Evaluating Color Rendering With TM-30
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

**Tools**

<table>
<thead>
<tr>
<th>CRI Calculation Engine</th>
<th>Average Fidelity</th>
<th>Specific Sample Fidelity</th>
</tr>
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<tbody>
<tr>
<td>Outdated Color Science</td>
<td>$R_a$ (CRI)</td>
<td>$R_9$</td>
</tr>
<tr>
<td>Limited Color Samples</td>
<td></td>
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</table>

**TM-30 Calculation Engine**

<table>
<thead>
<tr>
<th>Modern Color Science</th>
<th>High Level Average Values</th>
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<tbody>
<tr>
<td>New Color Samples</td>
<td>Fidelity Index ($R_f$)</td>
</tr>
<tr>
<td></td>
<td>Gamut Index ($R_g$)</td>
</tr>
</tbody>
</table>

**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)
Perfect Fidelity

Increase Saturation

Decrease Saturation

Positive Hue Shift

Negative Hue Shift

Constant Fidelity (CRI)

(Also possible to change lightness, not shown)
Color Fidelity

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

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…**
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)

Color Gamut

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

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

Gamut Shape

Changes over different hues

Color Vector Graphic, Hue Bin Chroma Shift
$R_f = 75 \ | \ R_g = 100 \ | \ \text{CCT} = 3500 \text{ K}$

Decreased Saturation

$R_f = 75 \ | \ R_g = 100 \ | \ \text{CCT} = 3500 \text{ K}$

Increased Saturation

Hue Shift
Same red fidelity, shift in opposite directions.
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Fidelity Metric Only</strong></td>
<td><img src="image" alt="Arrow" /></td>
<td><img src="image" alt="Arrow" /></td>
</tr>
<tr>
<td><strong>CIE 1964 U<em>V</em>W</strong>*</td>
<td><img src="image" alt="Arrow" /></td>
<td><img src="image" alt="Arrow" /></td>
</tr>
<tr>
<td>8 color samples</td>
<td><img src="image" alt="Arrow" /></td>
<td><img src="image" alt="Arrow" /></td>
</tr>
<tr>
<td>Medium chroma/lightness</td>
<td><img src="image" alt="Arrow" /></td>
<td><img src="image" alt="Arrow" /></td>
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<tr>
<td>Spectral sensitivity varies</td>
<td><img src="image" alt="Arrow" /></td>
<td><img src="image" alt="Arrow" /></td>
</tr>
<tr>
<td>Munsell samples only</td>
<td><img src="image" alt="Arrow" /></td>
<td><img src="image" alt="Arrow" /></td>
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<tr>
<td>Ref Illuminant Step Function</td>
<td><img src="image" alt="Arrow" /></td>
<td><img src="image" alt="Arrow" /></td>
</tr>
<tr>
<td>No lower limit for scores and inconsistent scales</td>
<td><img src="image" alt="Arrow" /></td>
<td><img src="image" alt="Arrow" /></td>
</tr>
</tbody>
</table>

References:

- [1, 2, 3, 4, 5]
- [6, 7, 8, 9, 10]
- [11, 12, 13, 14]
Which source is best?
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

- TM-30 Gamut Index, $R_g$
- TM-30 Fidelity Index, $R_f$
Experimental Conditions

![Graph showing TM-30 Gamut Index, $R_g$, vs. TM-30 Fidelity Index, $R_f$.]
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

$R^2 = 0.06$

Mean Preference Rating vs. Fidelity Index ($R_f$)
Preference vs. Fidelity/Gamut

Dislike

Like

IES TM-30 $R_g$
$p = 0.000$

IES TM-30 $R_f$
$p = 0.042$

Model $r^2 = 0.68$

Preference vs. Fidelity/Gamut
Gamut Shape/Red Rendering

Same Fidelity, Same Gamut, Significantly Different Rating.
Preference for Increased Red Saturation...with limits.

Mean Preference Rating vs. Hue Bin 16 Chroma Shift ($R_{cs,h16}$)

$R^2 = 0.81$

Dislike
Like

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($R_{cs,h16}$)

$R^2 = 0.9355$
Summary

Context =

Normalness = Fidelity + Red Saturation
\[ R_f > 80 \quad 0\% < R_{cs,h1} < 8\% \quad (R_{f,h1} > 80) \]

Saturation = Red Saturation

\[ R_f > 74 \quad 0\% < R_{cs,h16}, R_{cs,h1} \]

Preference = Fidelity + Red Saturation

\[ R_f > 74 \quad 0\% < R_{cs,h16} < 15\% \quad 0\% < R_{cs,h1} < 15\% \quad (R_g > 100) \]
A Look at Existing Sources

IES TM-30 $R_g$

IES TM-30 $R_f$

- Phosphor LED
- Color Mixed LED
- Hybrid LED
- Standard Halogen
- Filtered Halogen
- Triphosphor Fluorescent, 7XX
- Triphosphor Fluorescent, 8XX
- Triphosphor Fluorescent, 9XX
- Metal Halide

Experimental Preferred Zone
A Look at Existing Sources

The diagram illustrates the distribution of $R_{\text{seal16}}$ percentages across various sources. The experimental preferred zone is highlighted, covering the range from 0% to 10%, with values outside this range indicating deviations from the preferred condition. The data analysis suggests a wide variation in performance, with some sources significantly above or below the desired range.
Why so Few Red-Enhancing Sources?

1. Penalization by CRI
1. Penalization by CRI

Why so Few Red-Enhancing Sources?

Gamut Index

Fidelity Index

$R_p, R_g$ (TM-30)
$R_a$, GAI (rescaled)
Why so Few Red-Enhancing Sources?

1. Penalization by CRI

Gamut Index vs. Fidelity Index

- $R_p, R_g$ (TM-30)
- $R_a, GAI$ (rescaled)
1. Penalization by CRI

Why so Few Red-Enhancing Sources?

Gamut Index vs. Fidelity Index

- $R_p, R_g$ (TM-30)
- $R_a$, GAI (rescaled)
Why so Few Red-Enhancing Sources?

1. Penalization by CRI

[Bar chart showing the distribution of CIE Ra and IES TM-30 Rf values for different condition IDs in rank order of rated preference.]

Most Liked

Least Liked
Why so Few Red-Enhancing Sources?

2. Efficiency Considerations

\[ R_a = 84, \, R_g = -7, \, \text{LER 343} \]

\[ R_a = 83, \, R_g = 21, \, \text{LER 311} \]
Why so Few Red-Enhancing Sources?

2. Efficiency Considerations

Coefficient of Determination ($r^2$) with LER

Hue Angle Bin ($j$)

26 Experimental Sources
212 Commercial Sources
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!)
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

Application webinar co-sponsored by US Department of Energy and Illuminating Engineering Society:
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:
http://dx.doi.org/10.1080/15502724.2015.1091356

LEUKOS editorial discussing next steps:
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

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