Color Quality Issues
– IES TM-30 and preferred color quality of lighting –

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Color Quality = CCT and CRI?

CCT: Correlated Color Temperature (CIE 15, CIE S017 ILV)
CRI: Color Rendering Index (CIE 13.3)

Some example

CCT = 3050 K
CRI (Ra) = 91

This product is not acceptable. Why?

CCT does not tell the whole story of chromaticity.

Too yellowish!
Color Quality = CCT and CRI?

CCT=4000 K
CRI $R_a=94$

CCT=4000 K
CRI $R_a=78$

CRI does not tell the whole story of color rendering.

This looks better (for most people)
Why perception differ from the CRI scores?

CRI Ra=94

CRI Ra=78

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

The area within such plots is called “gamut area”

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

Test light

Reference

Red and green are critical

Looks better
Color Gamut and Perception

De-saturated
Looks poor

Neutral
Good

Over-saturated
Looks better

Perception and CRI agree (CRI works okay)

Perception and CRI do not agree

$R_a = 63$

$R_a = 82$

$R_a = 85$

$R_a = 82$
CRI test sample problem

8 test samples for Ra

$R_a = 82$

Saturated color samples

$R_9 = -90$

- Cannot catch the problems with saturated colors
- 8 samples are too few (it allows gaming)
IES TM-30 IES Method for Evaluating Light Source Color Rendition

- Two-metric system
  - Fidelity index $R_f$
  - Gamut index $R_g$

- 99 test samples

- Latest color space and chromatic adaptation formula

- Calculation tool

Improvement of CRI $R_a$
Information for preference

Works accurately for all colors of object

Provide details beyond $R_f$ and $R_g$. 
Concept of Two-Metric System

- 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

More saturated

Unnatural

Preferred

Less saturated

Fidelity R_f

R_g = 100
R_f = 75

R_g = 100
R_f = 75

Image from Michael Royer

More saturated

Preferred

Less saturated

Fidelity R_f
Graphics for expert users

Calculation Tool distributed with TM-30 purchase.

R_f-R_g Chart

Color Vector Graphic

Color Distortion Graphic
Position of TM-30

IES position statement on CRI (2015)

- TM-30 is not a required standard. (CRI is still the required standard.)
- TM-30 is issued for evaluation by the industry and international community toward a national/ international standard.

CIE position statement on CRI and color quality metrics (Oct. 2015)

- CIE (TC1-90) is discussing TM-30 R_f toward international recommendation.

Start using TM-30 with CRI. Experience it. Send feedback to TM-30 Chair: M. Royer (PNNL).
Wait for international recommendation to use it in regulations.
2014 Vision Experiment at NIST on preferred chroma saturation level

- 20 subjects
- 3 CCTs (2700, 3500, 5000 K)
  - Duv = -0.015 (3500 K only)
- Goal – develop a Color Preference scale

![Color Preference Diagram](image)

ΔC* _ab_ = 16

Most saturated

ΔC* _ab_ = -16

Most de-saturated
Experimental Conditions

**Condition 1:** mixed fruits/vegetable and room

**Condition 2:** Skin tone

**Condition 3:** Red Fruits/Vegetables

**Condition 4:** Green Fruits/Vegetables
Results

Average Preference for $\Delta C$

Percent of Participants who preferred the Point

De-saturated $\leftrightarrow$ $\Delta C^*_ab$ $\rightarrow$ More saturated

Neutral

Developing Color Preference Scale at NIST

Fidelity reference illuminant

Preference reference illuminant

<table>
<thead>
<tr>
<th>CPS Calculation (2015-9)</th>
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<tr>
<td>Weiting factor 0.5 1</td>
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<td>DC weighting factor for hue</td>
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General Color Preference scale

CRI Ra

De saturated Saturated
Chromaticity shift below Planckian Locus

People experience: Lights below Planckian locus look better.

Experiment on perceived white point by LRC (CR&A 2013)

Experiment on preferred lighting by NRC (LEUKOS 2014)

neodymium lamp
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”.

2016 DOE SSL R&D Workshop 17
Results

Chromaticity perceived most natural (2013 average)

Proposal in ANSI C78.377 WG – addition of “preference-based specification”


- Experiment was repeated in 2015 with modified spectra of lights, with nearly the same results.
- Field tests are desired for real applications.

Efficacy (lm/W) drop:
- 3 % at Duv = -0.006
- 6 % at Duv = -0.012
Summary

- Color fidelity alone (as provided by CRI) is not sufficient for perceived color quality.

- TM-30 $R_f$ (with possible modifications) to be an international recommendation by CIE.

- Possibility of preferred lighting with
  - Negative Duv sources
  - Color-enhanced light sources
  
  These new features are penalized or not allowed in current standards. Work in progress in ANSI and CIE.

- Use of color fidelity and color preference metrics in the future.

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

Thank you for your attention!