Improving Color Rendering Assessment of Sources:
International Standardization Work

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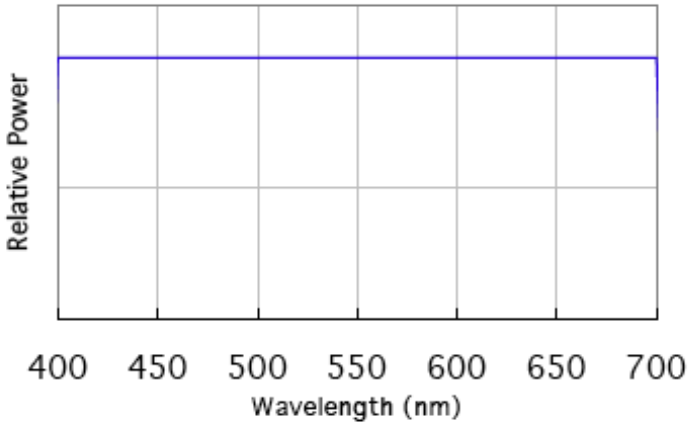
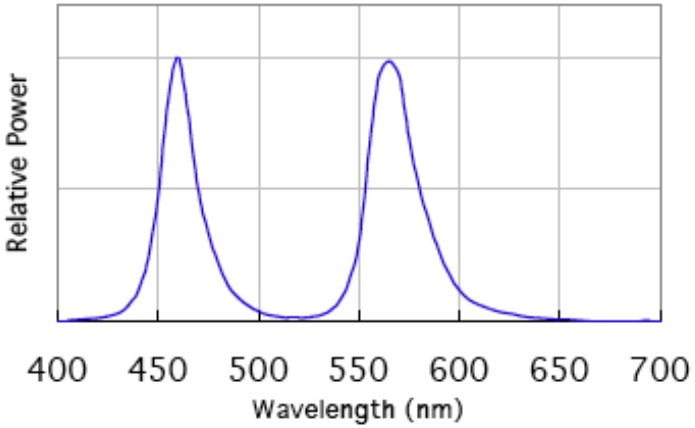
What is Color Rendering?

Equal Energy



Blue & Yellow LED



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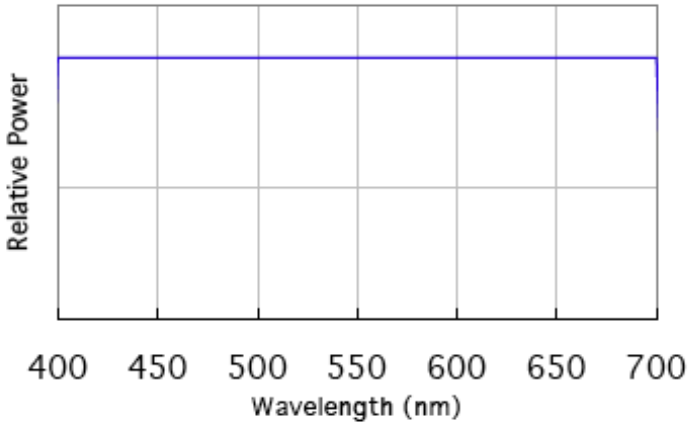

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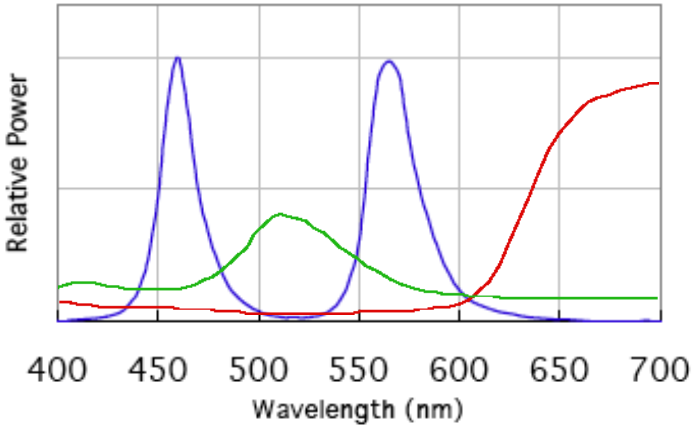
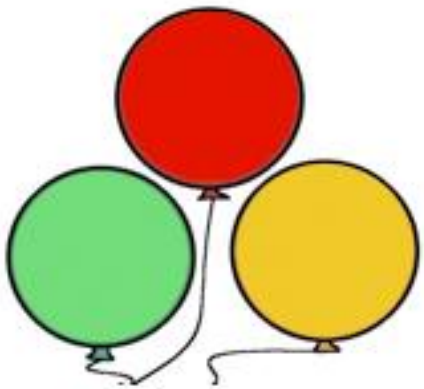
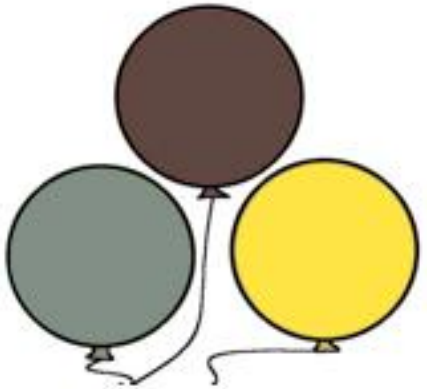
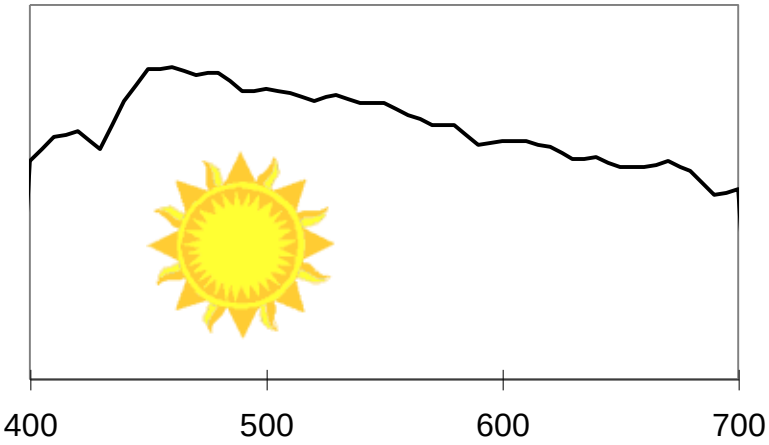


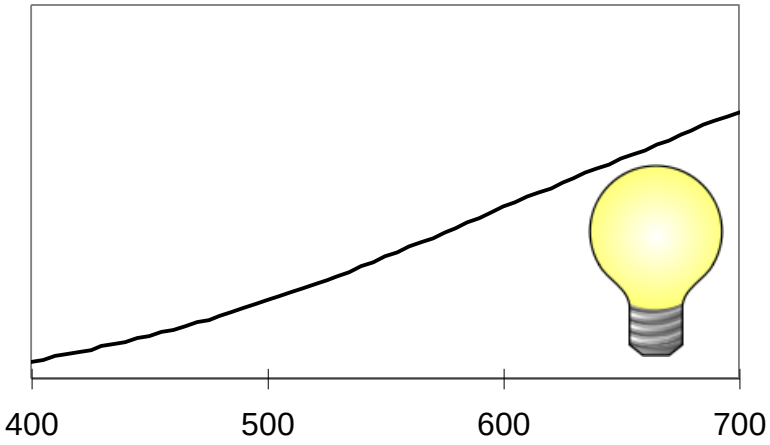




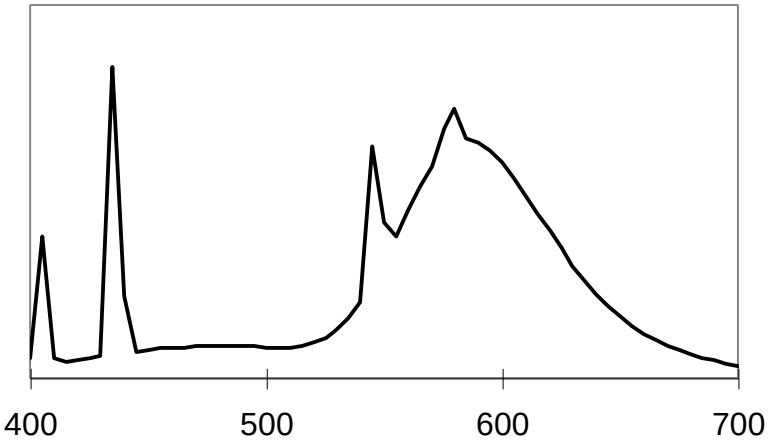
Why Measure Color Rendering?

Before: sun, fire, and incandescent sources





Then: fluorescent lamps…



History: CIE Progress

1948: 8 band Spectral Band Method (SBM), deviation from full radiator

1955: established WC 1.3.2 to address terminology and compare SBM with test sample method

1961: agreed on test color method, with 8 test samples

1964: Publication 13 (1st edition), published test sample method

History: CIE Progress

1974: Publication 13 (2nd edition)

Defined reference illuminants

Test samples: 8 + 6

Von Kries chromatic adaptation transform

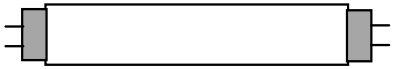
Use the CIE 1964 UCS

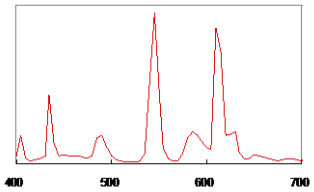
Scaling: Warm white halophosphate lamp to Ra=50

Developed the CRI as we know it today

Color Rendering Index (CRI)

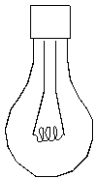
Test source



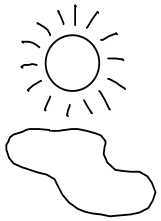


Same CCT [K]

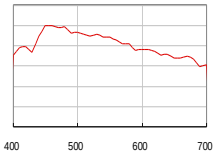
Reference source



Planckian
(CCT<5000 K)

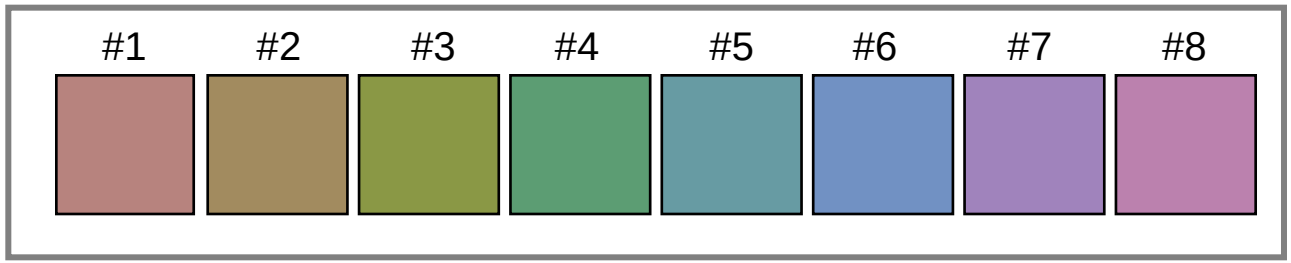


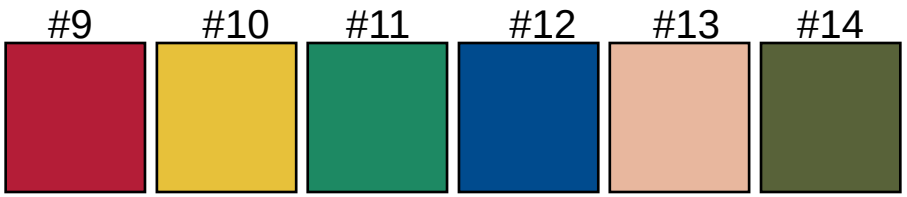
Standard Daylight
(CCT > 5000 K)

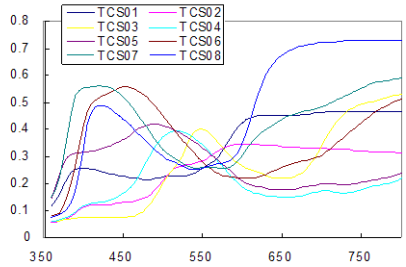


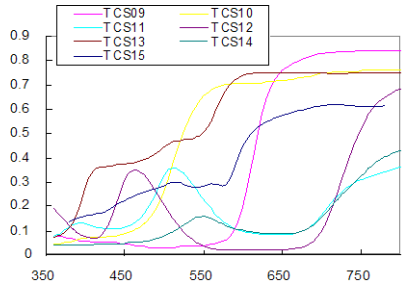
CIE
Dxx

R_a





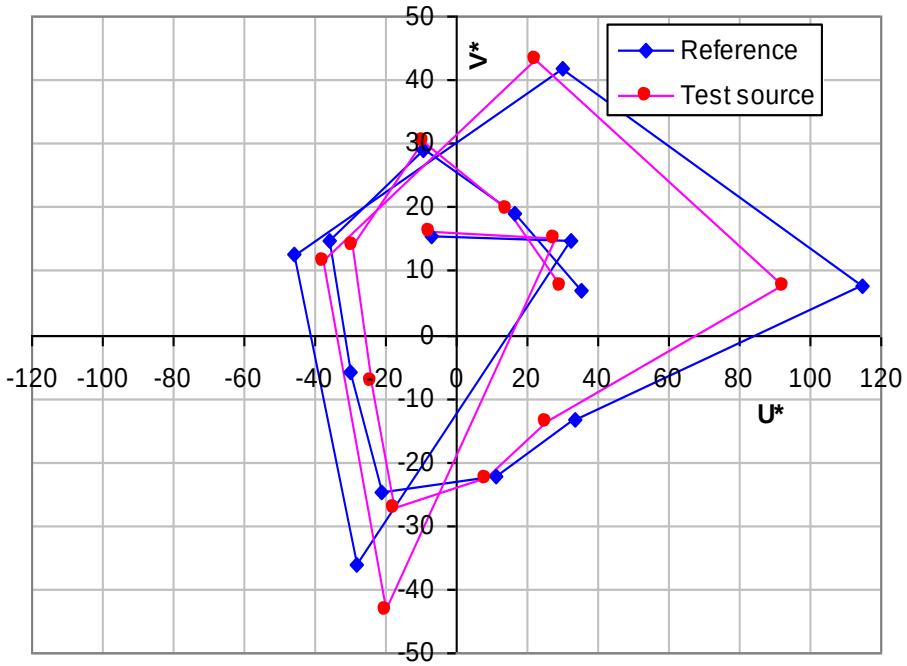




NIST

Color Rendering Index (CRI)

*W*U*V** object color space



Chromatic adaptation (von Kries)

Color differences

$$\Delta E_i = \sqrt{\left(U^*_{r,i} - U^*_{k,i}\right)^2 + \left(V^*_{r,i} - V^*_{k,i}\right)^2 + \left(W^*_{r,i} - W^*_{k,i}\right)^2}$$

Special CRI

$$R_i = 100 - 4.6\Delta E_i$$

General CRI

$$R_a = \frac{1}{8}\sum_{i=1}^{8} R_i$$

History: CIE Progress

1980s: new Technical Committee worked on subject, but closed without recommendations due to member disagreements

1995: Publication 13 (3rd edition), no substantive changes from 2nd edition, just fixed some errors

1999: Another Technical Committee (TC 1-33) closed without reaching consensus. Industry opposed proposed new procedures due to lack of visual experiments

History: Other Approaches

Gamut-based proposals

Two main presumptions:

Increased gamut increases discriminability between colors

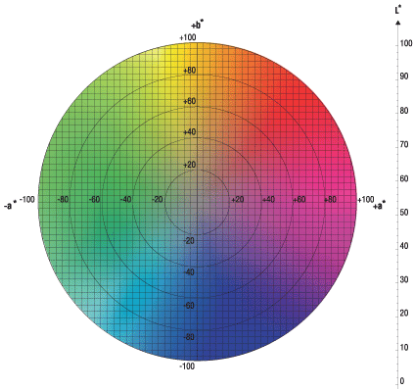
Increased gamut leads to increased object chroma

Color Discrimination Index (Thornton, 1972)

Cone Surface Area (Fotios, 1997)

Color Rendering Capacity (Xu, 1993)

Feeling of Contrast Index
(Hashimoto, Yano, & Nayatani, 2000)



History: Other Approaches

Other proposals

Use method very similar to CRI, but penalties for color differences are based on deviations from “preferred shifts.”

Flattery Index (Judd, 1967)

Color Preference Index (Thornton, 1974)

Examples of preferred shifts:

Skin tones (Caucasian) ⟶ more reddish

Foliage (green) ⟶ more yellowish

Recent CIE Activity

2007: TC 1-62 published CIE 177

Studied color rendering of white LED sources

Recommended the development of a new color rendering metric (or set of metrics)

Recommended concurrent use of CRI and new metric, at least at first

The new metric should be applicable to all types of light sources

Current CIE Activity

TC 1-69: Colour Rendition by White Light Sources

Started in late, 2006

Chair: Wendy Davis, US

Terms of Reference: To investigate new methods for assessing the colour rendition properties of white-light sources used for illumination, including solid-state light sources, with the goal of recommending new assessment procedures.

TC 1-69

Membership:

31 active members from 12 countries

8 interested observers

Meetings:

Physical meetings held annually

Electronic communications critical:

- web site for sharing papers, data, etc.
- e-mail list with accessible archive

TC 1-69 Working Plan

1) Agree on some basic criteria for a new metric (or system of metrics) such that it (or they) could be developed to be scientifically sound, acceptable to lighting industry, and useful.

2) Solicit, share, and discuss proposals for new assessment procedures for colour rendition properties of white light sources.

3) Evaluate proposed assessment procedures with visual experiments and compatibility with basic criteria (in #1).

4) Recommend a new metric (or system of metrics) based on evaluation (in #3).

5) Prepare a CIE Technical Report on recommended new metric (or system of metrics), including calculation procedures and justification for recommendation.

TC 1-69 2007 Meeting

47 attendees in Beijing, China

Voted:

- design new metric assuming that CRI may not exist in the future
- new metric to have one number output, with optional supplementary indices
- scale new metric to be ~comparable to CRI for traditional lamps, but acknowledge the exact ordering of certain existing lamps may change

We agreed that color fidelity will be important in new metric. Inclusion of other aspects of color quality will be dependent on experimental results.

TC 1-69 Timeline

Established and approved at the 2007 meeting

Timeline:

Two weeks (by 7/24): chair will send out questionnaire on planned or current experiments.

Two months (by 9/24): members will return questionnaires with detailed experimental plans

Six months (through 3/08): Light sources will be manufactured for experiments needing them; experimental guidelines subgroup will see where we can make experiments consistent

One year (through 3/09): Conduct experiments

One year (through 3/10): Evaluate data

TC 1-69 Experiment Plans

15 experimental plans were submitted

From six research groups/institutions

from five different countries

Topics include:

- Chromatic discrimination
- Visual preferences
- Color rendition of skin complexion and hair
- Color harmony
- Color fidelity and color differences
- Relationship between illuminance and chroma…

TC 1-69 Future

Next Meeting:

June 14, 2008 in Stockholm, Sweden

Updates on experiments in progress

Next Steps:

According to timeline, experiments should be completed by March, 2009

Committee will have one year to evaluate experiments, form consensus recommendation, and write report

NIST's Work for TC 1-69

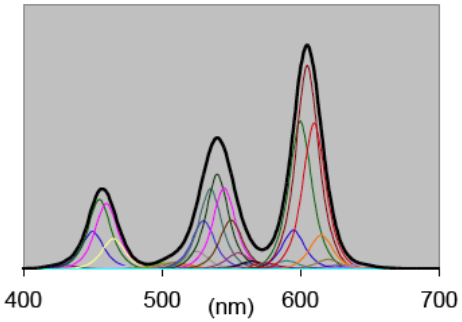
Color Quality Scale (CQS)

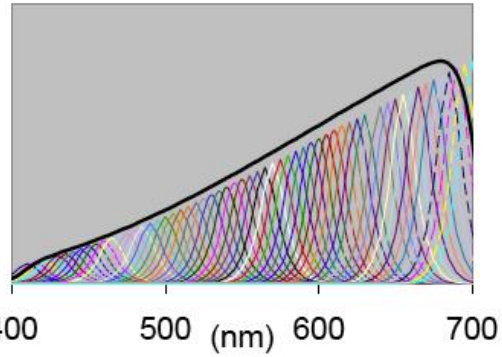
- Shares many traits with CRI
- Updates/fixes problematic aspects of CRI (e.g., uniform color space, reflective samples, etc.)
- Some substantial deviations: doesn't penalize lamps for increasing object chroma, penalizes for extreme CCTs, etc.

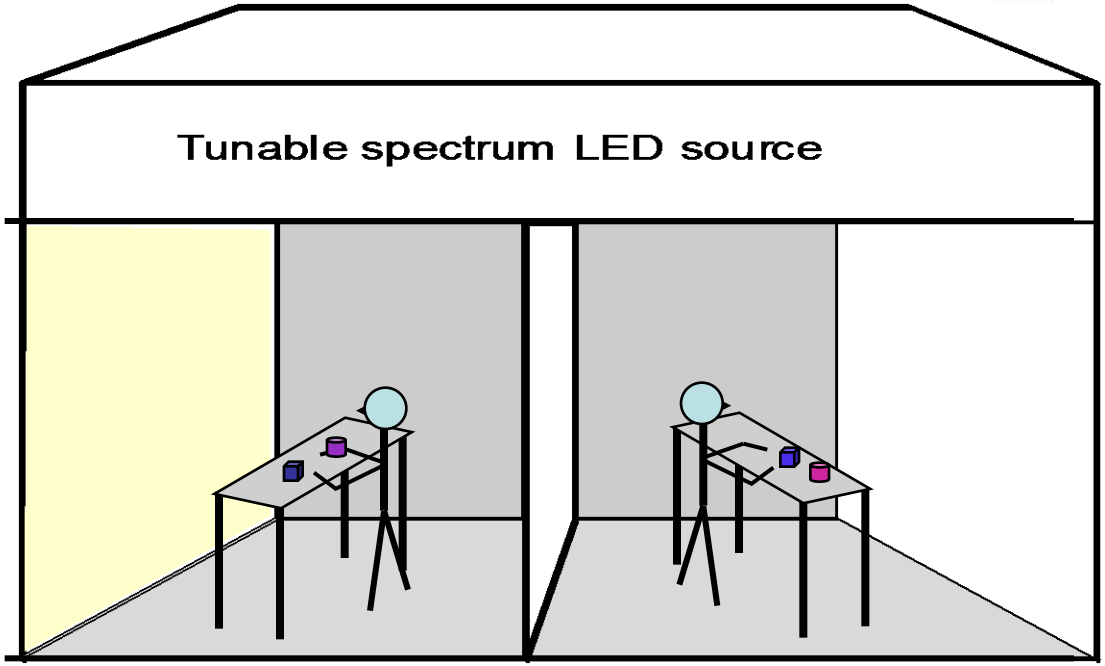
NIST's Work for TC 1-69

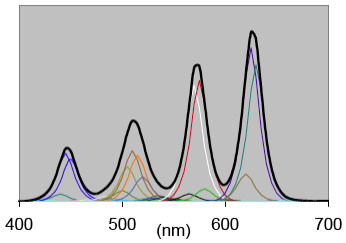
Experimental Facilities

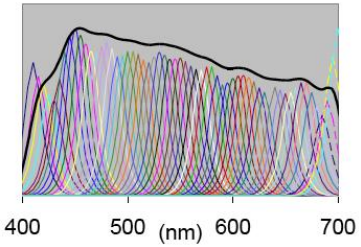
Spectrally tunable light source
Illuminating a real-size room!

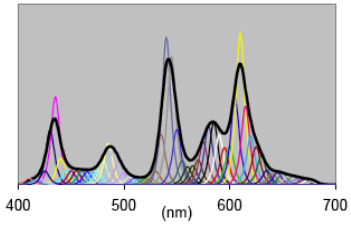


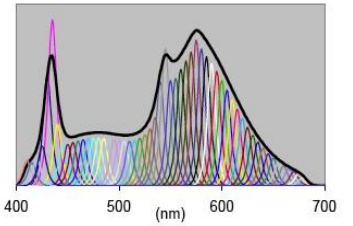












NIST's Work for TC 1-69

Experiments

- Chromatic discrimination as a function of gamut
- Overall judgments of visual preference
- Relationship between illuminance and chroma; effect on perceived "naturalness"