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METHOD TO ESTABLISH A COLOUR QUALITY AND LUMINOUS EFFICACY RANKING FOR LIGHT SOURCES

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Abstract

A method for calculating two indexes that involves both luminous efficacy of radiation (LER) and colour quality (CQ) is presented. The generic name of these new indexes is Efficacy and Colour Quality (ECQ) and they are designed to classify groups of light sources in a ranking by analysing several of their spectrum features. With this calculation the optimal CQ/LER trade-off can be defined through the value given to a coefficient representing the weight that colour quality should have in the ranking established. Using a linear combination between the General Colour Quality Scale - Qa (Davis, 2010) and the Gamut Volume index (Oc) (Quintero, Hunt, Carreras, 2012), we obtained an suitable ranking over the 121-spectra database studied. Furthermore, it was demonstrated that the Gamut Volume index Oc has a very similar behaviour to the Gamut Area Scale index - Qg (Davis, 2010), indicating that both indexes are good predictors for object colour saturation of a light source.

Keywords: Colour Rendering Index, Colour Quality, Luminous Efficacy, LED.

1 Introduction

The selection of an adequate light source for a specific application involves the assessment of multiple factors, both subjective and objective, including colour temperature, preference for chroma enhancement (an increase of object colour saturation), and the well-known trade-off between Colour Quality (CQ) and Luminous Efficacy of Radiation (LER) required for each specific application. Currently, the only CIE standard index representing colour quality of a light source is the Colour Rendering Index -CRI (CIE, 1974). However, because this index has several limitations in correctly predicting colour rendering of emerging light sources such as LED, there is a general consensus about its re-evaluation. For these reasons, there have been several proposals to complement or replace this index which has not been updated since 1974. One of these proposals was presented in (Quintero, Sudria, Hunt, Carreras, 2012), consisting in a graphical representation of the colour rendering of a light source that can be accompanied with a numerical index such as the ECQ proposed here. In a previous analysis (Quintero, Hunt, Carreras, 2012), the authors found that a good predictor for colour quality of a light source should have at least two components or indexes representing colour rendering and object colour saturation in order to deliver optimum colour fidelity and colour preference. With the aim to proposing an index to value colour quality of a light source, we start by calculating the optimal colour volume generated by the optimal colours solid limit proposed by (MacAdam, 1935a) and (MacAdam, 1935b). This optimal colour volume is calculated over the 121-spectra light sources of Davis and Ohno work, (Davis, 2010) by using the algorithm proposed by (Masaoka, 2010). In these terms, we calculate Oc, presented in (Quintero, Hunt, Carreras, 2012) as the ratio between optimal colour volumes of test and reference light sources.

Since Oc is similar to CQS-Qg proposed by (Davis, 2010), but calculated using theoretical maximum values for the object colour saturation, we can say that both are good indexes representing object colour saturation of a light source.

In order to find an adequate expression for colour quality to calculate the indexes Efficacy and Colour Quality (ECQ) and Efficacy and Colour Quality with Colour Temperature (ECQt) that combine both luminous Efficacy of radiation and Colour Quality, we evaluate different combinations between two indexes that predict colour rendering, i.e. CIE-CRI and CQS-Qa, and two indexes that represent the object colour saturation: CQS-Qg and Oc. To meet the requirement, the Colour Quality equation has to give the highest score to well-recognized light sources having high colour quality. We used various math expressions to find an average between CIE-CRI and Oc using a trial and error process. We found a linear combination satisfying this requirement by using the square of the coefficients of correlation given in (Quintero, Hunt, Carreras, 2012). Finally, after having defined indexes to be used and how to calculate colour quality, it is possible to calculate ECQ and ECQt indexes based on weight functions of light source indexes, such as LER, CRI, Qa, Qg, Oc, and CCT. Thus, the indexes ECQ and ECQt can serve as a tool for the selection or analysis of a spectra collection of light sources in order to choose a light source with specific characteristics in the balance between colour quality, luminous efficacy of radiation and colour temperature. In this way, these indexes also can be useful as objective functions in optimization algorithms intended to synthesize light sources spectra with specific characteristics of colour quality, luminous efficiency of radiation and colour temperature of light sources based on monochromatic clusters of LEDs.

2 Method

In order to define and validate the behaviour of the ECQ and ECQt indexes we used the 121-spectra database taken from the spread sheet supplied courtesy of Davis and Ohno from (Davis, 2010). We calculated the following indexes: The Gamut Volume Oc - calculated applying the model presented in (Masaoka, 2010)-, general colour Quality Scale (CQS-Qa), Gamut Area Scale (CQS-Qg), CIE-CRI, Correlated Colour Temperature (CCT) and Luminous Efficacy of Radiation (LER). Moreover, statistics such as 100 percentiles were also calculated for the first five indexes mentioned above.

2.1 Definition of the weight functions

Prior to defining the basic equations for ECQ and ECQt, we have to define the weight function for six indexes: LER, CIE-CRI, CQS-Qa, CQS-Qg, Oc and CCT. Each weight function defined for these indexes has an input range that covers all possible values of the respective index, and the output range goes from 0 to 1. They are intended to give more or less influence to the corresponding index according to their frequency distribution, or what the user or lighting application requires. Five weight functions were created by following the curve generated by 100 percentiles for these indexes calculated over the 121-spectra database and shown in Fig.1-(a) to Fig.1-(e). In contrast to these functions, the sixth weight function that corresponds to CCT is a Gaussian function with parameters T_d and σ.

$$f_{wt}(CCT, T_d, \sigma) = e^{-\left(\frac{CCT - T_d}{\sigma}\right)^2} \qquad (1)$$

Equation (1) shows this function where T_d (mean) represents the preferred colour temperature for the output ranking; this parameter can vary from 1 700 K to 7 500 K. The second parameter σ represents the width of the Gaussian bell covering the desired colour temperature T_d. This parameter can take values from 1 000 (default) to more than 100 000. When σ takes lower values (narrow bell), this function gives high influence to the CCTs near to T_d; on the other hand, when σ takes values higher than 100 000, the function gives almost the same importance to every CCT at the input, in other words, the effect of the CCT in the output ranking almost disappears. These parameters are defined by the user: T_d depends on the lighting application, and σ represents the weight that user want to give to the desired temperature T_d. Figure 1-(f) represents this function with the parameters of T_d = 4 000 K, and *σ* taking values 1 000, 5 000 and 100 000.

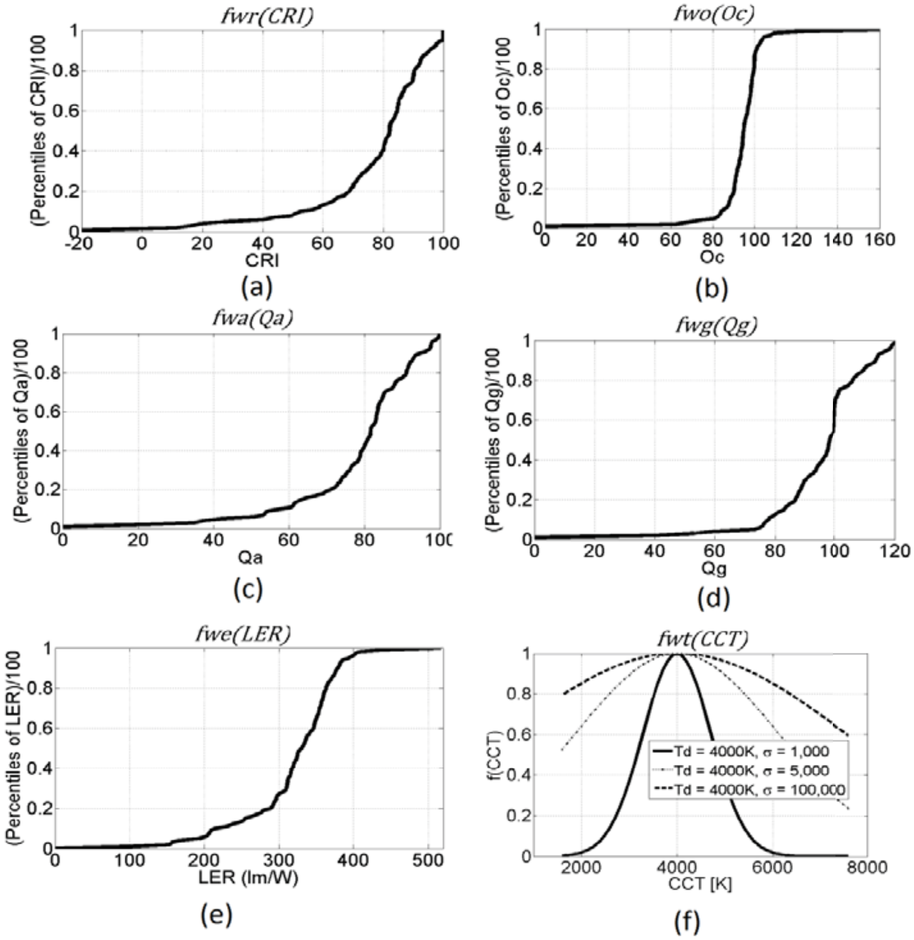

Figure 1 – The weight functions based on 100 percentiles for parameters CRI, Oc, Qa, Oc and LER, (a) to (e). Sub-plot (f) represents the weight function for CCT based in a Gaussian function plotted for T_d = 4 000 K and σ taking values: 1 000; 5 000 and 100 000.

2.2 Definition of the colour quality term

As was shown in (Quintero, Hunt, Carreras, 2012), a good index for colour quality of a light source should involve at least two indexes: One showing the colour rendering, i.e. by colour comparison (or colour fidelity), and another representing the object colour saturation that involves a subjective issue of colour preference.

In order to obtain the terms that can properly represent quality colour of a light source, we found the coefficients to calculate a weighted average between the CIE-CRI and Oc indexes, as explained above. We also wanted to evaluate other possibilities for this colour quality expression by using other three possible combinations including CQS-Qa and CQS-Qg indexes and the coefficients of correlation between these four parameters, as shown in Table 1.

Table 1 – Pearson coefficients of correlation of color rendering and object color saturation for the 121-spectra database

	CIE-CRI	CQS-Qa	CQS-Qg	Oc
CRI	1	**0,9496**	**0,6188**	**0,5773**
Qa		1	**0,7319**	**0,6064**
Qg			1	0,7913
Oc				1

Note: All values from this table have *p*-values for significance of correlation less than 0,001.

Now, we can formulate four options for a colour quality equation ranging between 0 to 1, by keeping the same structure of the equation found to evaluate colour quality by trial and error process and using the weight functions with their coefficients of correlation in Table1.

$$f_1(CQ) = \frac{0{,}9496^2 f_{wa} + 0{,}6188^2 f_{wg}}{0{,}9496^2 + 0{,}6188^2} \tag{2}$$

$$f_2(CQ) = \frac{0{,}9496^2 f_{wa} + 0{,}5773^2 f_{wo}}{0{,}9496^2 + 0{,}5773^2} \tag{3}$$

$$f_3(CQ) = \frac{0{,}9496^2 f_{wr} + 0{,}7319^2 f_{wg}}{0.9496^2 + 0.7319^2} \tag{4}$$

$$f_4(CQ) = \frac{0{,}9496^2 f_{wr} + 0{,}6064^2 f_{wo}}{0{,}9496^2 + 0{,}6064^2} \tag{5}$$

Where f_w are weight functions defined by 100 percentiles of the metrics calculated over the 121-spectra database and showed in figure 1, as follows:

f_{wa} = Weight function for Qa.
f_{wr} = Weight function for CRI.
f_{wg} = Weight function for Qg.
f_{wo} = Weight function for Oc.

In these terms we have to analyse four options, in order to conclude which one is the best option for the term corresponding to “Colour Quality” in the calculus of ECQ and ECQt indexes.

2.3 Definition of ECQ and ECQt indexes

As it was mentioned above, ECQ and ECQt indexes are intended to generate a ranking of several light source spectra. In this ranking the user has the possibility to choose the desired trade-off between luminous efficacy and colour quality by varying the value assigned to a input coefficient called k_{cq} (coefficient of colour quality); the user can give to it values from 0 to 1, where k_{cq} = 0 means zero importance to the colour quality in the ranking generated, while k_{cq} = 1 means 100 % of importance to the colour quality, Equations (6) and (7) show the basic form, or rms value, of the indexes ECQ and ECQt respectively.

$$ECQ_{rms} = \frac{1}{\sqrt{2}}\sqrt{[k_{cq} * f(CQ)]^2 + [(1 - k_{cq}) * f_{we}(LER)]^2} \tag{6}$$

$$ECQt_{rms} = \frac{1}{\sqrt{3}}\sqrt{[k_{cq} * f(CQ)]^2 + [(1 - k_{cq}) * f_{we}(LER)]^2 + [f_{wt}(CCT, T_d, \sigma)]^2} \tag{7}$$

where:

k_{cq}: Coefficient of Colour Quality, it can take values from 0.0 to 1.0
T_d: Desired colour temperature in Kelvin.
σ: Wide of the weight function for CCT, by default this parameter is set to 1000.
f(CQ): One of the four Colour Quality functions equation (2) to equation (5).
f_w: One of the six weight functions in figure 1.

From equations (6) and (7), we can see that when the coefficient k_{cq} increases, the weight to the Color Quality term also increases, but the weight of the LER term decreases. In these terms, when k_{cq} equals zero, the output value of the ECQ, depends exclusively on the weight function for LER. In other words, the ECQ index gives ranking to the spectra database, based only on their luminous efficacy of radiation value. The other extreme is presented when k_{cq} equals to one, in this case, the output ranking generated depends exclusively on the colour quality function.

In order to adjust the output values of ECQ and ECQt indexes to a range between 0 and 100, an extensive calculation of the equations (6) and equation (7) was performed using the four options for the colour quality term, equations (2) to (5), and varying values of T_d from 1 700 K to 7 500 K in steps of 10 K, k_{cq} from 0 to 1 in steps of 0,01 and $\boldsymbol{\sigma}$ from 1 000 K to 7 000 K in steps of 200 K. Table 2 shows the maximum and minimum values found for the 121-spectra database. These values are used to define the intercept and scale factor (slope) of the linear equation for calculating ECQ and ECQt indexes.

Table 2 – Maximum and minimum values found for ECQ_{rms} and $ECQt_{rms}$ over the 121-spectra database

	ECQ_{rms}	$ECQt_{rms}$
(Max)*100	70,71	81,65
(Min)*100	0,15	0,15

Finally, equations (8) and (9) show how to calculate indexes ECQ and ECQt respectively. The use of these equations over the 121-spectra database guarantees that their output values are in the range from 0 to 100.

$$ECQ = \frac{(ECQ_{rms} - 0{,}0015)}{(0{,}7071 - 0{,}0015)} * 100 \quad (8)$$

$$ECQt = \frac{(ECQt_{rms} - 0{,}0015)}{(0{,}8165 - 0{,}0015)} * 100 \quad (9)$$

3 Results

3.1 ECQ and ECQt with k_{cq} = 0,0 (full luminous efficacy required)

The score for the first 15 items ranked by ECQ and ECQt with k_{cq}= 0,0 (**ECQ_0**, **$ECQt_0$**), T_d = 4 500 K and σ = 1 000 calculated over the 121-spectra database are shown in Table 3. Here we can see that the score of the ECQ column is defined entirely by the values of the parameter LER, regardless of the colour quality function *f(CQ)* and CCT values. While the values of the ECQt column are affected by the CCT values, giving higher scores to light source with colour correlated temperature close to 4 500 K.

Here we have to highlight that the value of the ECQ_0 for a specific light source gives an idea of its position in the group respect to the maximum efficacy attainable (ECQ_0 = 100). For example, from the values of ECQ_0 in Table 3, we can say that all 15^{th} light sources are approximately in the fourth quartile of the luminous efficacy of radiation for the 121-spectra database.

Table 3 – First 15 items of the ranking defined by ECQ and ECQt with k_{cq} = 0,0; *T*d = 4 500 K and σ = 1 000 for the 121-spectra database

Lamp_Type	Efficacy	CCT	CRI	ECQ_0	$ECQt_0$
(#_ Description)	lm/W	K	---	---	---
013_LPS	516,9	1720	-47	100,0	70,7
014_457-540-605	408,3	3303	80	98,0	71,3
068_RGB(Ra=67)	404,8	3304	67	98,0	71,3
070_RGB(Ra=80)p.c	402,6	3304	80	97,0	70,6
018_3-LED-2Yellow	399,9	3306	85	96,0	69,9
032_Ide_Prim_Col	393,0	4240	69	95,0	94,2
082_Duv=+0.010(47	396,1	3005	86	95,0	67,5
081_Duv=+0.006(47	383,9	3003	85	93,0	66,1
093_4peak3012Kds4	382,6	2981	70	93,0	66,1
047_C100S54(HPS)	381,9	1970	16	92,0	65,0
062_F34T12/LW/RS	380,5	4165	50	91,0	90,2
009_HPS	380,9	2074	20	91,0	64,3
072_RGB_CRI_optim	378,3	3302	90	90,0	65,8
055_F34T12WW/RS/E	376,5	3013	50	89,0	63,3
094_4peak3020Kds3	375,6	2986	76	88,0	62,6

3.2 ECQ for k_{cq} = 1,0 (full colour quality required)

In this case, a comparison between the results of using each one of the colour quality function in equations (2) to (5) was performed. As a result, Table 4 shows the first 15 items ranked by ECQ with k_{cq} = 1,0 (**ECQ_{100}**) using the four options for the colour quality term in equation (8).

Table 4 – First 15 items of the ranking defined by ECQ with k_{cq} = 1,0 (ECQ_{100}) using four different options for the colour quality term and evaluated over the 121-spectra database

Lamp_Type	f_4(CQ); eq.(5) using CRI & Oc		f_2(CQ); eq.(3) using Qa & Oc		f_1(CQ); eq.(2) using Qa & Qg		f_3(CQ); eq.(4) using CRI & Qg	
(Description)	ECQ_{100}	Ranking	ECQ_{100}	Ranking	ECQ_{100}	Ranking	ECQ_{100}	Ranking
126_CIE_illum_A	83,9	1	92,5	5	86,1	9	86,2	2
131_CIE_illum_D75	83,6	2	94,2	4	87,5	3	85,6	6
127_CIE_illum_D65	83,2	3	94,5	3	87,2	4	84,6	8
130_CIE_illum_D55	83,1	4	95,8	2	87,1	6	82,8	11
129_CIE_illum_D50	82,2	5	96,2	1	87,2	5	81,4	15
011_Incandescent	80,5	6	91,5	6	84,8	12	82,3	13
046_60A/W(SofW	80,5	7	91,5	7	84,8	13	82,3	14
102_Broad4030Kref	79,0	8	89,0	9	86,6	7	85,9	4
041_CIE-F8	78,9	9	90,9	8	82,1	**16**	78,4	**17**
092_Broad3050	77,9	10	87,7	12	80,2	**20**	78,2	**18**
128_CIE_illum_C	77,2	11	88,6	11	88,0	2	85,9	5
031_EEW(380-780nm	76,1	12	88,7	10	88,2	1	85,1	7
057_F40/C75	74,5	13	86,7	13	82,5	15	78,8	**16**
019_461-526-576-6	74,1	14	81,7	**18**	84,8	11	86,3	1
097_4peak3000Kneu	73,9	15	82,6	15	85,2	10	86,0	3

If we take as a reference the ranking given by ECQ_{100} calculated by using equation (5), i.e. by using CIE-CRI and Oc, as Table 4 shows, we can see that several differences exist with the ranking established using the other functions for colour quality. To evaluate these differences over the 121-spectra database, we calculated the average of the ranking number difference ($D_{j,k}$), as is expressed in equation (10).

$$D_{j,k} = \frac{1}{121}\sum_{i=1}^{121}\sqrt{\left(R_{i,j} - R_{i,k}\right)^2} \tag{10}$$

where:

j and k can take values: 1, 2, 3 or 4 (four different options for the colour quality term in ECQ).

$R_{i,j}$ is the ranking number assign by ECQ_{100} for the i-th spectrum of the 121-spectra database with the j-th option for colour quality term.

Table 5 – Average differences of the ranking between the four options for ECQ_{100} in Table 4 calculated over the 121-spectra database

	$f_1(CQ)$ Qa&Qg	$f_2(CQ)$ Qa&Oc	$f_3(CQ)$ CRI&Qg	$f_4(CQ)$ CRI&Oc
$f_1(CQ)$; Qa&Qg	0	5,3	8,5	10,6
$f_2(CQ)$; Qa&Oc	5,3	0	10,9	**8,7**
$f_3(CQ)$; CRI&Qg	8,5	10,9	0	**8,0**
$f_4(CQ)$; CRI&Oc	10,6	8,7	8,0	0

From Table 5, we can determine how different the ranking established are over the 121-spectra using the four options presented in Chapter 2.2 for calculation of ECQ. We can take as a reference the function $f_4(CQ)$, with the CRI is a CIE standard, Oc is a value based on a theoretical maximum and the first seven items of its ranking generated by ECQ_{100} correspond to light sources that are well-recognized having high colour quality. Therefore, we can conclude by the difference of ranking with $f_4(CQ)$ and because the light sources ranked in the first 7 positions, that $\mathbf{f_2(CQ)}$, using weight functions of CQS-Qa and Oc, works adequately as a colour quality term for the calculation of ECQ and ECQt.

In addition, we can see that the lowest difference in ranking is presented between $f_1(CQ)$ and $f_2(CQ)$ functions; since both of them have as common factor CQS-Qa, we can infer that CQS-Qg and Oc indexes have very similar performance, as was already found in (Quintero, Hunt, Carreras, 2012).

3.3 Representation of ECQ

Figure 2 shows a 3D representation of ECQ index that was calculated by using equations (8) and (3) with σ = 1 000, and varying parameters k_{cq} and T_d. Here we can highlight that the light source with the maximum LER in the 121-spectra database (517 lm/W and CCT = 1 700 K) obtain a ECQ = 100 when the colour quality coefficient, k_{cq} = 0.0 (only the luminous efficacy term is taken into account), while this same light source got an ECQ = 0, for k_{cq} = 1,0 (only the colour quality term is taken into account), because its CQS-Qa and Oc are zero.

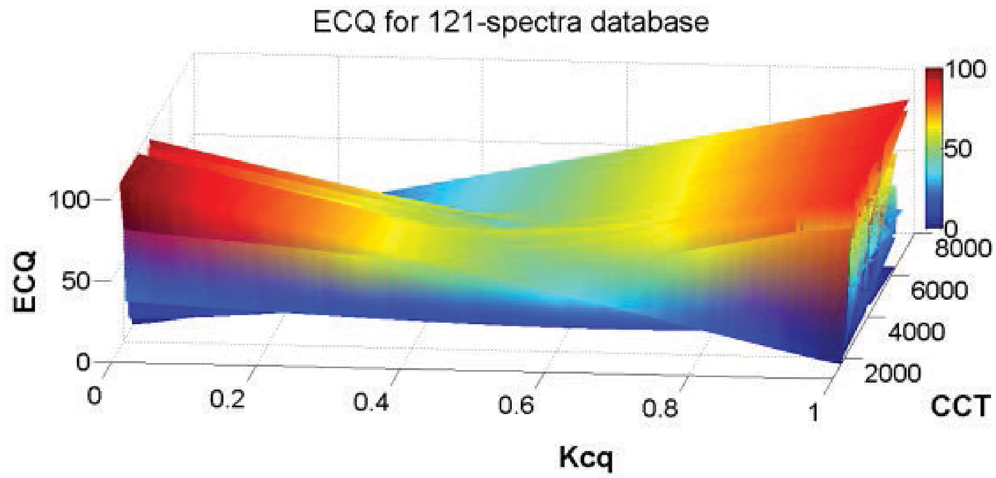

Figure 2 – 3D representation for ECQ calculated over the 121-spectra database

In general terms, we can say that this graphical representation of the ECQ index gives a quick and general idea of how well a ligh source can perform for its luminous efficacy of radiation and/or quality color characteristics. This could be useful in the process of selecting a light source for a especific aplication, in other words, a defined balance between luminous efficacy and color quality.

3.4 ECQ_{50}, ECQ_0 and ECQ_{100}

Table 6 shows the first 15^{th} items ranked by ECQ_{50} (k_{cq} = 0.5) using the selected colour quality function $f_2(CQ)$ that involve the weight functions CQS-Qa and Oc.

Table 6 – First 15 items of the ranking defined by ECQ with k_{cq} = 0,5 (ECQ_{50}), and its values with k_{cq}=0 and 1 (ECQ_0 and ECQ_{100}) using the selected colour quality function $f_2(CQ)$ evaluated over the 121-spectra database

Lamp_Type	LER	CCT	CRI	Qa	Qg	Oc	ECQ_{50}	R	ECQ_0	R	ECQ_{100}	R
(Description)	lm/W	K	---	---	---	---	---	#	---	#	---	#
019_461-526-576-6	360	3300	98	93	102	97	56,0	1	77	28	82	18
022_4LEDwith_ yel	359	3300	94	91	106	98	54,4	2	76	30	78	26
071_RGB(Ra=80)	375	3303	80	85	108	97	54,2	3	87	16	65	44
021_4LED_no_yel	354	3304	92	92	97	98	52,3	4	70	37	78	27
081_Duv=+0.006(47	384	3003	85	81	95	95	52,2	5	93	8	48	65
018_3-LED-2Yellow	400	3306	85	77	90	96	51,7	6	96	5	39	77
032_Ide_Prim_Col	393	4240	69	69	115	167	51,5	7	95	6	40	74
082_Duv=+0.010(47	396	3005	86	78	91	95	51,4	8	95	7	40	75
124_CreeF	357	3036	90	87	100	98	50,6	9	72	34	71	35
078_TriDuv=+0.010	371	3010	84	79	94	109	50,5	10	85	18	55	54
097_4peak3000Kneu	342	2950	95	93	107	98	50,4	11	58	51	83	15
020_4-LED-2(447	347	3300	91	92	98	98	50,4	12	61	47	81	22
125_CreeF2	353	3062	90	88	101	99	50,2	13	67	40	75	32
014_457-540-605	408	3303	80	74	95	90	50,2	14	98	2	23	99
073_4-color(Ra=90	349	3300	90	91	97	98	49,9	15	64	44	77	28

We have to highlight here, that using only the ECQ index, with different values of the coefficient k_{cq} (0,0; 0,5 and 1,0; in the case of Table 6), it is possible to obtain a quick idea of how a light source behaves for luminous efficacy and colour quality; this characteristic could be very useful in spectrum synthetizing algorithms, in order to match a light source spectrum with specific characteristics of colour quality and luminous efficacy.

3.5 $ECQt_{50}$, $ECQt_0$ and $ECQt_{100}$ with Td =3000K and σ=1000.

Table 7 shows the first 15 items ranked by $ECQt_{50}$ (k_{cq} = 0.5) using the selected colour quality function $f_2(CQ)$, and parameters T_d = 3000K and σ=1 000 (high weight to the correlated colour temperature).

From the data of Table 7, we can see that ECQt has higher values than ECQ, because the third CCT term increases the score. The ranking of Table 7 is quite influenced by the Correlated Colour Temperature of the light source, so it is evident that the highest score of $ECQt_{50}$ is given to the light source having the highest luminous efficacy and colour quality with the closest CCT to 3 000 K.

Data from Table 7 shows that ECQt index could be very useful in the process of selection a light source for a specific application that defines the "level" of colour quality and the colour temperature of the light source desired.

Table 7 – First 15 items of the ranking defined by ECQt with k_{cq} = 0,5 ($ECQt_{50}$), and its values with k_{cq}=0 and 1 (ECQ_0 and ECQ_{100}) using the selected colour quality function $f_2(CQ)$ with parameters T_d = 3 000 K and σ = 1 000 evaluated over the 121-spectra database

Lamp_Type	LER	CCT	CRI	Qa	Qg	Oc	$ECQt_{50}$	R	$ECQt_0$	R	$ECQt_{100}$	R
(Description)	lm/W	K	---	---	---	---	---	#	---	#	---	#
081_Duv=+0.006(47	384	3003	85	81	95	95	79,8	1	97	2	78	31
082_Duv=+0.010(47	396	3005	86	78	91	95	79,5	2	98	1	76	33
078_TriDuv=+0.010	371	3010	84	79	94	109	79,2	3	93	10	81	26
124_CreeF	357	3036	90	87	100	98	79,2	4	87	18	87	10
079_Duv=0.000(474	367	3003	82	83	100	94	79,0	5	92	12	81	25
097_4peak3000Kneu	342	2950	95	93	107	98	79,0	6	82	31	92	5
125_CreeF2	353	3062	90	88	101	99	78,9	7	85	24	88	9
095_4peak3022Kds2	363	2984	84	84	96	94	78,8	8	91	14	82	22
096_4peak3000Kds1	357	2964	90	88	99	95	78,8	9	87	19	86	14
092_Broad3050	325	3037	97	96	100	100	78,8	10	78	38	94	2
098_4peak3000Kst1	334	2952	88	91	111	100	78,4	11	80	33	91	6
093_4peak3012Kds4	383	2981	70	74	87	90	78,3	12	97	3	73	43
094_4peak3020Kds3	376	2986	76	78	90	91	78,0	13	94	7	74	40
077_TriDuv=+0.006	361	3008	85	82	99	96	78,0	14	90	15	80	28
099_4peak3010Kst2	327	2956	81	88	114	101	77,9	15	79	37	90	7

4 Conclusion

It was demonstrated that similar behaviour exist between CQS-Qg and Gamut volume-Oc indexes; since the latter is based on the maximum theoretical object colour saturation of a light source. We could infer that both indexes are good predictors for this feature. Moreover, it was found that a combination of CQS-Qa and the Volume Gamut–Oc indexes that represents quite well the colour quality term in the calculus of the ECQ and ECQt indexes. Finally the usefulness of the ECQ and ECQt indexes was demonstrated by establish an appropriate ranking for light sources that meets user and/or specific lighting application requirements and achieves a balanced trade-off between luminous efficacy and colour quality.

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