EPA Energy Star Lighting Webinar Series
Evaluating Color Quality – March 31, 2016

Color Quality of Lighting and Metrics – Where are we going to?

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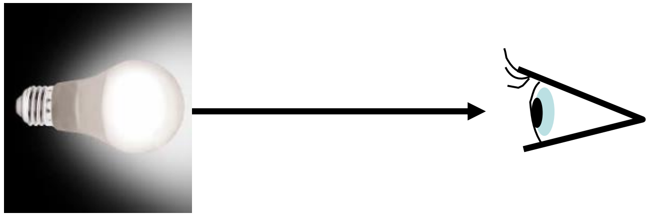
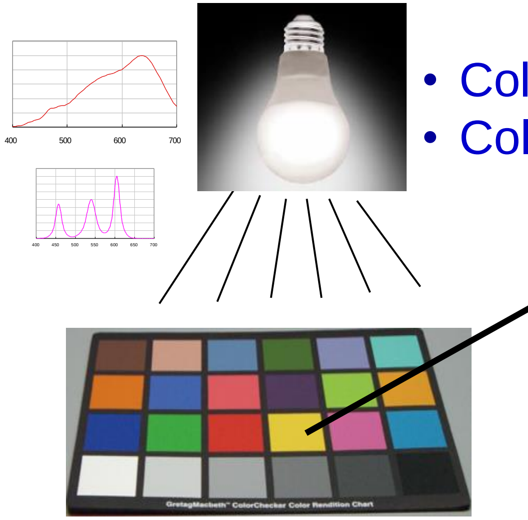
Color Quality of Lighting

Color Quality

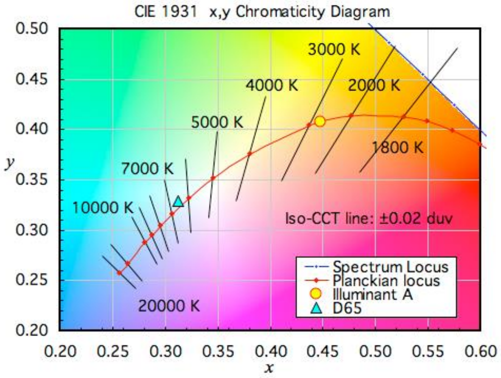
Chromaticity
(white light)

Color Rendition





- Color fidelity (CRI)
- Color preference



- CCT, Duv
- Chromaticity coordinates (*x*,*y*), (*u'*,*v'*)

OUTLINE

1. Research on White Light Chromaticity
2. Research on Color Saturation Preference
3. Understanding TM-30
4. Where are we going to?

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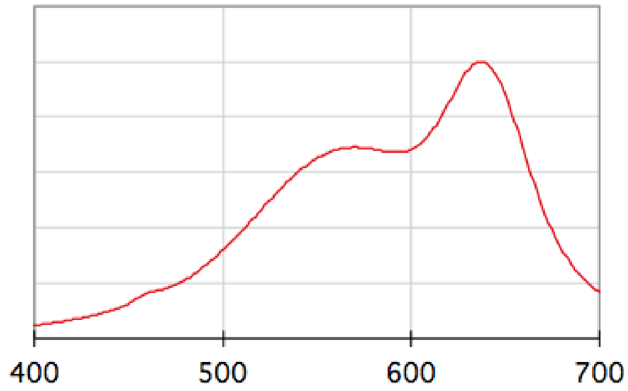
Color Quality = CCT and CRI ?

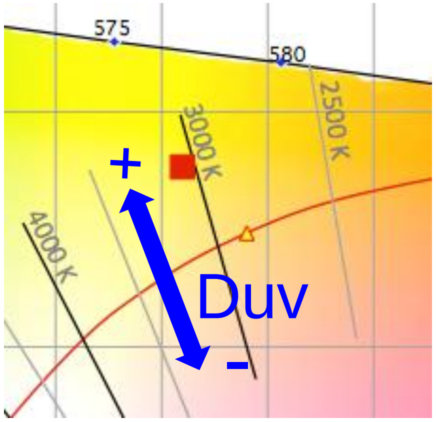
CCT: Correlated Color Temperature (CIE S017 ILV)
CRI: Color Rendering Index (CIE 13.3)

Some example

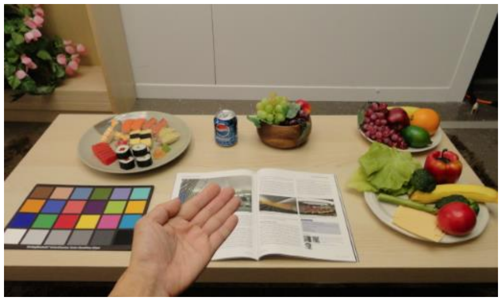
CCT = 3050 K
CRI (R_a)= 91



This product is not acceptable.
Why?



Too yellowish!

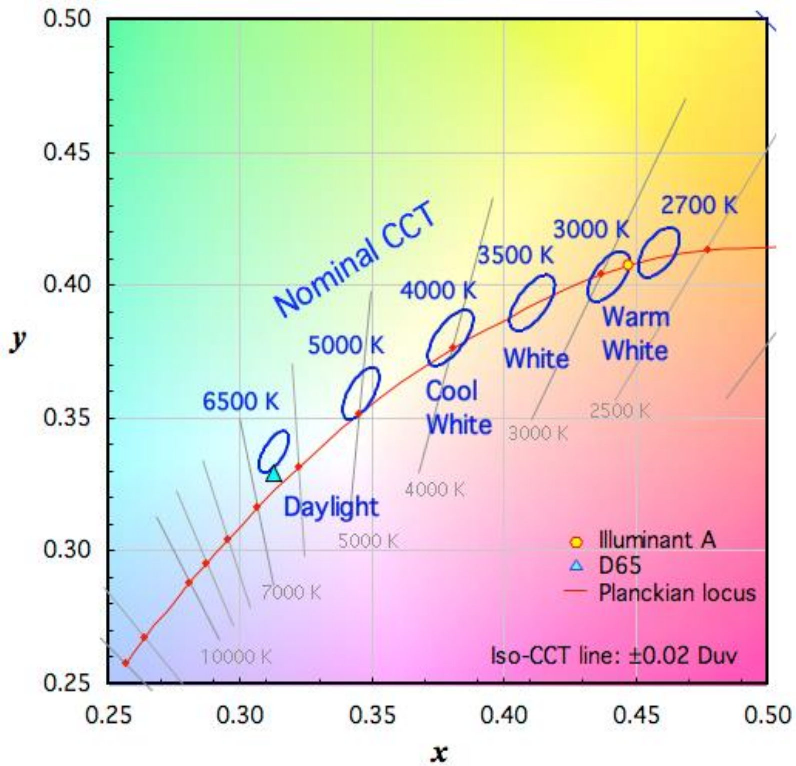


Normal

CCT does not tell the whole story of chromaticity.

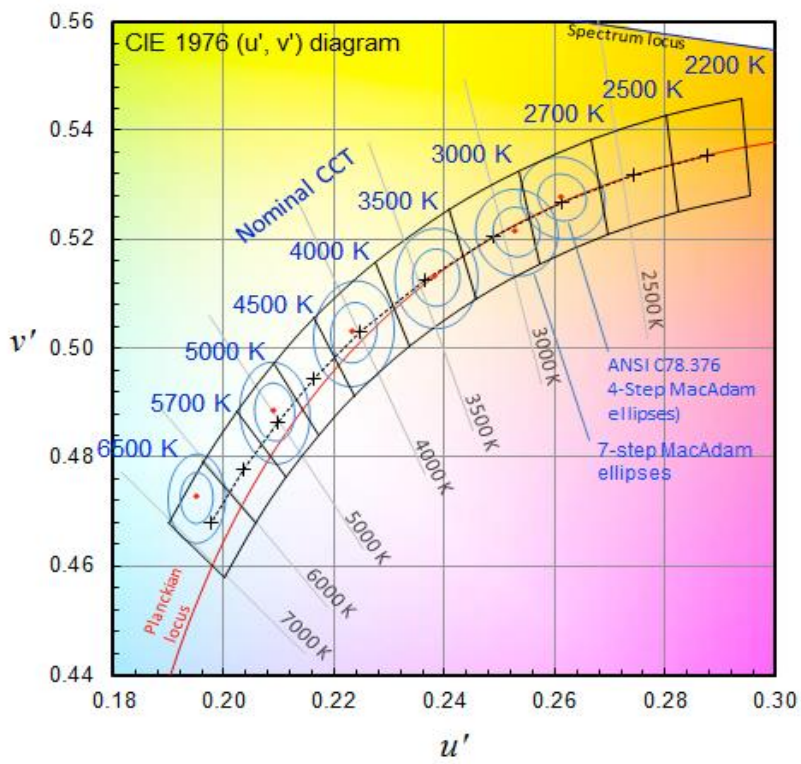
White Light Chromaticity

ANSI C78.376-2001 for linear fluorescent lamps



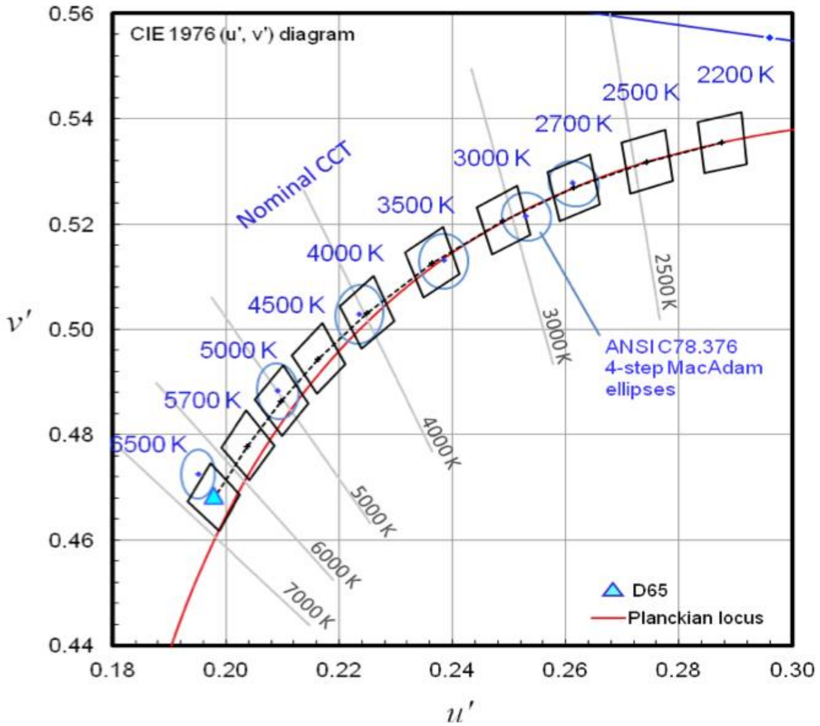
ANSI C78.377 for SSL

- Widely used, in Energy Star, DLC, IEA SSL Annex ,etc.
- First published in 2008
- Revisions in 2011, 2015

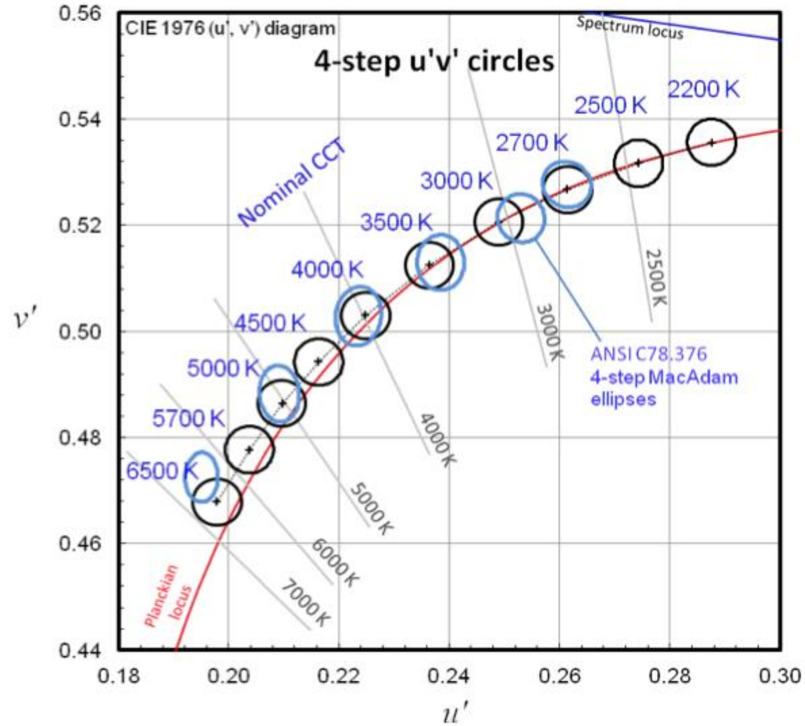


ANSI C78.377 Future Considerations

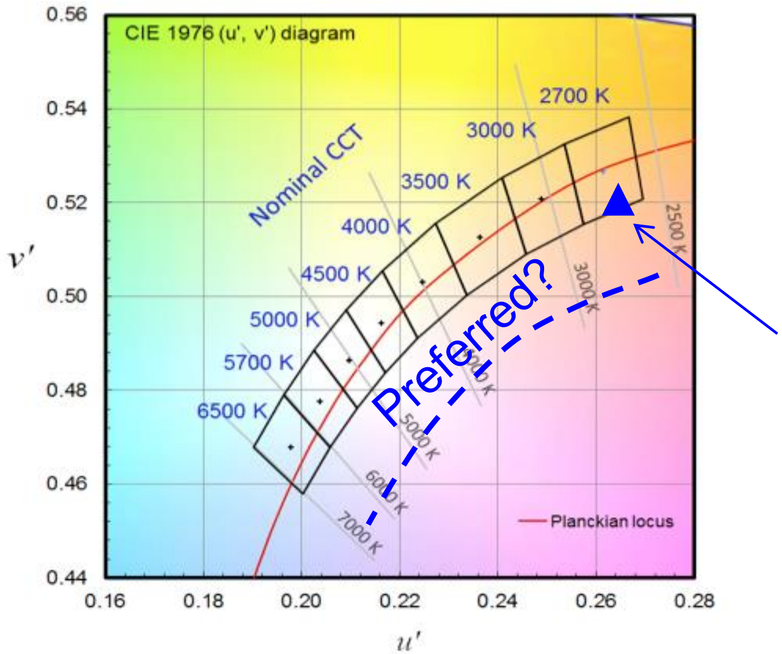
Annex B. 4-step quadrangle tolerances



Annex C. 4-step u'v' circles
(CIE TN001)



Preference to below blackbody

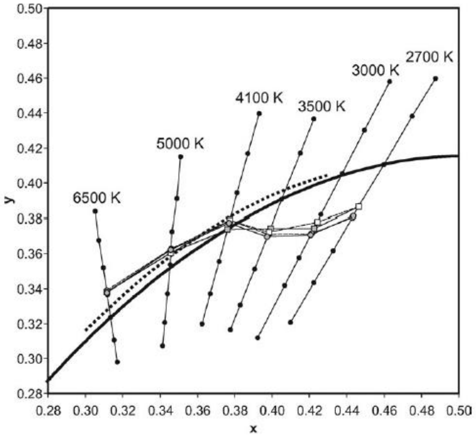


Known for many years but not covered in any standards.

An example:
Neodymium lamp

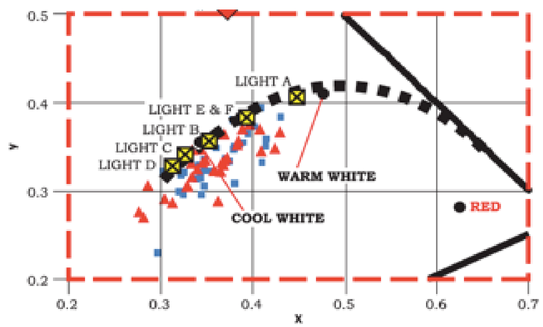
Recent Studies

Experiment on perceived white point by LRC (2013)



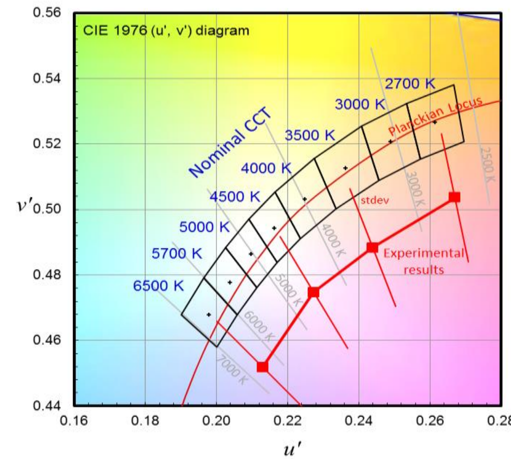
M. S. Rea,* J. P. Freyssinier, "White Lighting", CR&A**, 30-2**, 82-92, 2013.

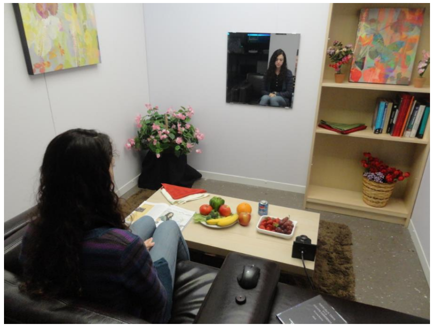
Experiment on preferred lighting by NRC, Canada (2013)



Dikel et al, "Preferred Chromaticity of Color-Tunable LED Lighting", LEUKOS, 10:2, 101-115, DOI: 10.1080/15502724.2013.855614 (2013).

NIST vision experiment in 2013

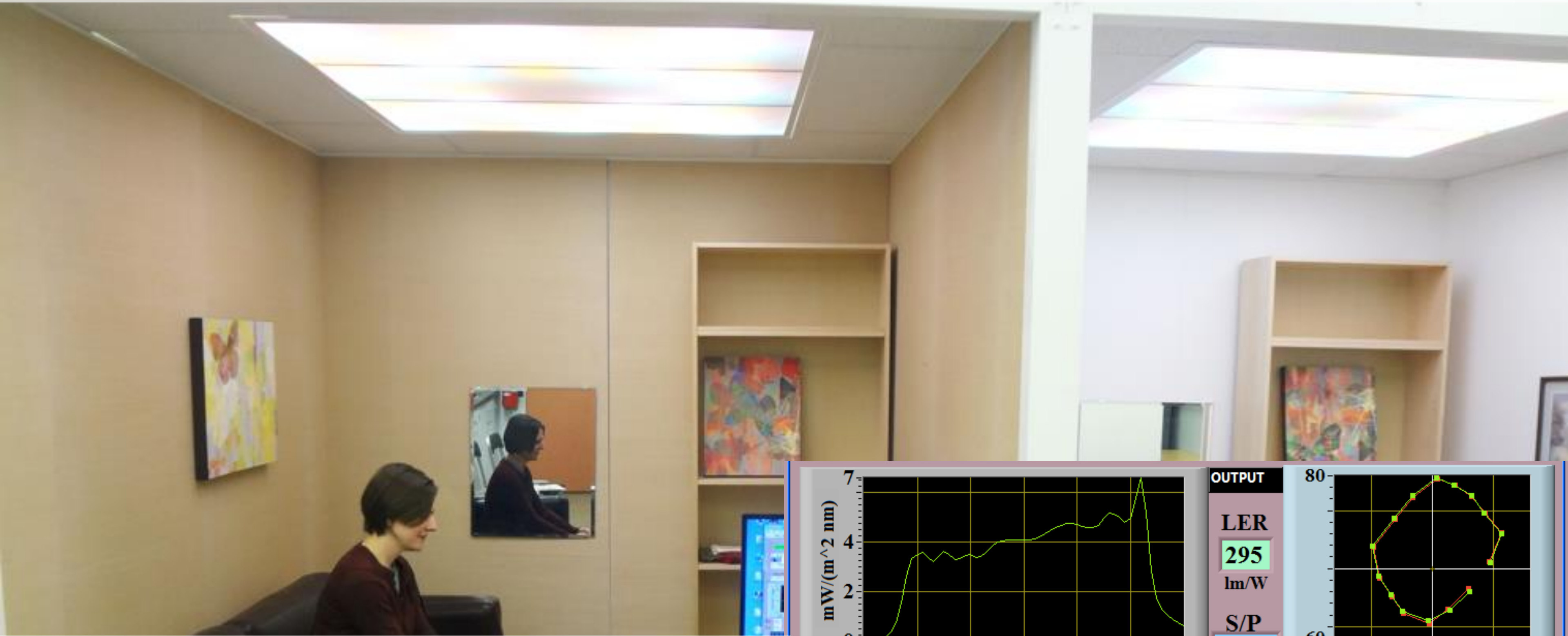


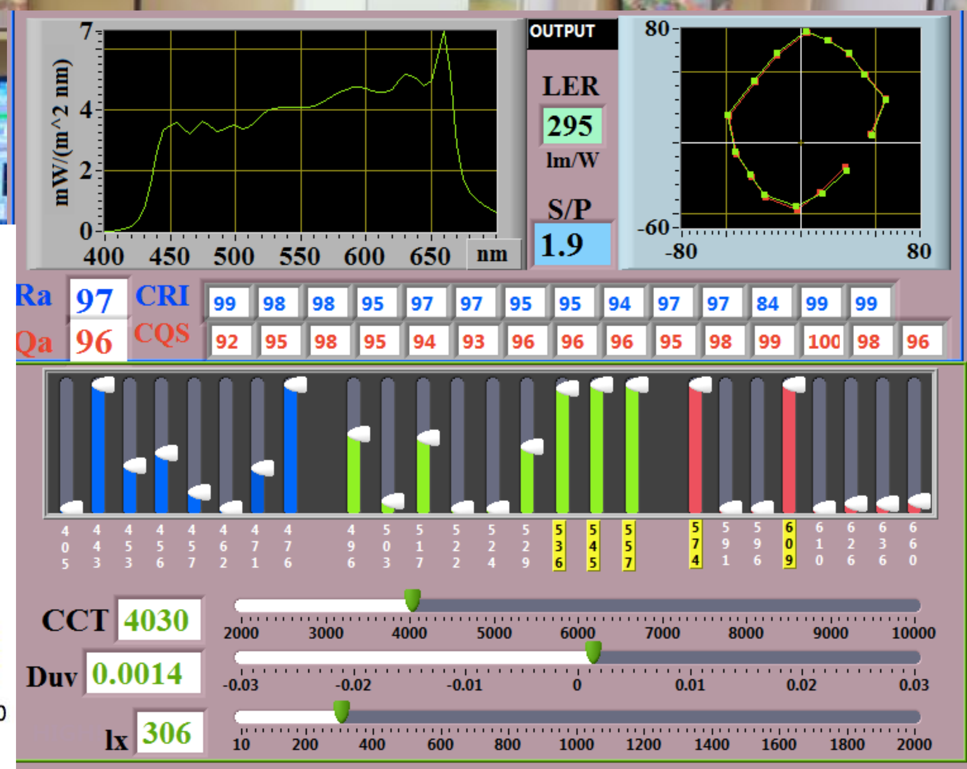


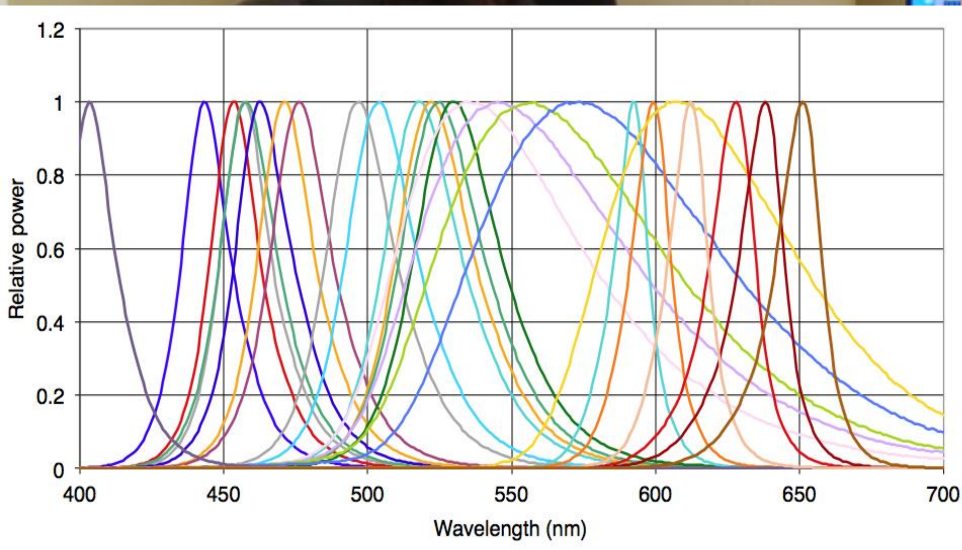
Ohno, Y., Fein, M., Vision Experiment on Acceptable and Preferred White Light Chromaticity for Lighting, CIE x039:2014, pp. 192-199 (2014).

NIST Spectrally Tunable Lighting Facility

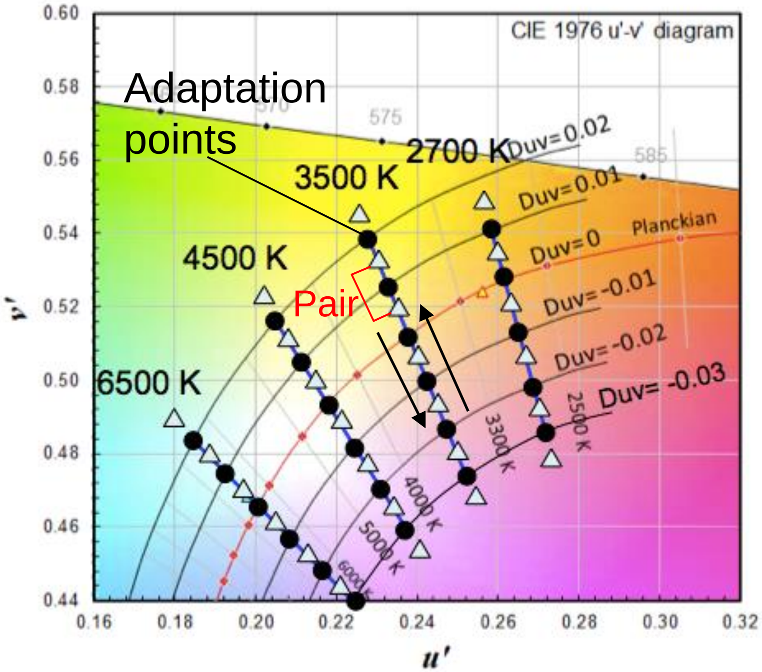
NIST Spectrally Tunable Lighting Facility







2013 Vision Experiment at NIST on Preferred and Acceptable level of Duv



6 Duv points at each CCT,
4 CCTs,
at total **23** points.
Total 50 spectra used.

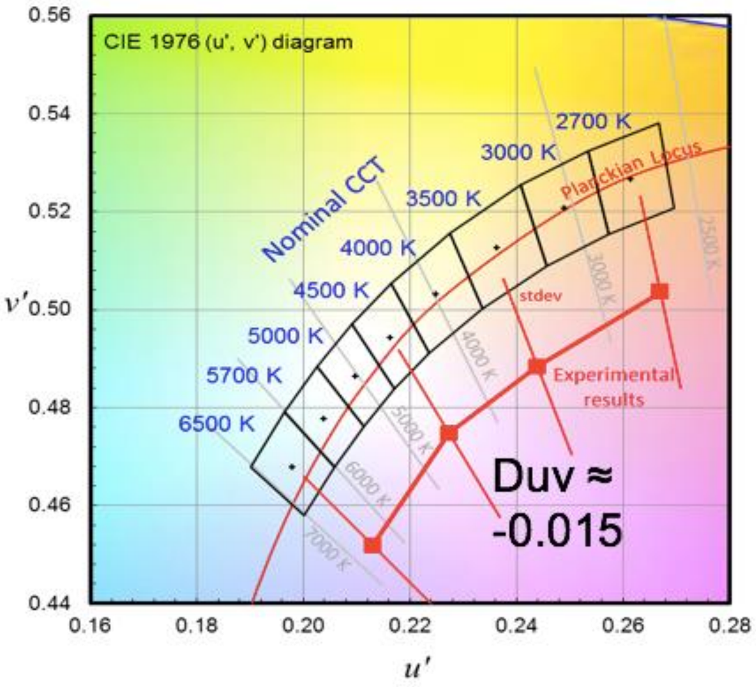
- NIST STLF at ~ 300 lx.
- 18 subjects (20 to 70 yrs old)
- Viewed **fruits/vegetables** on the table, his/her **skin tone** and the **whole room.**
- **Adapted** to each Duv point before judgement: which light is **"more natural".**

Which light looks more natural?   A

Which light looks more natural? B

2013 Vision Experiment at NIST on Preferred and Acceptable level of Duv

Average results of all subjects



Duv=~ -0.015 at all CCTs appeared most natural.

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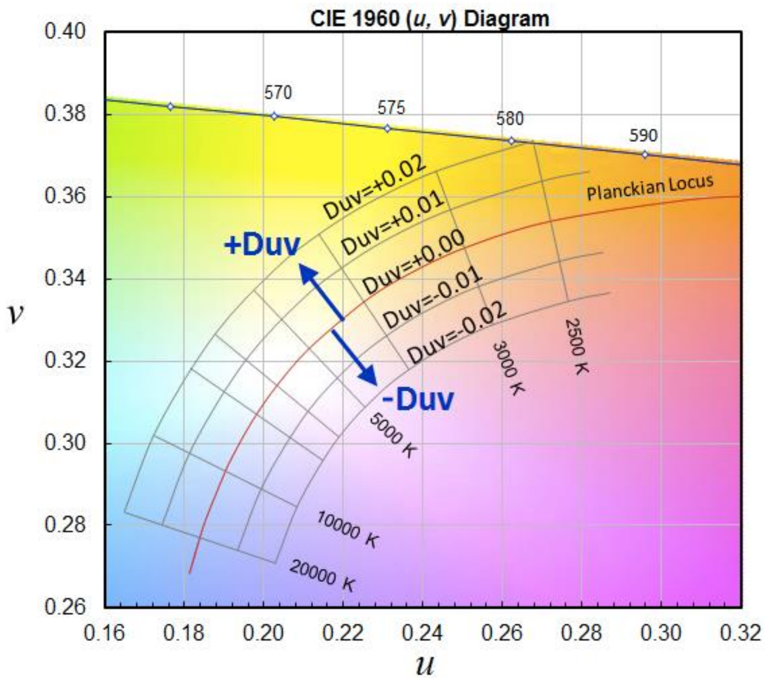
2013 Vision Experiment at NIST on Preferred and Acceptable level of Duv

Duv defined in ANSI C78.377.



Further reference
Y, Ohno, "Practical Use and Calculation of CCT and Duv" *LEUKOS* 10:1, 47-55, DOI: 10.1080/15502724.2014.839020 (2013).

- NIST STLF at ~ 300 lx.
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- **Adapted** to each Duv point before judgement: which light is **"more natural".**

Discussion by Minchen Wei & Kevin Houser

What Is the Cause of Apparent Preference for Sources with Chromaticity below the Blackbody Locus?

Minchen Wei[a] & Kevin W. Houser[a]

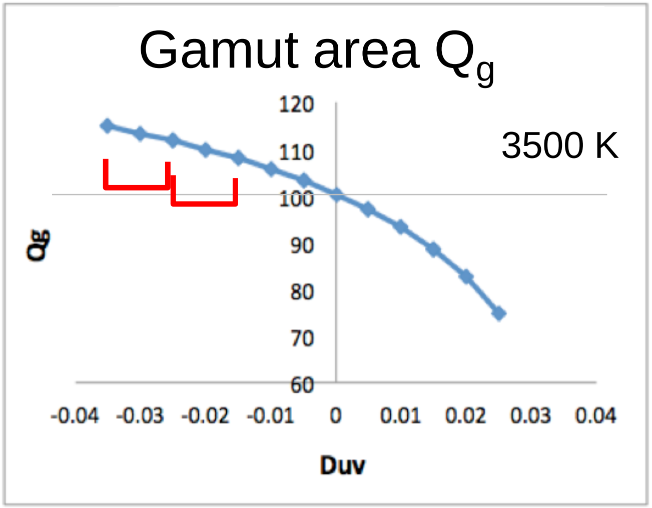
[a] Department of Architectural Engineering, The Pennsylvania State University, University Park, Pennsylvania, USA
Published online: 18 Apr 2015.

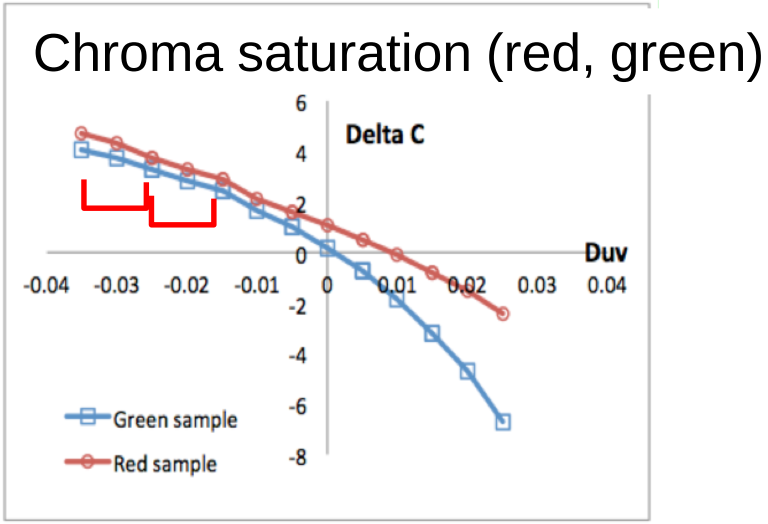
LEUKOS, **DOI:**10.1080/15502724.2015.1029131, April 2015
Vol. 12, Issue 1-2, 2016

"We infer that the preference expressed by participants in the studies by Dikel and others [2014] and Ohno and Fein [2014] may not be solely related to chromaticity."

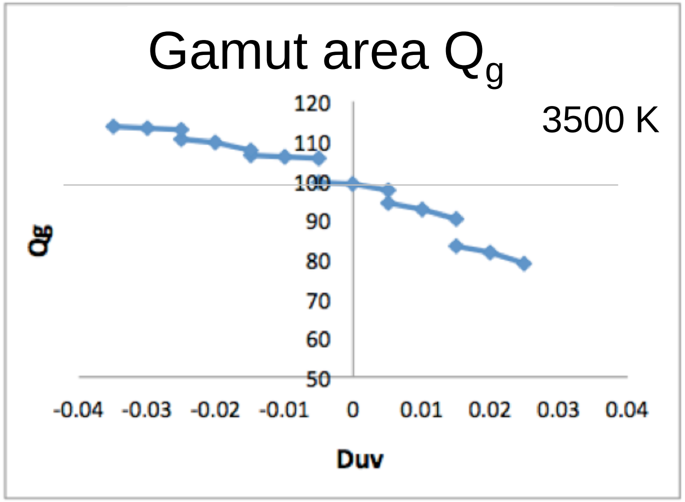
"aspects of color rendition (that is, color fidelity and relative gamut) may also influence preference."

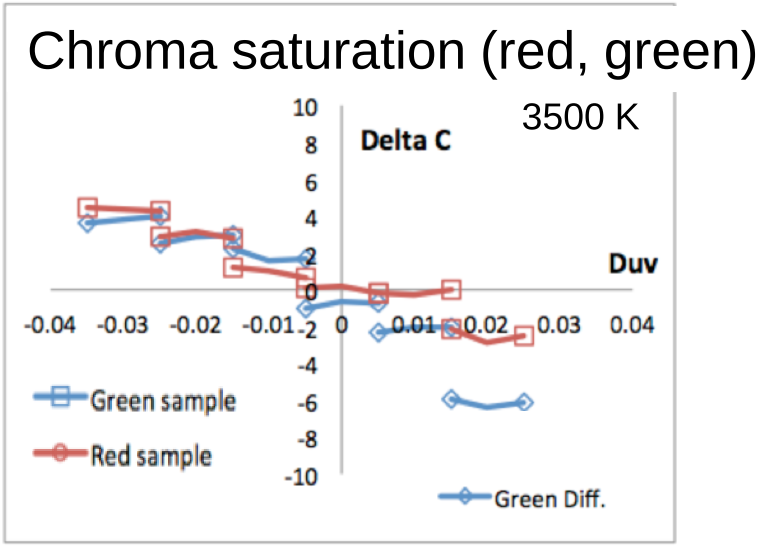
2013 Experiment



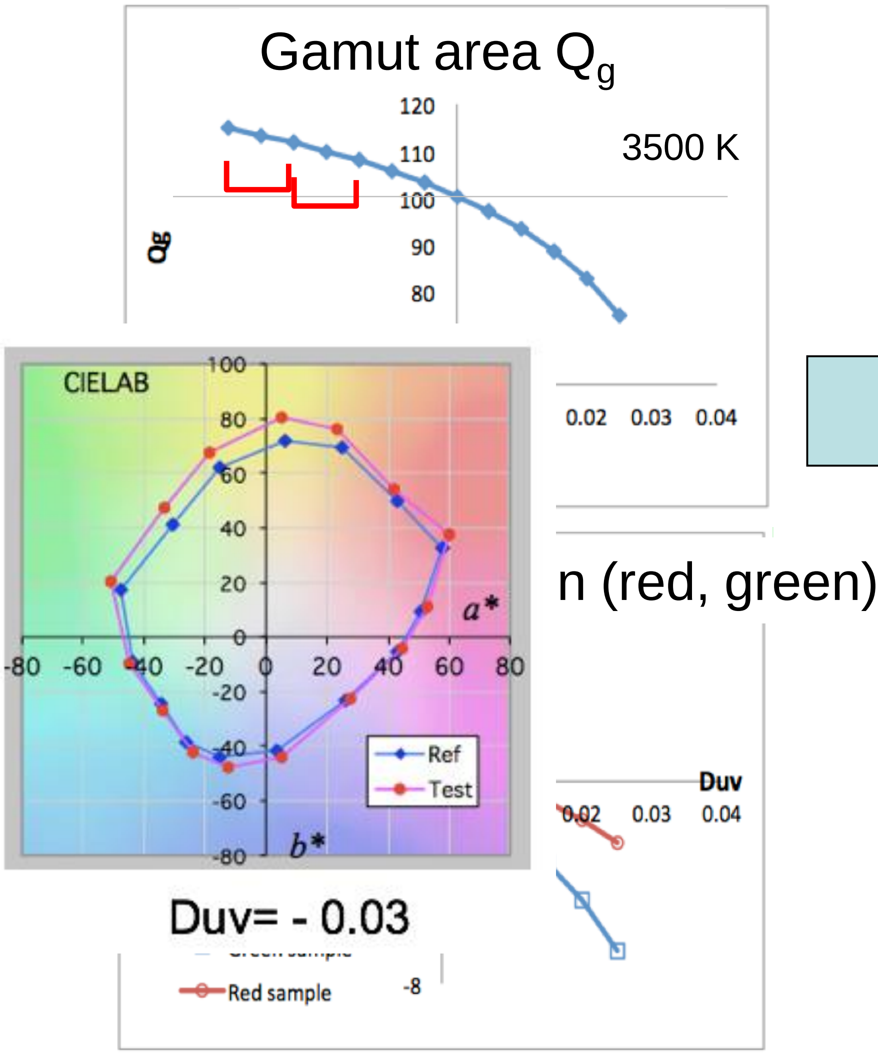


2015 Experiment

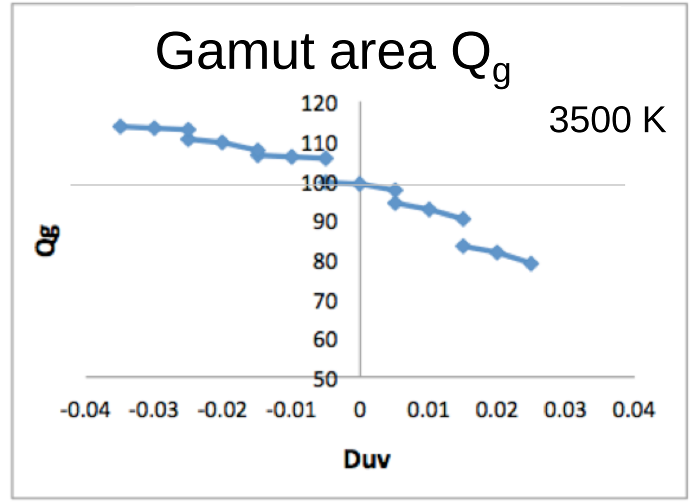


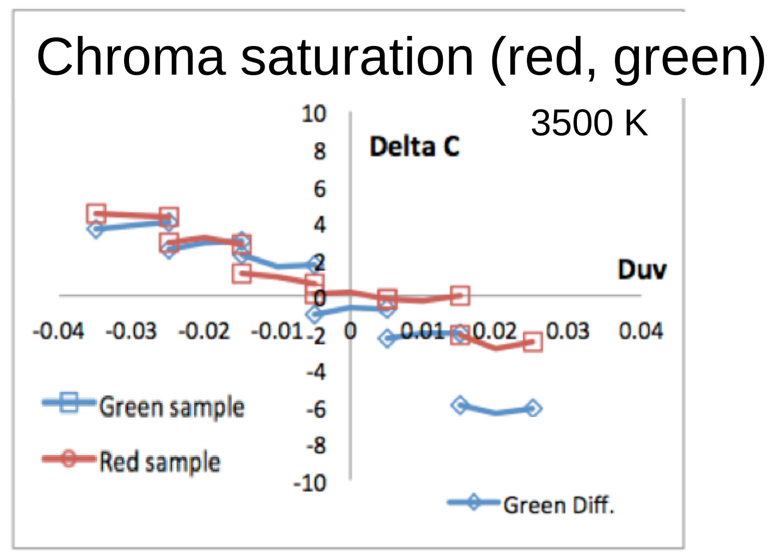


2013 Experiment



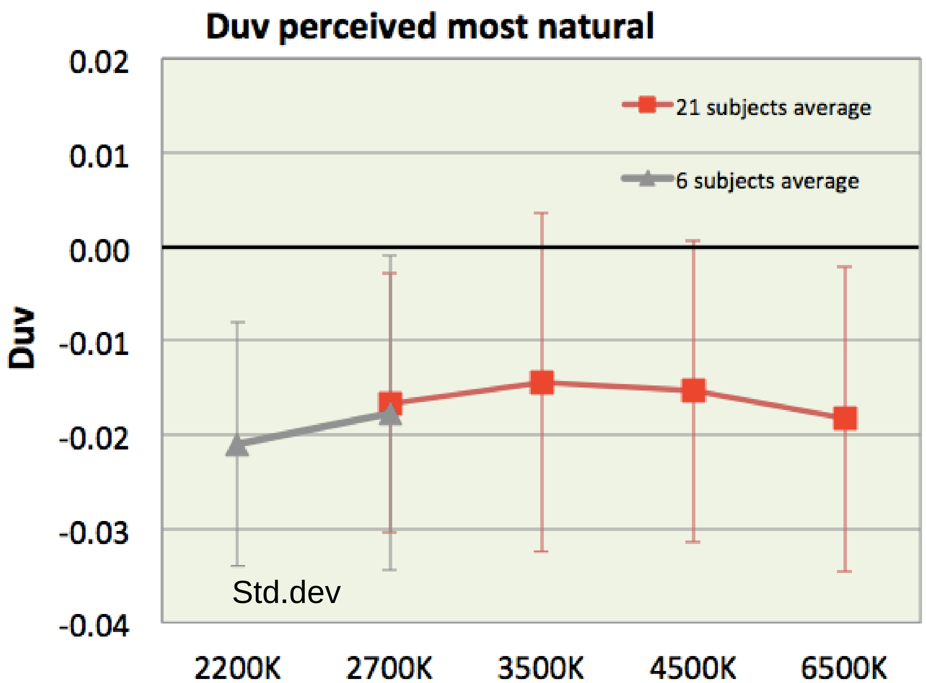
2015 Experiment



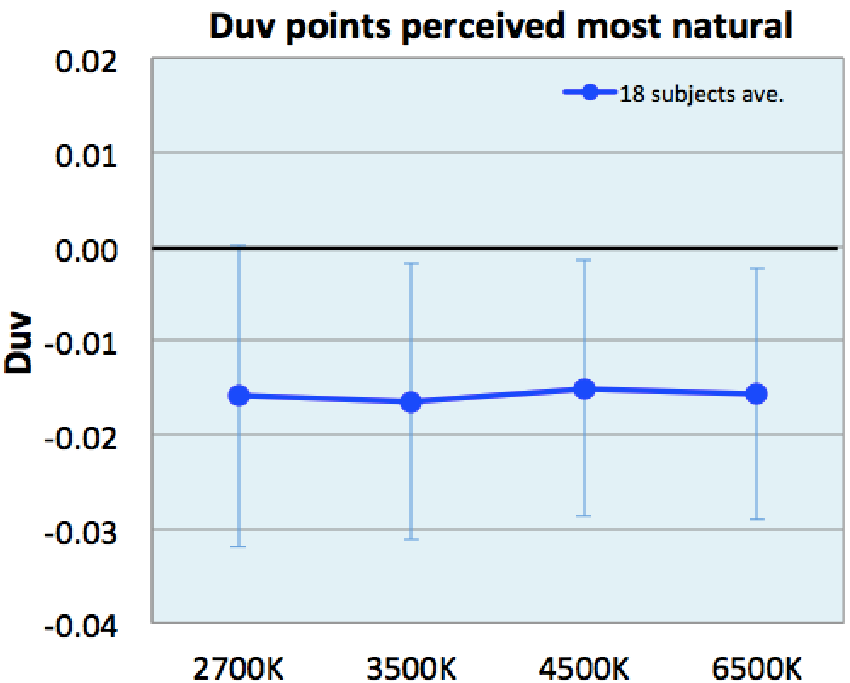


Average Results of 2015 vs 2013 Experiment

2015 results



2013 results



No significant differences found.

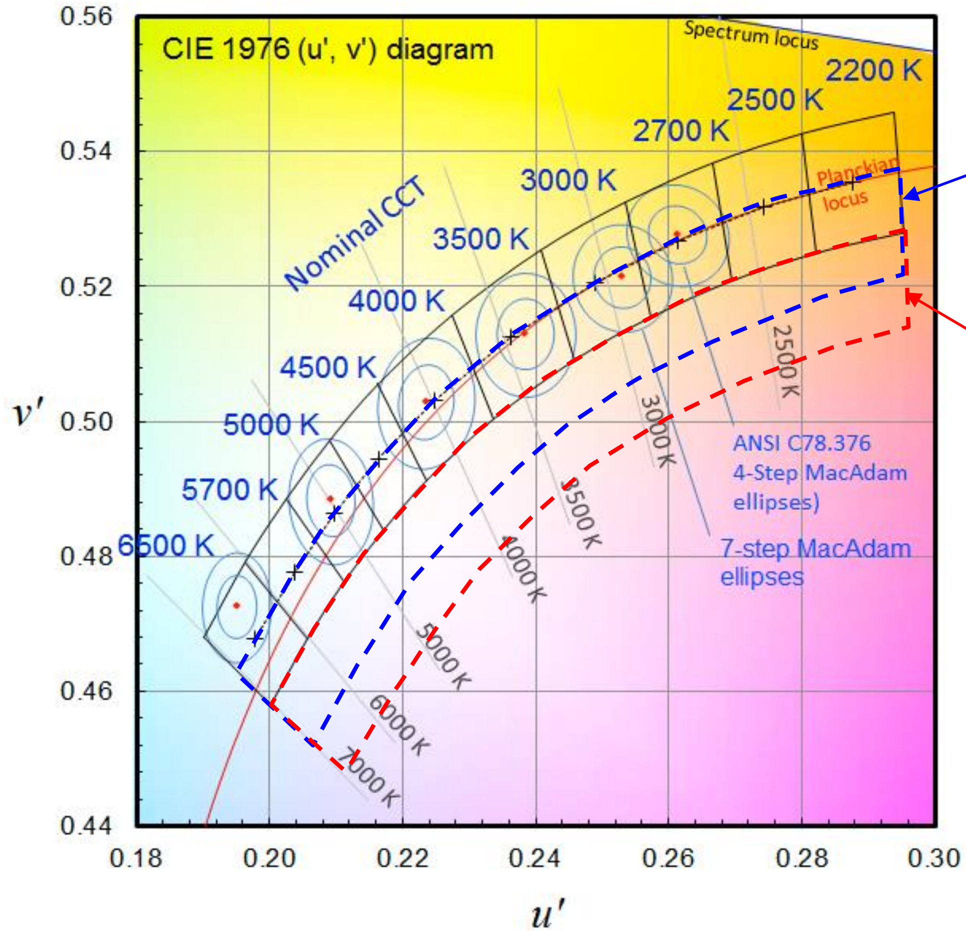
References

Ohno, Y., Oh, S., Vision Experiment II on White Light Chromaticity for Lighting, CIE x042:2016, pp. 175-184 (2016)

Ohno, Y., Fein, M., Vision Experiment on Acceptable and Preferred White Light Chromaticity for Lighting, CIE x039:2014, pp. 192-199 (2014)

Proposal for addition to ANSI C78.377

Proposal



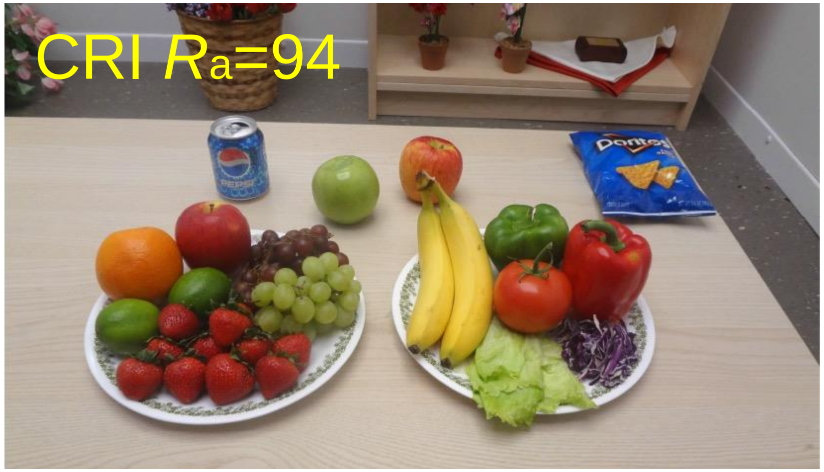
Flexible Duv
(Center Duv -0.002 to -0.012)

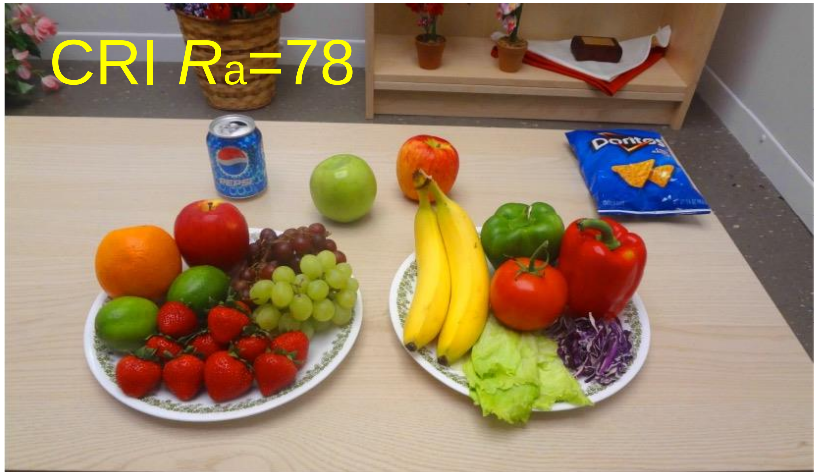
"Preference-based"
(Center Duv -0.012)

OUTLINE

1. Research on White Light Chromaticity
2. Research on Color Saturation Preference
3. Understanding TM-30 and CRI
4. Where are we going to?

Why perception differ from the CRI scores?

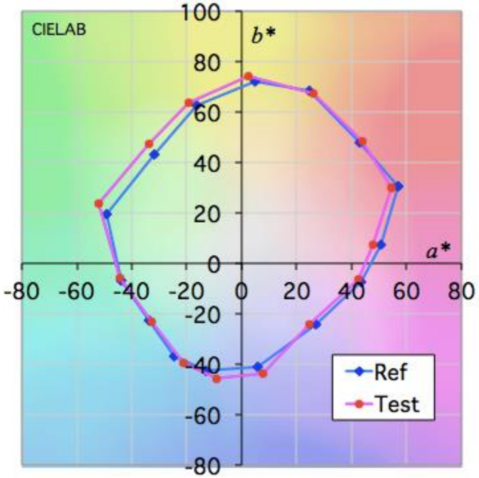




Looks better (for most people)

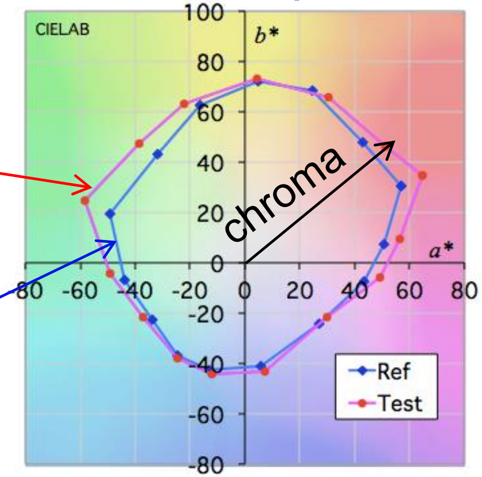
Plots of 15 CQS samples on CIELAB (a*,b*)

The area within such plots is called “gamut area”



Test light (R_a=78)

Reference (Planckian)

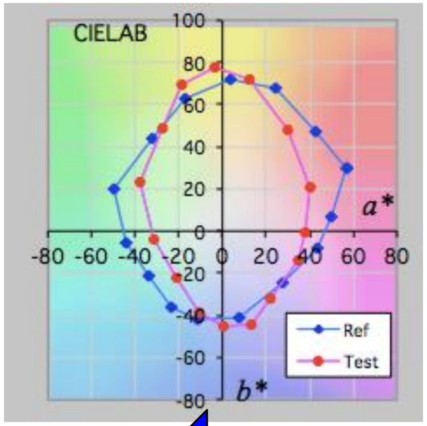


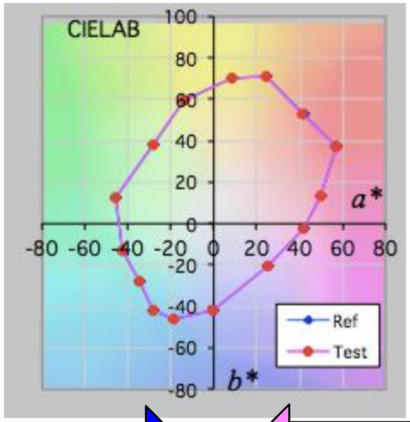
Red and green are critical

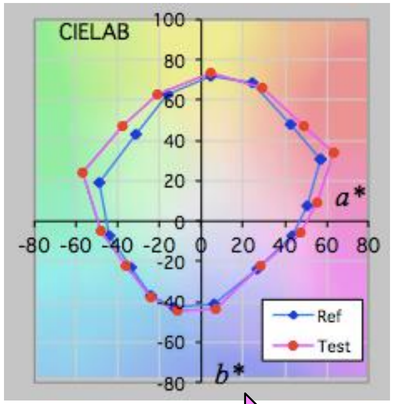
- **CRI is a color fidelity metric based on Reference Illuminant.**
- **Perception is different from color fidelity**

Color Gamut and Perception

De-saturated	Neutral	Over-saturated
Looks poor	Good	Looks better (to some extent)



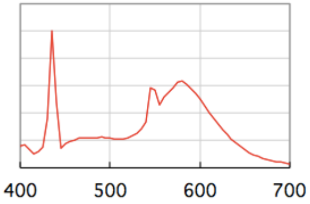




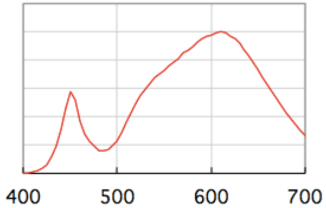
Perception and CRI agree (CRI works okay)

Perception and CRI do not agree

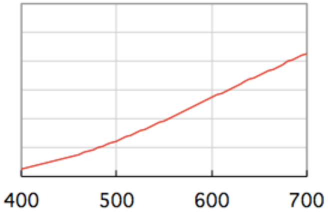
R_a=63



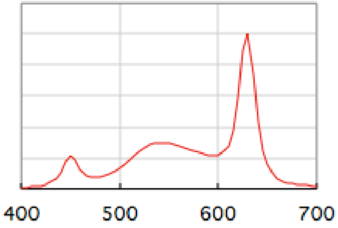
R_a=82



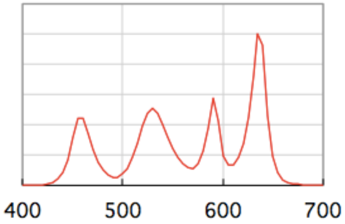
R_a=100



R_a=85

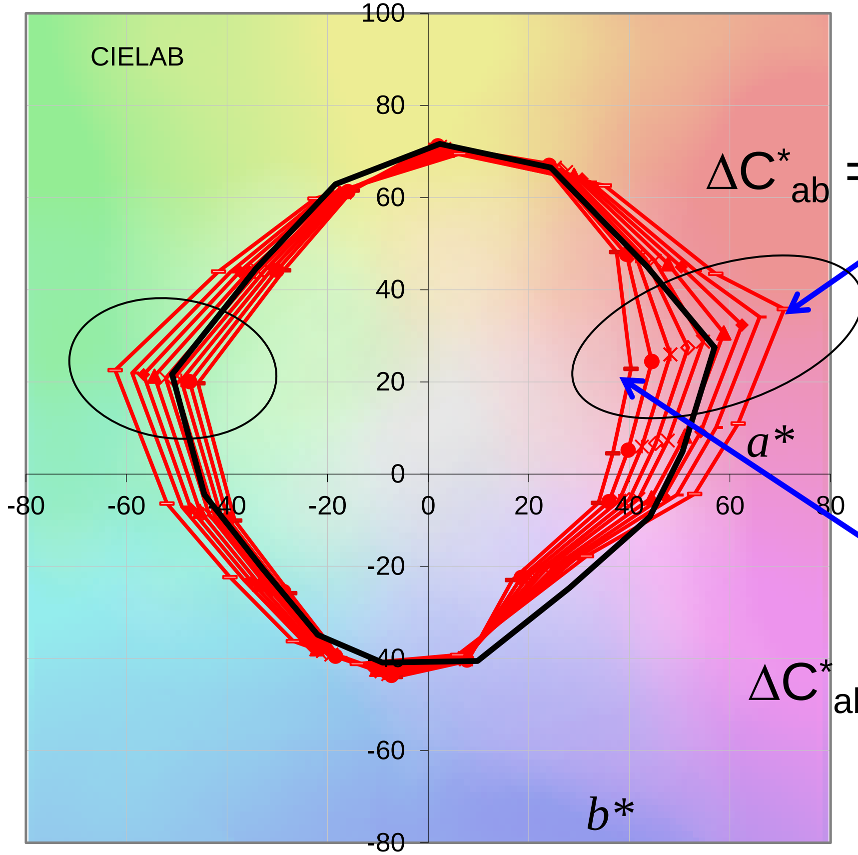


R_a=82



2014 Vision Experiment at NIST on preferred chroma saturation level

- 20 subjects
- 3 CCTs (2700, 3500, 5000 K), D_{uv}= 0
- 3500 K, D_{uv}= -0.015



ΔC^*_{ab} = 16

Most saturated

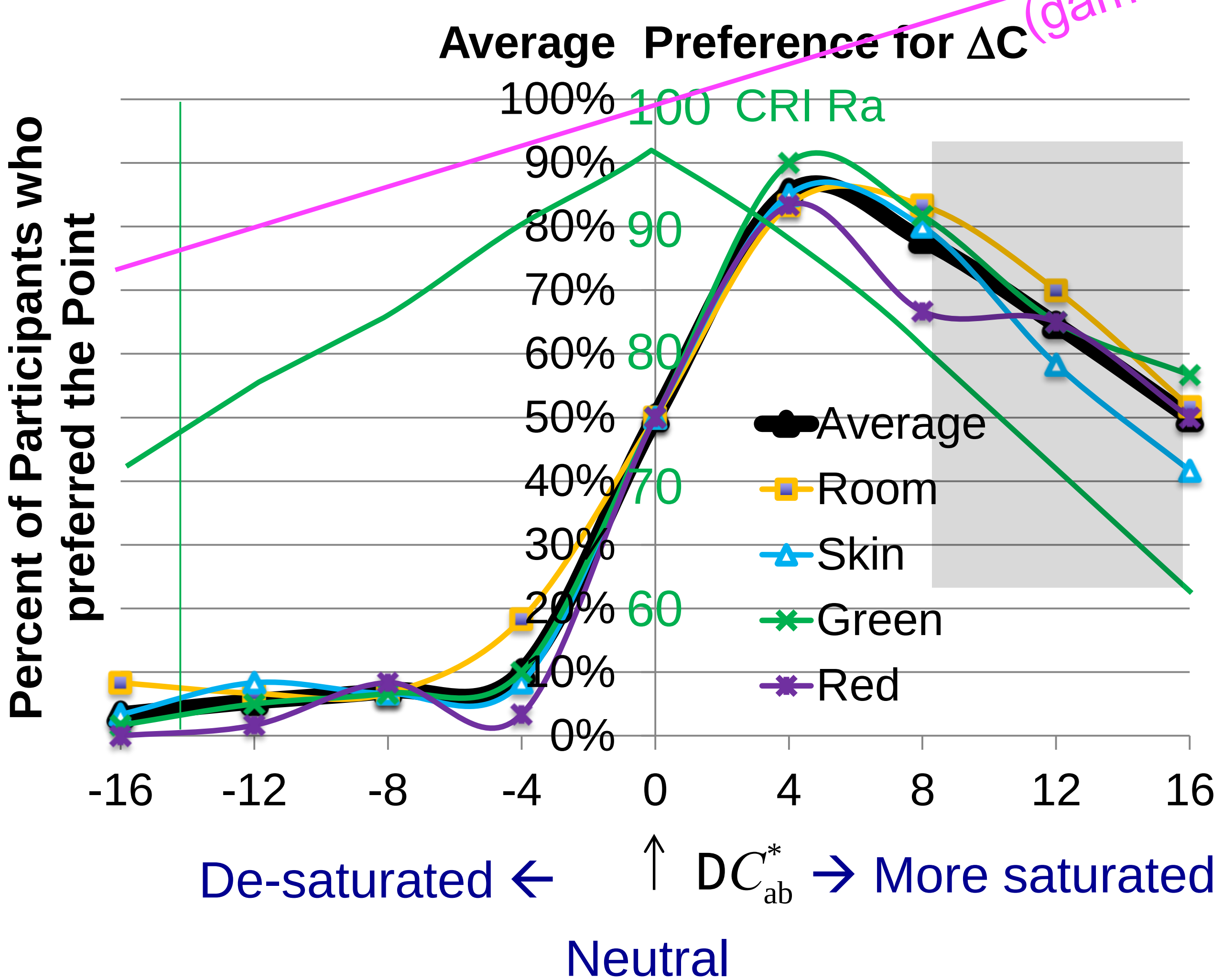
ΔC^*_{ab} = -16

Most de-saturated

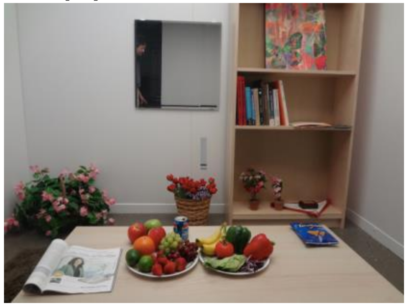
Which light looks better? A

Which light looks better? B

Results



(1) Entire room



(2) Skin tone of subject

(3) Red fruits/vegetables

(4) Green fruits/vegetables

Reference: Y. Ohno, M. Fein, C. Miller, Vision Experiment on Chroma Saturation for Color Quality Preference, CIE 216 :2015, pp. 60 – 69 (2015)

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2. Research on Color Saturation Preference
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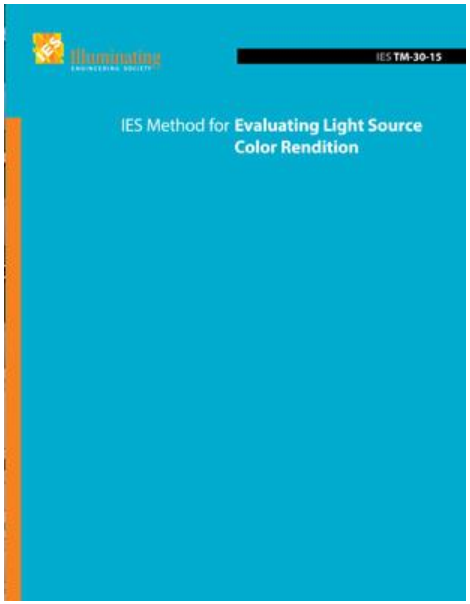
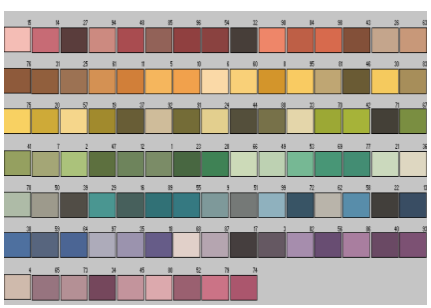
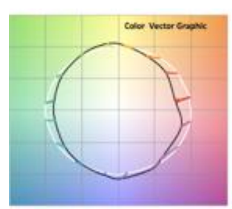
IES TM-30 IES Method for Evaluating Light Source Color Rendition





- ❑ Two-metric system
  - Fidelity index R_f → Color fidelity: Improvement of CRI R_a
  - Gamut index R_g → Information for preference
- ❑ 99 test samples
- ❑ Latest color space and chromatic adaptation formula → Works accurately for all colors of object and all spectra
- ❑ Calculation tool → Provide details beyond R_f and R_g.



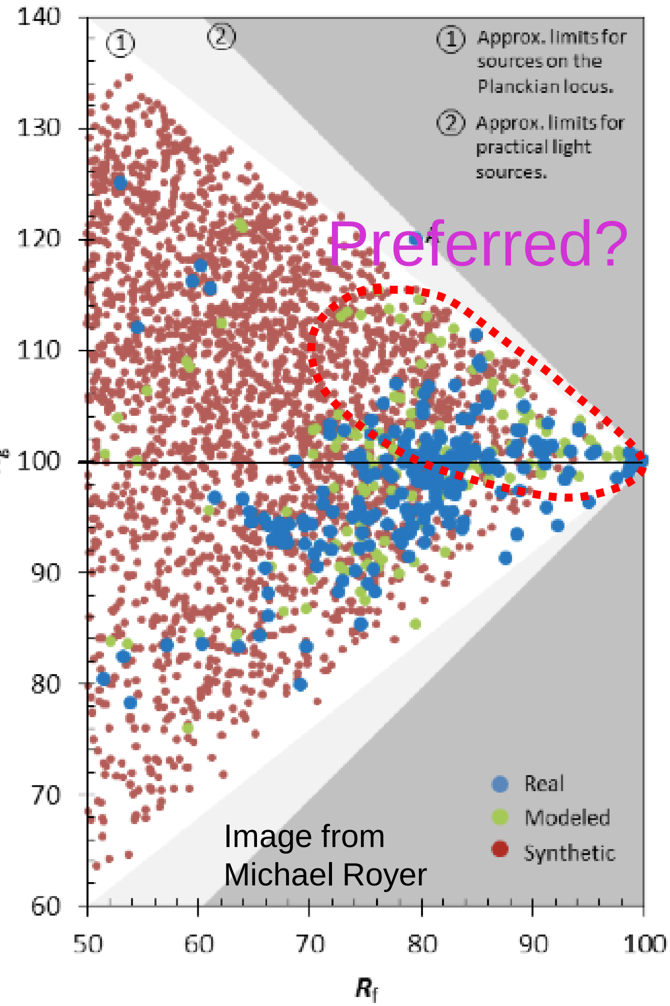
Color Vector Graphic

Concept of Two-Metric System

More saturated

Gamut R_g

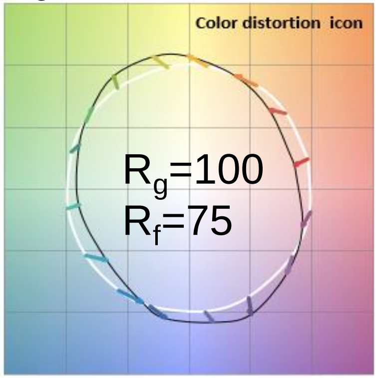
Less saturated

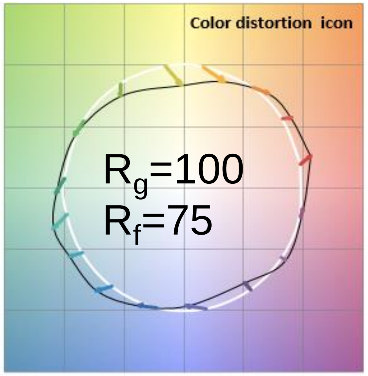


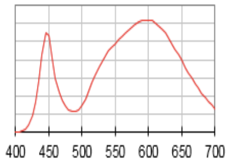
Fidelity R_f

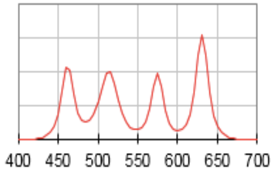
- R_g provides preference-related information.
- TM-30 does not provide design guidance for R_g
- Limitation of R_g - ave. of all hues

R_g equal but different shapes









Gamut area is not sufficient.

IES Position statement of CRI – 2015

Issued Sep. 2015

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PS-8-15
Color Rendering Index

The IES recognizes that the CIE Color Rendering Index (CRI), used to determine the accuracy of a light source's rendering of color compared to a reference, has shortcomings that limit its ability to fully represent how humans perceive color.

Since its adoption in 1964, several light source technologies have been introduced and commonly adopted for architectural lighting that yield a different visual experience than the CRI metric can describe.

As a substantial step toward solving this problem, IES TM-30-15, *IES Method for Evaluating Light Source Color Rendition*, has been developed for the benefit of the lighting community to provide: (a) a more accurate assessment of color fidelity; (b) an additional, complementary assessment of the influence of the preferred color appearance of objects (related to color gamut); and (c) more detailed information about the rendition of specific colors. As with any IES Technical Memorandum, TM-30-15 is not a required standard, and it does not provide design guidance or criteria for best practices. However, the issuance of TM-30-15 will enable the international lighting community to carefully evaluate it, providing a path leading to improved standards and design guidance. Technical analysis and feedback regarding the method described in TM-30 will be critical to continued development and standardization of color quality metrics.

The IES recognizes that while color rendering is important for consideration in energy regulations on the basis of maintaining lighting quality, the IES does not endorse any mandatory color rendering measures in energy regulations until there is a national or international consensus regarding an appropriate metric and range of values.

- IES recognize that CIE CRI has shortcomings, especially with new lighting technologies. TM-30 was developed to solve this problem.
- "TM-30-15 is not a required standard, and it does not provide design guidance or criteria for best practices."
- "the issuance of TM-30-15 will enable the international lighting community to carefully evaluate it, providing a path leading to improved standards and design guidance."

Link: https://www.ies.org/PDF/PositionStatements/PS-8-15.pdf

CIE Position statement on CRI and Color Quality Metrics

International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

CIE Position Statement on CRI and Colour Quality Metrics

October 15, 2015

Background

The Colour Rendering Index (CRI), defined by CIE Publication 13.3, is widely used for assessing the colour rendering characteristics of light sources. It was first published in 1965 after fluorescent lamps had emerged, and was last improved in 1974. Colour science has progressed considerably since then, and recognized improvements are available for many of the components used in the CRI. Nevertheless, the CRI has served fairly well for most light sources and has been well accepted over the past 40 years, though revision of the CRI was occasionally investigated (CIE Publication 135/2-1999).

However, with the rapid uptake of LED lighting, which has greater freedom in spectral design, the need to update the CRI has significantly increased. For some types of light sources, the CIE General Colour Rendering Index, R_a, does not agree well with overall perceived colour rendering. The CIE investigated the problem and found that the disagreement tends to be significant for LED light sources that contain narrow-band spectral components and concluded that improvements of the CRI are now needed (CIE Publication 177:2007).

There are two different technical issues behind the problems of the CRI that have been highlighted by the current situation. The first is the inaccuracy of colour appearance evaluation arising from the original 1974 CRI formulae and the small number of colour test samples used in the CRI calculation.

The second is a limitation of the CRI due to the fact that it is simply a colour fidelity metric; that is, the CRI values are based on the colour appearance of objects compared to their appearance under the defined reference illuminant. Colour quality characteristics other than colour fidelity are also important, and different analysis methods are required to assess them in the context of lighting applications, tasks, and user preferences. This is especially important when samples undergo chroma enhancements arising from the source's narrowband spectral features. In some experiments, subjects generally preferred illumination that slightly enhanced the colour saturation of the illuminated objects they viewed, even though the chosen light sources had lower R_a values.

CIE Position Statement

The CIE recognizes that, because the Colour Rendering Index has several significant sources of colorimetric inaccuracy, it should be updated with the latest well-accepted formulae and an improved set of test samples. CIE Technical Committee (TC) 1-90 is already in the process of developing a new improved colour fidelity metric that can update the CRI.

The CIE recognizes that the colour fidelity metrics including the CRI do not assess other important aspects of the colour qualities of light sources, in particular, those related to colour preference. CIE TC 1-91 is developing a Technical Report on this subject, which will be the groundwork for developing colour preference metric(s).

Link: http://www.cie.co.at/index.php?i_ca_id=981

Issued Oct. 2015.

- CRI has several significant sources of colorimetric inaccuracy. CRI needs to be updated. CIE TC1-90 is developing a new color fidelity metric.
- CIE supports the study of the recently published IES TM-30. TC1-90 accepted TM-30 R_f metric as basis for the TC's first draft.
- An orderly transition is needed when a new metric is to be introduced.
- Both TC reports to be completed by end of 2016.
- The colour fidelity metrics including the CRI do not assess other important aspects of the colour qualities of light sources, in particular, those related to colour preference. CIE TC 1-91 is developing a Technical Report on this subject.

GLA (Global Lighting Association) Position statement on CRI

GLOBAL LIGHTING ASSOCIATION

Position Statement on Colour Rendering Index

18 September 2015

Position

The Global Lighting Association (GLA) cautions against the establishment of regulatory or other minimum performance requirements for a colour rendering index (R_a) of greater than 80 for indoor lighting applications. For Europe, the GLA supports retention of legal minimum requirements on colour rendering (R_a) at the current level as defined in the EU Eco-design Regulations (EC 244/2009, EC 245/2009, EC 1194/2012). In the United States, the GLA supports the Environmental Protection Agency's Energy Star Program's current minimum requirement of 80 CRI.

The flexibility afforded by this allowance permits further innovation in the field of colour quality, colour acceptance and colour preference, while promoting energy efficiency and consumer satisfaction at competitive prices. This will facilitate the continued evolution and adoption of LED lighting worldwide.

The Global Lighting Association supports the need for an additional colour quality metric - for example, a colour saturation metric, in conjunction with the well-established fidelity metric R_a.

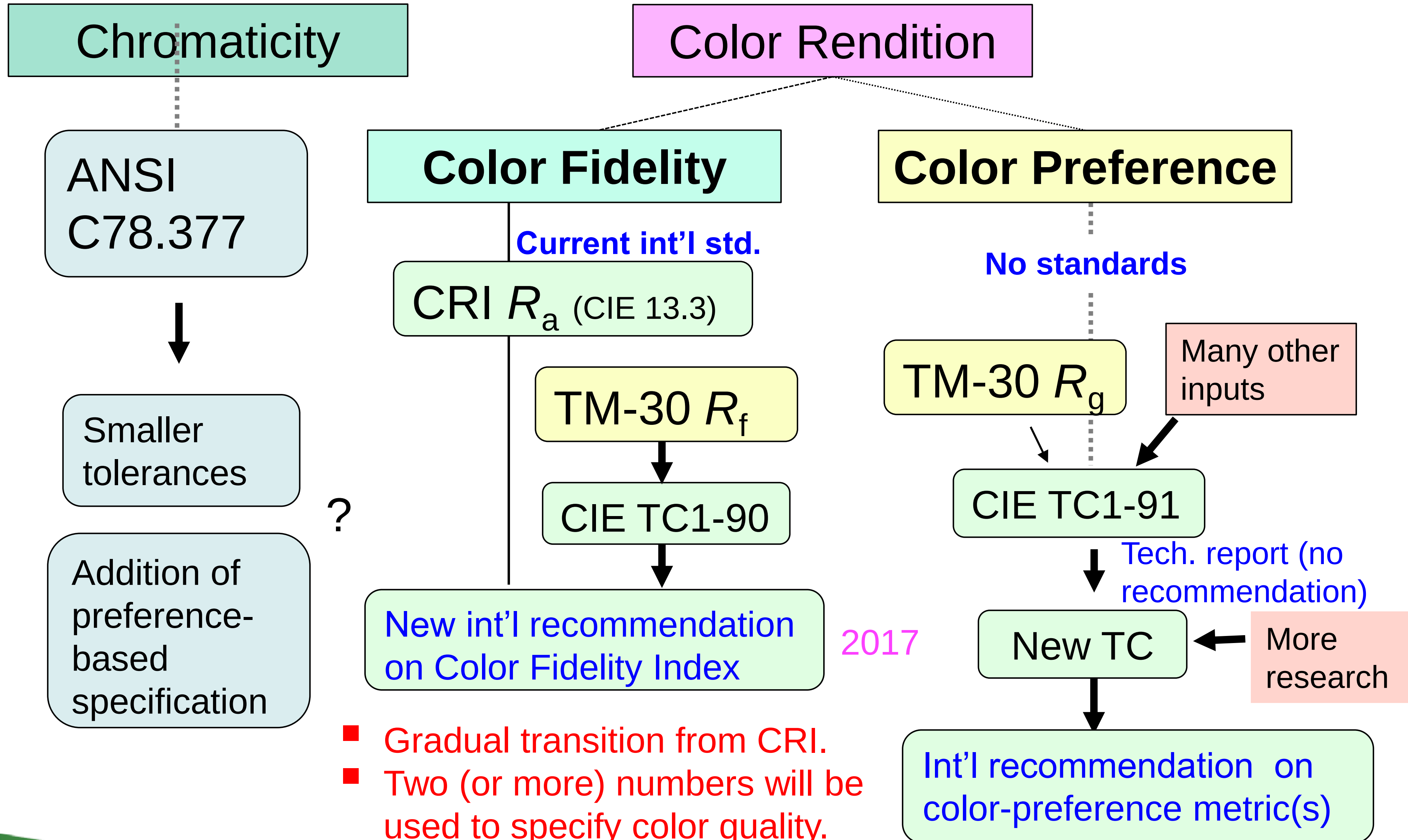
Reasoning

Higher legal minimum requirements for the colour rendering index (R_a) will not result in improved colour quality or acceptance, as R_a (representing colour fidelity) is only one aspect of colour quality. Colour saturation or 'colourfulness' is another important factor contributing to colour quality which - at least for LED lighting - is not captured in R_a. Hence consumer acceptance of lighting products

- GLA cautions against the establishment of regulatory or other minimum performance requirements for a colour rendering index (R_a) of greater than 80 for indoor lighting applications.
- GLA supports the need for an additional colour quality metric - for example, a colour saturation metric, in conjunction with the well-established fidelity metric *R*a.

Link: http://www.globallightingassociation.org/library (2nd item on this page)

Where are we going to? (CIE's perspective)



We thank DOE for their support on NIST research on SSL metrology and color quality.

THANK YOU for your attention.

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