2016 DOE Solid-State Lighting R&D Workshop
Feb. 2-4, 2016, Raleigh, NC
Panel: Lighting and Human Factors

Color Quality Issues

– IES TM-30 and preferred color quality of lighting –

Yoshi Ohno

(CIE President, IES Fellow, Ph.D.)

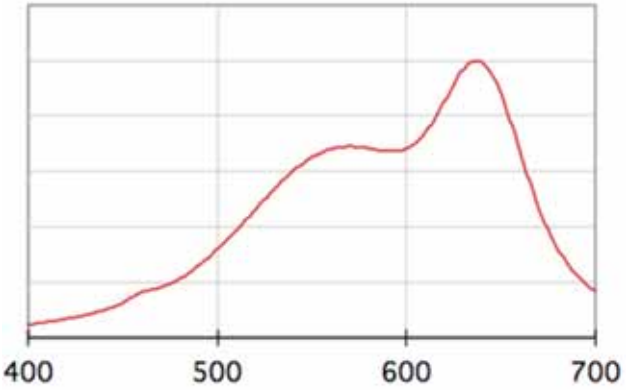
NIST Fellow, Sensor Science Division
National Institute of Standards and Technology
Gaithersburg, Maryland USA

Color Quality = CCT and CRI ?

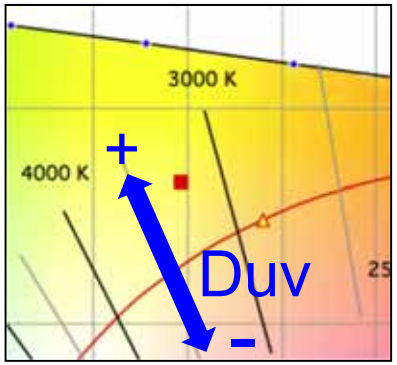
CCT: Correlated Color Temperature (CIE 15, CIE S017 ILV)
CRI: Color Rendering Index (CIE 13.3)

Some example

CCT = 3050 K
CRI (R_a)= 91



This product is not acceptable.
Why?



Too yellowish!

Normal

CCT does not tell the whole story of chromaticity.

Color Quality = CCT and CRI ?

CCT=4000 K

CRI R_a=94

CCT=4000 K

CRI R_a=78

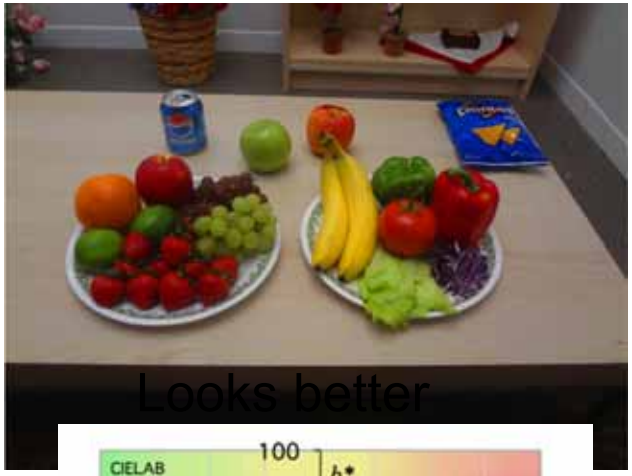
CRI does not tell the whole story of color rendering.

This looks better
(for most people)

Why perception differ from the CRI scores?

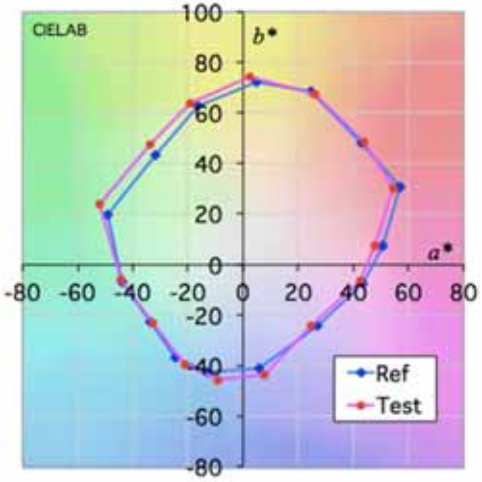
CRI R_a=94

CRI R_a=78



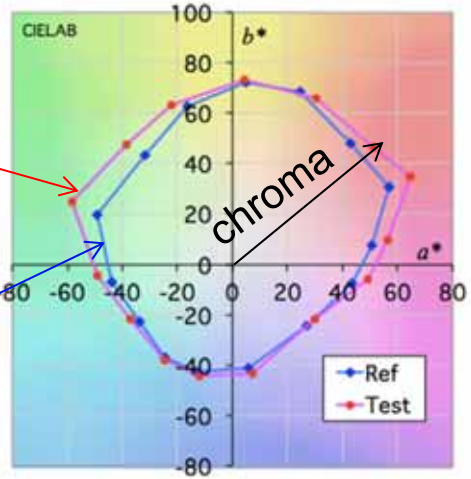
Plots of 15 CQS samples on CIELAB (a*,b*)

The area within such plots is called “gamut area”



Test light

Reference



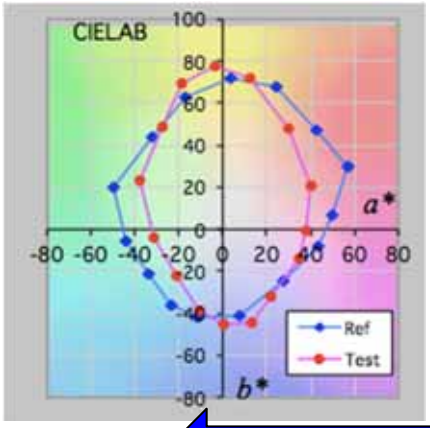
Red and green are critical

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

Color Gamut and Perception

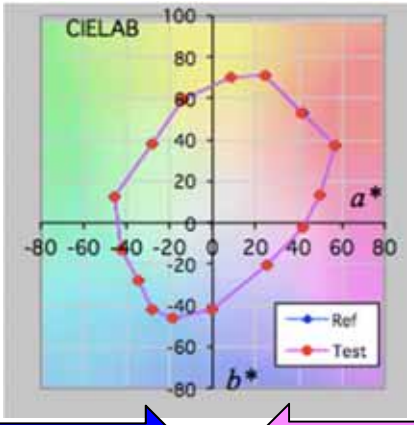
De-saturated

Looks poor



Neutral

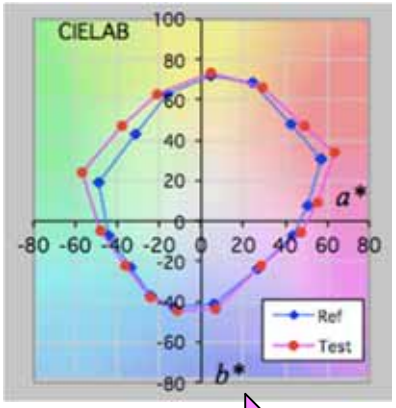
Good



Over-saturated

Looks better

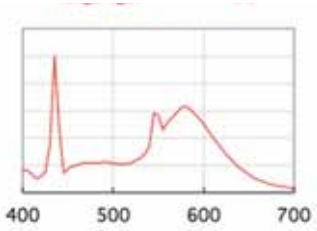
(to some limit)



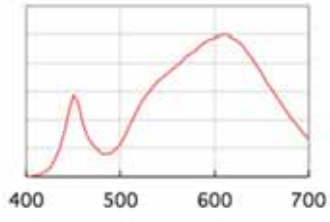
Perception and CRI agree (CRI works okay)

Perception and CRI do not agree

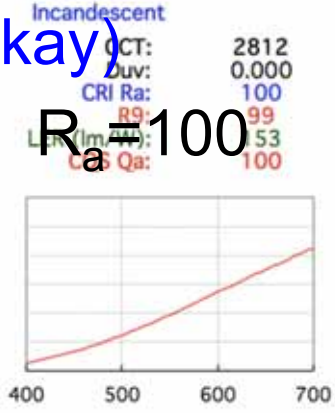
R_a=63



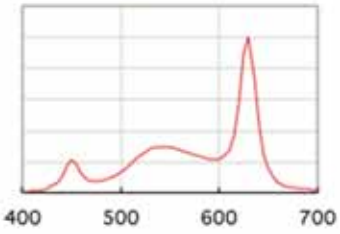
R_a=82



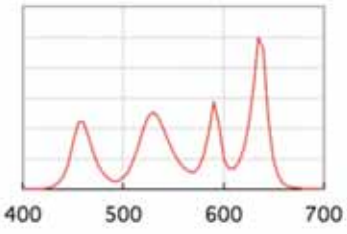
R_a=100



R_a=85

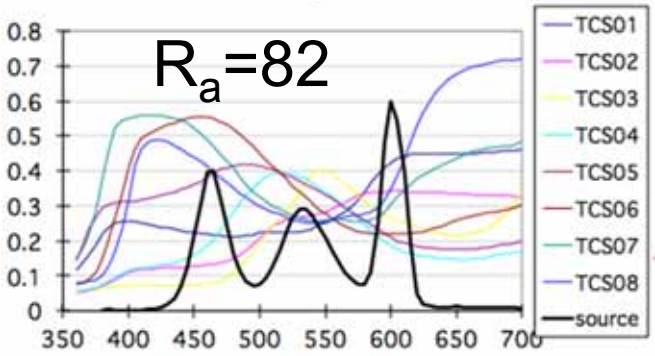


R_a=82

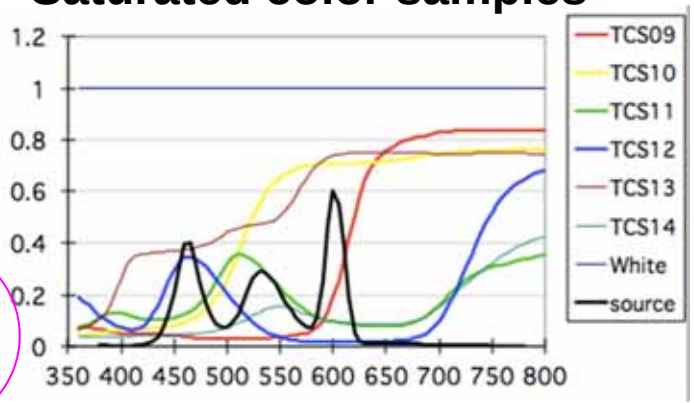


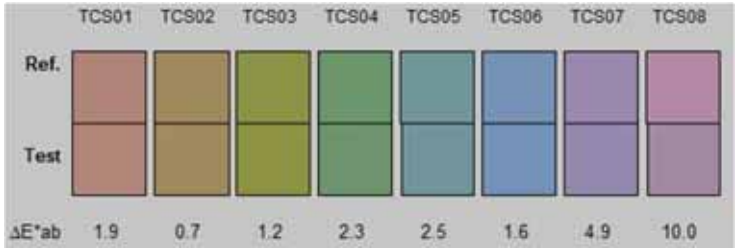
CRI test sample problem

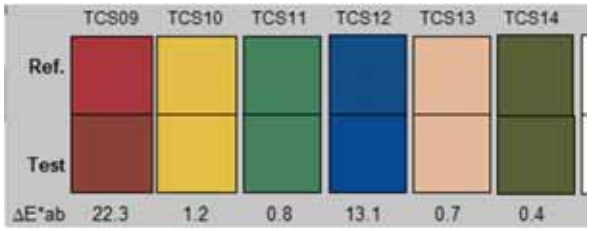
8 test samples for Ra



Saturated color samples

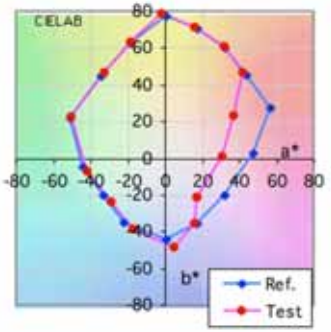




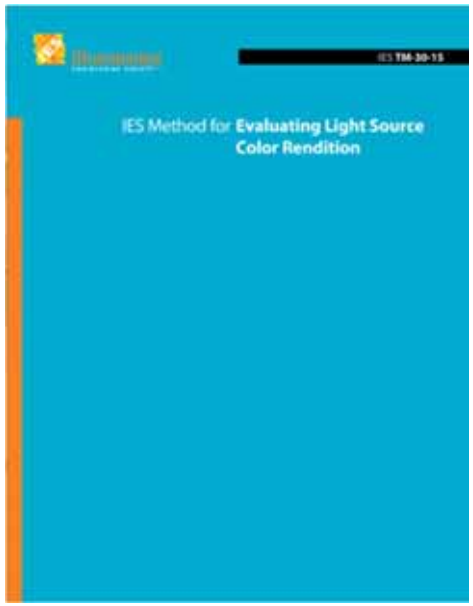


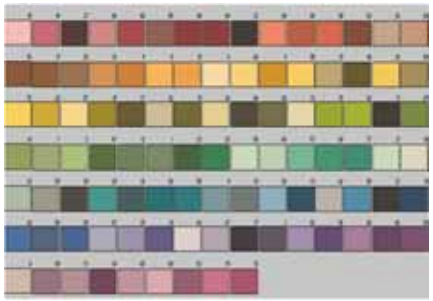
R_9=-90

- Cannot catch the problems with saturated colors
- 8 samples are too few (it allows gaming)



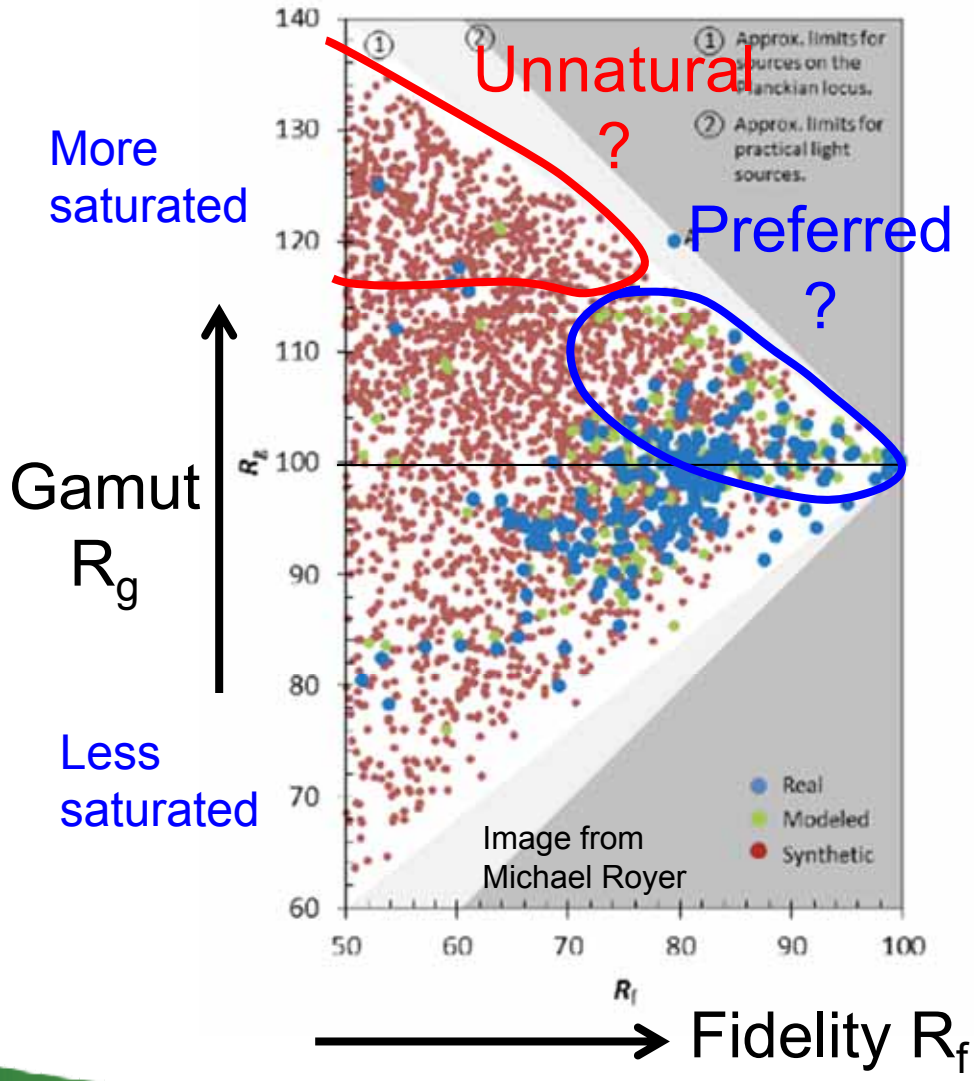
IES TM-30 IES Method for Evaluating Light Source Color Rendition





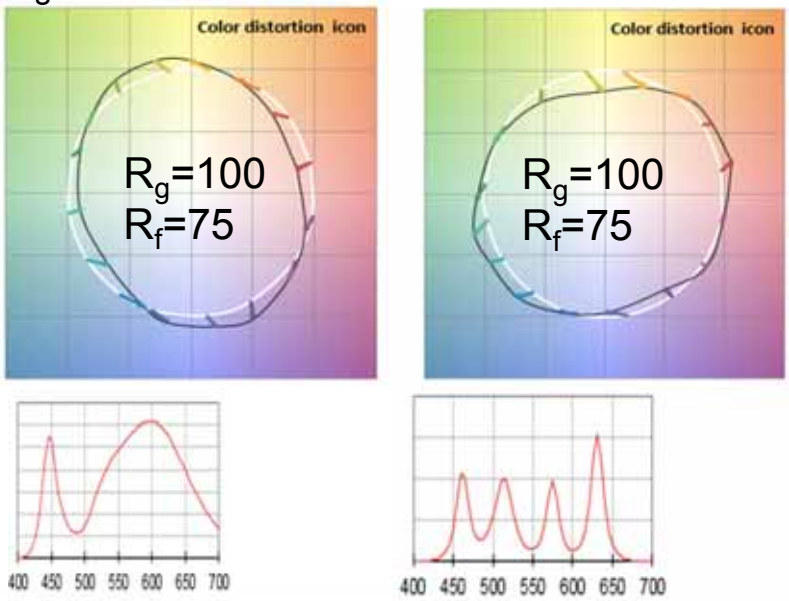
- ❑ Two-metric system
  - Fidelity index R_f → Improvement of CRI R_a
  - Gamut index R_g → Information for preference
- ❑ 99 test samples
- ❑ Latest color space and chromatic adaptation formula → Works accurately for all colors of object
- ❑ Calculation tool → Provide details beyond R_f and R_g.

Concept of Two-Metric System

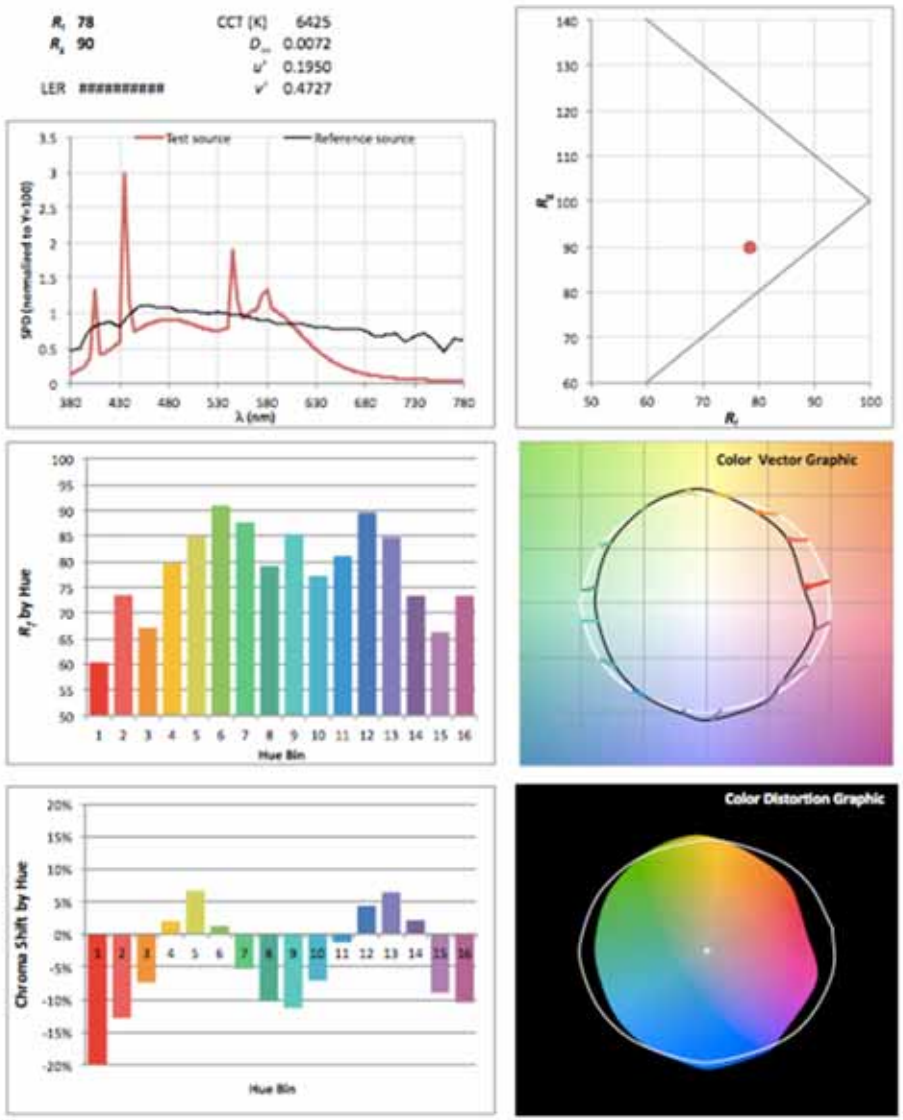


- R_g provides preference-related information.
- TM-30 does not provide design guidance for R_g
- Limitation of R_g - ave. of all hues

R_g equal but different shapes



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

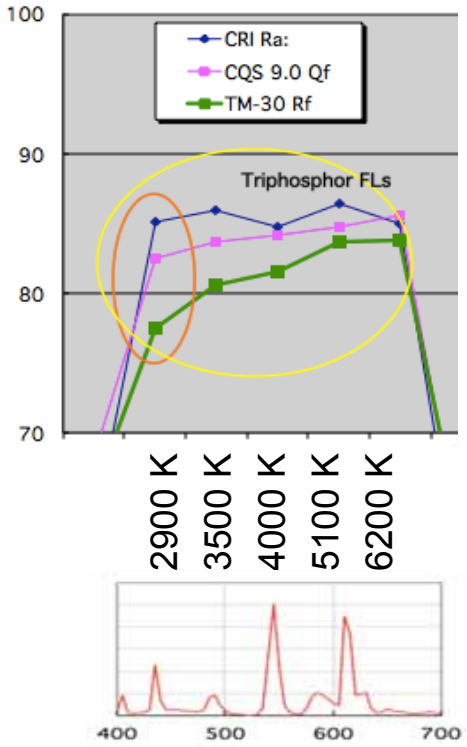
IES position statement on CRI (2015)

- 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.

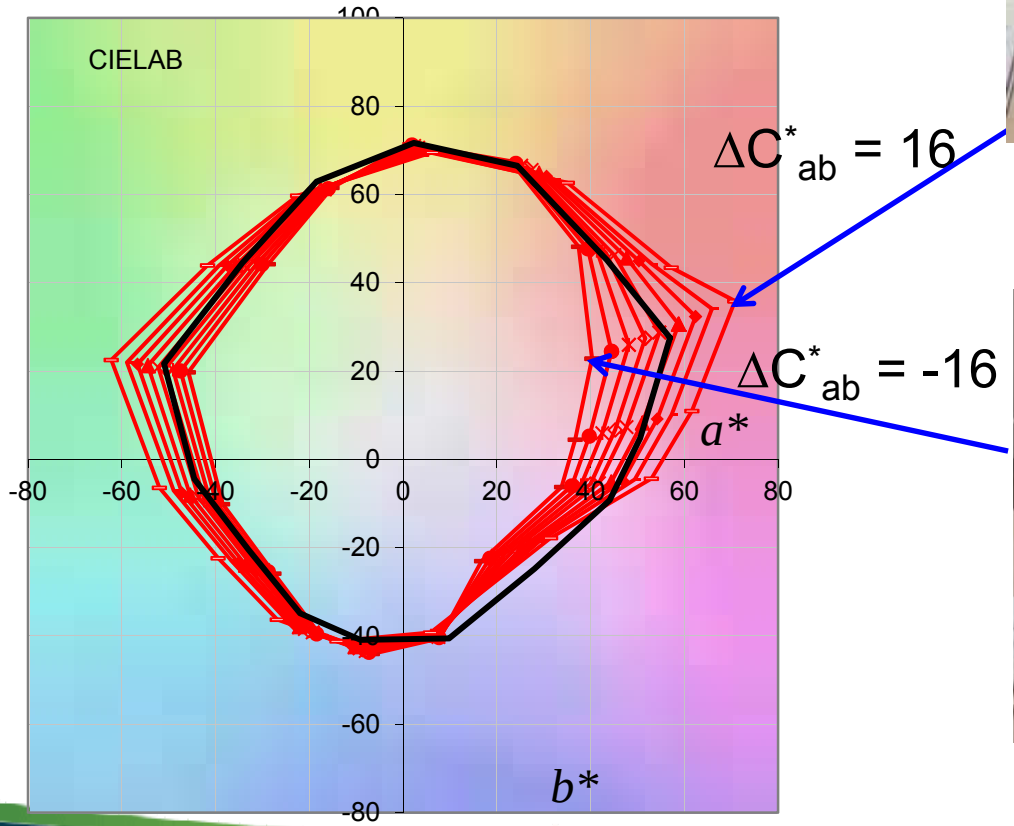
Example of score differences



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



$\Delta C^*_{ab} = 16$

Most saturated

$\Delta C^*_{ab} = -16$

Most de-saturated

Experimental Conditions

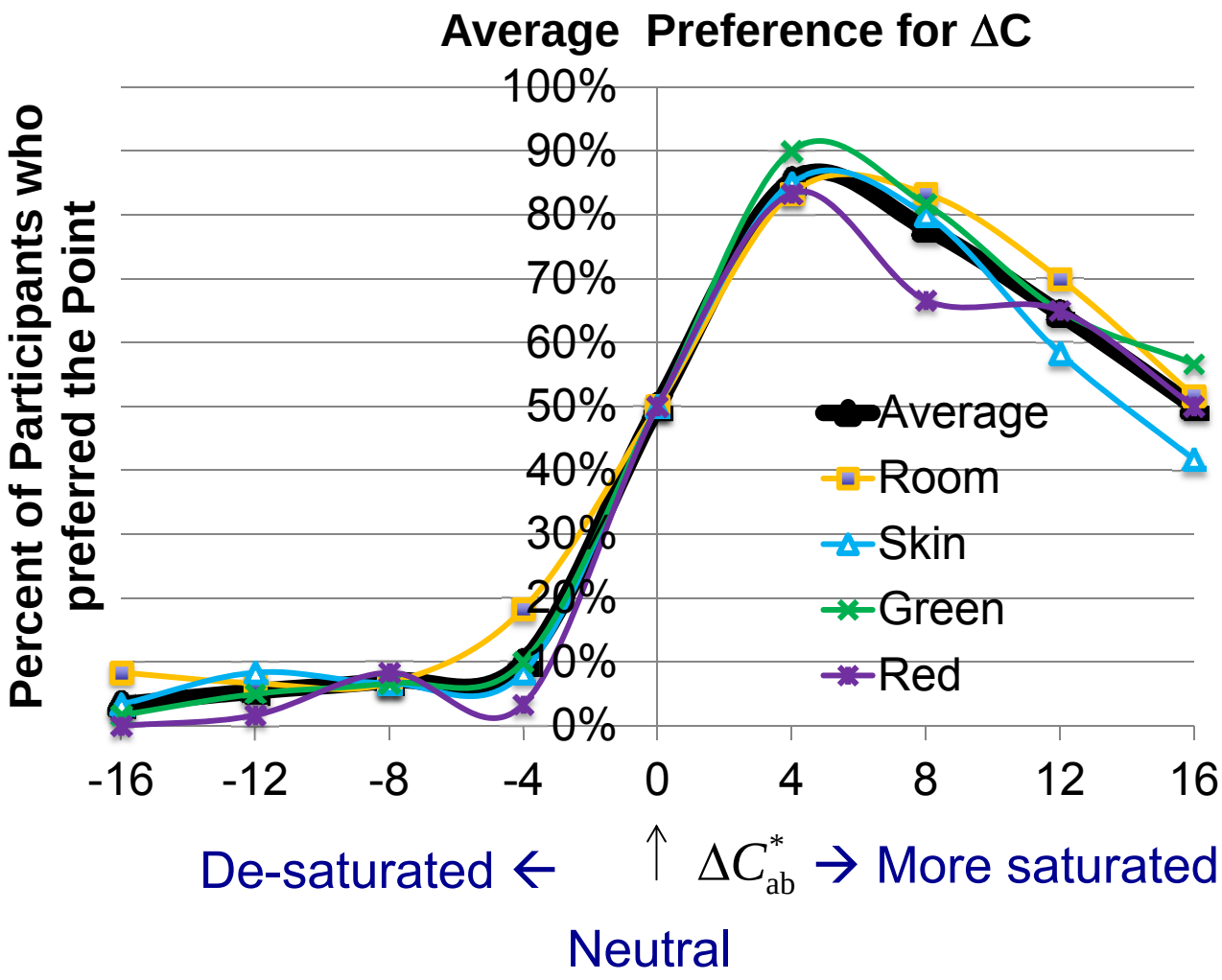
Condition 1: mixed fruits/vegetable and room

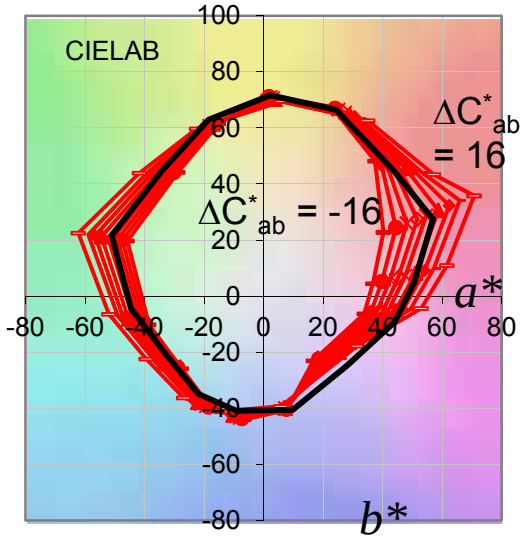
Condition 2: Skin tone

Condition 3: Red Fruits/Vegetables

Condition 4: Green Fruits/Vegetables

Results

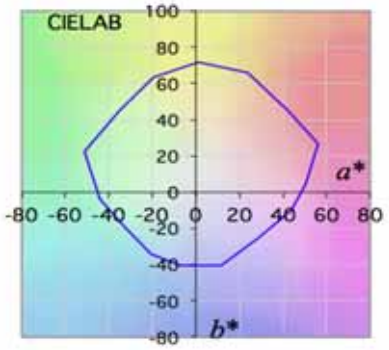




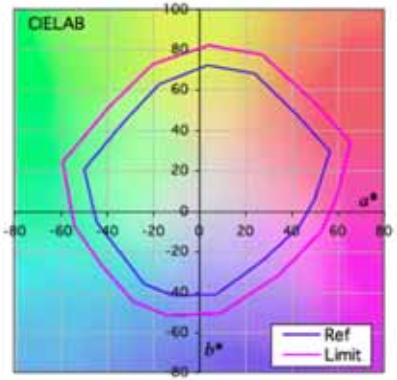
Y. Ohno, M. Fein, C. Miller, Vision Experiment on Chroma Saturation for Color Quality Preference, CIE 216 :2015, pp. 60 – 69 (2015)

Developing Color Preference Scale at NIST

Fidelity reference Illuminant

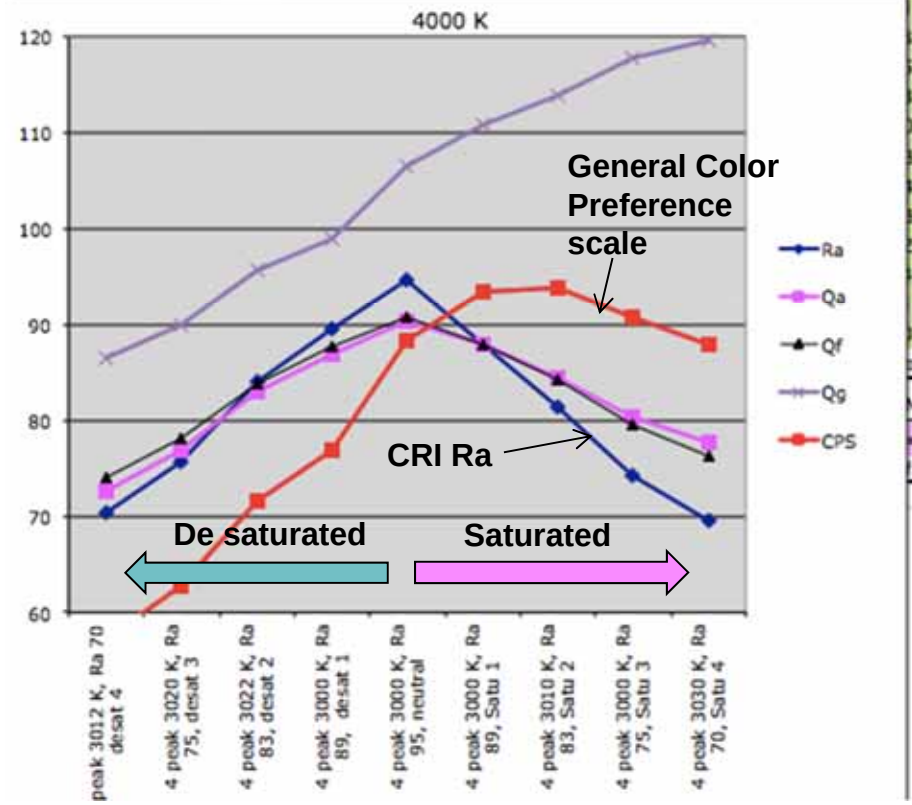


Preference reference Illuminant

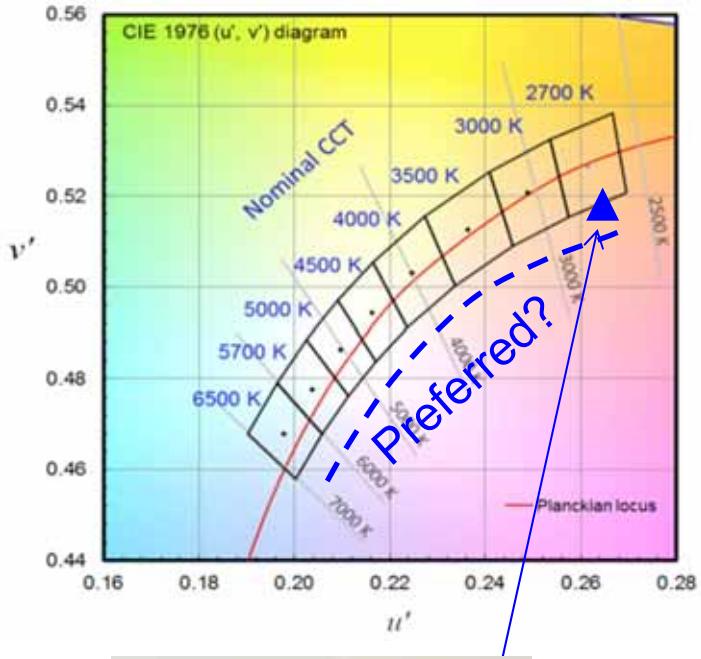


CPS Calculation (2015-9)

	a*	b*	C*ab	hue ang	in °	Δhue ang	ΔL*	ΔC*ab+	ΔC*ab-	ΔE(hue)	DC weighting factor for hue	ΔE*ab(weighte
				Weiting factor			0.5	1	1.2	0.5		
58	63.67	43.01	76.84	0.5941	34.0	0.01	2.5	4.33	0.00	0.72	3.00	13.07
79	48.50	53.07	71.89	0.8304	47.6	-0.08	-1.0	0.32	0.00	-5.54	2.17	2.89
25	28.96	71.79	77.41	1.1873	68.0	-0.05	-1.1	0.00	-1.97	-4.00	1.33	3.77
											0.50	1.37
											0.67	2.06
											0.83	1.49
											1.00	3.11
											0.88	2.04
											0.75	2.09
											0.38	2.37
											0.50	2.64
											0.50	2.48
											0.50	2.16
											1.33	2.39
											2.17	6.29
												3.35
												4.4
												92.1
											factor	1.80



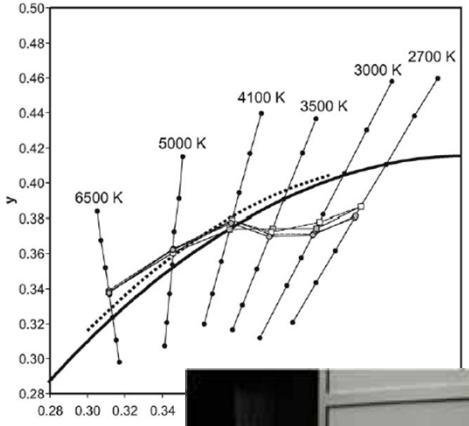
Chromaticity shift below Planckian Locus



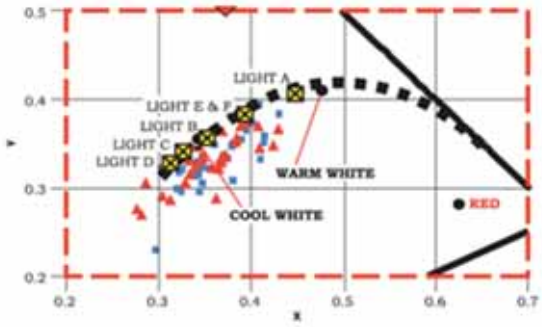
neodymium lamp

People experience: Lights below Planckian locus look better.

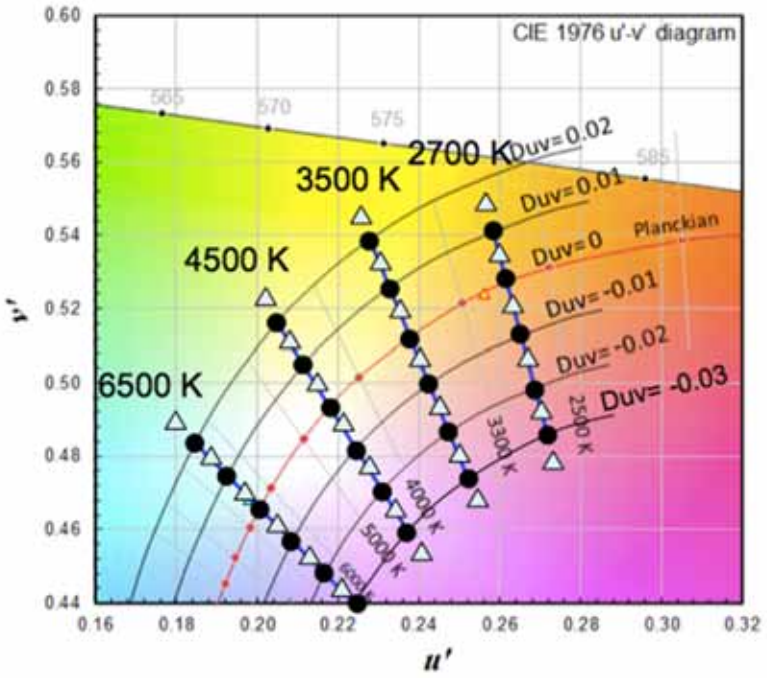
Experiment on perceived white point by LRC (CR&A 2013)



Experiment on preferred lighting by NRC (LEUKOS 2014)



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

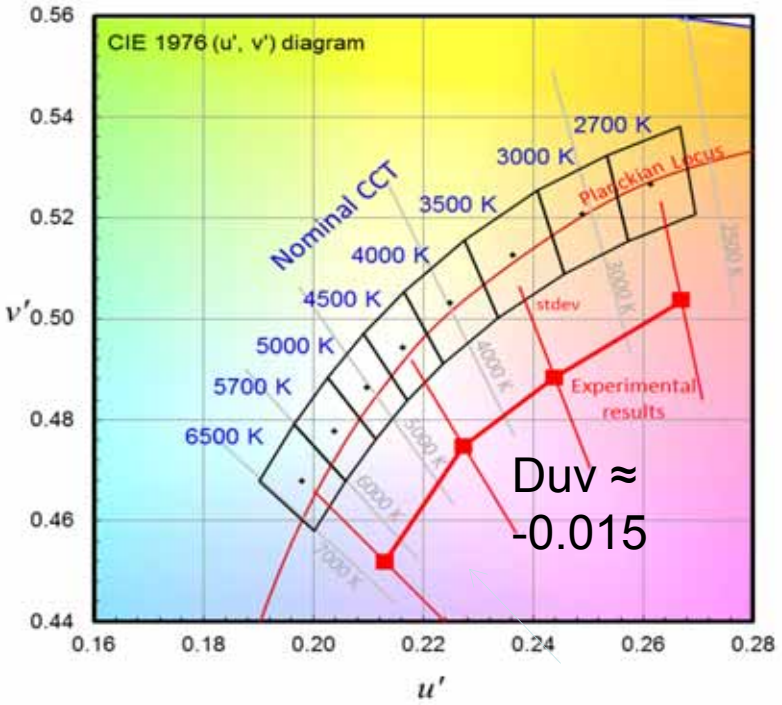


6 Duv points at each CCT,
4 CCTs,
at total **23** points.
Total 50 spectra used.

- 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".**

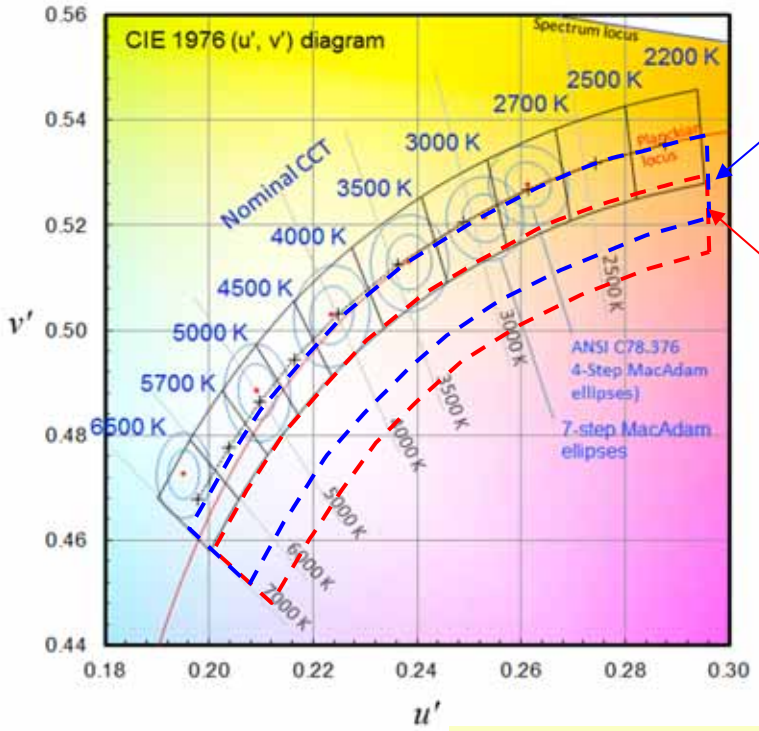
Results

Chromaticity perceived most natural (2013 average)



Y. Ohno and M. Fein, Vision Experiment on Acceptable and Pı
Chromaticity for Lighting, CIE x029:2014, pp. 192 – 199 (2014

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



Flex. Duv
Center Duv= -0.006

Center Duv = -0.012

- 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!