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METHOD FOR THE ASSESSMENT OF THE COLORIMETRIC PROPERTIES OF LUMINAIRES

THE TELEVISION LIGHTING CONSISTENCY INDEX (TLCI-2012) AND THE TELEVISION LUMINAIRE MATCHING FACTOR (TLMF-2013)

Source: FTV-LED

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Introduction

This document describes the measurement procedure for assessing the colorimetric quality of lighting when used in television production.

The method is intended to improve upon the Colour Rendering Index (CRI) for use in television production. The CRI was never intended for use in the television industry; it has limitations which makes it inappropriate for television use.

1. Principle of the TLCI-12 and TLMF-2013

Rather than assess the performance of a luminaire directly, as is done in the Colour Rendering Index, the TLCI and TLMF mimic a complete television camera and display, using only those specific features of cameras and displays which affect colour performance.

This is realised in practice using software rather than real television hardware. The only hardware that is required is a spectroradiometer to measure the spectral power distribution of the test luminaire and a computer on which to run the software analysis program to perform the calculations.

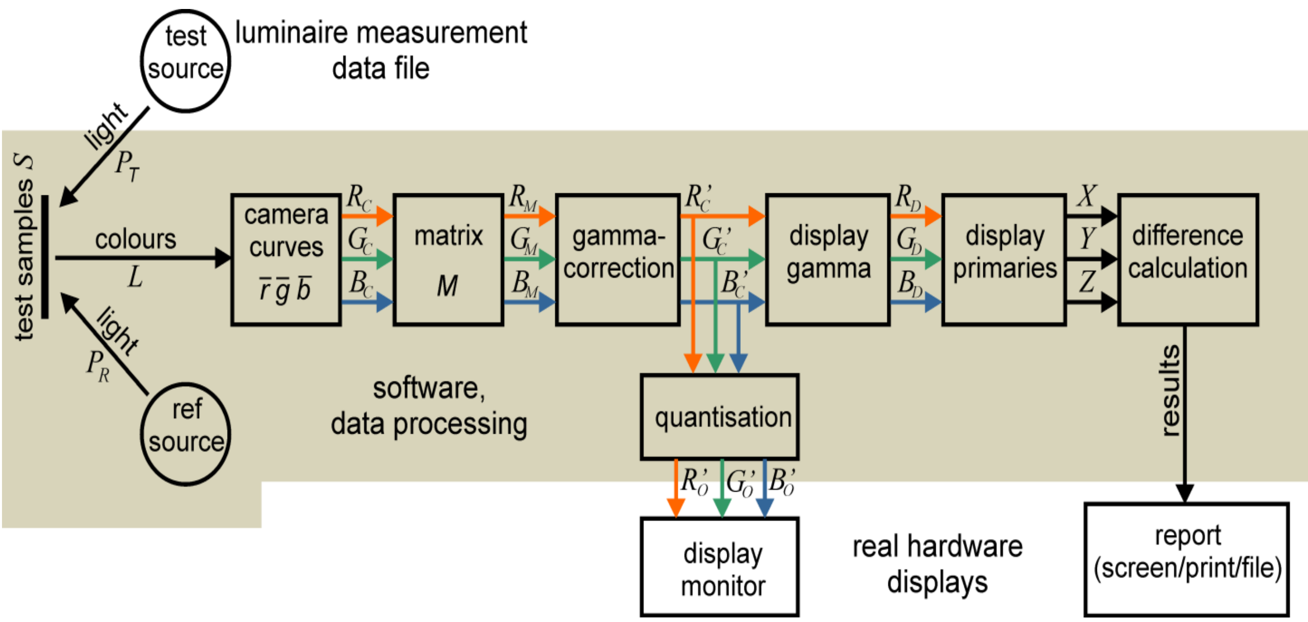


Figure 1: TLCI and TLMF process diagram

A mathematically-specified set of reflective colour samples is lit by either the Test luminaire or a Reference luminaire. The notional camera produces linear R_C G_C B_C signals which are then modified by a conventional 3 x 3 matrix followed by gamma-correction to compensate for the non-linear nature of the standard display. The display has a standard electro-optic gamma function and defined primaries. The output of the display is analysed using standard colorimetric processes to measure the differences between the performance of the Test and Reference luminaire for each colour sample, before producing a single result value *(Q)* from all the test samples.

At the output of the notional camera, non-linear R_C' G_C' B_C' signals are available which can drive a real display, either computer screen or television display. If this output is fed to a standard television display then the actual performance of the luminaires can be seen directly. Note that there is no transmission coding involved, since that should not affect colour rendering. Neither are any of the signals to be quantised except for this monitoring output, all mathematics should be performed in floating point arithmetic, and no values should be unnecessarily truncated or rounded[1].

The TLCI and TLMF are both calculated in exactly the same way, except that for the TLCI the Reference source is theoretical, a calculated spectral power distribution, whereas for the TLMF the Reference source can be a measurement of a real luminaire. Thus the TLCI calculates the performance of a single luminaire, while the TLMF calculates the effect of using mixed lighting.

1.1 Reference luminaire (TLCI only)

The Reference luminaire is specified to be one whose chromaticity falls on either the Planckian or Daylight locus and having a colour temperature which is that of the Correlated Colour Temperature (CCT) of the Test luminaire. This greatly simplifies calculations, since it forces the choice of Reference luminaire to be one whose spectral power distribution can be calculated using already-standardised procedures.

1.1.1 Calculation of Correlated Colour Temperature

After measuring the spectral power distribution of the Test luminaire ($P_{T,\lambda}$), the chromaticity coordinates must be found. This is a standard colorimetric calculation. $P_{T,\lambda}$ must be convolved with the CIE 1931 standard observer colour-matching functions $\overline{x_\lambda}$, $\overline{y_\lambda}$ and $\overline{z_\lambda}$, these functions are tabulated in Appendix 1. The result of convolution is integrated across the range of visible wavelengths to produce tristimulus values *(X, Y, Z)*, thus:

$$X_T = \sum_{\lambda=380}^{760} P_{T,\lambda}\overline{x_\lambda}\,,\; Y_T = \sum_{\lambda=380}^{760} P_{T,\lambda}\overline{y_\lambda} \text{ and } Z_T = \sum_{\lambda=380}^{760} P_{T,\lambda}\overline{z_\lambda} \qquad [1]$$

… although the summation should, ideally, be a continuous integration, but provided the data values are taken at not more than 5 nm intervals, this sampled alternative is perfectly acceptable. Then the CIE 1931 chromaticity coordinates are derived:

$$x = X/(X+Y+Z),\; y = Y/(X+Y+Z) \text{ and } z = Z/(X+Y+Z) \qquad [2]$$

… although z is not needed since $x+y+z=1$. But chromaticity coordinates are needed in CIE 1960 values:

$$u = 2x/(6y - x + 1.5) \text{ and } v = 3y/(6y - x + 1.5) \qquad [3]$$

Now, the CCT can be established. It is formally defined as the Colour Temperature on the Planckian

[1] The TLCI was first proposed and developed by W.N.Sproson and E.W.Taylor of BBC Research Department, from 1971 to 1988. The current TLCI-2012 is a logical extension and improvement of that work, expanded and updated, which was the subject of a paper at IBC 2011 and 2012.

locus (the locus of chromaticities of black body radiators at various temperatures) when expressed in CIE 1960 values, which most closely matches the test colour. Mathematically, this can be derived by calculating the colour on the locus which is closest in chromaticity values.

Although there is a simple way of doing this, using the 'McCamy equation', it is not sufficiently accurate for our purposes.

To ease the magnitude of the calculation, use pre-calculated values for the Planckian locus and the locus of the Daylight radiation. The values tabulated in Appendix 2 give such data at close intervals and to high precision. The calculation process is straightforward, simply scanning through the data values and calculating the angle from the chromaticity of the test colour to the locus, to find the colour temperature at which the angle is precisely ±90°.

To accomplish this, the data is scanned until the magnitudes of the angles from the test colour to two adjacent points on the locus are both less than 90°, and then the normal intersection is calculated using trigonometry.

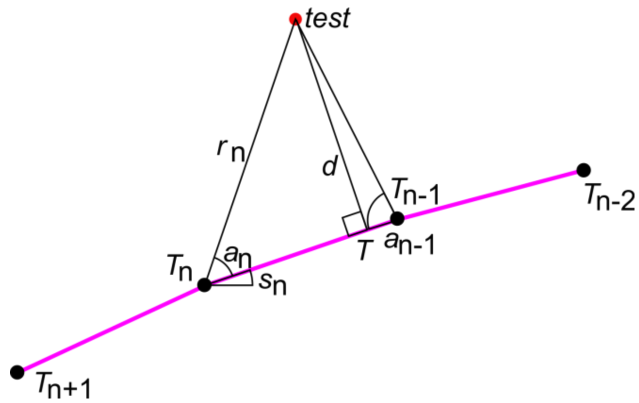


Figure 2: CCT calculation

At each point, n, the slope of the locus is calculated:

$$s_n = tan^{-1}\left(\frac{v_{n-1}-v_n}{u_{n-1}-u_n}\right) \quad [4]$$

… and the distance, r_n, between the test colour and the data point is:

$$r_n = \sqrt{(u_{test} - u_n)^2 + (v_{test} - y_n)^2} \quad [5]$$

…then the angle between the test colour and the horizontal is calculated:

$$a = tan^{-1}\left(\frac{v_{test}-v_n}{u_{test}-u_n}\right) \quad [6]$$

… from which the angle between the test colour and the CCT line is:

$$a_n = a - s_n \quad [7]$$

Care must be taken to ensure that the angles all lie between 0° and 360°. A match is defined as the pair of data points for which the angles a_n and a_{n-1} are both less (in magnitude) than 90°. At each point, the angle a_{n-1} is derived from the calculation for the previous point by subtracting it from 180°. However, this angle a_{n-1} is not needed in the further calculations; it is used only in the search for the nearest pair of data points.

If the test colour lies to the other side of the locus, then both internal angles will be negative.

The CCT, and its chromaticity coordinates, are found by trigonometry.

$$d_{uv} = \sqrt{(u_{test} - u_T)^2 + (v_{test} - v_T)^2} \quad [8]$$

The distance *d* is an indicator of the quality of the colour match; it is generally supposed that a value of 0.0054 is a 'just noticeable difference', and that this is a practical limit to the viability of the CCT, therefore *d* is normalised to this value.

If the Test colour lies towards the green side of the locus, the sign of *d* is reversed. This can be easily established, since u_T must be less than u_L.

1.1.2 Derivation of the power distribution of the Reference luminaire (TLCI only)

If the CCT is less than 3400 K, then a Planckian radiator is assumed.

If the CCT is greater than 5000 K, then a Daylight radiator is assumed.

If the CCT lies between 3400 K and 5000 K, then a mixed illuminant is assumed, being a linear interpolation between Planckian at 3400 K and Daylight at 5000 K.

Therefore, it is necessary to calculate spectral power distributions for both Planckian and Daylight radiators. The mathematics for both operations is defined in CIE Tech 15:2004.

1.1.2.1 Planckian radiation

This can be calculated directly from a simplified version of Planck's radiation law:

$$P_\lambda = 100\left(\frac{560}{\lambda}\right)^5 \frac{\exp\left(\frac{1.435\times10^7}{560T}\right)-1}{\exp\left(\frac{1.435\times10^7}{\lambda T}\right)-1} \qquad [9]$$

… where λ is the wavelength in nanometres (nm), and T the required Colour Temperature in kelvin. The values are normalised such that the value at 560 nm is 100.

1.1.2.2 Daylight radiation

This is calculated indirectly using values tabulated in Appendix 3. The formula is given in CIE Tech 15.2004. First, calculate the CIE 1931 chromaticity coordinates for the Correlated Colour Temperature T:

$$\text{For } T < 7000K,\ x_D = -4.6070\left(\frac{10^3}{T}\right)^3 + 2.9678\left(\frac{10^3}{T}\right)^2 + 0.09911\left(\frac{10^3}{T}\right) + 0.244063 \qquad [10]$$

$$\text{For } T \geq 7000K,\ x_D = -2.0064\left(\frac{10^3}{T}\right)^3 + 1.9018\left(\frac{10^3}{T}\right)^2 + 0.24748\left(\frac{10^3}{T}\right) + 0.237040 \qquad [11]$$

$$y_D = -3.000{x_D}^2 + 2.870x_D - 0.275 \qquad [12]$$

Then the spectral power distribution is given by:

$$D_\lambda = S_{0\lambda} + M_1 S_{1\lambda} + M_2 S_{2\lambda} \qquad [13]$$

… where S_0, S_1 and S_2 are tabulated spectral power distributions representing the major components of sunlight, specified in CIE Tech 15:2004 Appendix C, and tabulated here in Appendix 3. The values M_1 and M_2 are derived from the chromaticity coordinates:

$$M_1 = \frac{-1.77861 x_D + 5.90757 y_D - 1.34674}{0.25539 x_D - 0.73217 y_D + 0.02387} \text{ and } M_2 = \frac{-31.44464 x_D + 30.06400 y_D + 0.03638}{0.25539 x_D - 0.73217 y_D + 0.02387} \quad [14]$$

The resultant spectral distribution will be normalised such that the value at 560 nm is 100.

Note that if this spectral power distribution curve is processed normally to derive chromaticity coordinates from it, they may not exactly match the original chromaticity values. This is normal, and is the reason why values are tabulated here (Appendix 3) from spectral power distribution calculations.

1.1.2.3 Mixed radiation

When the Test luminaire has a CCT between 3400 K and 5000 K, a mixed Reference luminaire is needed. This is interpolated from a Planckian distribution at 3400 K and a Daylight distribution at 5000 K:

$$M_\lambda = \frac{D_{5000,\lambda}(T - 3400) + P_{3400,\lambda}(5000 - T)}{5000 - 3400} \quad [15]$$

Where $D_{5000,\lambda}$ and $P_{3400,\lambda}$ are the Daylight and Planckian values returned from the calculations at 5000 K and 3400 K respectively.

Under these conditions, the value of *d*, the chromaticity distance of the Test luminaire from its CCT, must be modified, since the Planckian and Daylight loci do not join, but run almost parallel but separated by a distance of about 0.9 in *d* units. However, since the chromaticity line joining $P_{3400,\lambda}$ and $D_{5000,\lambda}$ almost coincides with the Planckian locus up to 4000 K, the distance to the Planckian locus is used up to 4000 K. Between 4000 K and 5000 K however, linear interpolation is used:

$$d + 0.9 \frac{5000 - T}{5000 - 4000} \text{ for } d > 0 \text{, i.e. towards magenta} \quad [16]$$

$$d - 0.9 \frac{T - 4000}{5000 - 4000} \text{ for } d \le 0 \text{, i.e. towards green} \quad [17]$$

1.2 Test samples

Since the analysis is isomeric (using spectral data rather than tristimulus data), the test set must have known reflectivities (distribution of reflectance with wavelength). It is also important that the colour set is recognisable to television and lighting engineers.

Therefore the ColorChecker® was chosen, since it is affordable and readily available as a physical test chart, and it allows for the output of the algorithm to be checked against a real camera and display. It also presents colours with a good distribution of hues and saturations within the colour gamut of television.

Although originally designed as a photographic test chart, it can be used for testing television cameras. It comprises an array of 24 patches in four rows of six with calibration data available for each colour.

One of the colours (cyan, third row right) actually lies outside the colour gamut of television when lit by illuminant D65, but that is not a problem as will be shown in Appendix 4. The reflectivities of the colour patches are derived from earlier work at BBC Research Department for the original TLCI. Reflectivity data tables are given in Appendix 4. To ensure consistency of results, these data tables should be used rather than the results of any other measurements.

Figure 2: ColorChecker® chart

The spectral power distribution data for each luminaire, $P_{T,\lambda}$ and $P_{R,\lambda}$ is convolved with the reflectivity data for each sample, S_λ, in turn, to produce the spectral power distribution, L_λ, of the colour which reaches the camera sensors:

$$L_\lambda = P_\lambda S_\lambda \qquad [18]$$

Where λ is wavelength of light in nanometers (nm). For all spectral data in the TLCI and TLMF mathematics, the range is measured from 380 to 760 nm, the generally accepted range of visible wavelength, and in steps of 5 nm.

1.3 Camera

The camera is specified by three sets of parameters; the responsivity curves, linear matrix, and opto-electronic transfer function or gamma-correction.

1.3.1 Responsivity curves

The original TLCI work of Sproson and Taylor used a set of curves intended to simulate the performance of Plumbicon® tubes, but for this version of the algorithm a new set of data has been derived from modern HDTV cameras, CCD and CMOS. Although the technologies have changed dramatically since 1971, the curves have changed only slightly, nevertheless the new set is specified for use in the TLCI-2012 and TLMF-2013. Responsivity tables are given in Appendix 5. The work behind the development of these tables is reported in EBU Tech 3353.

The signals thus generated by the sensors are:

$$R_C = \sum_{\lambda=380}^{760} P_\lambda S_\lambda \overline{r_\lambda}, \quad G_C = \sum_{\lambda=380}^{760} P_\lambda S_\lambda \overline{g_\lambda} \quad \text{and} \quad B_C = \sum_{\lambda=380}^{760} P_\lambda S_\lambda \overline{b_\lambda} \qquad [19]$$

Where $\overline{r_\lambda}$, $\overline{g_\lambda}$ and $\overline{b_\lambda}$ are the responsivities of the sensors. Strictly, the summation should be a continuous integral of the convolutions, but this sampled approach is more than adequate for these purposes.

For the TLCI, the software must perform normalising and colour balancing operations with each of the luminaires in turn (Test and Reference), such that $R_C = G_C = B_C = 1$ when the colour sample is a neutral colour with equal reflectance at all wavelengths.

For the TLMF, the software must perform this normalising and balancing only for the Reference luminaire, while for the Test luminaire it must perform only normalising such that the camera luma signal level is unity.

Since the set of test samples includes a grey scale, with a white patch of reflectance 90.01%, the reflectance level of this neutral must be set to 0.9 (90%); this will then cause the white patch to generate peak white, which is the normal exposure procedure for television cameras. This exactly mimics normal camera usage, and removes the requirement in the CRI for estimation of the colour adaption process in the human eye.

Note that the patches of the grey scale must not be included in the TLCI-2012 analysis, they are presented merely because they exist and to demonstrate that the act of white-balancing to each luminaire in turn has been done correctly. However, the grey scale patches must be included in TLMF-2013 calculations since differences in colour-balance are highly visible.

1.3.2 Linear matrix, *M*

Since the camera responsivity curves can have only positive values, and the ideal curves for matching to any set of real display primaries must have negative lobes, a matrix is essential. The matrix cannot generate an exact match to the theoretically ideal curves for any given set of display primaries, but is usually optimised on colour performance to an acceptable degree. A matrix is a short-hand way of representing a set of simultaneous equations:

$$\begin{bmatrix} R_M \\ G_M \\ B_M \end{bmatrix} = M \bullet \begin{bmatrix} R_C \\ G_C \\ B_C \end{bmatrix} = \begin{bmatrix} c_{R,R} & c_{G,R} & c_{B,R} \\ c_{R,G} & c_{G,G} & c_{B,G} \\ c_{R,B} & c_{G,B} & c_{B,B} \end{bmatrix} \bullet \begin{bmatrix} R_C \\ G_C \\ B_C \end{bmatrix} \qquad [20]$$

is the same as:

$$R_M = c_{R,R}R_C + c_{G,R}G_C + c_{B,R}B_C \qquad [21]$$

… and so on. Note that the coefficients in each row are forced to sum to unity, to avoid a change in colour balance, and that the usual way to ensure this is to define only the cross-coefficients, deriving those of the main diagonal from them, thus:

$$c_{R,R} = 1 - c_{G,R} - c_{B,R}\ ,\ c_{G,G} = 1 - c_{R,G} - c_{B,G} \text{ and } c_{B,B} = 1 - c_{R,B} - c_{G,B} \qquad [22]$$

For the TLCI-2012 and TLMF-2013, a 3 x 3 matrix has been established which optimises the colour rendering performance of the standard camera when used with a standard HDTV display, to ITU-R.BT-709 parameters. In this instance, the matrix was optimised for best colour performance with the camera and display non-linearities, a different matrix might be needed for a linear system, or possibly for one with different camera gamma-correction. It would be equally possible to optimise a matrix for use with any other set of real display primaries. Values for the matrix terms are given in Appendix 5.

The camera also includes a Saturation control, which is applied after the camera matrix and white –balancing but before the gamma-correction. This is to prevent clipping of some colours when lit by some luminiares. It operates as a secondary matrix:

$$\begin{bmatrix} R_B \\ G_B \\ B_B \end{bmatrix} = \begin{bmatrix} 1-2a & a & a \\ a & 1-2a & a \\ a & a & 1-2a \end{bmatrix} . \begin{bmatrix} R_M \\ G_M \\ B_B \end{bmatrix} \qquad [23]$$

… where a is derived from the saturation level, S, in the range 0 (meaning monochrome) to 100:

$$a = (1 - S/100)/3 \qquad [24]$$

For the TLCI-2012 and TLMF-2013, the saturation level must be 90%, and thus the saturation matrix must be:

$$\begin{bmatrix} R_B \\ G_B \\ B_B \end{bmatrix} = \begin{bmatrix} 0.9\dot{3} & 0.0\dot{3} & 0.0\dot{3} \\ 0.0\dot{3} & 0.9\dot{3} & 0.0\dot{3} \\ 0.0\dot{3} & 0.0\dot{3} & 0.9\dot{3} \end{bmatrix} \cdot \begin{bmatrix} R_M \\ G_M \\ B_M \end{bmatrix} \qquad [25]$$

1.3.3 Opto-electronic transfer characteristic (gamma correction)

For use in the TLCI-2012 and TLMF-2013, only one curve makes sense, that of ITU-R BT.709, although arguably other curves produce subjectively better colour-rendering performance, thus:

$$R_C' = \begin{cases} 4.5R_B, & R_B < 0.018 \\ 1.099R_B^{0.45} . -0.099, & R_B \geq 0.018 \end{cases} \qquad [26]$$

and similarly for G_C' and B_C'. These are the signal values which drive the display.

1.4 Display

The display is defined by only two sets of parameters, the non-linearity or electro-optical transfer function, and the chromaticities of the set of primaries and white balance point.

1.4.1 Electro-optic transfer characteristic (gamma)

Historically, it has been widely assumed that the standard display follows a pure power law, thus:

$$V_D = V_C'^{\gamma} \qquad [27]$$

and that γ takes values of 2.2 for NTSC or 2.8 for PAL. However, neither of those values accurately represents the performance of modern displays, and a value of 2.4 has been specified by the ITU. Therefore, both TLCI-2012 and TLMF-2013 must use a value of 2.4:

$$R_D = R_C'^{2.4},\ G_D = G_C'^{2.4} \text{ and } B_D = B_C'^{2.4} \qquad [28]$$

1.4.2 Display primaries

The display primaries are chosen to be those of ITU-R BT.709 for HDTV systems. The results of using the EBU television primaries (PAL) produce insignificantly small differences, since the BT.709 primary set uses the red and blue of the EBU set, and the green primary is only slightly different from the EBU green. Therefore, the results from this calculation apply equally to HDTV/SDTV.

Table 1: ITU-R BT.709 primary chromaticities

	x	y
Red	0.64	0.33
Green	0.30	0.60
Blue	0.15	0.06
White balance, D65	0.3127	0.3290

The display synthesis matrix is derived directly from these primaries and balance colour. It is calculated with 15 decimal place precision and rounded to 6 places. It must be used with this precision:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.412391 & 0.357584 & 0.180481 \\ 0.212639 & 0.715169 & 0.072192 \\ 0.019331 & 0.119195 & 0.950532 \end{bmatrix} \bullet \begin{bmatrix} R_D \\ G_D \\ B_D \end{bmatrix} \qquad [29]$$

and it is these tristimulus values, $X_T\ Y_T\ Z_T$ and $X_R\ Y_R\ Z_R$ for the Test and Reference luminaires respectively, which are used for the calculation of the difference in colour appearance and the formulation of the TLCI-2012 and TLMF-2013 value.

1.5 Colour-difference calculations

Six different algorithms are available for calculating the visual magnitude of a colour-difference. The oldest, CIE 1964, was used in both the CRI and in the TLCI work initiated by Sproson and Taylor. The five later algorithms are each claimed to be better, in that they ever-more closely represent the visual experience.

During the development of TLCI-2012, subjective tests were conducted to establish which of these five later contenders performed best for television viewing, and this work is reported in EBU Tech 3354. The best-performing system was the latest available, CIEDE2000, which is the result of continuous fine adjustments to the CIELAB system.

Colour-difference calculations aim to derive a single numerical value (ΔE^*) for the perceptual colour difference between two appearances of a test sample, when separately illuminated by the Test and Reference sources. Throughout the following mathematics, subscript R refers to the performance with the Reference illuminant, subscript T to that with the Test illuminant, subscript i refers to the value for an individual colour sample, subscript a refers to a value for all the samples taken together. Subscript W refers to the display white point, $D65$.

The symbols used in the following explanation are those used by the CIE in CIE Tech 15:2004.

- First, calculate CIELAB values for the Test- and Reference-illuminated colour samples:

$$L^*_{T,i} = 116 f\left(Y_{T,i}/Y_W\right) - 16 \qquad L^*_{R,i} = 116 f\left(Y_{R,i}/Y_W\right) - 16 \quad [30]$$

…where $f(var)$ is a standard function:

$$f(var) = \begin{cases} \frac{1}{3}\left(\frac{116}{24}\right)^2 var + \frac{16}{116}, & var < \left(\frac{24}{116}\right)^3 \\ var^{1/3}, & var \geq \left(\frac{24}{116}\right)^3 \end{cases} \quad [31]$$

$$a^*_{T,i} = 500\left(f\left(\frac{X_{T,i}}{X_W}\right) - f\left(\frac{Y_{T,i}}{Y_W}\right)\right) \quad \text{and} \quad a^*_{R,i} = 500\left(f\left(\frac{X_{R,i}}{X_W}\right) - f\left(\frac{Y_{R,i}}{Y_W}\right)\right) \quad [32]$$

$$b^*_{T,i} = 200\left(f\left(\frac{Y_{T,i}}{Y_W}\right) - f\left(\frac{Z_{T,i}}{Z_W}\right)\right) \quad \text{and} \quad b^*_{R,i} = 200\left(f\left(\frac{Y_{R,i}}{Y_W}\right) - f\left(\frac{Z_{R,i}}{Z_W}\right)\right) \quad [33]$$

… where the $X_w\ Y_w\ Z_w$ values are the tristimulus values of the display white point.

- Then, calculate intermediate values for the manipulation of the CIELAB results for each test colour i:

$$C^*_{T,i} = \sqrt{a^{*\,2}_{T,i} + b^{*\,2}_{T,i}} \quad \text{and} \quad C^*_{R,i} = \sqrt{a^{*\,2}_{R,i} + b^{*\,2}_{R,i}} \quad [34]$$

$$\overline{C}^*_i = \left(C^*_{T,i} + C^*_{R,i}\right)/2 \quad [35]$$

$$g_i = \frac{1}{2}\left(1 - \sqrt{\frac{\overline{C}^{*\,7}_i}{\overline{C}^{*\,7}_i + 25^7}}\right) \quad [36]$$

$$a'_{T,i} = \left(1 + g_i\right)a^*_{T,i} \quad \text{and} \quad a'_{R,i} = \left(1 + g_i\right)a^*_{R,i} \quad [37]$$

$$C'_{T,i} = \sqrt{a'^{\,2}_{T,i} + b^{*\,2}_{T,i}} \quad \text{and} \quad C'_{R,i} = \sqrt{a'^{\,2}_{R,i} + b^{*\,2}_{R,i}} \quad [38]$$

$$h_{T,i} = \arctan\left(b*_{T,i} / a'_{T,i}\right) \text{ and } h_{R,i} = \arctan\left(b*_{R,i} / a'_{R,i}\right) \quad [39]$$

Note: the hue, h, is measured in degrees, not radians, and the calculations must correctly take into account the signs of a and b* to assign an angle in the range of 0° to 360°.*

$$\overline{L}'_i = \left(L*_{T,i} + L*_{R,i}\right)/2 \quad [40]$$

$$\overline{C}'_i = \left(C'_{T,i} + C'_{R,i}\right)/2 \quad [41]$$

$$\overline{h}_i = \left(h_{T,i} + h_{R,i}\right)/2 \quad [42]$$

$$\Delta h_i = h_{T,i} - h_{R,i} \quad [43]$$

Note: the hue difference, Δh, is measured in degrees, not radians, and the difference must lie in the range of -180° to +180°. If the difference lies outside this range, then 180 must be subtracted from the larger of the two hue angles and the mean and difference values re-calculated.

- Calculate further intermediate values for the colour under test.

$$S_{L,i} = 1 + \frac{0.015\left(\overline{L}'_i - 50\right)^2}{\sqrt{20 + \left(\overline{L}'_i - 50\right)^2}} \quad [44]$$

$$S_{C,i} = 1 + 0.045\overline{C}'_i \quad [45]$$

$$T_i = 1 - 0.17\cos\left(\overline{h}_i - 30\right) + 0.24\cos\left(2\overline{h}_i\right) + 0.32\cos\left(3\overline{h}_i + 6\right) - 0.2\cos\left(4\overline{h}_i - 63\right) \quad [46]$$

$$S_{H,i} = 1 + 0.015\overline{C}'_i T_i \quad [47]$$

$$R_{C,i} = 2\sqrt{\frac{\overline{C}*_i^7}{\overline{C}*_i^7 + 25^7}} \quad [48]$$

$$\Delta\theta_i = 30\exp\left(-\left(\frac{\overline{h}'_i - 275}{25}\right)^2\right) \quad [49]$$

$$R_{T,i} = -R_{C,i}\sin\left(2\Delta\theta_i\right) \quad [50]$$

- Finally, calculate the resulting CIEDE2000 difference values:

$$\Delta L = \frac{\left(L*_{T,i} - L*_{R,i}\right)}{k_L S_{L,i}} \quad [51]$$

$$\Delta C = \frac{\left(C'_{T,i} - C'_{R,i}\right)}{k_C S_{C,i}} \quad [52]$$

$$\Delta H_i = \frac{2\sin\left(\frac{h'_{T,i} - h'_{T,i}}{2}\right)\sqrt{C'_{T,i}C'_{R,i}}}{k_H S_{H,i}} \quad [53]$$

… where the k values are weighting factors, usually unity. They can be varied to customise the metric, affecting lightness, chroma and hue, respectively, and can be separately specified for each test colour on an experimental basis. If they are varied from unity, the their values must be included in the name of the system, e.g. CIEDE2000(2:1:1).

For use in the TLCI-2012 and TLMF-2013, all the *k* factors must be set to unity.

- And then calculate the resulting difference value:

$$\Delta E^*_i = \sqrt{\Delta L_i^2 + \Delta C_i^2 + \Delta H_i^2 + R_{T,i}\Delta C_i \Delta H_i} \quad [54]$$

1.5.1 Derivation of TLCI-2012 and TLMF-2013 value, *Q*

Both the CRI and the TLCI work of Sproson and Taylor used a simple formula to derive a final value R_a from the mean ΔE^* value:

$$R_a = 100 - 4.6\Delta E^*_a \quad [55]$$

… where ΔE^*_a is the mean value for all the test colours. The value 4.6 was chosen such that, when a 'warm white' fluorescent tube was assessed, the R_a value became exactly 50. There are two problems with this equation:

- It is possible to have negative values of R_a, should ΔE^*_a exceed about 22, which is admittedly a very large error.
- The original (CIE Tech 13, 1974) version of CRI takes a simple average of the individual errors:

$$\Delta E^*_a = \frac{1}{n}\sum_{i=1}^{n}\Delta E^*_i \quad \textbf{[56]}$$

  … which dilutes the effect of the worst-reproduced colours, which are the most likely to be noticed. The original TLCI work of Sproson and Taylor, and the latest CRI specification (CIE Tech 13.3) both use RMS calculations:

$$\Delta E^*_a = \left(\frac{1}{n}\sum_{i=1}^{n}\Delta E^{*2}_i\right)^{1/2} \quad [57]$$

A new formulation is used for the TLCI-2012, which avoids the problems in those calculations:

$$Q_a = \frac{100}{1 + \left(\frac{\Delta E^*_a}{k}\right)^p} \quad [58]$$

… where ΔE^*_a is a power-average of the ΔE^*_i values for the individual test samples:

$$\Delta E^*_a = \left(\frac{1}{n}\sum_{i=1}^{n}(\Delta E^*_i)^4\right)^{1/4} \quad [59]$$

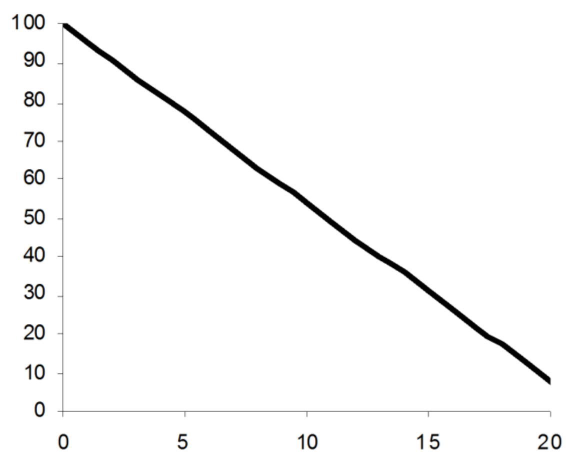
This better preserves the impact of the poorest performing colours (i.e. those with the largest values of ΔE^*). The effect is similar to ignoring all those colours whose ΔE^* result falls below the simple average, and taking the RMS value of the remaining, worst, colours, those which will be most noticeable in practice. Note that any test colour which is clipped in the mathematics, with any of the camera or display R G B values falling below zero, must be excluded from the calculations, since they would be clipped in a real camera and give a false colour.

For the TLCI-2012, only the first 18, coloured, test patches are used, excluding the grey scale.

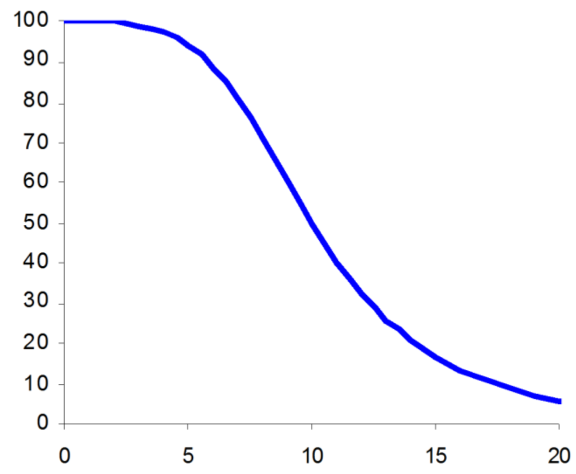
For the TLMF-2013, all 24 test patches are used, since errors in white balance are highly visible.

The constant k is chosen such that Q_a is 50 when a daylight fluorescent tube is being assessed for the TLCI-2012. This illuminant produces a ΔE^* error of 3.16 in the TLCI calculations, which appears to be a watershed value for television colourists in that errors greater than this are difficult to correct acceptably but lower values can usually be corrected with varying degrees of success.

The power value p is chosen to distribute the values more meaningfully than is done in the R_a formula.



Ra formula



Qa formula

Figure 3: Values of ΔE^*_a

Figure 3 shows the curves, plotted for values of ΔE^*_a from 0 to 20. The new Q_a formula compresses the effect of small errors, producing little change in Q_a (this is valid since small errors are not expected to be either visible or a problem), while expanding middling values (where critical decisions are needed as to the suitability of a luminaire for use in television). For this illustration only, k has been set to 10 such that the Q_a value approximately matches that of R_a for the same ΔE^* value of 10.

For the TLCI-2012 and TLMF-2013, k must be set to 3.16 and p to 2.4.

1.5.2 Meaning of the TLCI-2012 and TLMF-2013 value, *Q*

Neither the CRI nor the original work of Sproson and Taylor on the TLCI give any meaning to the computed value for R_a or Q_a. The TLCI-2012 and TLMF-2013 algorithms are intended to be more helpful.

The formulation for Q_a was constrained to produce a value of 50 for a typical daylight fluorescent tube, and this number appears to represent the watershed separating luminaires into those which are correctable for television use, and those which are not. Based on this intention, the Q_a scale can be labelled in two similar ways:

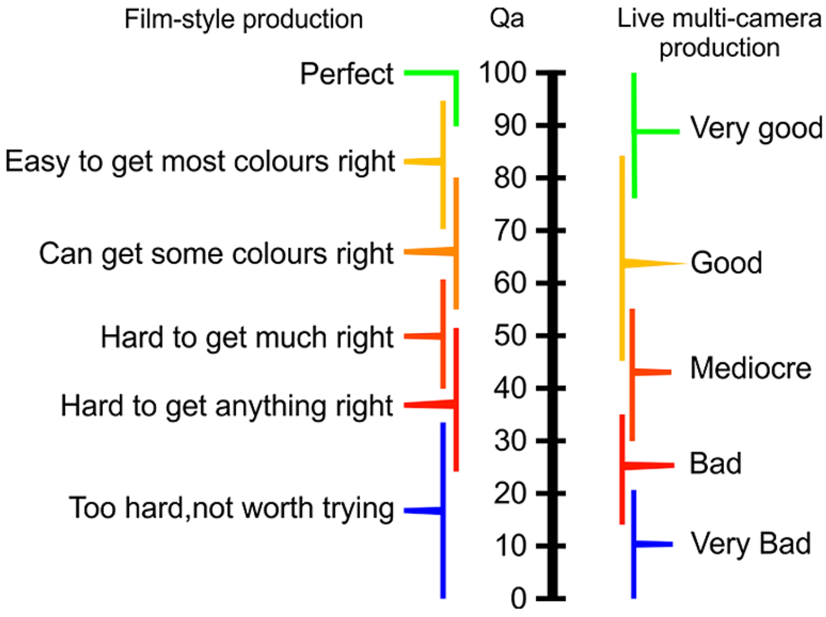


Figure 4: Q_a explanation

1. **Film-style production**, where possibly different cameras, locations and lighting need to be intercut or mixed. The scoring was derived from subjective tests conducted in 2012 by the EBU with professional colourists. Typically, this scale **is appropriate** for drama, wildlife and any production where significant post-processing is involved and pictures are required to match each other **well**.

2. **Live multi-camera production**, where many cameras are used together without inter-cutting **or mixing to different** locations or lighting. The scoring was derived from subjective tests conducted in 2015 with television professionals. Typically, this scale **is appropriate** for live production such as sport and news where pictures have no post-processing and the pictures are required only to be credible.

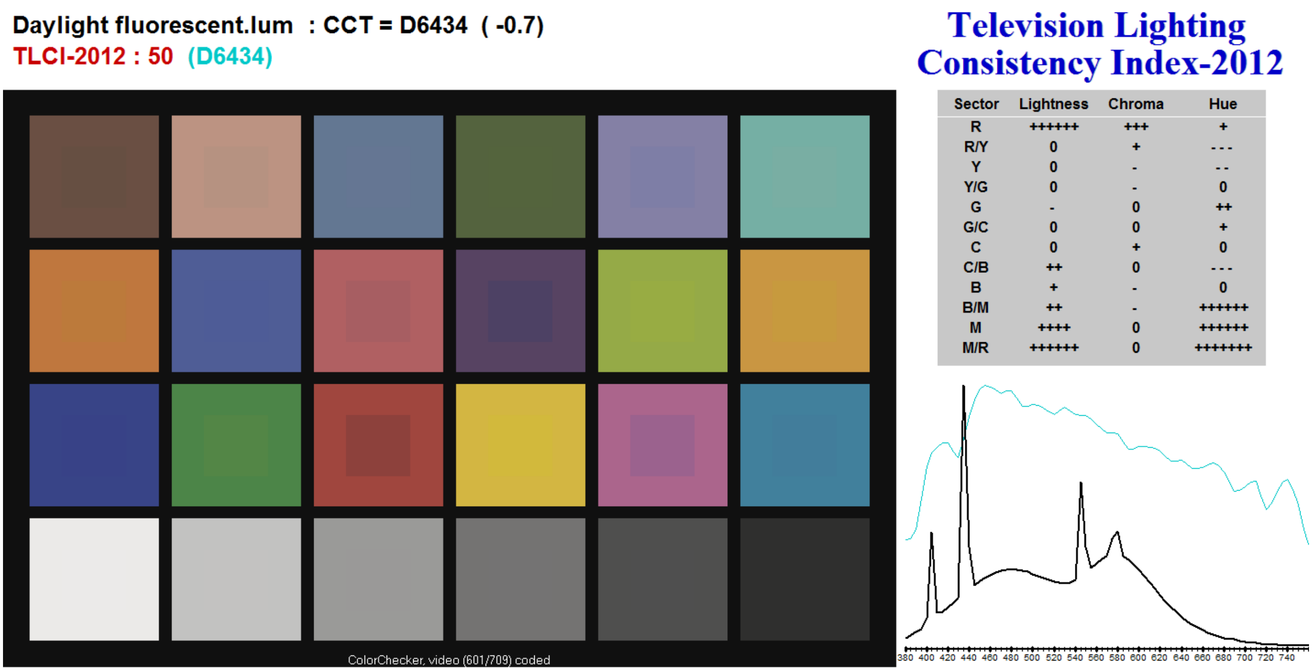
Note that these opinions do not form hard definitions; there is considerable overlap. This has two main causes; opinions varied, and the chosen colour-difference metric (CIEDE2000) is not perfect.

2. Presentation of results

While only the Q_a value is required for the assessment of a luminaire, it is helpful to provide the user with rather more information.

Figure 5 shows an example for the TLCI. The Test luminaire file is named at the top-left, and the derived CCT given together with the distance from the luminaire's chromaticity to that of the CCT. Note that this distance indicates the reliability of the calculations; only when this value is below 1 is the result truly credible (as stated in CIE Tech 15:2004). The resultant Q_a value is given in red, and the Reference source with which it was compared is given in cyan.

At the top-right, is a table of advice for colourists. This divides the hue circle into 12 sectors, and gives advice on how much correction is needed, and in which direction, for each hue sector. Obviously, "+" means increase, "-" means reduce, and the number of characters advises on the severity of the correction needed. For Hue correction, "+" means rotation anticlockwise (i.e. red towards yellow, green towards cyan and so on) while "-" means rotation clockwise (i.e. red towards magenta, green towards yellow and so on).



Sector	Lightness	Chroma	Hue
R	++++++	+++	+
R/Y	0	+	- - -
Y	0	-	- -
Y/G	0	-	0
G	-	0	++
G/C	0	0	+
C	0	+	0
C/B	++	0	- - -
B	+	-	0
B/M	++	-	++++++
M	++++	0	++++++
M/R	++++++	0	+++++++

Figure 5: Example of TLCI-2012 output

At the bottom-right, the spectral data for the Test (in black) and Reference (in cyan) luminaires are plotted together. Both are scaled to fit the available space on-screen.

The main panel of the output is a representation of the ColorChecker® test chart. Each patch is presented in the R_C' G_C' B_C' values created by the notional camera when exposed by the Reference luminaire, with inset into it the performance of the Test luminaire. The R_C' G_C' B_C' values should normally be quantised according to sRGB rules, for showing on a computer display or in print:

$$R_O' = 255R_C' ,\ G_O' = 255G_C' \text{ and } B_O' = 255B_C' \qquad [60]$$

… such that black is at 0 and peak signal is at 255. If the output is intended to be shown on a conventional television monitor or receiver, then the coding should be that of ITU-R BT.601 or 709:

$$R_O' = 16 + 219R_C' ,\ G_O' = 16 + 219G_C' \text{ and } B_O' = 16 + 219B_C' \qquad [61]$$

… such that black level is at digital level 16, and the nominal peak signals are at 235. Note that there is no need to clip the video signals at peak level, they can be allowed to pass level 235. In the presentation of the ColorChecker® chart, it should be made clear which coding rules have been used.

Presentation of TLMF-2013 results is the same, but must give the name of the Reference Luminaire as well. Also, the title of the results presentation must state that it is TLMF and not TLCI.

2.1 Calculation of the Colourist's Advice table

Each test colour must be assigned to a hue sector. The mathematics for this involves conventional television coding, since it is on this basis that a colourist will be making colour corrections. So, for each test sample i, when illuminated by the Test luminaire T, the hue can be calculated as a function, $f_{hue}(R,G,B)$, which takes $R_{C,T,i}'$ $G_{C,T,i}'$ and $B_{C,T,i}'$ as arguments:

$$Y' = 0.2126R_C' + 0.7152G_C' + 0.0722B_C' \qquad [62]$$

$$CR = 0.6350(R_C' - Y') \text{ and } CB = 0.5389(B_C' - Y') \qquad [63]$$

… and the hue can be calculated:

$$Hue = \begin{cases} 0, & CB = 0 \\ arctan\left(\frac{CR}{CB}\right), & CB <> 0 \end{cases} \qquad [64]$$

… which must be expressed in degrees.

If $CB < 0$ add 180 to *Hue*

If $CB > 0$ add 360 to *Hue*

… and care must be taken to ensure that the result lies between 0 and 360 degrees.

Then $f_{hue}(R,G,B) = Hue$.

Using this function, the hue sector can be identified:

$$Sector = \frac{f_{hue}\left(R'_{T,i}, G'_{T,i}, B'_{T,i}\right) - f_{hue}(1,0,0) + 15}{30} \qquad [65]$$

Note that $f_{hue}(1,0,0)$ is the hue angle of primary red, the starting point for the hue circle, and that the twelve sectors are each 30º wide, so this formula centres sectors on the primaries and secondaries, and on the intermediate colours between them. Also, $Sector$ is an integer, not a floating point number.

Having identified which sector a test sample falls into, individual averages can be made for ΔL^*, ΔC^* and ΔH^*. In the output report, the number of "+" or "-" signs shown is derived from:

$$6\Delta / k$$

Where Δ is ΔL^*, ΔC^* or ΔH^*, and k is the weighting value used in the formula for Q_a, 3.16.

> *Note:* *it is possible that some hue sectors may not have a colour allocated to them during the calculations. In such cases, the values in adjacent sectors can be interpolated to provide data for the table.*

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Appendix 1: CIE 1931 colour-matching functions, 2º observer

Values for this table are taken from CIE Tech.15:2004 'Colorimetry'.

nm	$\bar{x}$	$\bar{y}$	$\bar{z}$	nm	$\bar{x}$	$\bar{y}$	$\bar{z}$
380	0.001368	0.000039	0.006450	**575**	0.842500	0.915400	0.001800
385	0.002236	0.000064	0.010550	**580**	0.916300	0.870000	0.001650
390	0.004243	0.000120	0.020050	**585**	0.978600	0.816300	0.001400
395	0.007650	0.000217	0.036210	**590**	1.026300	0.757000	0.001100
400	0.014310	0.000396	0.067850	**595**	1.056700	0.694900	0.001000
405	0.023190	0.000640	0.110200	**600**	1.062200	0.631000	0.000800
410	0.043510	0.001210	0.207400	**605**	1.045600	0.566800	0.000600
415	0.077630	0.002180	0.371300	**610**	1.002600	0.503000	0.000340
420	0.134380	0.004000	0.645600	**615**	0.938400	0.441200	0.000240
425	0.214770	0.007300	1.039050	**620**	0.854450	0.381000	0.000190
430	0.283900	0.011600	1.385600	**625**	0.751400	0.321000	0.000100
435	0.328500	0.016840	1.622960	**630**	0.642400	0.265000	0.000050
440	0.348280	0.023000	1.747060	**635**	0.541900	0.217000	0.000030
445	0.348060	0.029800	1.782600	**640**	0.447900	0.175000	0.000020
450	0.336200	0.038000	1.772110	**645**	0.360800	0.138200	0.000010
455	0.318700	0.048000	1.744100	**650**	0.283500	0.107000	0.000000
460	0.290800	0.060000	1.669200	**655**	0.218700	0.081600	0.000000
465	0.251100	0.073900	1.528100	**660**	0.164900	0.061000	0.000000
470	0.195360	0.090980	1.287640	**665**	0.121200	0.044580	0.000000
475	0.142100	0.112600	1.041900	**670**	0.087400	0.032000	0.000000
480	0.095640	0.139020	0.812950	**675**	0.063600	0.023200	0.000000
485	0.057950	0.169300	0.616200	**680**	0.046770	0.017000	0.000000
490	0.032010	0.208020	0.465180	**685**	0.032900	0.011920	0.000000
495	0.014700	0.258600	0.353300	**690**	0.022700	0.008210	0.000000
500	0.004900	0.323000	0.272000	**695**	0.015840	0.005723	0.000000
505	0.002400	0.407300	0.212300	**700**	0.011359	0.004102	0.000000
510	0.009300	0.503000	0.158200	**705**	0.008111	0.002929	0.000000
515	0.029100	0.608200	0.111700	**710**	0.005790	0.002091	0.000000
520	0.063270	0.710000	0.078250	**715**	0.004109	0.001484	0.000000
525	0.109600	0.793200	0.057250	**720**	0.002899	0.001047	0.000000
530	0.165500	0.862000	0.042160	**725**	0.002049	0.000740	0.000000
535	0.225750	0.914850	0.029840	**730**	0.001440	0.000520	0.000000
540	0.290400	0.954000	0.020300	**735**	0.001000	0.000361	0.000000
545	0.359700	0.980300	0.013400	**740**	0.000690	0.000249	0.000000
550	0.433450	0.994950	0.008750	**745**	0.000476	0.000172	0.000000
555	0.512050	1.000000	0.005750	**750**	0.000332	0.000120	0.000000
560	0.594500	0.995000	0.003900	**755**	0.000235	0.000085	0.000000
565	0.678400	0.978600	0.002750	**760**	0.000166	0.000060	0.000000
570	0.762100	0.952000	0.002100				

	$\bar{x}$	$\bar{y}$	$\bar{z}$
sum	21.371524	21.371327	21.371540

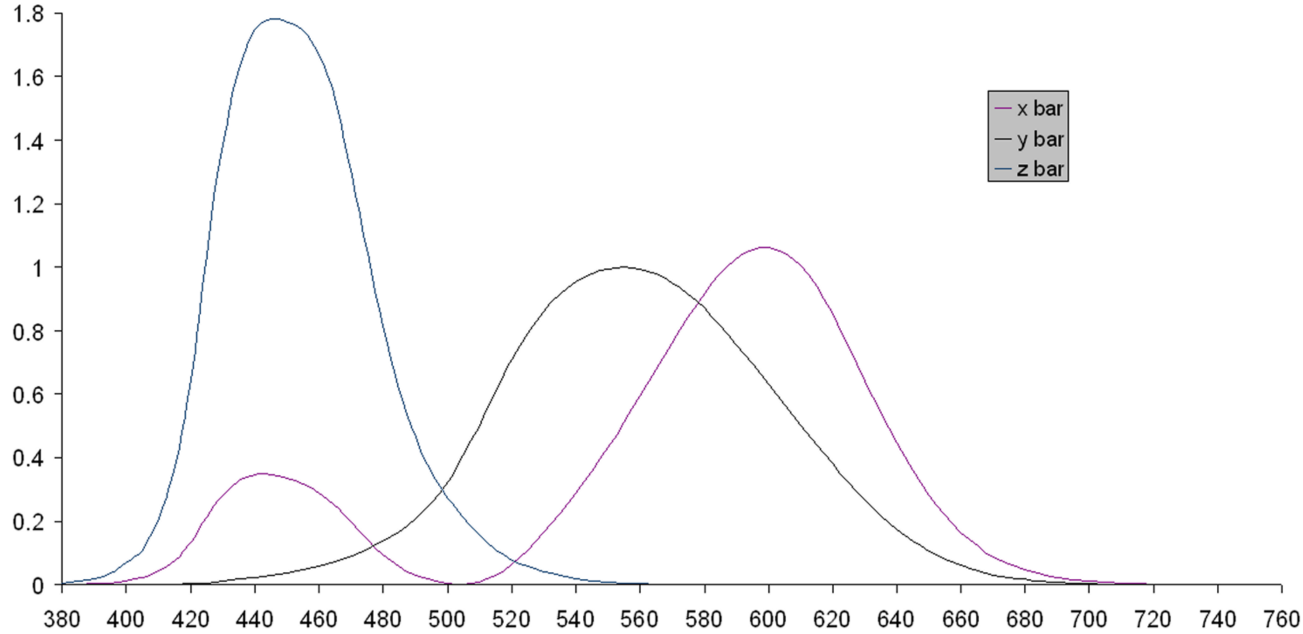

Figure A1.1: CIE 1931 colour-matching functions, 2° observer

Appendix 2: Chromaticities of Planckian and Daylight radiators

Values for these tables are calculated from first principles using 64-bit precisionand have not been previously published.

Planckian radiators								
T	*x*	*y*	*T*	*x*	*y*	*T*	*x*	*y*
1000	0.652355	0.344814	2020	0.523924	0.413702	3020	0.434958	0.403394
1020	0.649530	0.347301	2040	0.521763	0.413985	3030	0.434256	0.403144
1040	0.646716	0.349749	2060	0.519618	0.414238	3040	0.433557	0.402894
1060	0.643912	0.352157	2080	0.517488	0.414461	3050	0.432861	0.402642
1080	0.641119	0.354524	2100	0.515373	0.414656	3060	0.432169	0.402389
1100	0.638337	0.356848	2120	0.513275	0.414823	3070	0.431480	0.402135
1120	0.635567	0.359128	2140	0.511192	0.414963	3080	0.430795	0.401879
1140	0.632808	0.361364	2160	0.509124	0.415076	3090	0.430112	0.401623
1160	0.630061	0.363554	2180	0.507073	0.415164	3100	0.429433	0.401365
1180	0.627326	0.365697	2200	0.505037	0.415227	3110	0.428758	0.401107
1200	0.624603	0.367794	2220	0.503017	0.415265	3120	0.428085	0.400847
1220	0.621892	0.369843	2240	0.501013	0.415279	3130	0.427416	0.400587
1240	0.619192	0.371844	2260	0.499025	0.415271	3140	0.426750	0.400325
1260	0.616505	0.373797	2280	0.497053	0.415240	3150	0.426087	0.400062
1280	0.613830	0.375701	2300	0.495096	0.415187	3160	0.425427	0.399799
1300	0.611167	0.377555	2320	0.493156	0.415113	3170	0.424770	0.399535
1320	0.608516	0.379361	2340	0.491231	0.415019	3180	0.424117	0.399269
1340	0.605878	0.381117	2360	0.489323	0.414905	3190	0.423467	0.399003
1360	0.603251	0.382823	2380	0.487430	0.414772	3200	0.422820	0.398736
1380	0.600637	0.384480	2400	0.485553	0.414620	3210	0.422176	0.398469
1400	0.598035	0.386088	2420	0.483692	0.414450	3220	0.421535	0.398200
1420	0.595445	0.387646	2440	0.481847	0.414262	3230	0.420897	0.397931
1440	0.592868	0.389156	2460	0.480017	0.414058	3240	0.420263	0.397662
1460	0.590303	0.390617	2480	0.478204	0.413837	3250	0.419631	0.397391
1480	0.587751	0.392029	2500	0.476406	0.413600	3300	0.416518	0.396029
1500	0.585212	0.393393	2520	0.474624	0.413348	3350	0.413480	0.394653
1520	0.582684	0.394709	2540	0.472857	0.413081	3400	0.410515	0.393267
1540	0.580170	0.395977	2560	0.471106	0.412800	3450	0.407620	0.391871
1560	0.577669	0.397199	2580	0.469370	0.412505	3500	0.404795	0.390470
1580	0.575180	0.398374	2600	0.467650	0.412197	3550	0.402037	0.389064
1600	0.572705	0.399503	2620	0.465945	0.411876	3600	0.399345	0.387655
1620	0.570242	0.400586	2640	0.464256	0.411543	3650	0.396717	0.386246
1640	0.567793	0.401625	2660	0.462582	0.411197	3700	0.394152	0.384837
1660	0.565357	0.402619	2680	0.460923	0.410841	3750	0.391648	0.383431
1680	0.562935	0.40357	2700	0.459279	0.410473	3800	0.389203	0.382028
1700	0.560526	0.404477	2720	0.457650	0.410094	3850	0.386816	0.380630
1720	0.558131	0.405342	2740	0.456036	0.409705	3900	0.384485	0.379238
1740	0.555749	0.406166	2760	0.454437	0.409307	3950	0.382208	0.377853
1760	0.553382	0.406948	2780	0.452853	0.408899	4000	0.379985	0.376475
1780	0.551028	0.407689	2800	0.451283	0.408482	4100	0.375693	0.373747
1800	0.548689	0.408391	2820	0.449728	0.408056	4200	0.371597	0.371058
1820	0.546364	0.409054	2840	0.448187	0.407622	4300	0.367687	0.368413
1840	0.544054	0.409679	2860	0.446661	0.407179	4400	0.363953	0.365816
1860	0.541758	0.410266	2880	0.445149	0.406730	4500	0.360385	0.363269
1880	0.539476	0.410817	2900	0.443652	0.406273	4600	0.356975	0.360774
1900	0.537210	0.411331	2920	0.442168	0.405808	4700	0.353713	0.358334
1920	0.534958	0.41181	2940	0.440698	0.405338	4800	0.350593	0.355947
1940	0.532721	0.412254	2960	0.439243	0.404860	4900	0.347606	0.353616
1960	0.530499	0.412665	2980	0.437801	0.404377	**4999**	0.344774	0.351363
1980	0.528292	0.413043	3000	0.436373	0.403888	**5000**	0.344746	0.351341
2000	0.5261	0.413388	3010	0.435664	0.403641			

	x	y
sum	74.357659	60.180968

Daylight radiators								
T	x	y	T	x	y	T	x	y
5000	0.345747	0.358680	6450	0.313606	0.330016	7000	0.305366	0.321670
5001	0.345718	0.358657	6460	0.313441	0.329853	7100	0.304026	0.320275
5100	0.342875	0.356370	6470	0.313277	0.329690	7200	0.302732	0.318916
5200	0.340120	0.354109	6480	0.313113	0.329528	7300	0.301481	0.317594
5300	0.337478	0.351897	6490	0.312950	0.329367	7400	0.300271	0.316306
5400	0.334942	0.349735	6500	0.312787	0.329205	7500	0.299101	0.315052
5500	0.332508	0.347624	6510	0.312626	0.329045	7600	0.297968	0.313830
5600	0.330171	0.345563	6520	0.312464	0.328884	7700	0.296872	0.312640
5700	0.327926	0.343552	6530	0.312304	0.328724	7800	0.295809	0.311480
5800	0.325769	0.341592	6540	0.312144	0.328565	7900	0.294780	0.310350
5900	0.323694	0.339680	6550	0.311984	0.328406	8000	0.293782	0.309248
6000	0.321699	0.337818	6560	0.311825	0.328247	8250	0.291417	0.306613
6020	0.321309	0.337451	6570	0.311667	0.328089	8500	0.289221	0.304137
6040	0.320923	0.337086	6580	0.311509	0.327931	8750	0.287179	0.301807
6060	0.320539	0.336723	6590	0.311352	0.327773	9000	0.285276	0.299614
6080	0.320158	0.336362	6600	0.311195	0.327616	9250	0.283498	0.297545
6100	0.319780	0.336003	6620	0.310883	0.327304	9500	0.281834	0.295593
6120	0.319405	0.335646	6640	0.310574	0.326993	9750	0.280275	0.293747
6140	0.319032	0.335290	6660	0.310267	0.326683	10000	0.278811	0.292002
6160	0.318663	0.334937	6680	0.309962	0.326376	11000	0.273760	0.285879
6180	0.318296	0.334585	6700	0.309659	0.326070	12000	0.269721	0.280874
6200	0.317932	0.334235	6720	0.309359	0.325765	13000	0.266429	0.276722
6220	0.317571	0.333887	6740	0.309060	0.325462	14000	0.263701	0.273232
6240	0.317212	0.333541	6760	0.308764	0.325161	15000	0.261409	0.270265
6260	0.316857	0.333197	6780	0.308470	0.324862	16000	0.259459	0.267716
6300	0.316153	0.332514	6800	0.308178	0.324564	17000	0.257782	0.265506
6320	0.315805	0.332175	6820	0.307888	0.324267	18000	0.256327	0.263575
6340	0.315460	0.331838	6840	0.307600	0.323973	19000	0.255053	0.261874
6360	0.315117	0.331503	6860	0.307314	0.323679	20000	0.253930	0.260365
6380	0.314777	0.331169	6880	0.307030	0.323388	21000	0.252933	0.259020
6400	0.314439	0.330837	6900	0.306748	0.323098	22000	0.252042	0.257814
6410	0.314271	0.330672	6920	0.306467	0.322809	23000	0.251243	0.256726
6420	0.314104	0.330508	6940	0.306189	0.322522	24000	0.250521	0.255741
6430	0.313937	0.330343	6960	0.305913	0.322237	25000	0.249866	0.254845
6440	0.313771	0.330179	6980	0.305639	0.321953			

	x	y
sum	31.602241	33.132636

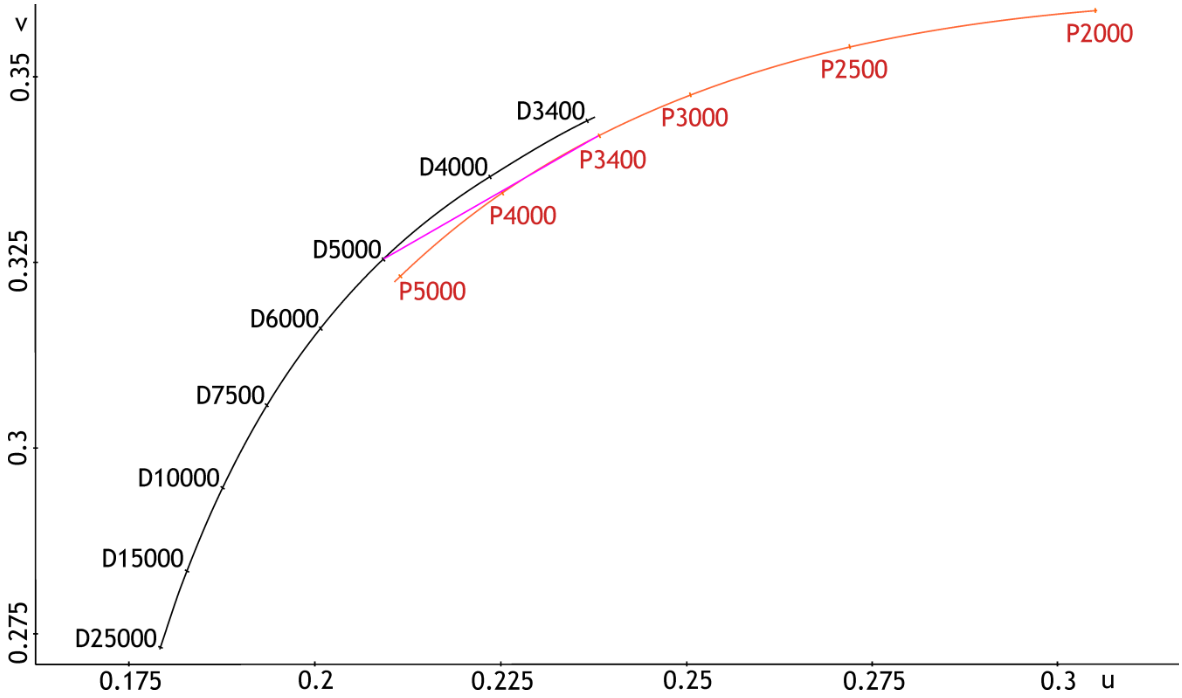

Figure A2.1: chromaticity diagram, Planckian & Daylight loci with mixed lighting locus, CIE 1960

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Appendix 3: Daylight radiation vectors

Values in this table are taken from CIE Tech.15:2004 'Colorimetry'.

nm	S_0	S_1	S_2
380	63.4	38.5	3.0
385	62.45000	35.98125	2.05
390	65.8	35.0	1.2
395	79.825	38.8	-0.1
400	94.8	43.4	-1.1
405	101.54375	45.525	-0.93125
410	104.8	46.3	-0.5
415	106.54375	45.70625	-0.53125
420	105.9	43.9	-0.7
425	100.35	40.375	-0.875
430	96.8	37.1	-1.2
435	104.05	36.525	-1.9125
440	113.9	36.7	-2.6
445	120.825	36.48125	-2.84375
450	125.6	35.9	-2.9
455	126.54375	34.49375	-2.88125
460	125.5	32.6	-2.8
465	123.39375	30.26875	-2.69375
470	121.3	27.9	-2.6
475	121.525	26.06875	-2.6375
480	121.3	24.3	-2.6
485	117.425	22.21875	-2.21875
490	113.5	20.1	-1.8
495	112.95625	18.075	-1.6125
500	113.1	16.2	-1.5
505	112.19375	14.74375	-1.3875
510	110.8	13.2	-1.3
515	108.3625	10.86875	-1.25
520	106.5	8.6	-1.2
525	107.6	7.18125	-1.125
530	108.8	6.1	-1
535	107.25	5.1375	-0.75
540	105.3	4.2	-0.5
545	104.90625	3.05	-0.3875
550	104.4	1.9	-0.3
555	102.39375	0.90625	-0.15
560	100.0	0.0	0.0
565	97.78125	-0.8	0.1
570	96.0	-1.6	0.2

nm	S_0	S_1	S_2
575	95.675	-2.65	0.2625
580	95.1	-3.5	0.5
585	91.95625	-3.475	1.25
590	89.1	-3.5	2.1
595	89.4375	-4.5625	2.69375
600	90.5	-5.8	3.2
605	90.60625	-6.55625	3.68125
610	90.3	-7.2	4.1
615	89.6125	-7.93125	4.43125
620	88.4	-8.6	4.7
625	86.0125	-9.05	4.8375
630	84.0	-9.5	5.1
635	84.475	-10.26875	5.8875
640	85.1	-10.9	6.7
645	83.525	-10.80625	7.01875
650	81.9	-10.7	7.3
655	81.90625	-11.2125	7.9125
660	82.6	-12.0	8.6
665	84.01875	-13.10625	9.25625
670	84.9	-14.0	9.8
675	83.83125	-14.025	10.19375
680	81.3	-13.6	10.2
685	76.225	-12.69375	9.19375
690	71.9	-12.0	8.3
695	72.38125	-12.575	8.9
700	74.3	-13.3	9.6
705	76.31875	-13.325	9.225
710	76.4	-12.9	8.5
715	69.45625	-11.6625	7.64375
720	63.3	-10.6	7.0
725	66.35	-10.91875	7.18125
730	71.7	-11.6	7.6
735	75.6125	-12.0875	7.91875
740	77.0	-12.2	8.0
745	72.525	-11.3875	7.46875
750	65.2	-10.2	6.7
755	54.40625	-8.6625	5.73125
760	47.7	-7.8	5.2

	S_0	S_1	S_2
sum	7140.45	545.05	201.55

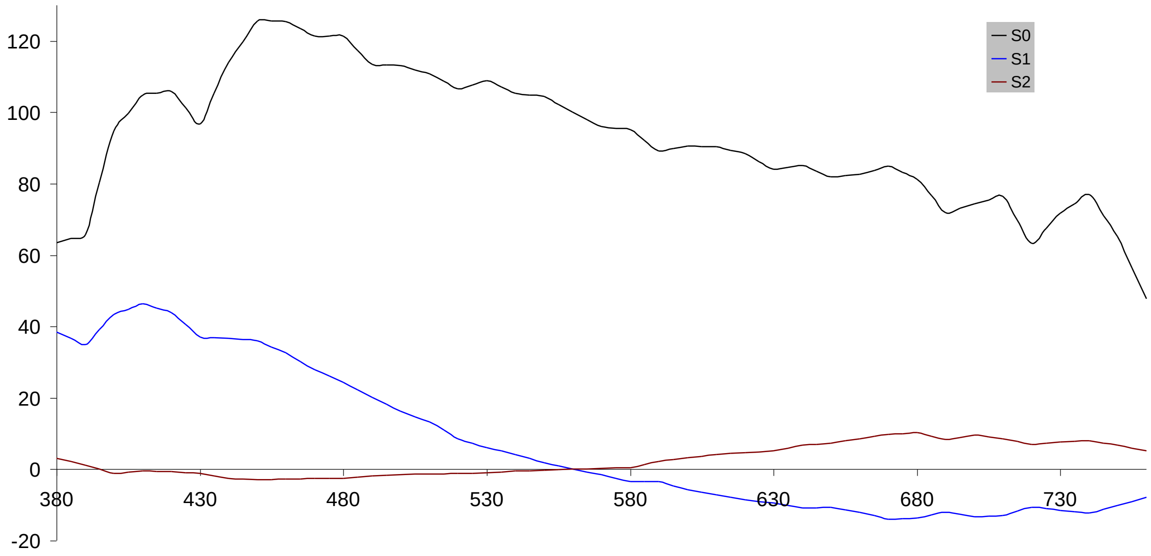

Figure A3.1: Daylight vectors

Appendix 4: ColorChecker® reflectivities

Values for these tables are taken from "The assessment of the colorimetric properties of light sources for use in television scene lighting", E.W. Taylor, BBC R&D Report 1988/2

	1	2	3	4	5	6	7	8	9
nm	Dark skin	Light skin	Blue sky	Foliage	Blue flower	Bluish green	Orange	Purplish blue	Moderate red
380	0.054	0.092	0.105	0.050	0.101	0.108	0.052	0.094	0.088
385	0.057	0.109	0.127	0.052	0.127	0.132	0.054	0.113	0.102
390	0.063	0.134	0.164	0.052	0.170	0.168	0.052	0.141	0.121
395	0.066	0.161	0.213	0.050	0.233	0.213	0.050	0.186	0.136
400	0.075	0.186	0.271	0.052	0.310	0.260	0.052	0.235	0.151
405	0.078	0.200	0.314	0.052	0.373	0.292	0.052	0.275	0.153
410	0.078	0.205	0.333	0.052	0.409	0.308	0.052	0.297	0.151
415	0.076	0.206	0.344	0.053	0.424	0.317	0.051	0.316	0.144
420	0.074	0.207	0.345	0.051	0.432	0.320	0.050	0.317	0.142
425	0.070	0.209	0.344	0.053	0.437	0.328	0.050	0.333	0.141
430	0.066	0.211	0.346	0.053	0.437	0.336	0.052	0.346	0.139
435	0.064	0.213	0.346	0.053	0.438	0.342	0.050	0.355	0.135
440	0.062	0.216	0.347	0.055	0.437	0.352	0.051	0.368	0.136
445	0.060	0.221	0.343	0.058	0.432	0.360	0.051	0.378	0.135
450	0.059	0.227	0.337	0.059	0.428	0.371	0.052	0.381	0.133
455	0.060	0.237	0.333	0.061	0.423	0.386	0.051	0.377	0.132
460	0.058	0.246	0.327	0.060	0.417	0.405	0.051	0.368	0.129
465	0.060	0.259	0.324	0.063	0.412	0.433	0.053	0.356	0.130
470	0.060	0.273	0.319	0.063	0.405	0.465	0.053	0.340	0.129
475	0.062	0.285	0.306	0.067	0.395	0.497	0.054	0.322	0.127
480	0.058	0.294	0.290	0.065	0.380	0.528	0.055	0.296	0.121
485	0.063	0.304	0.288	0.067	0.373	0.557	0.056	0.269	0.118
490	0.063	0.305	0.280	0.069	0.364	0.576	0.055	0.241	0.109
495	0.067	0.309	0.274	0.072	0.355	0.591	0.058	0.220	0.105
500	0.068	0.314	0.265	0.077	0.342	0.586	0.061	0.197	0.105
505	0.070	0.323	0.258	0.088	0.333	0.591	0.063	0.182	0.104
510	0.072	0.334	0.250	0.105	0.316	0.586	0.068	0.166	0.101
515	0.077	0.340	0.240	0.132	0.296	0.582	0.077	0.151	0.100
520	0.079	0.332	0.229	0.159	0.267	0.567	0.086	0.138	0.094
525	0.081	0.316	0.220	0.182	0.245	0.559	0.098	0.127	0.091
530	0.081	0.300	0.212	0.195	0.227	0.545	0.120	0.120	0.089
535	0.083	0.292	0.207	0.199	0.212	0.533	0.145	0.115	0.092
540	0.083	0.290	0.203	0.191	0.206	0.512	0.175	0.108	0.095
545	0.084	0.295	0.198	0.180	0.203	0.492	0.206	0.104	0.097
550	0.084	0.300	0.193	0.167	0.203	0.472	0.236	0.101	0.104
555	0.088	0.302	0.191	0.156	0.204	0.445	0.270	0.095	0.109
560	0.093	0.297	0.187	0.144	0.196	0.429	0.302	0.090	0.111
565	0.098	0.295	0.181	0.133	0.190	0.402	0.341	0.084	0.113
570	0.104	0.304	0.174	0.131	0.190	0.380	0.375	0.082	0.116
575	0.111	0.328	0.170	0.130	0.194	0.355	0.410	0.081	0.134
580	0.121	0.365	0.167	0.129	0.201	0.332	0.440	0.081	0.167
585	0.127	0.409	0.162	0.123	0.210	0.309	0.467	0.081	0.223
590	0.133	0.450	0.158	0.118	0.216	0.284	0.488	0.081	0.291
595	0.140	0.488	0.161	0.114	0.225	0.262	0.509	0.083	0.362
600	0.144	0.520	0.156	0.110	0.228	0.247	0.518	0.083	0.426
605	0.149	0.540	0.152	0.102	0.232	0.233	0.532	0.080	0.474

	1	2	3	4	5	6	7	8	9
nm	**Dark skin**	**Light skin**	**Blue sky**	**Foliage**	**Blue flower**	**Bluish green**	**Orange**	**Purplish blue**	**Moderate red**
610	0.151	0.556	0.150	0.101	0.238	0.224	0.540	0.079	0.511
615	0.154	0.566	0.145	0.103	0.240	0.217	0.551	0.080	0.537
620	0.160	0.574	0.142	0.104	0.236	0.212	0.557	0.081	0.551
625	0.164	0.582	0.137	0.105	0.236	0.209	0.562	0.081	0.562
630	0.170	0.593	0.133	0.105	0.240	0.207	0.568	0.084	0.565
635	0.175	0.602	0.132	0.106	0.248	0.205	0.575	0.089	0.570
640	0.179	0.607	0.126	0.102	0.261	0.200	0.581	0.092	0.575
645	0.184	0.625	0.127	0.102	0.289	0.198	0.584	0.096	0.574
650	0.193	0.631	0.121	0.101	0.322	0.199	0.585	0.103	0.579
655	0.203	0.639	0.118	0.101	0.362	0.197	0.590	0.107	0.577
660	0.213	0.655	0.115	0.101	0.407	0.199	0.601	0.112	0.579
665	0.220	0.661	0.115	0.101	0.446	0.203	0.596	0.111	0.577
670	0.236	0.687	0.112	0.107	0.488	0.210	0.600	0.112	0.580
675	0.241	0.693	0.110	0.115	0.512	0.216	0.596	0.109	0.581
680	0.248	0.711	0.110	0.132	0.546	0.218	0.604	0.104	0.579
685	0.257	0.722	0.109	0.152	0.546	0.226	0.603	0.102	0.581
690	0.269	0.737	0.108	0.185	0.555	0.232	0.606	0.099	0.581
695	0.280	0.757	0.108	0.233	0.563	0.236	0.607	0.099	0.583
700	0.289	0.768	0.106	0.283	0.564	0.238	0.608	0.100	0.581
705	0.300	0.786	0.105	0.339	0.575	0.242	0.615	0.100	0.581
710	0.314	0.798	0.105	0.383	0.578	0.242	0.617	0.103	0.580
715	0.337	0.815	0.106	0.419	0.586	0.239	0.621	0.106	0.586
720	0.346	0.822	0.106	0.444	0.590	0.232	0.622	0.109	0.585
725	0.361	0.823	0.105	0.445	0.589	0.227	0.619	0.113	0.584
730	0.382	0.835	0.107	0.465	0.601	0.229	0.625	0.122	0.589
735	0.404	0.845	0.105	0.473	0.604	0.230	0.628	0.127	0.587
740	0.425	0.855	0.106	0.477	0.606	0.237	0.630	0.138	0.590
745	0.439	0.848	0.105	0.480	0.605	0.248	0.627	0.153	0.582
750	0.464	0.862	0.108	0.489	0.614	0.256	0.635	0.173	0.589
755	0.476	0.861	0.107	0.492	0.616	0.269	0.639	0.193	0.592
760	0.490	0.868	0.110	0.498	0.617	0.274	0.640	0.215	0.590

	Dark skin	Light skin	Blue sky	Foliage	Blue flower	Bluish green	Orange	Purplish blue	Moderate red
sum	12.447	35.427	14.953	12.29	28.328	25.319	25.876	24.563	201.9

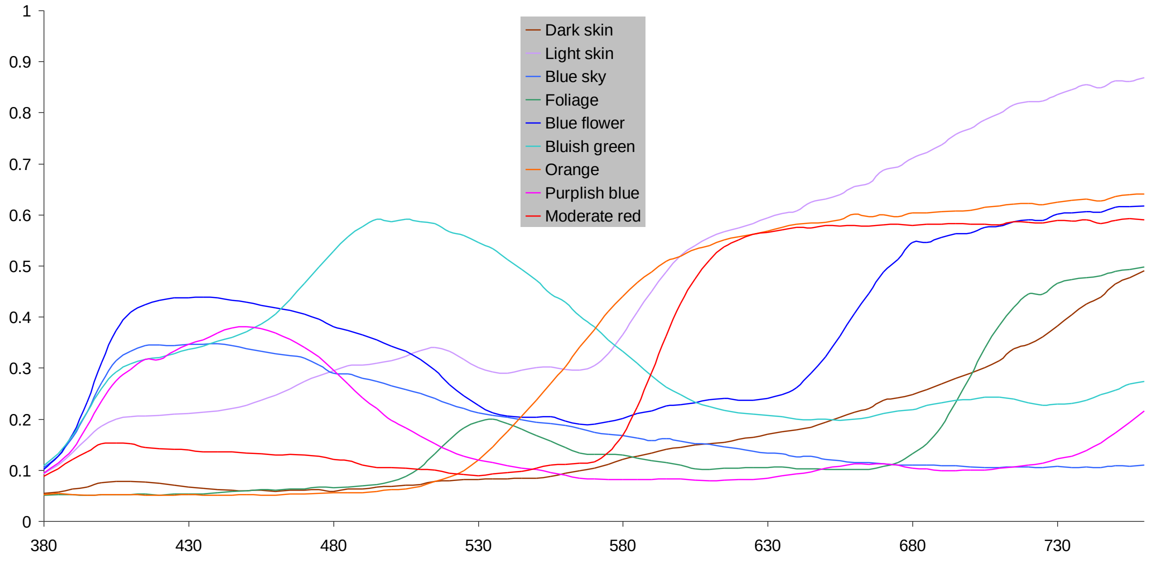

Figure A4.1: Reflectivities, samples 1 - 9

	10	11	12	13	14	15	16	17	18
nm	Purple	Yellow green	Orange yellow	Blue	Green	Red	Yellow	Magenta	Cyan
380	0.083	0.045	0.049	0.068	0.045	0.043	0.047	0.106	0.085
385	0.100	0.048	0.052	0.084	0.048	0.045	0.047	0.129	0.102
390	0.125	0.050	0.054	0.104	0.054	0.046	0.048	0.168	0.130
395	0.154	0.050	0.055	0.127	0.054	0.045	0.047	0.229	0.163
400	0.183	0.054	0.054	0.156	0.057	0.047	0.050	0.297	0.201
405	0.198	0.053	0.057	0.178	0.059	0.046	0.052	0.346	0.228
410	0.206	0.053	0.057	0.194	0.060	0.048	0.052	0.367	0.247
415	0.207	0.055	0.059	0.209	0.060	0.046	0.051	0.372	0.254
420	0.207	0.053	0.057	0.221	0.060	0.046	0.051	0.377	0.262
425	0.201	0.057	0.057	0.234	0.062	0.046	0.053	0.373	0.278
430	0.194	0.059	0.059	0.250	0.054	0.048	0.053	0.362	0.282
435	0.184	0.059	0.057	0.264	0.064	0.044	0.053	0.351	0.300
440	0.175	0.062	0.058	0.287	0.069	0.046	0.057	0.340	0.319
445	0.163	0.065	0.060	0.308	0.070	0.047	0.056	0.323	0.332
450	0.154	0.070	0.061	0.318	0.075	0.047	0.058	0.306	0.348
455	0.142	0.075	0.061	0.323	0.079	0.047	0.060	0.293	0.363
460	0.129	0.081	0.062	0.317	0.083	0.046	0.062	0.276	0.382
465	0.120	0.092	0.067	0.303	0.090	0.046	0.067	0.259	0.401
470	0.109	0.102	0.072	0.276	0.099	0.044	0.076	0.250	0.419
475	0.102	0.116	0.081	0.255	0.109	0.044	0.090	0.234	0.431
480	0.095	0.136	0.088	0.225	0.120	0.040	0.109	0.220	0.438
485	0.090	0.158	0.098	0.193	0.132	0.042	0.142	0.206	0.441
490	0.081	0.185	0.106	0.160	0.144	0.039	0.183	0.190	0.438
495	0.077	0.225	0.112	0.139	0.158	0.040	0.228	0.179	0.429
500	0.070	0.274	0.120	0.117	0.175	0.040	0.274	0.169	0.415
505	0.067	0.328	0.130	0.104	0.196	0.039	0.319	0.163	0.404
510	0.065	0.390	0.143	0.087	0.231	0.040	0.360	0.152	0.381
515	0.063	0.446	0.163	0.077	0.272	0.040	0.405	0.140	0.358
520	0.059	0.485	0.188	0.066	0.307	0.038	0.443	0.126	0.339
525	0.058	0.511	0.218	0.060	0.338	0.038	0.475	0.113	0.316
530	0.056	0.529	0.256	0.056	0.352	0.039	0.510	0.104	0.288
535	0.053	0.538	0.304	0.053	0.357	0.038	0.544	0.098	0.262
540	0.052	0.539	0.351	0.050	0.353	0.040	0.571	0.098	0.236

	10	11	12	13	14	15	16	17	18
nm	Purple	Yellow green	Orange yellow	Blue	Green	Red	Yellow	Magenta	Cyan
545	0.052	0.535	0.399	0.047	0.341	0.040	0.594	0.102	0.210
550	0.051	0.526	0.442	0.045	0.323	0.041	0.612	0.104	0.186
555	0.053	0.521	0.476	0.042	0.305	0.042	0.630	0.103	0.162
560	0.055	0.511	0.505	0.043	0.286	0.044	0.646	0.104	0.142
565	0.056	0.500	0.532	0.040	0.265	0.046	0.656	0.103	0.129
570	0.054	0.484	0.544	0.040	0.244	0.047	0.668	0.106	0.116
575	0.052	0.467	0.561	0.038	0.224	0.054	0.677	0.118	0.105
580	0.053	0.450	0.579	0.038	0.203	0.064	0.691	0.140	0.099
585	0.049	0.435	0.539	0.037	0.180	0.081	0.696	0.170	0.092
590	0.051	0.412	0.597	0.036	0.161	0.112	0.701	0.212	0.088
595	0.055	0.395	0.604	0.037	0.144	0.156	0.702	0.257	0.086
600	0.058	0.377	0.617	0.038	0.124	0.216	0.729	0.313	0.081
605	0.063	0.363	0.617	0.036	0.108	0.283	0.701	0.354	0.077
610	0.073	0.352	0.618	0.037	0.098	0.358	0.704	0.403	0.078
615	0.087	0.346	0.624	0.037	0.089	0.434	0.707	0.457	0.076
620	0.103	0.339	0.625	0.037	0.084	0.499	0.708	0.501	0.076
625	0.120	0.337	0.630	0.039	0.080	0.549	0.713	0.546	0.076
630	0.137	0.337	0.647	0.039	0.076	0.585	0.721	0.587	0.076
635	0.149	0.331	0.635	0.042	0.075	0.607	0.716	0.612	0.076
640	0.161	0.326	0.638	0.040	0.071	0.624	0.717	0.637	0.076
645	0.175	0.322	0.642	0.042	0.071	0.633	0.718	0.655	0.077
650	0.188	0.323	0.649	0.044	0.070	0.650	0.726	0.677	0.078
655	0.197	0.320	0.650	0.045	0.067	0.652	0.729	0.684	0.077
660	0.208	0.325	0.649	0.047	0.067	0.652	0.730	0.693	0.081
665	0.218	0.327	0.650	0.048	0.067	0.656	0.728	0.695	0.080
670	0.229	0.334	0.677	0.050	0.068	0.661	0.747	0.714	0.081
675	0.241	0.340	0.657	0.048	0.070	0.666	0.739	0.710	0.079
680	0.249	0.347	0.653	0.046	0.070	0.664	0.737	0.720	0.079
685	0.262	0.355	0.659	0.050	0.074	0.671	0.743	0.715	0.079
690	0.272	0.362	0.658	0.048	0.076	0.671	0.740	0.714	0.077
695	0.284	0.369	0.662	0.051	0.079	0.677	0.756	0.739	0.076
700	0.292	0.373	0.661	0.049	0.080	0.673	0.742	0.719	0.075
705	0.304	0.376	0.666	0.052	0.082	0.678	0.749	0.726	0.074
710	0.312	0.375	0.668	0.054	0.086	0.680	0.751	0.728	0.074
715	0.325	0.379	0.672	0.057	0.085	0.689	0.753	0.733	0.076
720	0.329	0.372	0.671	0.060	0.083	0.688	0.754	0.737	0.077
725	0.333	0.365	0.667	0.065	0.081	0.685	0.750	0.732	0.081
730	0.343	0.367	0.677	0.069	0.081	0.691	0.760	0.743	0.084
735	0.346	0.375	0.678	0.076	0.081	0.694	0.762	0.742	0.090
740	0.350	0.379	0.682	0.087	0.083	0.696	0.769	0.748	0.098
745	0.350	0.388	0.678	0.102	0.086	0.692	0.762	0.741	0.111
750	0.359	0.403	0.686	0.123	0.091	0.698	0.774	0.753	0.130
755	0.360	0.415	0.693	0.147	0.094	0.704	0.776	0.754	0.151
760	0.362	0.430	0.690	0.174	0.098	0.700	0.779	0.761	0.179

	Purple	Yellow green	Orange yellow	Blue	Green	Red	Yellow	Magenta	Cyan
sum	12.442	23.108	30.89	8.285	9.857	22.533	37.356	30.978	14.543

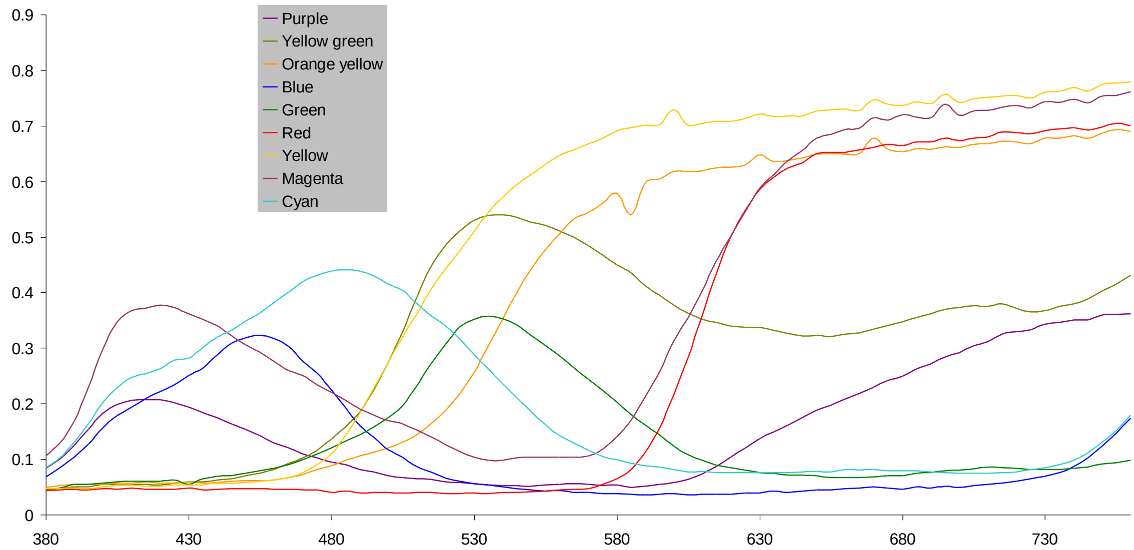

Figure A4.2: Reflectivities, samples 10 - 18

Values for the following table are taken from unpublished measurements made by A. Roberts at BBC R&D. Only the data for the white sample is from an actual measurement, data values for the other samples are scaled from it to the known reflectances of the individual samples. Note that these colours play no part in TLCI calculations.

	19	20	21	22	23	24
nm	**White, 90.01%**	**Neutral 8, 59.1%**	**Neutral 6.5, 36.2%**	**Neutral 5, 19.77%**	**Neutral 3.5, 9%**	**Black, 3.13%**
380	0.126	0.084	0.051	0.0277	0.0126	0.00439
385	0.169	0.113	0.068	0.0372	0.0169	0.00589
390	0.212	0.141	0.085	0.0465	0.0212	0.00737
395	0.264	0.176	0.106	0.0580	0.0264	0.00919
400	0.318	0.211	0.128	0.0698	0.0318	0.01105
405	0.491	0.327	0.198	0.1079	0.0491	0.01708
410	0.664	0.442	0.267	0.1457	0.0664	0.02308
415	0.757	0.504	0.305	0.1663	0.0757	0.02635
420	0.851	0.567	0.342	0.1869	0.0851	0.02961
425	0.868	0.578	0.349	0.1907	0.0868	0.03020
430	0.887	0.590	0.357	0.1947	0.0886	0.03084
435	0.888	0.591	0.357	0.1949	0.0887	0.03087
440	0.890	0.592	0.358	0.1954	0.0889	0.03094
445	0.893	0.594	0.359	0.1960	0.0893	0.03105
450	0.895	0.595	0.360	0.1965	0.0895	0.03112
455	0.896	0.596	0.360	0.1967	0.0896	0.03115
460	0.898	0.597	0.361	0.1971	0.0898	0.03122
465	0.900	0.599	0.362	0.1976	0.0900	0.03129
470	0.902	0.600	0.363	0.1980	0.0902	0.03136
475	0.900	0.599	0.362	0.1976	0.0900	0.03129
480	0.897	0.597	0.361	0.1969	0.0897	0.03119
485	0.904	0.602	0.364	0.1985	0.0904	0.03143
490	0.901	0.599	0.362	0.1978	0.0901	0.03133
495	0.900	0.599	0.362	0.1976	0.0900	0.03129
500	0.900	0.599	0.362	0.1976	0.0900	0.03129
505	0.898	0.597	0.361	0.1971	0.0898	0.03122
510	0.897	0.597	0.361	0.1969	0.0897	0.03119
515	0.900	0.599	0.362	0.1976	0.0900	0.03129

nm	19 White, 90.01%	20 Neutral 8, 59.1%	21 Neutral 6.5, 36.2%	22 Neutral 5, 19.77%	23 Neutral 3.5, 9%	24 Black, 3.13%
520	0.902	0.600	0.363	0.1980	0.0902	0.03136
525	0.902	0.600	0.363	0.1980	0.0902	0.03136
530	0.901	0.599	0.362	0.1978	0.0901	0.03133
535	0.900	0.599	0.362	0.1976	0.0900	0.03129
540	0.899	0.598	0.361	0.1974	0.0899	0.03126
545	0.896	0.596	0.360	0.1967	0.0896	0.03115
550	0.893	0.594	0.359	0.1960	0.0893	0.03105
555	0.895	0.595	0.360	0.1965	0.0895	0.03112
560	0.898	0.597	0.361	0.1971	0.0898	0.03122
565	0.900	0.599	0.362	0.1976	0.0900	0.03129
570	0.902	0.600	0.363	0.1980	0.0902	0.03136
575	0.904	0.602	0.364	0.1985	0.0904	0.03143
580	0.905	0.602	0.364	0.1987	0.0905	0.03147
585	0.906	0.603	0.364	0.1989	0.0906	0.03150
590	0.907	0.604	0.365	0.1991	0.0907	0.03154
595	0.905	0.602	0.364	0.1987	0.0905	0.03147
600	0.903	0.601	0.363	0.1982	0.0903	0.03140
605	0.904	0.602	0.364	0.1985	0.0904	0.03143
610	0.905	0.602	0.364	0.1987	0.0905	0.03147
615	0.907	0.604	0.365	0.1991	0.0907	0.03154
620	0.898	0.597	0.361	0.1971	0.0898	0.03122
625	0.897	0.597	0.361	0.1969	0.0897	0.03119
630	0.896	0.596	0.360	0.1967	0.0896	0.03115
635	0.898	0.597	0.361	0.1971	0.0898	0.03122
640	0.900	0.599	0.362	0.1976	0.0900	0.03129
645	0.900	0.599	0.362	0.1976	0.0900	0.03129
650	0.899	0.598	0.361	0.1974	0.0899	0.03126
655	0.901	0.599	0.362	0.1978	0.0901	0.03133
660	0.904	0.602	0.364	0.1985	0.0904	0.03143
665	0.904	0.602	0.364	0.1985	0.0904	0.03143
670	0.905	0.602	0.364	0.1987	0.0905	0.03147
675	0.902	0.600	0.363	0.1980	0.0902	0.03136
680	0.899	0.598	0.361	0.1974	0.0899	0.03126
685	0.899	0.598	0.361	0.1974	0.0899	0.03126
690	0.900	0.599	0.362	0.1976	0.0900	0.03129
695	0.899	0.598	0.361	0.1974	0.0899	0.03126
700	0.898	0.597	0.361	0.1971	0.0898	0.03122
705	0.898	0.597	0.361	0.1971	0.0898	0.03122
710	0.899	0.598	0.361	0.1974	0.0899	0.03126
715	0.898	0.597	0.361	0.1971	0.0898	0.03122
720	0.898	0.597	0.361	0.1971	0.0898	0.03122
725	0.899	0.598	0.361	0.1974	0.0899	0.03126
730	0.901	0.599	0.362	0.1978	0.0901	0.03133
735	0.898	0.597	0.361	0.1971	0.0898	0.03122
740	0.896	0.596	0.360	0.1967	0.0896	0.03115
745	0.895	0.595	0.360	0.1965	0.0895	0.03112
750	0.898	0.597	0.361	0.1971	0.0898	0.03122
755	0.899	0.598	0.361	0.1974	0.0899	0.03126
760	0.898	0.597	0.361	0.1971	0.0898	0.03122

	White, 90.01%	Neutral 8, 59.1%	Neutral 6.5, 36.2%	Neutral 5, 19.77%	Neutral 3.5, 9%	Black, 3.13%
sum	64.976	43.228	26.128	14.2649	6.4973	2.25924

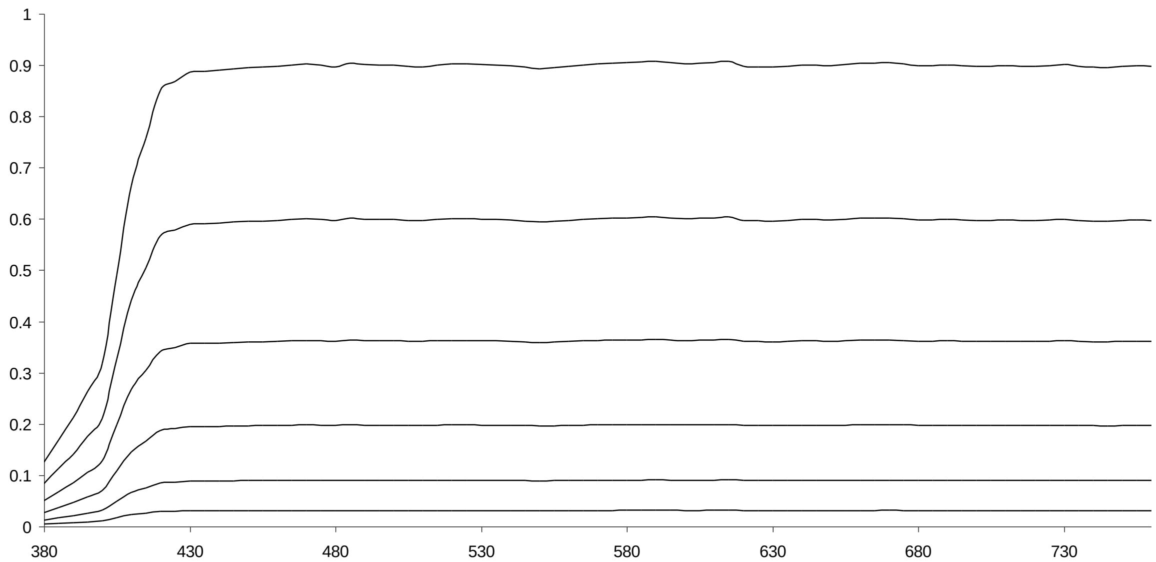

Figure A4.3: Reflectivities, samples 19 - 24, grey scale

The ColorChecker® colour-set is often regarded as not being ideally suited to use in television, because one colour (18, cyan) actually falls outside the colour gamut of television when lit by Illuminant *D*65, and another (16, yellow) lies very near the gamut boundary. However, neither of these apparent problems affects the appropriateness of the colour-set for use in the TLCI-2012.

The camera responsivity curves are not, and cannot be, ideal; the camera matrix provides only an approximation to ideal curves. In practice, the matrix is usually calculated to optimise the camera's colour reproduction when used without gamma-correction and feeding a notional, linear display. Subsequent inclusion of the camera and display non-linearities increases the saturation considerably, and provides much of what is colloquially known as the 'look' of a camera. For use in the TLCI-2012, the matrix has been optimised for use with both camera and display non-linearities included, and the performance of the skin tones (1 and 2) and desaturated colours (3 to 6) has been held as accurately as possible, consistent with reasonable accuracy for the other colours.

Figure A4.5 shows the chromaticity performance of the 18 colour samples via the standard camera. Each colour is marked in black at the chromaticity produced by illumination *D*65 independent of the television camera and display, the magenta vector to the cyan circle shows where the colour is reproduced via the camera and display with settings as used in the TLCI-2012.

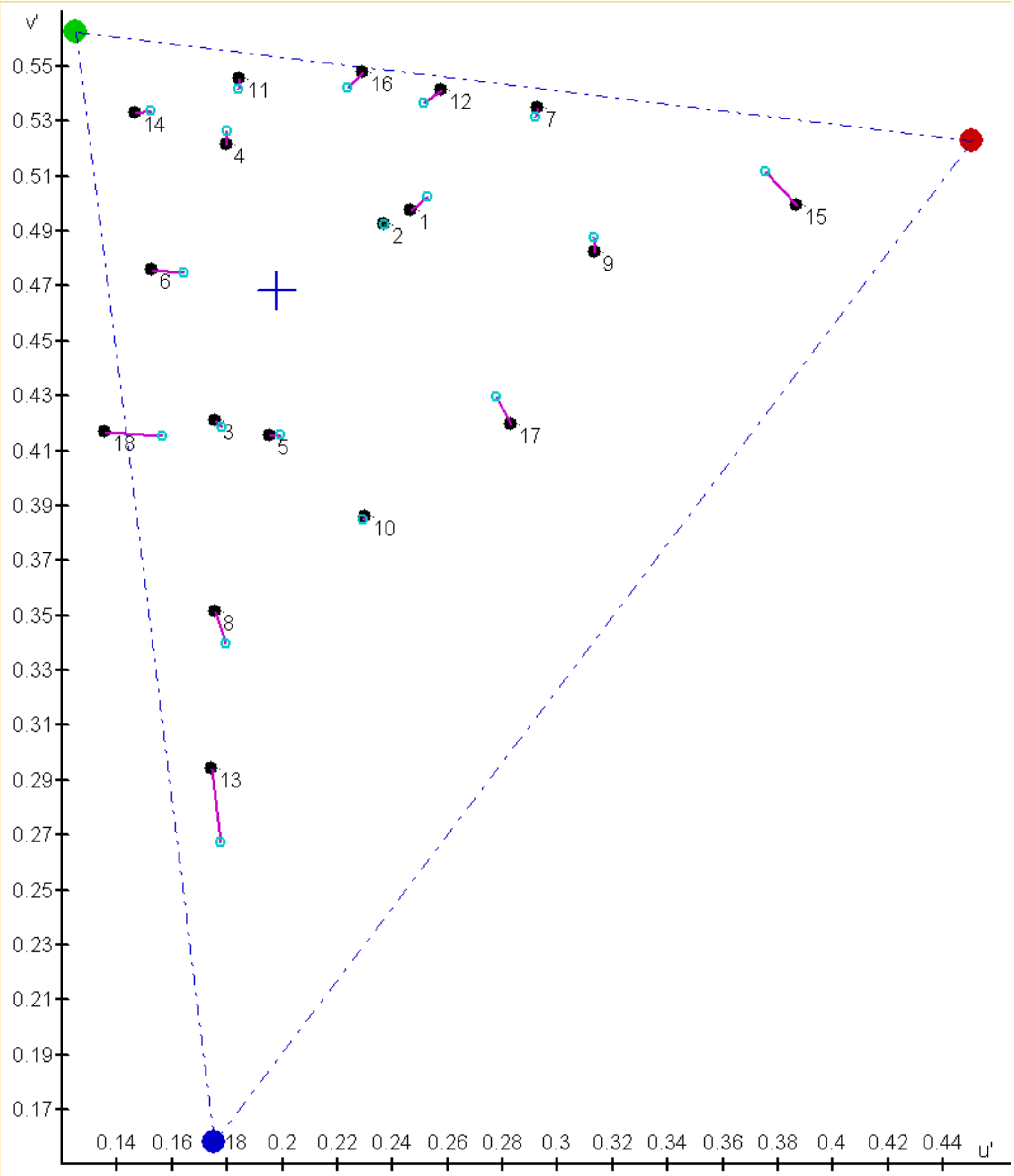

Figure A4.5: Chromaticity diagram, CIE 1976 u' v'

Appendix 5: EBU standard camera curves - 2012

Values for this table are derived from measurements made by Per Böhler [see EBU Tech 3353].

nm	$\bar{r}$	$\bar{g}$	$\bar{b}$	nm	$\bar{r}$	$\bar{g}$	$\bar{b}$
380	0.000000	0.000000	0.000000	**575**	0.032310	0.025210	0.000369
385	0.000000	0.000000	0.000215	**580**	0.054310	0.013264	0.000329
390	0.000000	0.000000	0.000649	**585**	0.067330	0.007350	0.000260
395	0.000000	0.000000	0.001397	**590**	0.072830	0.004418	0.000190
400	0.000000	0.000000	0.003902	**595**	0.073060	0.002611	0.000110
405	0.000000	0.000000	0.007905	**600**	0.071650	0.001707	0.000070
410	0.000450	0.000110	0.014223	**605**	0.068640	0.001084	0.000000
415	0.001000	0.000211	0.021958	**610**	0.063800	0.000482	0.000000
420	0.001230	0.000321	0.029294	**615**	0.059260	0.000030	0.000000
425	0.001300	0.000482	0.036253	**620**	0.054600	0.000011	0.000000
430	0.001300	0.000562	0.042739	**625**	0.049390	0.000008	0.000000
435	0.001190	0.000633	0.048916	**630**	0.044370	0.000006	0.000000
440	0.001120	0.000753	0.055513	**635**	0.039570	0.000003	0.000000
445	0.001040	0.000934	0.061881	**640**	0.034540	0.000000	0.000000
450	0.000930	0.001175	0.068628	**645**	0.029440	0.000000	0.000000
455	0.000860	0.001386	0.073179	**650**	0.025030	0.000000	0.000000
460	0.000820	0.001777	0.075694	**655**	0.021030	0.000000	0.000000
465	0.000820	0.002239	0.077461	**660**	0.017900	0.000000	0.000000
470	0.000890	0.002902	0.078010	**665**	0.014960	0.000000	0.000000
475	0.000890	0.003555	0.074377	**670**	0.012170	0.000000	0.000000
480	0.000970	0.004488	0.066582	**675**	0.009710	0.000000	0.000000
485	0.000890	0.006175	0.053601	**680**	0.007740	0.000000	0.000000
490	0.000890	0.010664	0.036619	**685**	0.005880	0.000000	0.000000
495	0.000890	0.021297	0.022597	**690**	0.004350	0.000000	0.000000
500	0.000930	0.036343	0.012366	**695**	0.002900	0.000000	0.000000
505	0.001040	0.046681	0.008274	**700**	0.002000	0.000000	0.000000
510	0.001120	0.054634	0.006138	**705**	0.001340	0.000000	0.000000
515	0.001340	0.059594	0.004461	**710**	0.000950	0.000000	0.000000
520	0.001490	0.062114	0.003254	**715**	0.000710	0.000000	0.000000
525	0.001710	0.063761	0.002455	**720**	0.000530	0.000000	0.000000
530	0.001790	0.065066	0.001996	**725**	0.000440	0.000000	0.000000
535	0.001670	0.066341	0.001707	**730**	0.000310	0.000000	0.000000
540	0.001410	0.067426	0.001407	**735**	0.000190	0.000000	0.000000
545	0.001150	0.068018	0.001228	**740**	0.000060	0.000000	0.000000
550	0.001120	0.068109	0.000998	**745**	0.000000	0.000000	0.000000
555	0.001190	0.066994	0.000928	**750**	0.000000	0.000000	0.000000
560	0.001710	0.063530	0.000779	**755**	0.000000	0.000000	0.000000
565	0.005920	0.054222	0.000599	**760**	0.000000	0.000000	0.000000
570	0.015630	0.041319	0.000489				

	$\bar{r}$	$\bar{g}$	$\bar{b}$
sum	1.000000	1.000000	1.000000

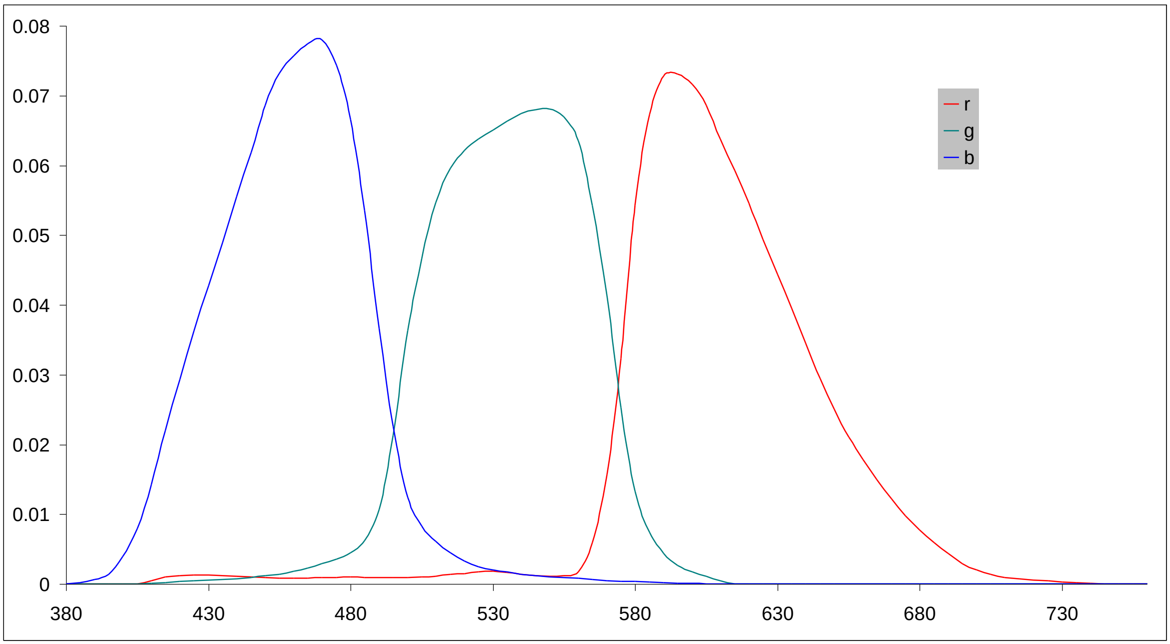

Figure A5.1: EBU standard camera responsivities - 2012

Optimised matrix

	R	G	B
R	1.182	-0.209	0.027
G	0.107	0.890	0.003
B	0.040	-0.134	1.094

	R	G	B
sum	1.329	0.547	1.124