LEDucation

Designers Light Forum

How to Use TM-30

Jason Livingston, Studio T+L, LLC
Wendy Luedtke, ETC
Michael Royer, PNNL

March 13, 2018

Credit(s) earned on completion of this course will be reported to AIA CES for AIA members. Certificates of Completion for both AIA members and non-AIA members are available upon request.

This course is registered with AIA CES for continuing professional education. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the AIA of any material of construction or any method or manner of handling, using, distributing, or dealing in any material or product.

Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

LEDucation

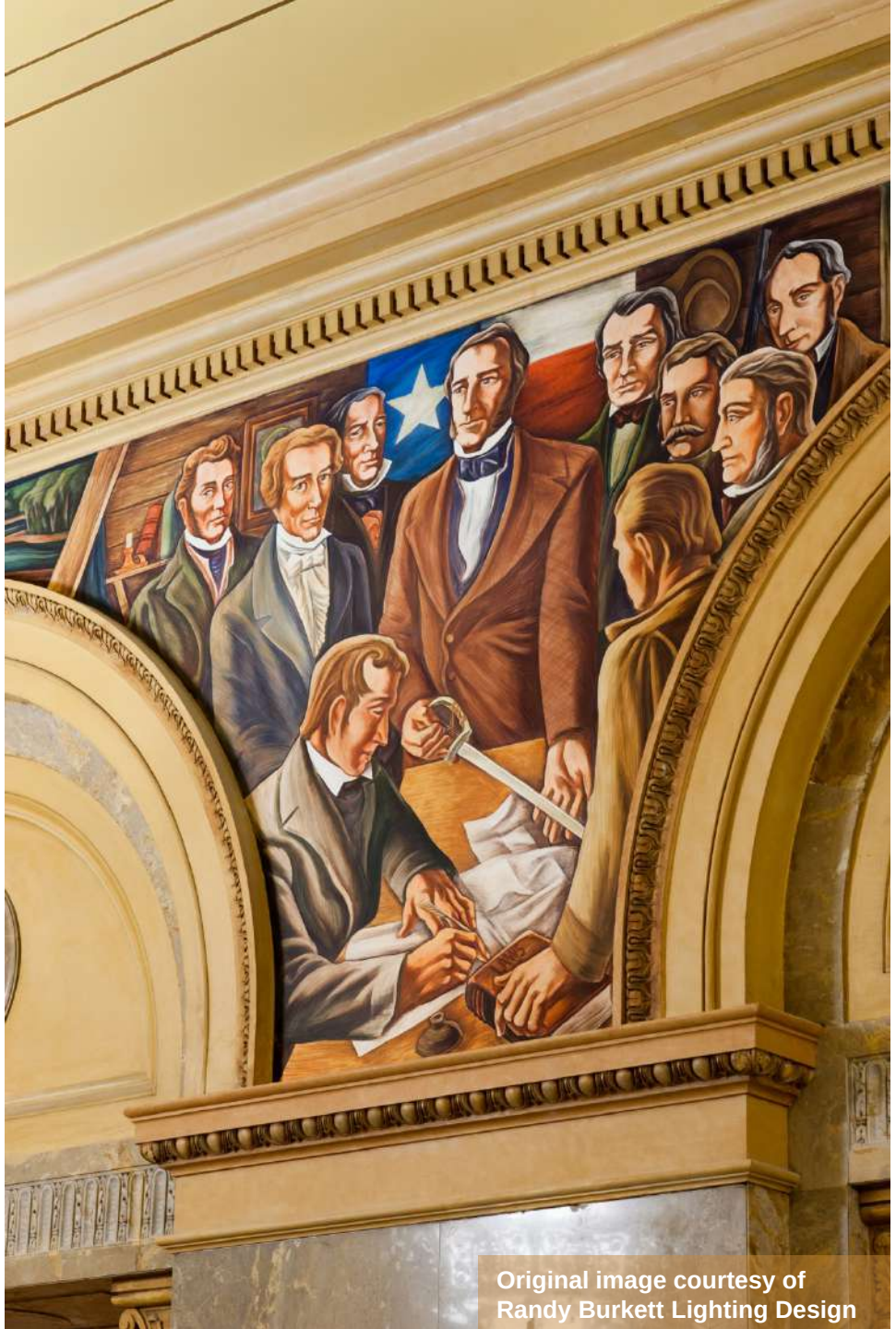
Learning Objectives

At the end of the this course, participants will be able to:

1. Become familiar with the calculation results of TM-30, both numerical and graphical
2. Interpret TM-30 information presented on a data sheet or in a full TM-30 report
3. Recognize the limitations of the system, and more generally recognize the limitations of all measures for color rendition
4. Understand how the objective information in TM-30 can be used to aid in subjective design decisions (i.e., matching the right source to an application)

LEDucation

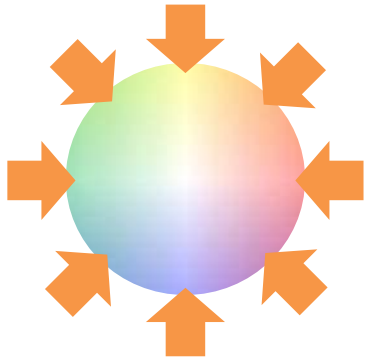
“Original” Baseline



Original image courtesy of
Randy Burkett Lighting Design

LEDucation

“CRI = 80” Desaturated

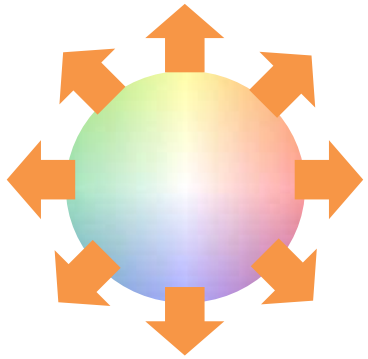


Original image courtesy of
Randy Burkett Lighting Design

leducation.org

LEDucation

“CRI = 80” Saturated

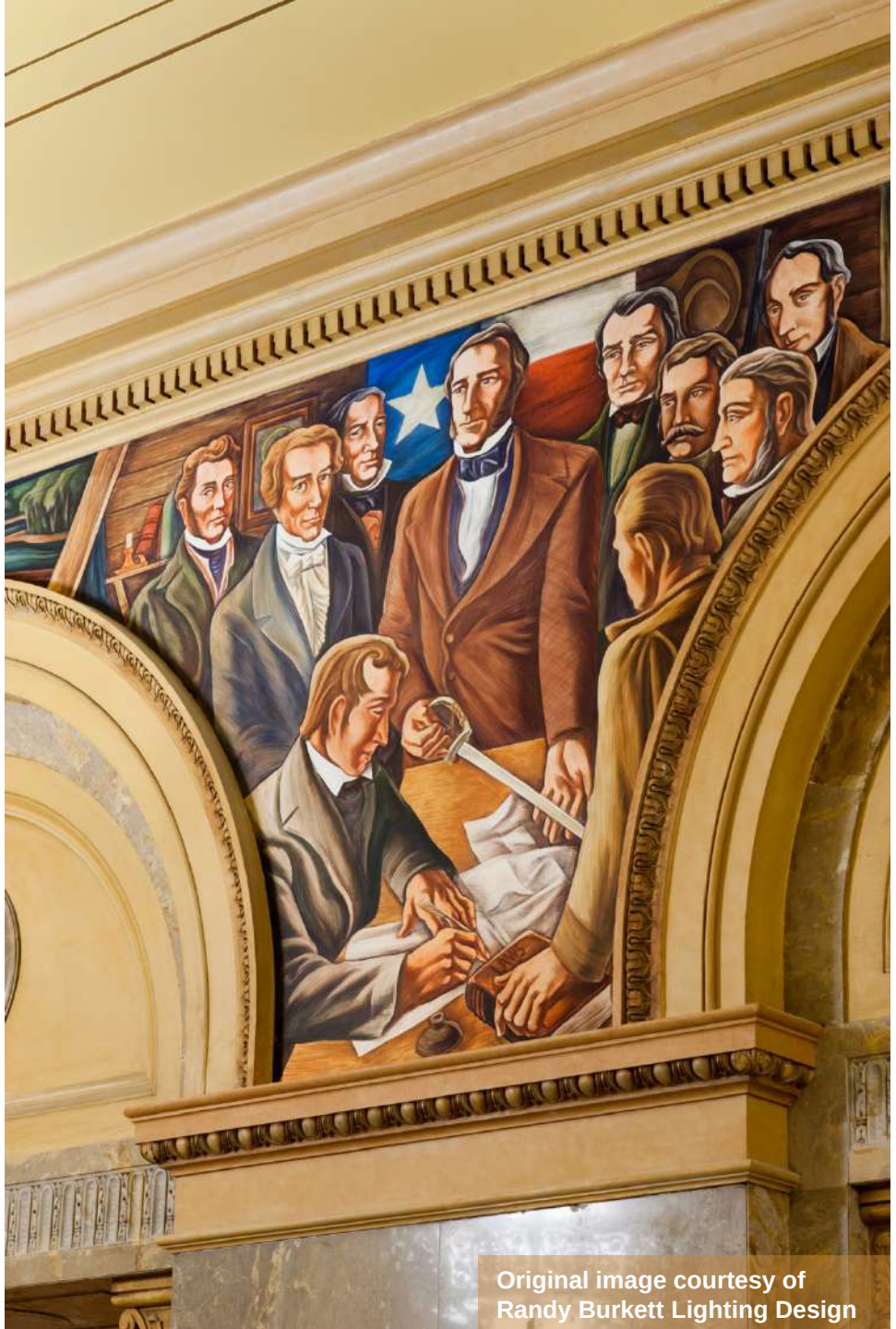


Original image courtesy of
Randy Burkett Lighting Design

leducation.org

LEDucation

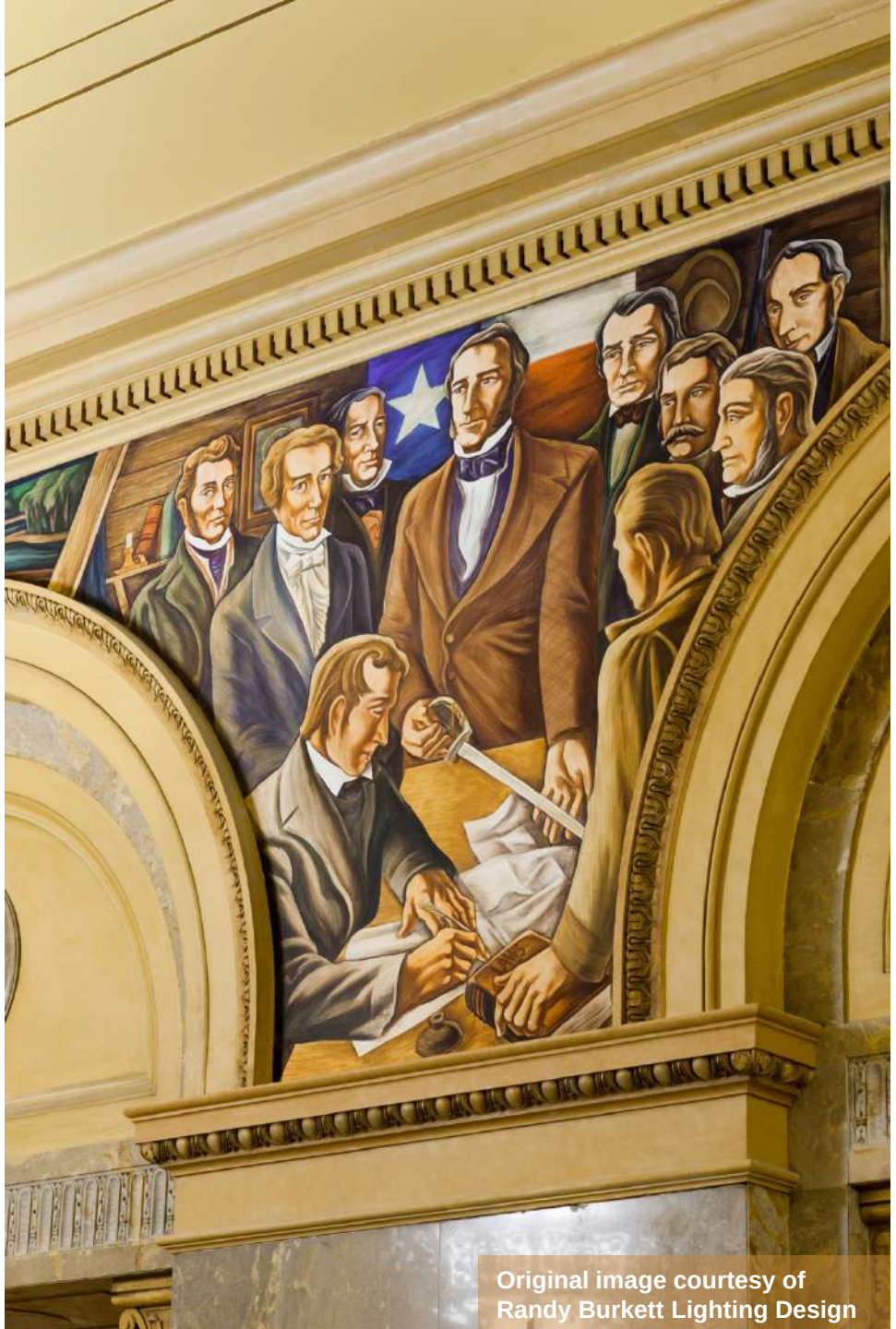
“Original” Baseline



Original image courtesy of
Randy Burkett Lighting Design

LEDucation

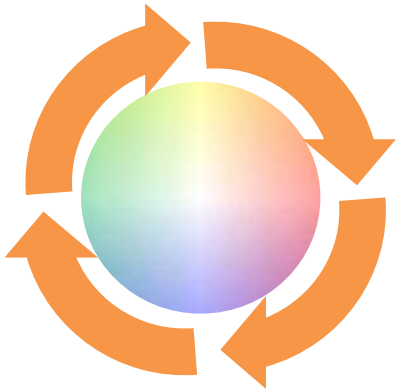
“CRI = 80” + Hue Shift



leducation.org

LEDucation

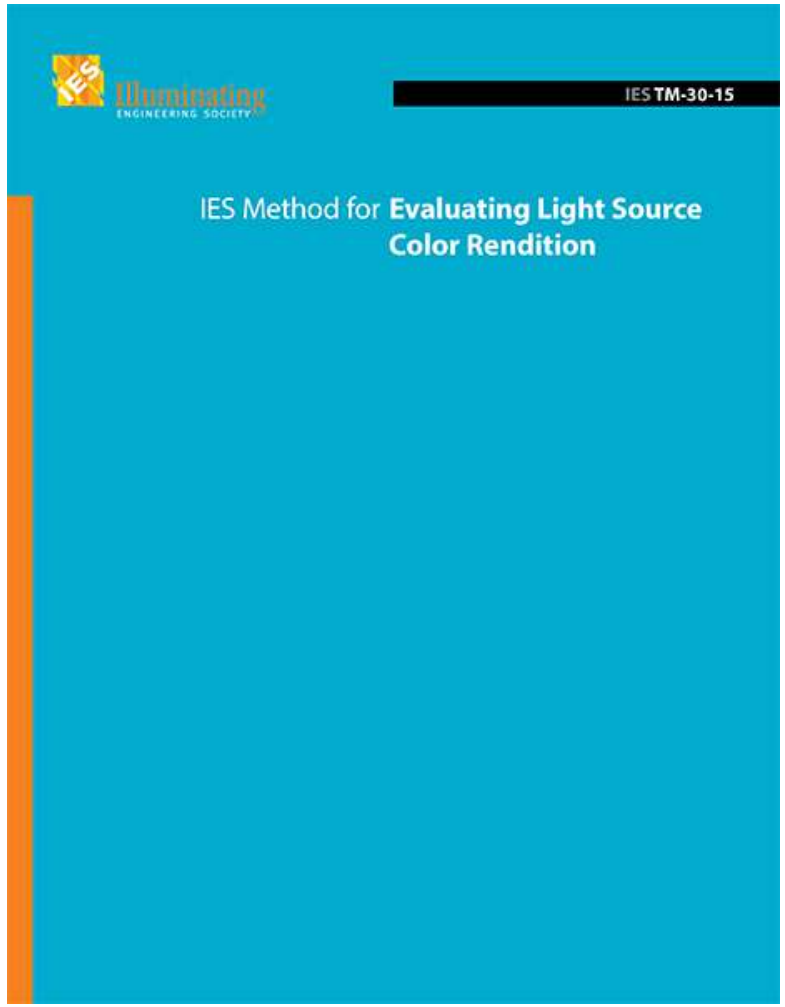
“CRI = 80” - Hue Shift



Original image courtesy of
Randy Burkett Lighting Design

leducation.org

LEDucation



IES TM-30-18 (PENDING APPROVAL)

Approved by Color Committee

In Process with Standards Commitee

Pending Submission to ANSI

Changes made to harmonize with CIE 224

A. Flat extrapolation for color sample data <400 nm and >700 nm (changed from derivative based)
B. Mixed reference zone now 4000 K to 5000 K (changed from 4500 K to 5500 K)
C. Scaling factor now 6.73 (changed from 7.54)

→ R_f 80 ~ 82

Additional updates

- Specification of Color Vector Graphic formatting
- Clarification on local value calculations and expected values
- Recommended specification sheets
- Updated calculator tools

All discussion in this presentation applies to both!

https://www.ies.org/store/technical-memoranda/ies-method-for-evaluating-light-source-color-rendition/

TM-30 Calculation Engine

1. Model of Human Color Vision (CAM02-UCS)
2. Model of Colors (99 CES)
3. Established Baseline (Reference)

Global Average Values

Fidelity Index (R_f)

Gamut Index (R_g)

Graphical Representations

Color Vector Graphic

Local Average Values (Hue-Angle Groups)

16 Local Color Fidelity($R_{f,hj}$)

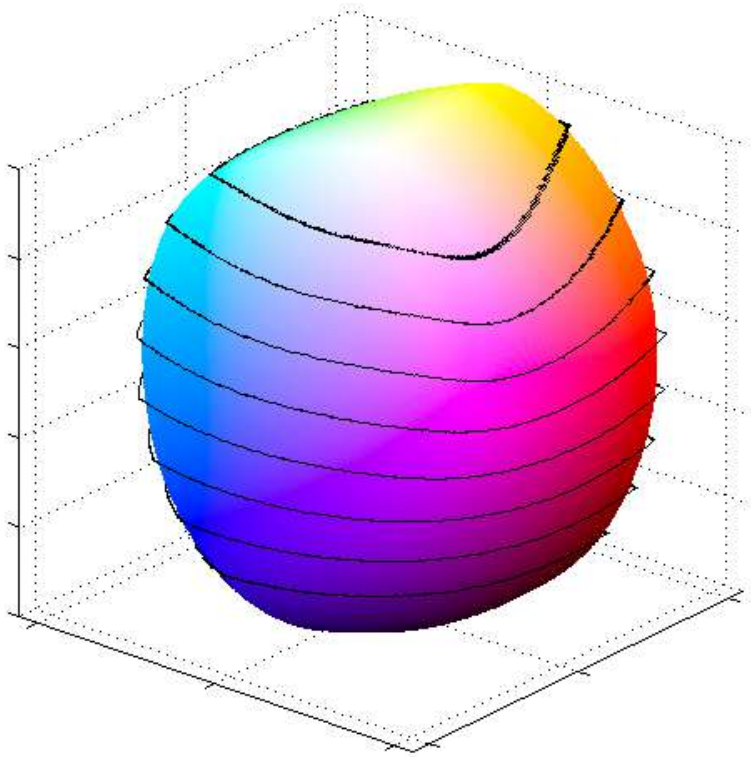
16 Local Chroma Shift ($R_{cs,hj}$)

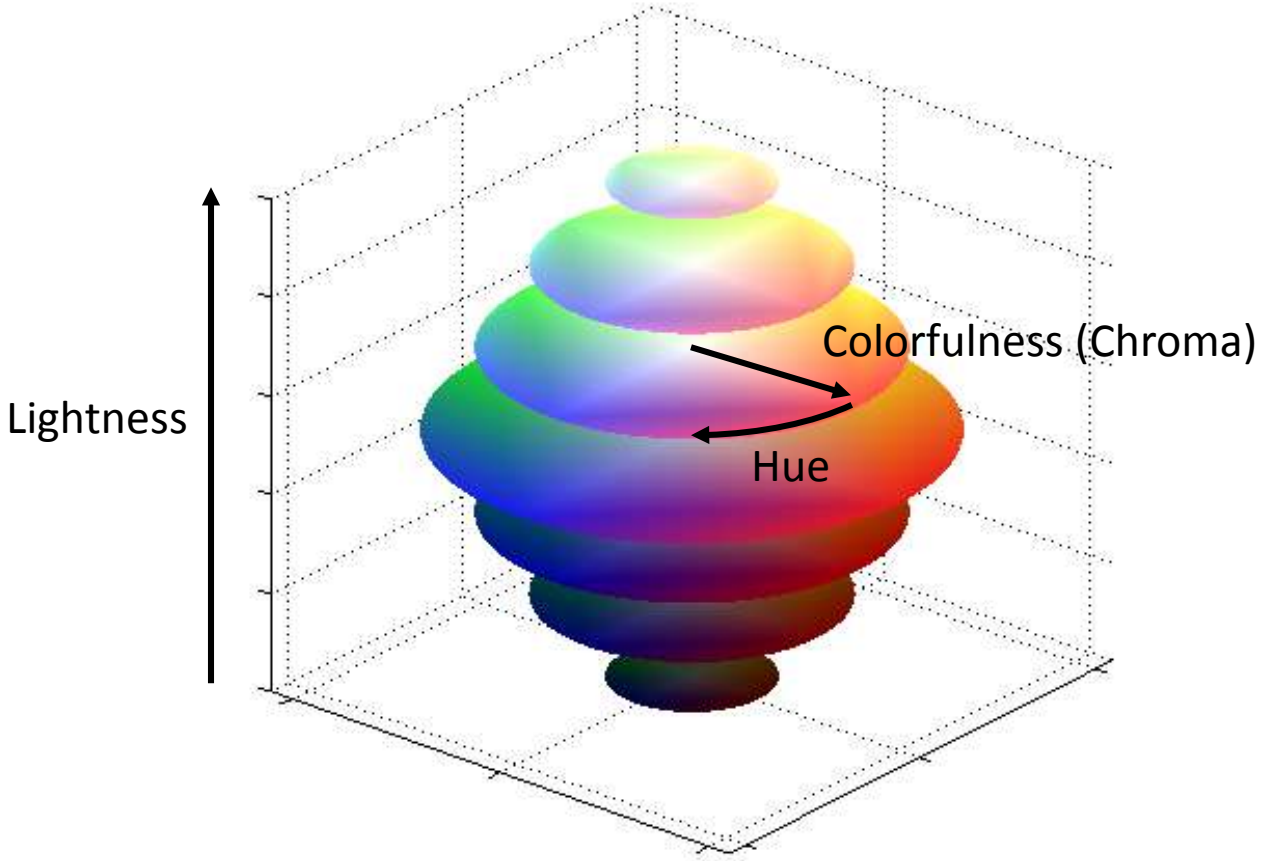
16 Local Hue Shift ($R_{hs,hj}$)

Sample Specific Values

Color Sample Fidelity ($R_{f,CESi}$)

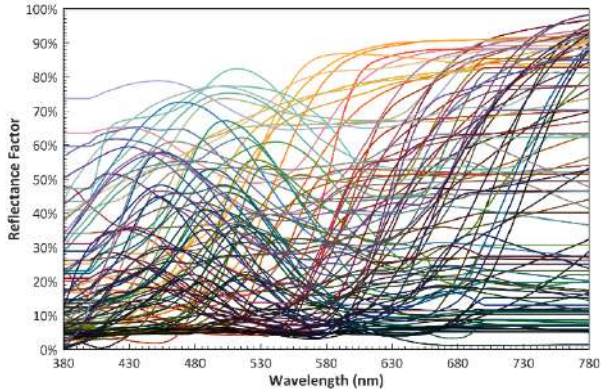
Color Volume
(CAM02-UCS)

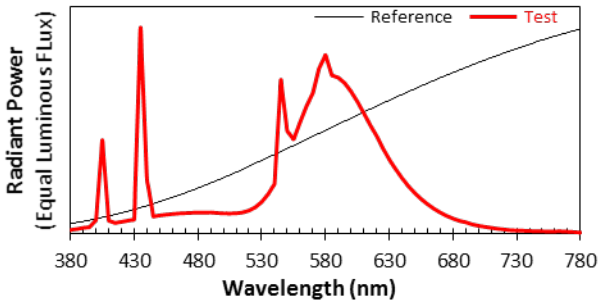




LEDucation

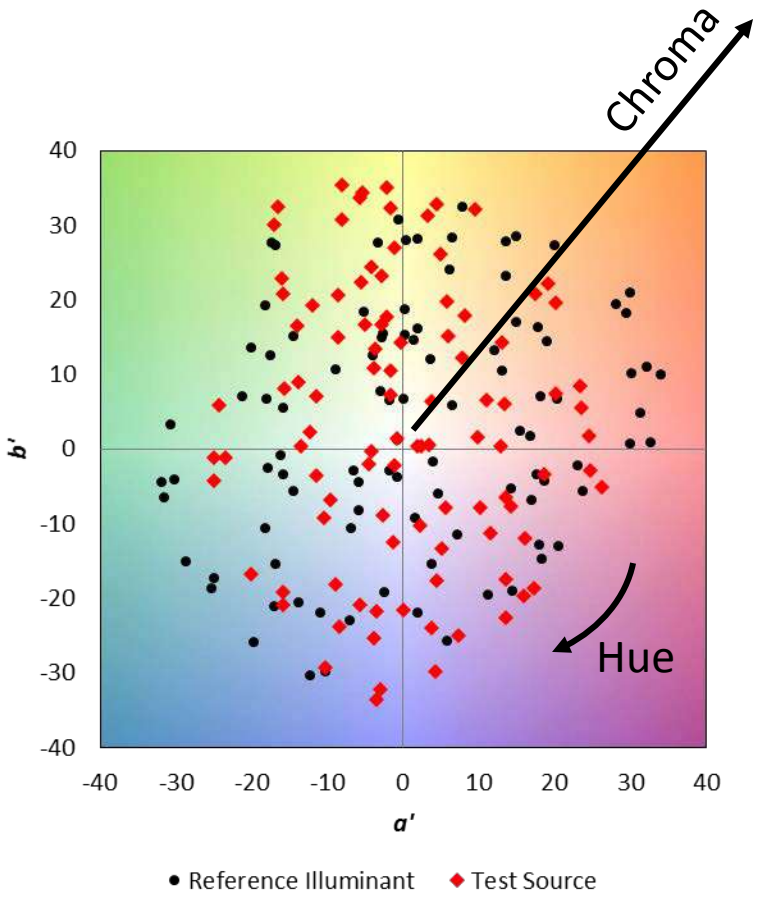
Yep – That's 99 Color Samples of Awesome.

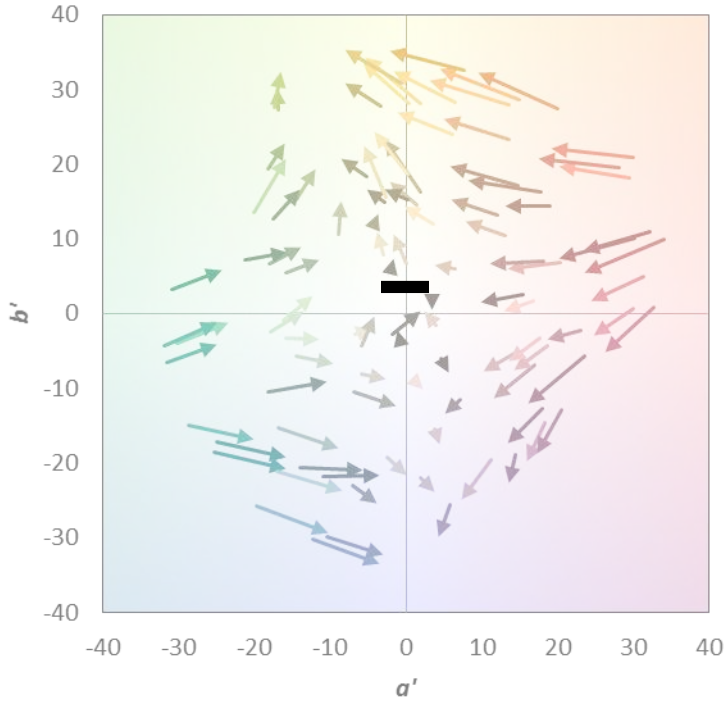




(CIE F4)

leducation.org





Average Color Fidelity

On average, how similar are colors rendered by the test source to the same colors rendered by the reference illuminant?

- Average length of arrows
- Does not capture direction of shift

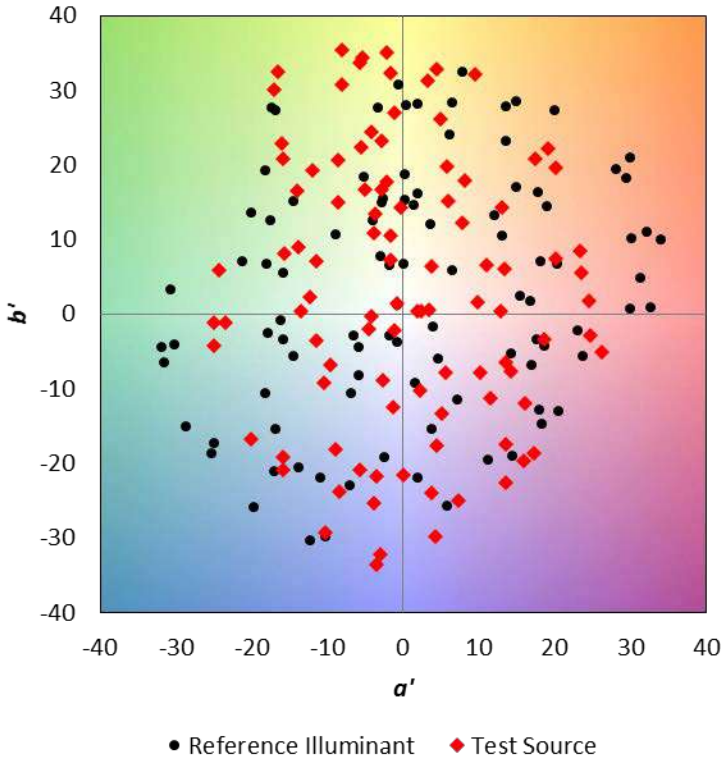
TM-30 Fidelity Index (R_f)

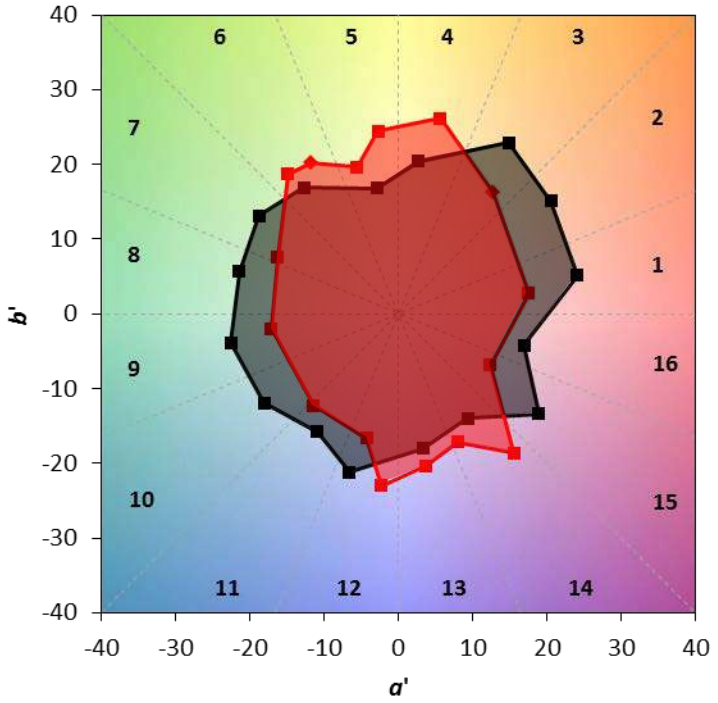
Range is 0 to 100, where 100 is an exact match.

TM-30-18 R_f = CIE 224 R_f

(pending final approval)

This is really a sphere, but it's compressed to 2D for ease of visualization!





Average Gamut Area

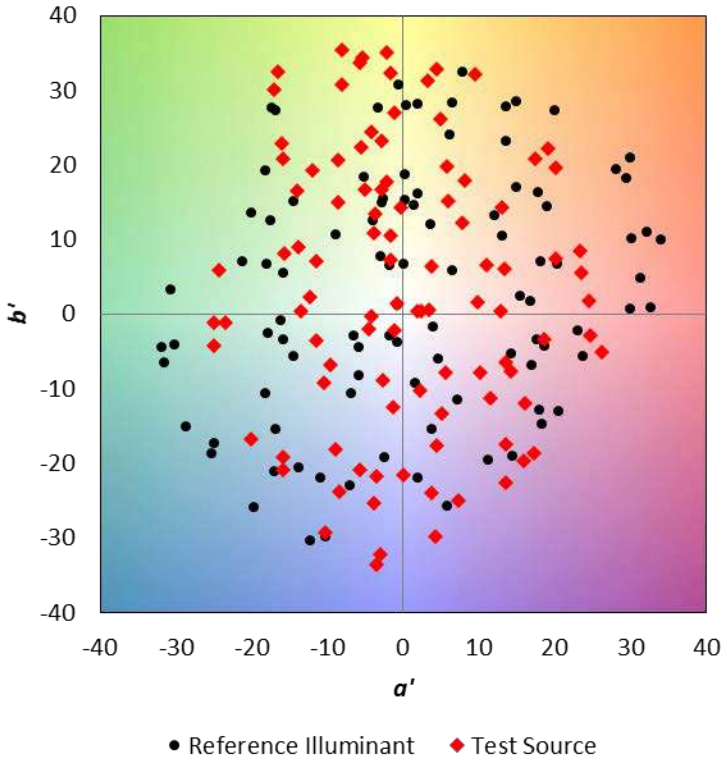
Approximation of average change in chroma.

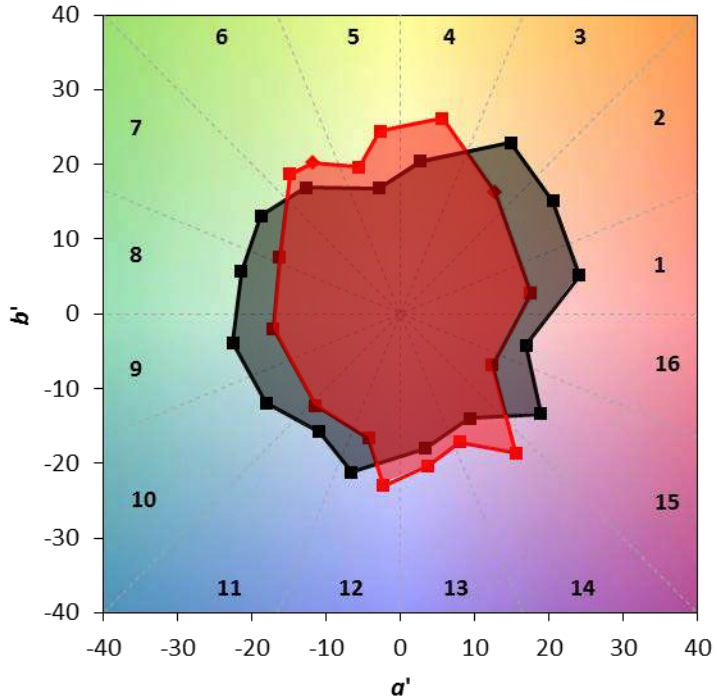
- Average area enclosed by samples
- Does not capture how changes vary for different hues

TM-30 Gamut Index (R_g)

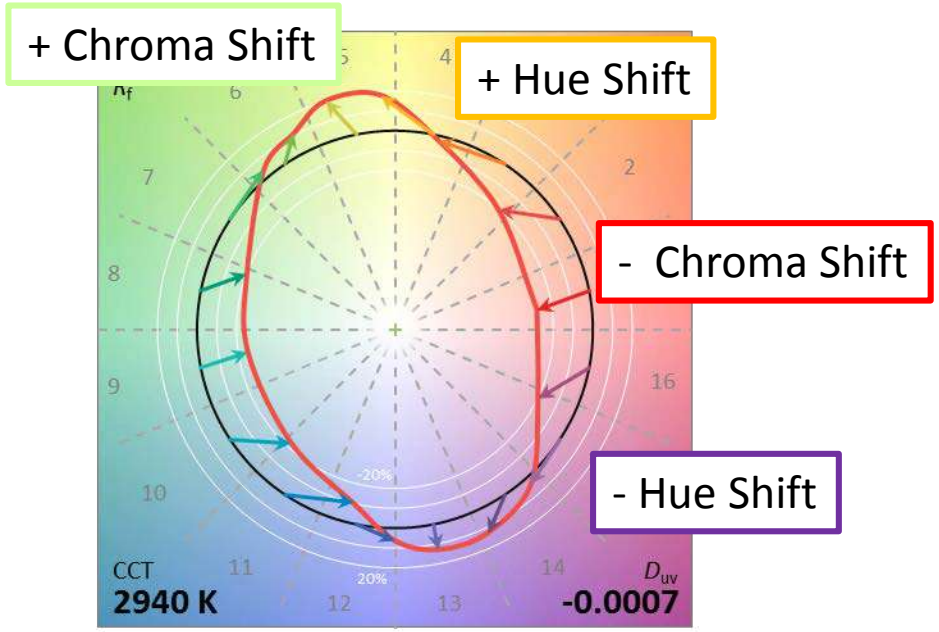
Range depends on R_f; about 80 to 120 at R_f = 80.

This is actually compressed to 2D for calculations!



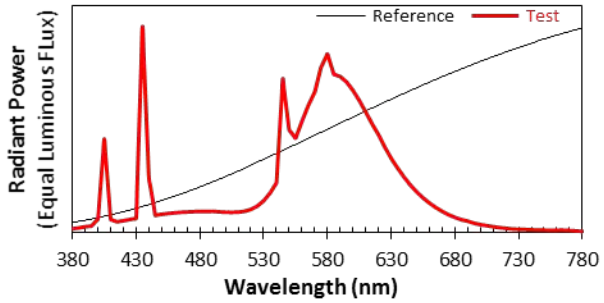


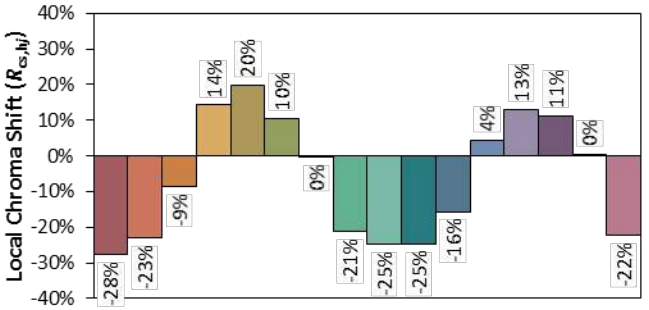
Color Vector Graphic

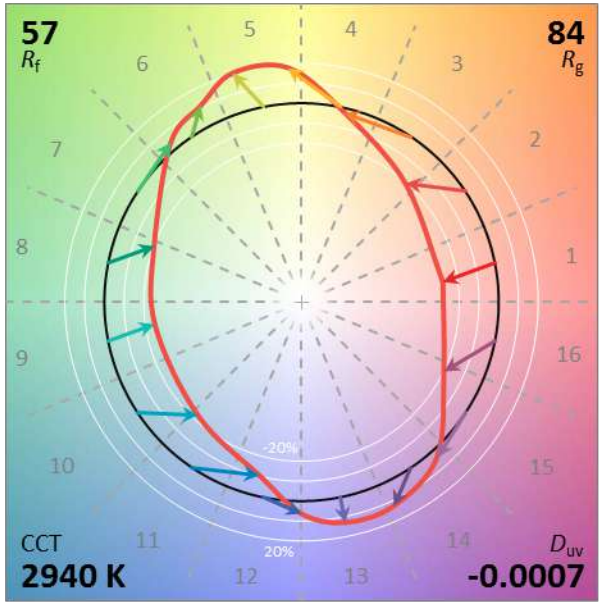


(Note: TM-30-18 Format is Pending Approval)

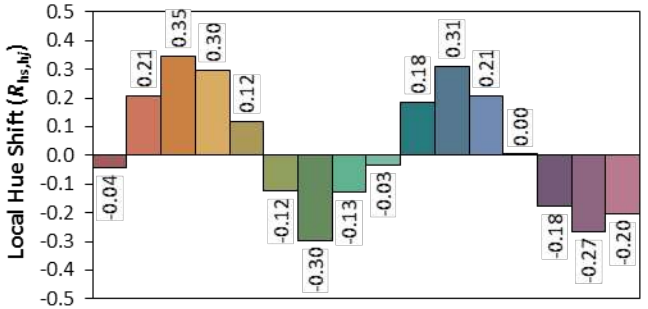
Gamut Shape = The average pattern of color shifts across hues.

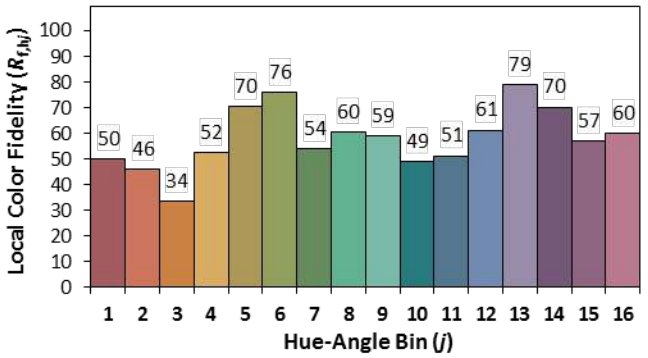






(Note: TM-30-18 Format is Pending Approval)





Local Chroma Shift

For a given range in hue angle, what is the average relative change in chroma. Values in percentages.

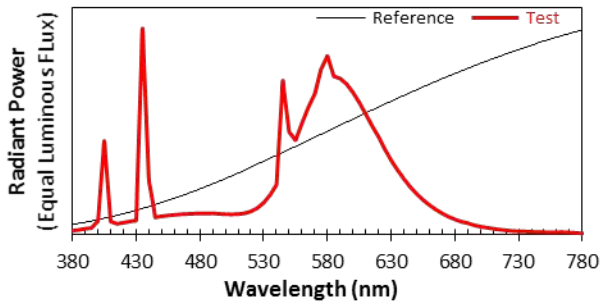
Local Hue Shift

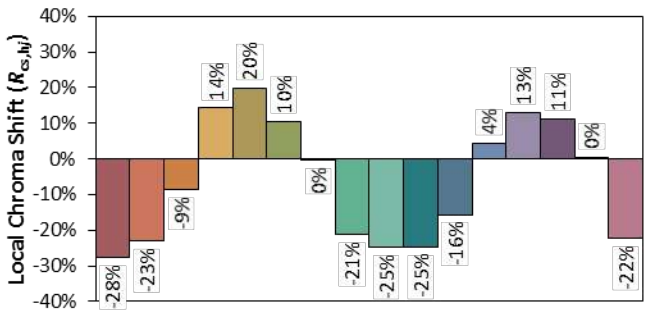
For a given range in hue angle, what is the average relative change hue. Values in radians.

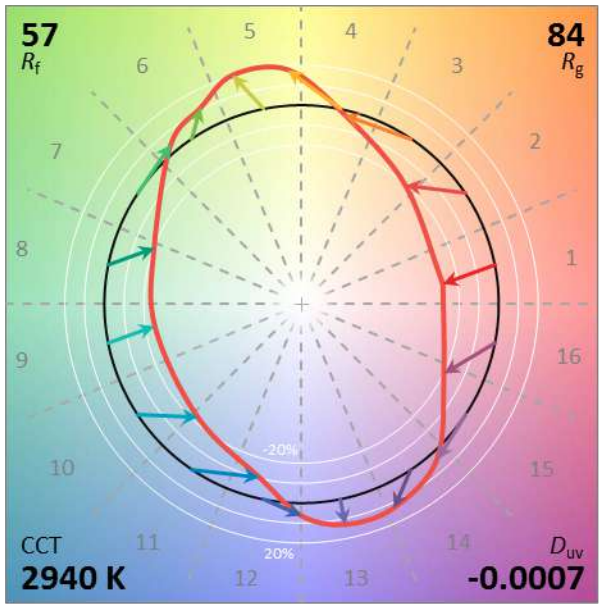
Local Color Fidelity

For a given range in hue angle, what is the average magnitude of change (3D). Values 0 – 100.

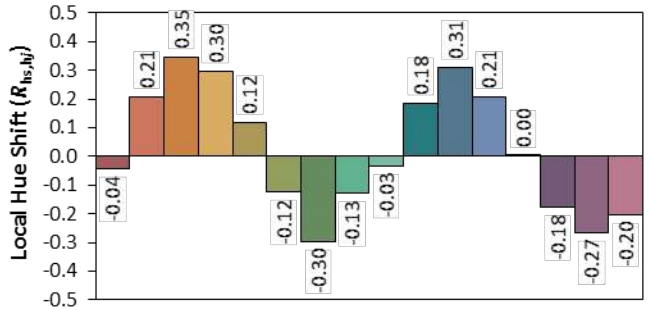
LEDucation

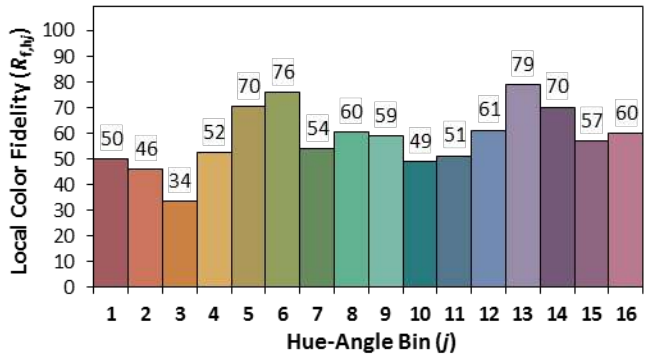




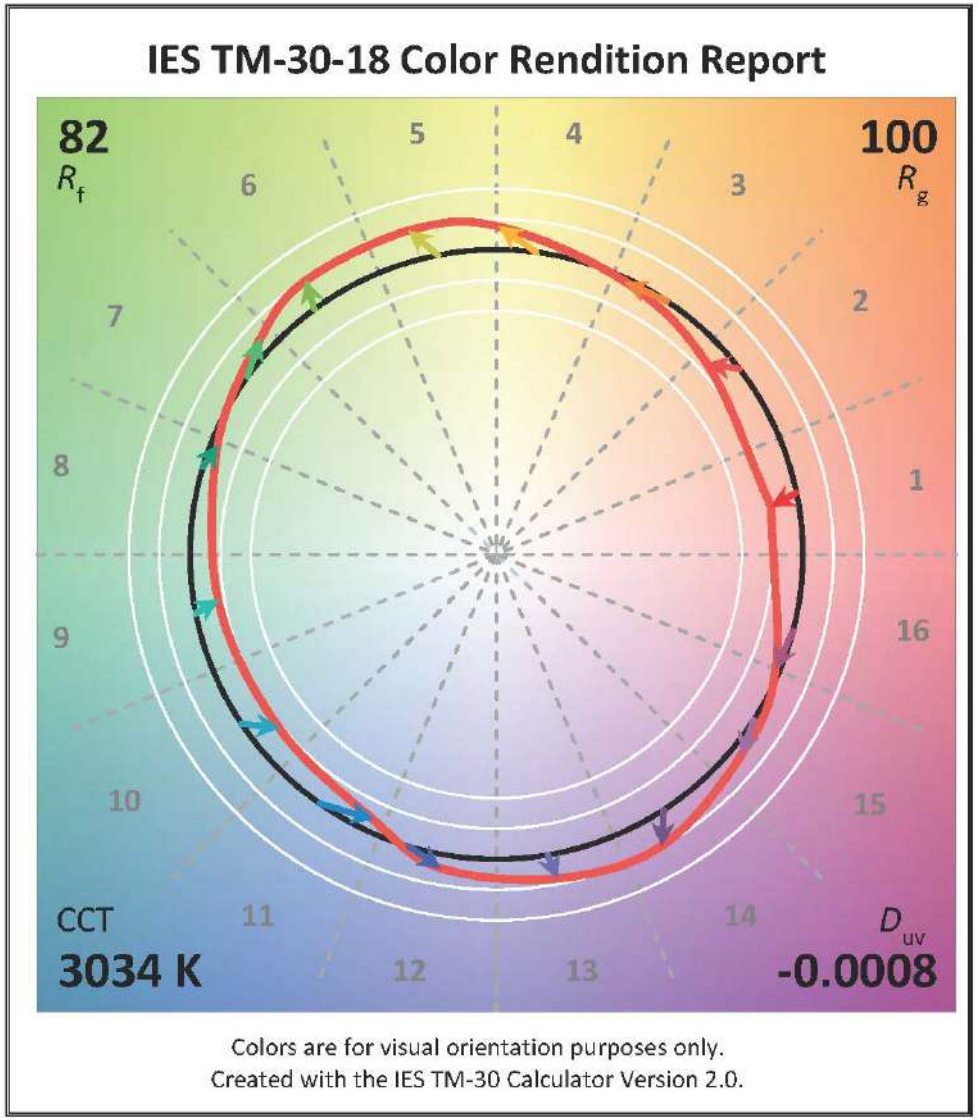


(Note: TM-30-18 Format is Pending Approval)





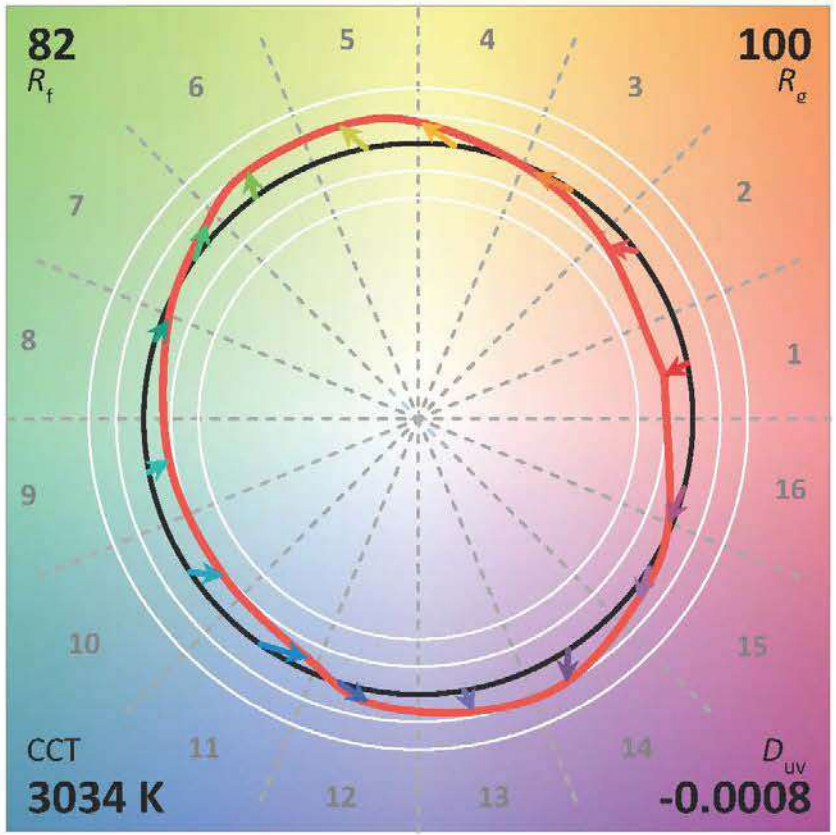
leducation.org

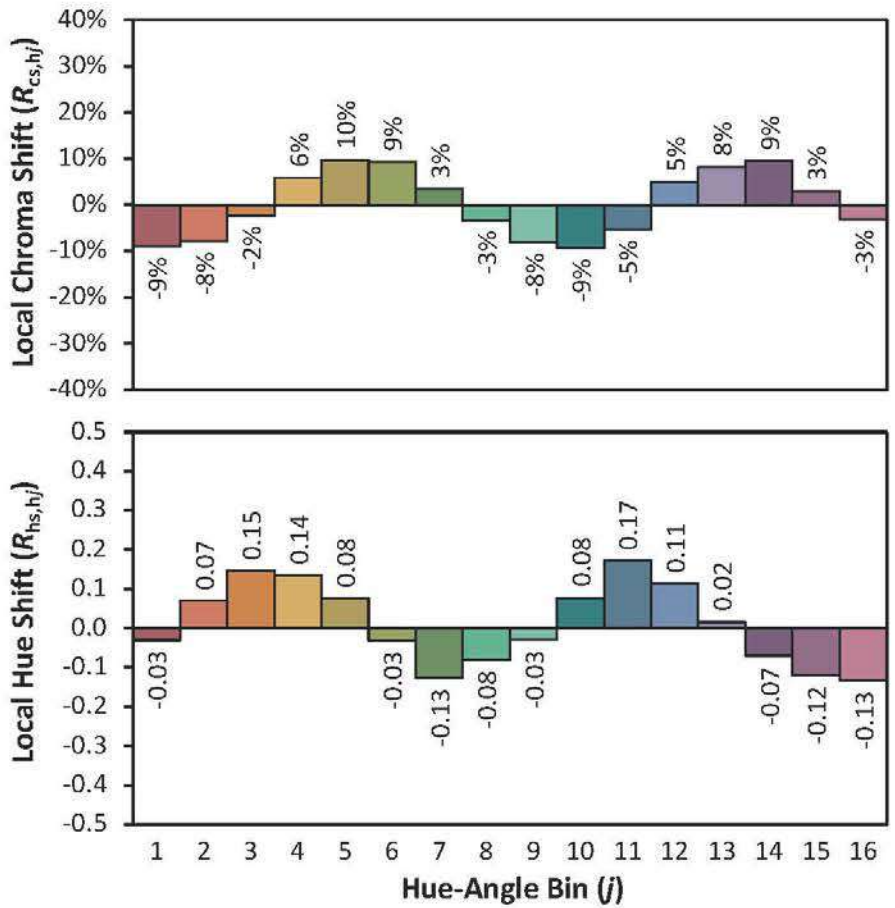


TM-30-18 Annex D
Simple Report
(Pending Approval)

LEDucation

IES TM-30-18 Color Rendition Report



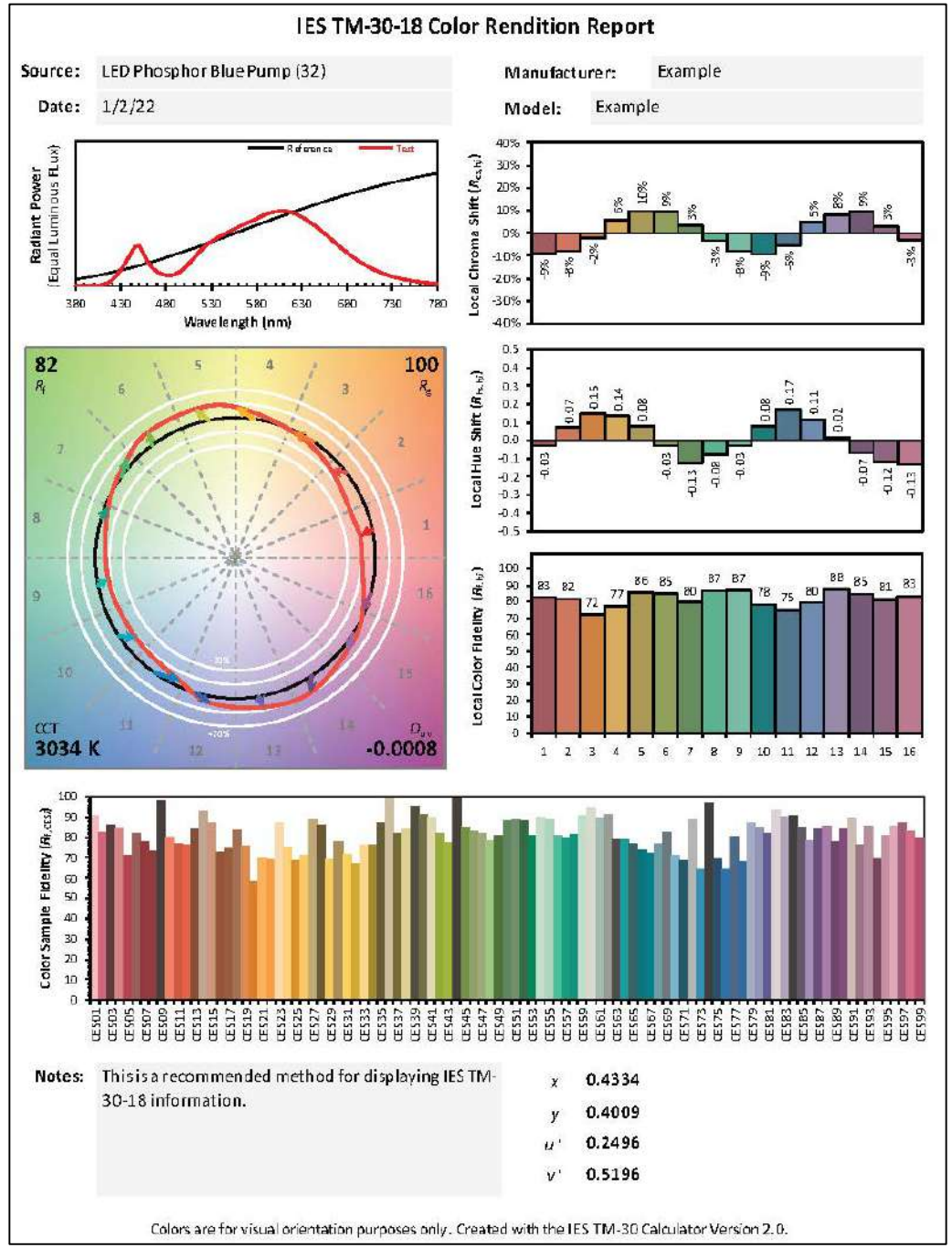


Colors are for visual orientation purposes only. Created with the IES TM-30 Calculator Version 2.0.

TM-30-18 Annex D
Intermediate Report
(Pending Approval)

leducation.org

LEDucation

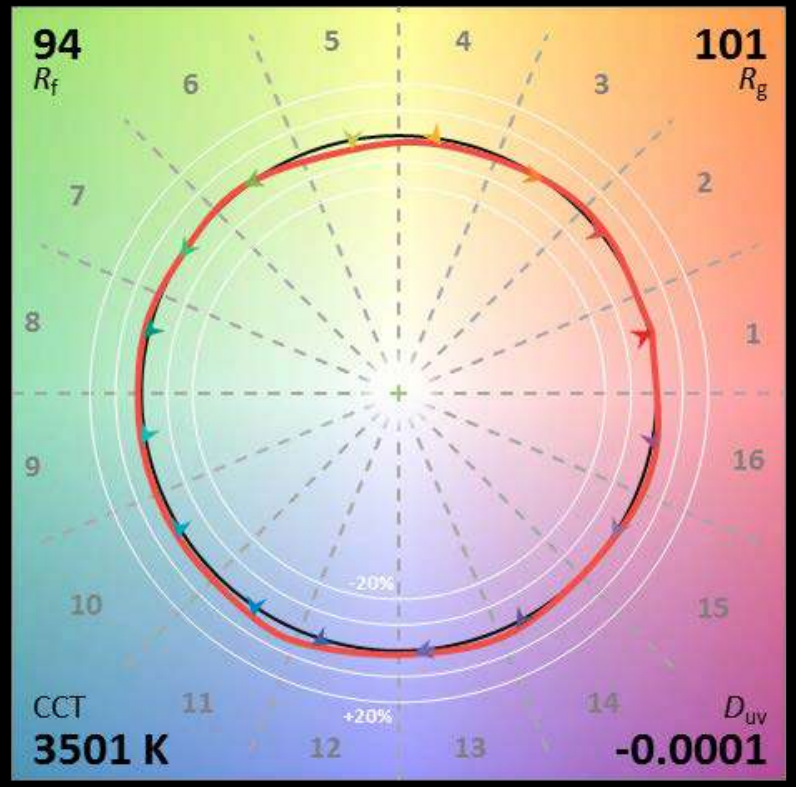


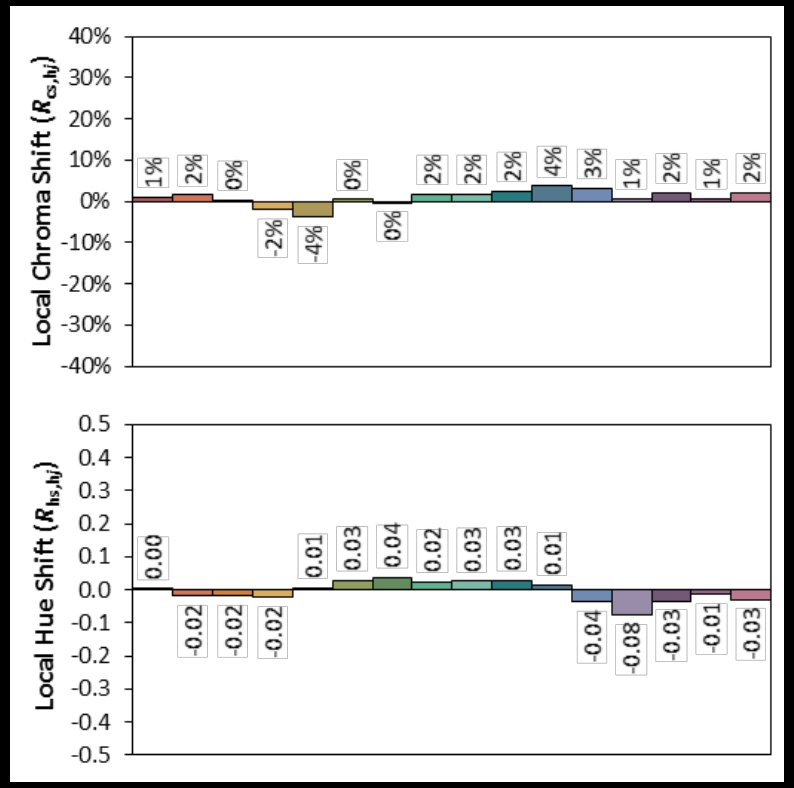
TM-30-18 Annex D
Full Report
(Pending Approval)

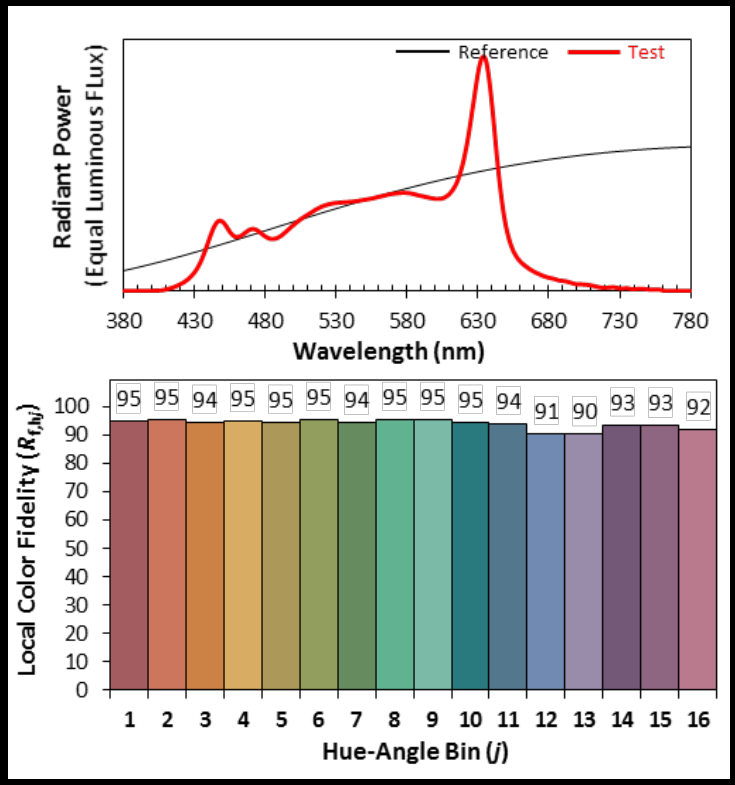
leducation.org

Demo Time

Our “Reference”



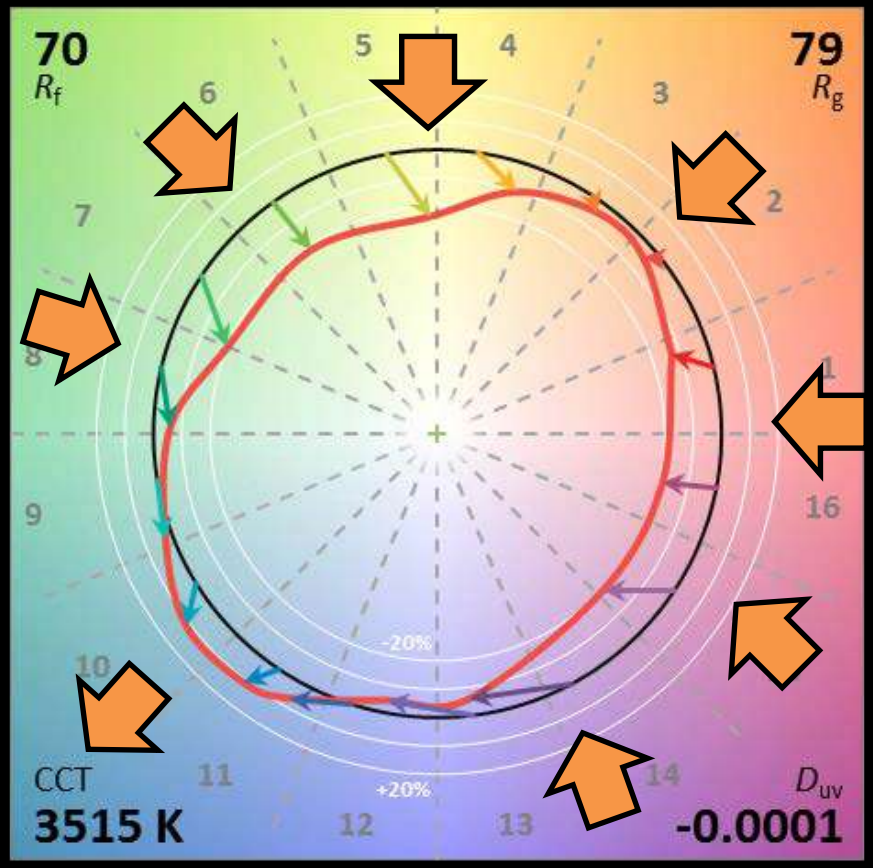




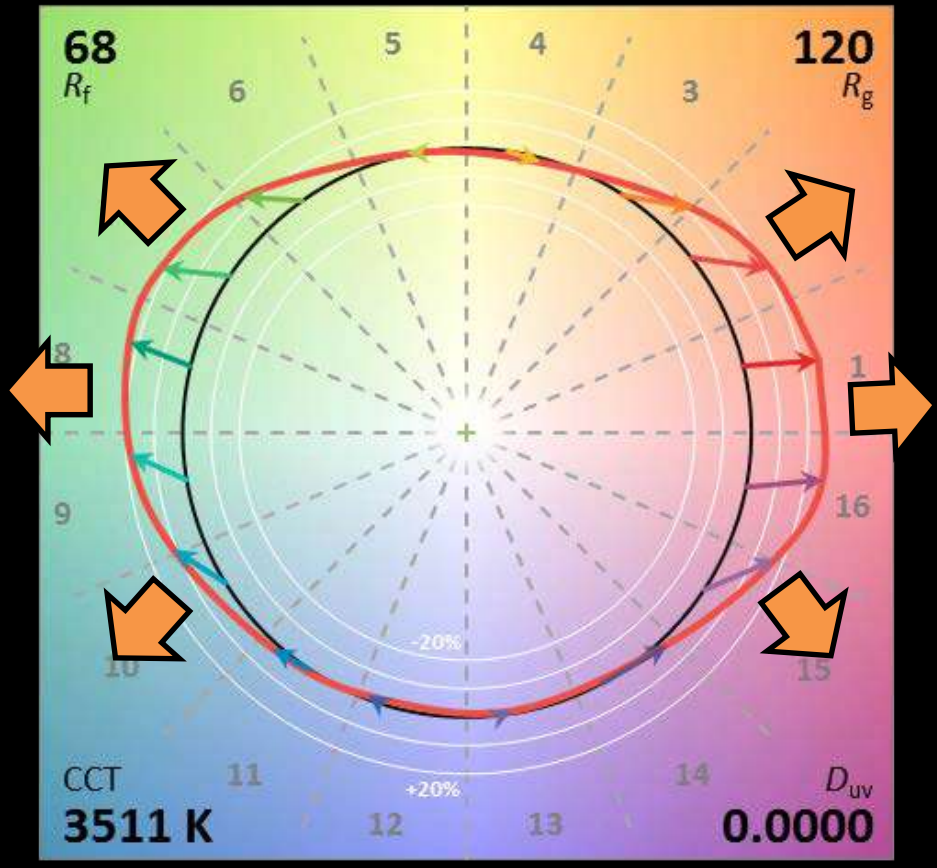
Note graphics shown are DRAFT IES TM-30-18, pending approval.

Demo Time

Under/ Over Saturation



1

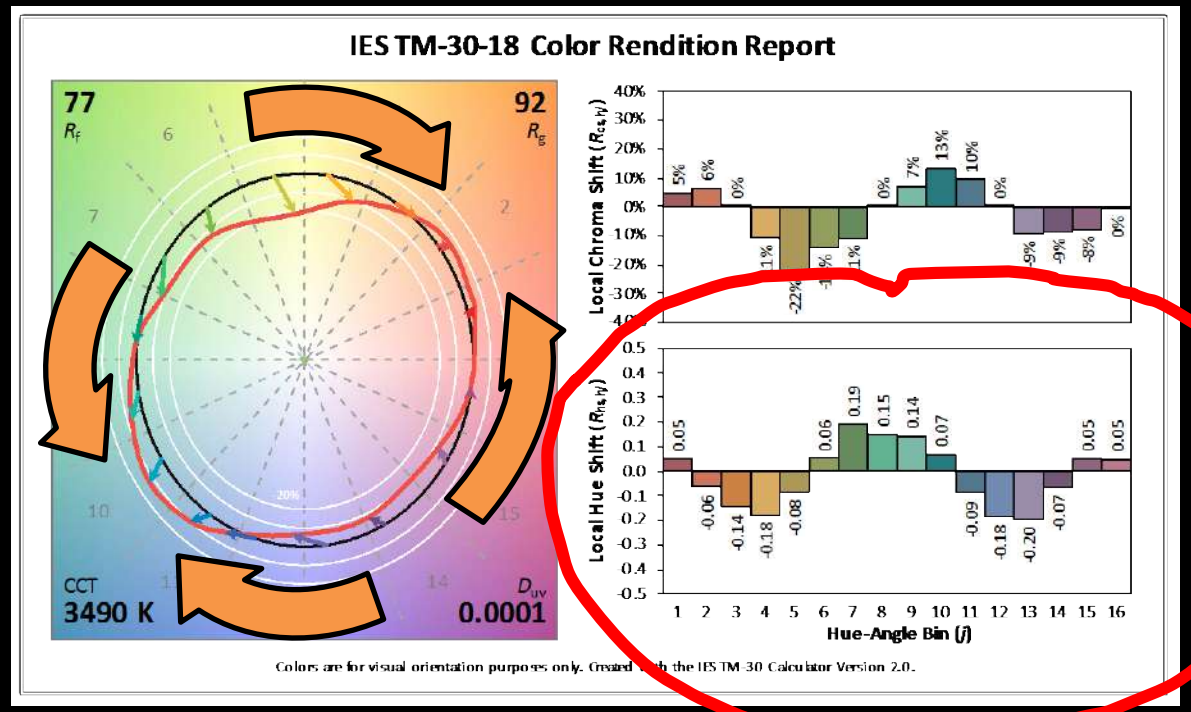


10

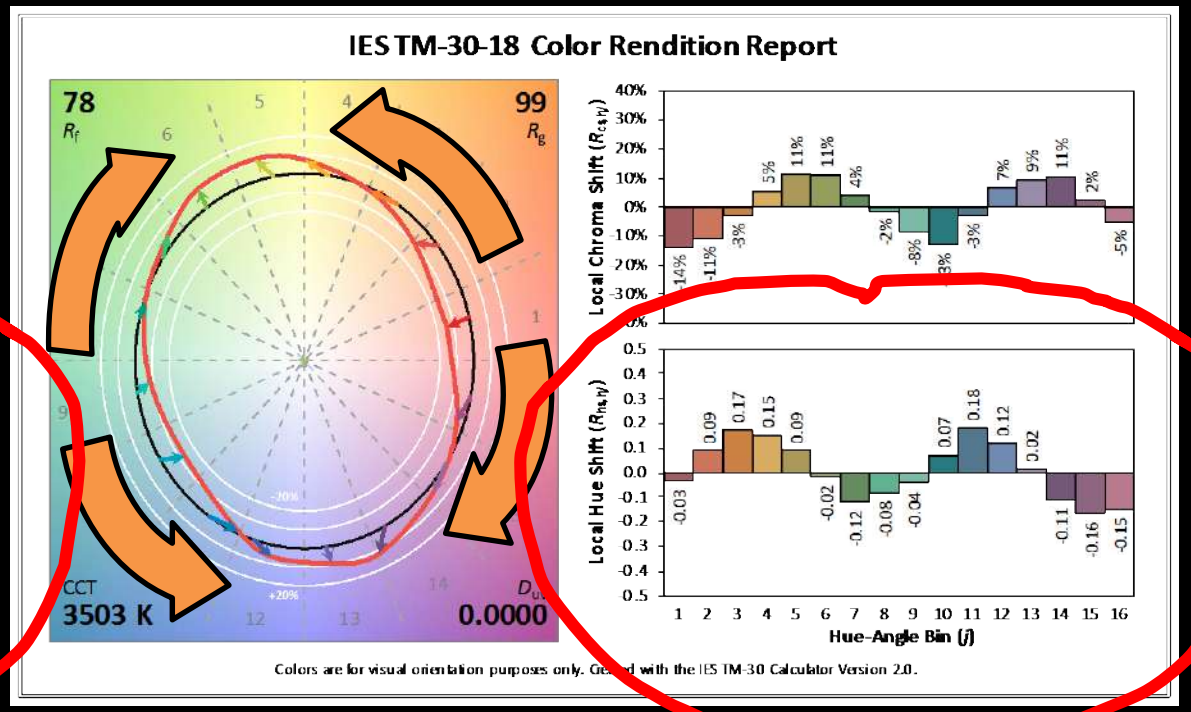
Note graphics shown are DRAFT IES TM-30-18, pending approval.

Demo Time

Hue Shift



12



13

Note graphics shown are DRAFT IES TM-30-18, pending approval.

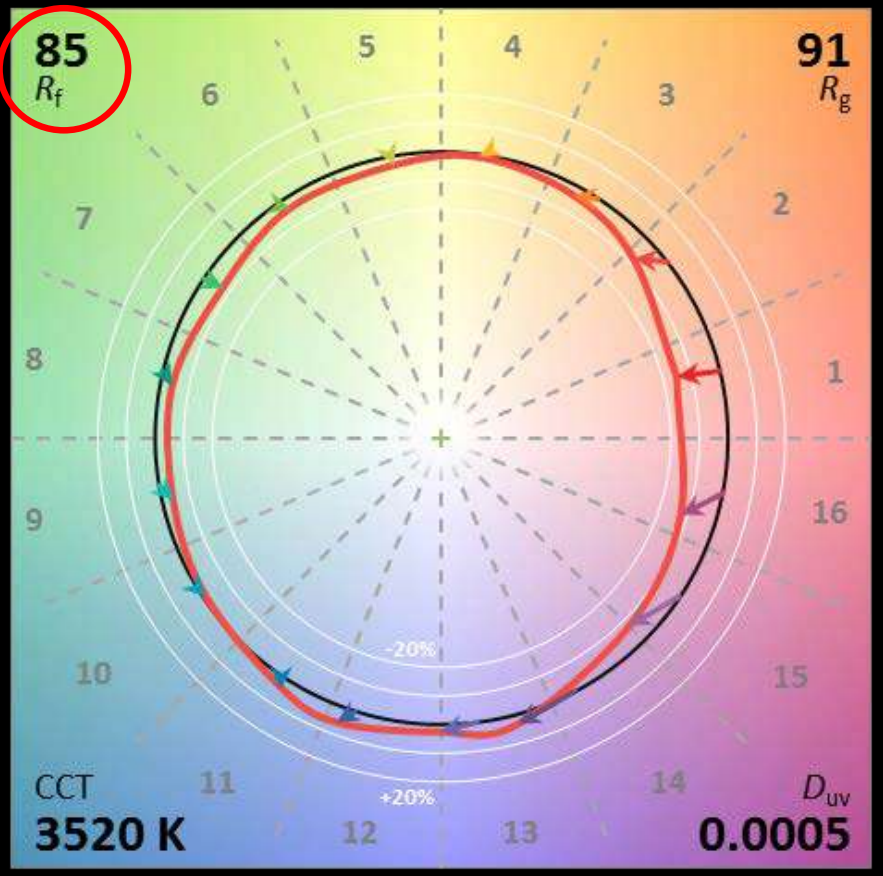
LEDucation

Understand the limitations of the tool:

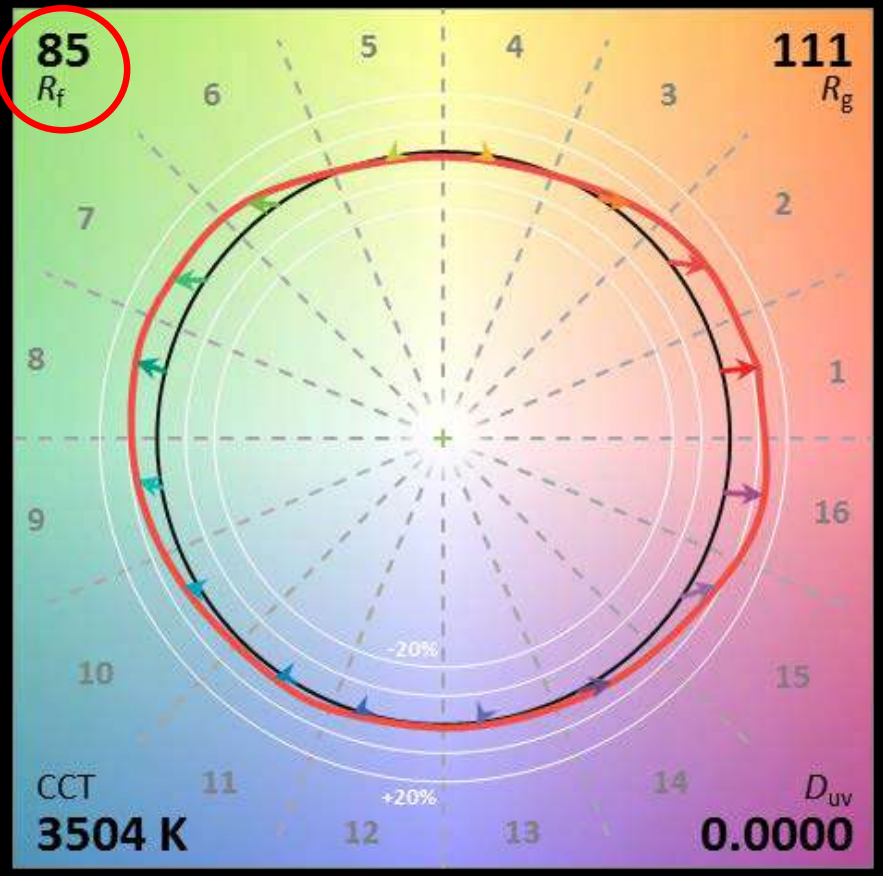
1. **Global average values (R_f, R_g) are simple, but have big limitations**
   - **When used alone (or as a pair) they are not closely related to any subjective aspect of color quality.**
2. IES TM-30 is not an RP, so it doesn't tell you what to do with or how to use the info
3. IES TM-30, like all measures of color rendition, does not consider:
   - Intensity (illuminance)
   - Chromaticity
   - Whiteness (OBAs, OWAs, FBAs, etc.)
   - Scene composition
   - Other contextual factors

Demo Time

Same R_f



19

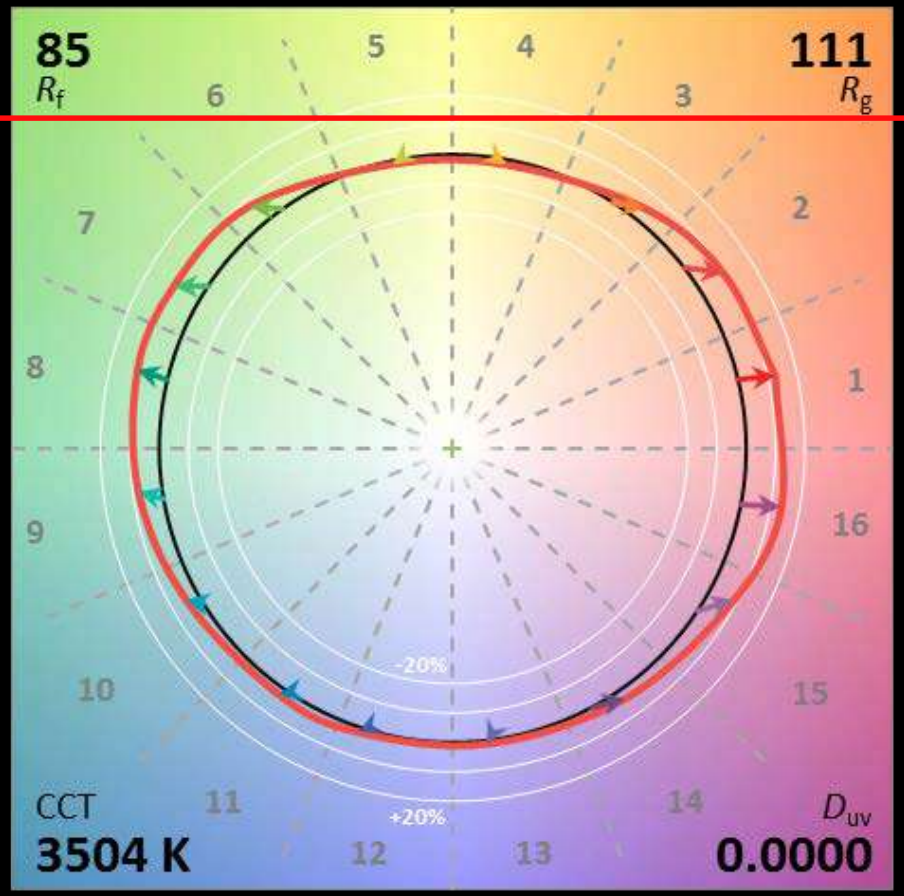


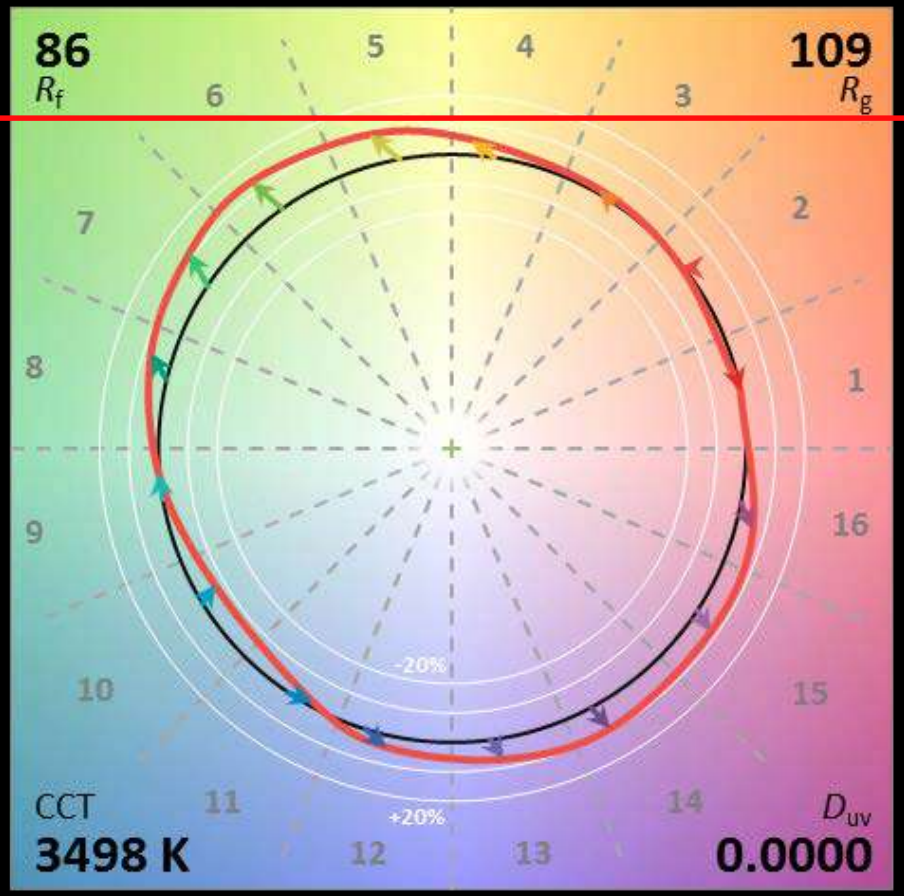
23

Note graphics shown are DRAFT IES TM-30-18, pending approval.

Demo Time

Same R_f and R_g

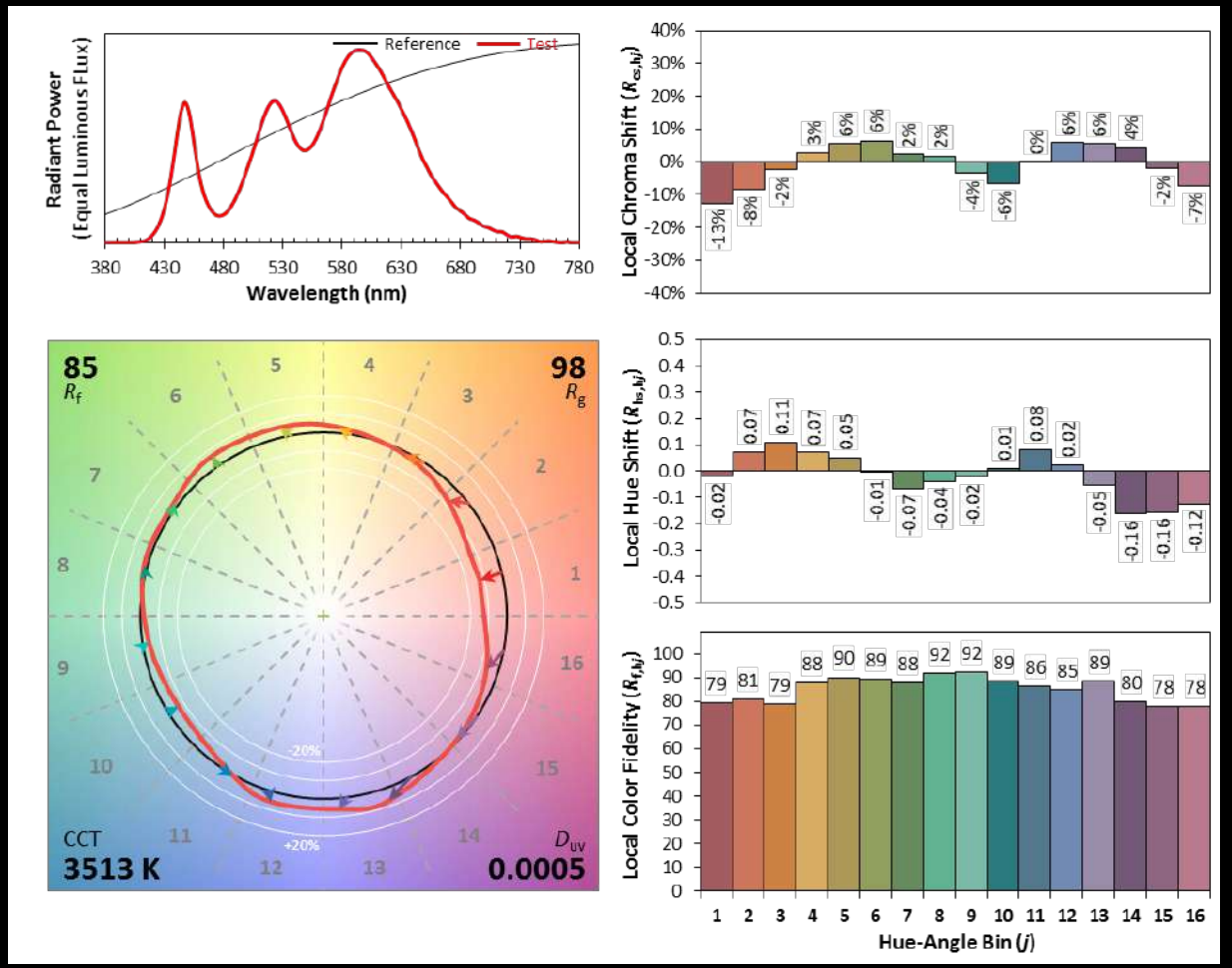




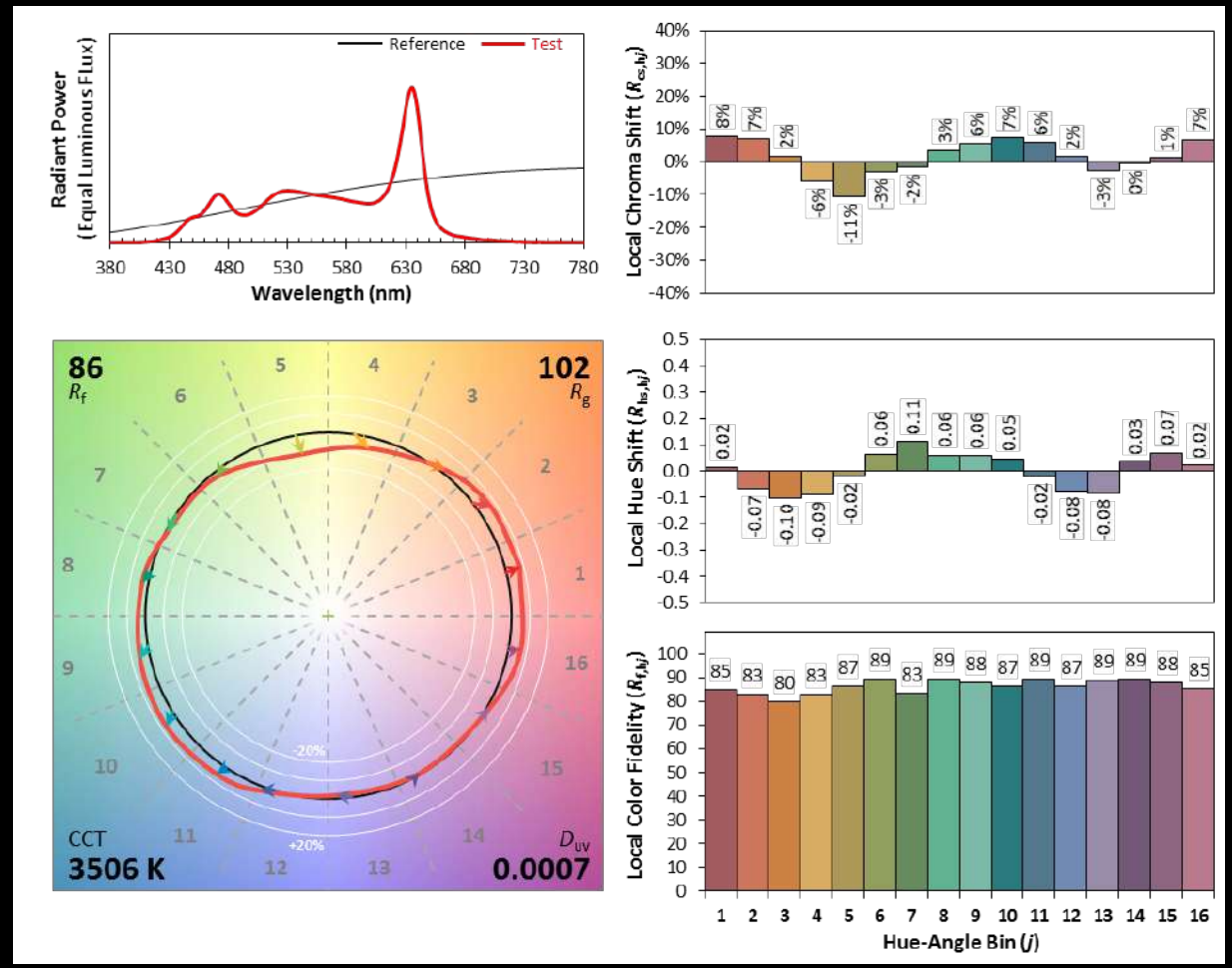
23

24

Note graphics shown are DRAFT IES TM-30-18, pending approval.

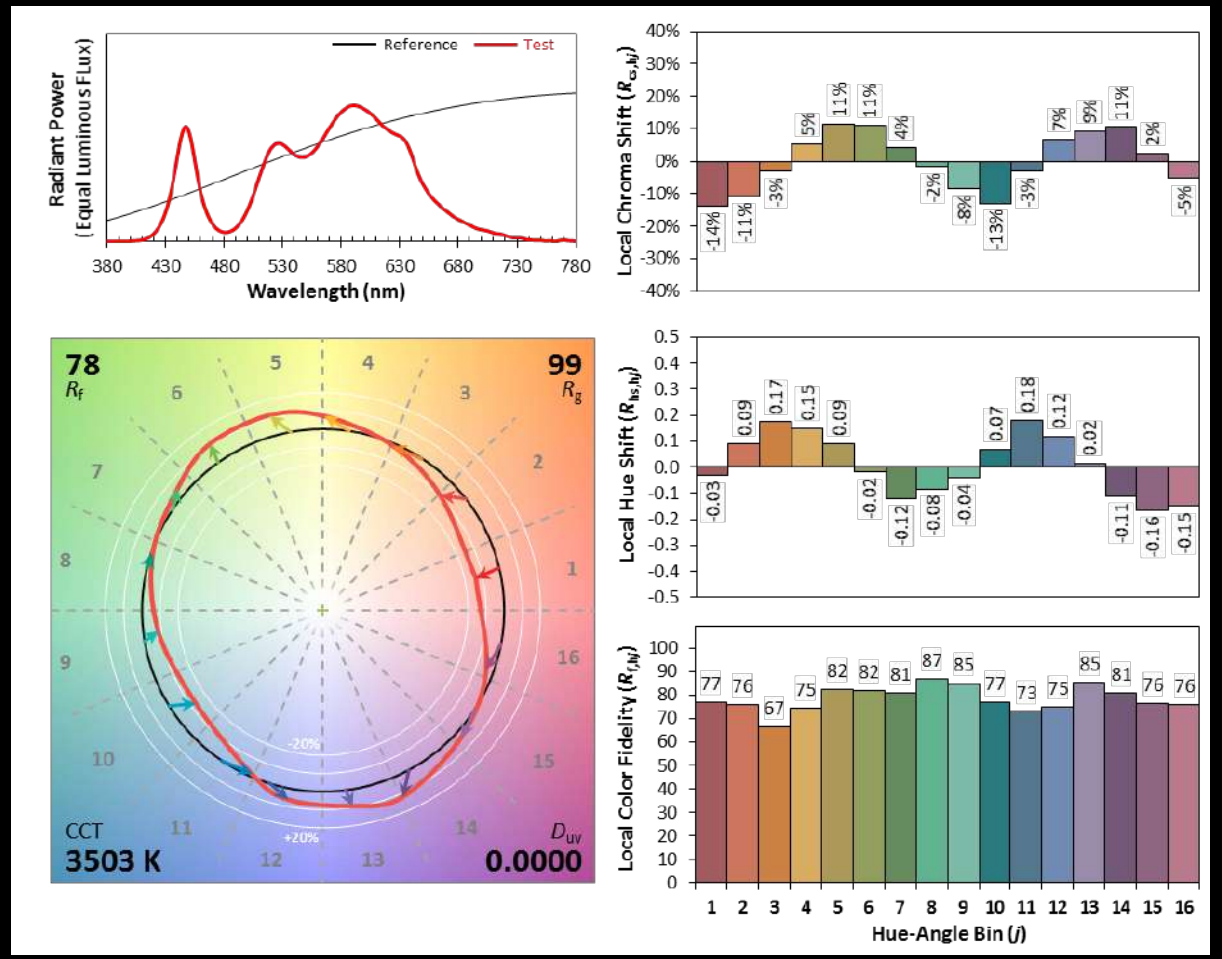


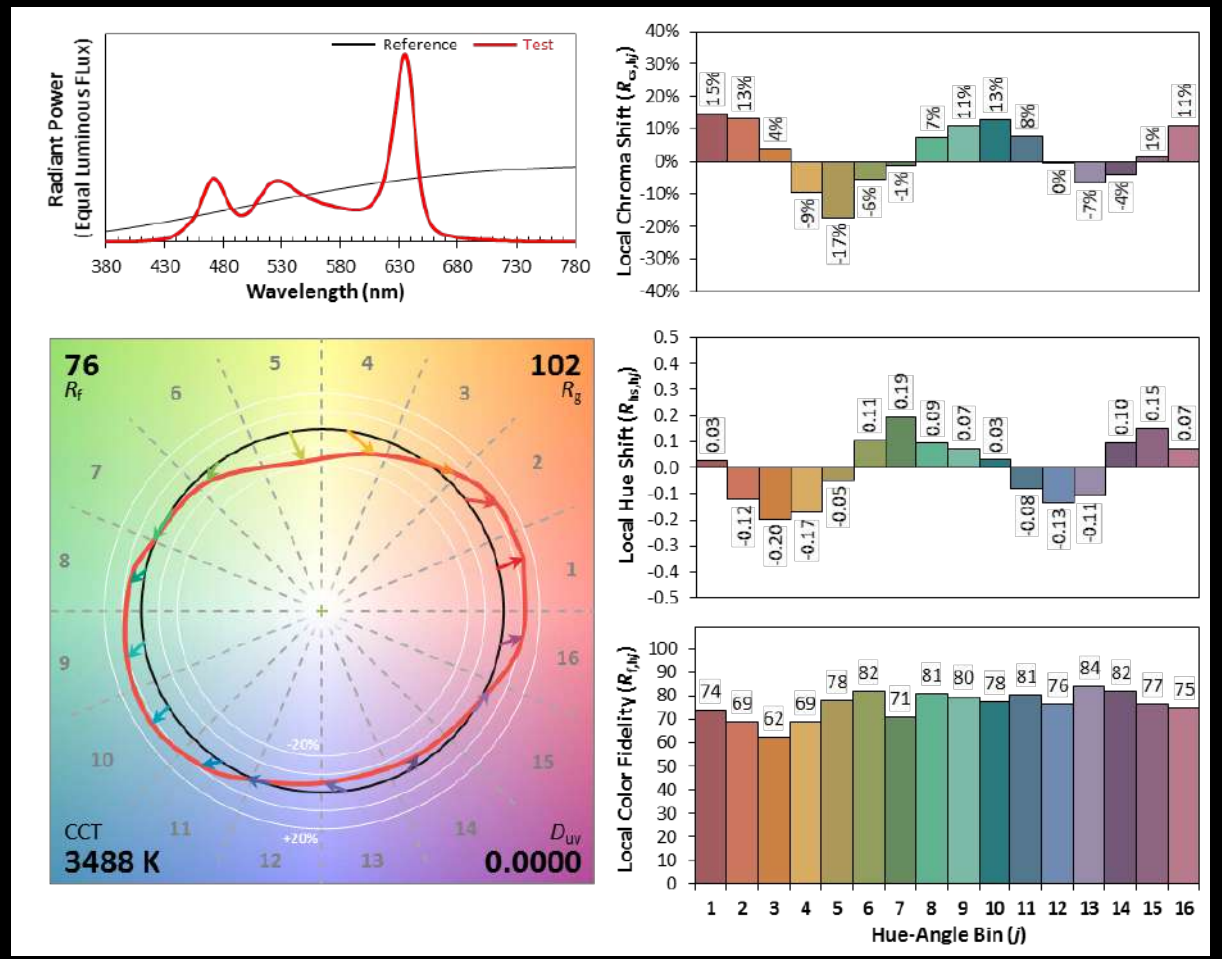
21



22

Note graphics shown are DRAFT IES TM-30-18, pending approval.





Note graphics shown are DRAFT IES TM-30-18, pending approval.

LEDucation

Understand the limitations of the tool:

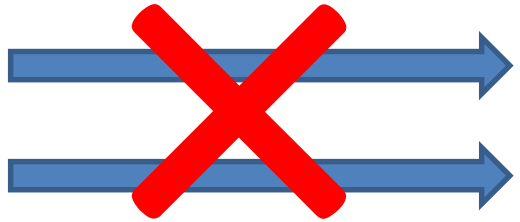
1. Global average values (R_f, R_g) are simple, but have big limitations
   - When used alone (or as a pair) they are not closely related to any subjective aspect of color quality.
2. **IES TM-30 is not an RP, so it doesn't tell you what to do with or how to use the info**
3. IES TM-30, like all measures of color rendition, does not consider:
   - Intensity (illuminance)
   - Chromaticity
   - Whiteness (OBAs, OWAs, FBAs, etc.)
   - Scene composition
   - Other contextual factors

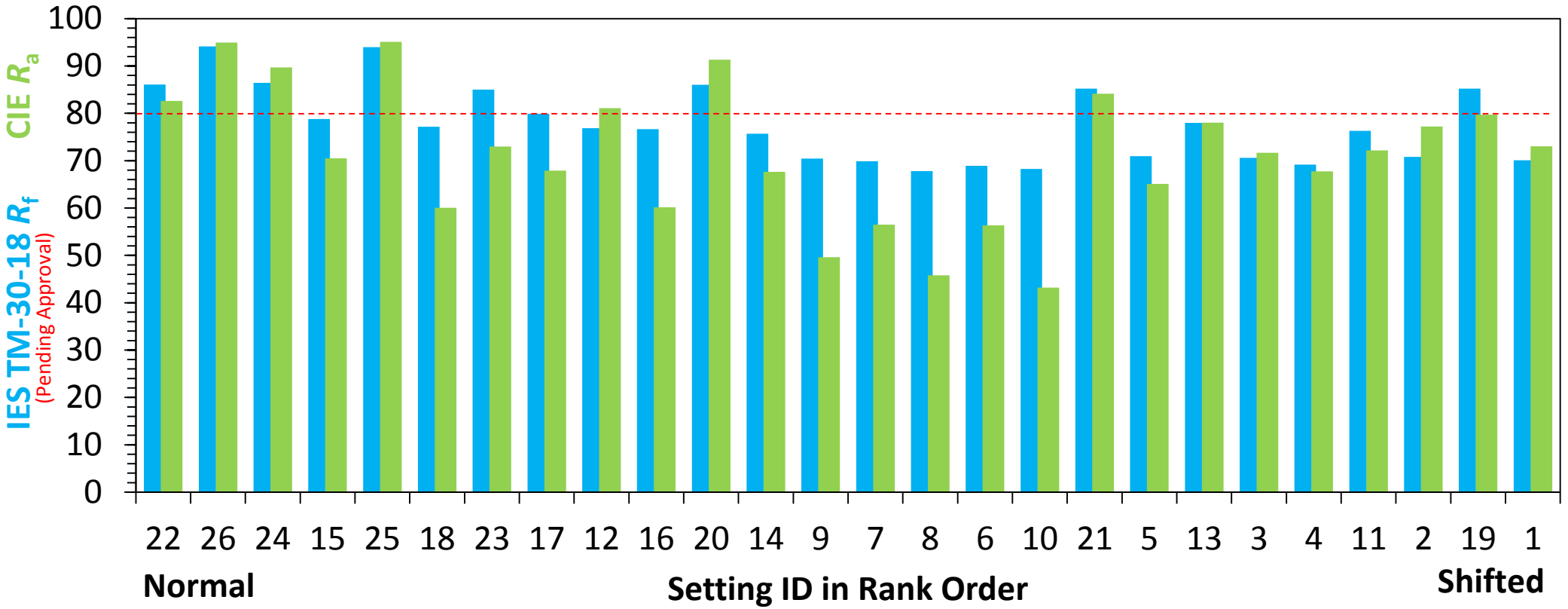
LEDucation

TM-30 is not an RP!

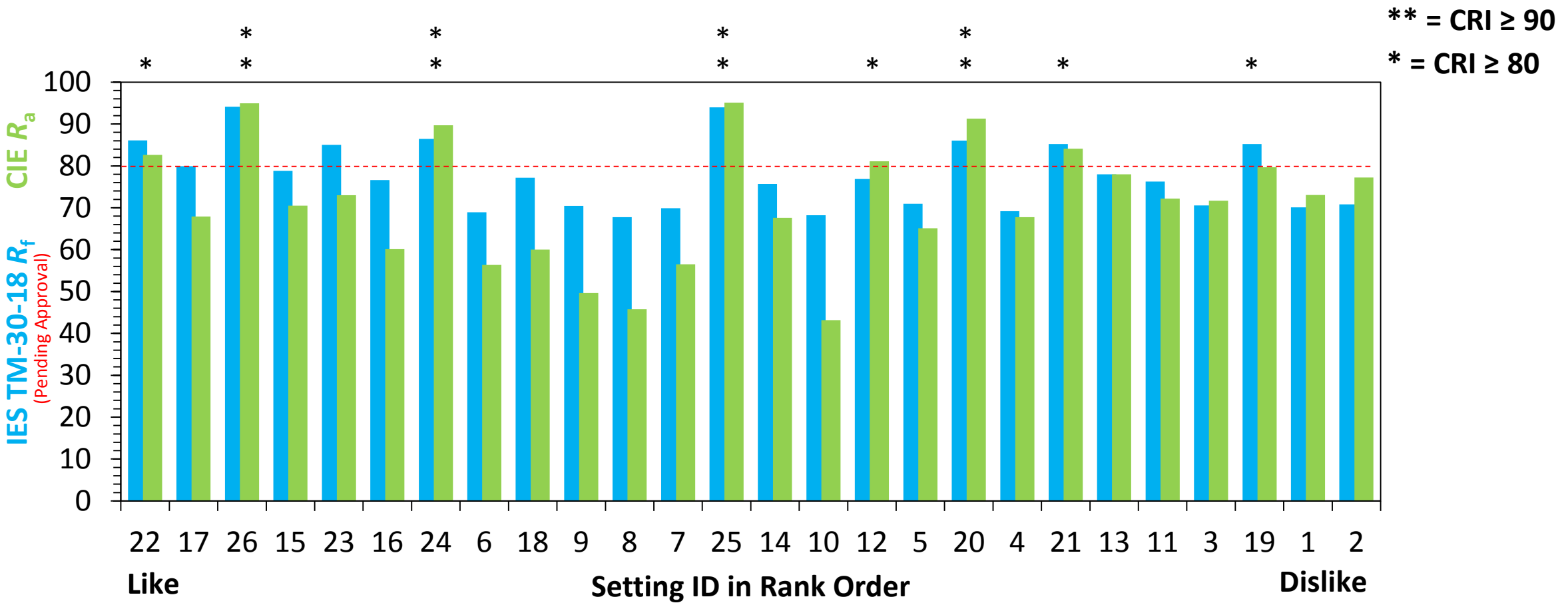
- **Establishing Criteria:**
  1. Experimental
     - Pros: Direct response from users; can vary light source properties in many ways
     - Cons: Does apparatus reflect real-world applications?
  2. Experience
     - Pros: Real-world applications
     - Cons: Takes a long time to build; chicken and the egg; limited light sources
  3. Benchmarking
     - Pros: Fast; cheap; relatively straightforward
     - Cons: Dependent on existing sources/those used for benchmarking; any limitations may be carried forward
- **Criteria Meaning:**
  - Minimum acceptability versus top performers
  - Criteria in context?

LEDucation

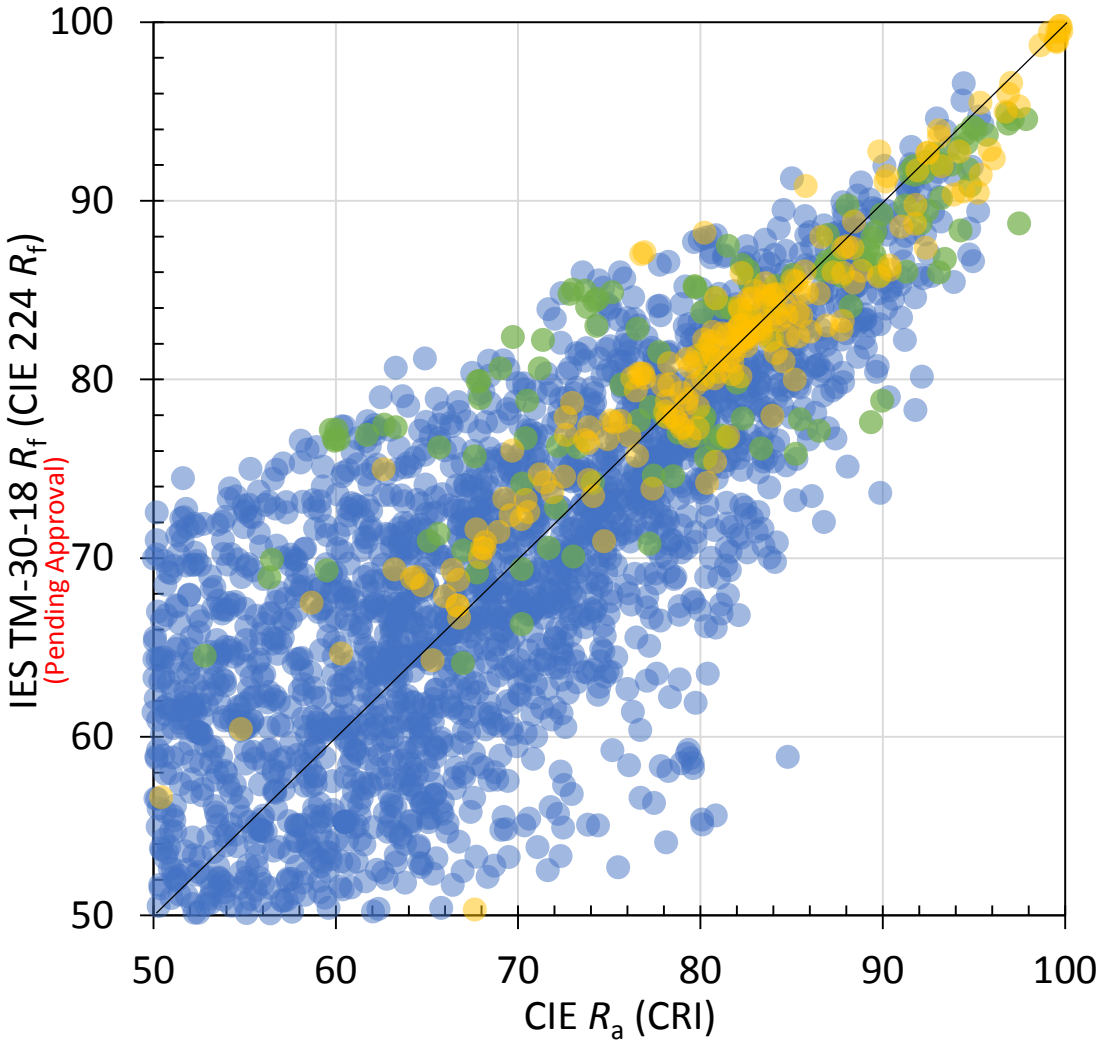
Subjective Qualities		Objective Values
Natural		Average Color Fidelity
Vivid/Vibrant		Gamut Area
Preferred		Color Vector Graphic/Gamut Shape
		16 x Local Chroma Shift
		16 x Local Hue Shift
		16 x Local Color Fidelity

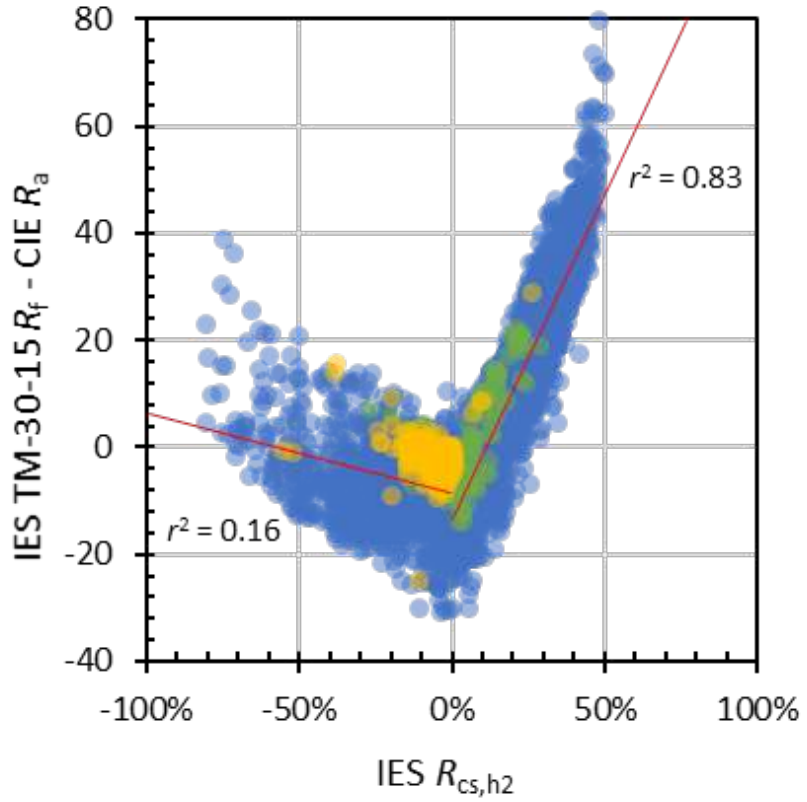


https://energy.gov/eere/ssl/color-rendition



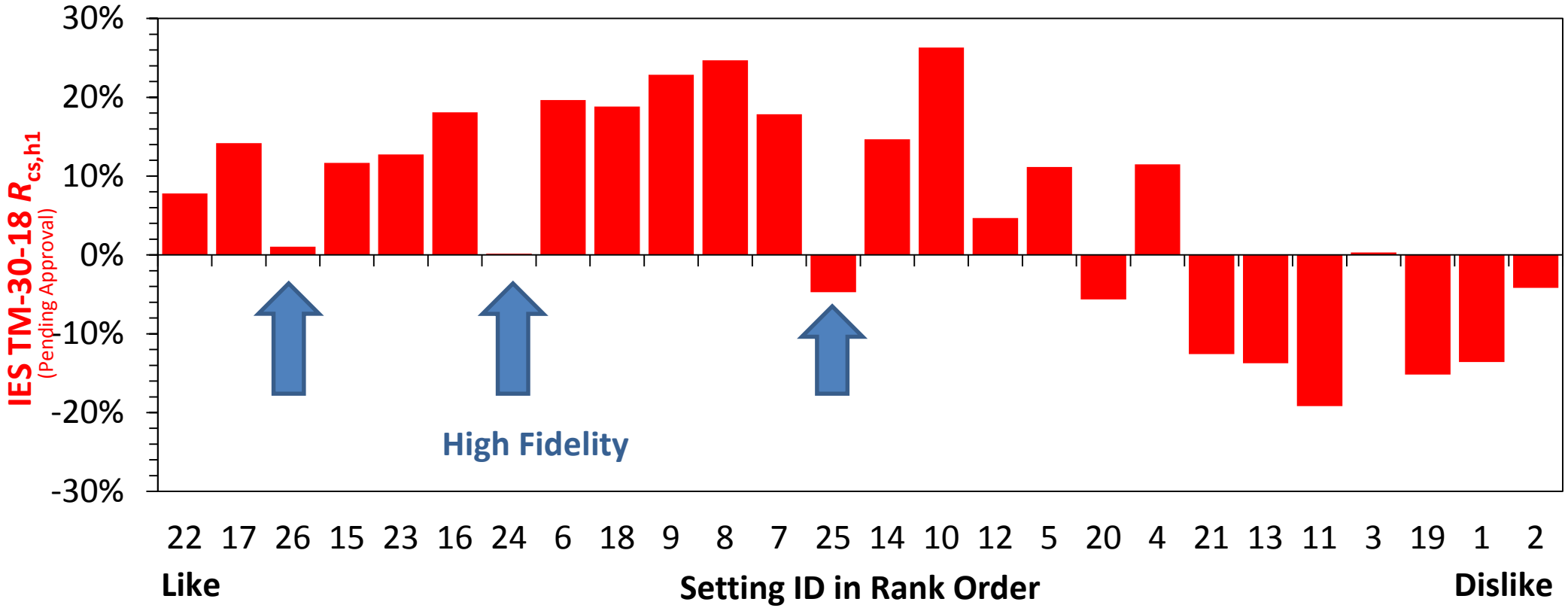
https://energy.gov/eere/ssl/color-rendition





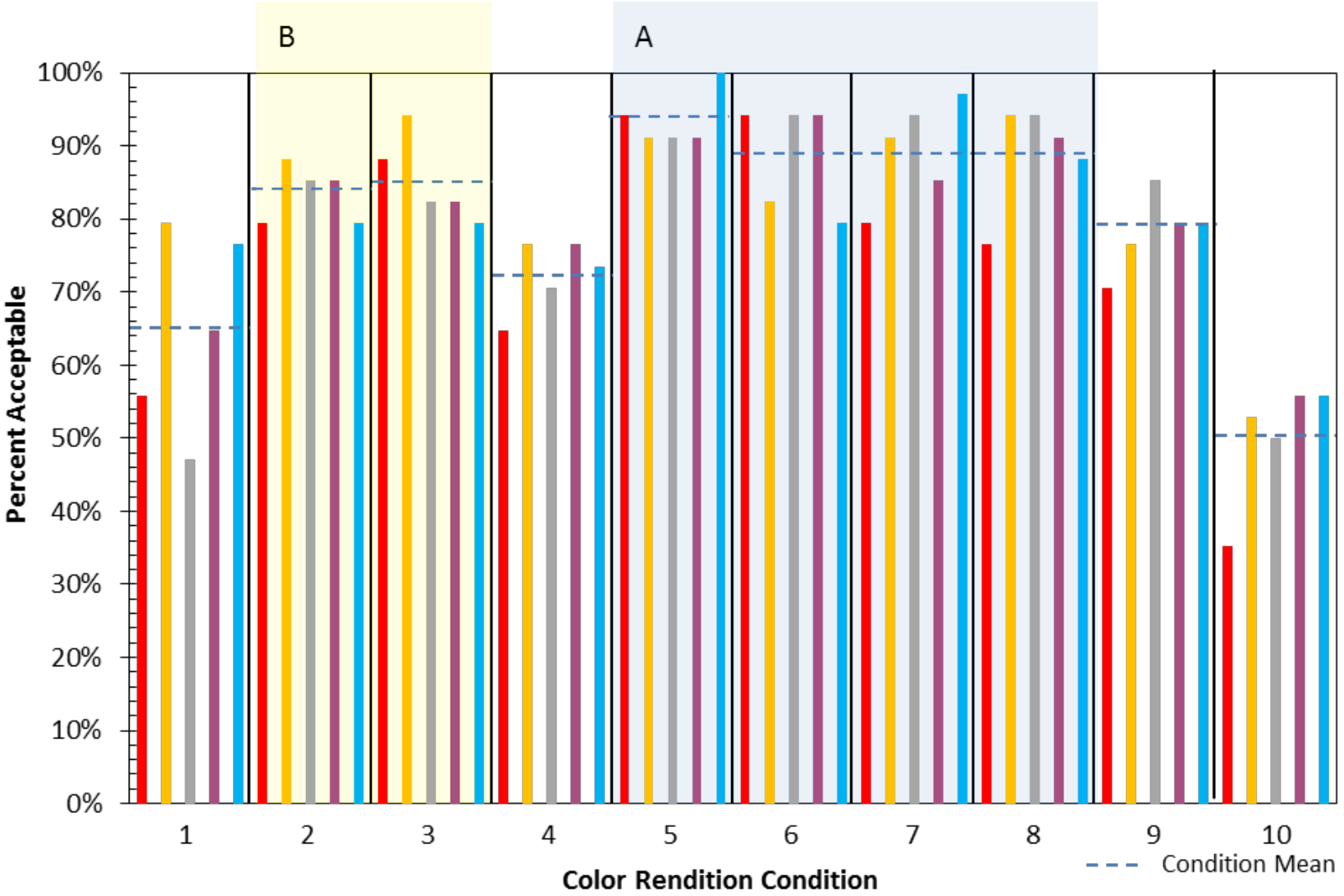
Commercially Available
Experimental
Theoretical

https://energy.gov/eere/ssl/color-rendition



https://energy.gov/eere/ssl/color-rendition

LEDucation



Chromaticity:

Group A	Group B	Group C	Group D	Group E
2700 K 0.000 D_{uv}	2700 K -0.007 D_{uv}	3500 K 0.000 D_{uv}	4300 K 0.000 D_{uv}	4300 K -0.007 D_{uv}

Composite (Condition Mean) Specification Criteria:

A: (> 89% acceptable)
- IES $R_f \geq 78$
- IES $R_g \geq 100$
- $-1\% \leq$ IES $R_{cs,h1} \leq 15\%$

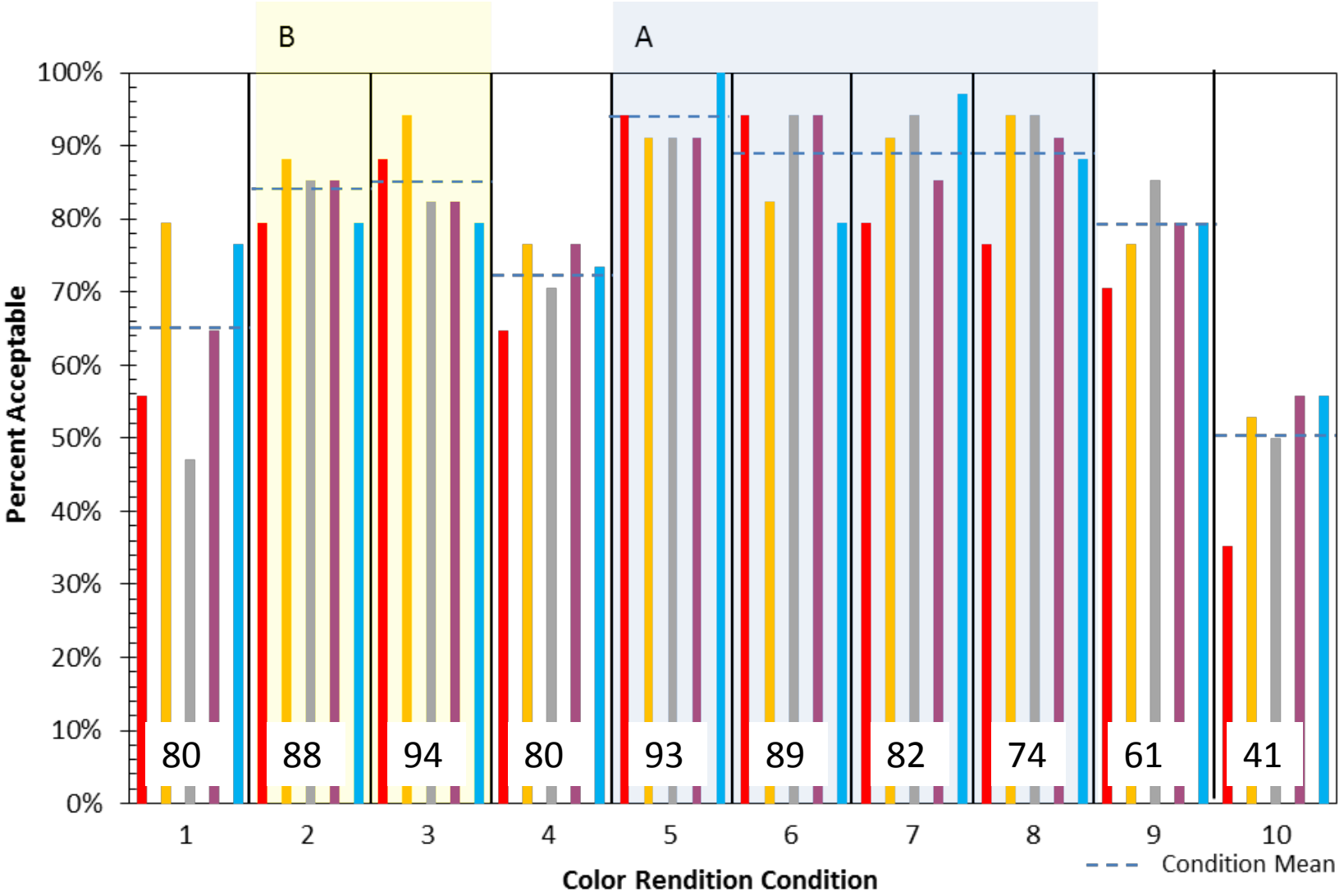
B: (> 84% acceptable)
- IES $R_f \geq 78$
- IES $R_g \geq 98$
- $-7\% \leq$ IES $R_{cs,h1} \leq 15\%$

http://journals.sagepub.com/doi/abs/10.1177/1477153517725974

https://energy.gov/eere/ssl/color-rendition

leducation.org

LEDucation



Composite (Condition Mean) Specification Criteria:

A: (> 89% acceptable)
IES $R_f \geq 78$
IES $R_g \geq 100$
$-1\% \leq$ IES $R_{cs,h1} \leq 15\%$

B: (> 84% acceptable)
IES $R_f \geq 78$
IES $R_g \geq 98$
$-7\% \leq$ IES $R_{cs,h1} \leq 15\%$

[CRI]

Chromaticity:

Group A	Group B	Group C	Group D	Group E
2700 K 0.000 D_{uv}	2700 K -0.007 D_{uv}	3500 K 0.000 D_{uv}	4300 K 0.000 D_{uv}	4300 K -0.007 D_{uv}

http://journals.sagepub.com/doi/abs/10.1177/1477153517725974

https://energy.gov/eere/ssl/color-rendition

leducation.org

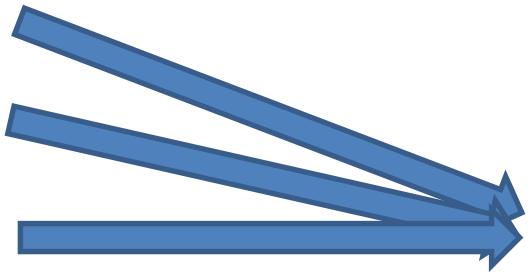
LEDucation

Subjective Qualities

Natural

Vivid/Vibrant

Preferred



Objective Values

Average Color Fidelity, R_f

Gamut Area, R_g

Color Vector Graphic/Gamut Shape

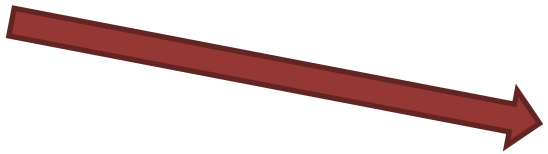
16 x Local Chroma Shift

16 x Local Hue Shift

16 x Local Color Fidelity

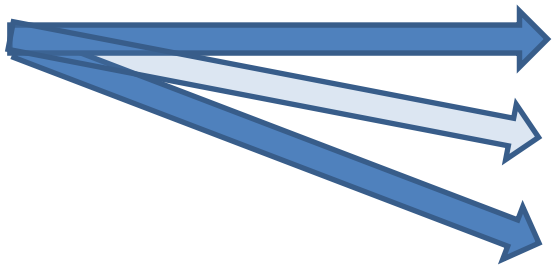
LEDucation

Subjective Qualities	Objective Values
Natural	Average Color Fidelity, R_f
Vivid/Vibrant	Gamut Area, R_g
Preferred	16 x Local Chroma Shift **Red, $R_{cs,h1}$**
	16 x Local Hue Shift
	16 x Local Color Fidelity



LEDucation

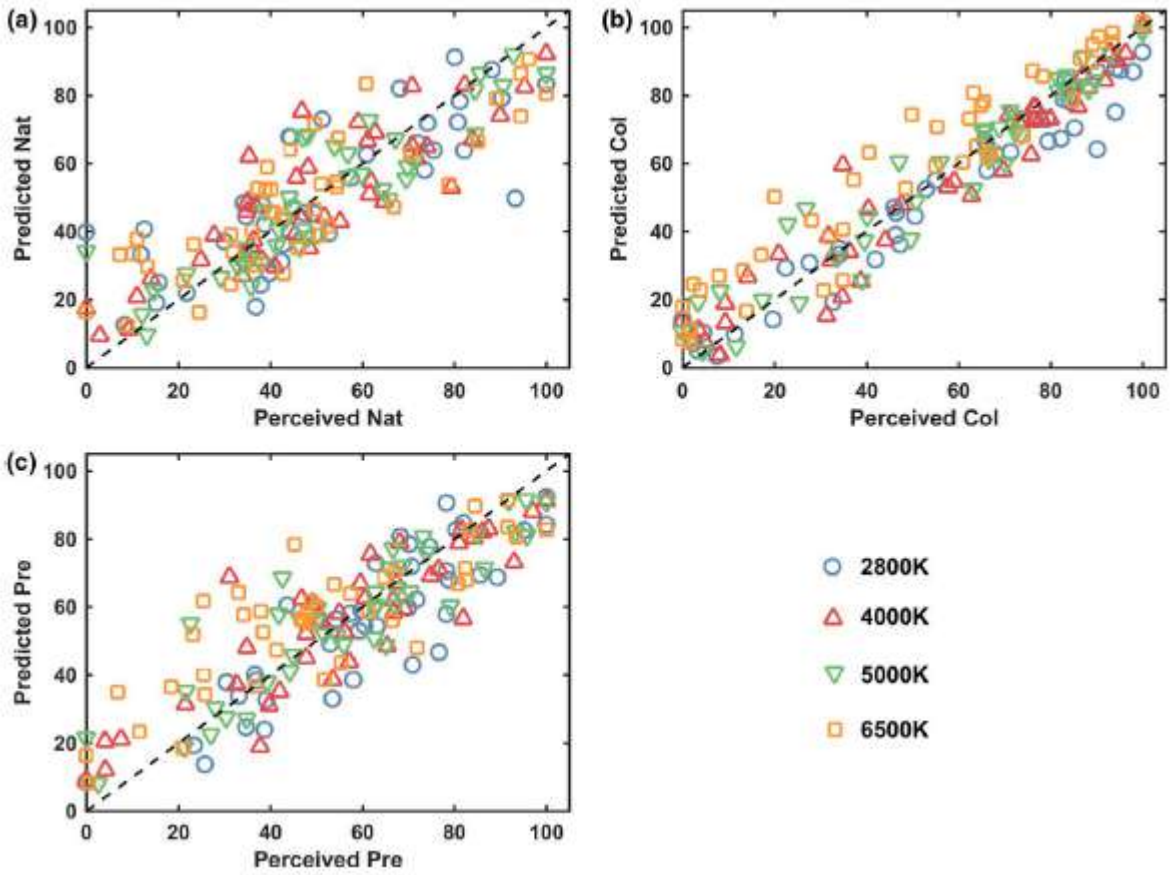
Subjective Qualities	Objective Values
Natural	Average Color Fidelity, R_f
Vivid/Vibrant	Gamut Area, R_g
Preferred	16 x Local Chroma Shift **Red, $R_{cs,h1}$**
	16 x Local Hue Shift
	16 x Local Color Fidelity



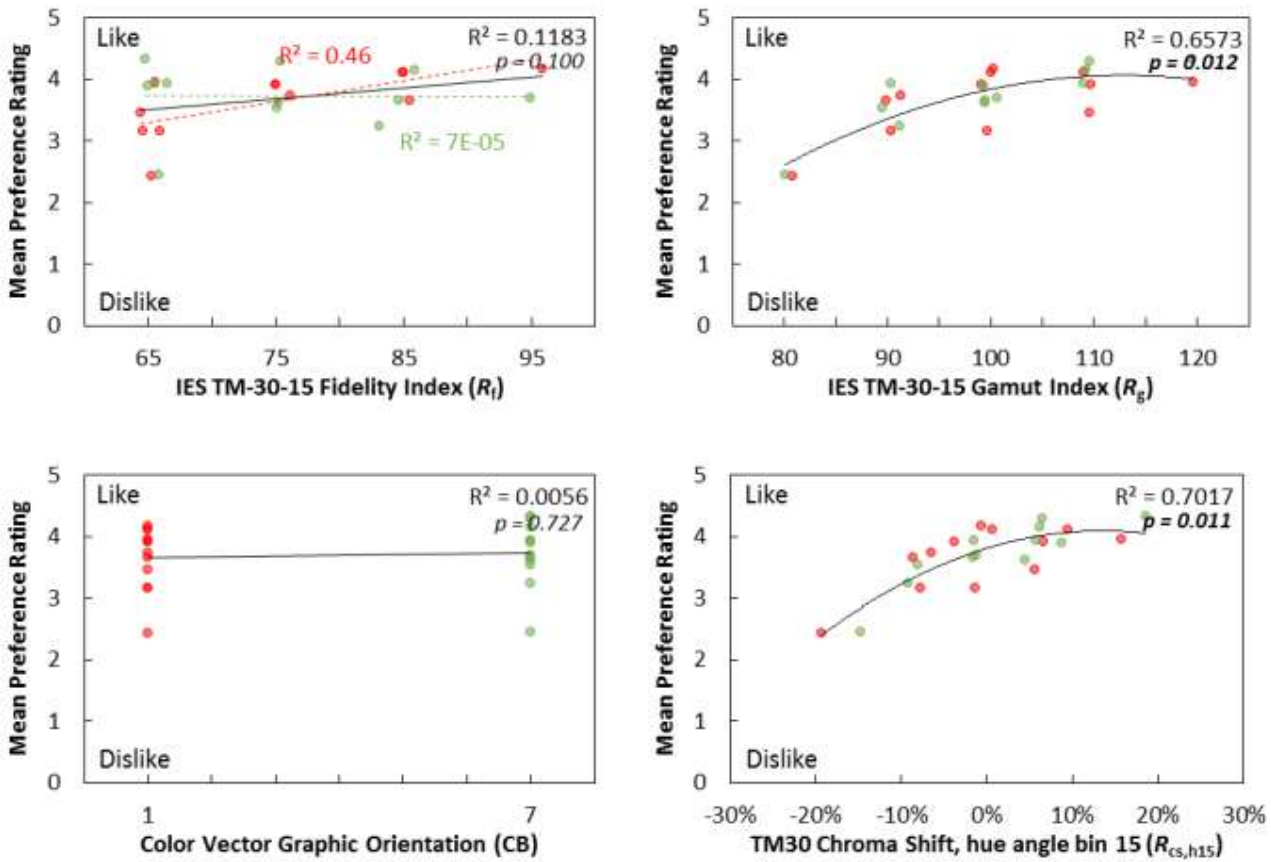
LEDucation

Subjective Qualities		Objective Values
Natural	→	Average Color Fidelity, R_f
Vivid/Vibrant	→	Gamut Area, R_g
Preferred	→	16 x Local Chroma Shift **Red, $R_{cs,h1}$**
		16 x Local Hue Shift
		16 x Local Color Fidelity

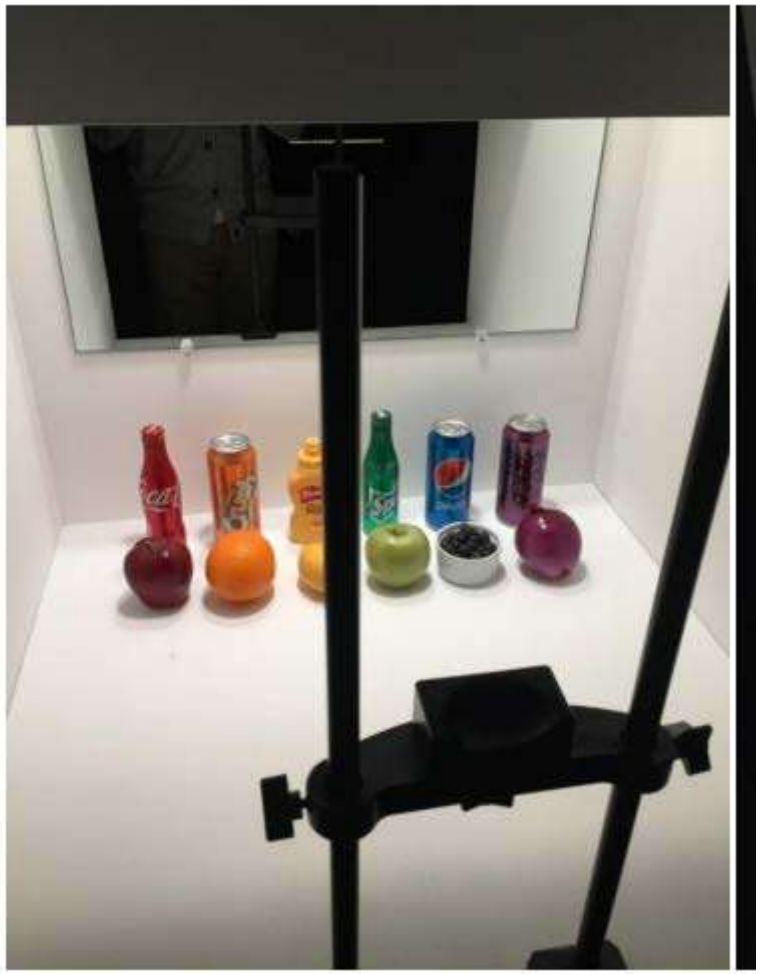
$$Q_{i,0} = C_0 + C_f R_f + C_g R_g + C_s R_{cs,h1} + C_{gs} R_g R_{cs,h1},$$



Zhang F, Xu H and Feng H. Toward a unified model for predicting color quality of light sources. *Applied Optics*. 2017; 56: 8186-95.



$$LIKE = 1.629 + 0.02686\ R_f + 3.423\ R_{cs,h16} - 10.01\ R_{cs,h16}^2 - 0.04866\ \psi + 0.000566\ R_f{*}\psi$$

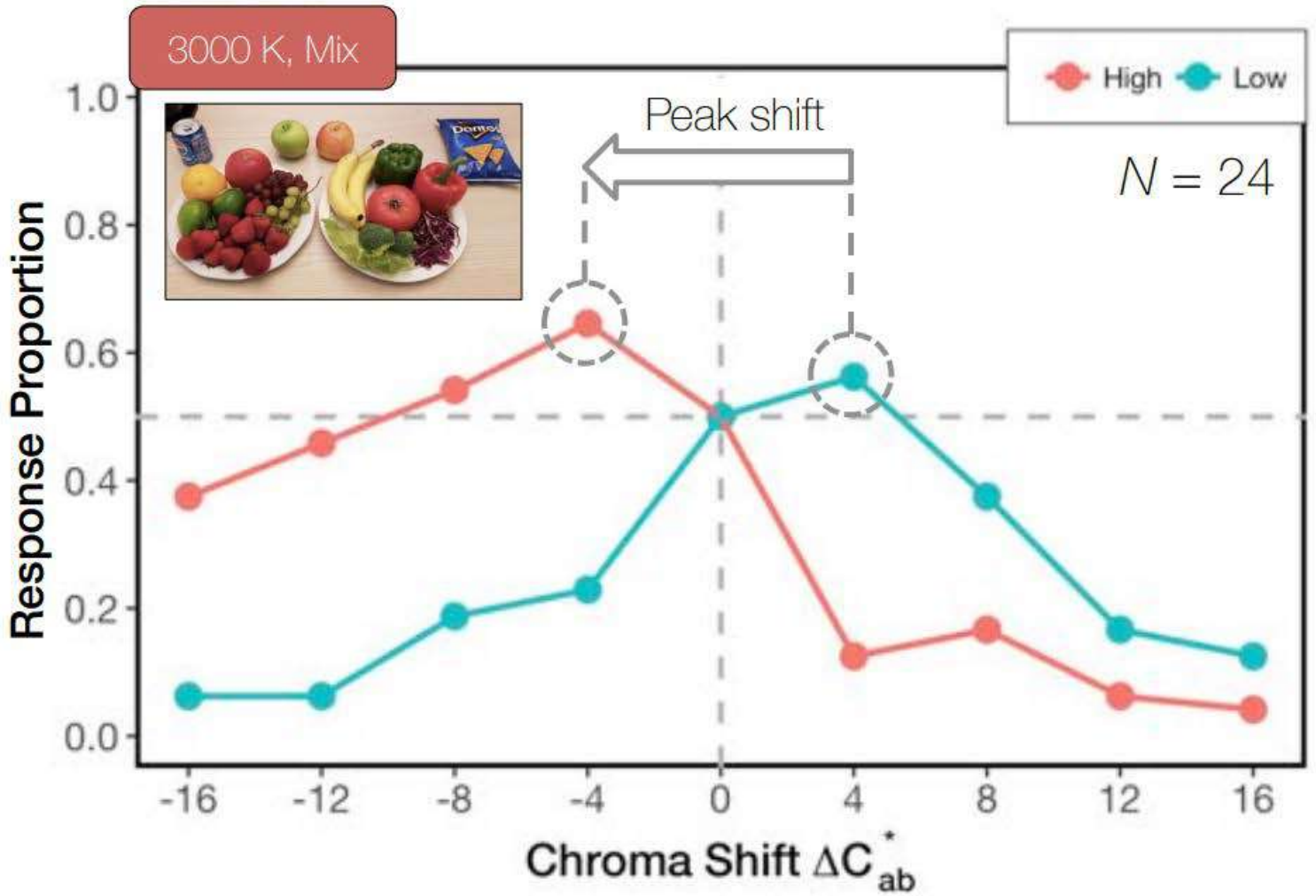


Esposito T. Modeling color rendition and color discrimination with average fidelity, average gamut, and gamut shape. [Doctoral Dissertation] Architectural Engineering. University Park, PA: Penn State University, 2016.

LEDucation

Understand the limitations of the tool:

1. Global average values (R_f, R_g) are simple, but have big limitations
   - When used alone (or as a pair) they are not closely related to any subjective aspect of color quality.
2. IES TM-30 is not an RP, so it doesn't tell you what to do with or how to use the info
3. **IES TM-30, like all measures of color rendition, does not consider:**
   - **Intensity (illuminance)**
   - **Preferred/Neutral Chromaticity**
   - **Whiteness (OBAs, OWAs, FBAs, etc.)**
   - **Scene composition**
   - **Other contextual factors**



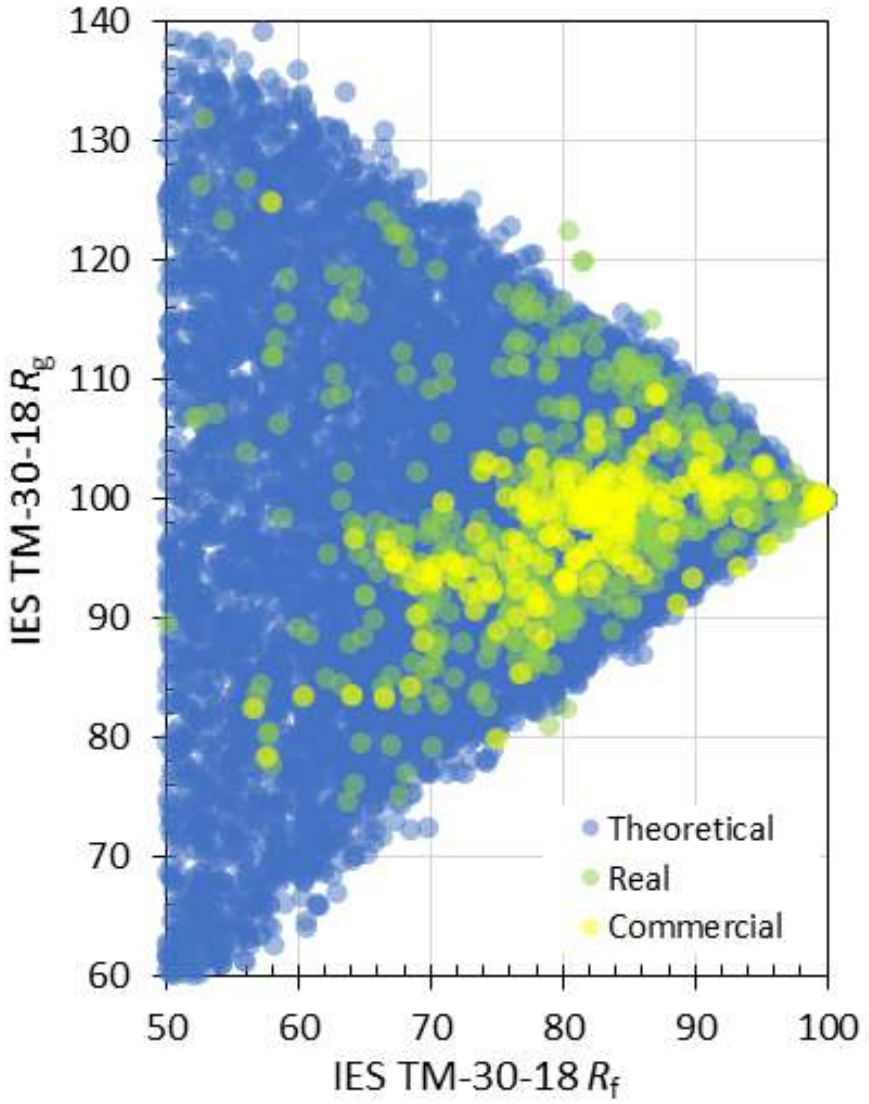
https://cms.cnc-cie.ca/images/documents/CIEjoint2017/Kawashima__CNC_CIE_USNC_2017.pdf

LEDucation

Ok, so here in the real world…

Expected Values: R_f and R_g

(Wait, you said we were going to talk about the real world…)



Theoretical

(a computer came up with these)

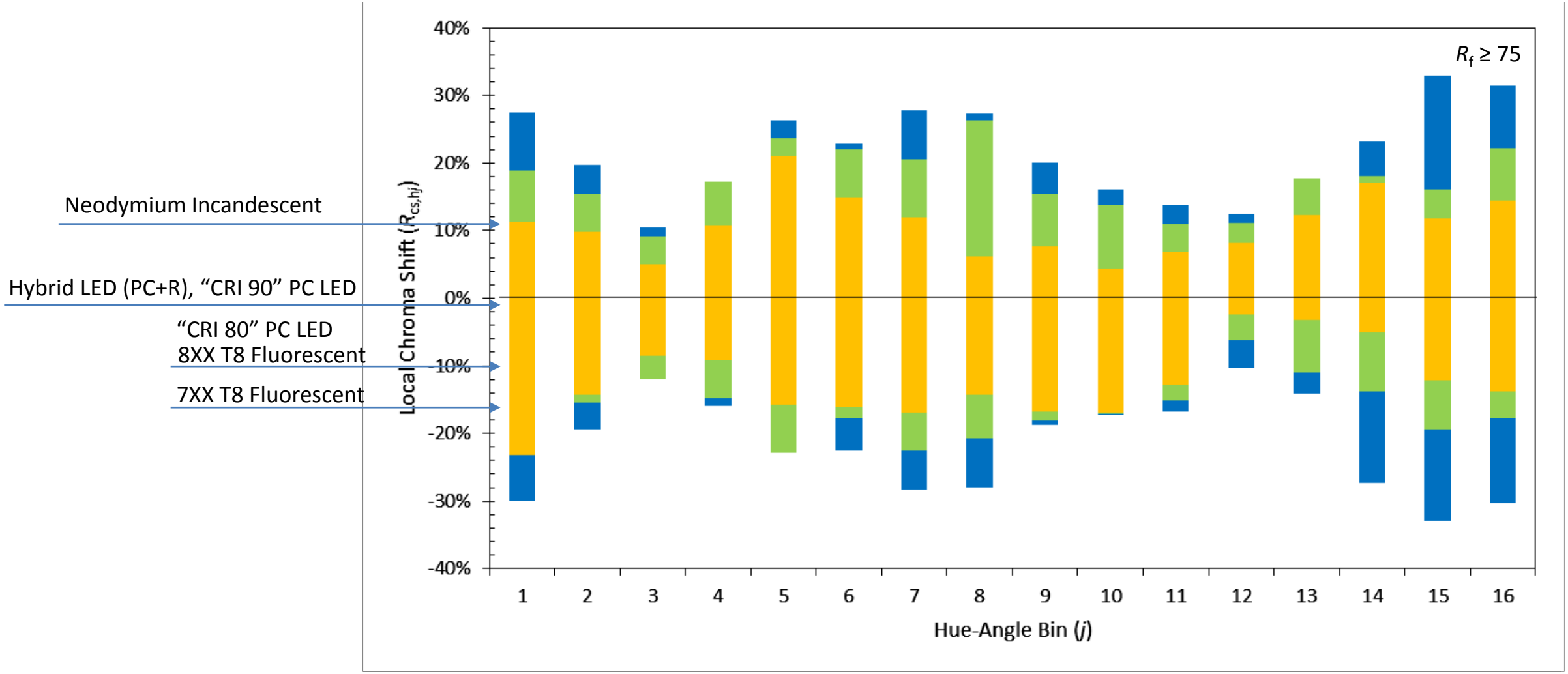
Real (Experimental)

(technically possible today, but not available commercially)

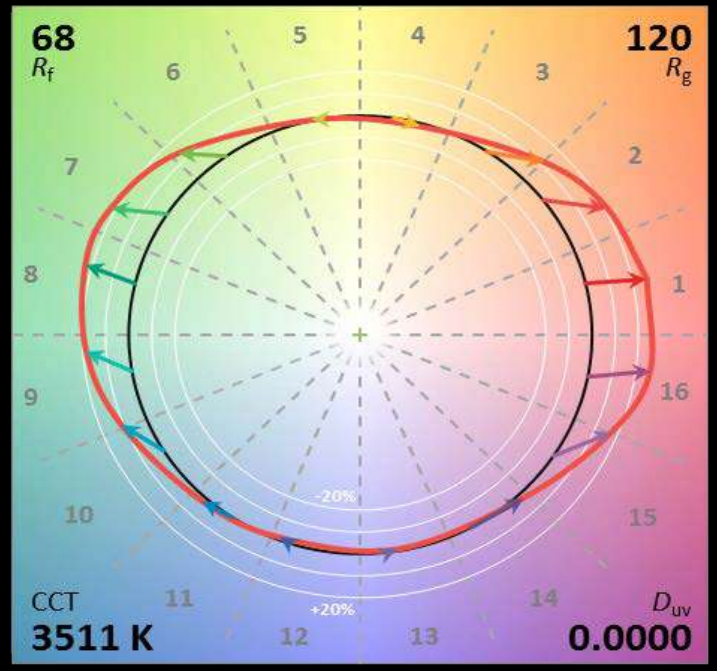
Commercial

(what's on the market today)

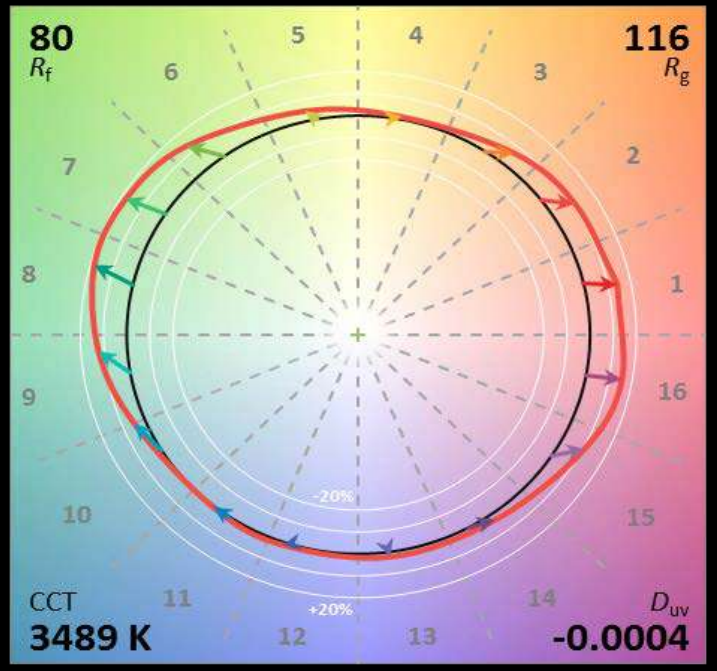
Expected Values: Local Chroma Shift



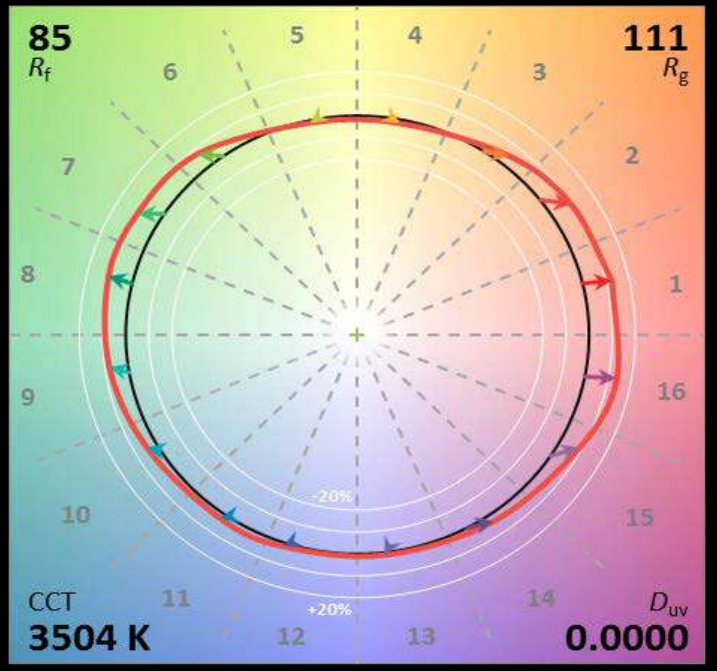
Demo Time
Is that local chroma shift good or bad?



10



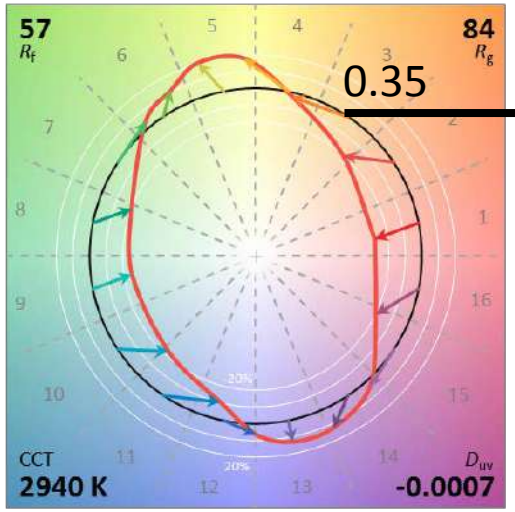
17



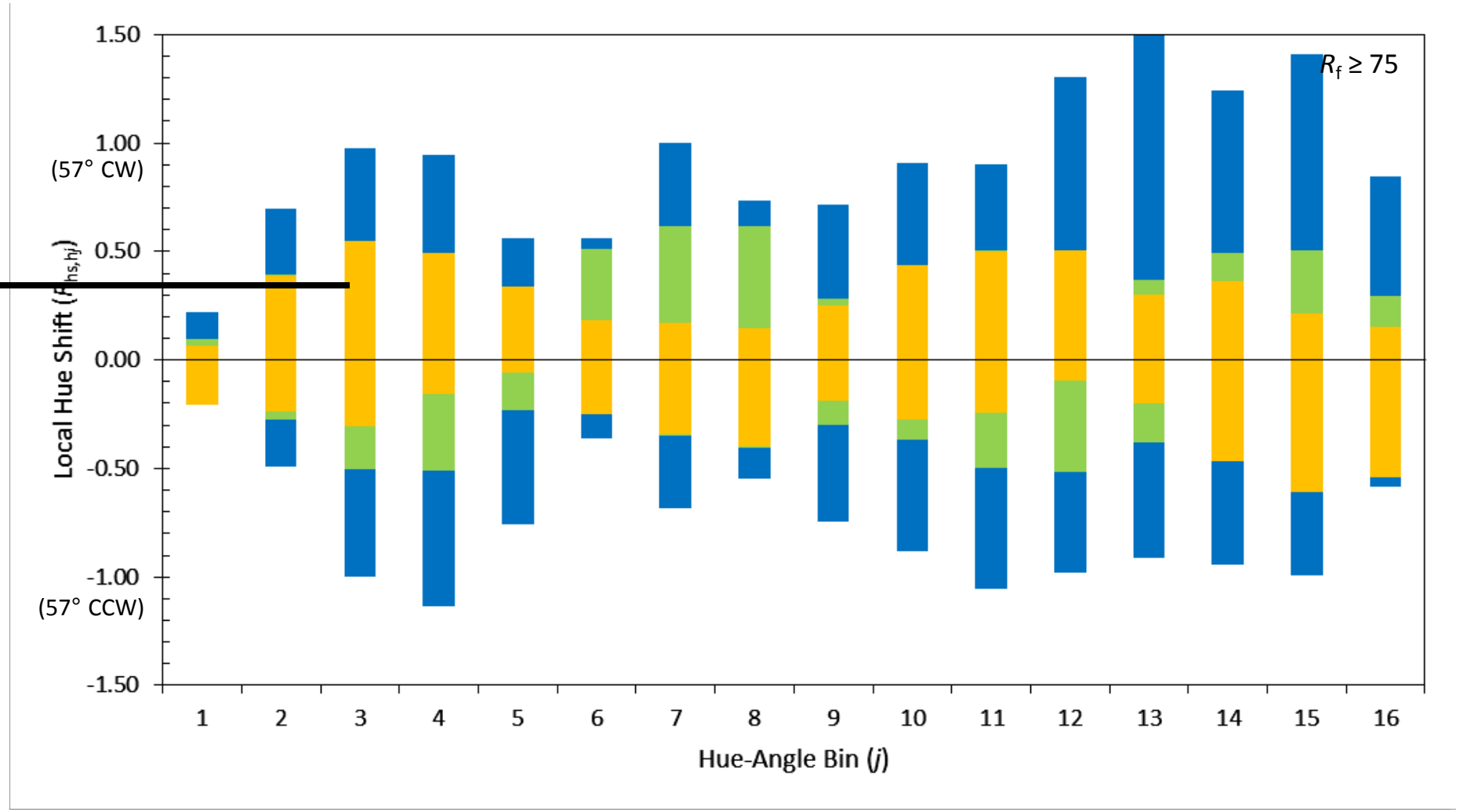
23

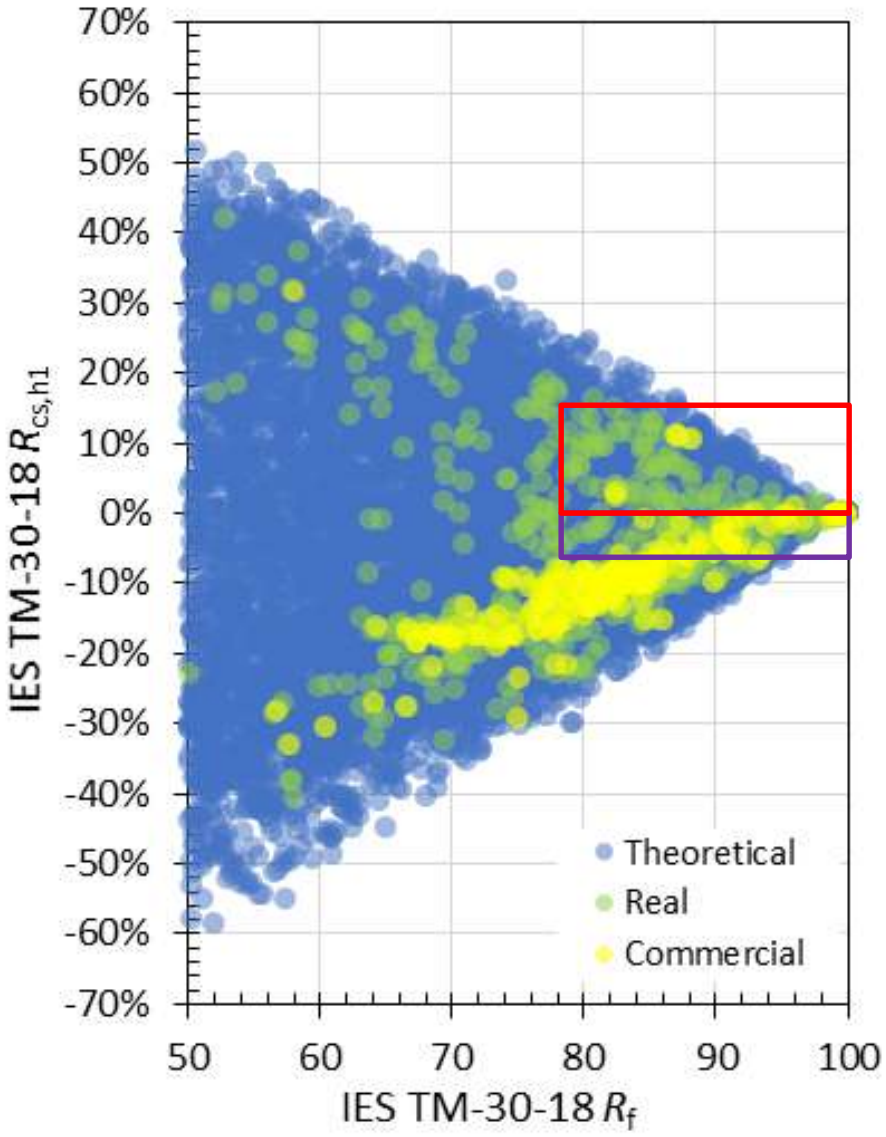
Note graphics shown are DRAFT IES TM-30-18, pending approval.

Expected Values: Local Hue Shift



IES TM-30-18 is pending approval.



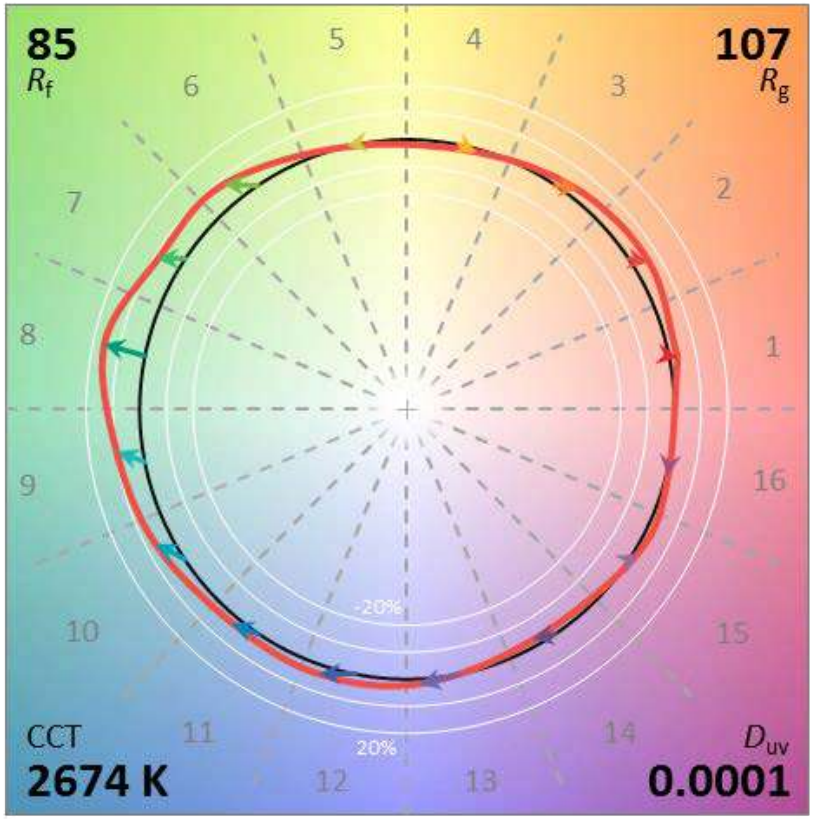


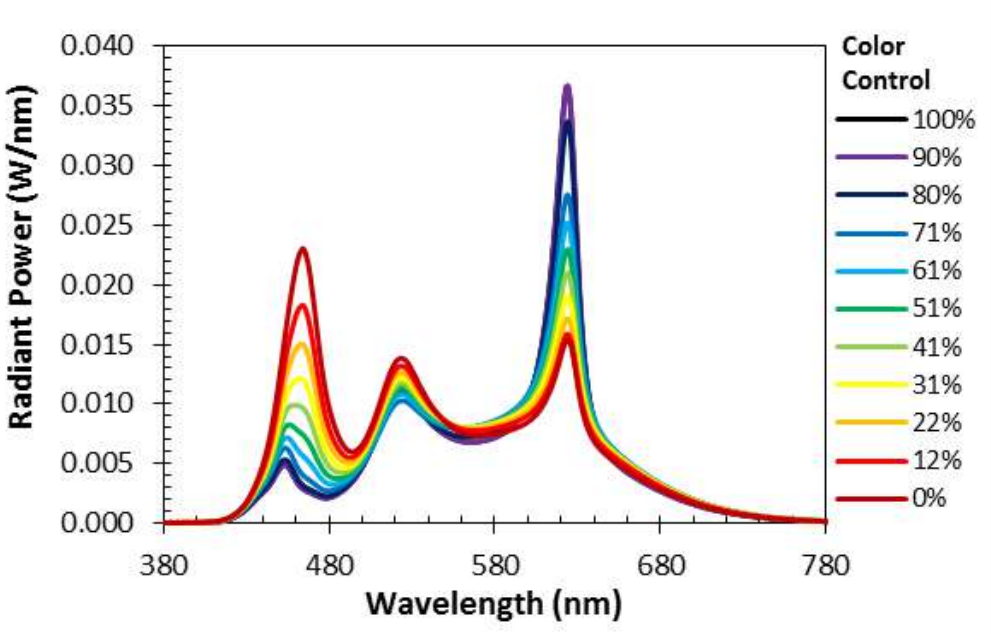
IES TM-30-18 is pending approval.

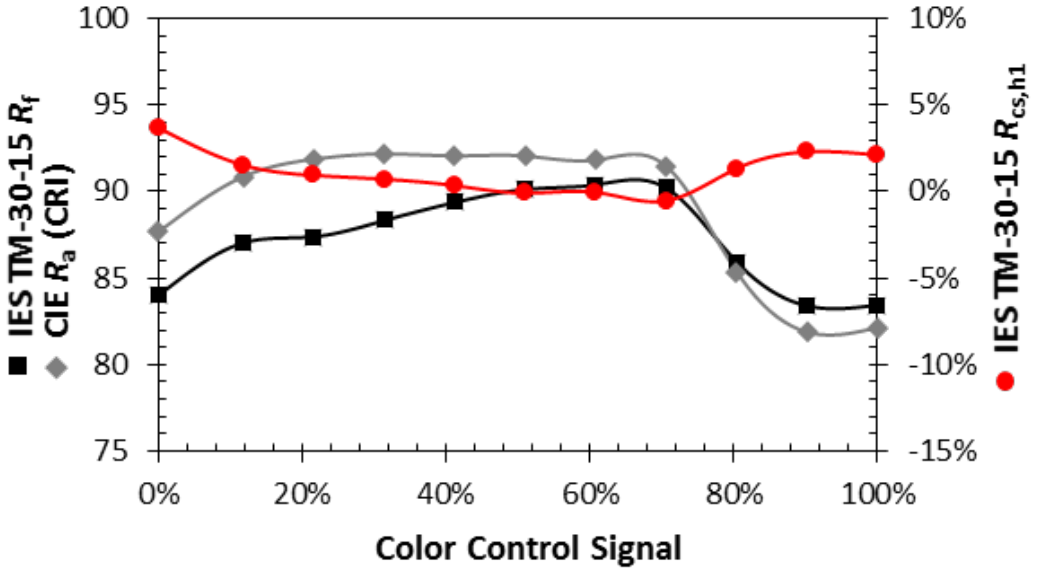
Commercially-available products in TM-30-15 library:

A. High Fidelity (R_f 90+) PC LED
   Some Hybrid (PC+R) LED
   Neodymium Incandescent
   Incandescent/halogen
   Some Specialty HID
B. Additional PC-LED (R_f 85+)
   Additional Hybrid LED (PC+R)

New products beginning to emerge…

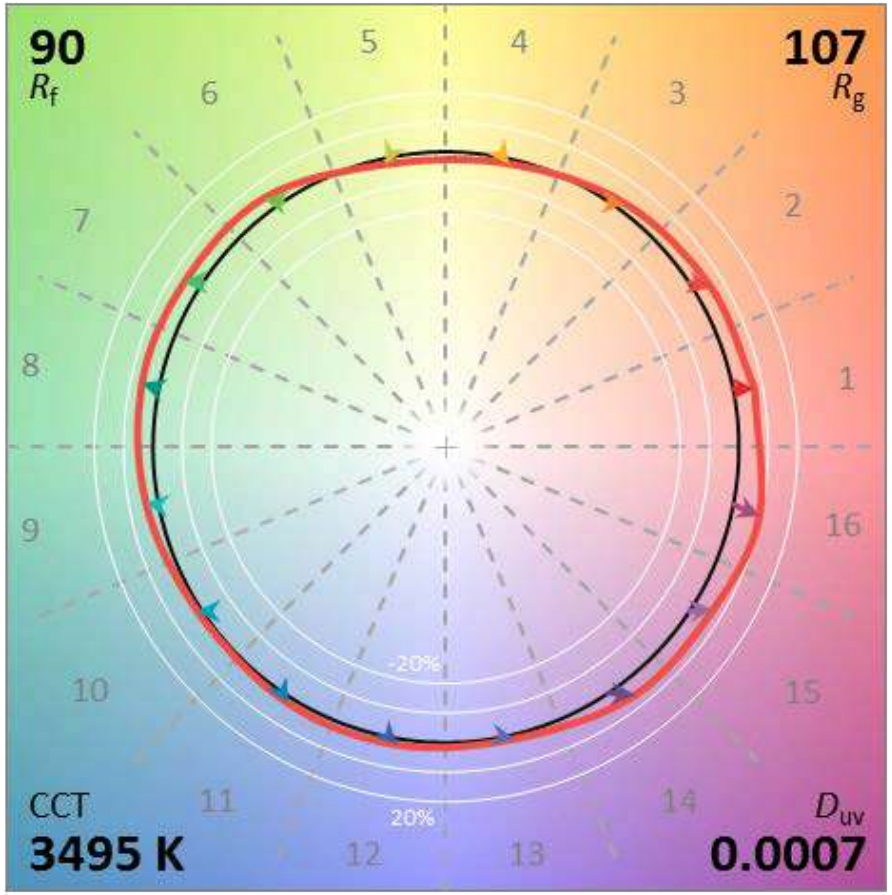






IES TM-30-18 is pending approval.

New products beginning to emerge…designed with the help of TM-30-15 (TM-30-18 data shown is Pending Approval)

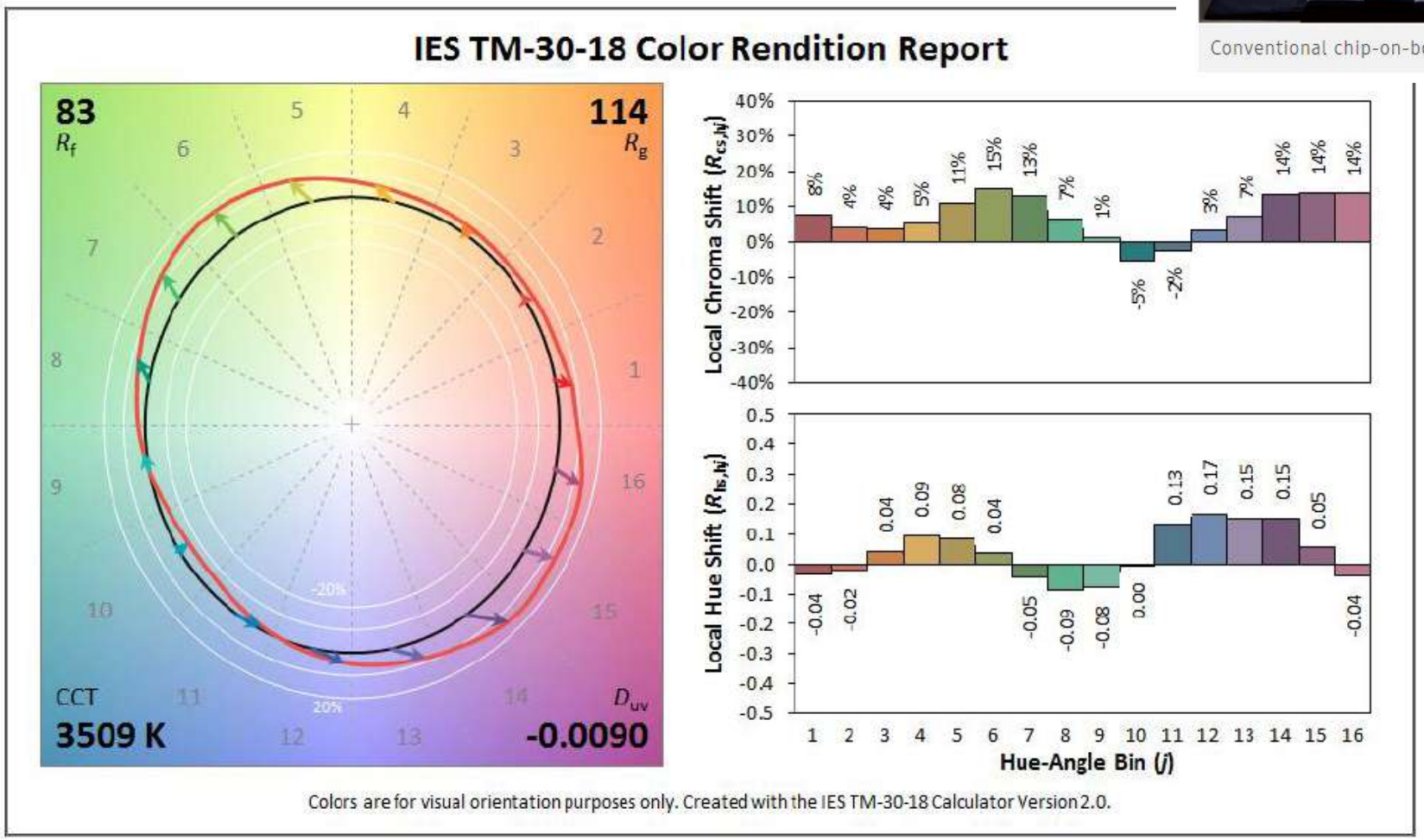


http://www.focalpointlights.com/PreferredLight

LEDucation

New products beginning to emerge…designed with the help of TM-30-15 (TM-30-18 data shown is Pending Approval)

Conventional chip-on-board LED lighting (left) and "D-series Special Color".



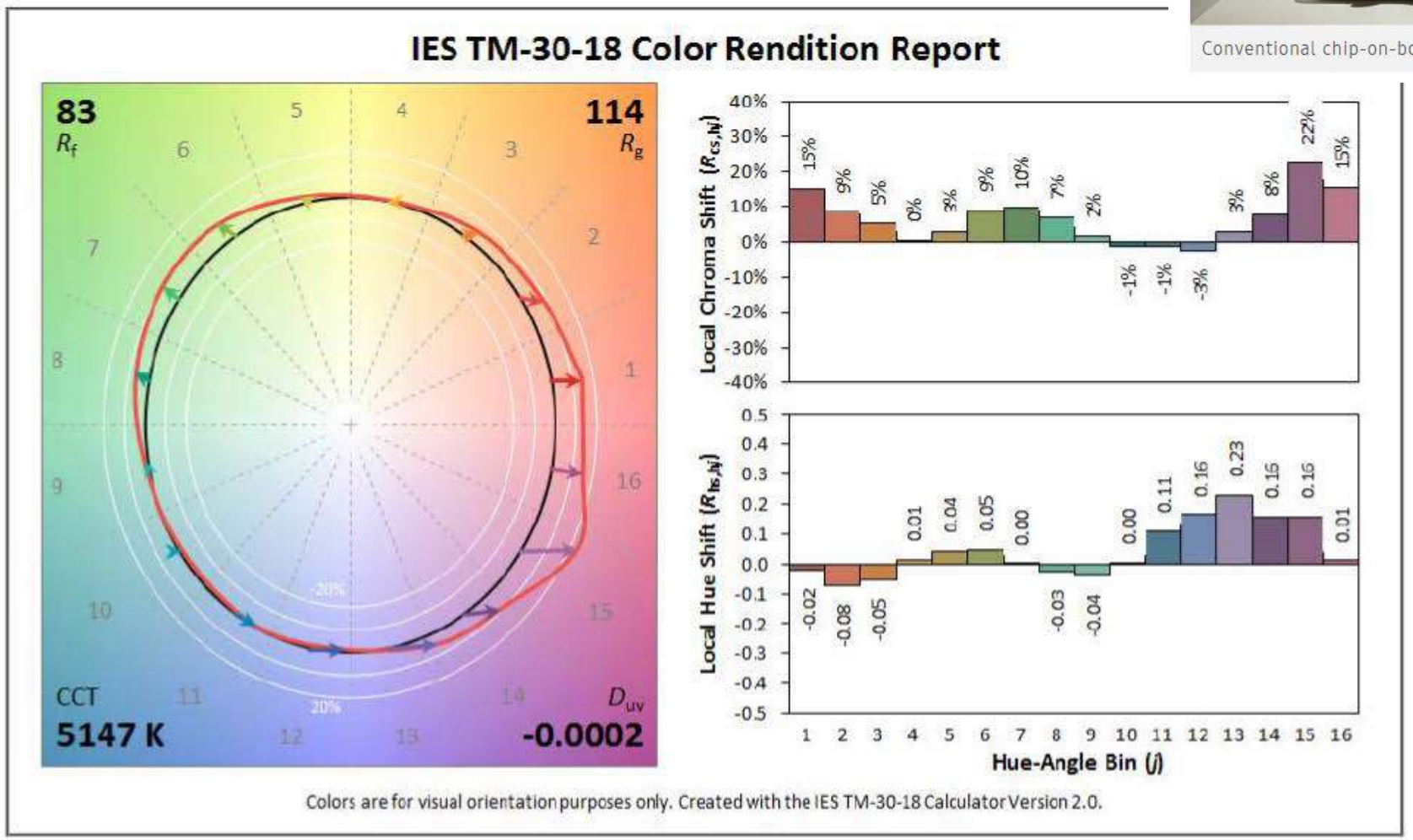
https://news.samsung.com/global/samsung-introduces-chip-on-board-led-packages-optimized-for-commercial-lighting

leducation.org

LEDucation

New products beginning to emerge…designed with the help of TM-30-15 (TM-30-18 data shown is Pending Approval)

Conventional chip-on-board LED lighting (left) and "D-series Special Color".



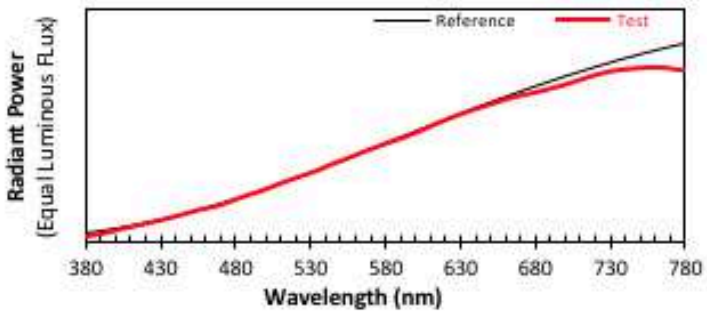
https://news.samsung.com/global/samsung-introduces-chip-on-board-led-packages-optimized-for-commercial-lighting

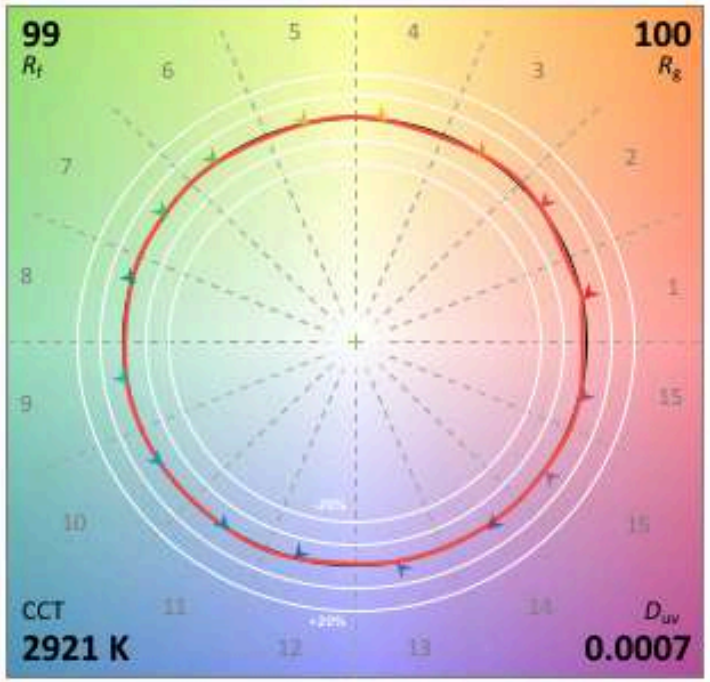
leducation.org

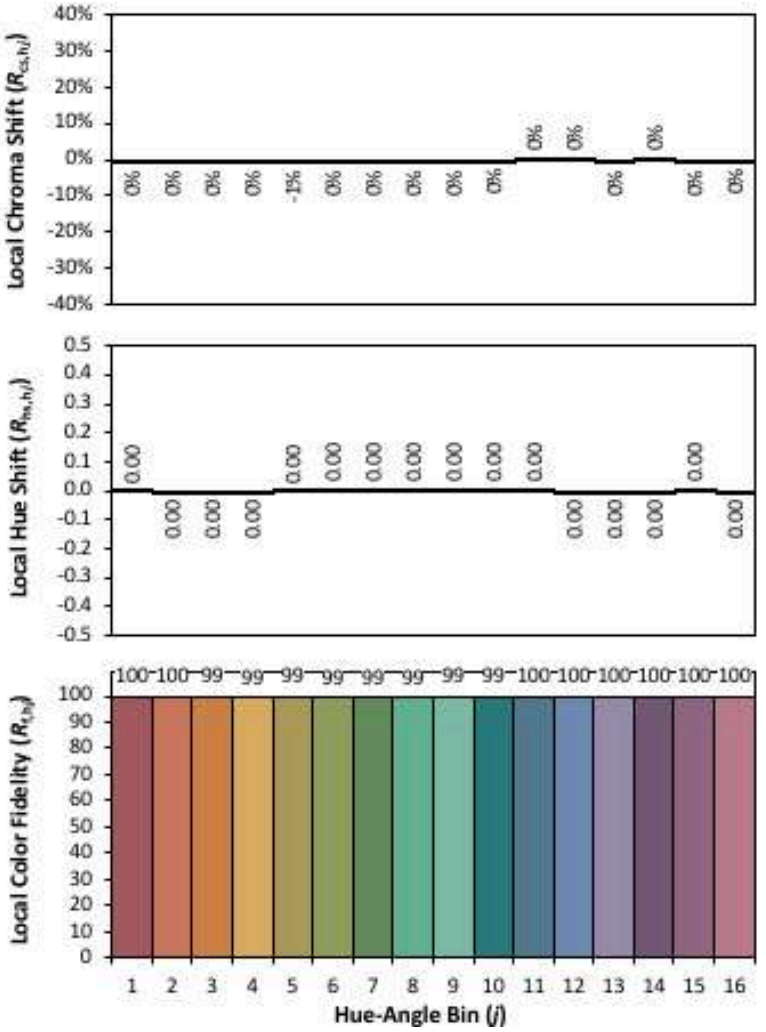
LEDucation

Your Context May Vary

Until now *Color Rendering* has meant *Color Fidelity*







IES TM-30-18 is pending approval.

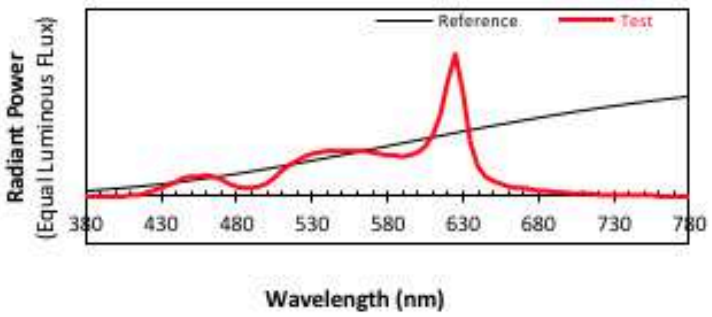
Until now *Color Rendering* has meant *Color Fidelity.*

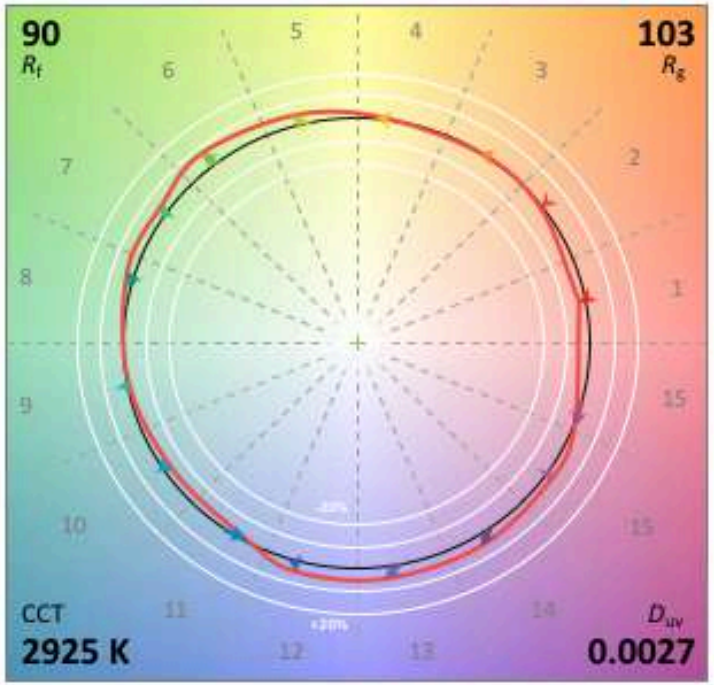
With the information provided by TM-30 *Color Rendering* means we are considering the interplay of:

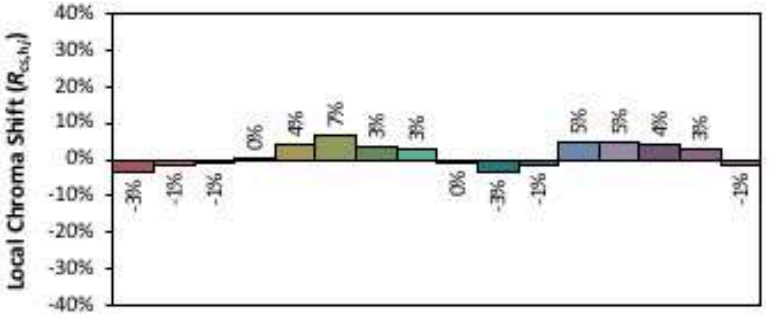
- Color Fidelity
- Chroma Shift
- Hue Shift
- Perceptual Implications of the above

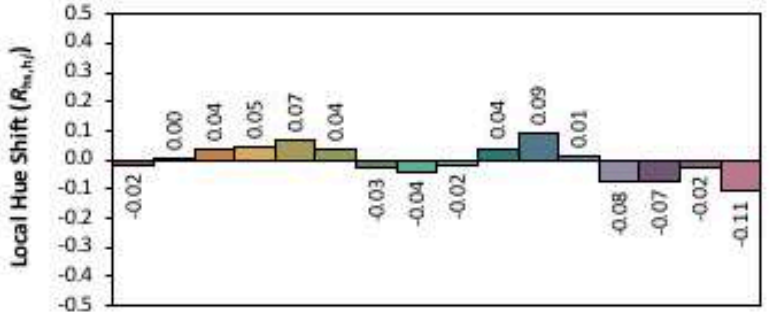
In many applications *Color Fidelity* may not be as important as *Chroma Shift* and/or *Hue Shift*.

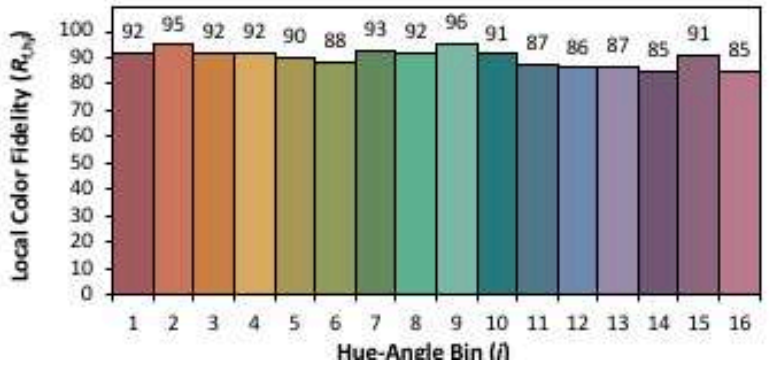
LEDucation







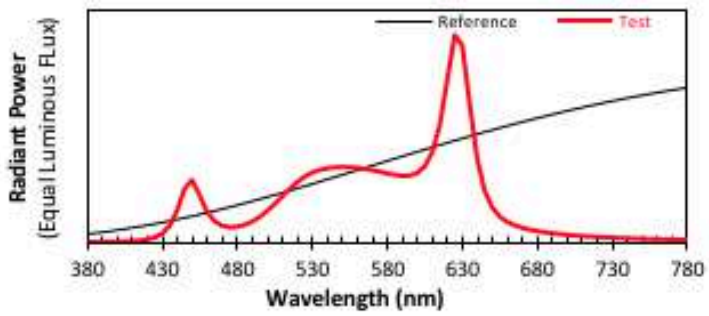


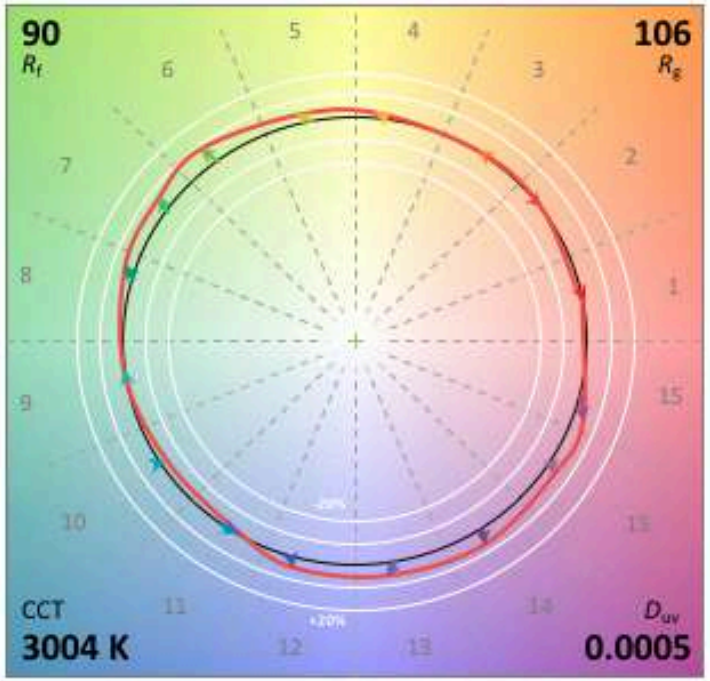


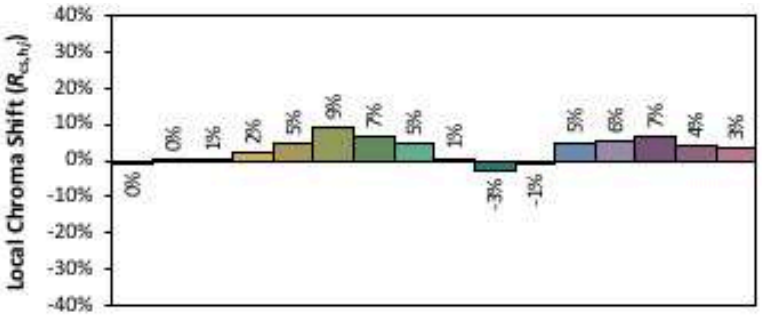
IES TM-30-18 is pending approval.

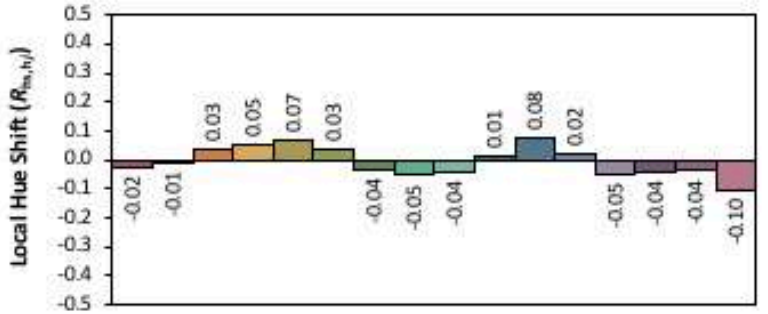
leducation.org

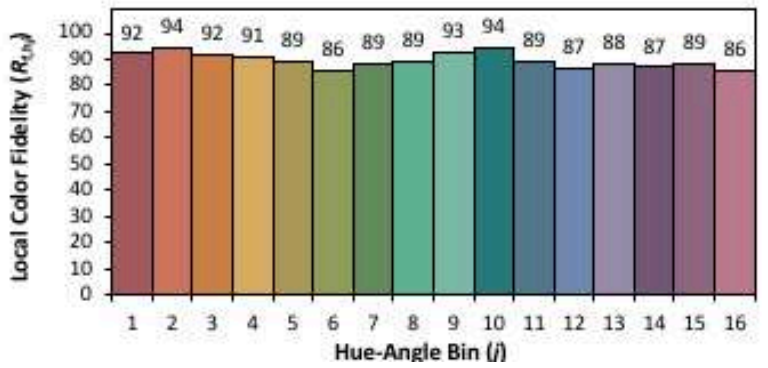
LEDucation







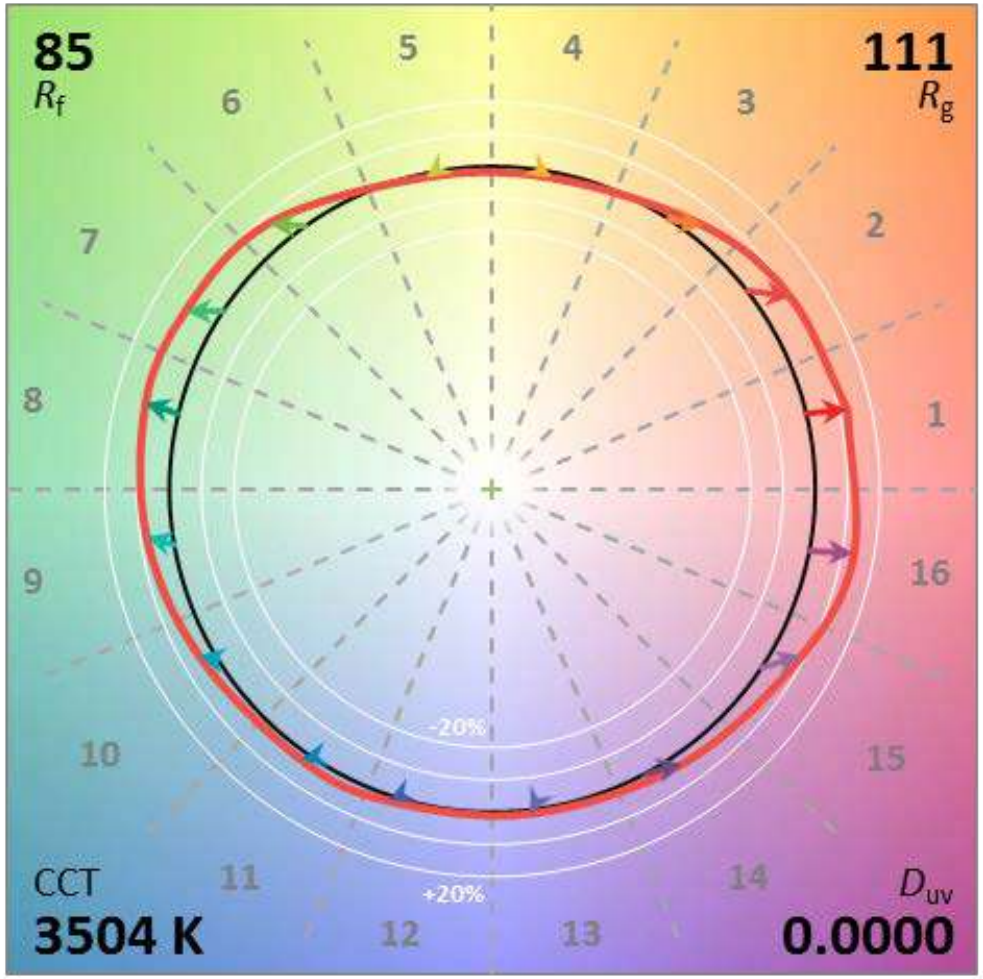




IES TM-30-18 is pending approval.

leducation.org

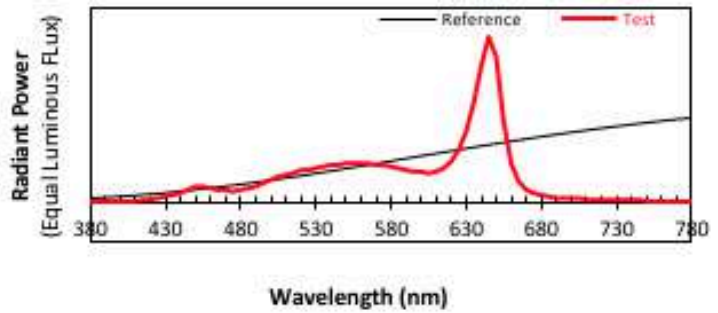
LEDucation

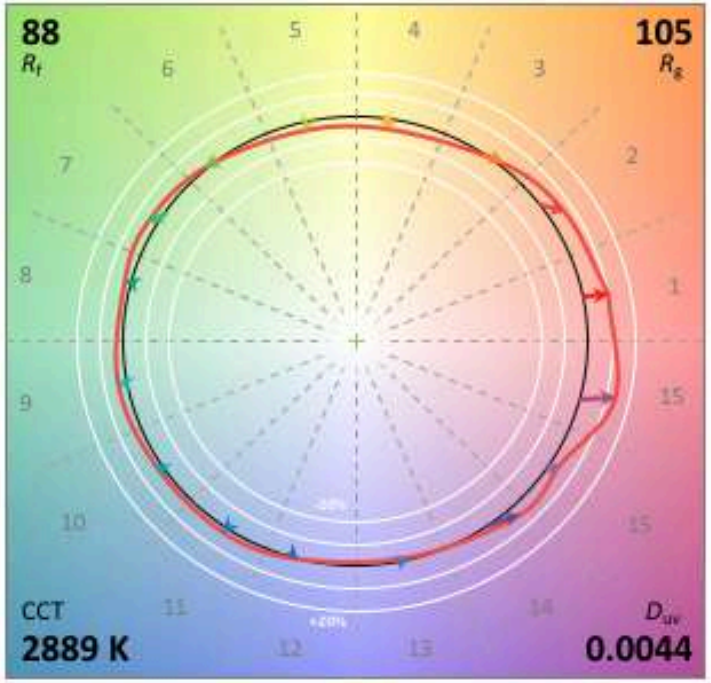


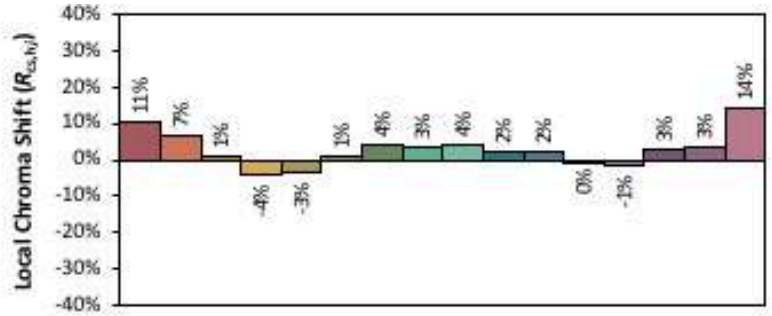
IES TM-30-18 is pending approval.

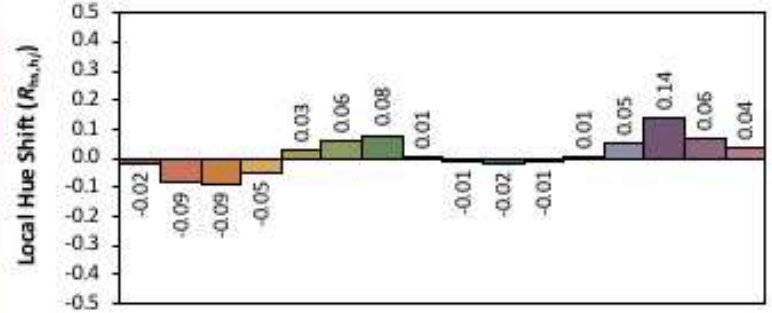
leducation.org

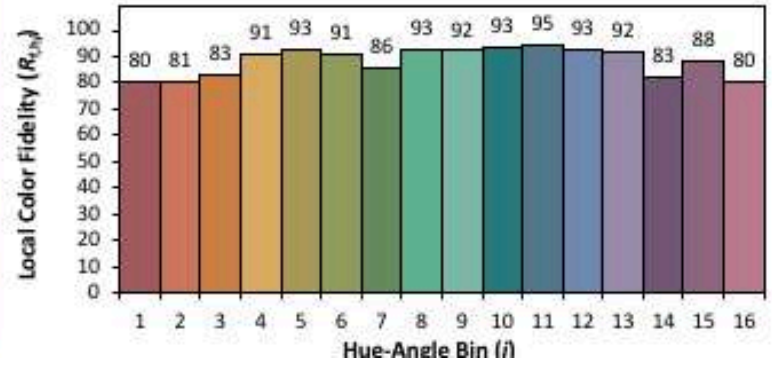
LEDucation







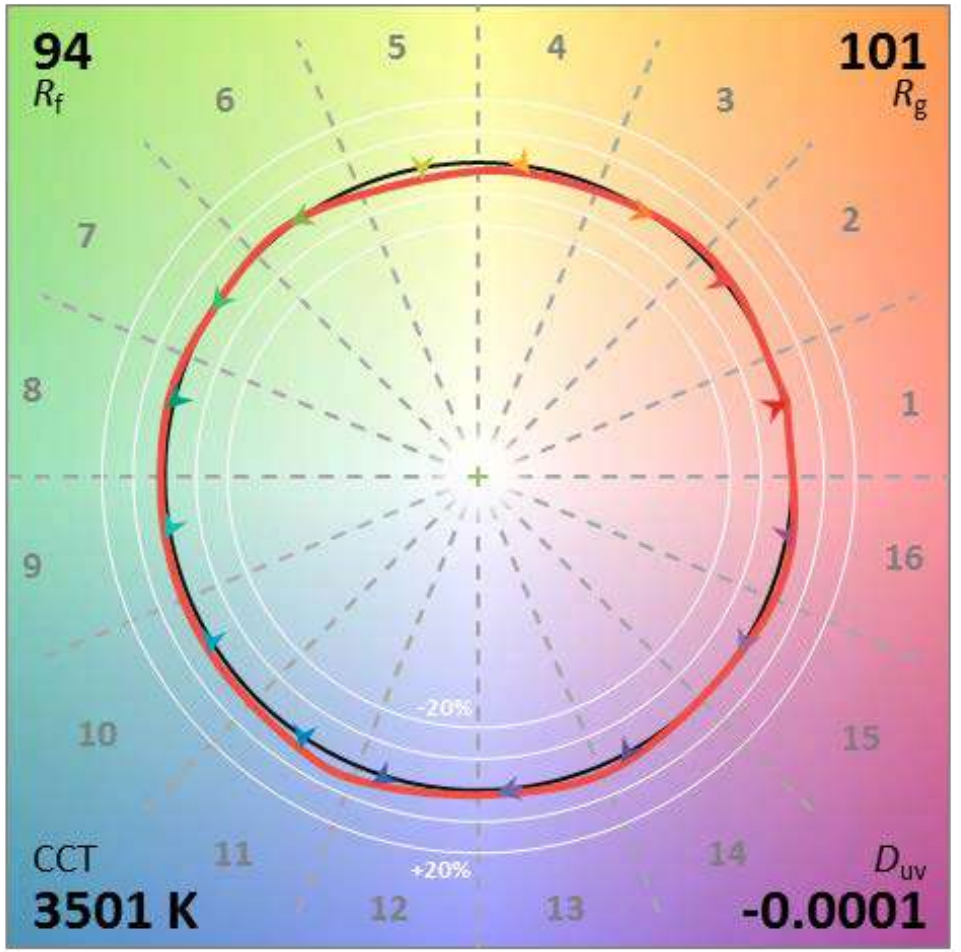




IES TM-30-18 is pending approval.

leducation.org

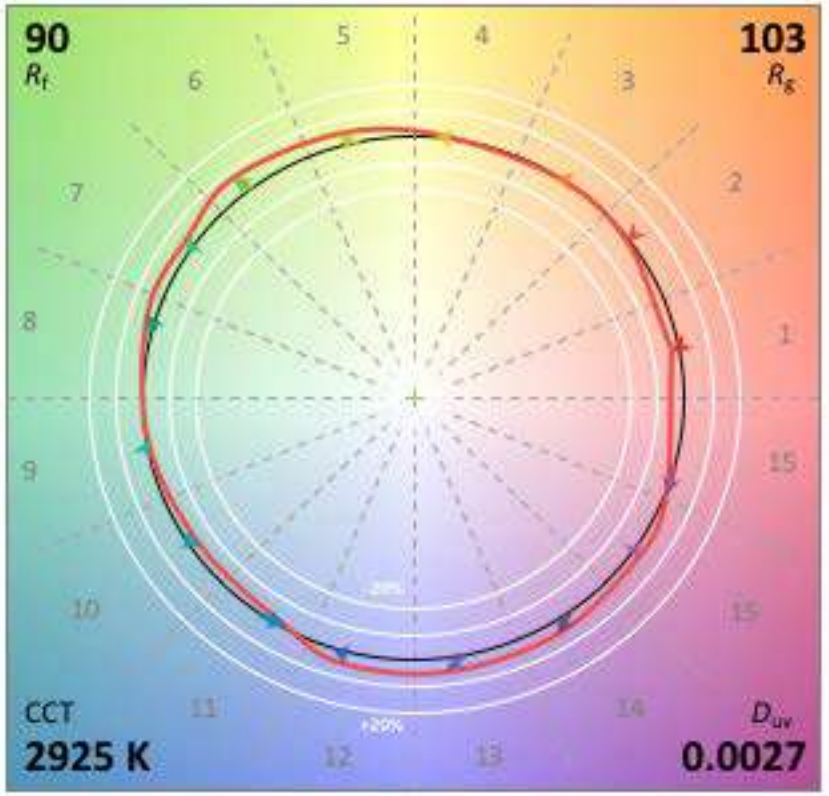
LEDucation



IES TM-30-18 is pending approval.

leducation.org

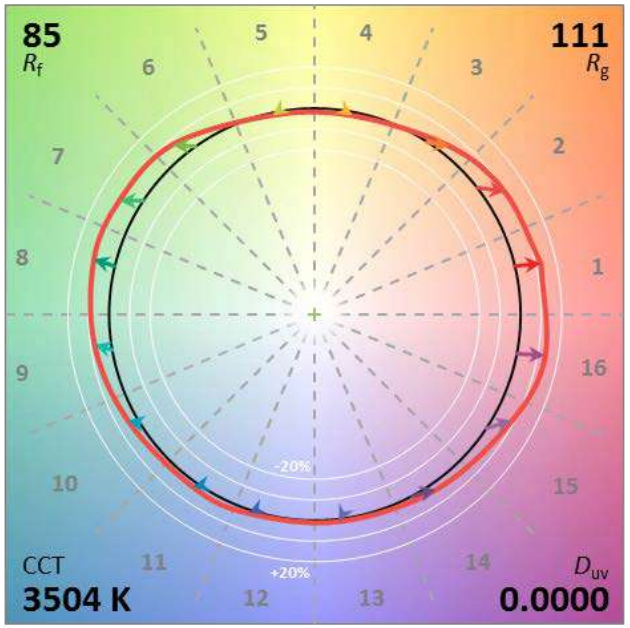
LEDucation

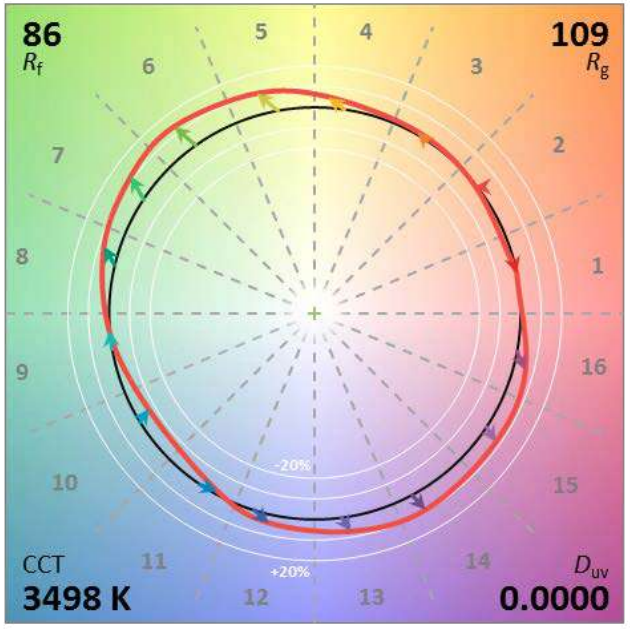


IES TM-30-18 is pending approval.

leducation.org

LEDucation





IES TM-30-18 is pending approval.

leducation.org

LEDucation

So what's a specifier to do?

- How do I get TM-30 info from manufacturers?
  - Right now you probably have to ask for it.
  - Ask for it every time from every manufacturer. Eventually they'll start to include it on their cut sheets (won't they?).

So what's a specifier to do?

- How do I write TM-30 into a spec?
  - Thresholds and ranges are still being researched. Here are a few guides.

LEDucation

https://energy.gov/eere/ssl/color-rendition

Composite (Condition Mean) Specification Criteria:

A: (> 89% acceptable)
- IES $R_f \geq 78$
- IES $R_g \geq 100$
- $-1\% \leq$ IES $R_{cs,h1} \leq 15\%$

B: (> 84% acceptable)
- IES $R_f \geq 78$
- IES $R_g \geq 98$
- $-7\% \leq$ IES $R_{cs,h1} \leq 15\%$

IES TM-30-18 is pending approval.

So what's a specifier to do?

A: (> 89% acceptable)
- IES $R_f \geq 78$
- IES $R_g \geq 100$
- $-1\% \leq$ IES $R_{cs,h1} \leq 15\%$

B: (> 84% acceptable)
- IES $R_f \geq 78$
- IES $R_g \geq 98$
- $-7\% \leq$ IES $R_{cs,h1} \leq 15\%$

US DOD Unified Facilities Criteria UFC 4-510-01 (November 2017)

IES TM-30-18 is pending approval.

IES R_f	≥ 80 (TM-30-18 = 82)
IES R_g	97 to 110
IES $R_{f,h1}$	≥ 78
IES $R_{cs,h1}$	-9% to 9%

LEDucation

Questions?

This concludes The American Institute of Architects Continuing Education Systems Course