Tunable White LED Lighting

The Next Generation for Lighting Systems

Presented by Rich Wilkens, LC
Learning Objectives

By the end of this presentation

• You will know what metrics to apply to a lighting system that is designed to change its appearance

• You will know the difference between “Dim to Warm” and “Tunable White” lighting systems

• You will understand the basics of a “Tunable White” lighting system

• You will understand the basics of an automated lighting system designed to provide lighting throughout the day that matches the natural cycle of day light.
51 Year History

- 1962  **First practical red LED invented on October 9 by Nick Holonyak (GE)**
- 1971  “Blue” GaN MIS-LED demonstrated (Pankove)
- 1972  Yellow, red, and red-orange improved 10X by George Craford (HP)
- 1991  High quality p-type GaN grown; first pn-junction GaN LED (Nichia)
- 1992  Short-lived ZnSe-CdZnSe blue laser developed (3M)
- 1993  **Commercial “candela-class” blue GaN LEDs introduced by Shuji Nakamura (Nichia)**
- 1995  Bright quantum-well blue and green LEDs introduced (Nichia)
- 1996  Room temperature nitride “blue” laser diode demonstrated (Nichia)
- 1997  US demonstrates room temperature “blue” laser diode (Cree)
- 2000  **First large area LED chips (Lumileds)**
- 2001  Surface roughening for improved light extraction (Taiwan)
- 2001  Patterned substrate technology for improved light extraction (Japan)
- 2004  SONY markets Blu-Ray (HD-DVD) players (23 GB/layer)
- 2005  Large area LED chips with roughened surfaced
- 2006  **Solid-state lighting revolution begins**
LED Sources – Now Surpass All other Lamp Types

- Beware, there is a wide range in LED source performance
- There are “lagging” and “leading” suppliers

LED is now the highest efficacy “white light” source on the market
Discrete LED: Packages & Types

Packaging Trends:
- Application-specific
- Smaller size
- Multi-die low-power
- Multi-die high-power
- Improved phosphor dispersion
- Higher wattage/flux packages
- Silicone + Phosphor encapsulate
- Chip on Board (COB)
Smaller Source Size

- Increased Lumen Density
- High CBCP
- Lower Assembly Cost

96% smaller than XR
78% smaller than XP
AC LEDs with ASIC

- ASIC controls drive current
- “Off time” keeps efficacy <85 LPW
- Dedicated/discrete input voltage (i.e. 120VAC)
- Phase dimming via “banks” of LEDs
- 0-10 V dimming is available in some products
Attention to details are important before install
The Language of Light

OMG
Correlated Color Temperature Chart

- 2000K: Candle Light
- 3000K: Summer Sun Light
- 4500K: Blue Sky Light
- 6500K: Blue Sky Light
- 9000K: Blue Sky Light
Color Rendering Index (CRI)

- IESNA: measure of the degree of color shift objects undergo when illuminated by the light source as compared with the color of those same objects when illuminated by a reference source, of comparable color temperature.

- Light sources differ in their ability to render the color of objects "correctly."

Source: Lighting Research Center Resource Collection
CRI measures how faithfully a light source renders specific reference colors compared to how those colors are rendered by an “ideal” or natural light source, typically a blackbody radiator.

If each color point is reproduced exactly as it is by a blackbody, then the color rendering is 100. Any deviation in any direction for any color point results in a CRI of less than 100.

The first 8 color samples are used to calculate the general color rendering index, Ra. The next 6 colors provide supplementary information.

Though CRI Ra is the most common reference metric for “color quality”, more colors from R9-R15 must be included for an appropriate evaluation.
Color Rendering Index (CRI)

Test Light Source

Blackbody radiator at the same CCT

Use formula to calculate R1 – R8

R1  R2  R3  R4  R5  R6  R7  R8

CRI or Ra = average
COLOR RENDERING INDEX (CRI)

LED Binning and Color Consistency

ANSI C78.377-2008 LED Standard

- 7 Step MacAdam Ellipses for DOE Energy Star CFLs
- ANSI C78.377-2008 LED Standard
COLOR RENDERING INDEX (CRI)

Larger Bin Quadrants vs. Smaller Bin Quadrants
CRI vs. SPD

3000K, 86CRI Fluorescent

3000K, 85CRI LED
The gamut area for Vibrant Series is offset and larger than the area for a blackbody radiator.

Each identified point represents colors R1 through R15 of CRI.
Color Space

There are many mathematical color metrics. One is the CIE xy chromaticity diagram.

It’s a 2D system that can’t begin to describe 3D object color. For today, please fuhgeddaboudit ...
TM-30-15

Prepared by the Color Metric Task Group and the Color Committee of the IES
IES TM-30 Overview (or What’s Different This Time?)

1. “Dream Team” Task Group Members:
   - Michael Royer (PNNL) – Chair
   - Yoshi Ohno (NIST) – inventor of CQS color metric system
   - Kevin Houser (Penn St.) – editor of IES LEUKOS journal
     – Minchen Wei (Penn St.) – grad student of Kevin's
   - Kees Teunissen (Philips Netherlands)
   - Aurelien David (Soraa)
   - Randy Burkett (independent lighting designer)
   - Paul Fini (Cree)

2. Two Metric System (Rf = Fidelity, Rg = Gamut)
   - Replaces one dimensional CRI Ra/R9 fidelity metrics (good–bad) with two distinct dimensions
   - Very easy to map user experience into Rf/Rg relationships

3. Loads of Improvements
   - 99 color samples vs 8-16
   - State-of-the-art color science
   - Additional tools for understanding exactly how colors are distorted (distortions can be desirable!)
Color Samples & Basic Calculation Flow

**TM-30: 99 color samples**

- **Input**: test source SPD
- **Determine CCT (with 2° CMFs) and reference illuminant**
- **Compute test chromaticity** \((I', a', b')\) of samples
- **Compute reference chromaticity** \((I'_r, a'_r, b'_r)\) of samples
- **Compute color errors**
- **Bin by hue, compute average chromaticity in each bin**
- **Calculation**
  - \(R_f\)
  - \(R_s\)

*Rf calculation method is extremely similar to CRI Ra calculation method*
**TM-30-15 Fidelity (Average)**

**Color Evaluation Sample**

\[
R_f' = 100 - 7.54 \left( \frac{1}{99} \sum_{i=1}^{99} (\Delta E_{f_{ab,i}}) \right)
\]

\[
R_f = 10 \ln \left( e^{R_f'/10} + 1 \right)
\]

- Arithmetic Mean
- Scaling Factor
- Maximum value of 100
- Lower limit = 0
### IES TM-30 Metrics

<table>
<thead>
<tr>
<th>Color Fidelity (Rf)</th>
<th>Color Gamut (Rg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>“On average, how <strong>faithfully</strong> does the test source illuminate the 99 color samples compared to the reference source?”</td>
<td>“On average, how much <strong>more saturated</strong> does the test source illuminate the 99 color samples compared to the reference source?”</td>
</tr>
</tbody>
</table>
| Scale: 0-100  
100 = perfect match                                                     | Scale: (no limits)  
>100 = test oversaturates vs reference  
<100 = test undersaturates vs reference |
Conclusions

- TM-30 is ready and available for use! Try it out and share your experiences.
- TM-30 offers substantial technical improvements via a new set of color samples and updated color science, each contributing to improved accuracy/usefulness.
- TM-30 greatly expands the scope of available information on color rendering, eliminating the limitations of considering a fidelity metric alone.
- TM-30 offers a single, cohesive method that includes a variety of measures suitable for various needs.
- The measures can be used together (and in combination with other important lighting metrics) to determine the most suitable source for a given application/user group.
IES PS-8-14

“...it is the position of the IES that CRI requirements should *not* be a metric used in energy regulations to characterize color attributes for solid state lighting until there is a consensus on the issue.”

**Title 24:** “With the exception of decorative, monochromatic LEDs, **Joint Appendix JA8** requires that LED luminaires designed for *indoor residential* use have a **minimum CRI of 90** and a CCT of 2700K – 4000K in order to qualify as high efficacy.”
A Rose by any other word?

RGB LED Lighting
Dim to Warm
Bright White

Vibrant White

RGBW LED Lighting
Crisp White
Perfect-Color

Circadian Rhythm Lighting

Circadian Balanced Illumination
Tunable White
Benefits of Tunable White Lighting Systems

Improved Productivity

Better Visual Acuity

Health Benefits/Circadian Rhythm

Energy Saving & Sustainability
Color-Tunable Lighting

Digital Lighting

**Technology:**
- 5 String Mixing: Full spectrum mixing
- Tunable White
- On Board Calibration
- Thermal Compensation
- Thermal Turn Down
- Built-in Wireless (with copy & paste functionality)
- 1% dimming
- Dim-to-Warm
- Saturation & Hue
- Scene Presets

**Market Opportunity:**
- Healthcare
- Hospitality
- Retail
- Office
- Education
In order to perceive a color, the source must produce and the object must reflect the color.
Dim to Warm

Typical product range is 3000K down to 1800K

Color Temperature change is tied to the dimming curve

Replace – Halogen Incandescent light sources
Dimming starts with premium white light that warms from 3000K to 1800K when dimmed. CRI and R9 values remain above 90 throughout entire dimming range, and the color stays within 1 SDCM on Black Body Locus.

Dimming fixtures are dimmable to 1% using 0-10V protocol.
Tunable White 3000K to 6500K

More Complex

Wide variety of Application

Simple or Complex controls
Case study
In der Alten Forst

<table>
<thead>
<tr>
<th>Location</th>
<th>Hamburg, Germany</th>
</tr>
</thead>
<tbody>
<tr>
<td>Philips Lighting</td>
<td>SchoolVision Lighting solution</td>
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“We saw for ourselves and the results confirmed that the specific application of light really can have a positive effect on learning and the learning environment.”

Andreas Wiedemann, School Director, In der Alten Forst
Errors relating to concentration: -44.9%

Reading performance: +34.8%

Restlessness: -76.6%

Source: “Wirksamkeit von dynamischen Licht in Hamburger Schulklassen”, May 2009
Universitätsklinikum Hamburg-Eppendorf, Klinik und Poliklinik für Kinder- und Jugendpsychosomatik, Michael Schulte-Markwort, Claus Barkmann & Nino Wessolowski
www.uke.de/kliniken/kinderspsychosomatik/index_53560.php
Lighting Matched to the activity

- Energy
- Standard
- Concentrate
- Relax
- Lecture
- “AV” - Presentations
Typical Classroom
Swedish Healthy Home
Promoting Health and Wellbeing while Minimizing Wasted Energy

Light-dark patterns reaching the retina synchronize human circadian rhythms, such as the sleep-wake cycle, with local time on Earth. If we do not receive a sufficient amount of light of the right spectrum, for a sufficient amount of time, and with the right timing, we can experience circadian desynchronization. Short-term circadian desynchronization leads to poor sleep and poor performance. Circadian disruption over many years has been associated with health risks, including diabetes, obesity, cardiovascular disease, and cancer.

The LRC is funded by the Swedish Energy Agency to develop a lighting system that promotes health and wellbeing through improved circadian entrainment while minimizing wasted energy via intelligent control of LED lighting. The Swedish Healthy Home system consists of wearable sensors that monitor user light exposures and activity patterns, a smartphone app that recommends a lighting scheme based on user data, sensors to determine user location, and a hub that integrates all the information to control the home lighting.

Wearable Sensors
The light logger is a wearable device that measures circadian stimulus (CS) over time via an RGB sensor. A wrist-worn activity logger with a 3-axis, cold-stone accelerometer measures activity over the day and night. The light and activity data are used to estimate circadian entrainment as well as sleep quality.

Smartphone Apps and Beacons
The primary app calculates a light treatment based on user data collected by the sensors and sends the treatment schedule to the hub. To determine which room users are in or if they are away from home, beacons are placed around the home. A secondary app works with the beacons to determine user location.

Connected Lighting and the Hub
The hub communicates with the apps, controls the connected lighting, and configures the lighting schemes. The connected lamps should have variable light levels and CRI in order to precisely control the circadian stimulus. The system provides lighting that is tailored to the needs of each individual, while minimizing energy usage.

Sponsor
Swedish Energy Agency

Lighting Research Center
Circadian Rhythm

- High alertness: 10:00
- Highest testosterone secretion: 09:00
- Bowel movement likely: 08:30
- Melatonin secretion stops: 07:30
- Sharpest rise in blood pressure: 06:45
- Lowest body temperature: 04:30
- Deepest sleep: 02:00
- Noon: 12:00
- Best coordination: 14:30
- Fastest reaction time: 15:30
- Greatest cardiovascular efficiency and muscle strength: 17:00
- Highest blood pressure: 18:30
- Highest body temperature: 19:00
- Melatonin secretion starts: 21:00
- Bowel movements suppressed: 22:30
Thank you!