to 780 nm, and the wavelength scale accuracy shall be less than 1 nm. The relative luminance uncertainty of measured luminance (relative to CIE illuminant A source) shall not be greater than 4 % for luminance values over 0,1 cd/m² and not be greater than 10 % for luminance values 0,1 cd/m² and below. Note that errors from spectral stray light within a spectroradiometer can be significant and shall be corrected. A simple matrix method may be used to correct the stray light errors, by which stray light errors can be reduced for one to two orders of magnitude. Details of this correction method are discussed in Reference [1]¹. If the obtained luminance is lower than LMD limitation, the lower limit of the LMD shall be recorded with measured luminance.

¹ Numbers in square brackets refer to the Bibliography.

4.2 Viewing direction coordinate system

The viewing direction is the direction under which the observer looks at the spot of interest on the display. During the measurement, the LMD is replacing the observer, looking from the same direction at a specified spot (i.e. measuring spot, measurement field) on the DUT. The viewing direction is conveniently defined by two angles: the angle of inclination θ (related to the surface normal of the DUT) and the angle of rotation ϕ (also called azimuth angle) as illustrated in Figure 1. The azimuth angle is related to the directions on a watch-dial as follows: $\phi = 0^\circ$ is referred to as the 3 o'clock direction ("right"), $\phi = 90^\circ$ as the 12 o'clock direction ("top"), $\phi = 180^\circ$ as the 9 o'clock direction ("left") and $\phi = 270^\circ$ as the 6 o'clock direction ("bottom").



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Key

θ : incline angle from normal direction

ϕ : azimuth angle

3 o'clock: right edge of the screen as seen from the user

6 o'clock: bottom edge of the screen as seen from the user

9 o'clock: left edge of the screen as seen from the user

12 o'clock: top edge of the screen as seen from the user

Figure 1 – Representation of the viewing direction (equivalent to the direction of measurement) by the angle of inclination, θ and the angle of rotation (azimuth angle), ϕ in a polar coordinate system

5 Measuring conditions

5.1 Standard measuring environmental conditions

Measurements shall be carried out under standard environmental conditions:

- Temperature: $25\text{ °C} \pm 3\text{ °C}$,
- Relative humidity: $25\text{ \% RH}$ to $85\text{ \% RH}$,
- Atmospheric pressure: 86 kPa to 106 kPa .

When different environmental conditions are used, they shall be noted in the measurement report.

5.2 Power supply

The power supply for driving the DUT shall be adjusted to the rated voltage $\pm 0,5\text{ \%}$. In addition, the frequency of power supply shall provide the rated frequency $\pm 0,2\text{ \%}$.

5.3 Warm-up time

Measurements shall be carried out after sufficient warm-up. Warm-up time is defined as the time elapsed from when the supply source is switched on, and a 100 % grey level of input signal is applied to the DUT, until repeated measurements of the display show a variation in luminance of no more than 2 % per minute and 5 % per hour.

5.4 Standard measuring dark-room conditions

The luminance contribution from the background illumination reflected off the test display shall be $< 0.01\text{ cd/m}^2$. If these conditions are not satisfied, then background subtraction is required and it shall be noted in the measurement report. In addition, if the sensitivity of the LMD is inadequate to measure these low levels, then the lower limit of the LMD shall be noted in the measurement report.

5.5 Standard set-up conditions

By default, the display shall be installed in the vertical position (Figure 2a), but the horizontal alternative (Figure 2b) is also allowed. When the latter alternative is used, it shall be noted in the measurement report.

The display shall be configured to the factory settings, default settings, or any viewing mode agreed on by the supplier and the customer, and the settings recorded in the test report. These settings shall be held constant for all measurements. It is important, however, to make sure that not only the adjustments are kept constant, but also that the resulting physical quantities remain constant during the measurement. This is not automatically the case because of, for example, warm-up effects or auto-dimming features. Any automatic luminance or gain control shall be turned off. Otherwise it should be noted in the report. The automatic brightness control (ABC) or ambient light control, which can reduce the display luminance level with dim ambient illumination, shall be turned off. If that is not possible, it is recommended to set it to turn on no lower than 300 lx to minimize the influence of the ABC as specified in IEC 62087-3:2015, 6.4.4. The state of the ABC shall be reported. In addition, if the display has an auto-dimming feature which reduces to less than 95 % of original luminance when a static image is displayed after a prolonged time, then a black frame shall be input and the display luminance shall be measured with 1 s sampling time until the display recovers its original luminance with 5 % error prior to rendering and measuring the desired test pattern. The measurements shall be completed before the dimming feature is triggered. When the display has the option to be set for different viewing modes, the viewing mode shall be defined by the test specification, and be used with consistency for all measurements. Additional viewing modes can also be measured. The viewing mode used during testing shall be reported. The display should be operated in a mode that does not have over-scan.

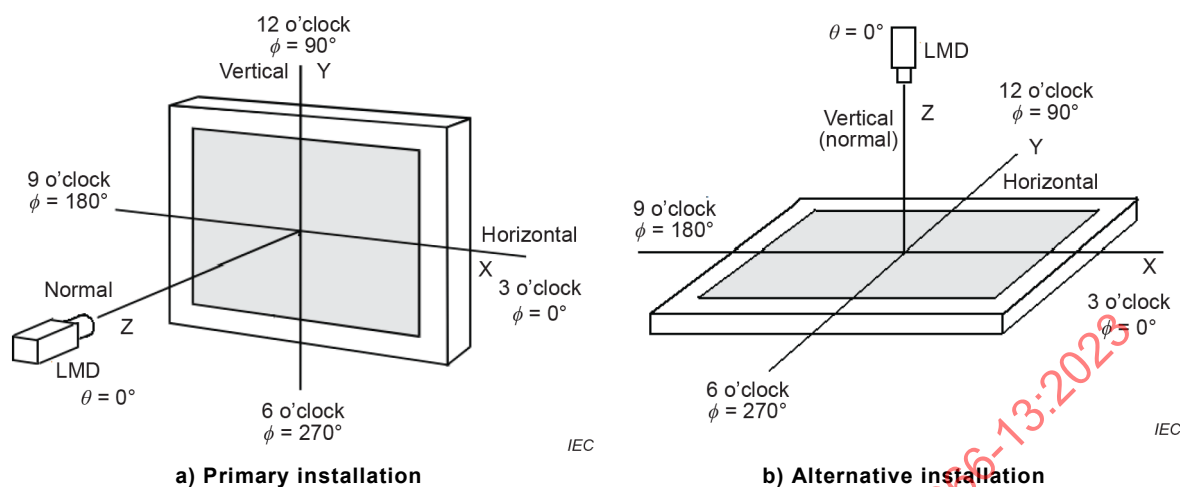


Figure 2 – DUT Installation conditions

6 Measuring methods

6.1 Individual colour-matching functions

CIE presented XYZ tristimulus representation based on cone fundamentals from the technical reports CIE 170-1 and CIE 170-2 in 2006 and 2015, respectively. In CIE 170-1, the cone fundamentals are defined as the spectral sensitivity functions, which are the long-wave sensitive (L-), medium-wave sensitive (M-) and short-wave sensitive (S-) cones, and effects of age and field size are incorporated. In CIE 170-2, linear transformations of the cone fundamentals in the form of cone-fundamental-based XYZ tristimulus values are presented for 2° and 10° field sizes. Thus, if the age and field size of an observer are given, corresponding XYZ tristimulus values can be computed based on CIE 170-1 and 170-2 technical reports. In this Technical Specification, the field size is set to 2°. The colour-matching functions of individual observers transformed from the cone fundamentals will be defined as individual CMFs, and they shall be used to compute the XYZ tristimulus values. Also, CIE CMFs which mean the functions $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ in the CIE 1931 standard colorimetric system will be called standard CMFs to distinguish them from the individual CMFs.

Since age is the only variable of the individual CMFs, age distribution data is necessary when deciding the weight of each individual CMFs. For the data on age distribution, only officially published data should be used. A representative example is the United Nations World Population Prospects data. Annex A shows an example of generating an individual CMFs dataset. Prepare a set of individual CMFs by referring to the method in Annex A and use it in the evaluation method.

6.2 Reference colours

To evaluate the observer-dependent colour rendering properties of a display, a set of reference colours to be compared with the DUT's spectral response to input test signals, is required. In this Technical Specification, the set is defined by the Macbeth colour checker patches 13-19 and the CIE D65 illuminant. Even though a variety of colour sets as reference colours have been used in the previous studies [2][3], only seven colours were selected as the reference colours. If it is necessary to evaluate a display using more colours, it is recommended to select a set of colours uniformly sampled in the CIE 1976 L*a*b* colour space with D65 as reference white.

For the illuminant of the reference colours, CIE standard illuminant D65 is used. The SPDs of the seven reference colours are summarised in Annex B. The D65 SPD in Annex B is normalised data, and in this Technical Specification, D65 SPD should be rescaled to have maximum luminance of the DUT.

6.3 Observer metamerism index

6.3.1 Purpose

The purpose of this method is to evaluate the observer metamerism of a display. See Annex E for a working example regarding the measurement and calculation process.

6.3.2 Measuring conditions

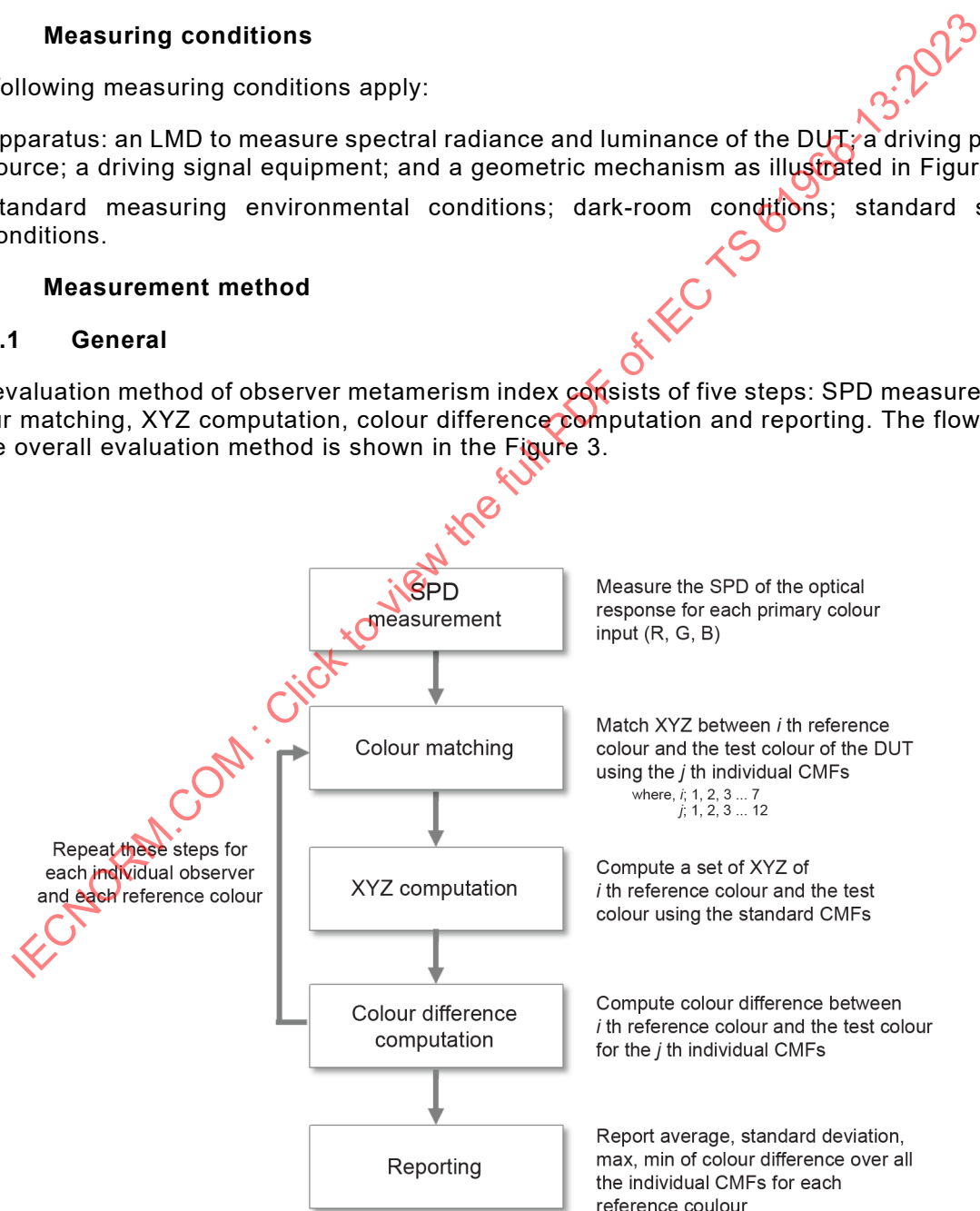
The following measuring conditions apply:

- Apparatus: an LMD to measure spectral radiance and luminance of the DUT; a driving power source; a driving signal equipment; and a geometric mechanism as illustrated in Figure 2.
- Standard measuring environmental conditions; dark-room conditions; standard setup conditions.

6.3.3 Measurement method

6.3.3.1 General

The evaluation method of observer metamerism index consists of five steps: SPD measurement, colour matching, XYZ computation, colour difference computation and reporting. The flowchart of the overall evaluation method is shown in the Figure 3.



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Figure 3 – Flowchart of the overall evaluation method

6.3.3.2 SPD measurement

- 1) Render the three area centre box patterns corresponding to normalised {R, G, B} input signals {1,0,0}, {0,1,0}, and {0,0,1} or, for 8-bit grey quantization, {255,0,0}, {0,255,0}, and {0,0,255}, respectively. Figure 4 shows an example of a centre box pattern with an APL of 4 %. If the DUT exhibits loading, reduce the APL with a requirement of minimum 0,5 %, making sure that the measurement field covers subpixels corresponding to at least 500 input pixels.

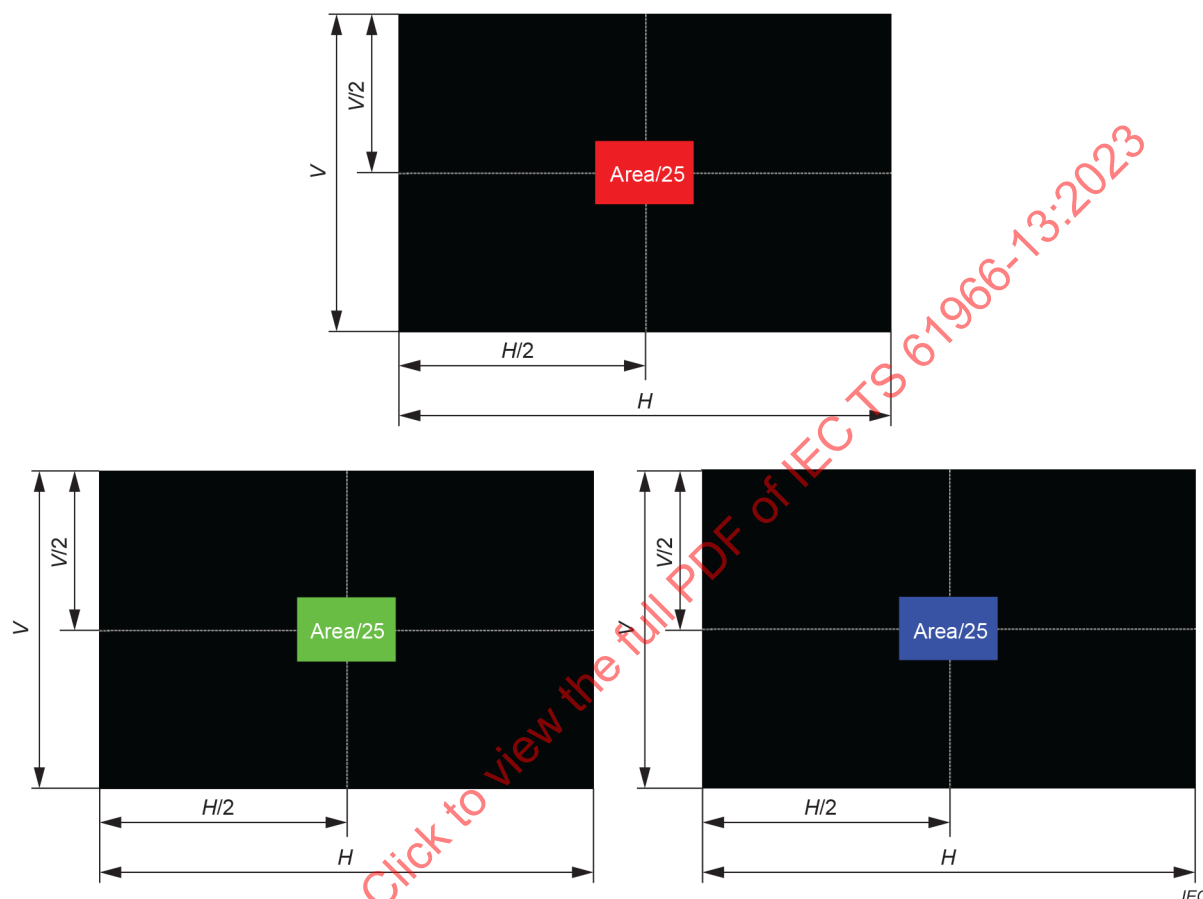


Figure 4 – 4 % area centre box patterns of primary colours

- 2) Align the LMD perpendicular to the display surface ($\theta = 0$, $\phi = 0$), and position it to the centre of the display.
- 3) Measure the SPDs of the primary colours respectively at the screen centre.

6.3.3.3 Colour matching

- 1) Calculate the XYZ values of i^{th} reference colour using individual CMFs, which stand for the CMFs of j^{th} individual observer, as shown in Equation (1). See Annex A for individual CMFs and Annex B for the SPDs of reference colours.

$$\begin{aligned} X'_{r(i,j)} &= L_s \cdot k_j \int_{390}^{780} \Phi_{r(i)}(\lambda) \cdot \bar{x}'_j(\lambda) d\lambda \\ Y'_{r(i,j)} &= L_s \cdot k_j \int_{390}^{780} \Phi_{r(i)}(\lambda) \cdot \bar{y}'_j(\lambda) d\lambda \\ Z'_{r(i,j)} &= L_s \cdot k_j \int_{390}^{780} \Phi_{r(i)}(\lambda) \cdot \bar{z}'_j(\lambda) d\lambda \end{aligned} \quad (1)$$

where

$X'_{r(i,j)}$, $Y'_{r(i,j)}$ and $Z'_{r(i,j)}$ denote the XYZ values of i^{th} reference colour using individual CMFs of j^{th} individual observer;

$\bar{x}'_j(\lambda)$, $\bar{y}'_j(\lambda)$ and $\bar{z}'_j(\lambda)$ denote the CMFs of j^{th} individual observer;

$\Phi_{r(i)}(\lambda)$ denotes the SPD of i^{th} reference colour defined in Equation (2):

$$\Phi_{r(i)}(\lambda) = S_{D65}(\lambda) \cdot R_i(\lambda) \quad (2)$$

where

$S_{D65}(\lambda)$ denotes the SPD of CIE Standard D_{65} illuminant;

$R_i(\lambda)$ denotes the spectral reflectance of the i^{th} reference colour;

L_s is the scaling factor to match the normalised relative XYZ values of reference colours with the absolute XYZ values of the test colours of the DUT. Here, use the maximum luminance of the DUT as explained in 6.2; k_j is the normalisation constant for j^{th} individual observer and is defined in Equation (3).

$$k_j = \frac{1}{\int_{390}^{780} S_{D65}(\lambda) \cdot \bar{y}'_j(\lambda) d\lambda} \quad (3)$$

- 2) Calculate the weighting factors of SPDs of the DUT response corresponding to the normalised inputs $\{1,0,0\}$, $\{0,1,0\}$, and $\{0,0,1\}$. The colour-matching process can be expressed as Equation (4) by adding up the SPDs to match the XYZ values of the DUT using the individual CMFs with the reference XYZ values calculated in item 1). The weighting factors can be calculated by solving the linear matrix in Equation (5) which is derived from Equation (4).

$$\begin{bmatrix} X'_{r(i,j)} \\ Y'_{r(i,j)} \\ Z'_{r(i,j)} \end{bmatrix} = \begin{bmatrix} X'_{R(j)} & X'_{G(j)} & X'_{B(j)} \\ Y'_{R(j)} & Y'_{G(j)} & Y'_{B(j)} \\ Z'_{R(j)} & Z'_{G(j)} & Z'_{B(j)} \end{bmatrix} \cdot \begin{bmatrix} w_{R(i,j)} \\ w_{G(i,j)} \\ w_{B(i,j)} \end{bmatrix} \quad (4)$$

$$\begin{bmatrix} w_{R(i,j)} \\ w_{G(i,j)} \\ w_{B(i,j)} \end{bmatrix} = \begin{bmatrix} X'_{R(j)} & X'_{G(j)} & X'_{B(j)} \\ Y'_{R(j)} & Y'_{G(j)} & Y'_{B(j)} \\ Z'_{R(j)} & Z'_{G(j)} & Z'_{B(j)} \end{bmatrix}^{-1} \cdot \begin{bmatrix} X'_{r(i,j)} \\ Y'_{r(i,j)} \\ Z'_{r(i,j)} \end{bmatrix} \quad (5)$$

where

$w_{R(i,j)}$, $w_{G(i,j)}$ and $w_{B(i,j)}$ are the weighting factors calculated from the colour-matching; $X'_{Q(j)}$, $Y'_{Q(j)}$ and $Z'_{Q(j)}$ ($Q = R, G, B$) are XYZ stimulus values of primary colours of the DUT using the j^{th} individual observer, and defined in Equation (6).

$$\begin{aligned} X'_{Q(j)} &= 683 \int_{390}^{780} \Phi_Q(\lambda) \cdot \bar{x}'_j(\lambda) d\lambda \\ Y'_{Q(j)} &= 683 \int_{390}^{780} \Phi_Q(\lambda) \cdot \bar{y}'_j(\lambda) d\lambda \\ Z'_{Q(j)} &= 683 \int_{390}^{780} \Phi_Q(\lambda) \cdot \bar{z}'_j(\lambda) d\lambda \end{aligned} \quad (6)$$

where

$\Phi_Q(\lambda)$ are the SPDs of the primary colours, and $Q = R, G$ and B .

As a result, the SPD of the test colour of the DUT matched with the i^{th} reference colour can be obtained by:

$$\Phi_{t(i,j)}(\lambda) = \begin{bmatrix} w_{R(i,j)} & w_{G(i,j)} & w_{B(i,j)} \end{bmatrix} \cdot \begin{bmatrix} \Phi_R(\lambda) & \Phi_G(\lambda) & \Phi_B(\lambda) \end{bmatrix}^T \quad (7)$$

where

$\Phi_{t(i,j)}(\lambda)$ is the SPD of the test colour matched with the i^{th} reference colour for j^{th} individual observer.

If the DUT has more than three ORUs, see Annex D.

6.3.3.4 XYZ computation

- 1) Calculate the XYZ values of the i^{th} reference colour using the CIE 1931 standard colorimetric observer, as shown in Equation (8).

$$\begin{aligned}
 X_{r(i)} &= L_s \cdot k \int_{390}^{780} \Phi_{r(i)}(\lambda) \cdot \bar{x}(\lambda) d\lambda \\
 Y_{r(i)} &= L_s \cdot k \int_{390}^{780} \Phi_{r(i)}(\lambda) \cdot \bar{y}(\lambda) d\lambda \\
 Z_{r(i)} &= L_s \cdot k \int_{390}^{780} \Phi_{r(i)}(\lambda) \cdot \bar{z}(\lambda) d\lambda
 \end{aligned} \tag{8}$$

where

$X_{r(i)}$, $Y_{r(i)}$, and $Z_{r(i)}$ are the XYZ values of i^{th} reference colour using the CIE 1931 standard colorimetric observer;

L_s is the scaling factor and k is the normalisation constant for the CIE 1931 standard colorimetric observer, defined in Equation (9).

$$k = \frac{1}{\int_{390}^{780} S_{D65} \cdot \bar{y}(\lambda) d\lambda} \tag{9}$$

- 2) Calculate the XYZ values of the test colour using the SPD of the test colour obtained in Equation (7) and the CIE 1931 standard colorimetric observer as shown in Equation (10).

$$\begin{aligned}
 X_{t(i,j)} &= 683 \int_{390}^{780} \Phi_{t(i,j)}(\lambda) \cdot \bar{x}(\lambda) d\lambda \\
 Y_{t(i,j)} &= 683 \int_{390}^{780} \Phi_{t(i,j)}(\lambda) \cdot \bar{y}(\lambda) d\lambda \\
 Z_{t(i,j)} &= 683 \int_{390}^{780} \Phi_{t(i,j)}(\lambda) \cdot \bar{z}(\lambda) d\lambda
 \end{aligned} \tag{10}$$

where

$X_{t(i,j)}$, $Y_{t(i,j)}$ and $Z_{t(i,j)}$ are the XYZ values of the test colour matched with i^{th} reference colour for j^{th} individual observer.

6.3.3.5 Colour difference computation

- 1) Transform both XYZ value sets obtained in steps 1) and 2) of 6.3.3.4 into the three-dimensional CIELAB colour space (per ISO 11664-4). The CIELAB L^* , a^* and b^* values are calculated from the transformed tristimulus values using the following equations:

$$\begin{aligned}
 L^* &= 116 \cdot f\left(\frac{Y}{Y_n}\right) - 16 \\
 a^* &= 500 \cdot \left[f\left(\frac{X}{X_n}\right) - f\left(\frac{Y}{Y_n}\right) \right] \\
 b^* &= 200 \cdot \left[f\left(\frac{Y}{Y_n}\right) - f\left(\frac{Z}{Z_n}\right) \right]
 \end{aligned} \tag{11}$$

where

$$f(t) = \begin{cases} t^{1/3} & t < \left(\frac{6}{29}\right)^3 \\ \frac{1}{3}\left(\frac{29}{6}\right)^2 t + \frac{16}{116} & \text{otherwise} \end{cases} \tag{12}$$

and X_n , Y_n and Z_n are defined as XYZ tristimulus values of the reference white multiplied by the scaling factor L_s as shown in Equation (13);

$$\begin{pmatrix} X_n \\ Y_n \\ Z_n \end{pmatrix} = L_s \cdot \begin{pmatrix} X_{\text{Ref_W}} \\ Y_{\text{Ref_W}} \\ Z_{\text{Ref_W}} \end{pmatrix} \tag{13}$$

where

$X_{\text{Ref_W}}$, $Y_{\text{Ref_W}}$ and $Z_{\text{Ref_W}}$ are the normalised XYZ values of the reference white, that is the CIE Standard D65 illuminant.

$$\begin{aligned}
 X_{\text{Ref_W}} &= k \int_{390}^{780} S_{\text{D65}}(\lambda) \cdot \bar{x}(\lambda) d\lambda \\
 Y_{\text{Ref_W}} &= k \int_{390}^{780} S_{\text{D65}}(\lambda) \cdot \bar{y}(\lambda) d\lambda \\
 Z_{\text{Ref_W}} &= k \int_{390}^{780} S_{\text{D65}}(\lambda) \cdot \bar{z}(\lambda) d\lambda
 \end{aligned} \tag{14}$$

- 2) Calculate the CIE DE2000 ΔE_{00} between the reference colour and the test colour according to the following equations:

$$C_{i,ab}^* = \sqrt{(a_i^*)^2 + (b_i^*)^2} \quad (15)$$

$$\bar{C}_{ab}^* = (C_{1,ab}^* + C_{2,ab}^*) / 2 \quad (16)$$

$$G = 0,5 \left(1 - \sqrt{\frac{(\bar{C}_{ab}^*)^7}{(\bar{C}_{ab}^*)^7 + 25^7}} \right) \quad (17)$$

$$a_i' = (1 + G) a_i^* \quad (18)$$

$$C_i' = \sqrt{(a_i')^2 + (b_i^*)^2} \quad (19)$$

$$h_i' = \begin{cases} 0 & \text{if } b_i^* = a_i' = 0 \\ \tan^{-1}(b_i^*, a_i') & \text{otherwise} \end{cases} \quad (20)$$

$$\Delta L' = L_2^* - L_1^* \quad (21)$$

$$\Delta C' = C_2' - C_1' \quad (22)$$

$$\Delta h_i' = \begin{cases} 0 & C_2' C_1' \neq 0 \\ h_2' - h_1' & C_2' C_1' \neq 0 & |h_2' - h_1'| \leq 180^\circ \\ (h_2' - h_1') - 360 & C_2' C_1' \neq 0 & (h_2' - h_1') > 180^\circ \\ (h_2' - h_1') + 360 & C_2' C_1' \neq 0 & (h_2' - h_1') < -180^\circ \end{cases} \quad (23)$$

$$\Delta H' = 2\sqrt{C_2' C_1'} \sin\left(\frac{\Delta h'}{2}\right) \quad (24)$$

$$\bar{L}' = (L_2^* - L_1^*) / 2 \quad (25)$$

$$\bar{C}' = (C_2' - C_1') / 2 \quad (26)$$

$$\bar{h}' = \begin{cases} \frac{h_1' + h_2'}{2} & |h_1' + h_2'| \leq 180^\circ & C_1' C_2' \neq 0 & C_1' C_2' \neq 0 \\ \frac{h_1' + h_2' + 360^\circ}{2} & |h_1' + h_2'| > 180^\circ & (h_1' + h_2') < 360^\circ & C_1' C_2' \neq 0 \\ \frac{h_1' + h_2' - 360^\circ}{2} & |h_1' + h_2'| > 180^\circ & (h_1' + h_2') \geq 360^\circ & C_1' C_2' \neq 0 \\ h_1' + h_2' & & & C_1' C_2' \neq 0 \end{cases} \quad (27)$$

$$T = 1 - 0,17 \cos(\bar{h}' - 30^\circ) + 0,24 \cos(2\bar{h}') + 0,32 \cos(3\bar{h}' + 6^\circ) - 0,2 \cos(4\bar{h}' - 63^\circ) \quad (28)$$

$$\Delta\theta = 30 \exp \left\{ - \left(\frac{\bar{h}' - 275^\circ}{25} \right)^2 \right\} \quad (29)$$

$$R_C = 2 \sqrt{\frac{\bar{C}^7}{\bar{C}^7 + 25^7}} \quad (30)$$

$$S_L = 1 + \frac{0,015 (\bar{L}' - 50)^2}{\sqrt{20 + (\bar{L}' - 50)^2}} \quad (31)$$

$$S_C = 1 + 0,045 \bar{C}' \quad (32)$$

$$S_H = 1 + 0,015 \bar{C}' T \quad (33)$$

$$R_T = -\sin(2 \cdot \theta) R_C \quad (34)$$

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L} \right)^2 + \left(\frac{\Delta C'}{k_C S_C} \right)^2 + \left(\frac{\Delta H'}{k_H S_H} \right)^2} + R_T \left(\frac{\Delta C'}{k_C S_C} \right) \left(\frac{\Delta H'}{k_H S_H} \right) \quad (35)$$

3) Repeat the process 4) to 10) for each individual observer.

4) Repeat the process 4) to 11) for each reference colour.

Annex C describes the process for evaluating the OMI between different displays.

6.3.3.6 Reporting

- 1) Report maximum, minimum, average and standard deviation of CIE DE2000 ΔE_{00} values for all the individual observers (see Table 1).
- 2) Report maximum, minimum, average and standard deviation of CIE DE2000 ΔE_{00} values for all the individual observers and all the reference colours to provide a set of representative OMI values (see Table 1).

7 Reporting form

Report maximum, minimum, average and standard deviation values of OMI obtained in 6.3.3.6 using the form shown in Table 1. Also, present a graph showing the spectral plots of metameric pairs of reference colour and DUT as shown in Figure 5.

Table 1 – Reporting form of observer metamerism index

Reference colour ($i = 1$ to 7)	Observer metamerism index			
	Maximum	Minimum	Average	Standard deviation
Macbeth white (1)				
Macbeth red (2)				
Macbeth green (3)				
Macbeth blue (4)				
Macbeth cyan (5)				
Macbeth magenta (6)				
Macbeth yellow (7)				
Total				

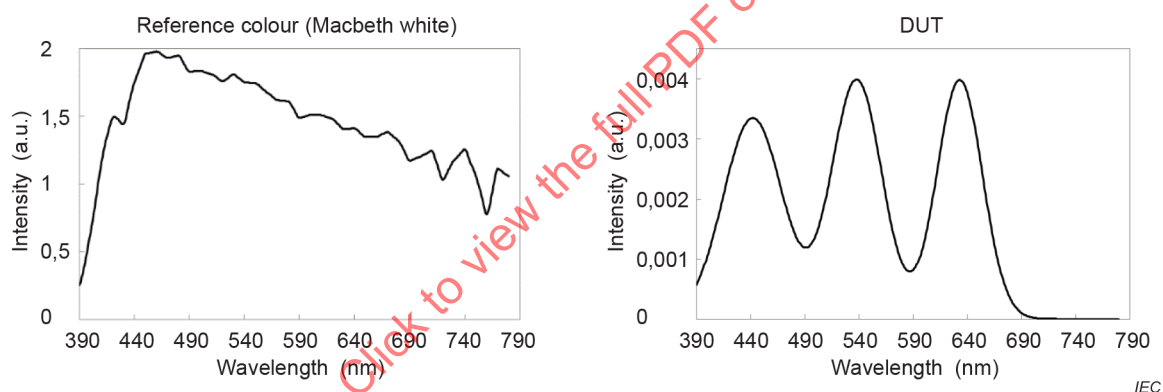


Figure 5 – Reporting example of a graph of colour-matched metameric pair of reference colour and DUT

Annex A (informative)

Generating a set of individual CMFs

A.1 Age distribution data

When generating a set of individual CMFs using CIE 170-1 and 2, age and field size (F_s) data are required. Among them, F_s can be selected by the standard user in consideration of the application field and the use environment of the DUT. The 2° field size is recommended in this Technical Specification.

For age distribution data, officially published data could be used such as the age distribution data published by the United Nations World Population Prospects [4]. Users of this Technical Specification can use various age distribution data depending on the purpose of measurement. In the case of the CIE 170-1 model, only the age range of 20 to 80 is reflected. Therefore, it is possible to reflect only the age range of 20 to 80 years of age distribution data.

Age distribution data determine the number of CMFs dataset. If the data is constructed with 1-year intervals, the number of datasets would be more than 150 datasets. If the age interval is 10 years, you get 1/10 of the dataset compared to the first one. For a large number of datasets, the appropriate number of datasets should be applied to the number of iterations of the evaluation. Therefore, it is easy to use the evaluation method to reduce the number of datasets without distorting the statistical significance of the age distribution. In this Technical Specification, it is recommended to use at least 20 datasets.

A.2 Example of individual CMFs dataset

Table A.1 shows the example of age distribution data. The original data are distribution data consisting of 5-year intervals from 20 to 79 years old, and the total is 100 %. The last column is the data in which the number of iterations is reduced without statistical distortion to simplify the measurement. If field size is fixed to 2° and using the reduced age distribution data, a total of 20 individual CMFs is generated and the Table A.2 shows the result.

Table A.1 – Example of age distribution data

Age	Original data [%]	Reduced data [%]
20 to 24	5 %	1 %
25 to 29	15 %	3 %
30 to 34	15 %	3 %
35 to 39	10 %	2 %
40 to 44	10 %	2 %
45 to 49	15 %	3 %
50 to 54	5 %	1 %
55 to 59	5 %	1 %
60 to 64	5 %	1 %
65 to 69	5 %	1 %
70 to 74	5 %	1 %
75 to 79	5 %	1 %
Total	100 %	20 %

The individual CMFs results using data of Table A.1 are shown in Table A.2 and Table A.3 to Table A.6. Table A.3 to Table A.6 show the SPDs data of individual CMFs generated with the 2° field size and the median value of each age group (i.e. 22 in the case of 20 to 24), and Table A.2 shows the number of each age group or the corresponding individual CMFs. That number will be used as the weight when calculating the average value of the OMI for the age groups or individual observers.

Table A.2 – Total number of individual CMFs example

Individual CMFs ($j = 1$ to 12)	Age range	Age group	Number
1	20 to 24	22	1
2	25 to 29	27	3
3	30 to 34	32	3
4	35 to 39	37	2
5	40 to 44	42	2
6	45 to 49	47	3
7	50 to 54	52	1
8	55 to 59	57	1
9	60 to 64	62	1
10	65 to 69	67	1
11	70 to 74	72	1
12	75 to 79	77	1
Total			20

The $\bar{x}$, $\bar{y}$, $\bar{z}$ data for each age group included in Table A.3 to Table A.6 are the calculated result using the 2° field size matrix in CIE 170-2. The cone fundamentals used in the calculation were calculated through the ocular media optical density function, which is a function reflecting age, and macular pigment optical density function, visual pigment optical density function, which is a function reflecting field size, referring to CIE 170-1. For details, please refer to CIE 170-1 and 170-2.

NOTE 2° field size matrix in CIE 170-2 is only for the average observer (32-year-old). However, in this document, the same matrix is used for all the age groups only to be used for the colour matching process.

Table A.3 – Spectral sensitivity data of the individual CMFs (age group: 22, 27 and 32)

Age group	22			27			32		
Wavelength (nm)	$\bar{x}'_1$	$\bar{y}'_1$	$\bar{z}'_1$	$\bar{x}'_2$	$\bar{y}'_2$	$\bar{z}'_2$	$\bar{x}'_3$	$\bar{y}'_3$	$\bar{z}'_3$
390	0,005 67	0,000 68	0,027 50	0,005 02	0,000 58	0,024 51	0,004 45	0,000 49	0,021 84
395	0,012 37	0,001 53	0,060 15	0,011 15	0,001 31	0,054 54	0,010 05	0,001 13	0,049 42
400	0,026 52	0,003 22	0,130 06	0,024 33	0,002 81	0,119 94	0,022 31	0,002 46	0,110 55
405	0,054 85	0,006 31	0,271 71	0,051 20	0,005 61	0,254 87	0,047 79	0,004 98	0,238 94
410	0,100 77	0,011 23	0,503 57	0,095 36	0,010 10	0,478 63	0,090 23	0,009 09	0,454 68
415	0,157 91	0,017 17	0,800 74	0,151 72	0,015 68	0,772 13	0,145 75	0,014 31	0,744 16
420	0,217 92	0,023 90	1,120 39	0,211 47	0,022 03	1,090 45	0,205 17	0,020 30	1,060 76
425	0,261 88	0,030 30	1,368 44	0,256 32	0,028 16	1,342 37	0,250 83	0,026 16	1,316 10
430	0,303 79	0,038 13	1,612 85	0,298 96	0,035 61	1,589 68	0,294 16	0,033 24	1,566 03
435	0,329 91	0,046 96	1,785 99	0,327 63	0,044 23	1,775 01	0,325 31	0,041 64	1,763 18

Age group	22			27			32		
Wavelength (nm)	$\bar{x}'_1$	$\bar{y}'_1$	$\bar{z}'_1$	$\bar{x}'_2$	$\bar{y}'_2$	$\bar{z}'_2$	$\bar{x}'_3$	$\bar{y}'_3$	$\bar{z}'_3$
440	0,351 18	0,056 15	1,934 85	0,351 17	0,053 21	1,934 85	0,351 09	0,050 41	1,933 85
445	0,339 90	0,063 25	1,911 65	0,342 29	0,060 33	1,923 72	0,344 64	0,057 52	1,934 85
450	0,316 57	0,070 48	1,821 64	0,320 84	0,067 61	1,843 38	0,325 12	0,064 83	1,864 42
455	0,274 87	0,078 21	1,627 59	0,279 89	0,075 32	1,653 42	0,284 99	0,072 50	1,678 79
460	0,239 52	0,091 42	1,479 10	0,244 97	0,088 32	1,507 33	0,250 55	0,085 28	1,535 31
465	0,211 85	0,113 05	1,378 64	0,217 69	0,109 58	1,409 77	0,223 75	0,106 18	1,440 85
470	0,171 09	0,137 98	1,202 34	0,176 43	0,134 00	1,231 89	0,182 06	0,130 09	1,261 51
475	0,121 06	0,162 19	0,955 51	0,125 37	0,157 94	0,981 63	0,130 05	0,153 74	1,007 93
480	0,075 84	0,188 10	0,719 08	0,078 79	0,183 57	0,740 36	0,082 17	0,179 07	0,761 88
485	0,042 25	0,216 39	0,532 77	0,043 84	0,211 57	0,549 61	0,045 92	0,206 78	0,566 68
490	0,019 33	0,248 50	0,387 47	0,019 58	0,243 36	0,400 40	0,020 37	0,238 24	0,413 55
495	0,007 81	0,296 75	0,292 58	0,006 72	0,291 10	0,302 86	0,006 26	0,285 45	0,313 34
500	0,005 68	0,361 60	0,223 24	0,003 09	0,355 21	0,231 42	0,001 24	0,348 80	0,239 78
505	0,009 78	0,442 55	0,161 01	0,005 45	0,435 45	0,167 19	0,001 99	0,428 30	0,173 53
510	0,024 95	0,536 44	0,109 73	0,018 69	0,528 83	0,114 17	0,013 44	0,521 13	0,118 72
515	0,055 85	0,637 19	0,076 94	0,047 64	0,629 33	0,080 21	0,040 58	0,621 35	0,083 57
520	0,095 46	0,735 16	0,052 33	0,085 41	0,727 11	0,054 63	0,076 64	0,718 90	0,057 01
525	0,145 17	0,811 22	0,034 65	0,133 68	0,803 46	0,036 22	0,123 53	0,795 51	0,037 85
530	0,202 09	0,872 99	0,022 45	0,189 48	0,865 86	0,023 51	0,178 26	0,858 49	0,024 60
535	0,262 20	0,921 29	0,014 39	0,248 79	0,914 82	0,015 08	0,236 78	0,908 10	0,015 80
540	0,332 48	0,966 62	0,009 02	0,318 51	0,961 16	0,009 47	0,305 94	0,955 44	0,009 93
545	0,403 21	0,991 13	0,005 60	0,389 18	0,986 91	0,005 89	0,376 52	0,982 41	0,006 19
550	0,471 47	0,995 99	0,003 45	0,457 86	0,993 13	0,003 63	0,445 56	0,989 98	0,003 82
555	0,548 99	1,003 70	0,002 11	0,535 98	1,002 19	0,002 23	0,524 22	1,000 40	0,002 35
560	0,632 80	0,998 72	0,001 30	0,620 65	0,998 34	0,001 37	0,609 67	0,997 68	0,001 45
565	0,718 74	0,989 46	0,000 80	0,707 90	0,990 43	0,000 84	0,698 13	0,991 13	0,000 89
570	0,810 68	0,969 84	0,000 49	0,801 57	0,972 09	0,000 52	0,793 44	0,974 09	0,000 55
575	0,895 38	0,936 62	0,000 30	0,888 41	0,940 03	0,000 32	0,882 31	0,943 23	0,000 34
580	0,969 35	0,888 45	0,000 19	0,964 90	0,892 85	0,000 20	0,961 20	0,897 08	0,000 21
585	1,052 08	0,849 30	0,000 12	1,050 07	0,854 40	0,000 13	1,048 70	0,859 36	0,000 14
590	1,106 29	0,800 93	0,000 08	1,106 77	0,806 60	0,000 08	1,107 81	0,812 16	0,000 09
595	1,135 69	0,742 99	0,000 05	1,138 63	0,749 02	0,000 05	1,142 04	0,754 99	0,000 06
600	1,140 07	0,680 51	0,000 03	1,144 73	0,686 43	0,000 03	1,149 80	0,692 29	0,000 04
605	1,120 72	0,615 70	0,000 02	1,127 12	0,621 56	0,000 02	1,133 86	0,627 39	0,000 02
610	1,068 19	0,547 64	0,000 01	1,075 60	0,553 17	0,000 02	1,083 31	0,558 70	0,000 02
615	0,990 71	0,479 59	0,000 01	0,998 69	0,484 72	0,000 01	1,006 93	0,489 86	0,000 01
620	0,897 93	0,414 03	0,000 00	0,905 89	0,418 62	0,000 00	0,914 06	0,423 22	0,000 00
625	0,797 93	0,353 00	0,000 00	0,805 60	0,357 05	0,000 00	0,813 44	0,361 11	0,000 00
630	0,678 02	0,291 16	0,000 00	0,685 15	0,294 69	0,000 00	0,692 44	0,298 24	0,000 00
635	0,562 60	0,235 76	0,000 00	0,569 01	0,238 77	0,000 00	0,575 56	0,241 81	0,000 00
640	0,461 72	0,189 28	0,000 00	0,467 39	0,191 83	0,000 00	0,473 16	0,194 41	0,000 00
645	0,375 00	0,150 68	0,000 00	0,379 73	0,152 74	0,000 00	0,384 55	0,154 82	0,000 00

Age group	22			27			32		
Wavelength (nm)	$\bar{x}'_1$	$\bar{y}'_1$	$\bar{z}'_1$	$\bar{x}'_2$	$\bar{y}'_2$	$\bar{z}'_2$	$\bar{x}'_3$	$\bar{y}'_3$	$\bar{z}'_3$
650	0,292 16	0,116 13	0,000 00	0,295 94	0,117 74	0,000 00	0,299 79	0,119 37	0,000 00
655	0,221 80	0,087 32	0,000 00	0,224 78	0,088 57	0,000 00	0,227 83	0,089 84	0,000 00
660	0,166 21	0,064 84	0,000 00	0,168 50	0,065 79	0,000 00	0,170 83	0,066 74	0,000 00
665	0,122 99	0,047 63	0,000 00	0,124 68	0,048 32	0,000 00	0,126 41	0,049 02	0,000 00
670	0,089 77	0,034 61	0,000 00	0,091 01	0,035 11	0,000 00	0,092 27	0,035 62	0,000 00
675	0,064 61	0,024 83	0,000 00	0,065 51	0,025 19	0,000 00	0,066 42	0,025 56	0,000 00
680	0,045 84	0,017 58	0,000 00	0,046 47	0,017 83	0,000 00	0,047 12	0,018 09	0,000 00
685	0,032 03	0,012 26	0,000 00	0,032 48	0,012 44	0,000 00	0,032 93	0,012 62	0,000 00
690	0,022 01	0,008 42	0,000 00	0,022 32	0,008 54	0,000 00	0,022 63	0,008 67	0,000 00
695	0,015 33	0,005 86	0,000 00	0,015 54	0,005 95	0,000 00	0,015 76	0,006 03	0,000 00
700	0,010 67	0,004 08	0,000 00	0,010 82	0,004 14	0,000 00	0,010 97	0,004 20	0,000 00
705	0,007 40	0,002 83	0,000 00	0,007 51	0,002 87	0,000 00	0,007 61	0,002 91	0,000 00
710	0,005 07	0,001 94	0,000 00	0,005 14	0,001 97	0,000 00	0,005 22	0,002 00	0,000 00
715	0,003 47	0,001 33	0,000 00	0,003 52	0,001 35	0,000 00	0,003 57	0,001 37	0,000 00
720	0,002 40	0,000 92	0,000 00	0,002 43	0,000 93	0,000 00	0,002 47	0,000 95	0,000 00
725	0,001 66	0,000 64	0,000 00	0,001 68	0,000 65	0,000 00	0,001 70	0,000 65	0,000 00
730	0,001 15	0,000 44	0,000 00	0,001 17	0,000 45	0,000 00	0,001 19	0,000 46	0,000 00
735	0,000 81	0,000 31	0,000 00	0,000 82	0,000 31	0,000 00	0,000 83	0,000 32	0,000 00
740	0,000 56	0,000 22	0,000 00	0,000 57	0,000 22	0,000 00	0,000 58	0,000 22	0,000 00
745	0,000 40	0,000 15	0,000 00	0,000 40	0,000 15	0,000 00	0,000 41	0,000 16	0,000 00
750	0,000 28	0,000 11	0,000 00	0,000 28	0,000 11	0,000 00	0,000 29	0,000 11	0,000 00
755	0,000 20	0,000 08	0,000 00	0,000 20	0,000 08	0,000 00	0,000 20	0,000 08	0,000 00
760	0,000 14	0,000 05	0,000 00	0,000 14	0,000 06	0,000 00	0,000 14	0,000 06	0,000 00
765	0,000 10	0,000 04	0,000 00	0,000 10	0,000 04	0,000 00	0,000 10	0,000 04	0,000 00
770	0,000 07	0,000 03	0,000 00	0,000 07	0,000 03	0,000 00	0,000 07	0,000 03	0,000 00
775	0,000 05	0,000 02	0,000 00	0,000 05	0,000 02	0,000 00	0,000 05	0,000 02	0,000 00
780	0,000 04	0,000 01	0,000 00	0,000 04	0,000 02	0,000 00	0,000 04	0,000 02	0,000 00

Table A.4 – Spectral sensitivity data of the individual CMFs (Age group: 37, 42 and 47)

Age group	37			42			47		
Wavelength (nm)	$\bar{x}'_4$	$\bar{y}'_4$	$\bar{z}'_4$	$\bar{x}'_5$	$\bar{y}'_5$	$\bar{z}'_5$	$\bar{x}'_6$	$\bar{y}'_6$	$\bar{z}'_6$
390	0,003 92	0,000 41	0,019 34	0,003 46	0,000 35	0,017 13	0,003 05	0,000 29	0,015 17
395	0,009 01	0,000 97	0,044 52	0,008 08	0,000 83	0,040 11	0,007 25	0,000 71	0,036 14
400	0,020 36	0,002 14	0,101 31	0,018 58	0,001 87	0,092 84	0,016 97	0,001 63	0,085 08
405	0,044 38	0,004 42	0,222 73	0,041 22	0,003 93	0,207 61	0,038 29	0,003 49	0,193 52
410	0,084 93	0,008 18	0,429 44	0,079 96	0,007 36	0,405 60	0,075 29	0,006 62	0,383 09
415	0,139 27	0,013 07	0,713 07	0,133 10	0,011 93	0,683 28	0,127 22	0,010 89	0,654 73
420	0,197 99	0,018 71	1,025 93	0,191 08	0,017 24	0,992 26	0,184 45	0,015 89	0,959 68
425	0,244 10	0,024 30	1,282 93	0,237 58	0,022 58	1,250 59	0,231 26	0,020 97	1,219 07
430	0,287 80	0,031 03	1,533 85	0,281 61	0,028 97	1,502 34	0,275 57	0,027 04	1,471 47

Age group	37			42			47		
Wavelength (nm)	$\bar{x}'_4$	$\bar{y}'_4$	$\bar{z}'_4$	$\bar{x}'_5$	$\bar{y}'_5$	$\bar{z}'_5$	$\bar{x}'_6$	$\bar{y}'_6$	$\bar{z}'_6$
435	0,321 14	0,039 21	1,741 35	0,317 06	0,036 91	1,719 79	0,313 04	0,034 75	1,698 50
440	0,348 93	0,047 76	1,921 72	0,346 82	0,045 25	1,909 67	0,344 74	0,042 87	1,897 69
445	0,344 92	0,054 85	1,934 85	0,345 21	0,052 29	1,934 85	0,345 51	0,049 86	1,934 85
450	0,327 41	0,062 16	1,874 84	0,329 74	0,059 60	1,885 32	0,332 09	0,057 15	1,895 86
455	0,288 32	0,069 79	1,694 74	0,291 71	0,067 18	1,710 83	0,295 14	0,064 66	1,727 09
460	0,254 56	0,082 35	1,554 81	0,258 64	0,079 53	1,574 56	0,262 79	0,076 80	1,594 55
465	0,228 38	0,102 88	1,464 14	0,233 11	0,099 69	1,487 81	0,237 94	0,096 60	1,511 87
470	0,186 47	0,126 30	1,284 41	0,191 00	0,122 62	1,307 72	0,195 64	0,119 04	1,331 46
475	0,133 80	0,149 65	1,028 99	0,137 69	0,145 67	1,050 48	0,141 71	0,141 80	1,072 43
480	0,084 89	0,174 68	0,779 50	0,087 74	0,170 40	0,797 53	0,090 74	0,166 23	0,815 99
485	0,047 54	0,202 10	0,580 93	0,049 31	0,197 52	0,595 53	0,051 22	0,193 05	0,610 50
490	0,020 87	0,233 23	0,424 67	0,021 51	0,228 33	0,436 09	0,022 30	0,223 54	0,447 81
495	0,005 62	0,279 91	0,322 32	0,005 13	0,274 48	0,331 55	0,004 80	0,269 16	0,341 04
500	-0,000 69	0,342 51	0,247 01	-0,002 46	0,336 34	0,254 46	-0,004 05	0,330 28	0,262 13
505	-0,001 46	0,421 27	0,179 06	-0,004 74	0,414 36	0,184 78	-0,007 83	0,407 57	0,190 67
510	0,008 27	0,513 55	0,122 75	0,003 28	0,506 09	0,126 92	-0,001 52	0,498 74	0,131 22
515	0,033 62	0,613 48	0,086 58	0,026 87	0,605 71	0,089 69	0,020 31	0,598 05	0,092 91
520	0,068 00	0,710 79	0,059 14	0,059 56	0,702 78	0,061 36	0,051 33	0,694 87	0,063 66
525	0,113 53	0,787 65	0,039 33	0,103 72	0,779 87	0,040 86	0,094 10	0,772 18	0,042 46
530	0,167 19	0,851 21	0,025 60	0,156 29	0,843 99	0,026 63	0,145 56	0,836 84	0,027 71
535	0,224 92	0,901 43	0,016 46	0,213 20	0,894 83	0,017 15	0,201 64	0,888 29	0,017 87
540	0,293 50	0,949 76	0,010 36	0,281 17	0,944 13	0,010 81	0,268 97	0,938 54	0,011 28
545	0,363 95	0,977 94	0,006 46	0,351 47	0,973 50	0,006 75	0,339 08	0,969 09	0,007 06
550	0,433 31	0,986 84	0,004 00	0,421 12	0,983 73	0,004 19	0,408 98	0,980 65	0,004 38
555	0,512 47	0,998 62	0,002 46	0,500 75	0,996 85	0,002 58	0,489 04	0,995 10	0,002 70
560	0,598 68	0,997 03	0,001 52	0,587 69	0,996 40	0,001 59	0,576 69	0,995 77	0,001 67
565	0,688 34	0,991 84	0,000 94	0,678 50	0,992 57	0,000 98	0,668 63	0,993 30	0,001 03
570	0,785 25	0,976 11	0,000 58	0,777 00	0,978 14	0,000 61	0,768 69	0,980 19	0,000 64
575	0,876 14	0,946 45	0,000 36	0,869 89	0,949 70	0,000 38	0,863 57	0,952 96	0,000 40
580	0,957 42	0,901 34	0,000 23	0,953 56	0,905 62	0,000 24	0,949 62	0,909 94	0,000 25
585	1,047 27	0,864 36	0,000 14	1,045 77	0,869 40	0,000 15	1,044 19	0,874 47	0,000 16
590	1,108 80	0,817 77	0,000 09	1,109 72	0,823 43	0,000 10	1,110 59	0,829 13	0,000 10
595	1,145 42	0,761 01	0,000 06	1,148 76	0,767 08	0,000 06	1,152 07	0,773 21	0,000 07
600	1,154 85	0,698 22	0,000 04	1,159 90	0,704 20	0,000 04	1,164 93	0,710 23	0,000 04
605	1,140 61	0,633 28	0,000 03	1,147 39	0,639 23	0,000 03	1,154 17	0,645 24	0,000 03
610	1,091 05	0,564 28	0,000 02	1,098 82	0,569 92	0,000 02	1,106 64	0,575 62	0,000 02
615	1,015 22	0,495 06	0,000 01	1,023 56	0,500 32	0,000 01	1,031 96	0,505 63	0,000 01
620	0,922 29	0,427 87	0,000 00	0,930 58	0,432 58	0,000 00	0,938 94	0,437 34	0,000 00
625	0,821 35	0,365 23	0,000 00	0,829 33	0,369 39	0,000 00	0,837 38	0,373 60	0,000 00
630	0,699 79	0,301 84	0,000 00	0,707 22	0,305 48	0,000 00	0,714 72	0,309 16	0,000 00
635	0,582 17	0,244 90	0,000 00	0,588 85	0,248 02	0,000 00	0,595 61	0,251 18	0,000 00
640	0,479 00	0,197 02	0,000 00	0,484 91	0,199 67	0,000 00	0,490 89	0,202 35	0,000 00

Age group	37			42			47		
Wavelength (nm)	$\bar{x}'_4$	$\bar{y}'_4$	$\bar{z}'_4$	$\bar{x}'_5$	$\bar{y}'_5$	$\bar{z}'_5$	$\bar{x}'_6$	$\bar{y}'_6$	$\bar{z}'_6$
645	0,389 43	0,156 93	0,000 00	0,394 37	0,159 06	0,000 00	0,399 37	0,161 23	0,000 00
650	0,303 68	0,121 02	0,000 00	0,307 62	0,122 70	0,000 00	0,311 62	0,124 40	0,000 00
655	0,230 91	0,091 13	0,000 00	0,234 03	0,092 43	0,000 00	0,237 20	0,093 75	0,000 00
660	0,173 19	0,067 71	0,000 00	0,175 58	0,068 70	0,000 00	0,178 01	0,069 70	0,000 00
665	0,128 16	0,049 73	0,000 00	0,129 94	0,050 46	0,000 00	0,131 74	0,051 19	0,000 00
670	0,093 55	0,036 13	0,000 00	0,094 85	0,036 66	0,000 00	0,096 16	0,037 19	0,000 00
675	0,067 34	0,025 93	0,000 00	0,068 28	0,026 30	0,000 00	0,069 22	0,026 68	0,000 00
680	0,047 77	0,018 35	0,000 00	0,048 44	0,018 62	0,000 00	0,049 11	0,018 89	0,000 00
685	0,033 39	0,012 81	0,000 00	0,033 85	0,012 99	0,000 00	0,034 32	0,013 18	0,000 00
690	0,022 94	0,008 79	0,000 00	0,023 26	0,008 92	0,000 00	0,023 59	0,009 05	0,000 00
695	0,015 98	0,006 12	0,000 00	0,016 20	0,006 21	0,000 00	0,016 43	0,006 30	0,000 00
700	0,011 12	0,004 26	0,000 00	0,011 28	0,004 32	0,000 00	0,011 44	0,004 38	0,000 00
705	0,007 72	0,002 95	0,000 00	0,007 82	0,003 00	0,000 00	0,007 93	0,003 04	0,000 00
710	0,005 29	0,002 03	0,000 00	0,005 36	0,002 06	0,000 00	0,005 44	0,002 08	0,000 00
715	0,003 62	0,001 39	0,000 00	0,003 67	0,001 41	0,000 00	0,003 72	0,001 43	0,000 00
720	0,002 50	0,000 96	0,000 00	0,002 54	0,000 97	0,000 00	0,002 57	0,000 99	0,000 00
725	0,001 73	0,000 66	0,000 00	0,001 75	0,000 67	0,000 00	0,001 78	0,000 68	0,000 00
730	0,001 20	0,000 46	0,000 00	0,001 22	0,000 47	0,000 00	0,001 24	0,000 48	0,000 00
735	0,000 84	0,000 32	0,000 00	0,000 85	0,000 33	0,000 00	0,000 86	0,000 33	0,000 00
740	0,000 58	0,000 23	0,000 00	0,000 59	0,000 23	0,000 00	0,000 60	0,000 23	0,000 00
745	0,000 41	0,000 16	0,000 00	0,000 42	0,000 16	0,000 00	0,000 42	0,000 16	0,000 00
750	0,000 29	0,000 11	0,000 00	0,000 29	0,000 11	0,000 00	0,000 30	0,000 12	0,000 00
755	0,000 21	0,000 08	0,000 00	0,000 21	0,000 08	0,000 00	0,000 21	0,000 08	0,000 00
760	0,000 15	0,000 06	0,000 00	0,000 15	0,000 06	0,000 00	0,000 15	0,000 06	0,000 00
765	0,000 10	0,000 04	0,000 00	0,000 11	0,000 04	0,000 00	0,000 11	0,000 04	0,000 00
770	0,000 08	0,000 03	0,000 00	0,000 08	0,000 03	0,000 00	0,000 08	0,000 03	0,000 00
775	0,000 05	0,000 02	0,000 00	0,000 05	0,000 02	0,000 00	0,000 06	0,000 02	0,000 00
780	0,000 04	0,000 02	0,000 00	0,000 04	0,000 02	0,000 00	0,000 04	0,000 02	0,000 00

Table A.5 – Spectral sensitivity data of the individual CMFs (Age group: 52, 57 and 62)

Age group	52			57			62		
Wavelength (nm)	$\bar{x}'_7$	$\bar{y}'_7$	$\bar{z}'_7$	$\bar{x}'_8$	$\bar{y}'_8$	$\bar{z}'_8$	$\bar{x}'_9$	$\bar{y}'_9$	$\bar{z}'_9$
390	0,002 69	0,000 25	0,013 44	0,002 38	0,000 21	0,011 91	0,001 86	0,000 15	0,009 40
395	0,006 51	0,000 61	0,032 56	0,005 84	0,000 53	0,029 34	0,004 74	0,000 39	0,023 94
400	0,015 49	0,001 43	0,077 96	0,014 15	0,001 24	0,071 45	0,011 86	0,000 96	0,060 25
405	0,035 58	0,003 09	0,180 38	0,033 07	0,002 75	0,168 14	0,028 66	0,002 18	0,146 54
410	0,070 91	0,005 96	0,361 83	0,066 79	0,005 36	0,341 75	0,059 42	0,004 36	0,305 53
415	0,121 62	0,009 94	0,627 38	0,116 29	0,009 08	0,601 17	0,106 47	0,007 60	0,552 68
420	0,178 06	0,014 64	0,928 18	0,171 92	0,013 50	0,897 71	0,160 39	0,011 51	0,840 27
425	0,225 14	0,019 48	1,188 34	0,219 20	0,018 10	1,158 38	0,207 83	0,015 68	1,100 85

Age group	52			57			62		
Wavelength (nm)	$\bar{x}'_7$	$\bar{y}'_7$	$\bar{z}'_7$	$\bar{x}'_8$	$\bar{y}'_8$	$\bar{z}'_8$	$\bar{x}'_9$	$\bar{y}'_9$	$\bar{z}'_9$
430	0,269 69	0,025 25	1,441 23	0,263 97	0,023 57	1,411 62	0,252 80	0,020 61	1,353 94
435	0,309 10	0,032 72	1,677 47	0,305 24	0,030 81	1,656 70	0,297 36	0,027 38	1,614 72
440	0,342 69	0,040 62	1,885 79	0,340 67	0,038 48	1,873 96	0,336 16	0,034 62	1,848 39
445	0,345 83	0,047 54	1,934 85	0,346 16	0,045 33	1,934 85	0,346 10	0,041 29	1,931 82
450	0,334 46	0,054 80	1,906 46	0,336 86	0,052 54	1,917 11	0,340 80	0,048 39	1,934 85
455	0,298 61	0,062 25	1,743 49	0,302 13	0,059 92	1,760 05	0,308 32	0,055 60	1,789 72
460	0,267 00	0,074 16	1,614 80	0,271 28	0,071 62	1,635 31	0,279 00	0,066 87	1,673 09
465	0,242 87	0,093 61	1,536 31	0,247 89	0,090 70	1,561 14	0,257 12	0,085 24	1,607 80
470	0,200 41	0,115 58	1,355 63	0,205 29	0,112 21	1,380 24	0,214 25	0,105 85	1,426 86
475	0,145 86	0,138 03	1,094 83	0,150 14	0,134 37	1,117 70	0,158 01	0,127 40	1,161 47
480	0,093 87	0,162 16	0,834 86	0,097 15	0,158 20	0,854 18	0,103 06	0,150 61	0,891 41
485	0,053 28	0,188 69	0,625 84	0,055 47	0,184 43	0,641 57	0,059 26	0,176 23	0,672 07
490	0,023 24	0,218 85	0,459 85	0,024 31	0,214 26	0,472 22	0,025 87	0,205 38	0,496 30
495	0,004 62	0,263 94	0,350 81	0,004 59	0,258 83	0,360 86	0,003 89	0,248 90	0,380 52
500	-0,005 48	0,324 34	0,270 03	-0,006 75	0,318 51	0,278 17	-0,010 03	0,307 11	0,294 16
505	-0,010 74	0,400 90	0,196 76	-0,013 48	0,394 34	0,203 04	-0,019 85	0,381 44	0,215 42
510	-0,006 12	0,491 51	0,135 67	-0,010 55	0,484 39	0,140 28	-0,020 51	0,470 25	0,149 39
515	0,013 95	0,590 49	0,096 25	0,007 77	0,583 04	0,099 71	-0,005 98	0,568 09	0,106 59
520	0,043 28	0,687 06	0,066 04	0,035 43	0,679 35	0,068 52	0,018 03	0,663 72	0,073 45
525	0,084 66	0,764 58	0,044 11	0,075 41	0,757 05	0,045 83	0,054 93	0,741 65	0,049 27
530	0,135 00	0,829 77	0,028 83	0,124 60	0,822 76	0,030 00	0,101 55	0,808 20	0,032 35
535	0,190 22	0,881 80	0,018 61	0,178 96	0,875 37	0,019 39	0,153 90	0,861 80	0,020 96
540	0,256 90	0,932 99	0,011 77	0,244 95	0,927 49	0,012 28	0,218 19	0,915 56	0,013 31
545	0,326 78	0,964 71	0,007 37	0,314 57	0,960 36	0,007 70	0,287 02	0,950 56	0,008 37
550	0,396 90	0,977 58	0,004 58	0,384 88	0,974 53	0,004 80	0,357 45	0,967 16	0,005 23
555	0,477 36	0,993 37	0,002 83	0,465 70	0,991 65	0,002 97	0,438 72	0,986 77	0,003 24
560	0,565 68	0,995 16	0,001 75	0,554 67	0,994 56	0,001 84	0,528 76	0,991 79	0,002 01
565	0,658 73	0,994 05	0,001 09	0,648 79	0,994 81	0,001 14	0,624 76	0,994 64	0,001 25
570	0,760 32	0,982 25	0,000 67	0,751 90	0,984 33	0,000 71	0,730 65	0,986 69	0,000 78
575	0,857 18	0,956 24	0,000 42	0,850 71	0,959 55	0,000 44	0,833 18	0,964 30	0,000 49
580	0,945 61	0,914 28	0,000 27	0,941 51	0,918 66	0,000 28	0,928 62	0,925 52	0,000 31
585	1,042 54	0,879 59	0,000 17	1,040 82	0,884 74	0,000 18	1,032 56	0,893 14	0,000 20
590	1,111 40	0,834 87	0,000 11	1,112 15	0,840 67	0,000 11	1,108 82	0,850 38	0,000 13
595	1,155 34	0,779 39	0,000 07	1,158 58	0,785 63	0,000 07	1,160 28	0,796 28	0,000 08
600	1,169 94	0,716 33	0,000 05	1,174 94	0,722 48	0,000 05	1,180 37	0,733 05	0,000 05
605	1,160 97	0,651 31	0,000 03	1,167 78	0,657 44	0,000 03	1,177 06	0,668 09	0,000 04
610	1,114 48	0,581 38	0,000 02	1,122 37	0,587 21	0,000 02	1,134 12	0,597 37	0,000 02
615	1,040 41	0,511 00	0,000 01	1,048 92	0,516 43	0,000 01	1,062 29	0,525 97	0,000 02
620	0,947 36	0,442 15	0,000 00	0,955 85	0,447 02	0,000 00	0,969 61	0,455 59	0,000 00
625	0,845 50	0,377 86	0,000 00	0,853 70	0,382 17	0,000 00	0,867 27	0,389 77	0,000 00
630	0,722 30	0,312 90	0,000 00	0,729 95	0,316 67	0,000 00	0,742 89	0,323 38	0,000 00
635	0,602 45	0,254 38	0,000 00	0,609 35	0,257 62	0,000 00	0,621 22	0,263 41	0,000 00

Age group	52			57			62		
Wavelength (nm)	$\bar{x}'_7$	$\bar{y}'_7$	$\bar{z}'_7$	$\bar{x}'_8$	$\bar{y}'_8$	$\bar{z}'_8$	$\bar{x}'_9$	$\bar{y}'_9$	$\bar{z}'_9$
640	0,496 94	0,205 07	0,000 00	0,503 06	0,207 82	0,000 00	0,513 72	0,212 77	0,000 00
645	0,404 43	0,163 43	0,000 00	0,409 56	0,165 66	0,000 00	0,418 53	0,169 66	0,000 00
650	0,315 66	0,126 12	0,000 00	0,319 75	0,127 87	0,000 00	0,326 95	0,131 01	0,000 00
655	0,240 40	0,095 10	0,000 00	0,243 65	0,096 46	0,000 00	0,249 40	0,098 91	0,000 00
660	0,180 47	0,070 71	0,000 00	0,182 96	0,071 74	0,000 00	0,187 38	0,073 59	0,000 00
665	0,133 56	0,051 93	0,000 00	0,135 41	0,052 68	0,000 00	0,138 70	0,054 05	0,000 00
670	0,097 50	0,037 73	0,000 00	0,098 85	0,038 28	0,000 00	0,101 25	0,039 26	0,000 00
675	0,070 19	0,027 07	0,000 00	0,071 16	0,027 46	0,000 00	0,072 89	0,028 17	0,000 00
680	0,049 79	0,019 16	0,000 00	0,050 49	0,019 44	0,000 00	0,051 72	0,019 94	0,000 00
685	0,034 80	0,013 37	0,000 00	0,035 28	0,013 56	0,000 00	0,036 15	0,013 91	0,000 00
690	0,023 92	0,009 18	0,000 00	0,024 25	0,009 31	0,000 00	0,024 84	0,009 55	0,000 00
695	0,016 65	0,006 39	0,000 00	0,016 89	0,006 48	0,000 00	0,017 30	0,006 65	0,000 00
700	0,011 59	0,004 45	0,000 00	0,011 76	0,004 51	0,000 00	0,012 04	0,004 63	0,000 00
705	0,008 04	0,003 09	0,000 00	0,008 16	0,003 13	0,000 00	0,008 35	0,003 21	0,000 00
710	0,005 51	0,002 12	0,000 00	0,005 59	0,002 15	0,000 00	0,005 73	0,002 20	0,000 00
715	0,003 77	0,001 45	0,000 00	0,003 83	0,001 47	0,000 00	0,003 92	0,001 51	0,000 00
720	0,002 61	0,001 00	0,000 00	0,002 64	0,001 02	0,000 00	0,002 71	0,001 04	0,000 00
725	0,001 80	0,000 69	0,000 00	0,001 83	0,000 70	0,000 00	0,001 87	0,000 72	0,000 00
730	0,001 25	0,000 48	0,000 00	0,001 27	0,000 49	0,000 00	0,001 30	0,000 50	0,000 00
735	0,000 87	0,000 34	0,000 00	0,000 89	0,000 34	0,000 00	0,000 91	0,000 35	0,000 00
740	0,000 61	0,000 24	0,000 00	0,000 62	0,000 24	0,000 00	0,000 63	0,000 25	0,000 00
745	0,000 43	0,000 17	0,000 00	0,000 44	0,000 17	0,000 00	0,000 45	0,000 17	0,000 00
750	0,000 30	0,000 12	0,000 00	0,000 31	0,000 12	0,000 00	0,000 31	0,000 12	0,000 00
755	0,000 21	0,000 08	0,000 00	0,000 22	0,000 08	0,000 00	0,000 22	0,000 09	0,000 00
760	0,000 15	0,000 06	0,000 00	0,000 15	0,000 06	0,000 00	0,000 16	0,000 06	0,000 00
765	0,000 11	0,000 04	0,000 00	0,000 11	0,000 04	0,000 00	0,000 11	0,000 04	0,000 00
770	0,000 08	0,000 03	0,000 00	0,000 08	0,000 03	0,000 00	0,000 08	0,000 03	0,000 00
775	0,000 06	0,000 02	0,000 00	0,000 06	0,000 02	0,000 00	0,000 06	0,000 02	0,000 00
780	0,000 04	0,000 02	0,000 00	0,000 04	0,000 02	0,000 00	0,000 04	0,000 02	0,000 00

Table A.6 – Spectral sensitivity data of the individual CMFs (Age group: 67, 72 and 77)

Age group	67			72			77		
Wavelength (nm)	$\bar{x}'_{10}$	$\bar{y}'_{10}$	$\bar{z}'_{10}$	$\bar{x}'_{11}$	$\bar{y}'_{11}$	$\bar{z}'_{11}$	$\bar{x}'_{12}$	$\bar{y}'_{12}$	$\bar{z}'_{12}$
390	0,001 21	0,000 08	0,006 16	0,000 79	0,000 05	0,004 03	0,000 51	0,000 03	0,002 64
395	0,003 25	0,000 23	0,016 59	0,002 24	0,000 14	0,011 50	0,001 54	0,000 08	0,007 97
400	0,008 62	0,000 61	0,044 20	0,006 28	0,000 38	0,032 43	0,004 58	0,000 24	0,023 79
405	0,022 08	0,001 46	0,113 78	0,017 03	0,000 98	0,088 35	0,013 15	0,000 65	0,068 60
410	0,047 87	0,003 06	0,247 90	0,038 62	0,002 15	0,201 14	0,031 19	0,001 49	0,163 20
415	0,090 13	0,005 59	0,470 53	0,076 38	0,004 12	0,400 60	0,064 78	0,003 01	0,341 06
420	0,140 21	0,008 74	0,737 90	0,122 69	0,006 64	0,648 00	0,107 44	0,005 01	0,569 06

Age group	67			72			77		
Wavelength (nm)	$\bar{x}'_{10}$	$\bar{y}'_{10}$	$\bar{z}'_{10}$	$\bar{x}'_{11}$	$\bar{y}'_{11}$	$\bar{z}'_{11}$	$\bar{x}'_{12}$	$\bar{y}'_{12}$	$\bar{z}'_{12}$
425	0,186 73	0,012 23	0,992 38	0,167 92	0,009 54	0,894 60	0,151 12	0,007 39	0,806 45
430	0,231 06	0,016 35	1,240 10	0,211 34	0,012 97	1,135 83	0,193 44	0,010 21	1,040 33
435	0,279 81	0,022 34	1,520 48	0,263 45	0,018 23	1,431 73	0,248 21	0,014 76	1,348 17
440	0,323 28	0,028 85	1,776 67	0,311 05	0,024 04	1,707 74	0,299 48	0,019 88	1,641 48
445	0,340 37	0,035 14	1,896 24	0,334 86	0,029 92	1,861 31	0,329 66	0,025 27	1,827 03
450	0,341 93	0,041 97	1,934 85	0,343 17	0,036 41	1,934 85	0,344 65	0,031 34	1,934 85
455	0,313 85	0,048 86	1,813 02	0,319 58	0,042 94	1,836 63	0,325 67	0,037 45	1,860 55
460	0,287 66	0,059 39	1,712 87	0,296 69	0,052 75	1,753 59	0,306 31	0,046 50	1,795 28
465	0,268 80	0,076 57	1,664 89	0,281 15	0,068 80	1,724 01	0,294 47	0,061 34	1,785 22
470	0,226 19	0,095 69	1,487 18	0,238 99	0,086 53	1,550 05	0,253 03	0,077 64	1,615 58
475	0,168 99	0,116 19	1,221 46	0,181 06	0,106 00	1,284 55	0,194 69	0,095 95	1,350 89
480	0,111 56	0,138 35	0,944 34	0,121 31	0,127 11	1,000 42	0,132 81	0,115 89	1,059 82
485	0,064 80	0,162 90	0,716 63	0,071 70	0,150 62	0,764 14	0,080 50	0,138 19	0,814 81
490	0,028 11	0,190 90	0,532 23	0,031 79	0,177 47	0,570 76	0,037 51	0,163 72	0,612 08
495	0,002 66	0,232 61	0,410 40	0,003 02	0,217 44	0,442 63	0,005 62	0,201 69	0,477 38
500	-0,015 34	0,288 35	0,318 81	-0,018 86	0,270 79	0,345 53	-0,019 87	0,252 34	0,374 49
505	-0,030 19	0,360 10	0,234 81	-0,038 51	0,340 03	0,255 94	-0,044 06	0,318 60	0,278 97
510	-0,036 80	0,446 75	0,163 90	-0,050 89	0,424 50	0,179 82	-0,061 98	0,400 26	0,197 28
515	-0,028 68	0,543 09	0,117 71	-0,049 06	0,519 29	0,129 99	-0,066 30	0,492 72	0,143 54
520	-0,010 91	0,637 48	0,081 51	-0,037 44	0,612 40	0,090 45	-0,060 82	0,583 78	0,100 37
525	0,020 59	0,715 65	0,054 94	-0,011 38	0,690 70	0,061 27	-0,040 41	0,661 49	0,068 32
530	0,062 60	0,783 50	0,036 25	0,025 89	0,759 70	0,040 62	-0,008 30	0,730 97	0,045 52
535	0,111 31	0,838 67	0,023 58	0,070 77	0,816 33	0,026 53	0,032 26	0,788 47	0,029 85
540	0,172 38	0,895 13	0,015 05	0,128 32	0,875 32	0,017 01	0,085 60	0,849 37	0,019 24
545	0,239 49	0,933 64	0,009 51	0,193 33	0,917 20	0,010 81	0,147 66	0,894 13	0,012 28
550	0,309 75	0,954 33	0,005 97	0,263 00	0,941 85	0,006 82	0,215 78	0,922 38	0,007 78
555	0,391 41	0,978 13	0,003 72	0,344 61	0,969 76	0,004 27	0,296 28	0,954 07	0,004 90
560	0,482 97	0,986 76	0,002 32	0,437 33	0,981 94	0,002 67	0,389 07	0,969 63	0,003 08
565	0,581 87	0,994 04	0,001 45	0,538 71	0,993 63	0,001 68	0,491 69	0,985 58	0,001 94
570	0,692 25	0,990 47	0,000 91	0,653 22	0,994 43	0,001 06	0,609 02	0,990 74	0,001 23
575	0,800 99	0,972 23	0,000 57	0,767 88	0,980 39	0,000 67	0,728 35	0,981 02	0,000 78
580	0,904 33	0,937 16	0,000 36	0,878 94	0,949 09	0,000 43	0,846 01	0,953 78	0,000 50
585	1,016 25	0,907 47	0,000 23	0,998 82	0,922 18	0,000 27	0,972 78	0,929 92	0,000 32
590	1,101 08	0,867 05	0,000 15	1,092 30	0,884 16	0,000 18	1,074 16	0,894 68	0,000 21
595	1,161 43	0,814 66	0,000 10	1,161 72	0,833 56	0,000 12	1,152 19	0,846 33	0,000 14
600	1,188 21	0,751 31	0,000 06	1,195 44	0,770 13	0,000 08	1,192 78	0,783 33	0,000 09
605	1,191 84	0,686 53	0,000 04	1,206 30	0,705 56	0,000 05	1,211 01	0,719 53	0,000 06
610	1,153 45	0,615 01	0,000 03	1,172 74	0,633 24	0,000 03	1,182 75	0,646 96	0,000 04
615	1,084 70	0,542 55	0,000 02	1,107 31	0,559 70	0,000 02	1,121 35	0,572 93	0,000 03
620	0,992 89	0,470 50	0,000 00	1,016 53	0,485 94	0,000 00	1,032 46	0,498 01	0,000 00
625	0,890 42	0,403 03	0,000 00	0,914 04	0,416 76	0,000 00	0,930 87	0,427 62	0,000 00
630	0,765 10	0,335 09	0,000 00	0,787 88	0,347 25	0,000 00	0,804 93	0,357 06	0,000 00

Age group	67			72			77		
Wavelength (nm)	$\bar{x}'_{10}$	$\bar{y}'_{10}$	$\bar{z}'_{10}$	$\bar{x}'_{11}$	$\bar{y}'_{11}$	$\bar{z}'_{11}$	$\bar{x}'_{12}$	$\bar{y}'_{12}$	$\bar{z}'_{12}$
635	0,641 71	0,273 55	0,000 00	0,662 80	0,284 09	0,000 00	0,679 20	0,292 75	0,000 00
640	0,532 21	0,221 44	0,000 00	0,551 32	0,230 48	0,000 00	0,566 63	0,238 03	0,000 00
645	0,434 13	0,176 68	0,000 00	0,450 29	0,184 00	0,000 00	0,463 37	0,190 14	0,000 00
650	0,339 50	0,136 52	0,000 00	0,352 50	0,142 28	0,000 00	0,363 12	0,147 13	0,000 00
655	0,259 44	0,103 24	0,000 00	0,269 87	0,107 75	0,000 00	0,278 52	0,111 59	0,000 00
660	0,195 12	0,076 87	0,000 00	0,203 17	0,080 28	0,000 00	0,209 89	0,083 20	0,000 00
665	0,144 45	0,056 44	0,000 00	0,150 43	0,058 95	0,000 00	0,155 43	0,061 09	0,000 00
670	0,105 46	0,041 00	0,000 00	0,109 84	0,042 82	0,000 00	0,113 50	0,044 37	0,000 00
675	0,075 93	0,029 42	0,000 00	0,079 08	0,030 72	0,000 00	0,081 72	0,031 83	0,000 00
680	0,053 87	0,020 82	0,000 00	0,056 11	0,021 74	0,000 00	0,057 99	0,022 53	0,000 00
685	0,037 65	0,014 53	0,000 00	0,039 22	0,015 17	0,000 00	0,040 53	0,015 72	0,000 00
690	0,025 88	0,009 97	0,000 00	0,026 95	0,010 42	0,000 00	0,027 86	0,010 79	0,000 00
695	0,018 02	0,006 94	0,000 00	0,018 77	0,007 25	0,000 00	0,019 40	0,007 51	0,000 00
700	0,012 55	0,004 83	0,000 00	0,013 07	0,005 05	0,000 00	0,013 51	0,005 23	0,000 00
705	0,008 70	0,003 35	0,000 00	0,009 07	0,003 50	0,000 00	0,009 37	0,003 63	0,000 00
710	0,005 96	0,002 30	0,000 00	0,006 21	0,002 40	0,000 00	0,006 42	0,002 49	0,000 00
715	0,004 08	0,001 57	0,000 00	0,004 25	0,001 64	0,000 00	0,004 40	0,001 70	0,000 00
720	0,002 82	0,001 09	0,000 00	0,002 94	0,001 14	0,000 00	0,003 04	0,001 18	0,000 00
725	0,001 95	0,000 75	0,000 00	0,002 03	0,000 79	0,000 00	0,002 10	0,000 82	0,000 00
730	0,001 36	0,000 53	0,000 00	0,001 41	0,000 55	0,000 00	0,001 46	0,000 57	0,000 00
735	0,000 95	0,000 37	0,000 00	0,000 99	0,000 38	0,000 00	0,001 02	0,000 40	0,000 00
740	0,000 66	0,000 26	0,000 00	0,000 69	0,000 27	0,000 00	0,000 71	0,000 28	0,000 00
745	0,000 46	0,000 18	0,000 00	0,000 48	0,000 19	0,000 00	0,000 50	0,000 20	0,000 00
750	0,000 33	0,000 13	0,000 00	0,000 34	0,000 13	0,000 00	0,000 35	0,000 14	0,000 00
755	0,000 23	0,000 09	0,000 00	0,000 24	0,000 09	0,000 00	0,000 25	0,000 10	0,000 00
760	0,000 16	0,000 06	0,000 00	0,000 17	0,000 07	0,000 00	0,000 18	0,000 07	0,000 00
765	0,000 12	0,000 05	0,000 00	0,000 12	0,000 05	0,000 00	0,000 13	0,000 05	0,000 00
770	0,000 08	0,000 03	0,000 00	0,000 09	0,000 03	0,000 00	0,000 09	0,000 04	0,000 00
775	0,000 06	0,000 02	0,000 00	0,000 06	0,000 03	0,000 00	0,000 07	0,000 03	0,000 00
780	0,000 04	0,000 02	0,000 00	0,000 05	0,000 02	0,000 00	0,000 05	0,000 02	0,000 00

Annex B (informative)

XYZ values of reference colour

Table B.1 shows the XYZ data converted from the SPDs data of seven reference colours under CIE D65 illuminant with CIE 1931 standard colorimetric observer. [5]

Table B.1 – Reference XYZ values using CIE 1931 standard colorimetric observer

		X	Y	Z
Reference white		0,950 4	1,000 0	1,088 5
Reference colour	Macbeth white	0,841 3	0,887 3	0,953 6
	Macbeth red	0,202 0	0,118 5	0,052 0
	Macbeth green	0,145 1	0,235 5	0,095 4
	Macbeth blue	0,084 0	0,062 4	0,299 3
	Macbeth cyan	0,144 9	0,198 8	0,395 1
	Macbeth magenta	0,294 4	0,193 0	0,302 6
	Macbeth yellow	0,560 5	0,596 2	0,095 9

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Annex C (informative)

Measurement method of observer metamerism between different displays

C.1 General

Evaluating the colour difference of several observations using a reference colour is an important part of evaluating the performance of a display. However, when it is necessary to evaluate the observer colour difference between different displays, a direct comparison between each display is required. This annex describes the process for evaluating the OMI between different displays.

C.2 Reference colours and measurement method

In order to evaluate the observer-dependent colour properties of two different displays, two displays are defined as DUT A and DUT B. The reference colours are the same as in the main body. The standard set-up condition and measuring condition are also the same as in 6.3. The measurement process is as follows.

- a) Carry out the steps 1) to 2) in 6.3.3.5 with the DUT A to obtain XYZ tristimulus values for each individual observer.
- b) Repeat the process a) with the DUT B.
- c) Calculate the CIE DE2000 ΔE_{00} between the DUT A and the DUT B for each individual observer as described in 6.3.3.5 2).
- d) Repeat the process a) to c) for each reference colour.
- e) Report observer metamerism indices using the reporting form in Table 1.

Annex D (informative)

Colour-matching process for multi-ORU DUTs

If the DUT has more than three ORUs (i.e. multi-ORU DUT such as RGBW, RGBY, etc.), and the multi-ORU rendering algorithm is unknown, calculate the test SPD match as follows.

- a) Perform adjustment of input RGB signals for the DUT until the colour difference between the reference colour and the initial test colour becomes smaller than 1,0 in CIE ΔE_{00} .
- b) Measure the SPD of the initial test colour that was adjusted at step a) and calculate XYZ of the initial test colour.
- c) Select the most three significant ORUs for the DUT. If the ORUs include R, G and B, those are recommended.
- d) Solve the weighting factors of three significant ORUs using following equation.

$$\begin{bmatrix} X'_{r(i,j)} \\ Y'_{r(i,j)} \\ Z'_{r(i,j)} \end{bmatrix} = \begin{bmatrix} X'_{t(i,j),n} \\ Y'_{t(i,j),n} \\ Z'_{t(i,j),n} \end{bmatrix} + \begin{bmatrix} X'_{1(j)} & X'_{2(j)} & X'_{3(j)} \\ Y'_{1(j)} & Y'_{2(j)} & Y'_{3(j)} \\ Z'_{1(j)} & Z'_{2(j)} & Z'_{3(j)} \end{bmatrix} \begin{bmatrix} w_{1(i,j)} \\ w_{2(i,j)} \\ w_{3(i,j)} \end{bmatrix} \quad (\text{D.1})$$

$$\begin{bmatrix} w_{1(i,j)} \\ w_{2(i,j)} \\ w_{3(i,j)} \end{bmatrix} = \begin{bmatrix} X'_{1(j)} & X'_{2(j)} & X'_{3(j)} \\ Y'_{1(j)} & Y'_{2(j)} & Y'_{3(j)} \\ Z'_{1(j)} & Z'_{2(j)} & Z'_{3(j)} \end{bmatrix}^{-1} \begin{bmatrix} X'_{r(i,j)} - X'_{t(i,j),n} \\ Y'_{r(i,j)} - Y'_{t(i,j),n} \\ Z'_{r(i,j)} - Z'_{t(i,j),n} \end{bmatrix} \quad (\text{D.2})$$

where

$X'_{t(i,j),n}$, $Y'_{t(i,j),n}$ and $Z'_{t(i,j),n}$ denote the XYZ values of the initial test colour measured in step b);

$X'_{q(j)}$, $Y'_{q(j)}$ and $Z'_{q(j)}$ are the XYZ values ($q = 1, 2$ and 3 which denote three significant ORUs) calculated in step b), which are of i^{th} reference colour using individual CMFs of j^{th} individual observer;

$w_{q(i,j)}$ is weighting factor calculated from step d), and q also has 1, 2 and 3 for the three significant ORUs.

- e) The final test spectral distribution can be obtained as below.

$$\Phi_{t(i,j)}(\lambda) = \Phi_{t(i,j),n}(\lambda) + \begin{bmatrix} w_{1(i,j)} & w_{2(i,j)} & w_{3(i,j)} \end{bmatrix} \cdot \begin{bmatrix} \Phi_1(\lambda) & \Phi_2(\lambda) & \Phi_3(\lambda) \end{bmatrix}^T \quad (\text{D.3})$$

where

$\Phi_{t(i,j),n}(\lambda)$ is the SPD of the initial test colour measured in step b);

$\Phi_q(\lambda)$ is the SPD of the significant ORU ($q = 1, 2$ and 3).

NOTE 1 This method can be applied when testers are able to measure the independent SPD of single ORU. If testers are not able to radiate and measure SPD of single ORU, this method cannot be applied.

NOTE 2 Out-of-gamut chromaticity can be judged by representing them on the CIE 1931 xy chromaticity diagram. Then exclude and report any reference colour patch illuminated by D65 that is outside the DUT chromaticity gamut boundary.

NOTE 3 It is recommended the luminance is set with an input signal that is 1,2 times higher than the luminance of the match target. After that, the R, G and B input signals are finely adjusted to perform colour matching.

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Annex E (informative)

Working example of observer metamerism index

E.1 Purpose

This annex aims to provide a working example regarding the measurement and calculation process in 6.3.

E.2 DUT

For this annex, an arbitrarily generated display with optical characteristics as shown in Table E.1 below was used. The optical characteristics and R, G, B, W spectra of the display are shown in the Table E.1, Figure E.1 and Table E.6. For convenience of explanation, the used DUT satisfies the additivity law and the gamma was set to 2,2.

Table E.1 – Optical properties of the DUT

	X	Y	Z	x	y
White	190,08	200.00	217.89	0.3126	0.3290
Red	99,31	46.63	0.03	0.6803	0.3195
Green	53,71	140.52	8.92	0.2644	0.6917
Blue	37,05	12.85	208.95	0.1431	0.0496
Gamma	2,2				

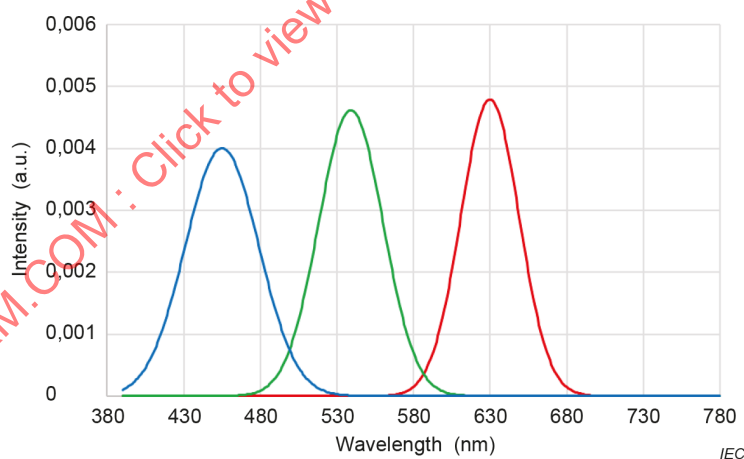


Figure E.1 – RGB primary spectrum of the DUT

E.3 Process

E.3.1 General

If the DUT satisfies colour additivity, the SPD of the colour-matched DUT should be obtained by calculating the weighting factors of primary colours SPDs as explained in 6.3.

E.3.2 Colour-matching

E.3.2.1 General

In the colour matching stage, the goal is to make the colour difference between the reference colour and the test pattern displayed on the DUT as small as possible.

E.3.2.2 Reference colour XYZ

Calculate the XYZ value of each reference colour and each individual CMFs using Equation (1). In the case of the Macbeth white colour (Table B.1) under D65 illuminant and age group 22's individual CMFs (Table A.3), the result of XYZ is (178,06, 188,95, 196,77). Other XYZ values of the reference colour are listed in Table E.2.

Table E.2 – Reference colour XYZ values of age group 22 individual CMFs

Reference colour	X	Y	Z
Macbeth white	178,06	188,95	196,77
Macbeth red	42,39	25,43	10,88
Macbeth green	31,26	48,92	18,55
Macbeth blue	17,05	14,45	61,83
Macbeth cyan	30,13	43,33	79,63
Macbeth magenta	61,91	42,14	65,38
Macbeth yellow	119,69	124,23	17,85

E.3.2.3 Calculating R, G and B weighting factors

Calculate the R, G and B weighting factors of the DUT to match the reference colour and the DUT colour as described in 6.3.3. The R, G and B weighting factors of the matched colour (age group 22) are listed in Table E.3. Refer to the below Table E.7 for the results of the other age groups.

Table E.3 – R, G and B weighting factors of the matched colours (age group 22)

Reference colour	Weighting factor		
	R	G	B
Macbeth white	0,888 9	0,891 4	0,895 6
Macbeth red	0,363 6	0,042 8	0,049 7
Macbeth green	0,103 7	0,295 3	0,078 3
Macbeth blue	0,036 0	0,051 1	0,288 0
Macbeth cyan	0,022 5	0,247 8	0,365 7
Macbeth magenta	0,429 3	0,103 7	0,303 1
Macbeth yellow	0,789 4	0,580 8	0,066 9

E.3.3 Calculating the SPD of the DUT

Calculate the SPD of the test colour which was colour matched in process 2).

E.3.4 XYZ computation

Calculate the XYZ values of the matched colour, Macbeth white of DUT using CIE 1931 standard colorimetric observer as shown in Equation (10).

E.3.5 Colour difference computation

Calculate the CIE DE2000 ΔE_{00} between the reference colour and the DUT according to Equations (15) to (35). Reference XYZ data using CIE 1931 standard colorimetric observer are in Table B.1. The OMI calculation result of all 7 reference colours and age groups are listed in Table E.4.

Table E.4 – OMI calculation result of all 7 colours and age groups

Age group	Observer metamerism index						
	Macbeth white	Macbeth red	Macbeth green	Macbeth blue	Macbeth cyan	Macbeth magenta	Macbeth yellow
22	1,22	0,48	0,13	0,12	1,16	1,17	0,04
27	1,02	0,43	0,13	0,12	0,95	1,05	0,15
32	0,87	0,39	0,13	0,11	0,74	0,93	0,27
37	0,78	0,35	0,12	0,11	0,55	0,81	0,39
42	0,77	0,31	0,12	0,10	0,42	0,71	0,51
47	0,83	0,27	0,12	0,10	0,41	0,60	0,63
52	0,94	0,24	0,13	0,11	0,52	0,50	0,76
57	1,09	0,21	0,13	0,11	0,70	0,41	0,88
62	1,40	0,16	0,15	0,12	1,12	0,25	1,12
67	1,97	0,09	0,21	0,15	1,89	0,19	1,55
72	2,52	0,04	0,29	0,18	2,68	0,39	1,97
77	3,06	0,03	0,39	0,22	3,47	0,61	2,41

E.3.6 Reporting

Report maximum, minimum, average and standard deviation of OMI values for each reference colour (see Table E.5), and present a pair of graphs showing the spectral plots of metameric pairs of reference colour and DUT colour (see Figure E.2). Here, one metameric pair of Macbeth white is given as an example.

Table E.5 – Reporting of OMI results

Reference colour	Observer metamerism index			
	Maximum	Minimum	Average	Standard deviation
Macbeth white	3,06	0,77	1,17	0,61
Macbeth red	0,48	0,03	0,29	0,13
Macbeth green	0,39	0,12	0,15	0,07
Macbeth blue	0,22	0,10	0,12	0,03
Macbeth cyan	3,47	0,41	0,99	0,79
Macbeth magenta	1,17	0,19	0,72	0,27
Macbeth yellow	2,41	0,04	0,68	0,62
Total	3,47	0,03	0,59	0,60

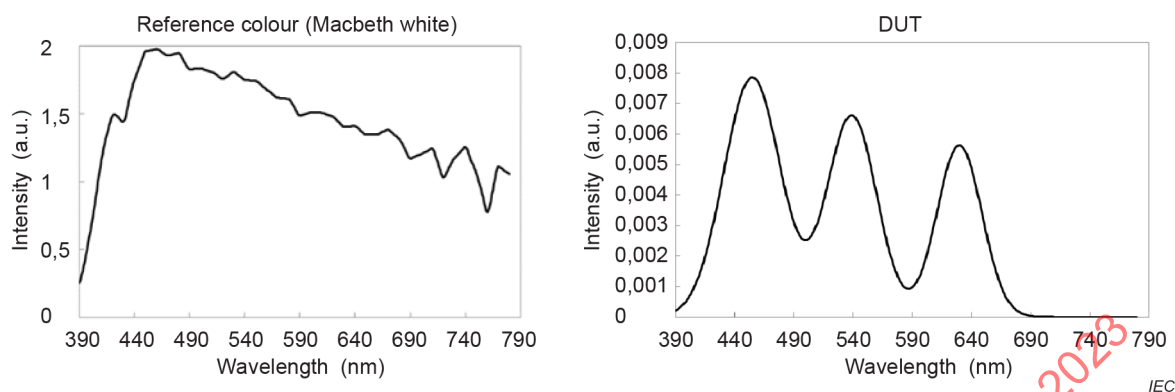


Figure E.2 – Example of graphs of colour-matched metameric pair of reference colour (Macbeth white) and test colour of the DUT

Table E.6 – R, G, B, W spectra of the DUT

Wavelength (nm)	Red	Green	Blue	White
390	0	0	0,000 101	0,000 101
391	0	0	0,000 114	0,000 114
392	0	0	0,000 128	0,000 128
393	0	0	0,000 142	0,000 142
394	0	0	0,000 16	0,000 16
395	0	0	0,000 178	0,000 178
396	0	0	0,000 196	0,000 196
397	0	0	0,000 215	0,000 215
398	0	0	0,000 238	0,000 238
399	0	0	0,000 265	0,000 265
400	0	0	0,000 288	0,000 288
401	0	0	0,000 32	0,000 32
402	0	0	0,000 352	0,000 352
403	0	0	0,000 384	0,000 384
404	0	0	0,000 42	0,000 42
405	0	0	0,000 457	0,000 457
406	0	0	0,000 498	0,000 498
407	0	0	0,000 544	0,000 544
408	0	0	0,000 589	0,000 589
409	0	0	0,000 64	0,000 64
410	0	0	0,000 69	0,000 69
411	0	0	0,000 745	0,000 745
412	0	0	0,000 804	0,000 804
413	0	0	0,000 868	0,000 868
414	0	0	0,000 932	0,000 932
415	0	0	0,001 001	0,001 001
416	0	0	0,001 069	0,001 069
417	0	0	0,001 142	0,001 142

Wavelength (nm)	Red	Green	Blue	White
418	0	0	0,001 22	0,001 22
419	0	0	0,001 302	0,001 302
420	0	0	0,001 384	0,001 384
421	0	0	0,001 467	0,001 467
422	0	0	0,001 558	0,001 558
423	0	0	0,001 645	0,001 645
424	0	0	0,001 741	0,001 741
425	0	0	0,001 832	0,001 832
426	0	0	0,001 933	0,001 933
427	0	0	0,002 029	0,002 029
428	0	0	0,002 129	0,002 129
429	0	0	0,002 23	0,002 23
430	0	0	0,002 33	0,002 33
431	0	0	0,002 431	0,002 431
432	0	0	0,002 531	0,002 531
433	0	0	0,002 632	0,002 632
434	0	0	0,002 732	0,002 732
435	0	0	0,002 833	0,002 833
436	0	0	0,002 929	0,002 929
437	0	0	0,003 025	0,003 025
438	0	0	0,003 116	0,003 116
439	0	0	0,003 207	0,003 207
440	0	0	0,003 294	0,003 294
441	0	0	0,003 381	0,003 381
442	0	0	0,003 459	0,003 459
443	0	0	0,003 536	0,003 536
444	0	0	0,003 605	0,003 605
445	0	0	0,003 673	0,003 673
446	0	0	0,003 733	0,003 733
447	0	0	0,003 788	0,003 788
448	0	0	0,003 838	0,003 838
449	0	0	0,003 883	0,003 883
450	0	0	0,003 92	0,003 92
451	0	0	0,003 952	0,003 952
452	0	0	0,003 975	0,003 975
453	0	0	0,003 993	0,003 993
454	0	0	0,004 002	0,004 002
455	0	0	0,004 007	0,004 007
456	0	0	0,004 002	0,004 002
457	0	0	0,003 993	0,003 993
458	0	0	0,003 975	0,003 975
459	0	0,000 006	0,003 952	0,003 958
460	0	0,000 006	0,003 92	0,003 926

Wavelength (nm)	Red	Green	Blue	White
461	0	0,000 006	0,003 883	0,003 89
462	0	0,000 006	0,003 838	0,003 844
463	0	0,000 006	0,003 788	0,003 794
464	0	0,000 006	0,003 733	0,003 739
465	0	0,000 006	0,003 673	0,003 68
466	0	0,000 012	0,003 605	0,003 617
467	0	0,000 012	0,003 536	0,003 549
468	0	0,000 012	0,003 459	0,003 471
469	0	0,000 019	0,003 381	0,003 4
470	0	0,000 019	0,003 294	0,003 313
471	0	0,000 025	0,003 207	0,003 232
472	0	0,000 025	0,003 116	0,003 141
473	0	0,000 031	0,003 025	0,003 056
474	0	0,000 037	0,002 929	0,002 966
475	0	0,000 044	0,002 833	0,002 876
476	0	0,000 05	0,002 732	0,002 782
477	0	0,000 056	0,002 632	0,002 688
478	0	0,000 069	0,002 531	0,002 6
479	0	0,000 075	0,002 431	0,002 506
480	0	0,000 087	0,002 33	0,002 417
481	0	0,000 1	0,002 23	0,002 329
482	0	0,000 112	0,002 129	0,002 241
483	0	0,000 131	0,002 029	0,002 16
484	0	0,000 15	0,001 933	0,002 082
485	0	0,000 169	0,001 832	0,002 001
486	0	0,000 187	0,001 741	0,001 928
487	0	0,000 212	0,001 645	0,001 857
488	0	0,000 237	0,001 558	0,001 795
489	0	0,000 268	0,001 467	0,001 735
490	0	0,000 3	0,001 384	0,001 684
491	0	0,000 337	0,001 302	0,001 639
492	0	0,000 375	0,001 22	0,001 594
493	0	0,000 412	0,001 142	0,001 554
494	0	0,000 462	0,001 069	0,001 531
495	0	0,000 512	0,001 001	0,001 513
496	0	0,000 562	0,000 932	0,001 494
497	0	0,000 618	0,000 868	0,001 486
498	0	0,000 681	0,000 804	0,001 485
499	0	0,000 749	0,000 745	0,001 494
500	0	0,000 818	0,000 69	0,001 508
501	0	0,000 893	0,000 64	0,001 532
502	0	0,000 968	0,000 589	0,001 557
503	0	0,001 055	0,000 544	0,001 599

Wavelength (nm)	Red	Green	Blue	White
504	0	0,001 143	0,000 498	0,001 641
505	0	0,001 236	0,000 457	0,001 693
506	0	0,001 336	0,000 42	0,001 756
507	0	0,001 436	0,000 384	0,001 82
508	0	0,001 542	0,000 352	0,001 894
509	0	0,001 655	0,000 32	0,001 974
510	0	0,001 767	0,000 288	0,002 055
511	0	0,001 886	0,000 265	0,002 151
512	0	0,002 01	0,000 238	0,002 248
513	0	0,002 135	0,000 215	0,002 35
514	0	0,002 26	0,000 196	0,002 457
515	0	0,002 391	0,000 178	0,002 569
516	0	0,002 522	0,000 16	0,002 682
517	0	0,002 653	0,000 142	0,002 795
518	0	0,002 791	0,000 128	0,002 919
519	0	0,002 922	0,000 114	0,003 036
520	0	0,003 053	0,000 101	0,003 154
521	0	0,003 184	0,000 091	0,003 276
522	0	0,003 315	0,000 082	0,003 398
523	0	0,003 446	0,000 073	0,003 52
524	0	0,003 565	0,000 064	0,003 629
525	0	0,003 69	0,000 055	0,003 745
526	0	0,003 802	0,000 05	0,003 853
527	0	0,003 915	0,000 046	0,003 96
528	0	0,004 021	0,000 041	0,004 062
529	0	0,004 114	0,000 037	0,004 151
530	0	0,004 208	0,000 032	0,004 24
531	0	0,004 289	0,000 027	0,004 317
532	0	0,004 364	0,000 023	0,004 387
533	0	0,004 427	0,000 018	0,004 445
534	0	0,004 489	0,000 018	0,004 507
535	0	0,004 533	0,000 014	0,004 547
536	0	0,004 57	0,000 014	0,004 584
537	0	0,004 595	0,000 014	0,004 609
538	0	0,004 614	0,000 009	0,004 623
539	0	0,004 62	0,000 009	0,004 629
540	0	0,004 614	0,000 009	0,004 623
541	0	0,004 601	0,000 005	0,004 606
542	0	0,004 577	0,000 005	0,004 581
543	0	0,004 539	0,000 005	0,004 544
544	0	0,004 495	0,000 005	0,004 5
545	0	0,004 439	0,000 005	0,004 444
546	0	0,004 377	0,000 005	0,004 381