U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Evaluating Color Rendering With **TM-30**

ENERGY STAR Webinar

March 31, 2016

Dr. Michael Royer, PNNL

1. How do I know how the colors in a space will appear?

2. Will a given appearance be liked (or perceived as natural, saturated, etc.)?

Tools

CRI Calculation Engine

Outdated Color Science
Limited Color Samples

Average Fidelity
R_a (CRI)

Specific Sample Fidelity
R_9

High Level Average Values
Fidelity Index (R_f)
Gamut Index (R_g)

TM-30 Calculation Engine

Modern Color Science
New Color Samples

Graphical Representations
Color Vector Graphic
Color Distortion Graphic

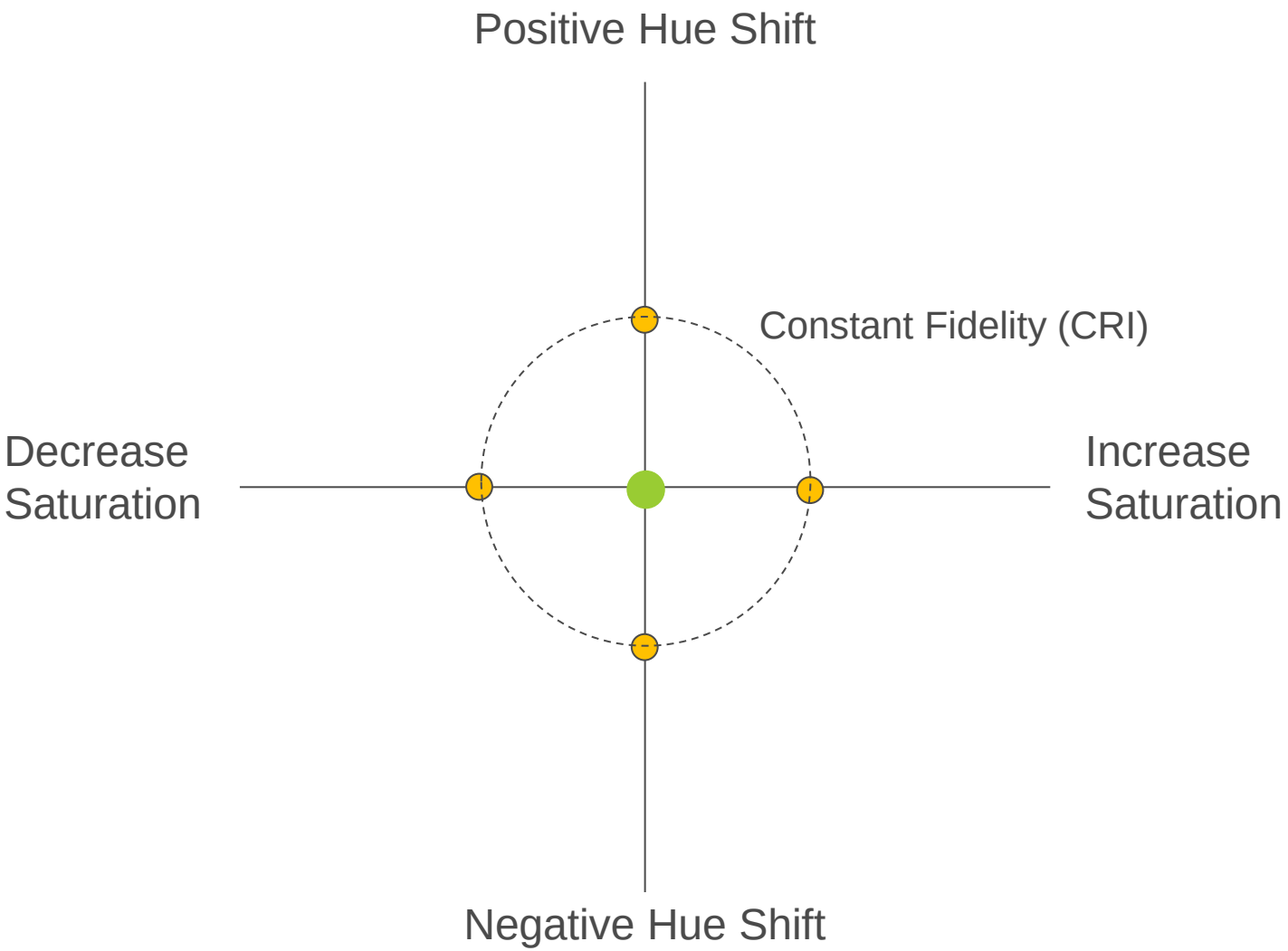
Detailed Values
Skin Fidelity ($R_{f,skin}$)
Fidelity by Hue ($R_{f,h\#}$)
Chroma Shift by Hue ($R_{cs,h\#}$)
Fidelity by Sample ($R_{f,CES\#}$)

TM-30 Method for Color Rendition

Color Fidelity

The accurate rendition of color so that they appear as they would under familiar (reference) illuminants

Fidelity Index (R_f)
(0-100)



(Also possible to change lightness, not shown)

TM-30 Method for Color Rendition

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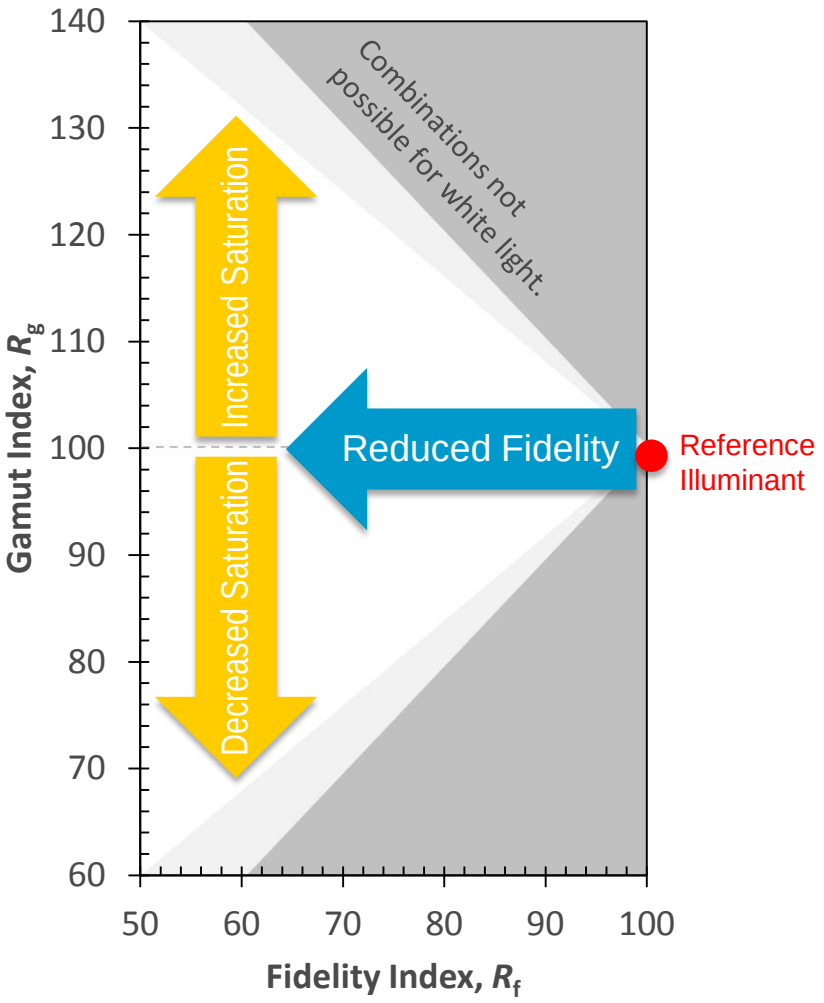
Fidelity Index (R_f)
(0-100)

Color Gamut

The average level of saturation relative to familiar (reference) illuminants.

Gamut Index (R_g)
~60-140 when $R_f > 60$

- Evaluate tradeoffs between fidelity and saturation.
- When disparate fidelity and gamut measures are used together, the tradeoffs are less apparent.
- **But average values don't tell the whole story…**



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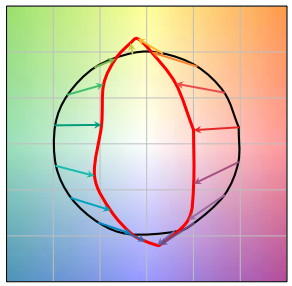
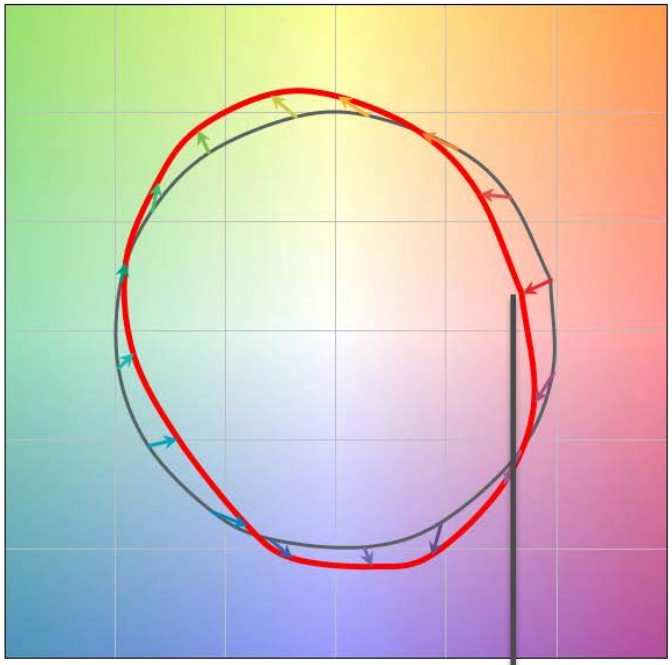
Gamut Shape

Changes over different hues

Color Vector Graphic, Hue Bin Chroma Shift

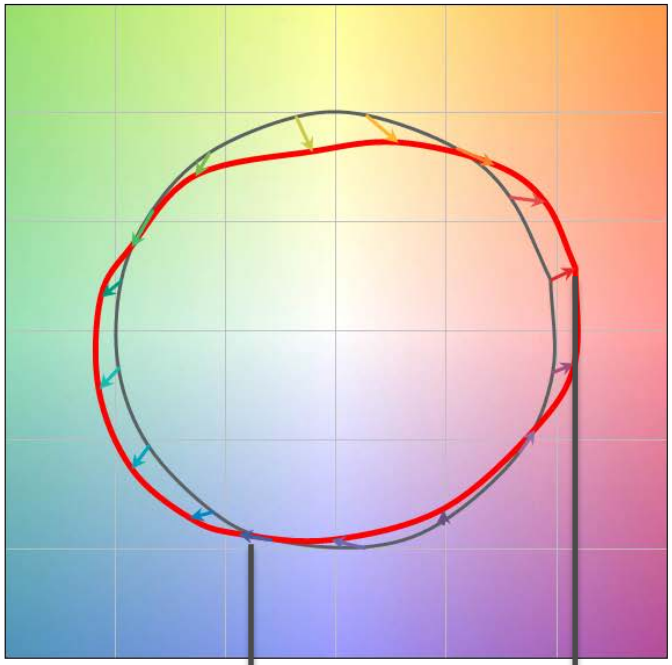


R_f = 75 | R_g = 100 | CCT = 3500 K



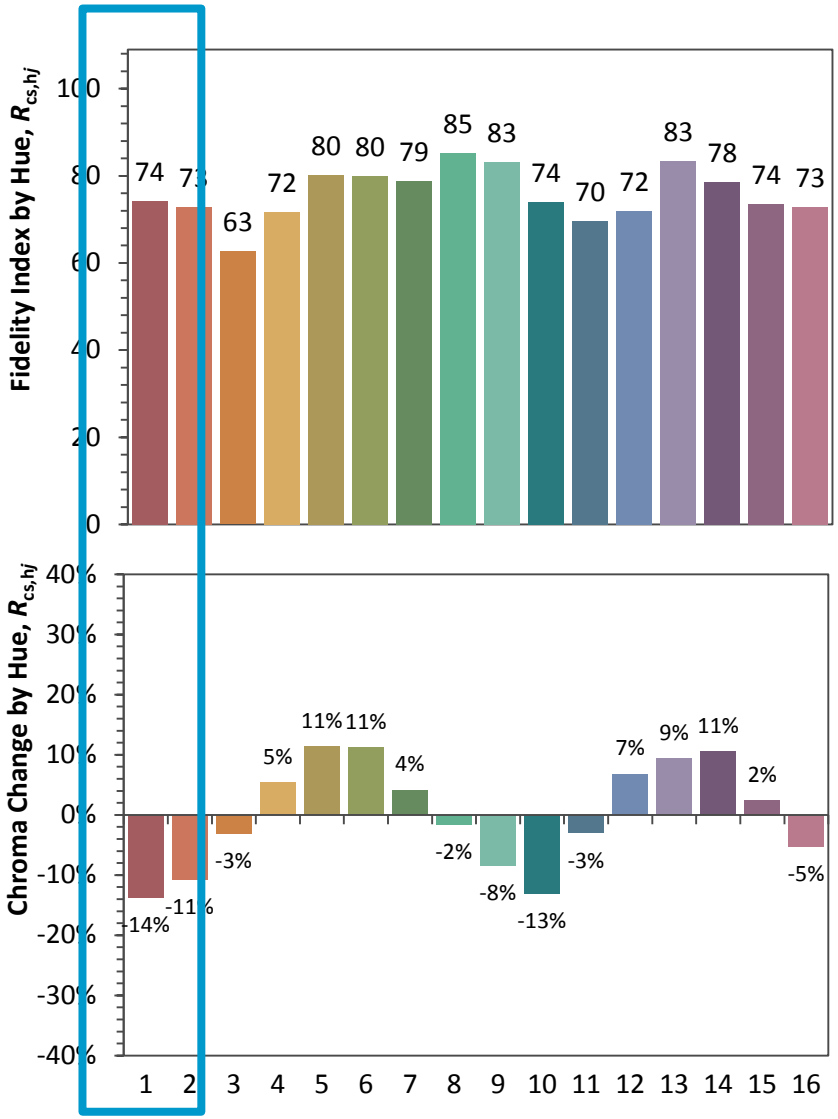
Decreased Saturation

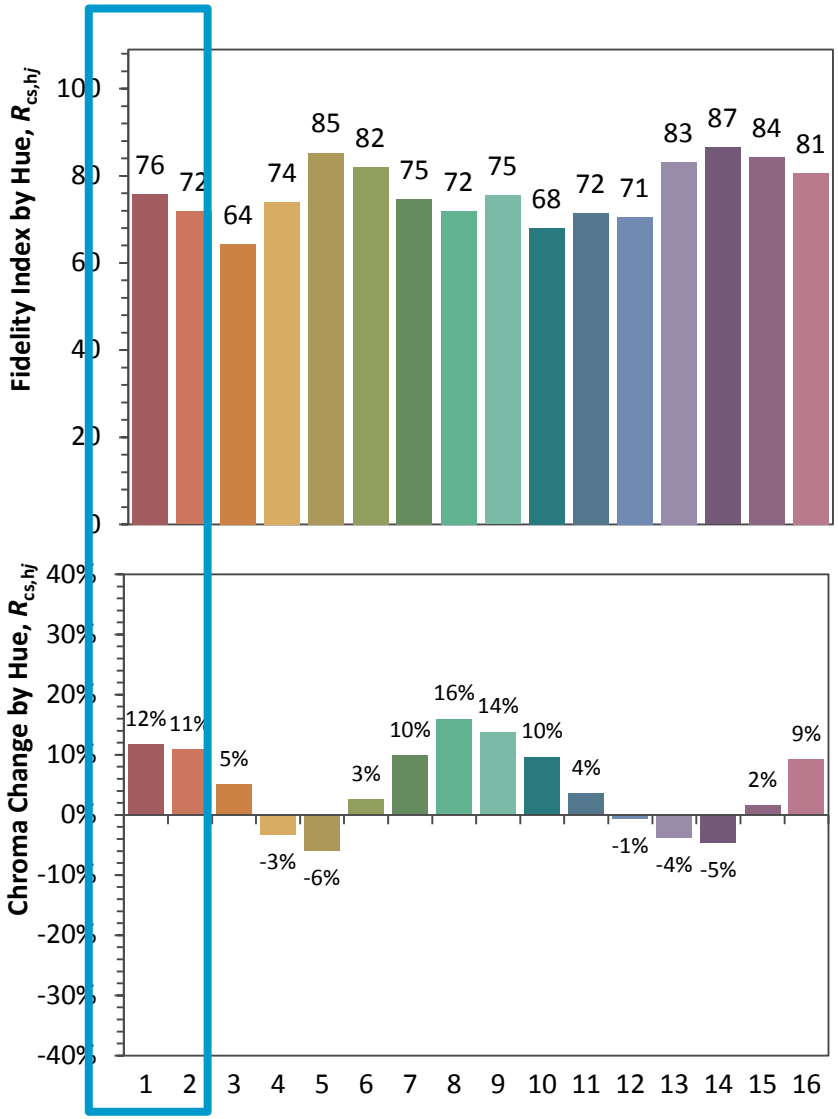
R_f = 75 | R_g = 100 | CCT = 3500 K



Hue Shift

Increased Saturation





Same red fidelity, shift in opposite directions.

10

CIE CRI (1965/1974)		IES TM-30-15 (2015)	
Fidelity Metric Only	⇨	Fidelity, Gamut, Graphical, Detailed/Hues	[1, 2, 3, 4, 5]
CIE 1964 U*V*W*	⇨	CAM02-UCS (CIE CAM02)	[6, 7, 8, 9, 10]
8 color samples Medium chroma/lightness Spectral sensitivity varies Munsell samples only	⇨	99 color samples Uniform color space coverage Spectral sensitivity neutral Variety of real objects	[11, 12, 13, 14]
Ref Illuminant Step Function	⇨	Ref Illuminant Continuous (Uses same reference sources, but blended between 4500 K and 5500 K)	
No lower limit for scores and inconsistent scales	⇨	0 to 100 scale (fidelity)	

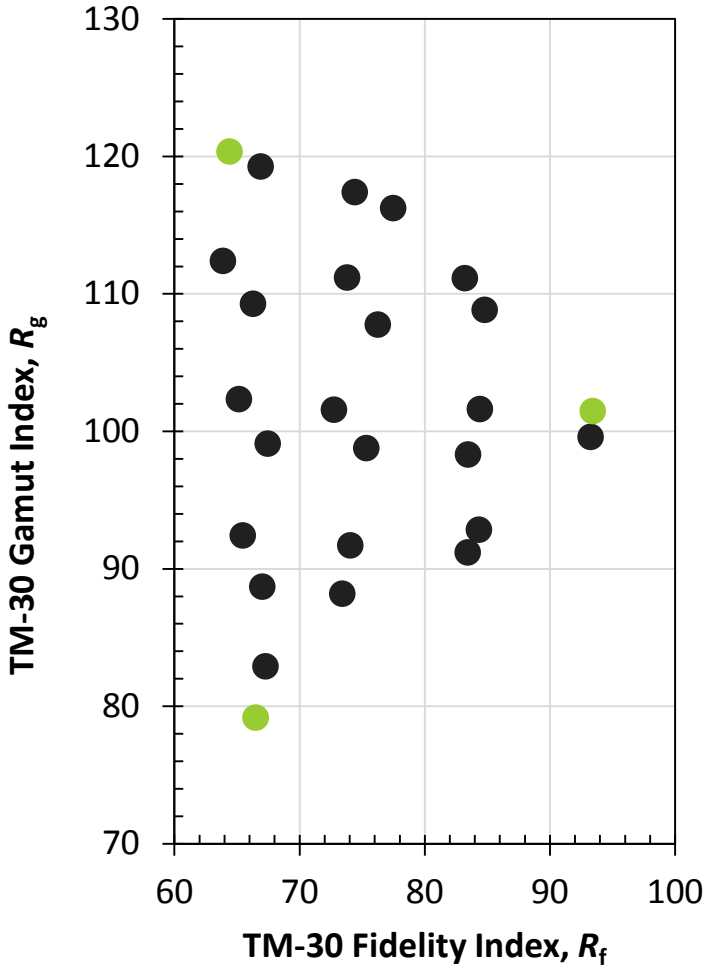
Which source is best?

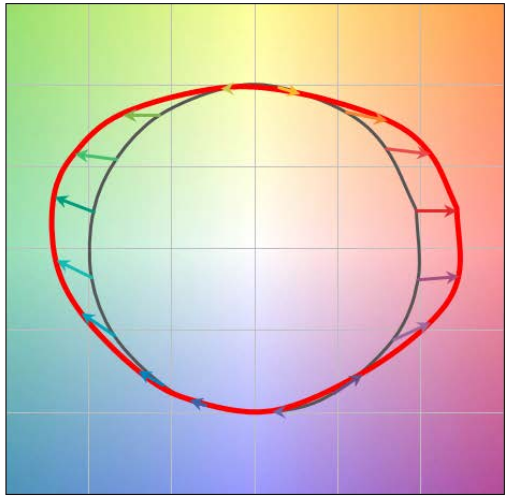
Experimental Room

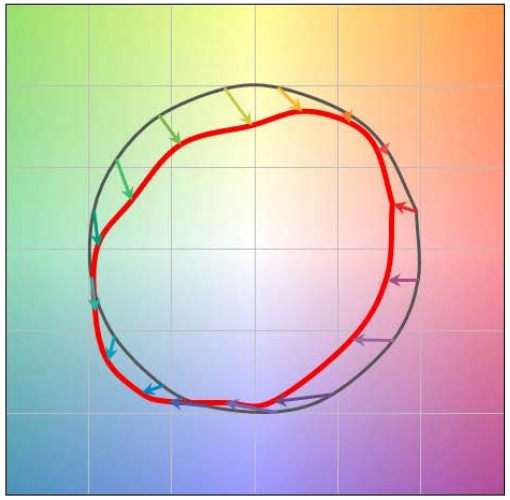
Experimental Room: Context

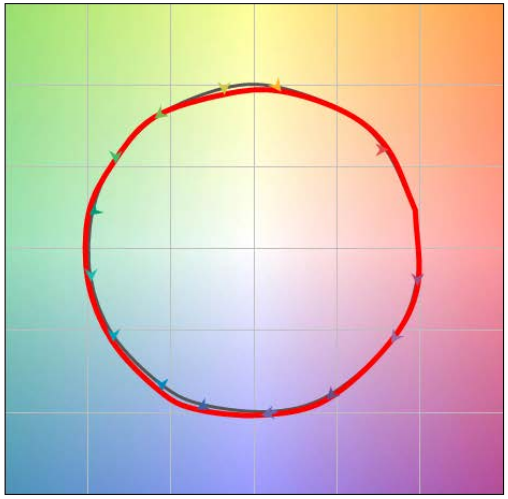
Lighting Conditions: 26
Illuminance: 20 fc
CCT: 3500 K (on Planckian)
Objects: Generic consumer goods, balanced hues
Application: Undefined
Participants: 19-65, 16 females 12 males
Rating Questions: Normal-Shifted, Saturated-Dull, Like-Dislike

Experimental Conditions









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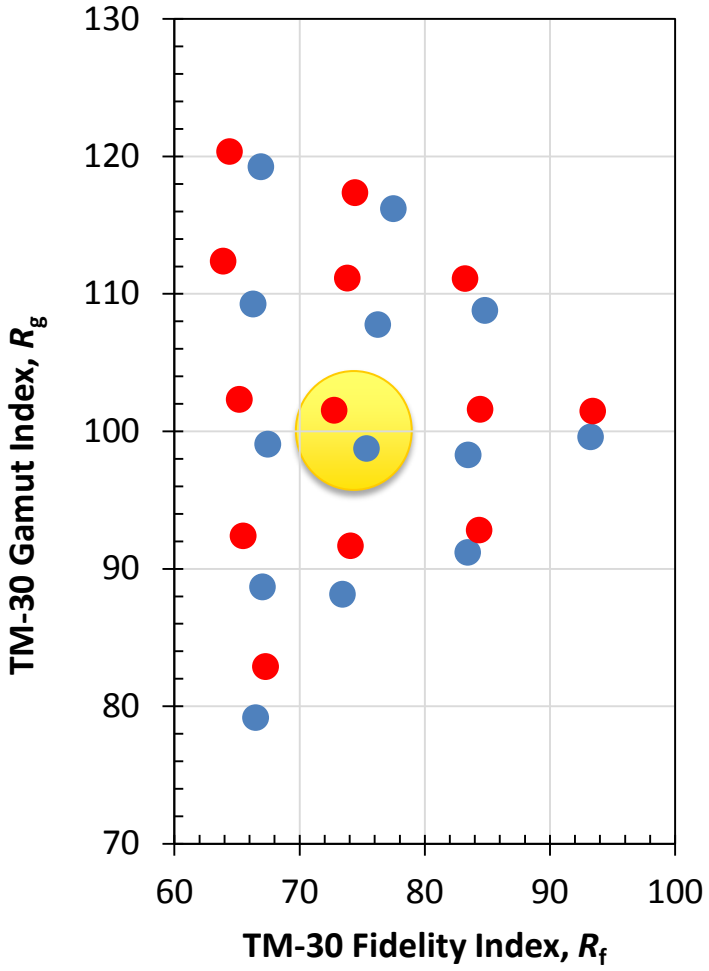
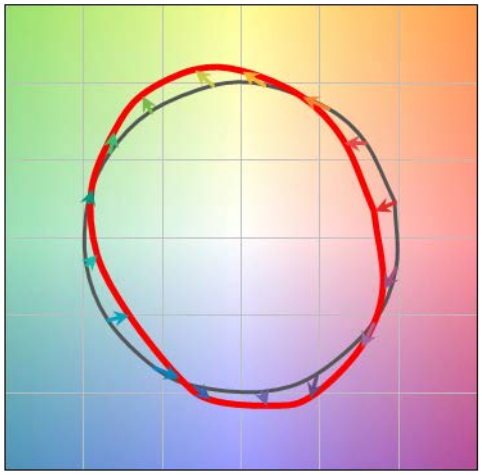
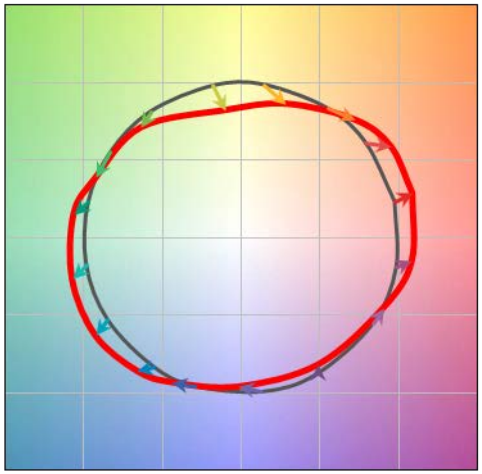






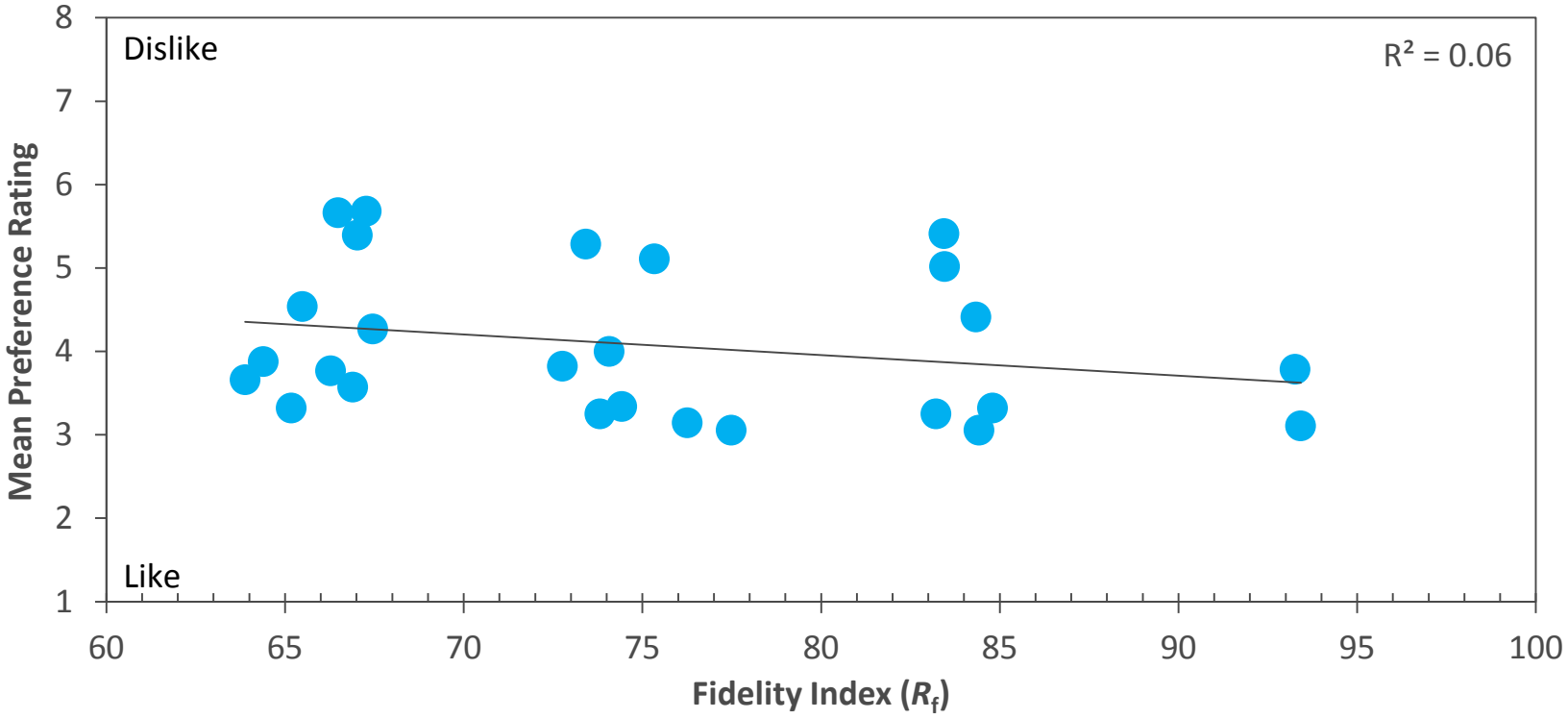
We’re going to look at averages (means)….

…but the person to person differences are substantial!

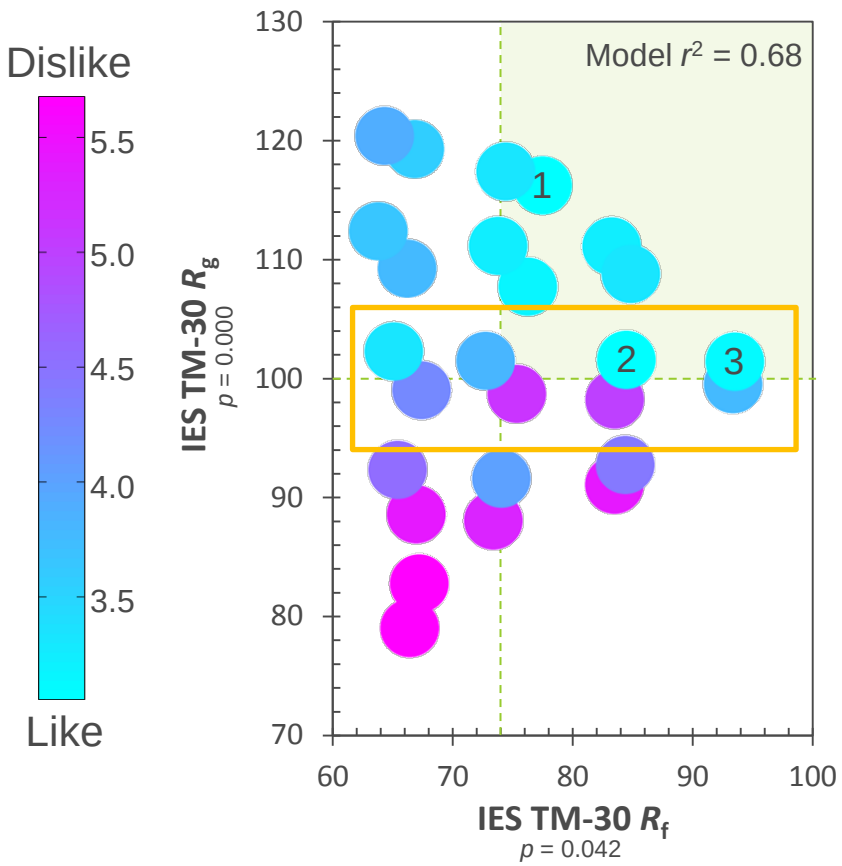
Almost every source received ratings across the full range for each question. (Normalness, Saturation, Preference)

If you’re a specifier, you get to decide what you like for the given space!

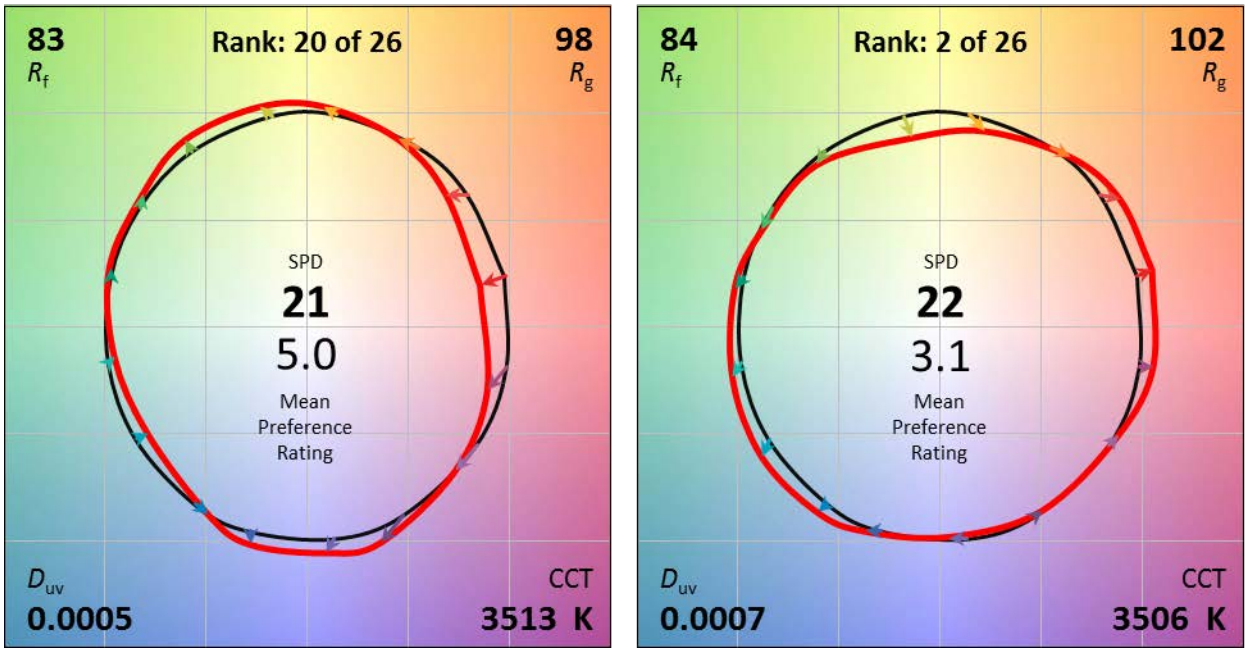
Preference vs. Fidelity



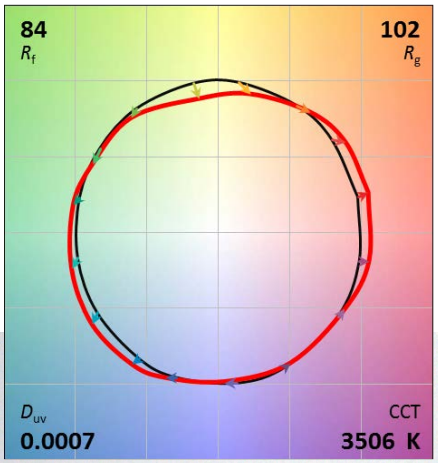
Preference vs. Fidelity/Gamut

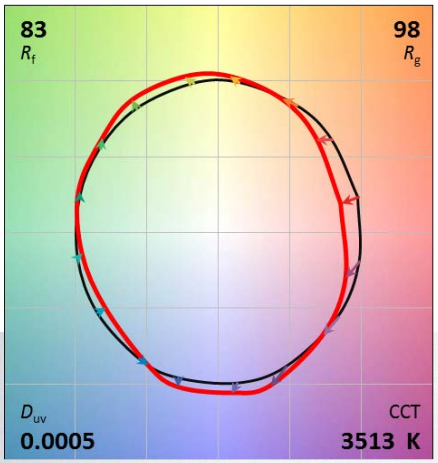


Gamut Shape/Red Rendering

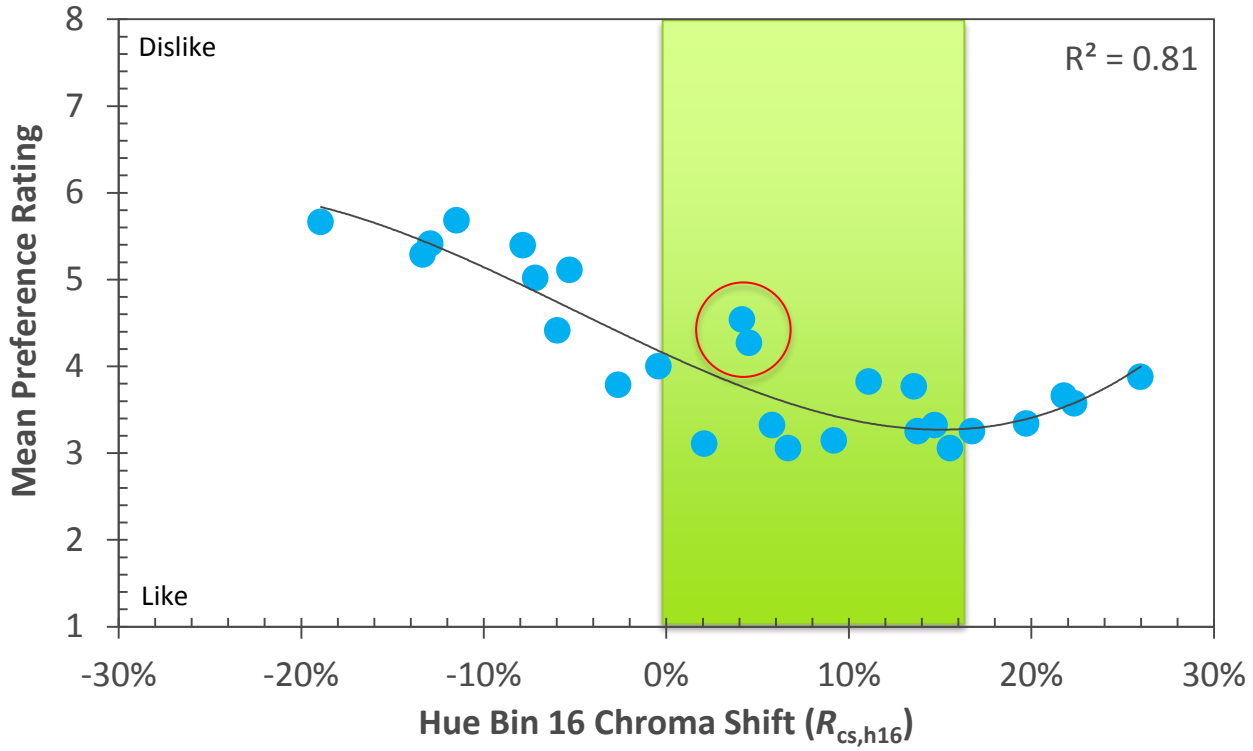


Same Fidelity, Same Gamut, Significantly Different Rating.

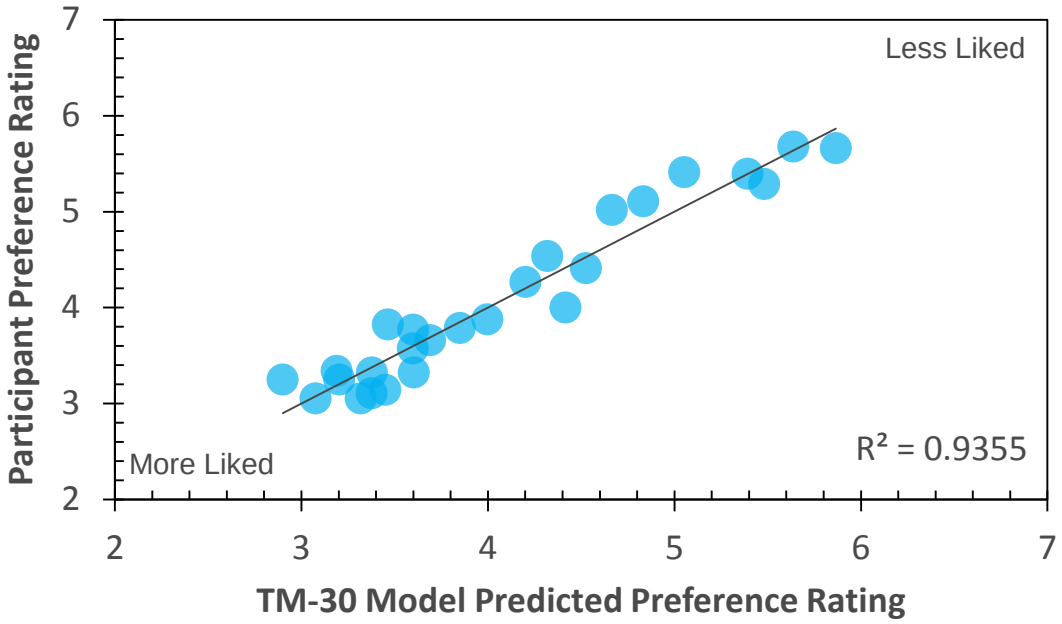

84
R_f
102
R_g
D_{uv}
0.0007
CCT
3506 K


83
R_f
98
R_g
D_{uv}
0.0005
CCT
3513 K

Preference for Increased Red Saturation…with limits.



Preference Model for this Experiment



Best Model for Preference:

Like-Dislike = 7.396 - 0.0408(R_f) + 103.4($R_{cs,h16}^3$) - 9.949($R_{cs,h16}$)

Summary

Context =

Normalness = Fidelity + Red Saturation

$R_f > 80$ $0\% < R_{cs,h1} < 8\%$ $(R_{f,h1} > 80)$

Saturation = Red Saturation

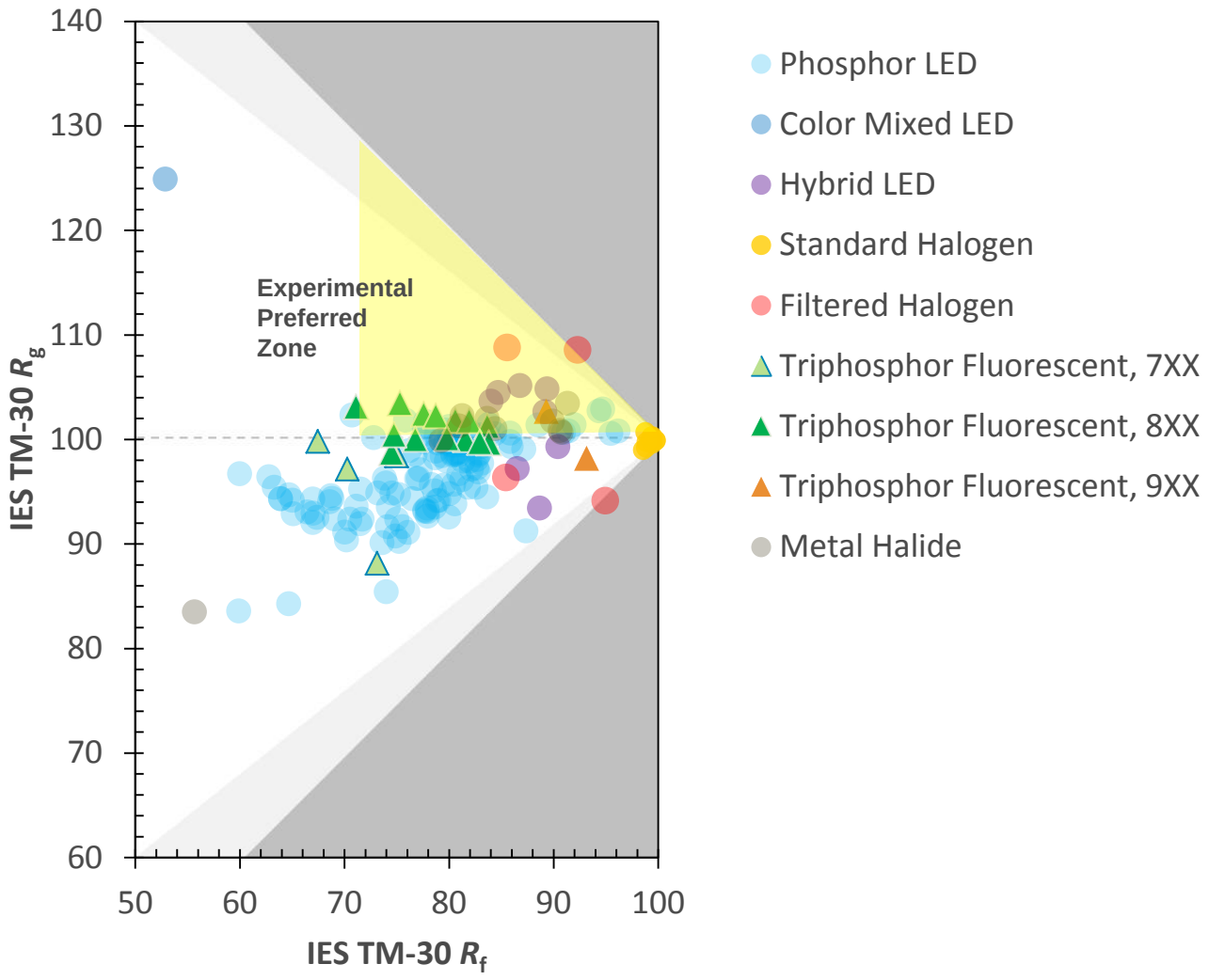
Maximize $R_{cs,h16}$, $R_{cs,h1}$

Preference = Fidelity + Red Saturation

$R_f > 74$ $0\% < R_{cs,h16} < 15\%$ $(R_g > 100)$

$0\% < R_{cs,h1} < 15\%$

A Look at Existing Sources



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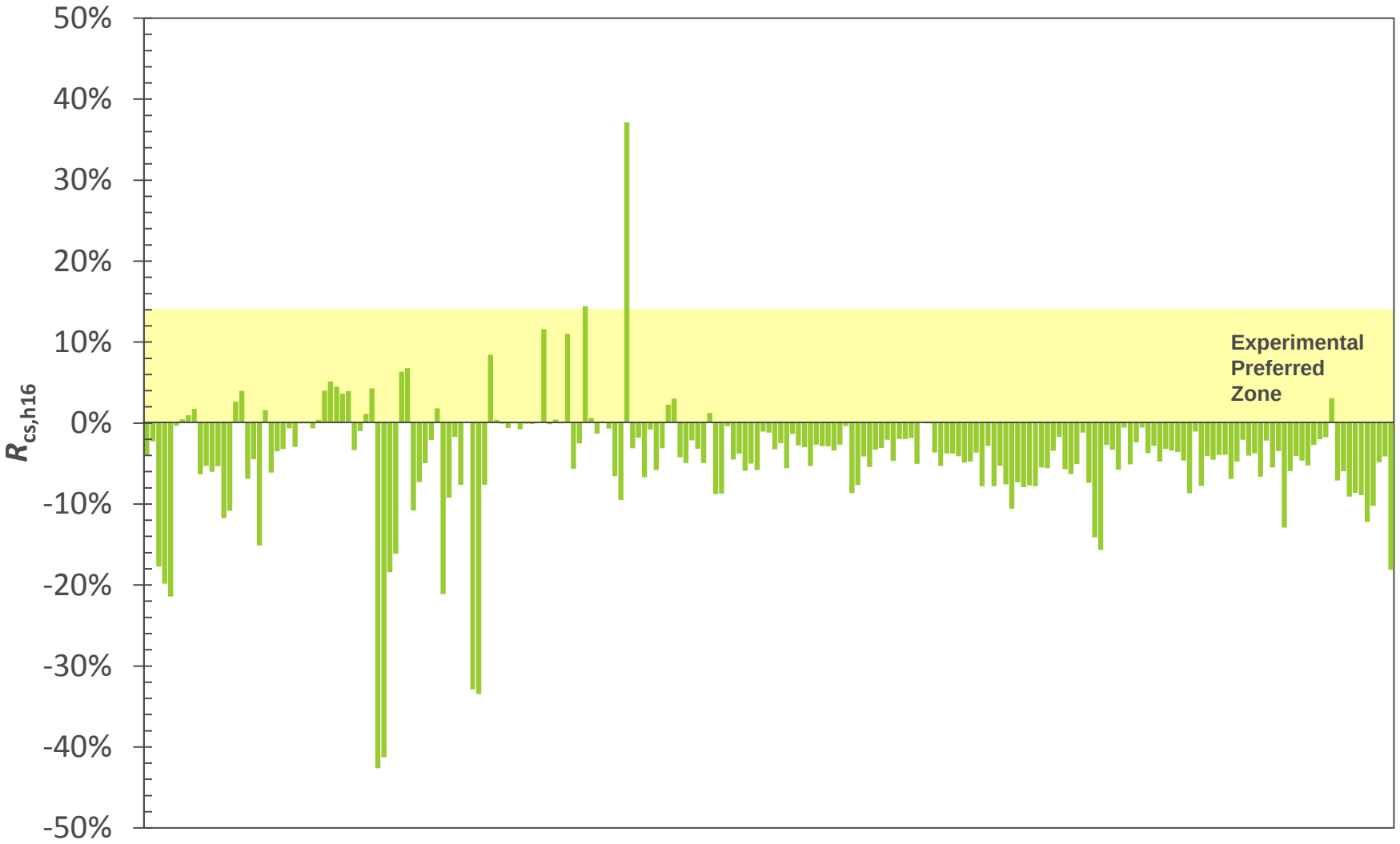
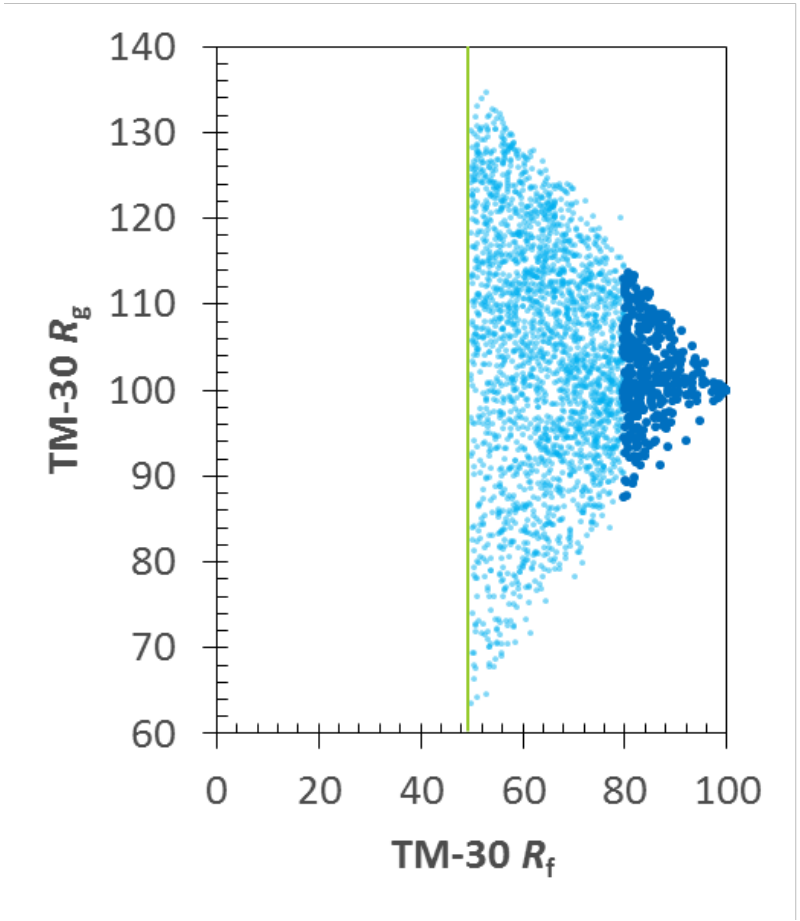
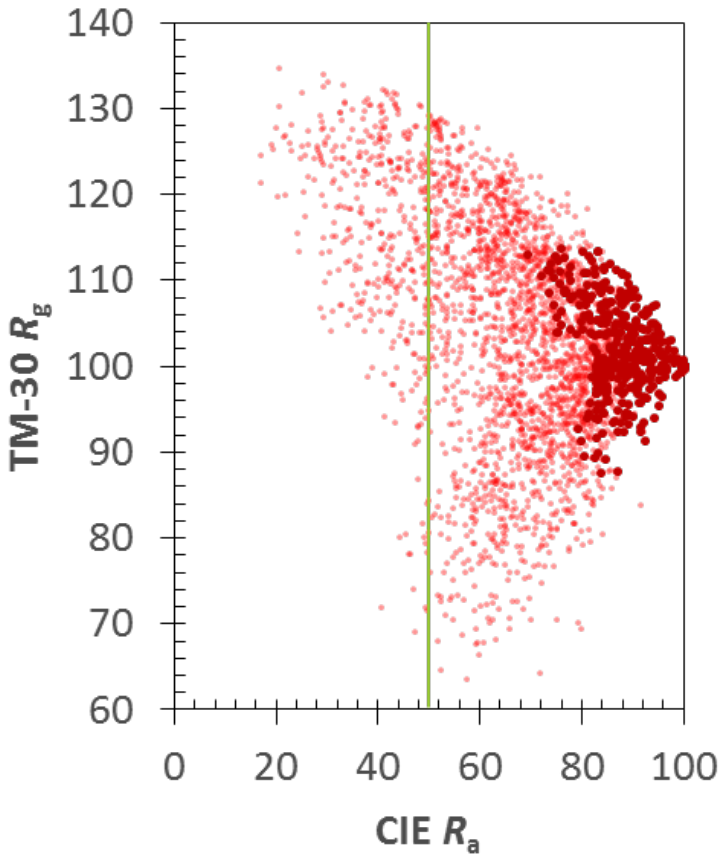


Why so Few Red-Enhancing Sources?

1. Penalization by CRI





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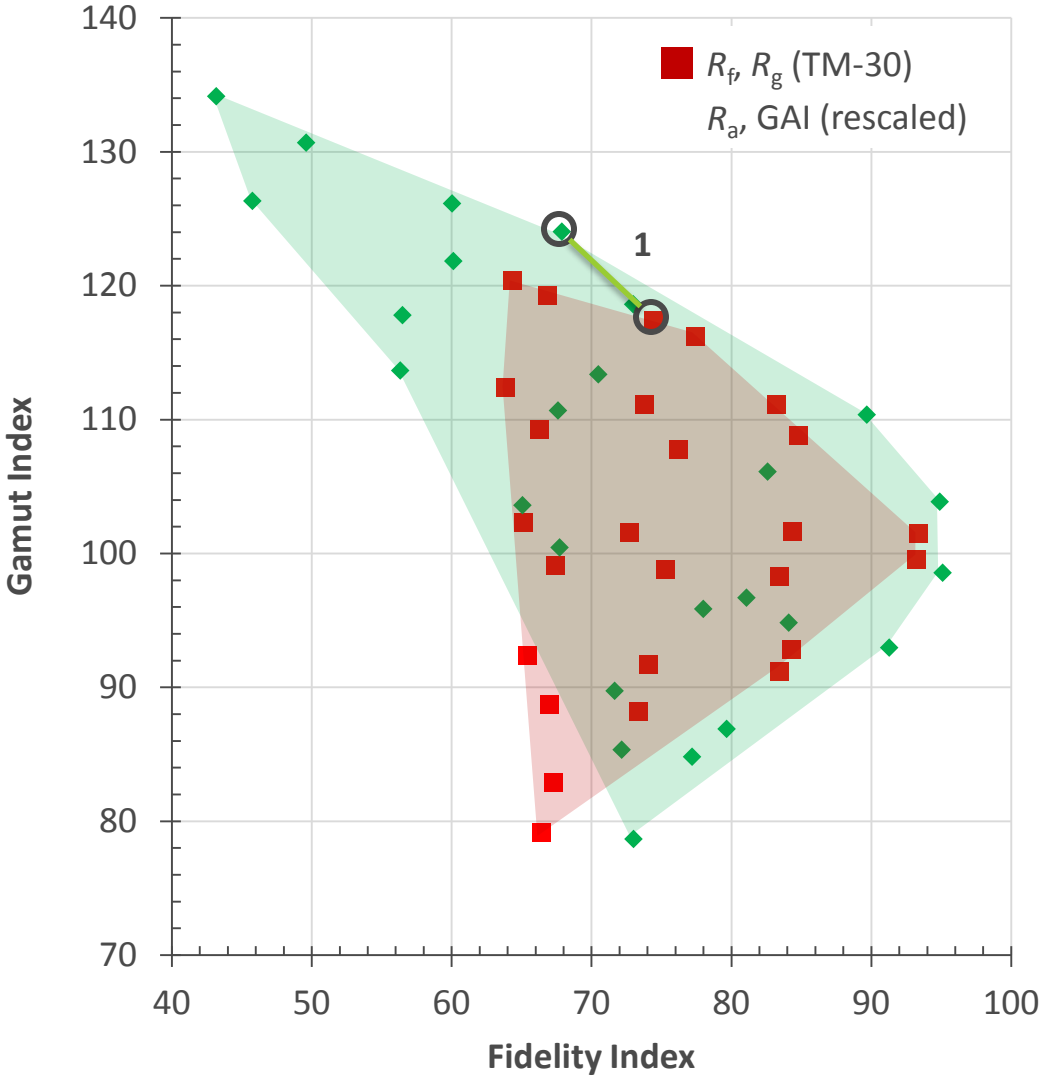

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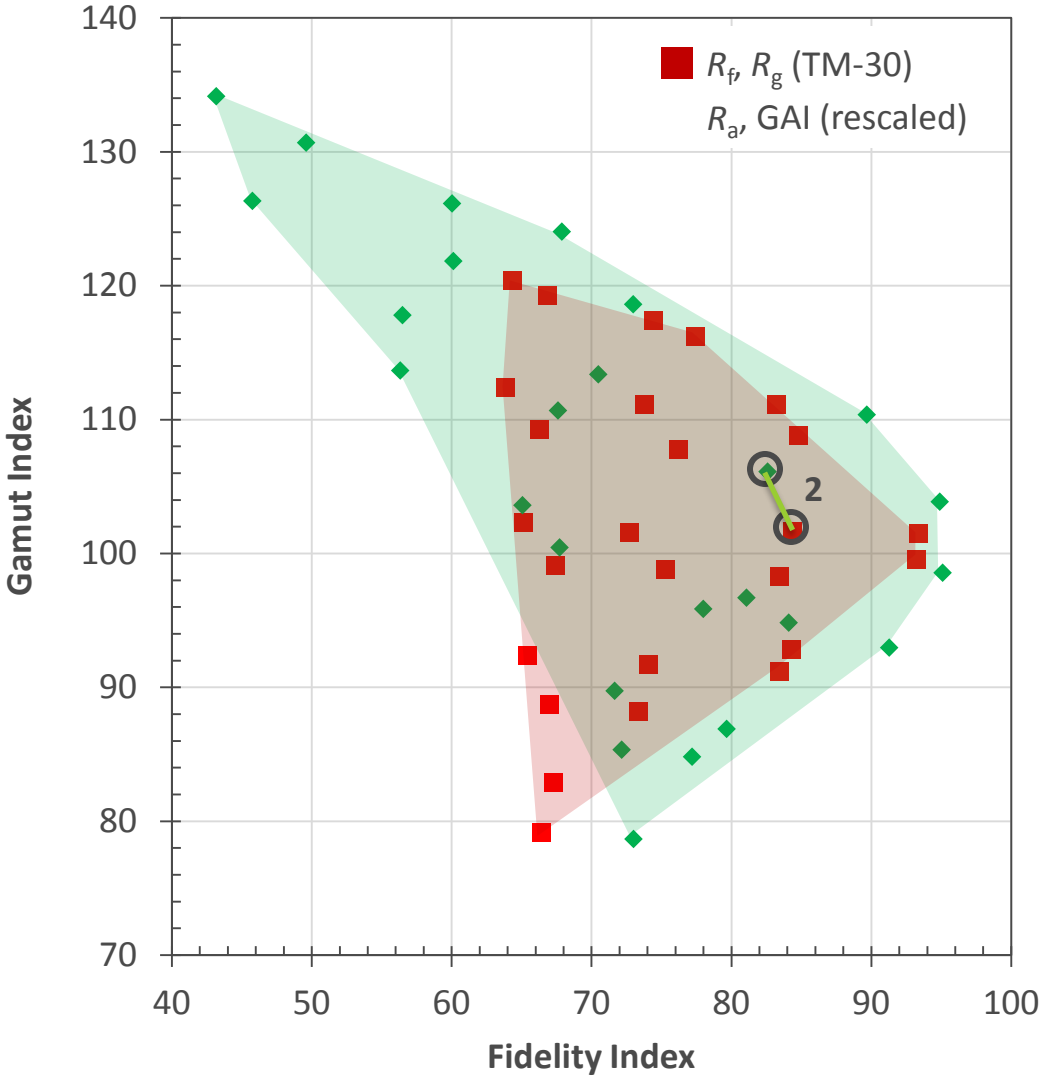

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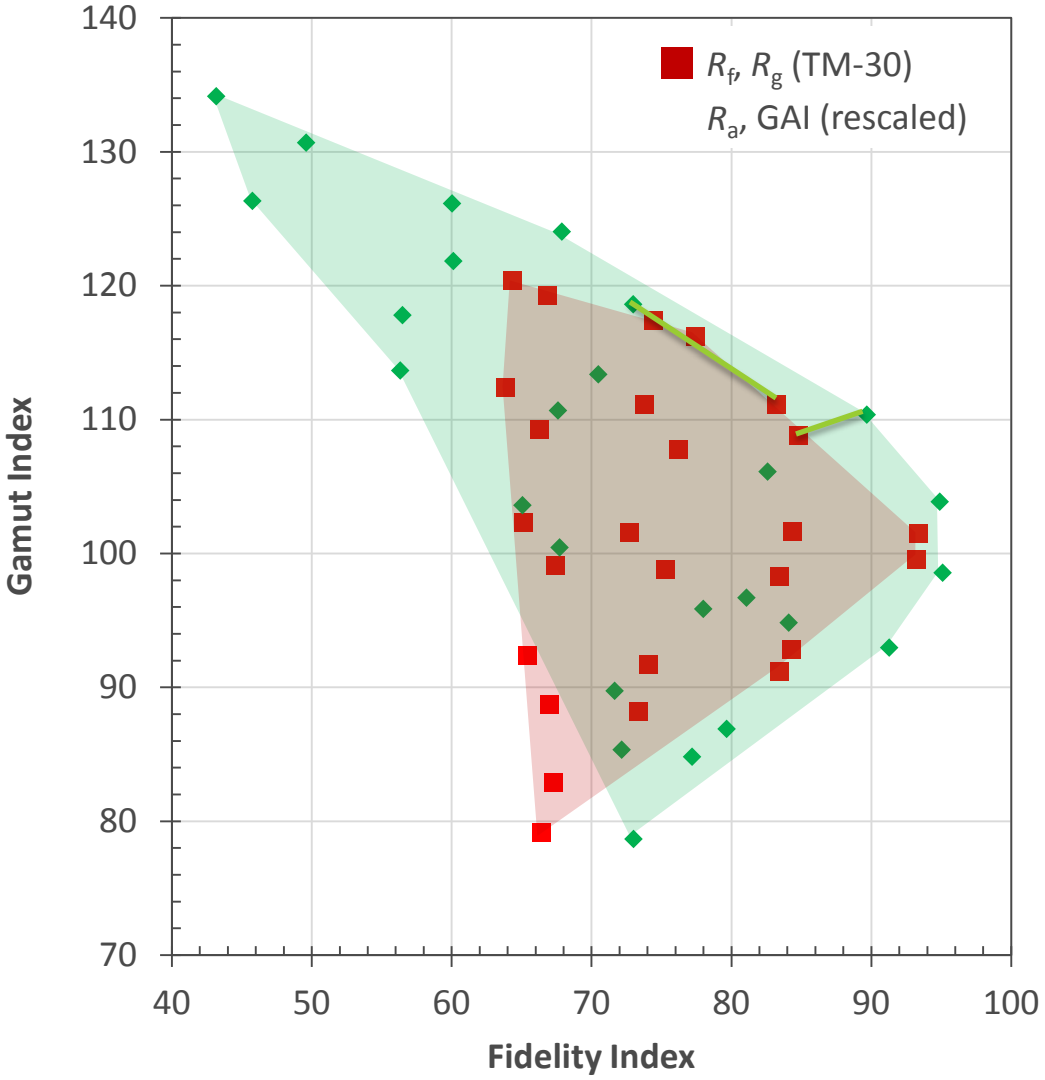

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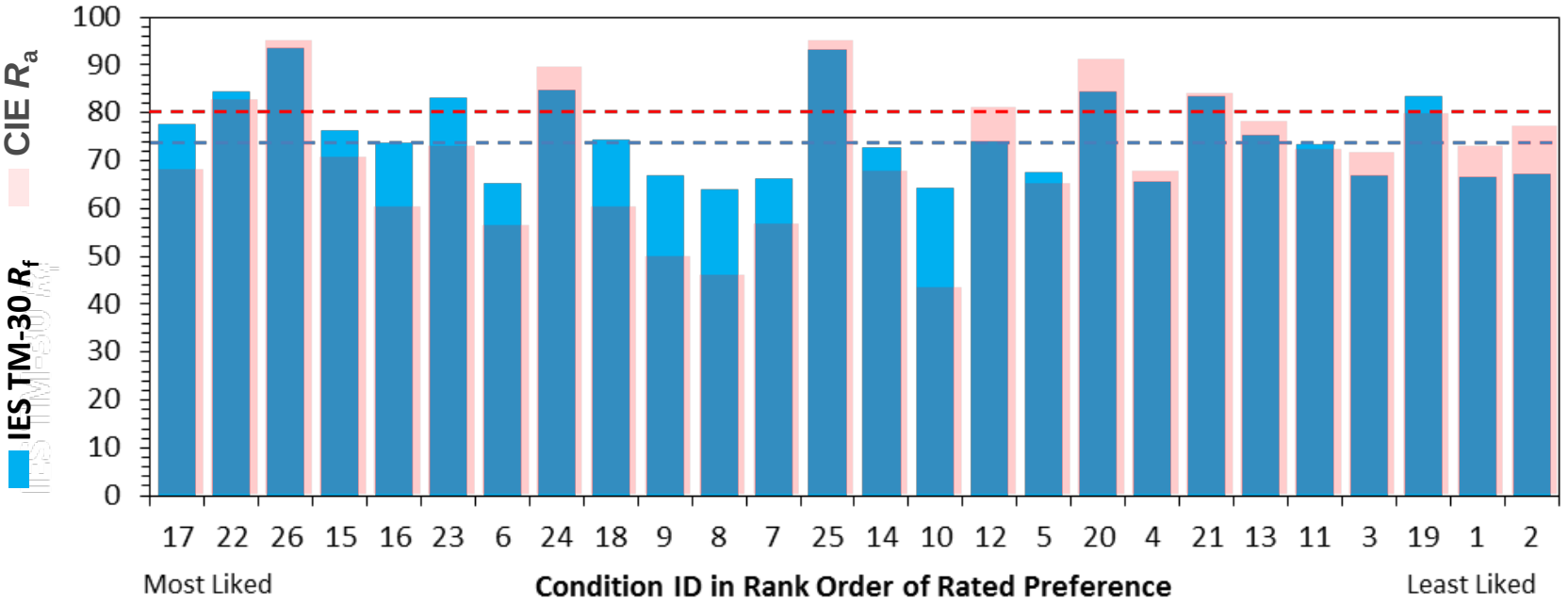
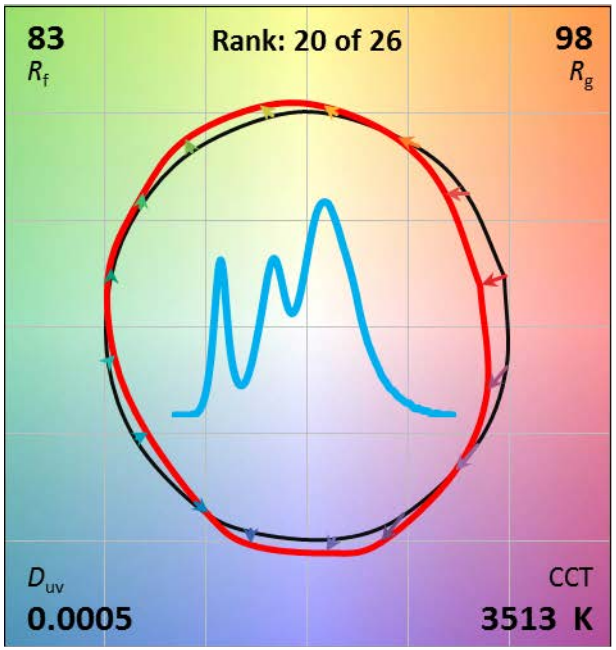
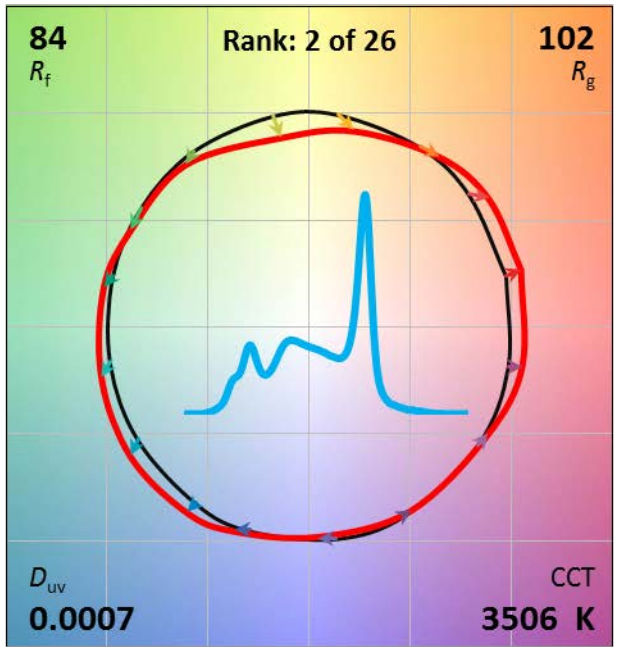


Why so Few Red-Enhancing Sources?

2. Efficiency Considerations



R_a 84, R_9 = -7, **LER 343**



R_a 83, R_9 = 21, **LER 311**

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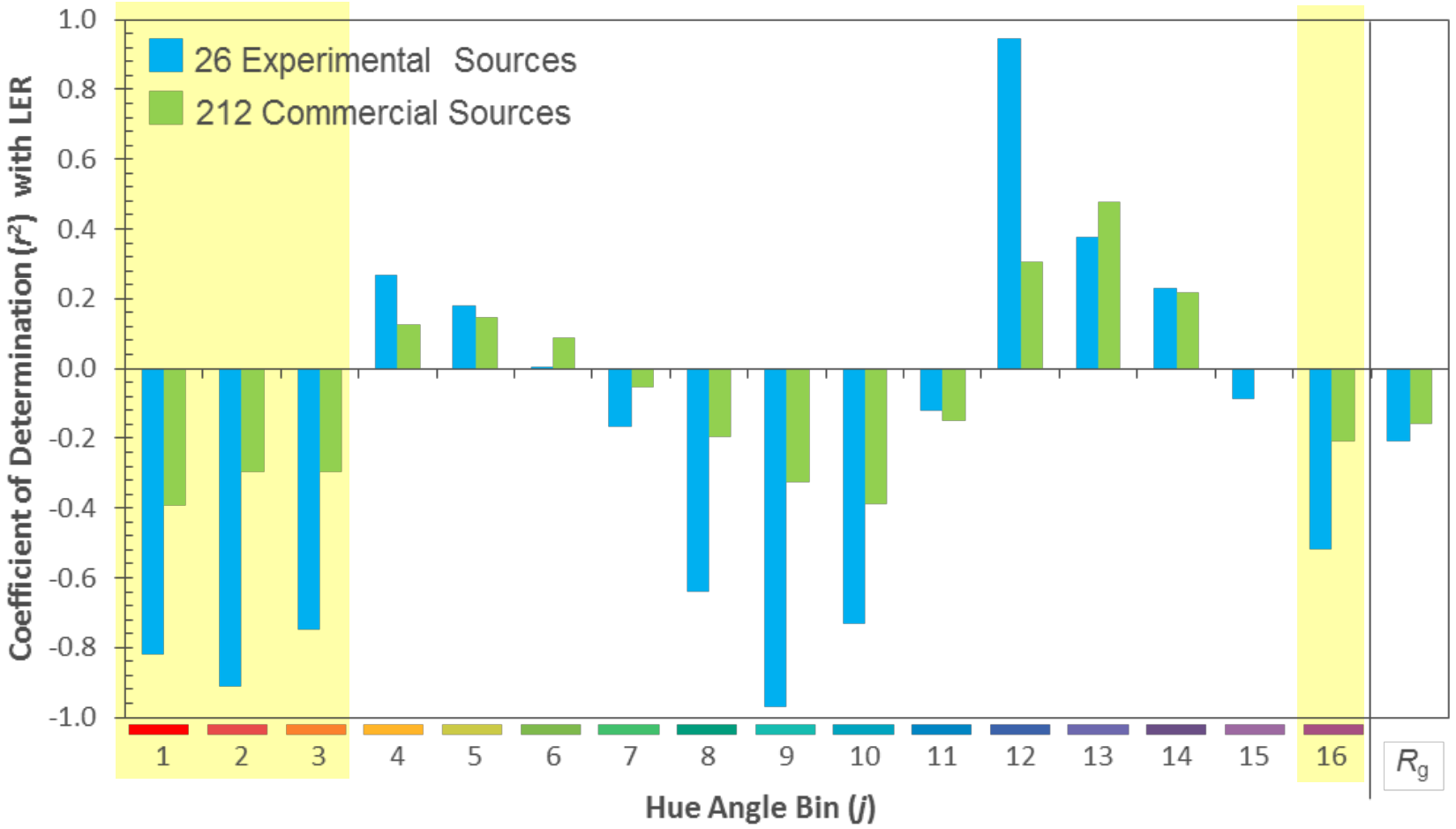
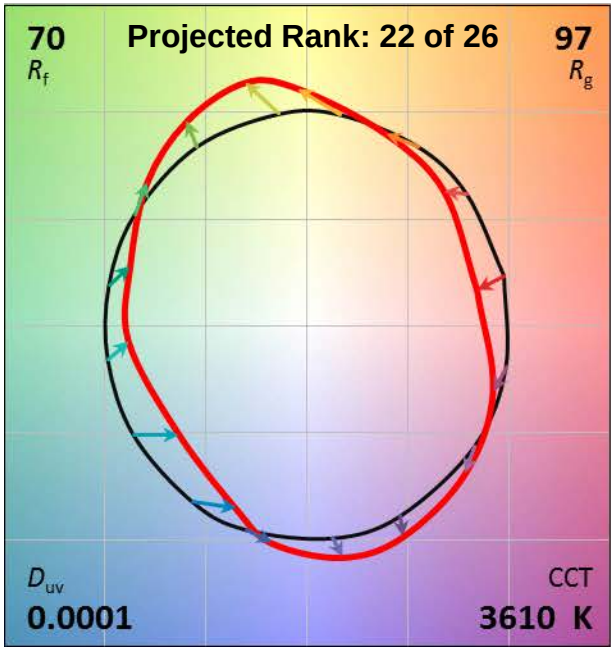


Common Commercially Available Sources

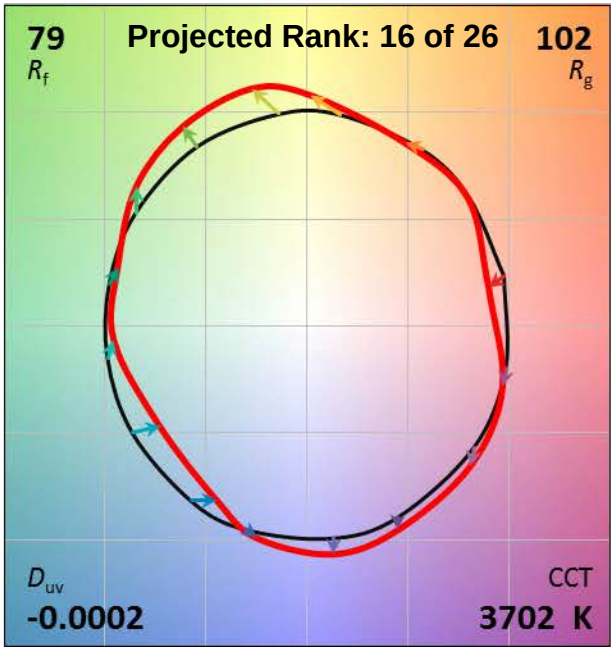
(Developed for CRI R_a):

F32T8/735



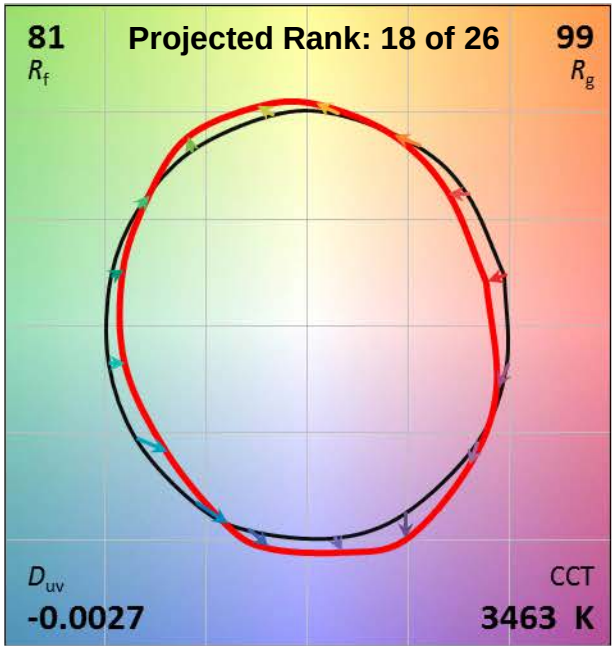
R_a 74, LER 348

F32T8/835



R_a 85, LER 343

Blue-Pump Phosphor LED (81 CRI)



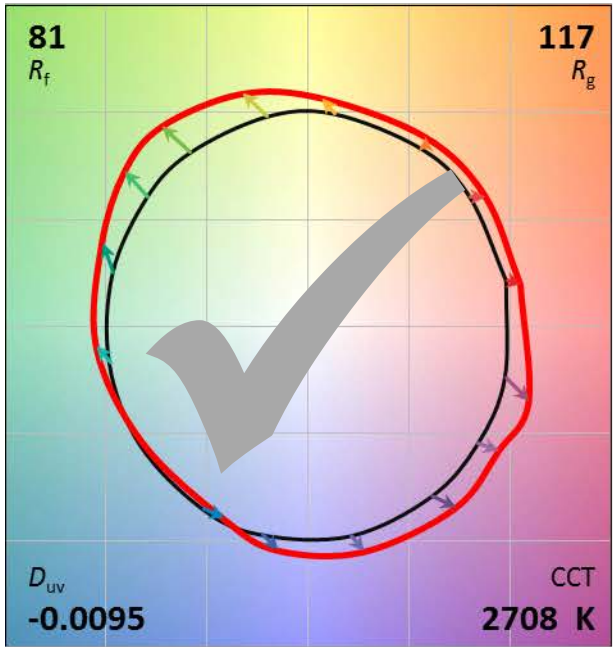
R_a 83, LER 309

Enhanced Sources

(Developed for CRI R_a and/or Gamut Area)

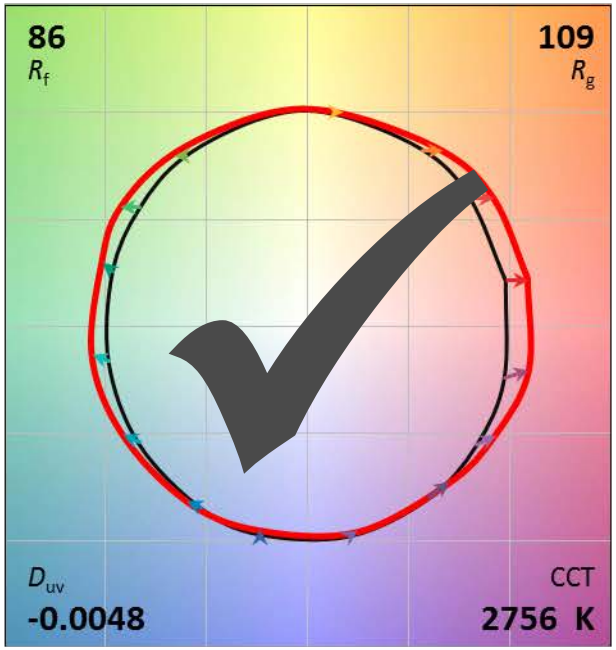
(Note different CCT)

LED (Patent Application)



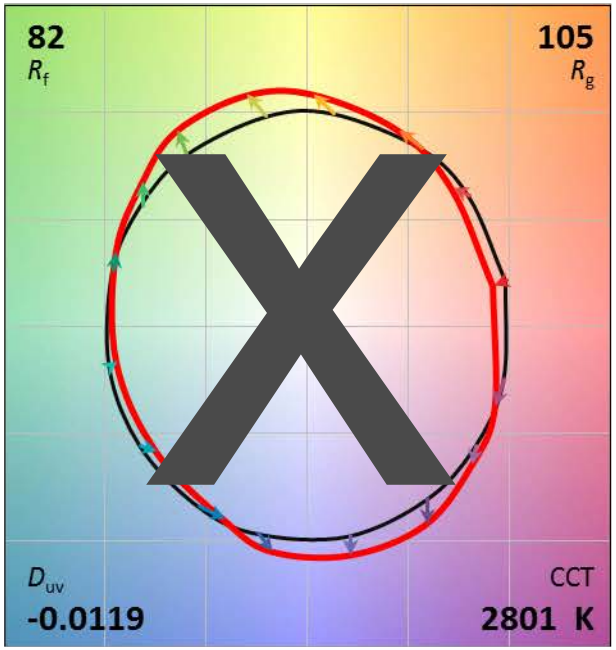
R_a 80, LER 272

Neodymium Incandescent



R_a 77, LER 136

LED (Available Product)



R_a 87, LER 295

(Might be perfect for a different application!)

Case Studies


tion to Being a
GAR BRIGHTER
than the rest
LAUGHING OUT
overindulge
Late
we
in:
RULES BEING
BROKEN,
REWRITTEN, and
Broken, over again.
having


HUSSMANN

Additional Resources

IES Technical Memorandum (TM) 30-15 (Includes Excel Calculators):
IES Method for Evaluating Light Source Color Rendition
http://bit.ly/1IWZxVu

Optics Express journal article that provides overview of the IES method:
Development of the IES method for evaluating the color rendition of light sources
http://bit.ly/1J32ftZ

Application webinar co-sponsored by US Department of Energy and Illuminating Engineering Society:
Understanding and Applying TM-30-15: *IES Method for Evaluating Light Source Color Rendition*
http://1.usa.gov/1YEkbBZ

Technical webinar co-sponsored by US Department of Energy and Illuminating Engineering Society:
A Technical Discussion of TM-30-15: Why and How it Advances Color Rendition Metrics
http://1.usa.gov/1Mn15LG

LEUKOS journal article supporting TM-30's technical foundations:
Smet KAG, David A, Whitehead L. 2015. **Why Color Space and Spectral Uniformity Are Essential for Color Rendering Measures.** *LEUKOS*. 12(1,2):39-50.
http://dx.doi.org/10.1080/15502724.2015.1091356

LEUKOS editorial discussing next steps:
Royer MP. 2015. **IES TM-30-15 Is Approved—Now What? Moving Forward with New Color Rendition Measures.** *LEUKOS*. 12(1,2):3-5.
http://dx.doi.org/10.1080/15502724.2015.1092752

Lighting Research and Technology, Open Letter:
Correspondence: In support of the IES method of evaluating light source colour rendition
(More than 30 authors)
http://dx.doi.org/10.1177/1477153515617392

DOE Fact Sheet on TM-30
http://energy.gov/eere/ssl/downloads/evaluating-color-rendition-using-ies-tm-30-15

DOE TM-30 FAQs Page:
http://energy.gov/eere/ssl/tm-30-frequently-asked-questions

References

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4. Wei M, Houser KW, David A, Krames MR. 2016. Effect of Gamut Shape on Color Preference. CIE 2016 “Lighting Quality & Energy Efficiency”, Melbourne, Australia, 2016.
5. Ohno Y, Fein M, Miller C. 2015. Vision experiment on chroma saturation for color quality preference. Proceedings of the 28th CIE Session. Manchester, UK. CIE Publication 216:2015 1(1).
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7. Smet KAG, David A, Whitehead L. 2015. Why color space uniformity and sample set spectral uniformity are essential for color rendering measures. Leukos 12(1–2):39–50.
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9. Jost-Boissard S, Avouac P, Fontoynont M. 2015. Assessing the colour quality of LED sources: Naturalness, attractiveness, colourfulness and colour difference. Lighting Res Technol 47:769–794. DOI: 10.1177/1477153514555882.
10. Luo MR, Gu HT, Liu XY, Liu HY, Wang BY. 2015. Testing colour rendering indices using visual data under different LED sources. Proceedings of the 28th CIE Session. Manchester, UK. CIE Publication 216:2015 1(1).
11. David A. 2014. Color Fidelity of Light Sources Evaluated over Large Sets of Reflectance Samples. Leukos 10(2):59–75, DOI: 10.1080/15502724.2013.844654
12. Žukauskas A, Vaicekauskas R, Ivanauskas F and others. 2009. Statistical approach to color quality of solid-state lamps. IEEE Quantum Electronics 15(4):1189–1198.
13. van Der Burgt PJM, van Kemenade JTC. 2010. About color rendition of light sources: the balance between simplicity and accuracy. Col Res App 35(2):85–93
14. Li C, Luo MR, Pointer MR, Green P. 2014. Comparison of real colour gamuts using a new reflectance database. Col Res App 39(5):442-451.