EMRP ENG05: Stakeholder Meeting

Guidelines on Application of SSL in State of the Art Lighting Applications

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25th April 2013

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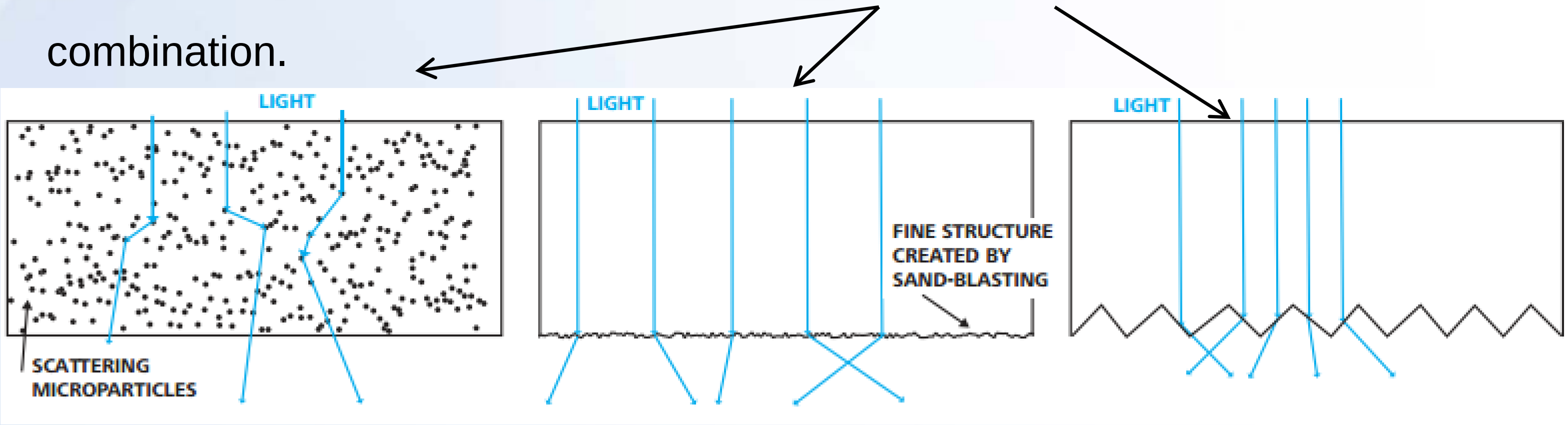
Overview for:
State of the art lighting application of SSL

- Lighting (including SSL) of public interior space have to fulfil requirements defined in EN 12464 and the relevant national and professional standards for the application, e.g. Museum lighting
- Interior applications: office, corridor, industrial, hospital, dentist, laboratory, spot, ambient, museum/gallery
- Criteria for lighting installations defined in EN 12464:

	Mainteined Illuminance $\overline{E}_m$ [lx]				Uniformity $U_0 = \frac{E_{\min}}{\overline{E}_m}$ [-]			CRI R_a [-]	UGR [-]
	Task area	Immediate surrounding	Ceiling	Walls	Task area	Immediate surrounding	Ceiling and Walls		
Min Required Value	20 - 5000	20 - 500	> 30	> 50	≥ 0.7	≥ 0.4	≥ 0.1	20-90	16 - 28

Aspects contributing to high visual comfort and pleasantness (1)

- To provide a smooth illumination of the environment, i.e. mitigate shadows (high uniformity U_0), minimize spatial chromaticity variations.
- First avoid a direct view of bare LEDs!
- Use of optical components (sheet or foil) diffuser/microprism/Fresnel or combination.



- Smaller spacing between LED chips leads to higher number of LED chips used but increases efficacy and uniformity.
- Longer distance between LED module & diffuser improves uniformity.

Aspects contributing to high visual comfort and pleasantness (2)

- For reflectors, indirect optical designs for luminaires can produce better performance.
- High reflecting surfaces are preferable,
- In many applications with partial diffusivity or faceted reflector

Specular reflection

Partial diffusivity

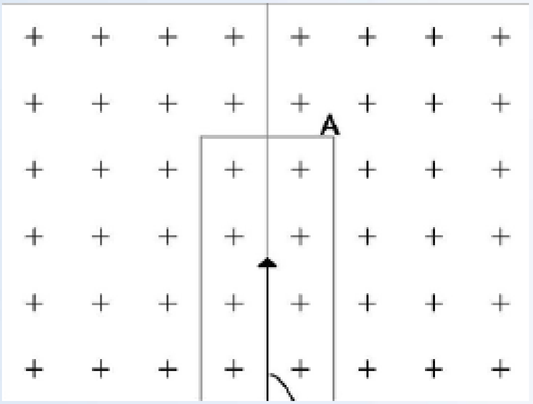
Glare and glare estimation

- UGR estimates glare of a lighting system illuminating a room in the given luminaire spacing of one luminaire
- Described in CIE 117:1995 & CIE 190:2010

Luminaire Spacing:

$CIE_{117:1995}$: 0.25H
$CIE_{190:2010}$: 1H

H – *Distance between line of sight & luminaire*



$$UGR = 8\log\left[\frac{0.25}{L_b}\sum_i \frac{L_i^2\omega}{p_i^2}\right]$$

L_b – luminance of the background

L_i – luminance of the luminous part

p_i – luminance of the luminous part

UGR table

glare rating acc. to UGR											
ρ-ceiling		70	70	50	50	30	70	70	50	50	30
ρ-walls		50	30	50	30	30	50	30	50	30	30
ρ-floor		20	20	20	20	20	20	20	20	20	20
room size X	Y	crosswise to lamp axis					parallel to lamp axis				
2H	2H	18.5	19.3	18.8	19.5	19.7	18.5	19.3	18.8	19.5	19.7
	3H	18.4	19.2	18.7	19.4	19.6	18.4	19.2	18.7	19.4	19.6
	4H	18.4	19.1	18.7	19.3	19.6	18.4	19.1	18.7	19.3	19.6
	6H	18.4	19.0	18.7	19.3	19.6	18.4	19.0	18.7	19.3	19.6
	8H	18.3	19.0	18.7	19.3	19.6	18.3	19.0	18.7	19.3	19.6
	12H	18.4	18.9	18.7	19.3	19.6	18.4	18.9	18.7	19.3	19.6
4H	2H	18.3	19.0	18.6	19.3	19.5	18.3	19.0	18.6	19.3	19.5
	3H	18.3	18.9	18.6	19.2	19.5	18.3	18.9	18.6	19.2	19.5
	4H	18.2	18.8	18.6	19.1	19.4	18.2	18.8	18.6	19.1	19.4
	6H	18.2	18.7	18.6	19.1	19.4	18.2	18.7	18.6	19.1	19.4
	8H	18.2	18.7	18.6	19.0	19.4	18.2	18.7	18.6	19.0	19.4
	12H	18.3	18.7	18.7	19.1	19.5	18.3	18.7	18.7	19.1	19.5
8H	4H	18.1	18.6	18.6	19.0	19.4	18.1	18.6	18.6	19.0	19.4
	6H	18.2	18.5	18.6	18.9	19.4	18.2	18.5	18.6	18.9	19.4
	8H	18.2	18.5	18.7	18.9	19.4	18.2	18.5	18.7	18.9	19.4
	12H	18.3	18.6	18.8	19.0	19.5	18.3	18.6	18.8	19.0	19.5
12H	4H	18.1	18.5	18.5	18.9	19.3	18.1	18.5	18.5	18.9	19.3
	6H	18.1	18.4	18.6	18.9	19.4	18.1	18.4	18.6	18.9	19.4
	8H	18.2	18.4	18.7	18.9	19.4	18.2	18.4	18.7	18.9	19.4
variation of observer position											
S =	1.0H	+3.5 / -5.3					+3.5 / -5.3				
	1.5H	+6.1 / -6.5					+6.1 / -6.5				
	2.0H	+8.0 / -6.6					+8.0 / -6.6				
standard-table		BK00					BK00				
correction		0.2					0.2				
corrected glare indices for 1894lm total flux											

Properties of UGR as it was defined in the CIE documents

- Purely numerical method characterizing the similarly as CRI.
- It is calculated from Luminous Intensity Distribution of curve of the luminaire
- Can be easily re-calculated for different parameters of the luminaire (flux, dimensions, installation height), e.g.:

$$UGR_1 = UGR_0 + 8\log\frac{\Phi_1}{\Phi_0}$$

- UGR can get negative
- Estimation of L_b uses lumen method and transfer factor values.
- Does not take into account luminance non-uniformity of the luminous parts.
- Does not take into account spectral composition of the light.

Effect of CCT and Colour Rendering/Shift on the User's pleasantness (1): Experimental set-up

	CCT [K]	ΔCCT [%]	CIE Ra	CRICAM-UCS	Observer's Preference Score
FL	4745	-5.10	93.7	94.3	85.35
LED NUV	5024	0.48	98.1	98.51	86.74
LED CW	5481	9.62	70.68	71.02	64
LED RGB	5293	5.86	35.58	49.72	40.23
LED WR	2906	7.63	88.56	86.79	88.14
CFL	2708	0.30	82	75.97	90.93
LED RGBY	2781	3.00	76.2	80.27	88.14
HAL	2739	1.44	99.7	99.02	97.91
LED WW	2624	-2.81	82.78	78.82	77.91

FL – *Fluorescent light*

LED NUV – *nUV peak LED with 3 Broadband phosphors*

LED CW – *Blue peak LED with yellow phosphor*

LED RGB – *RGB cluster*

LED RGBY – *RBGY cluster*

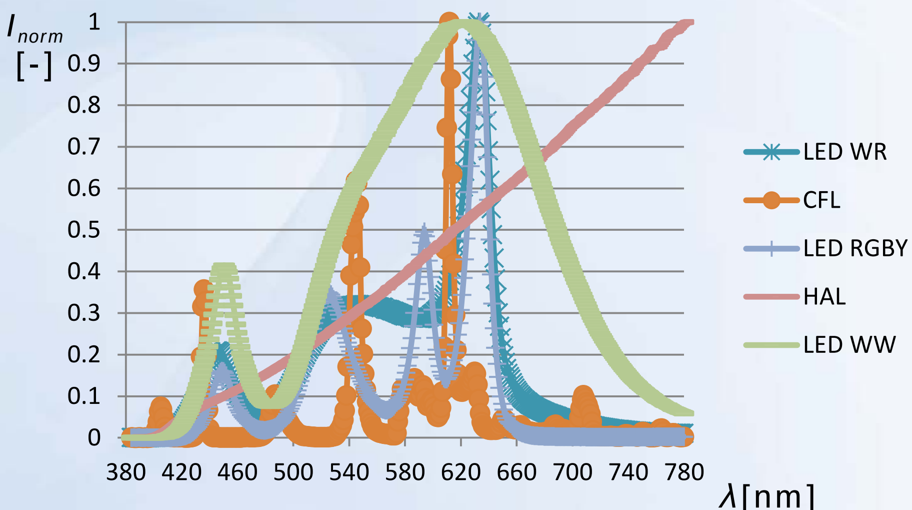
CFL – *Compact FL*

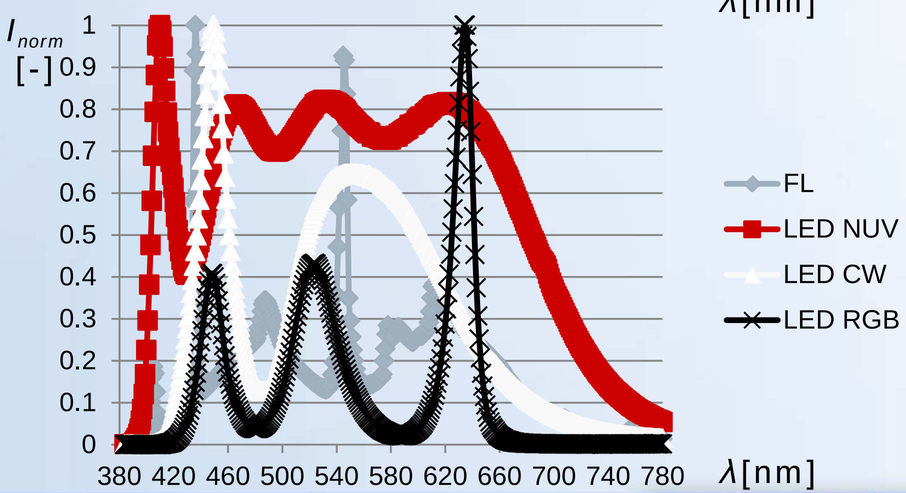
A80 – *Blue & Red peak LED with yellow phosphor*

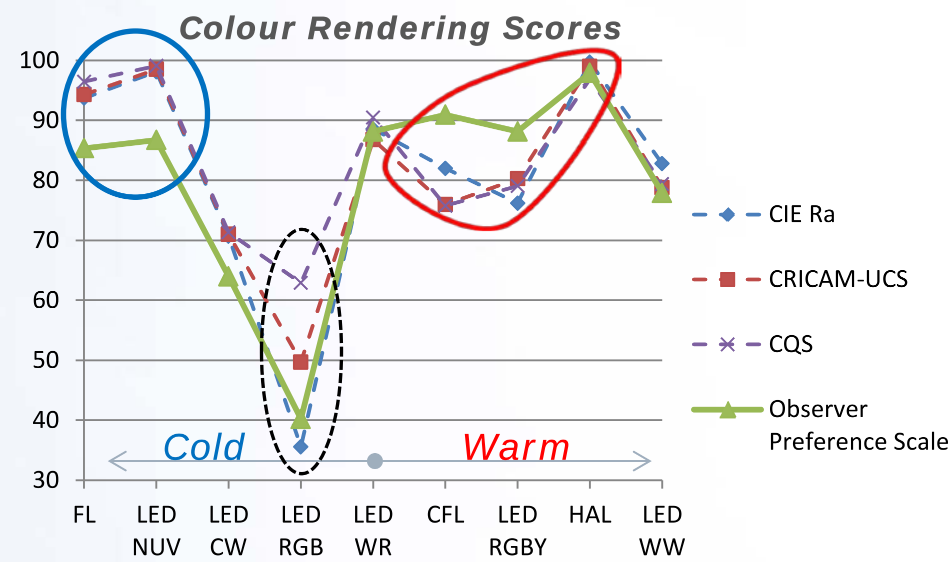
HAL – *Incandescent halogen*

LED WW – *Blue peak LED with yellow phosphor*

Effect of CCT and Colour Rendering/Shift on the User's pleasantness (2): Results



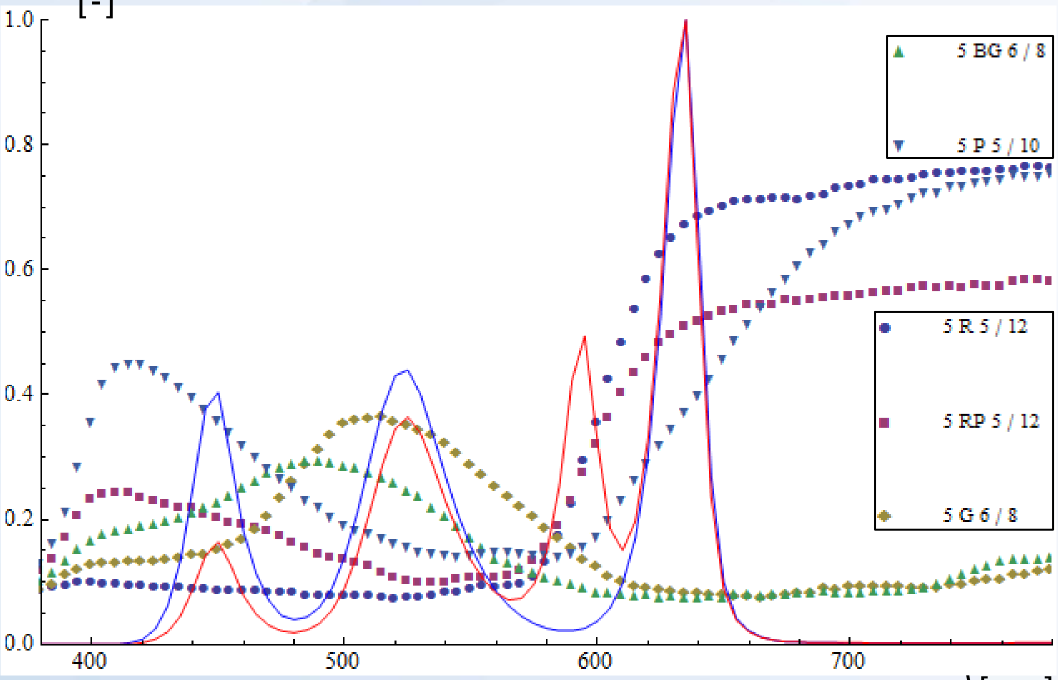




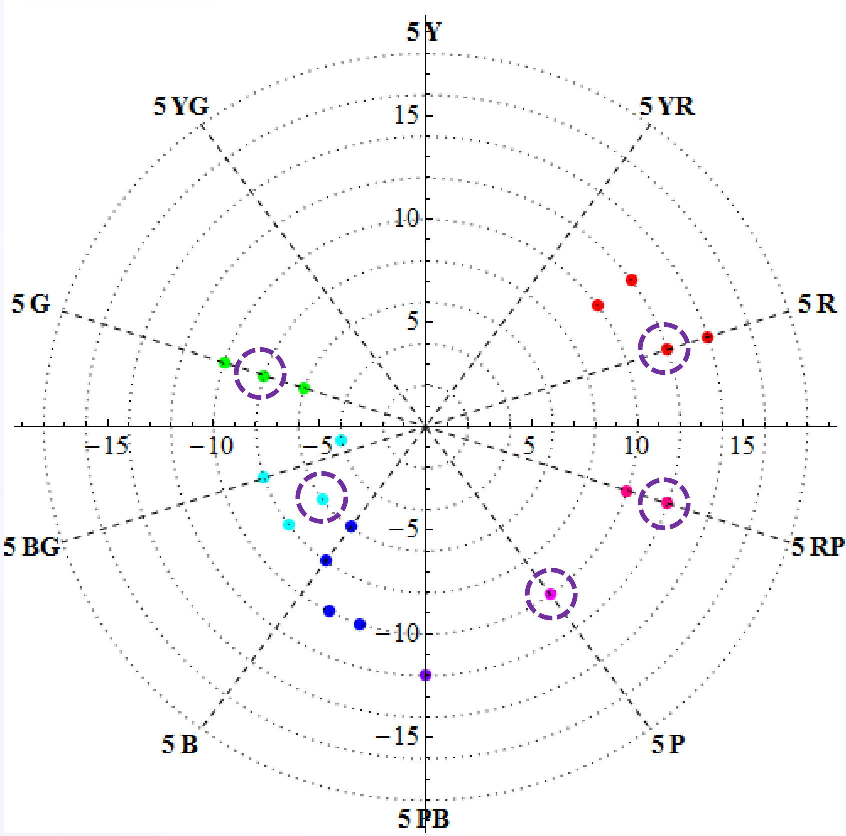
	CCT [K]	CQS	CIE Ra	CRICAM-UCS	Observer's Preference Score
FL	4745	96.45	93.7	94.3	85.35
LED NUV	5024	99.1	98.1	98.51	86.74
LED CW	5481	71.33	70.68	71.02	64
LED RGB	5293	62.89	35.58	49.72	40.23
LED WR	2906	90.48	88.56	86.79	88.14
CFL	2708	75.78	82	75.97	90.93
LED RGBY	2781	79.06	76.2	80.27	88.14
HAL	2739	96.91	99.7	99.02	97.91
LED WW	2624	79.4	82.78	78.82	77.91

Colour Rendering/Shift for RGB and RGBY Spectral Compositions – preword

Reflectance spectra of Matt Munsell TCSs and *spd* of the RGB and RGBY light

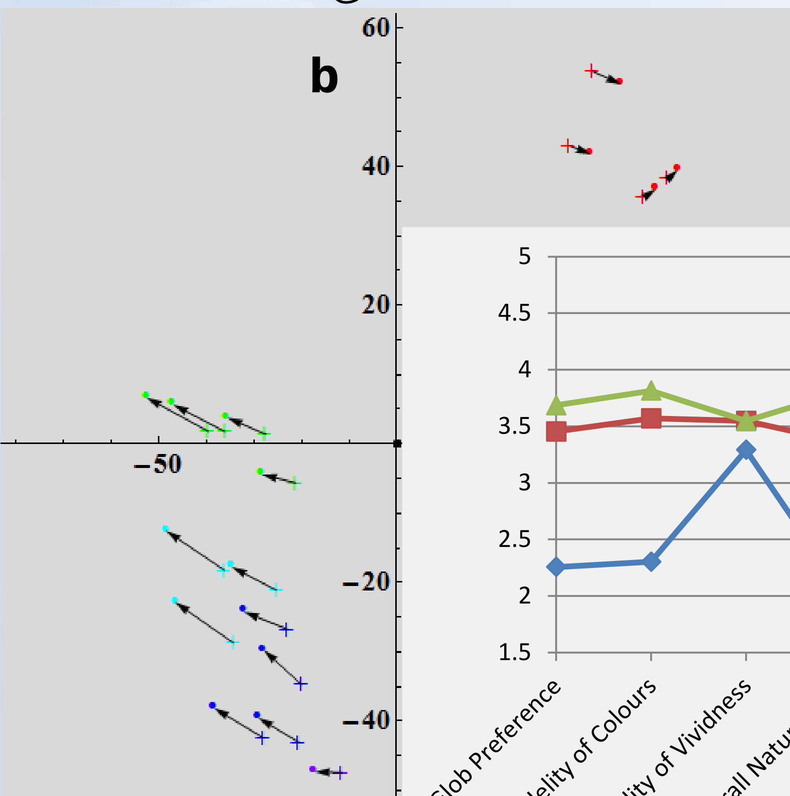


Position of the TCSs in Munsell Uniform Colour Space

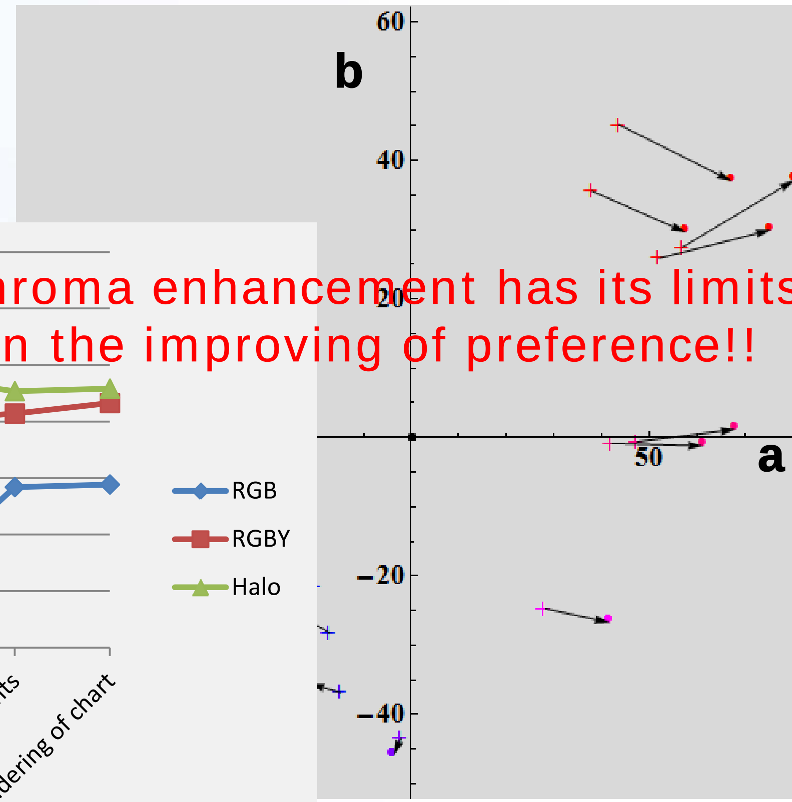


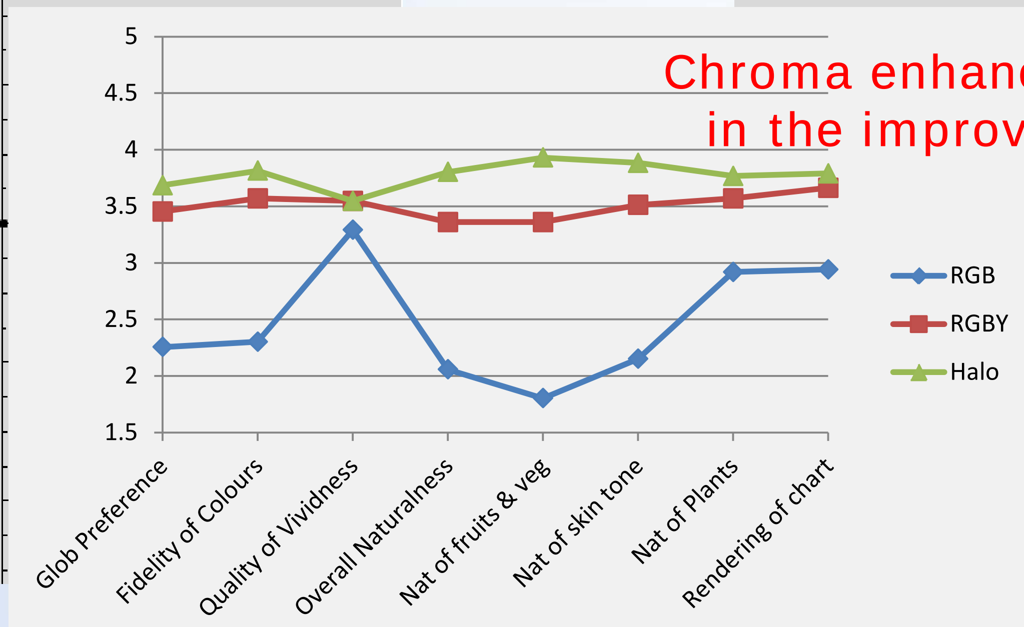
Colour Rendering/Shift for RGB and RGBY Spectral Compositions - Modelling & Appraisal

Colorimetric shifts of RGBY vs Planck radiator @ 2700K in Lab



Colorimetric shifts of RGB vs D50 in Lab





Chroma enhancement has its limits in the improving of preference!!

5 B 5 / 6	6.1	25.2	4.1	13.9
5 B 4 / 8	6.9	6.1	5.2	2.
7.5 B 5 / 10	7.7	10.7	5.6	6.5
10 B 5 / 10	6.4	4.8	4.5	2.7
5 PB 5 / 12	5.	6.	3.4	3.3
5 P 5 / 10	5.2	32.4	0.2	2.8
5 RP 5 / 10	4.7	46.	1.5	4.6
5 RP 5 / 12	7.6	43.7	2.3	2.8

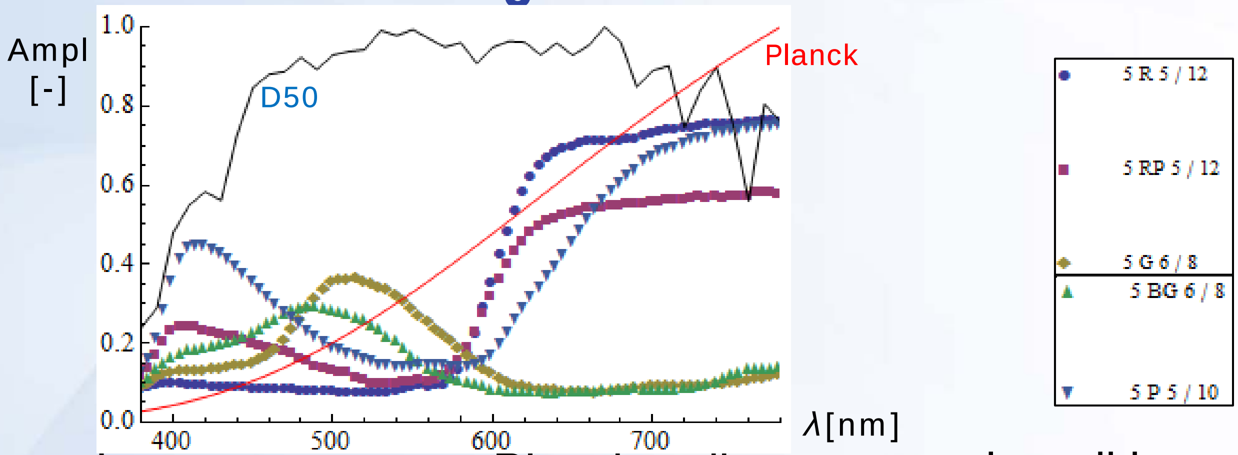
Effect of CCT and Colour Rendering/Shift on the User's pleasantness (3): Overall insight

- In the living room conditions observers did not feel comfortable in the environment illuminated by artificial cold CCT light – it has reminded hospital/dentist or workspace.
- Such response of the observers occurred even if the spectral composition of the light was very close to the daylight.
- Why is it so and what shall be investigated?

  Due to light coming from the ceiling, not a window??

  Due to broader surrounding, i.e. test room located in a huge laboratory hall, which the observer has memorised/related to??
- High observers' preference of CFL indicates that a "widely exploited spectrum" may win over preference. Users get used to it and appreciate.
- Thus memory colours effect shall be included in the colour rendering quality metric.
- However, other tendencies observed in the preference results.

Interaction of light and a coloured surface



- Low temperatures Planck radiators – good rendition of red hues.
- Daylight spectra with CCT ≥ 5000K – good rendition of blue hues.
- Warm lighting may benefit by (chroma) enhancing of the blue hues.
- Cold lighting may benefit by (chroma) enhancing of the red hues.
- Otherwise chroma enhancements can have disturbing effects on the Colour Rendering.
- LED solutions can provide all possibilities of chroma enhanecement – spectral compositions leading to disharmonious Colour Rendering shall be avoided.

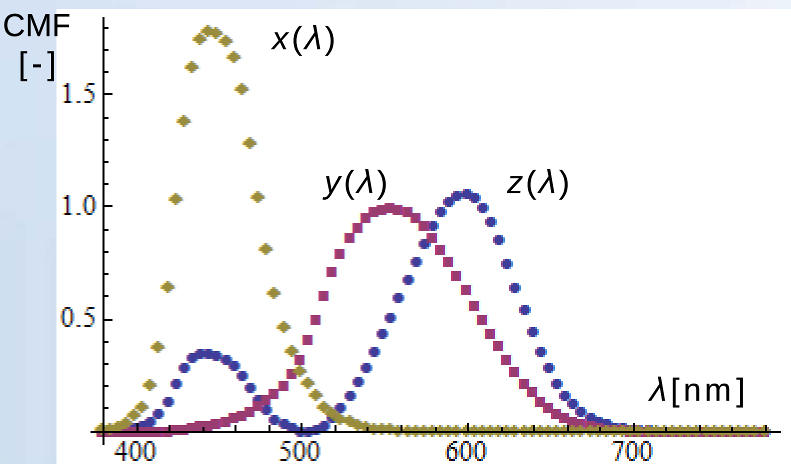
Assessment of Colour Rendition

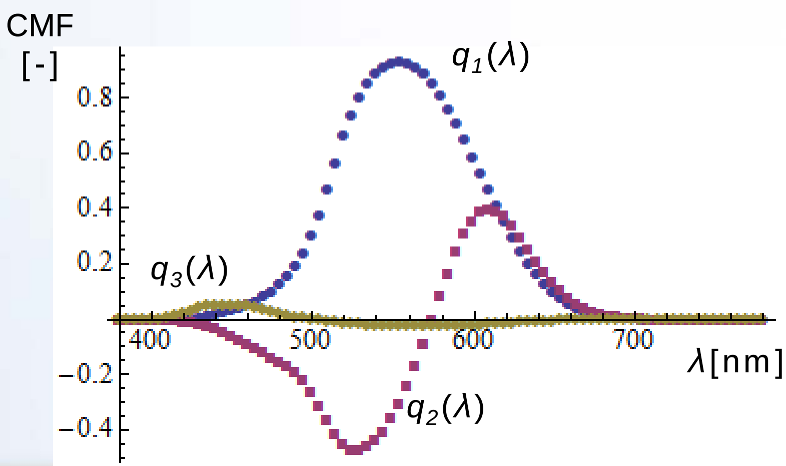
Traditional approach to the Colour Rendering

- Estimation of CR based on colour shifts of many (and preferably wisely selected) TCSs followed by applying a weighting procedure.

Alternative to the traditional approach

- Application of Opponent-Colour system Colour Matching Functions (CMFs): $a(\lambda)$, $t(\lambda)$, $d(\lambda)$; derived from 1931 CIE CMFs $x(\lambda)$, $y(\lambda)$, $z(\lambda)$ by a linear transformation.
- For more details about the method: J.A. Worthey, "Colour rendering: a calculation that estimates colorimetric shifts," Col. Res. Appl. (29), (2004).





Colour Rendering Metrics for the Tested spectral illumincances

- Two Reference/Pivot illuminance spectra used:
  Planck 2700K – good rendition of red hues,
  Daylight with CCT = 5000K – good rendition of blue hues.
- Colour rendering matrices are derived for the testing spectra used in the subjective experiment.
- Preference rating is provided too.

	Daylight 5000K	Preference Rating
FL	$\begin{pmatrix} 1. & 0.03 & 0. \\ 0.03 & 1.06 & 0.02 \\ 0. & 0.02 & 1.03 \end{pmatrix}$	85.35
LED NUV	$\begin{pmatrix} 1. & -0.03 & -0.01 \\ -0.03 & 1. & 0.01 \\ -0.01 & 0.01 & 0.88 \end{pmatrix}$	86.74
LED CW	$\begin{pmatrix} 1. & -0.01 & -0.02 \\ -0.01 & 0.81 & 0. \\ -0.02 & 0. & 1.17 \end{pmatrix}$	64
LED RGB	$\begin{pmatrix} 1. & -0.31 & -0.04 \\ -0.31 & 1.45 & 0.08 \\ -0.04 & 0.08 & 1.46 \end{pmatrix}$	40.23

	Planck 2700K	Preference Rating
LED WR	$\begin{pmatrix} 1. & -0.04 & -0.01 \\ -0.04 & 1.1 & 0.03 \\ -0.01 & 0.03 & 1.4 \end{pmatrix}$	88.14
CFL	$\begin{pmatrix} 1. & -0.08 & -0.04 \\ -0.08 & 1.06 & 0.08 \\ -0.04 & 0.08 & 1. \end{pmatrix}$	90.93
LED RGBY	$\begin{pmatrix} 1. & -0.06 & 0. \\ -0.06 & 1.31 & 0.04 \\ 0. & 0.04 & 1.27 \end{pmatrix}$	88.14
HAL	$\begin{pmatrix} 1. & -0.01 & 0. \\ -0.01 & 0.99 & 0. \\ 0. & 0. & 0.98 \end{pmatrix}$	97.91
LED WW	$\begin{pmatrix} 1. & 0.03 & -0.02 \\ 0.03 & 0.93 & 0.03 \\ -0.02 & 0.03 & 1.17 \end{pmatrix}$	77.91

Acknowledgement

- Acknowledgement to the collaborators, especially:
  - LNE
  - OMS

- The research leading to these results has received funding from the European Union on the basis of Decision No 912/2009/EC.

Thank you for your attention