JUNTA DE ANDALUCIA

CONSEJERÍA DE AGRICULTURA, GANADERÍA, PESCA Y DESARROLLO SOSTENIBLE
Dirección General de Calidad Ambiental y Cambio Climático

Correlated colour temperature (CCT), used up now, described the colour of the light as it is perceived by the human eye, but it is not a true measure of the amount of blue light emitted.

Colour temperature in kelvins

SPECTRAL G
INDEX

Spectral index G measures the amount of blue light emitted by a light source in the visible range. This colour is more harmful at night for biodiversity and for astronomical observations.
This Ministry, with the aim of protecting the areas with best sky quality, is going to restrict the amount of blue light using spectral index G.

Luminic zone	Spectral index G	Comparison spectral index G / CCT (K) for different light sources	
		Fulfill	**Do not fulfill**
E1, E2 and E3 inside E1	G≥2.0	Amber PC: 4.9 / 1727 Low pressure sodium: 3.8 / 1834 High pressure sodium: 2.2 / 2010 Incandescent: 2.1 / 2554 Fluorescent: 2.05 / 3000 LED: 2.1 / 2244 LED: 2.02 / 2500	LED: 1.9 / 2340 LED: 1.6 / 2680 Incandescent: 1.5 / 2574
E3	G≥1.5	LED: 1.6 / 3000	Fluorescent: 1.46 / 2569 Metal halide: 1 / 2719 LED: 1.2 / 3000
E4	G≥1.0	LED: 1.06 / 4000	Metal halide: 0.4 / 4700 LED: 0.8 / 4000

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CONSEJERÍA DE MEDIO AMBIENTE Y ORDENACIÓN DEL TERRITORIO

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1. CONTEXT

The outstanding quality of the night skies over Andalusia is a natural heritage, an identity symbol, that provides added value to the biological and geological diversity of our region. In fact, **82% of land surface has night skies dark enough to allow observing the Milky Way**; this implies that 17% of the population can enjoy this privilege not having to leave their municipality. Thus, **our sky provides a scientific, economic, cultural and landscape resource that generates green employment related to its preservation**, materialised in sectors such as astrotourism, specialised consulting and R+i, these two last demanding high qualification levels.

As an evidence of all this, **the Community houses the astronomical observatories of Calar Alto and Sierra Nevada, both of them of international relevance,** that help to raise the scientific level in Andalusia through outstanding findings such as the ring surrounding the dwarf planet Haumea, or the participation in pioneer projects as CARMENES, that has developed an unique instrument that already has given its first fruits with the discovery of several new exoplanets. Beside these, there are other observatories in Andalusia that contribute to the production of relevant data, and to education and public outreach as well.

However, **this natural heritage is endangered by the light pollution caused by lighting installations designed not taking into account sustainability criteria, and by a misguiding culture of light** that links development to energy waste.

Notwithstanding, it is worth noting that the industry of outdoor lighting has experienced an evolution from the origin, when only luminotechnical and monetary criteria were applied, to later incorporate the concept of energy efficiency and, finally, during recent years, environmental criteria as well.

Adverse effects of artificial light reach more than 100 km from the point where it is emitted, what means that light pollution generated in one area may exert negative impact on another, even if this is located far away. This means that public professionals bear the responsibility to guarantee, in the frame of our competences, that public lighting systems are designed and managed under sustainability criteria. This

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way we will guarantee not only the preservation of the night sky, but also of ecosystems and health, beside the reduction of energy costs and emission of atmospheric pollutants at municipalities.

To this end, the Andalusian regional government, **Junta de Andalucía, raised stakes for the preservation of the natural darkness of night more than one decade ago,** through the inclusion of this subject in the regional regulation by means of the Law for the Integrated Management of Environmental Quality (Ley 7/2007 de 9 de julio de Gestión Integrada de la Calidad Ambiental) and its ancillary regulation, in year 2010.

Lots of work have been done since then, based on a close cooperation among different administrations, what allowed optimising public resources and establishing a valuable network of collaborators at both national and international levels.

Now, **the Andalusian Ministry for Agriculture, Livestock, Fishing and Sustainable Development (Consejería de Agricultura, Ganadería, Pesca y Desarrollo Sostenible) deals with a new ancillary regulation for the preservation of the natural darkness of night against light pollution.** This regulation includes at its core several measures for a sustainable design of outdoor lighting, through the implementation of the following environmental guidelines: **light has to be shed only where and when needed, with levels and colours adapted to the activities to be developed in the lighted area.**

One of these guidelines stands out in recent years: the colour of light. This is due to the increasing spread of white light with high blue content, the kind of emissions more harmful to biodiversity and to astronomical observations. At the same time, according to most of the studies published, blue-rich light acts strongly on human health.

These are the reasons why this Ministry set up, in year 2011, an international group of experts to reach a common position regarding lighting and, specially, to promote using warm light, instead of white cool light. The conclusions of this group were published in German, English, Italian and Spanish, recommending light sources with reduced emissions in the blue band.

As a consequence of this Declaration, the Spanish Lighting Committee (Comité Español de Iluminación) set up a working group to analyse possible hazards linked to lighting based on LED technology. This

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Ministry was invited to participate in this group, that emitted its conclusions in year 2018 showing the need to restrict blue-white light at night.

The spectral index G has been developed with the aim of quantifying this parameter. This index is, result of a 100% Andalusian R+i effort powered by this Ministry, characterizes the spectral properties of light sources in a way that allows their quantitative and accurate classification according to the true amount of blue light compared to the total amount of visible light. Including this parameter among the technical specifications of lamps would provide a new sustainability criterium to commercial lighting products.

This Ministry will incorporate the spectral index G to the new ancillary regulation for the preservation of the natural darkness of night against light pollution, aiming to guarantee that light sources with the minimum amount of blue light content are used, during the night, across all the Andalusian territory. Specific thresholds on G will be established depending on the lighiting zone in which the lighting facility is to be installed. Also, to facilitate the computation of this value, a free tool based on open software has been developed and it is available at our web site.

During 2018 this Ministry was sharing criteria on sustainable lighting with the European Commission's Joint Research Centre, and this collaboration lead to the recommendation to use spectral index G to quantify and to limit the emission of blue light, in their publication Green Public Procurement of Road Lighting.

2. PURPOSE

This document provides all the information that any interested person may need in order to compute values of the G index for a light source. Section 3 offers a general description at the level of public outreach, and Section 4 describes the foundations for the computation. After that, Section 5 includes the restrictions to light sources that, based on the spectral index G, will be implemented in the future regulation for the preservation of the natural darkness of night against light pollution. Three final annexes explore in depth several mathematical aspects, and offer practical examples for using the index in design cases.

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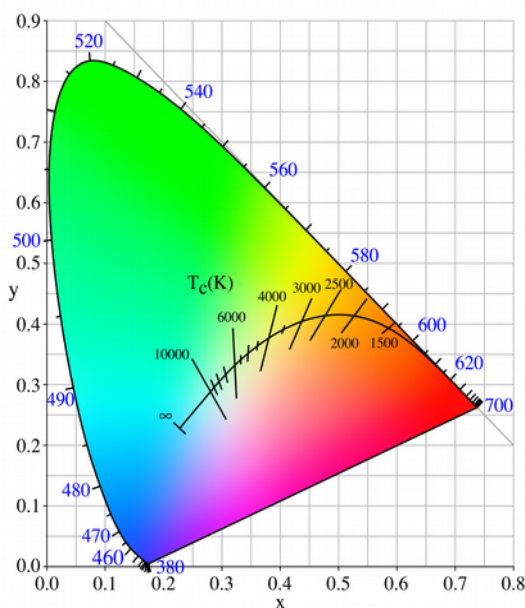
3. SPECTRAL INDEX G: DESCRIPTION

For a long time, the colour of artificial light was considered an aspect of secondary importance for the design of lighting facilities, a characteristic with an interest closer to decoration or aesthetics. The situation has changed in recent decades.

3.1. HOW TO MEASURE THE COLOUR OF A LIGHT SOURCE

Chromatic Reproduction Index (CRI)

This parameter evaluates the performance of light sources to allow the human eye to distinguish colours in illuminated objects. It is relevant in design cases in which a correct reproduction of colours is required for the main use of the space as, for example, in events that are going to be broadcasted by TV.

Fig. 1. One of the most usual versions of the colorimetric diagram of CIE. Coordinates x,y determine the hue perceived by the human eye. The rim of the figure with fingerprint shape corresponds to pure spectral hues, labelled with their wavelength in nanometres. The central curve is the black body "locus", and the corresponding colour temperatures are given. Source: Wikimedia Commons.

The Colorimetric Diagram

The International Commission for Lighting (CIE) uses a *colorimetric diagram* in which two coordinates (x and y) specify any of the colour hues that the human sight can distinguish (Figure 1).

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Colour Temperature and Correlated Colour Temperature

This parameter dates from the times when lighting systems were based on incandescent lamps. Any incandescent body emits light for the simple reason of being hot. When the object temperature is low, then most of the radiation emitted belongs to the infra-red part of the spectrum, this is the reason why heat systems based on electric resistances are called "infra-red heaters". A metal piece heated enough gets "red-hot", and further heating may lead to whitish hues before the material gets fused. Incandescent and halogen lamp filaments are designed not to fuse when reaching very high temperatures, and this makes the light from some halogen lamps to become very white, or even bluish.

All objects that emit light for the simple reason of being hot receive, in physics, the denomination of "black bodies", and their colorimetric coordinates fall on a single line in the diagram depicted in Figure 1. Thus, the *colour temperature* of an incandescent lamp is determined by the location of its temperature mark on the colorimetric diagram, and it is measured in the Kelvin, absolute scale, equivalent to adding 273 units to the usual temperature measurement in Celsius. The Sun itself is an incandescent source with a colour temperature around 5800 kelvins.

But today we do not light with incandescent lamps any more. Modern lamps are based on physical principles very different to black bodies. Even though, lighting industry still follows the tradition of describing the approximate hue of the light emitted by lamps by means of the temperature that a black body should have in order to display a colour as similar as possible to that of the lamp. This is the origin of the concept of *correlated colour temperature (CCT)*: given a lamp, instead of specifying the colorimetric coordinates *x,y* for its light (what would provide an exact diagnose of its perceived colour), we look for the black body (incandescent lamp) whose colour is closest, and we give the temperature of that black body, in kelvins.

Of course, this procedure means that, in some general way, lamps labelled with higher CCT values emit light that is whiter (with a larger blue component, less reddish), because this is what happens with black bodies, i.e., with incandescent and halogen lamps. However, important deviations arise. If we want to evaluate the amount of blue light produced by a light source, then CRI and CCT are not optimum parameters, even though they may have some orientative value and, in fact, they are being used with this purpose, lacking better suited measurement systems.

3.2. THE NEED FOR A NEW METRIC FOR BLUE LIGHT

Let us underline that all these systems, CRI, CCT and colorimetric coordinates *(x,y)*, are linked to the human perceptual system, and they provide their most useful services in this context. However, studies performed during the last decades have shown the convenience of restricting the amount of blue light injected into the nocturnal environment, for reasons related to the protection of the night sky and the ecosystems, and to protect human health.

Controlling blue light is, thus, one of the actions to be undertaken to assess the environmental sustainability of outdoor lighting installations, and we wee that the parameters being used up to now to evaluate this aspect (CRI, CCT, colorimetric coordinates) have only an orientative value, they do not fulfil the function we pursue.

We conclude that we have to develop a measurement system that quantifies what we want to control: the amount of blue light emitted by a lamp, per unit of visible light produced.
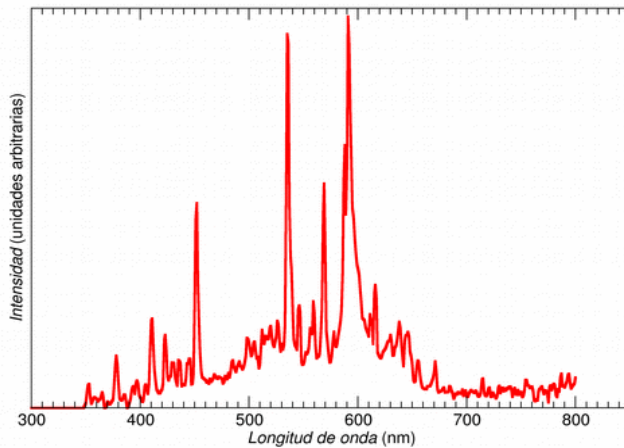
3.3. INDEX G: FROM SPECTRUM TO MEASUREMENT

All the information about the light emitted by a lamp is contained in a graph named *spectrum*. This graph displays light wavelength at the horizontal axis. We know that light is an electromagnetic wave that is described, among other parameters, by the distance between two consecutive peaks, the *wavelength.* This length is so tiny that it is specified using very small units, normally nanometres.

The wavelength of visible light extends from 470 nm to 780 nm, and there exists a relation between wavelength and perceived colour, in such a way that from one extreme to the other we cover the traditional colours of the rainbow: violet, blue, yellow, orange and red. For wavelengths lower than 470 nm we talk about *ultraviolet* , and about *infra-red* above 780 nm.
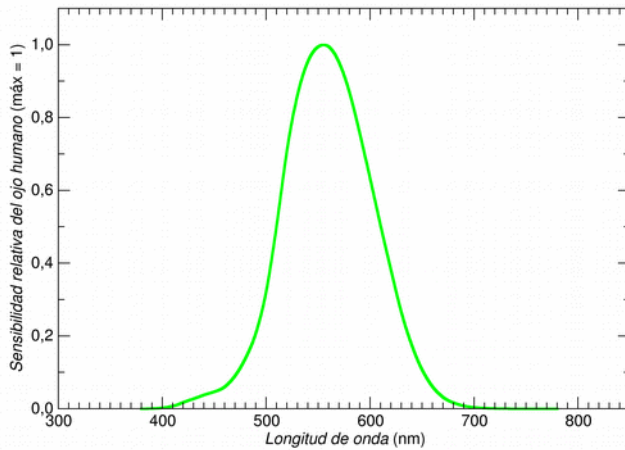
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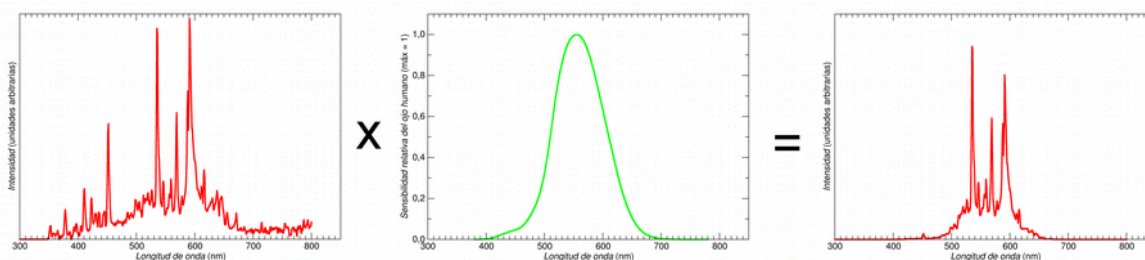*Dirección General de Calidad Ambiental y Cambio Climático*

Fig. 2: Spectrum for a metal halide lamps. For each wavelength (horizontal axis), the emitted intensity in arbitrary units (vertical axis) is provided.

The spectrum is the graph that gives, for each wavelength, the intensity of light emitted by the lamp.

Fig. 3: Human eye photopic sensitivity curve. This graph is at the basis of the metrological system used in lighting technology, and it is implicitly included in the definition of units as lumen, candela, lux, and their derivatives.

The human eye is not equally sensitive to all wavelengths. The photopic curve shows that humans are specially sensitive to light with green pure spectral hues, but much less to blue and reddish colours. The units of measurement used in lighting technology (candelas, lumens, luxes and their derivatives) are linked to this sensitivity curve. For this reason, taking a lamp spectrum and multiplying it by the photopic curve, we get the part of the spectrum that is acting in an effective manner for lighting purposes.

Fig. 4: First step for the calculation of index G. The lamp spectrum (left) is multiplied by the photopic sensitivity curve (centre) to obtain the part of the spectrum that represents visually effective light (right). Summing up the values in the resulting graph we get a quantity that is proportional to the lumens emitted by the lamps. After this, a similar process is applied to the same spectrum, in order to extract from it the "blue" part (emission from 380 nm to 500 nm) and summing up.

The spectral index G allows the computation of the blue content produced by each unit of visually effective light. For a deeper analysis, see Section 4 of this document. As a final comment, let us underline that, according to its definition, higher values of the G index mean lower amounts of blue light.

4. SPECTRAL INDEX G: COMPUTATION

The spectral index G is a luminotechnical parameter that measures the quantity of blue radiation emitted by a lamp, per unit of visible light, or per lumen. The value of G increases when the quantity of blue light diminishes. Section 3 includes a summary, for general readers, about the way this index works. Now we proceed to provide a rigorous definition, with mathematical support, and to interpret it in its adaptation to legal texts.

The information we want is the amount of blue light from a lamp, in relation to the total amount of useful light that it produces. To get these quantities we have to eliminate from the spectrum the part of radiation that is not interesting, and this is made by means of specific filters.

A spectral filter F is a function of wavelength λ, $F(\lambda)$, that takes values from zero to unity, and that selects a specific interval of wavelengths when it is multiplied by an emission spectrum $E(\lambda)$. Given the spectrum of a light source, we select a filter that allows the pass of radiation only at the wavelength zone of interest, around the interval where the filter function reaches its maximum value of unity.

This way, **the filtered spectrum $F(\lambda) \cdot E(\lambda)$ obtained results null for the wavelengths where $F(\lambda)$ is zero, is equal to $E(\lambda)$ wherever $F(\lambda)$ is one, and takes values lower than $E(\lambda)$ for wavelengths where $F(\lambda)$ has intermediate values, if any.** Figure 4 shows an example of this operation.

The spectral filters used in to compute the spectral index G are defined as:

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a) **H380×L500: allows radiation only from 380 to 500 nm.** This means that it is equal to unity for λ values between 380 nm and 500 nm, and it is null for any λ value outside this interval.

b) **V: allows radiation only in the part of the spectrum to which the human eye is sensitive.** It is equivalent to the photopic sensitivity curve defined by the standards of the Commission International de l'Éclairage, normalised to maximum unity. This curve is shown in Figure 3.

This way, the spectral index G relates the radiation to be restricted, the amount of blue light (radiation below 500 nm, down to 380 nm) to the radiation visually useful, i.e., the amount of visible light (radiation allowed by the photopic filter, that produces useful lumens).

This document includes in Annex I the technical justification for the selection of these two spectral filters.

Let us go through the process to compute G from spectral data obtained in laboratories:

Given the spectrum E of a light source, and given the spectral filters H380×L500 and V, all three curves defined as functions of wavelength λ as E(λ), H380×L500(λ), V(λ), the spectral index G is computed as the result of multiplying factor -2.5 by the decimal logarithm of the quotient of the integrals of the filtered spectra, being the numerator E(λ)·H380×L500(λ) and the denominator E(λ)·V(λ). The integration variable is wavelength and the integrals are computed in the interval 380-780 nm.

Integrals are interesting only from the point of view of the rigorous, theoretical definitions, but in laboratory and engineering practice, empirical spectra are available always as discrete tables, for which integrals translate into simple summations. For this reason, for its legal use, the practical computation of index G is formulated in terms of summations, and it is specified that the source tables have a step equal to 1 nanometre in wavelength. From this adaptation, and from the definition, we deduce the following formula, to be applied to the light source spectrum E(λ) tabulated with 1 nm resolution, and from the photopic sensitivity curve of human sight V(λ) normalised to maximum unity and tabulated with the same resolution:

$$G = -2.5 \log_{10} \frac{\sum_{\lambda=380\,\text{nm}}^{500\,\text{nm}} E(\lambda)}{\sum_{\lambda=380\,\text{nm}}^{780\,\text{nm}} E(\lambda)V(\lambda)}$$

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Pay attention to the fact that filter H380×L500 disappears from the practical formula, because it is substituted by the summation limits specified in the numerator (there the spectrum is summed up only from 380 to 500 nm).

If the resulting G value is equal to zero, then this means equilibrium: the lamp emits the same quantity of energy in blue radiation as in visually effective light.

G increases for sources ever "redder". The higher the G value, the more visible light there is, compared to blue emissions.

This definition for the spectral index G has several interesting implications. For instance, G can be computed from any lamp spectrum independently from the measurement units used to express intensity. The spectral index G is not referred to any standard source: for its computation, the lamp spectrum itself acts as self-calibrator. G is easy to compute, because the data already produced and used in laboratories to deduce CRI, CCT, etc., are more than enough to find the G value for any lamp. The logarithmic character of the scale makes it easy to compare lamps by means of simple additions and subtractions. Furthermore, this logarithmic scale is the same already used in astronomy, what means that the units are the same featured in studies on light pollution for the measurement of sky brightness in magnitudes per square arcsecond, studies that are already getting into the field of colour analysis, what leads in the most natural way to exactly the same scale used to define G.

This Ministry has developed a simple tool to make easier the computation of this new indicator. The spreadsheet is available at our website.

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5. SPECTRAL INDEX G IN THE FUTURE ANDALUSIAN REGULATION

Index G is included in the future regulation for the preservation of the natural darkness of night against light pollution with the aim of establishing environmental requirements for light sources depending on the luminic zones in which the lighting devices are installed.

This table summarises these spectral requirements:

Luminic zone	Spectral index G
E1, E2 y E3 inside E1	G≥2.0
E3	G≥1.5
E4	G≥1.0

In influence areas of reference points, defined as those in which astronomical observatories develop their activities, the regulation will allow only **amber light sources assimilable to monochromatic.** This assimilation is understood as having **spectral index G equal to or larger than 3.5**, effective wavelength in the interval 585-605 nm, and spectrum with equal to or smaller than 25 nm. The definition of these additional concepts are provided in the annexes to this document.

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ANNEX I: FILTERS TO COMPUTE THE SPECTRAL INDEX G

These are the considerations taken into account to select the spectral filters used in the definition of the spectral index G, H380×L500 and V:

1. **Filter H380×L500**: it allows radiation only from 380 nm to 500 nm. The limit of 500 nm is frequently used in scientific studies to evaluate the detrimental effects of artificial light at night, because many perturbations are due to light below this wavelength. The limit at 380 nm is set for technical reasons, to make easier the computation of G at laboratories, because all certifying lighting laboratories use spectrographs that yield data from, at least, this threshold.

1. **Filter V**: We use symbol V to denote the photopic sensitivity curve of human vision, displayed in Figure 2 in the main body of this document. All luminotecnic parameters, the candela and its derived units (lumen, lux, etc.), are computed using the photopic curve. Thus, if we want the index G to mean amount of blue light per lumen, it is necessary to make its computation compatible with this metrological scale. This way, the spectral index G relates the radiation to be restricted, i.e., the amount of blue light (radiation from 380 to 500 nm) to the useful radiation produced, i.e., the amount of visible light (radiation allowed bye the photopic filter, generating useful lumens).

Let us add that, even though the lighting industry currently tends to use the argument that the mesopic regime is dominant, this would be correct only in theory because, in practice, unfortunately, lighting systems are designed at light levels leading to the photopic regime in most cases. In any case, the candela and its derived units are still the foundation of the metrological system of luminotechnics, what forces to use the photopic curve to establish a meaningful link.

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ANNEX II: COMPLEMENTARY FORMULAE RELATED TO THE SPECTRAL INDEX G

Definition of *G*:

$$G = -2.5 \log_{10} \frac{\sum\limits_{\lambda=380\,\text{nm}}^{500\,\text{nm}} E(\lambda)}{\sum\limits_{\lambda=380\,\text{nm}}^{780\,\text{nm}} E(\lambda) V(\lambda)} = -2.5 \log_{10} \frac{B}{V} = -2.5 \log_{10} Q \quad (1)$$

Where $E(\lambda)$ is the lamp spectrum and $V(\lambda)$ stands for the photopic sensitivity curve. B (summation at the numerator) is the power emitted in the blu, and V (summation at the denominator) is the visually effective power, or visual flux. Both B and V are measured in units of power (or related to power), and these units will depend on how the original spectrum $E(\lambda)$ is expressed, but these units are not relevant to the effects of defining G, because the quotient is adimensional in any case. Do not confuse the photopic curve $V(\lambda)$ and the summation V. Q is the quotient of summations.

Definition of effective wavelength:

Effective wavelength is one of the legal criteria to decide whether a light source can be assimilated, or not, to monochromatic. For practical purposes it is defined this way:

$$\lambda_{\text{ef}} = \frac{\sum\limits_{\lambda=380\,\text{nm}}^{780\,\text{nm}} \lambda\, E(\lambda)}{\sum\limits_{\lambda=380\,\text{nm}}^{780\,\text{nm}} E(\lambda)} \quad (2)$$

Effective wavelength may be understood as the lambda value corresponding to the "centre of gravity" of the spectrum. For smooth spectra, such as those of black bodies or LED lamps, this wavelength will fall on a value placed at a spectral area with a significant amount of emission, but for discharge lamps this value may be placed at a location with whatever intensity value. In theory, the computation of this "centre of gravity" should be performed over the whole spectrum, but in practice the calculation is restricted to the wavelength interval most usual for certification lighting laboratories.

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Definition of spectrum width:

The second parameter that plays a role to decide if a source is assimilable to monochromatic is spectrum width, defined in practical terms as:

$$\Delta \lambda = \frac{1}{E_{máx}} \sum_{\lambda=380\,nm}^{780\,nm} E(\lambda) \quad \text{(3)}$$

Spectrum width admits, too, an intuitive interpretation. It is the width of a rectangle that, having the same height as the maximum value of the spectrum, has an area equal to the total area embraced behind the spectrum graph. Again, the computation is restricted to the interval most usual at laboratories.

Power quotient Q from spectral index G:

The logarithmic index is translated into the corresponding quotient just isolating Q from the definition (1):

$$Q = \frac{B}{V} = 10^{-0.4\,G} \quad \text{(4)}$$

Where B is the blue power and V the visually effective power, quantities identified with the summations in (1).

Emitted blue power :

$$B = V\,10^{-0.4\,G} \quad \text{(5)}$$

B is got, this way, in the same units in which the visual effective power V is expressed, and attention has to be paid to the units of the original spectrum to make sure that both V and B are yielded in watts, for instance. In what follows we will admit that this is the case; thus, normally we will have V (also B) in watts, V [W].

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Lamp luminous flux *L* in lumens:

The candela, and its derived units (lumen among them), is defined in the International System including the arbitrary, and exact, constant 683 lm/W:

$$L[\mathrm{lm}] = 683\, V[\mathrm{W}] \qquad (6)$$

Blue power per lumen:

$$P_B[\mathrm{W/lm}] = \frac{B[\mathrm{W}]}{L[\mathrm{lm}]} = \frac{V[\mathrm{W}]10^{-0.4G}}{683\, V[\mathrm{W}]} = \frac{10^{-0.4G}}{683} = \frac{1}{683\cdot 10^{0.4G}} = \frac{1}{683\cdot 10^{\frac{2}{5}G}} \qquad (7)$$

This expression shows very clearly the interesting result, that P_B in watts per lumen can be derived from *G* no matter what units were used for the original lamp spectrum. Given *G*, you have also the value of blue watts per lumen. If, in addition, the luminous flux of the lamp in lumens, *L*, is known (because your are able to deduce it from the spectrum as 683 · *V* –equation (6)–, or because it appears in the documentation of the lamp), then the total blue power emitted, in watts, *B*, results multiplying P_B by the number of lumens, as shown below:

Total blue power:

$$B[\mathrm{W}] = \frac{L[\mathrm{lm}]}{683} 10^{-0.4G} \qquad (8)$$

This is not strange, because *L*[lm]/683 is *V* in watts (equation (6)), and for this reason this formula is equivalent to the previous equation (5).

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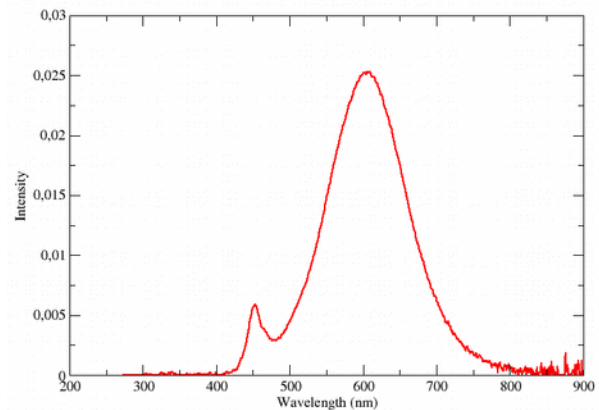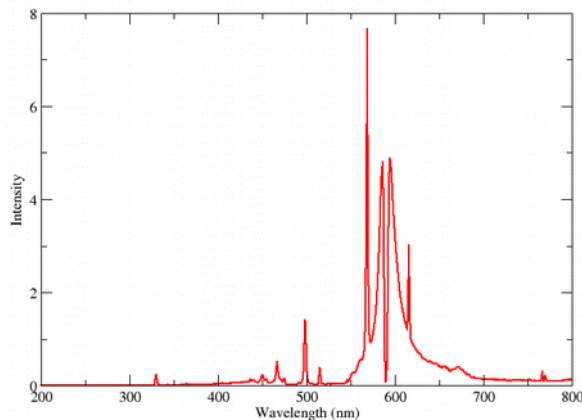
ANNEX III: TWO PRACTICAL EXAMPLES

One of the advantages of the spectral index G is that it is possible to perform numerical computations that are useful in design cases, something absolutely impossible if parameters such as CRI or CCT are used to evaluate (in a necessarily approximated way) the total amount of blue light emitted by an installation. We are going to work out two design cases. In one of them we compare sodium lamps to LEDs. In the second one we will compare to LEDs of different kinds.

Blue light in a change from high pressure sodium to LED

Let us consider a project case in which high pressure sodium lamps (HPS) are removed, to be replaced by LEDs. We want to answer the following question: if the light intensity of the installation is to be mantained (same total luminous power in lumens), what does the change imply in terms of total blue light?

First of all, let us pay a look to the lamp spectra. Let us suppose that they are these:

The original system is using HPS lamps labelled as CCT = 1880 K, and the new LED lamps that will be installed instead are 2500 K. But these values are not relevant in our problem. First of all, let us consider the G values. These may be computed from the spectra, or they may be stated among the technical specifications of the lamps. In this case, for HPS we have $G = 2.342$ and for this specific LED $G = 2.044$. These values clearly show that, according to the index G, HPS lamps are "redder". Thus, we assign label r (red) to sodium, and b (blue) to LED: $G_r = 2.342$, $G_b = 2.044$.

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Equation (5) from a Annex II can be arranged this way:

$$V = B \cdot 10^{0.4\,G}$$

Where exponent 0.4 is now positive, because it changed side in the process to isolate V. Stating this for both lighting systems:

$$V_r = B_r \cdot 10^{0.4 G_r}$$
$$V_b = B_b \cdot 10^{0.4 G_b}$$

But in our case the luminous power in lumens is conserved, thus $V_r = V_b$ and we get:

$$B_r \cdot 10^{0.4 G_r} = B_b \cdot 10^{0.4\,G_b}$$

$$\frac{B_b}{B_r} = 10^{0.4 G_4} \cdot 10^{-0.4 G_b} = 10^{0.4(G_r - G_b)}$$

But $G_r - G_b = 0.290$, what implies that $B_b/B_r = 1.316$ or, in other words, the new installation generates an amount of blue light equal to 1.316 times the original one, i.e., we have a blue light increase equivalent to almost 32 %.

The difference of G values is directly related to the increase (or reduction) of total blue light, if the total number of lumens is maintained.
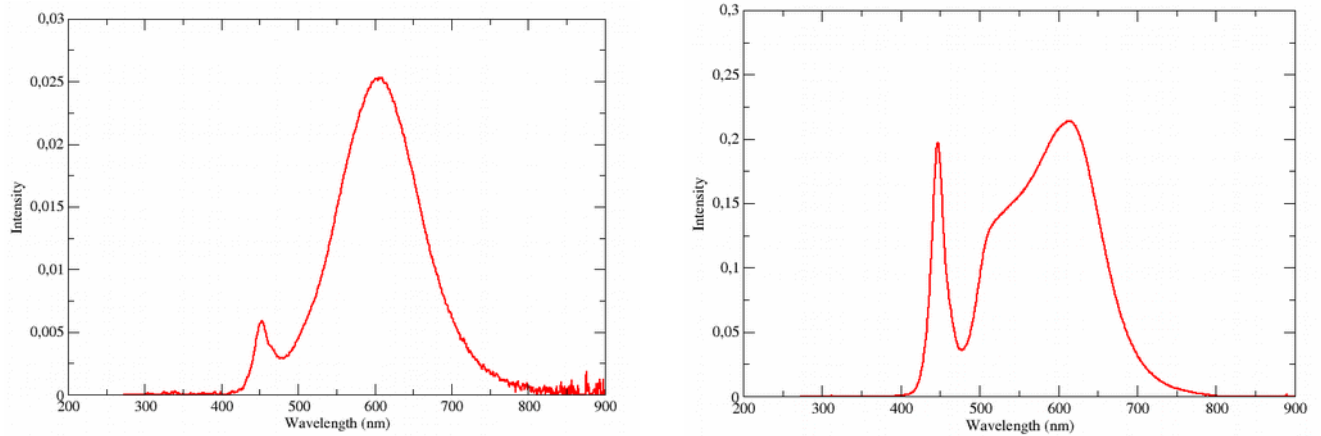

Limiting blue light in a wrong lamp change

In our second example we are going to consider what happens when we go from a LED installation with low blue emission to other LEDs with excessive blue output. Obviously, this should never be done but, as a case of study, it allows to ask: how much should we reduce the total luminous intensity (lumens) of the new system, is we want to keep the same total amount of blue emission of the original system?

As we see, this example is, in a sense, symmetric to the previous one. Now we start from Equation (5) from Annex II as it is, and we impose that B values have to be the same. Then, we compute the quotient of luminous fluxes that would provide this result.

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We suppose that the lams implied display these spectra:

The LED featured left is the same from the first example and has $G = 2.044$. The spectrum on the right (or its specifications sheet) indicates $G = 1.109$. Now the first LED is redder and the second is bluer; so, we have: $G_r = 2.044$, $G_b = 1.109$. By the way, let us comment that the second LED is labelled as having CCT = 3500 K, although this information is not useful now for us.

Again, we go to equation (5) from annex II and imposing that $B_r = B_b$ we deduce:

$$B_r = V_r \cdot 10^{-0.4 G_r}$$
$$B_b = V_b \cdot 10^{-0.4 G_b}$$

$$V_r \cdot 10^{-0.4 G_r} = V_b \cdot 10^{-0.4 G_b}$$

$$\frac{V_r}{V_b} = 10^{0.4 (G_r - G_b)}$$

The index difference is $G_r - G_b = 0.935$, what yields $V_r/V_b = 2.366$. We conclude that if we want to keep the same amount of blue light after the change of lamps, then we have to divide the luminous power installed by 2.366. This is equivalent to multiplying by factor 0.423. The new luminous power has to be 42 % of the original, if we do not want to inject more blue light into the environment.

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