Metrology
for Solid State Lighting

EURAMET
European Association of National Metrology Institutes

ENG05
Stakeholder
Presentation

LNE
Le progrès, une passion à partager

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Laboratoire national de métrologie et d'essais

ENG05 – Stakeholder Presentation
April 24th 2013 – NPL Teddington

WP3 : Human Perception of SSL

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WP3 : Human Perception of SSL

WP1: Traceability for SSL Measurements

WP2: Basic measurement methods for SSL characterisation

WP3: Human perception of SSL

- **Task 3.1 : Colour rendering**
- **Task 3.2 : Visual comfort**
- **Task 3.3 : Mesopic vision for outdoor lighting**

WP4: Quality metrics for SSL characterisation

WP5: Creating impact

WP6: JRP Management and Coordination

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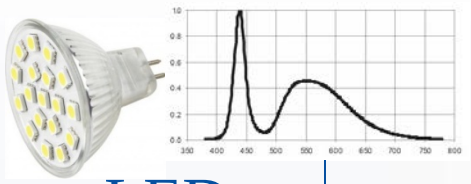
Introduction to the study on colour rendering metrics – task 3.1

The study on colour rendering was carried out following steps 1 to 6 for the ENG05, LNE will continue to work on step 7 to 8. We present today the achieved steps (1->5) and the direction of the step in progress (6).

1. **reviewing and analysing all proposals of metrics,**
2. **implementing relevant metrics,**
3. **applying implemented metrics on a collection of SPDs,**
4. **performing a real life subjective experiment in a real size test room,**
5. **processing and comparing subjective ratings with metric's predictions,**
6. *complementing and/or supplementing current CIE CRI index with refined proposals for a better correlation with subjective scoring/ranking,*
7. *performing another subjective experiment for validation and further study,*
8. *Continuing the development for improved colour rendering metric.*

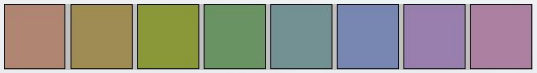
Colour Rendering: Reference-based approach implementation

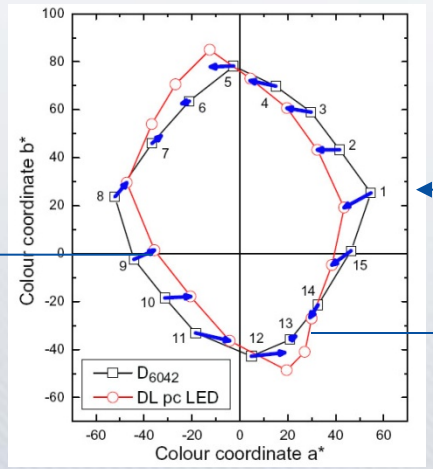
Test ⟷ comparison ⟷ **Reference**



LED → CCT → CIE Daylight / 5000 K / Planckian Radiator

Set of TCS → uniform colour space → Set of TCS





$\overline{\Delta E}$ ← |3D vector| (CRV) → Gamut (area)

(graph from Zukauskas – Colour rendition properties SSL paper)

Fidelity → **Quality Index** ← Vividness

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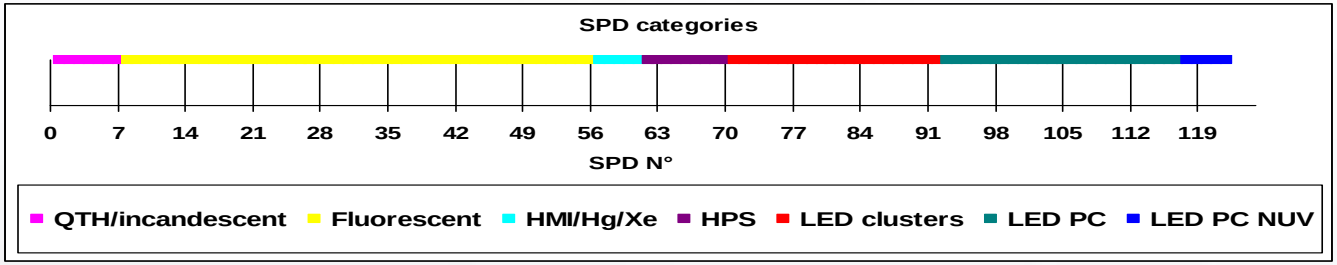
Review and implementation of proposals for a new metric

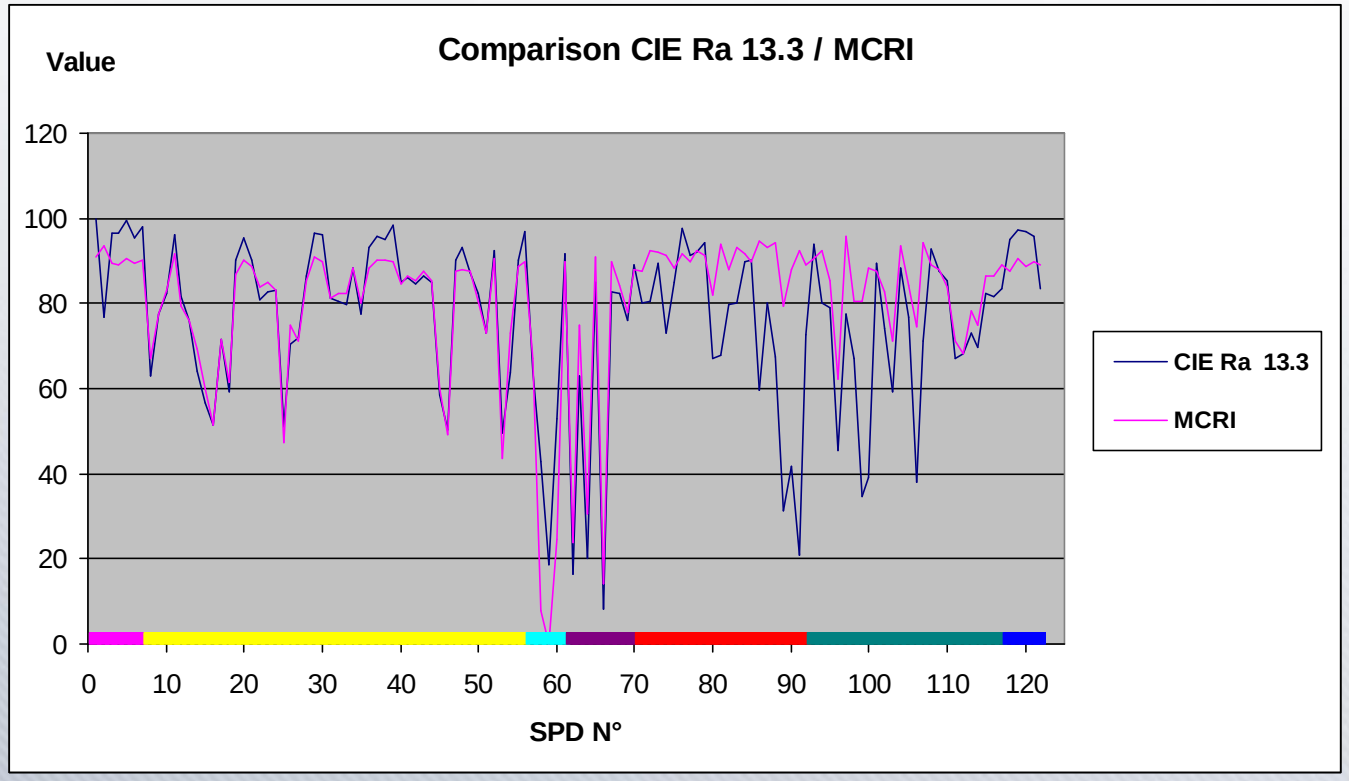
A review of proposals for colour rendition metrics has been conducted, then the metrics have been sorted and implemented.

- **Reference source based methods – magnitude of colour distortion between target and reference (daylight, Planckian radiator) of same CCT and on a set of TCS** :
  - Fidelity based methods (CRI, CRI-CAMUCS update of CRI, RCRI ranking)
  - Non-fidelity based methods (CQS : discounts positive chroma shift)
  - Gamut based methods (GAI, GAS, FCI with luminance) – to supplement CRI, CQS – combined metric - [absolute/relative gamut]
  - Statistical methods : colour categories CCRI, CRV map, multidimensional criterion on fidelity, saturation , hue (counts on CRV tolerance)
  - Specific attribute based methods : colour harmony (HRI) / colour categories CCIR
- **Non reference source based methods :**
  - Memory colours : similarity functions of memory colour objects (MCRI)
  - Miscellaneous : fidelity based but with modified TCS for reference (Flattery index)

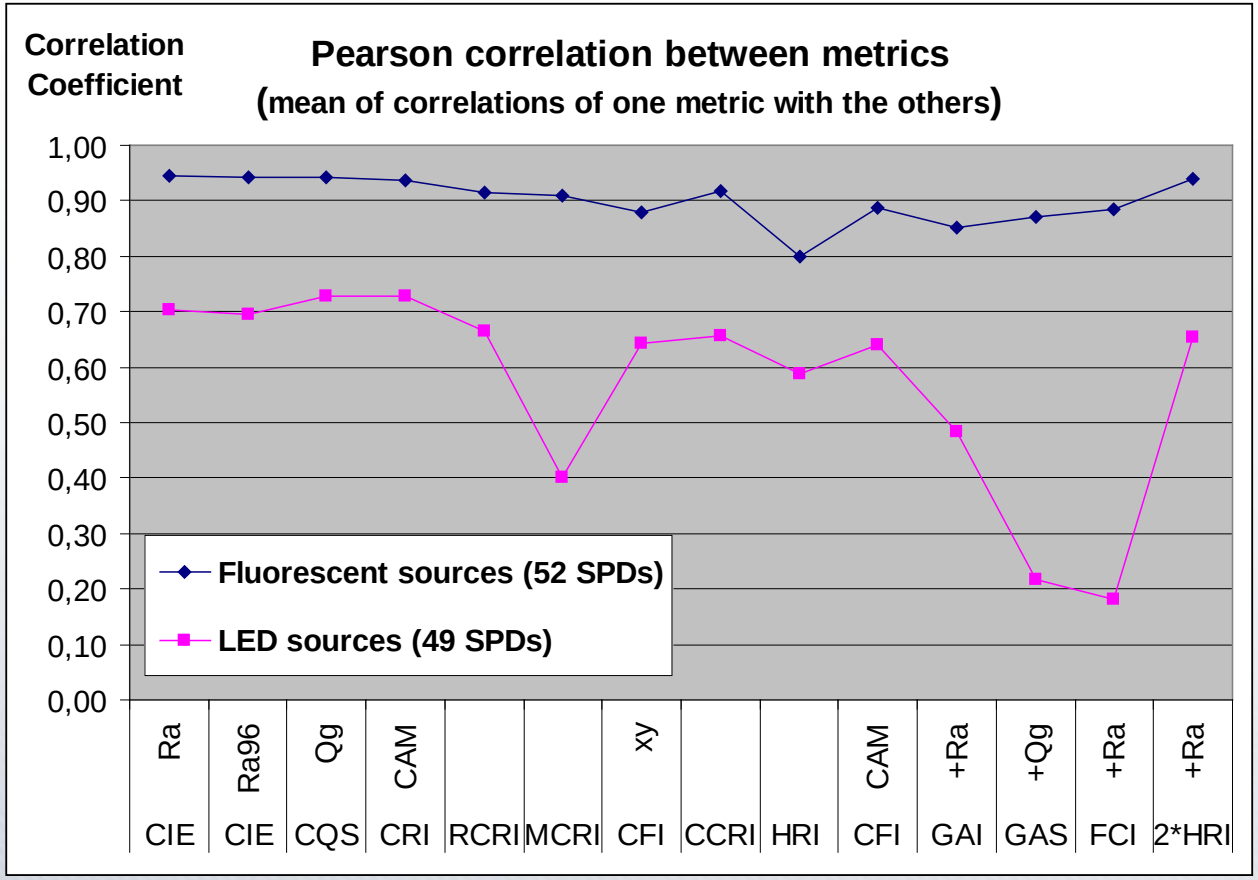
Review of proposals for a new metric : results on 122 SPDs

Application of the reviewed metrics on a set of 122 spectra of light sources representing all technologies.





Review of proposals for a new metric : results on 122 SPDs



Pearson correlation coefficients between metrics for the LED sources are quite low in comparison to those obtained with fluorescent sources demonstrating the special dimension of LED lighting

The colour subjective experiment

Objective of the experiment

To obtain from a panel of naïve observers the rating of **global preference** and detailed quality attributes - **without reference lighting source** - in a **common environment** and with all the common lighting technologies (QTH, FL tube, CFL, LED cluster, LED Phosphor-Converted (blue/NUV LED).

Attributes to be judged with proposed definition and on 5 point-scale

- Global preference (observer's own criterion)
- Fidelity of colours (feeling of "true – false" colours)
- Quality of vividness (like – dislike)
- Naturalness: global, foliage, fruits/vegetables, skin (perceived degree of naturalness)
- Quality of the colour chart (colour discrimination, saturation, shading,…)

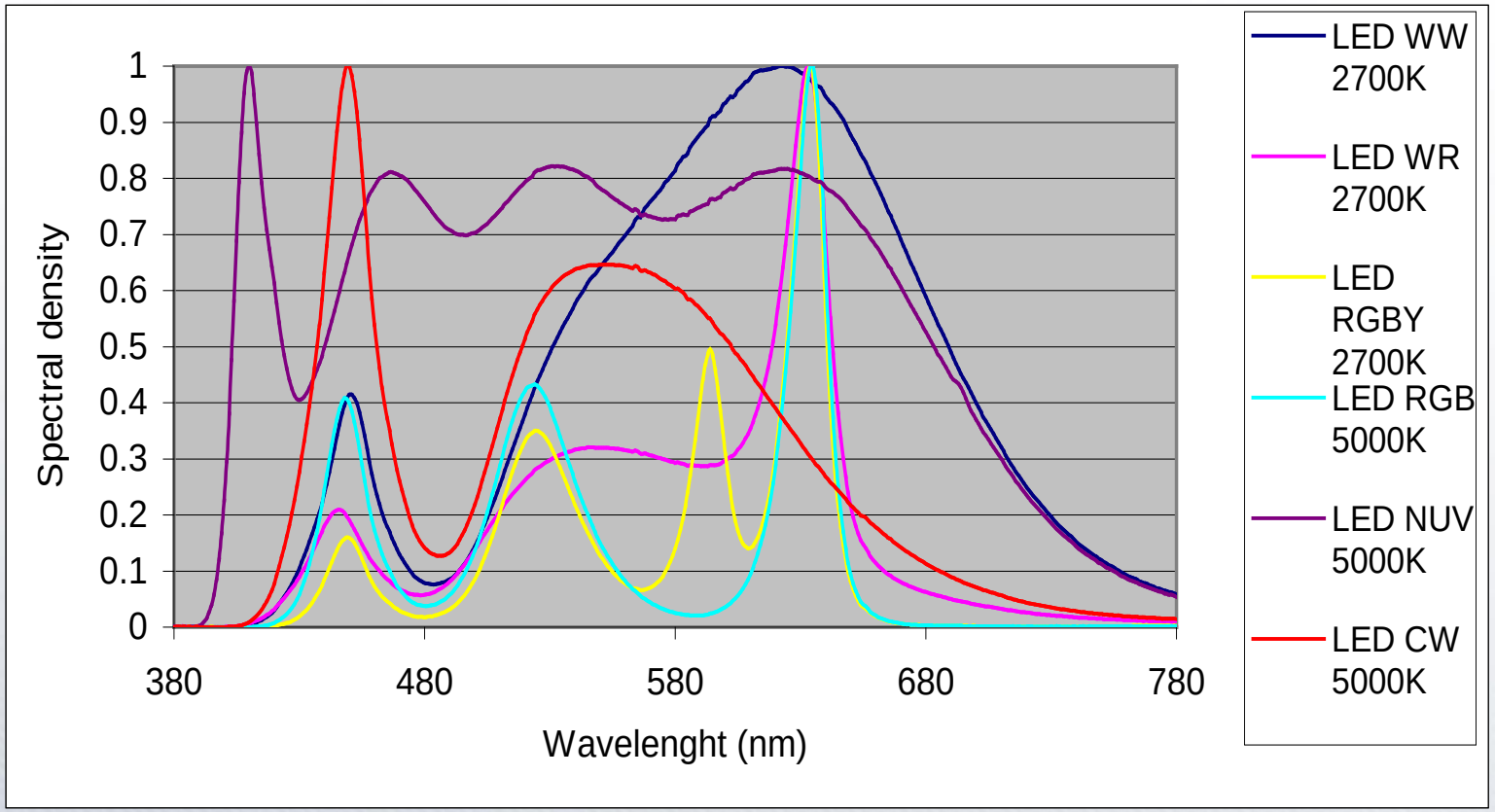
Panellist's data

43 Panellists: from 20 to 61 years old, 29 males / 14 females

Subjective experiment : test room

Light panel : lamps behind a diffuser and attached to 3 frames

Subjective experiment : LED SPDs

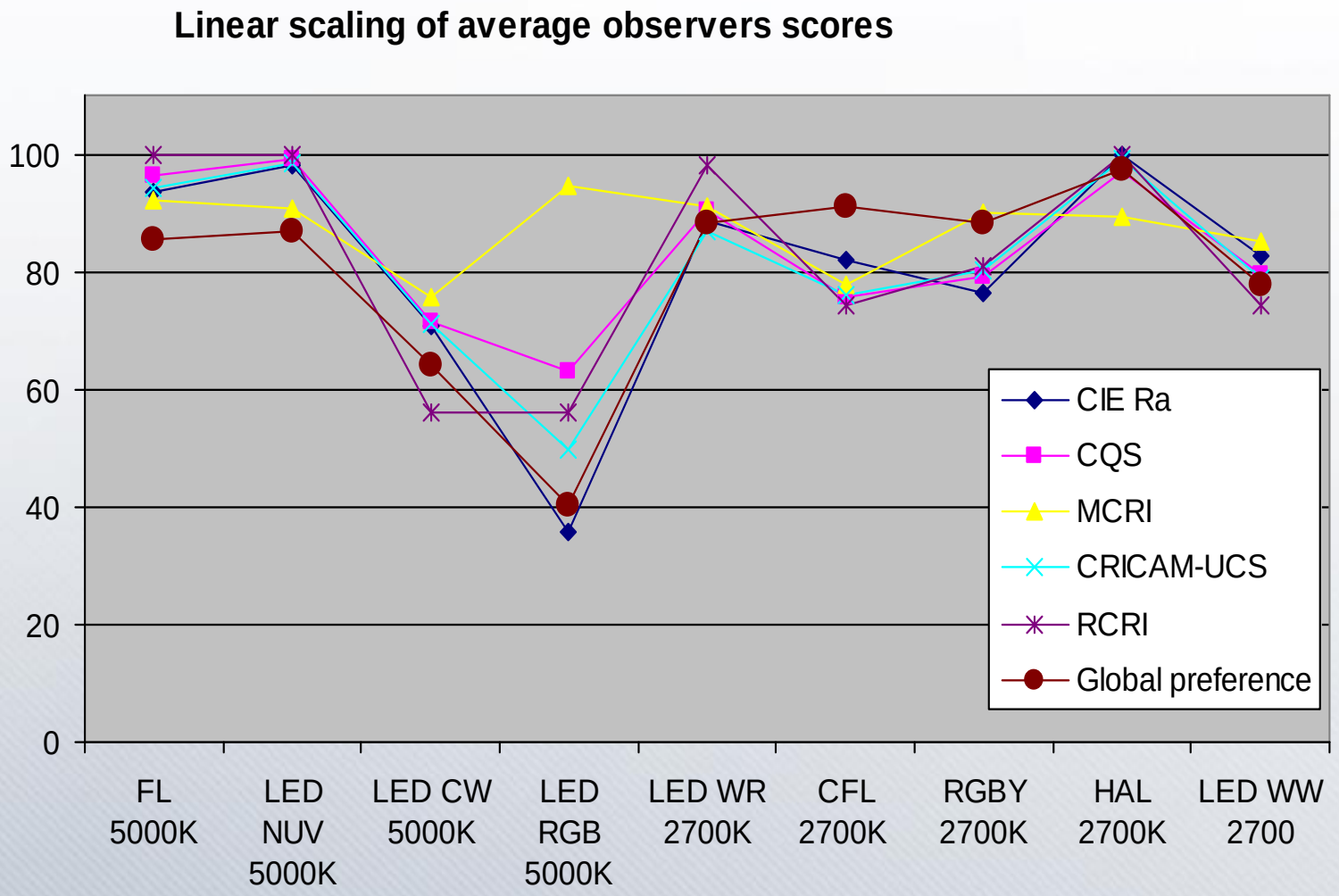


SPD of 6 LED light sources used in the experiment

Subjective experiment : average ratings of the quality attributes

The result of the PCA is that all attributes are represented with the first principal component ”factor 1” at a level of 66 % (total variability) and in the same direction.

Comparison of predictions with subjective preference



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Comparison of predictions with subjective preference : correlations

The following tables are the Pearson (linear) and Spearman (rank) coefficients of correlation of metrics with the subjective rating of preference – [scores are rounded at +/- 1%].

Pearson	CIE Ra	CQS Qg	MCRI	CRI CAMUCS	RCRI
all light sources	0,918	0,778	-0,028	0,868	0,788
cold lights	0,997	0,968	-0,022	0,996	0,895
warm lights	0,666	0,606	0,136	0,738	0,648
all LED sources	0,921	0,847	0,026	0,913	0,829
all cold LED	1,000	0,958	-0,236	0,997	0,853
all warm LED	0,000	0,500	0,945	0,693	0,693

Spearman	CIE Ra	CQS Qg	MCRI	CRI CAMUCS	RCRI
all light sources	0,616	0,466	-0,112	0,605	0,538
cold lights	0,949	0,949	-0,316	0,949	0,943
warm lights	0,526	0,289	-0,026	0,359	0,526
all LED sources	0,667	0,750	0,074	0,812	0,794
all cold LED	1,000	1,000	-0,500	1,000	0,866
all warm LED	0,000	0,500	0,866	0,866	0,866

These results show that there is a difference of metrics correlation between warm light sources and cold light sources. While current CRI Ra fails for warm LEDs, proposals better perform but exhibits lower correlation for cold light sources – Better correlation calculation and more samples by categories are needed to give better statements.

Assessment of Colour Rendering Metrics: Conclusion

- Differences in dimensions of colour rendering (fidelity, preference), in approach of proposals, in predictions, and in assessments with subjective experiments show that a good deal of work is needed to validate metric and reach consensus.
- one outcome of the experiment is that for low gamut/low quality (low CCT) enhancement such as chroma increase (LED lighting property), is preferred but for higher gamut/quality (high CCT) increase of saturation has no effect or is not desirable. We will propose a metric based on this principle.
- Industries will not adopt a metric not endorsed by CIE, and CIE will not adopt metrics not thoroughly tested by subjective experiments. Among metrics under consideration at CIE TC1-69 there are the CQS and the nCRI - nCRI is based on CRI-CAM02US with a larger set of TCS, selected with regards to low and high colour constancy, and with scaling formulae method similar to CQS.

Introduction to the study on visual comfort – Task 3.2

The study has been conducted through the following steps:

1. Performing specialized subjective experiments (2) -
2. Performing subjective experiments in real situations (3) with 50 people
3. Characterising visual fields (spectro-radiometers, goniometric photometric camera)
4. Modelling and combining influent parameters

There is no model of visual comfort, the following parameters are usually considered :

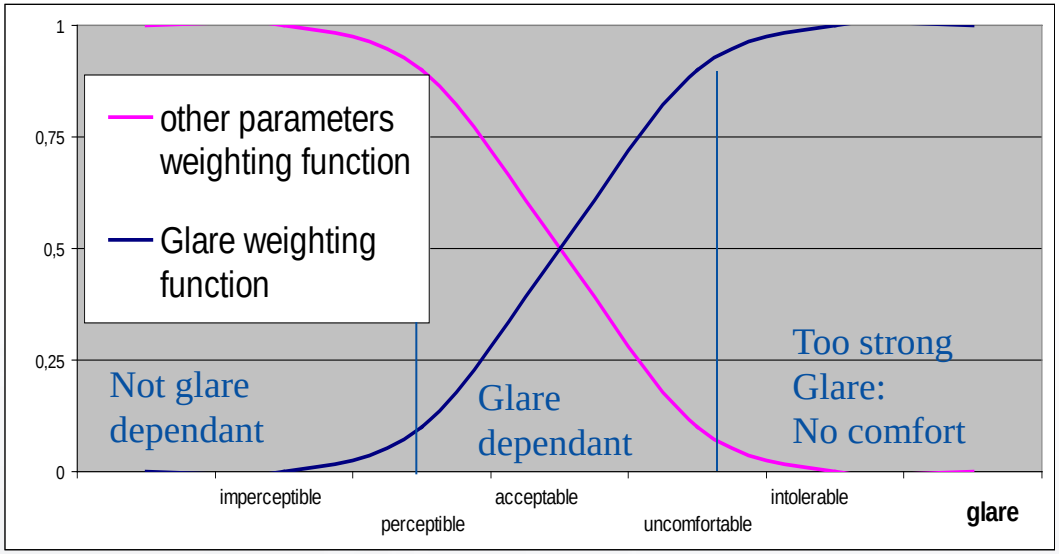
- Glare : the only existing metric (CIE UGR for interior lighting)
- Light distribution (luminance, illuminance levels and distributions)
- Spectral content (CCT, colour rendition properties)
- Flicker (not addressed in this task)

Illustrative pictures of the 5 subjective experiments for visual comfort

Visual Comfort: A model ?

Visual comfort is not only glare

but too much glare = no comfort regardless other characteristics



1/ Glare → UGR normal/small source

2/ Lighting utility:

- Aesthetical effect
- ease of Task

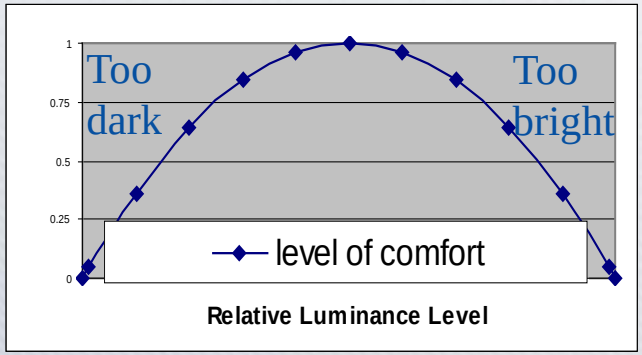
(Level, distribution, colour properties)

→ Fidelity/ naturalness (CRI-CAMUCS) – vividness (gamut GAI)

→ Office : uniformity of working plane

→ Office : enough light but not too much on working plane

Ratio between working plane/background



3/ Appearance of luminaires → Distribution on the area around the luminaire

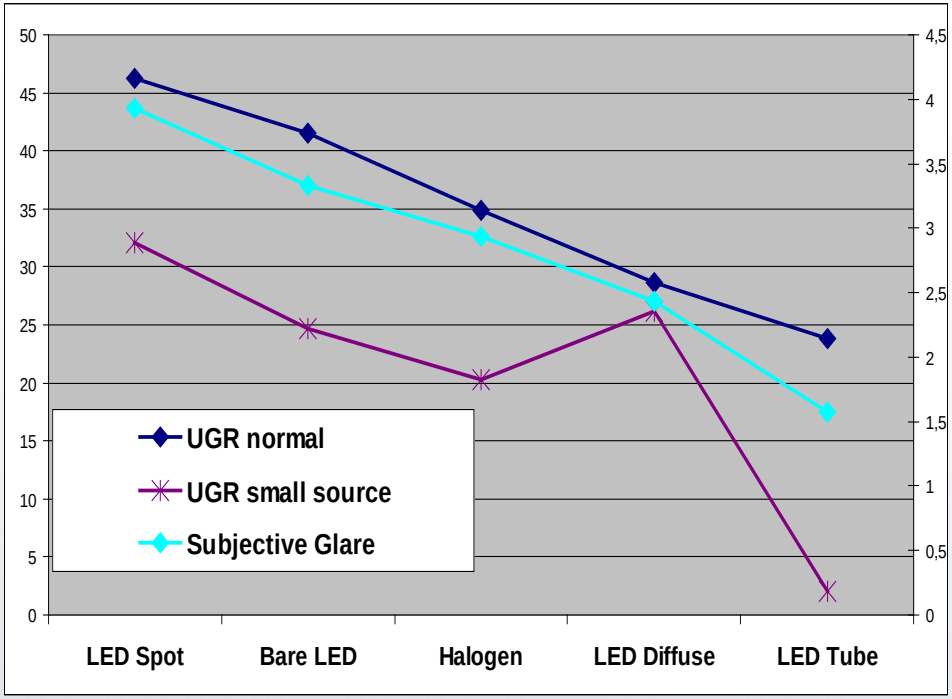
4/ Spectral effect → Not in the model

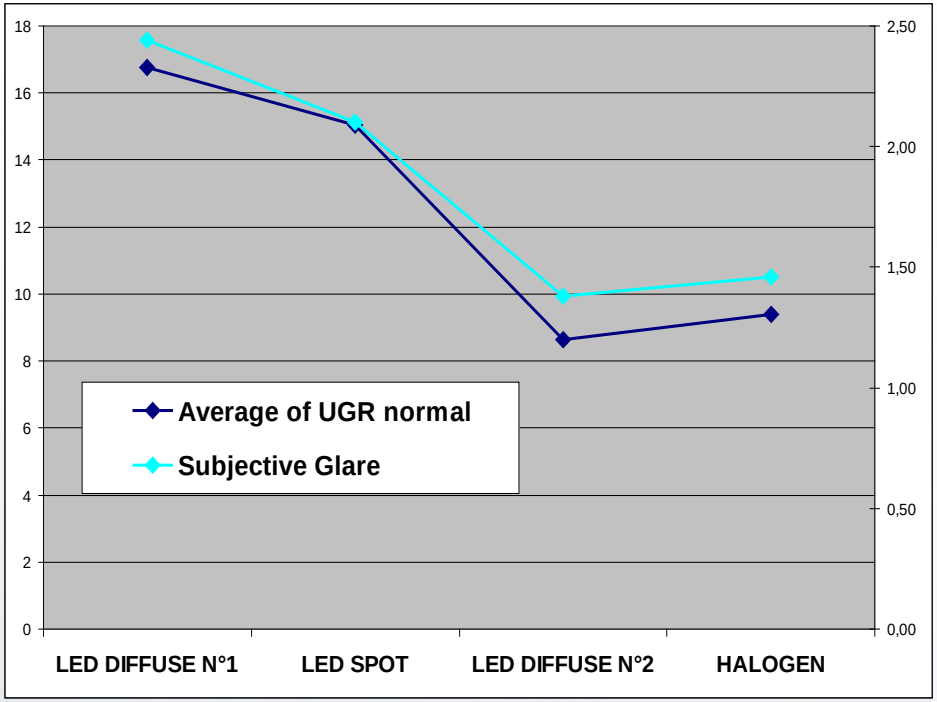
Calculation on high definition polar Luminance Maps 120°(V)x 135°(H) - array of 4096 x 4096 floats.

Images of luminance maps with a log scale

Luminance maps are reconstructed from 72 pictures acquired with the photometric camera, mounted on a goniometric platform, with 3 integration times and 3 optical densities (648 images).

Comparison of rating of glare sensation and CIE UGR formula: normal and small source

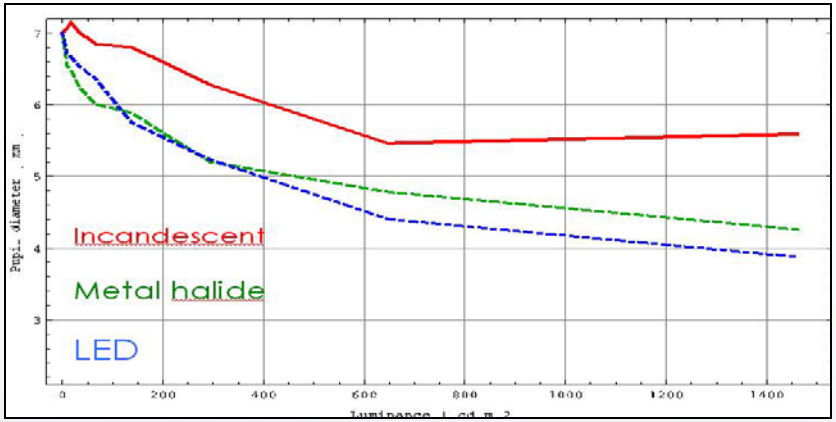




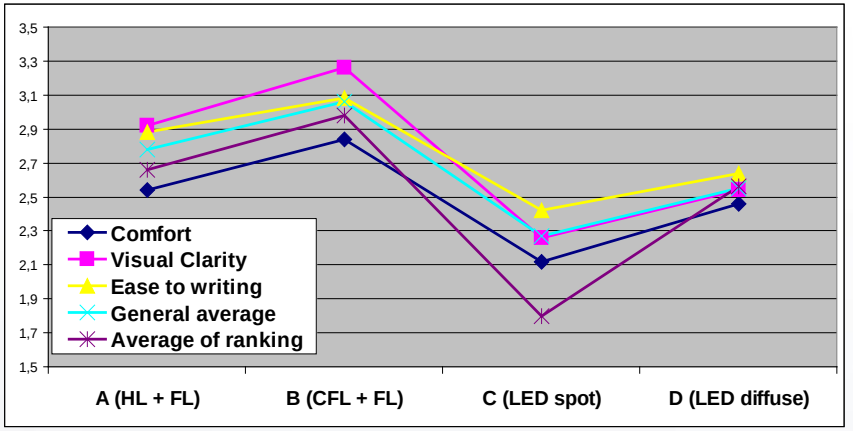
led	LED Spot	Bare LED	Halogen	LED Diffuse	LED Tube
cm²	2.05	1.45	1.92	19.95	11.05

Note on CIE glare formula : luminance of small source = luminance of a 50 cm² source of the same intensity.

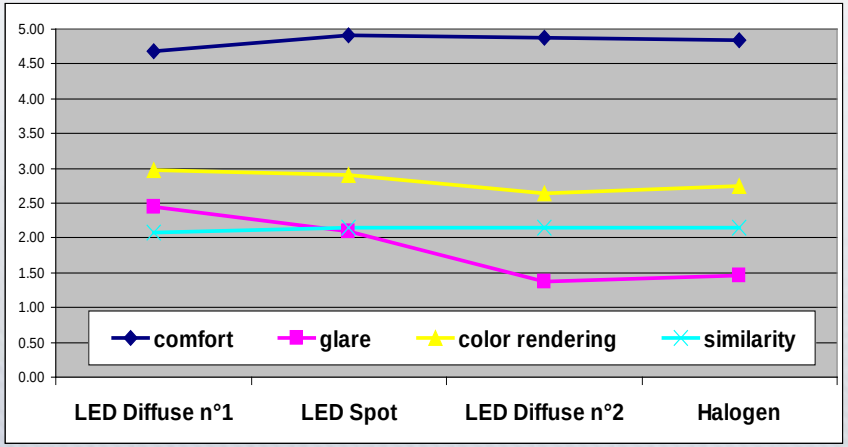
Graphs of subjective experiments results with LED and traditional light



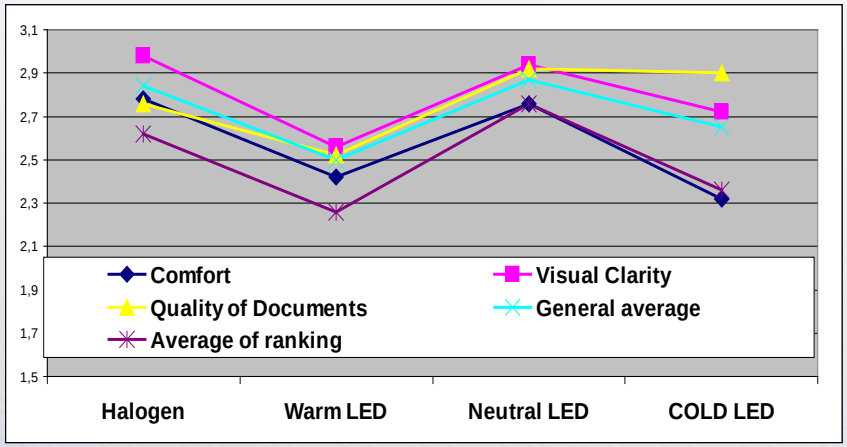
Pupil size decreases with CCT



Office subjective ratings : CFL best



Living room : LED spot best



Compartments : halogen – neutral LED best

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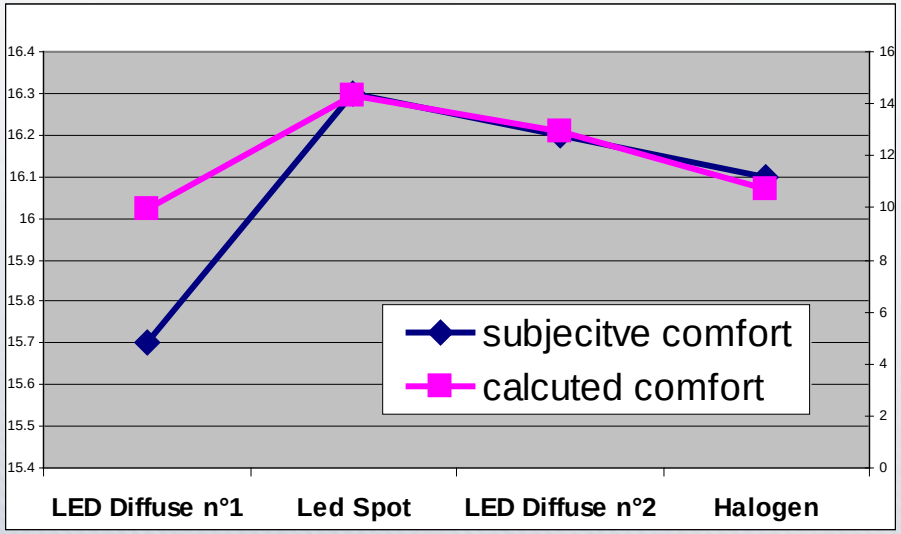
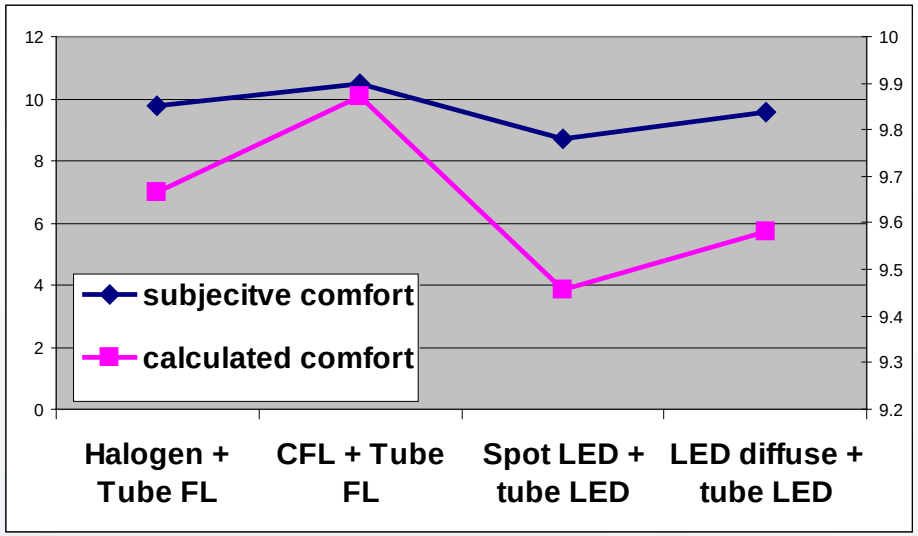
Visual comfort : First Model Results

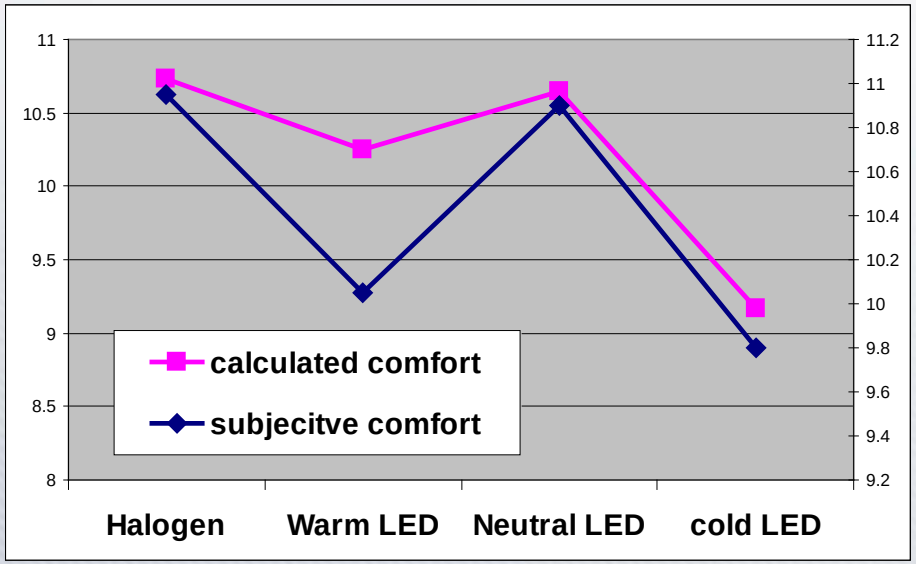
Office →

Living Room ↓



Compartments →





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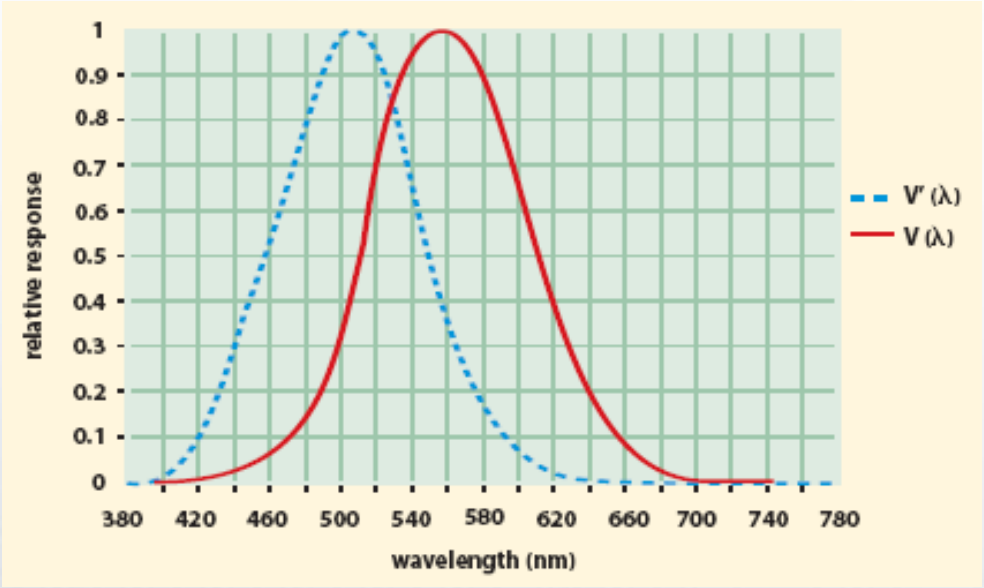
Introduction to the study on mesopic vision – Task 3.3

Mesopic system: bridges the gap between CIE Photopic and scotopic observer functions



Because **no/few results** on mesopic measurements/devices **were available before ENG05**, standards are not considering the mesopic conditions.

ENG05 results will be used for standardisation

BUT spectrum knowledge and angular distribution will be necessary to improve design calculations

Contribution to standard activities – mesopic vision

Sources can be identified by S/P **ratio :**

S/P = Scotopic output / Photopic output

High values improves mesopic performance

The **spectra** emitted by SSL luminaires **change** with the **angular direction** of emission, so the ratio photopic/mesopic luminous intensity is not constant with direction.

As a consequence, a road lighting installation designed considering photopic quantities could not satisfy uniformity and average requirements when measured in mesopic conditions.

Field trials on SSL-based street and tunnel lightings have been performed with the detectors developed in WP1.

Measurement procedures for mesopic characterisation of SSL of street lighting luminaires are the output of this task.

Thank you for your attention !