Tunable White LED Lighting

The Next Generation for Lighting Systems

lighting group northwest

Presented by Rich Wilkens, LC

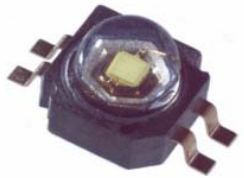
Learning Objectives

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.

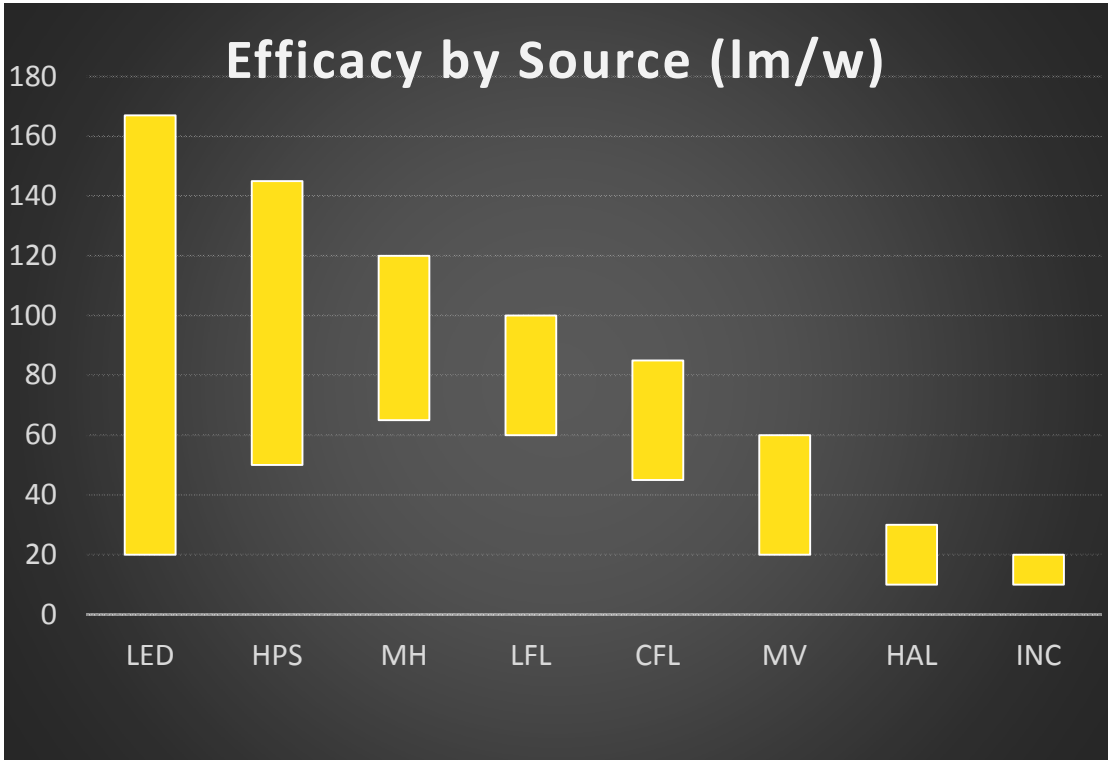
Evolution of the LED

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



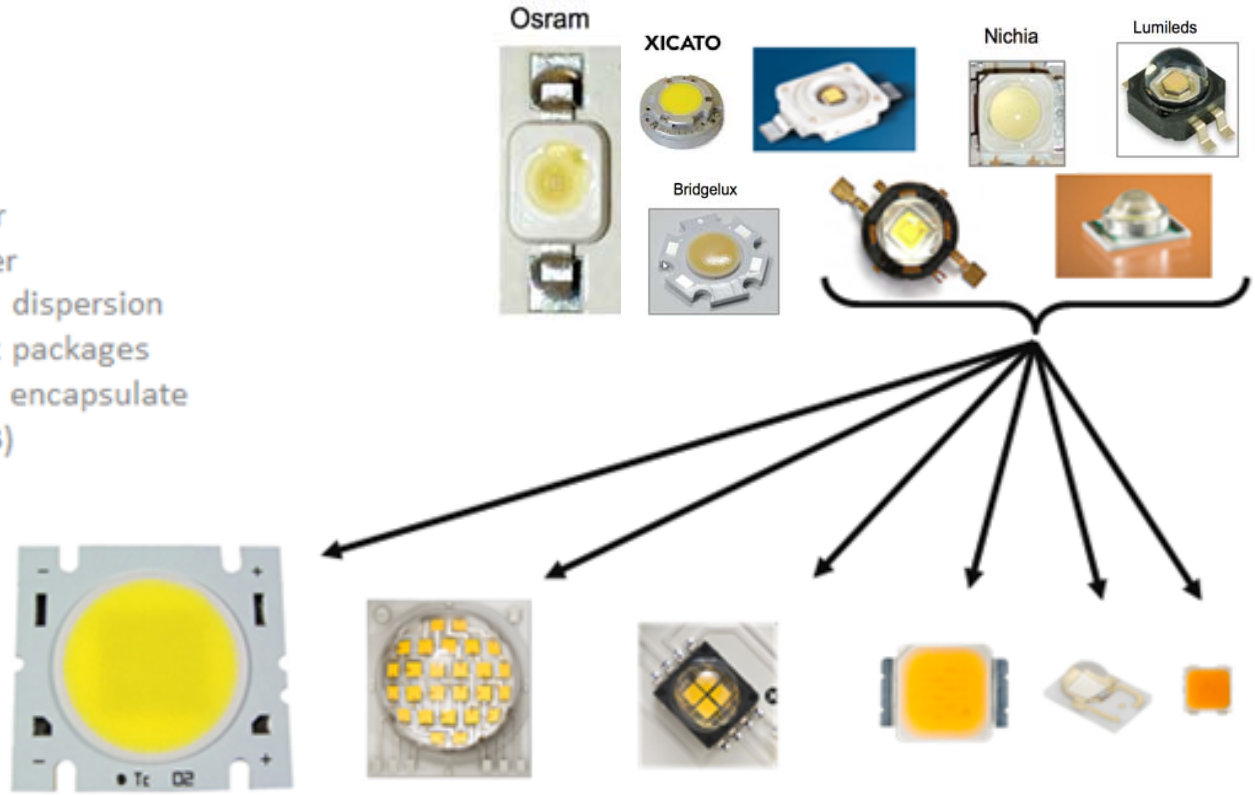
- **Beware, there is a wide range in LED source performance**
- **There are "lagging" and "leading" suppliers**

LED is now the highest efficacy "white light" source on the market

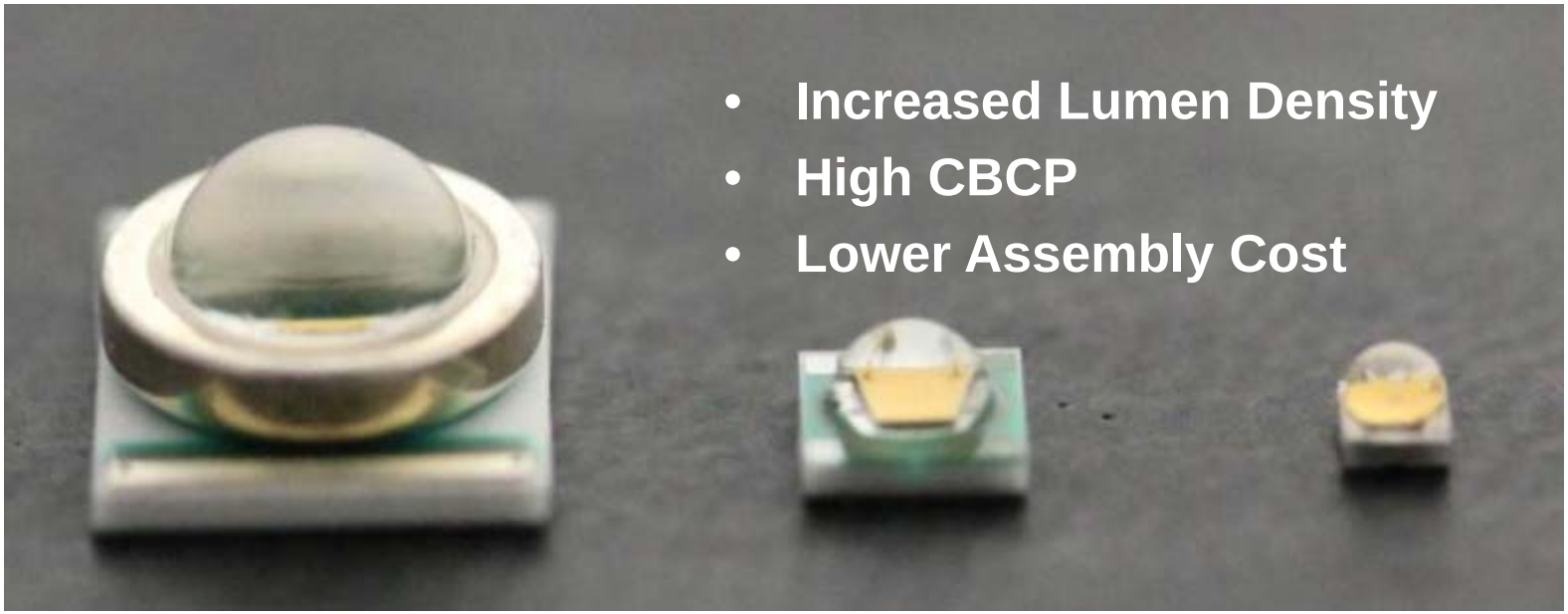
Discrete LED: Packages & Types

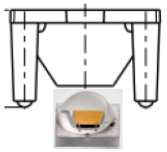
Packaging Trends:

- 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



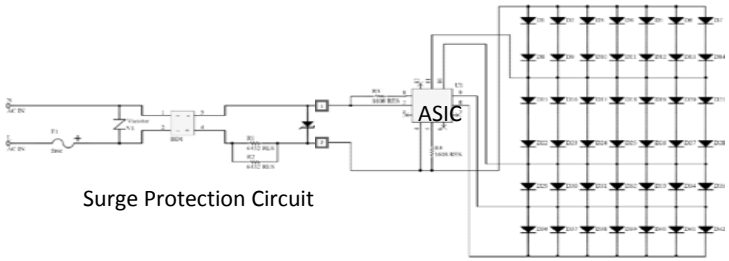


96% smaller than XR

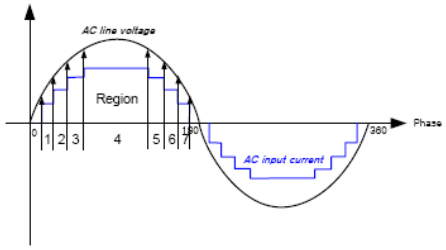
78% smaller than XP

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

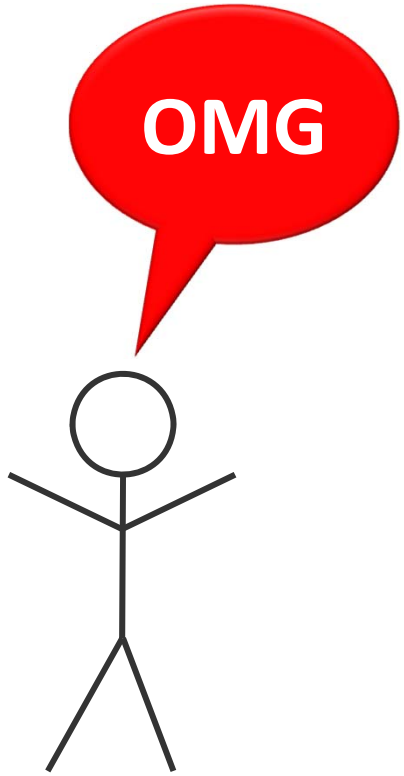


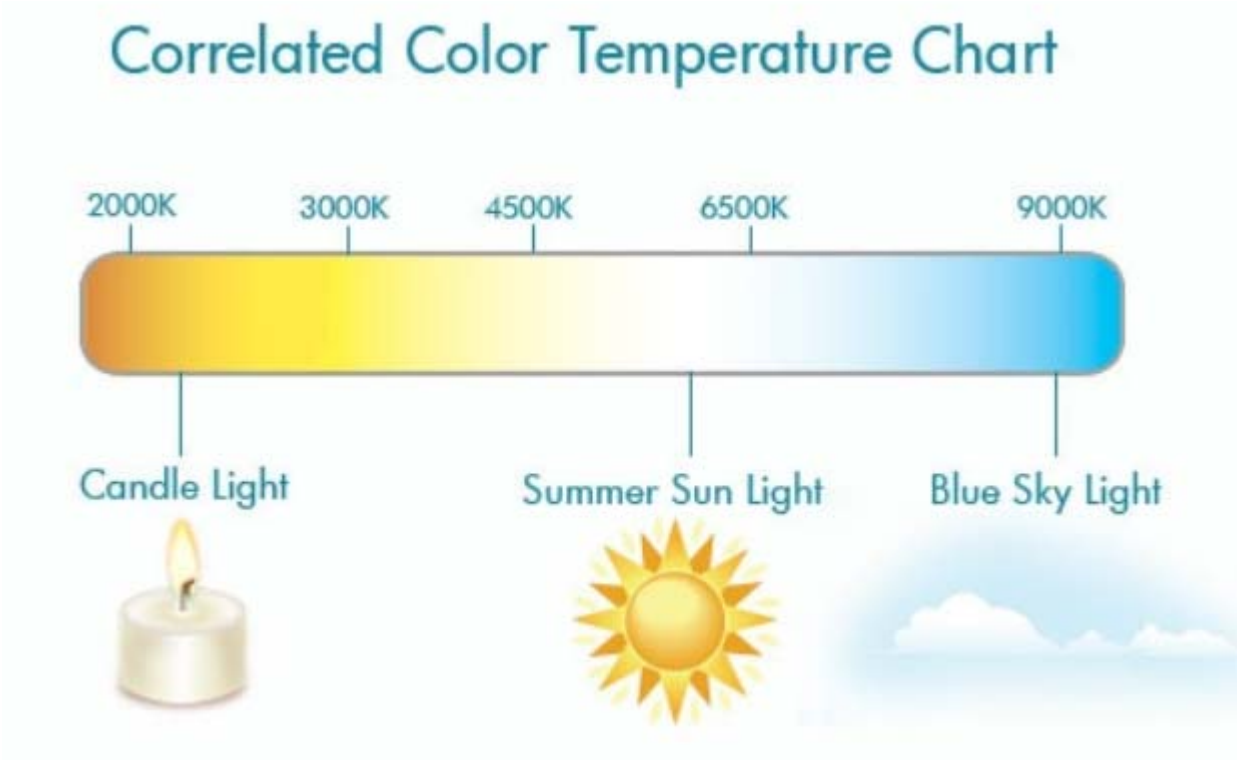
Surge Protection Circuit



Attention to details are important before install

The Language of Light




Correlated Color Temperature Chart
2000K
3000K
4500K
6500K
9000K
Candle Light
Summer Sun Light
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."

Photo: Javier Ten

CRI=90 CRI=70 CRI=50

CRI is a general indicator of how "natural" object colors will appear when illuminated by a particular light source. Generally, a CRI of 70 and above will be required for most lighting applications.

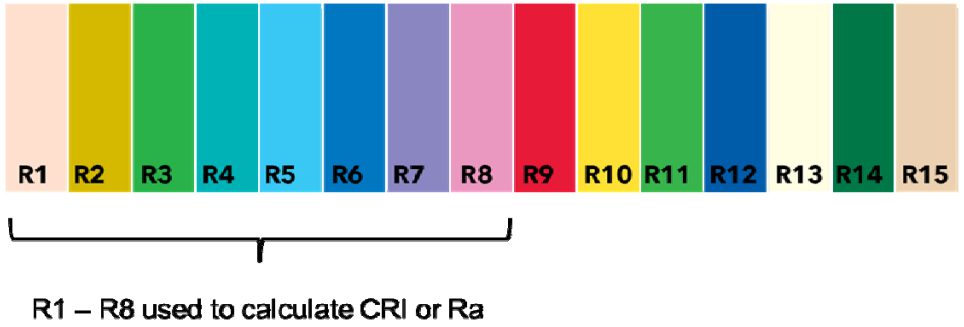
Source: Lighting Research Center Resource Collection

Re-introduction to Color Rendering Index (CRI)

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.

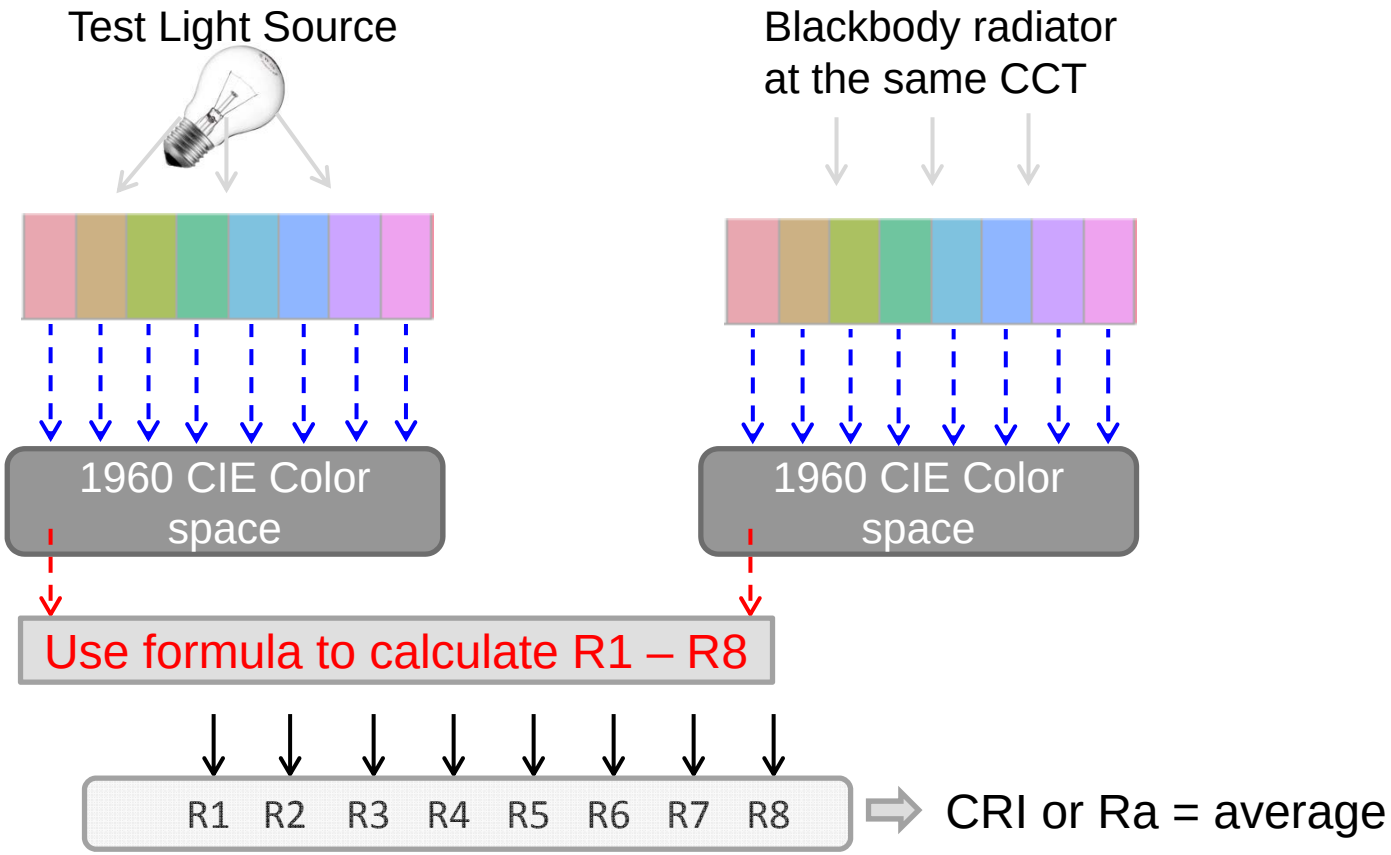
If each color point is reproduced exactly as it is by a blackbody, then the color rendering is 100. Any deviation in any direction for any color point results in a CRI of less than 100.

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



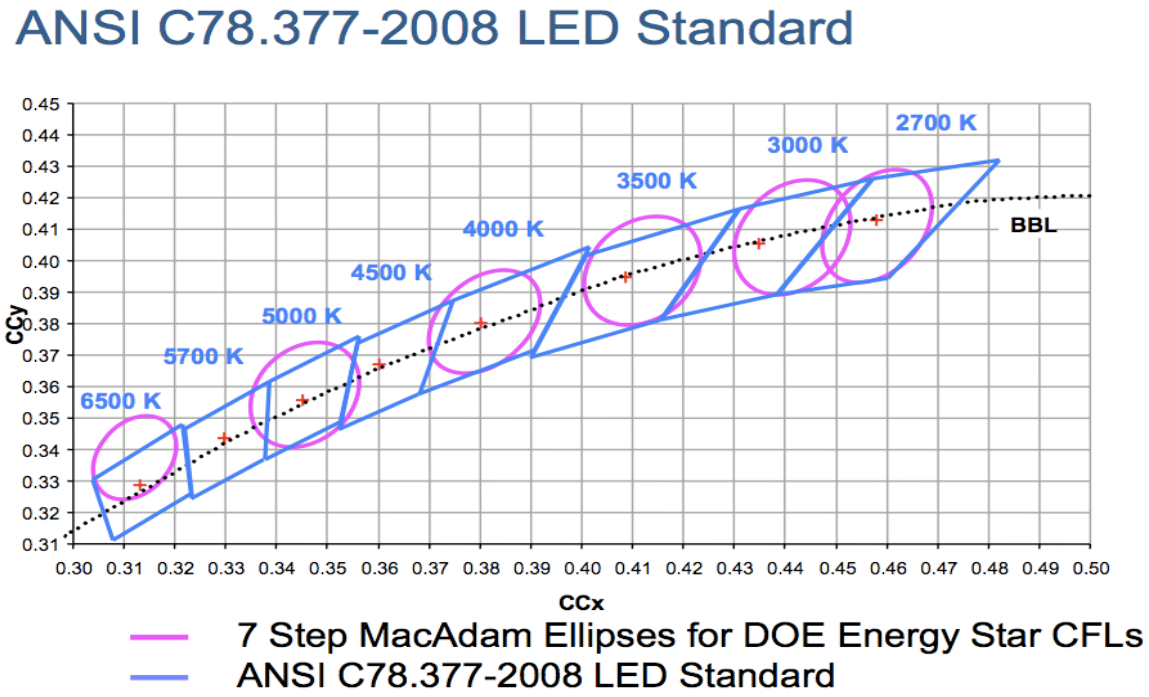
Though CRI Ra is the most common reference metric for “color quality”, more colors from R9-R15 must be included for an appropriate evaluation.

Color Rendering Index (CRI)



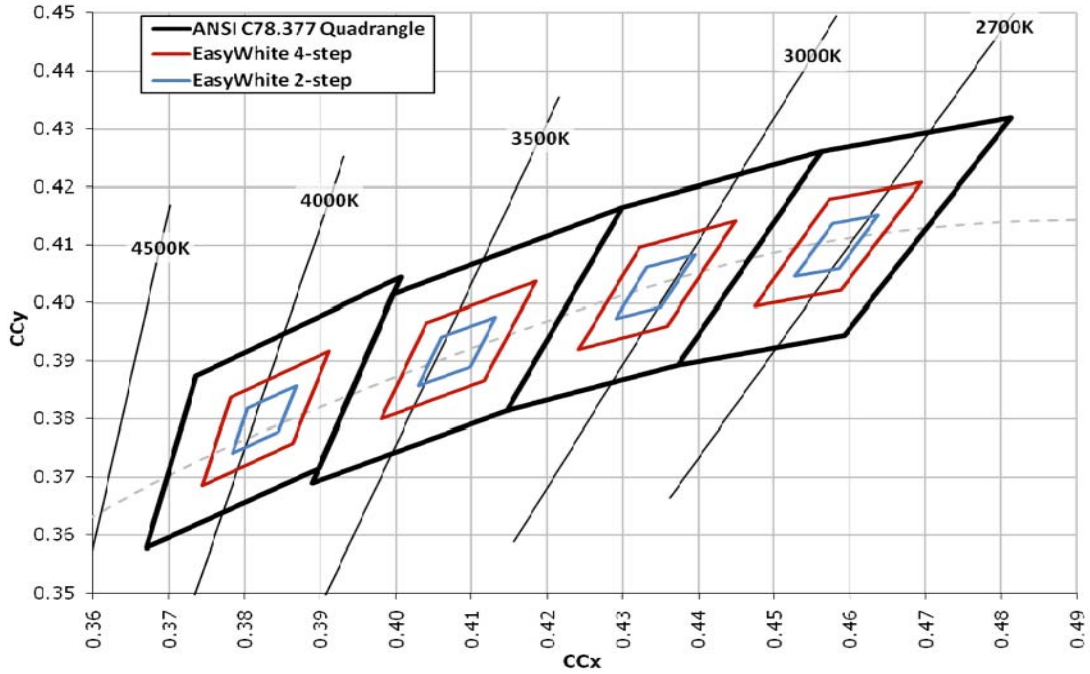
COLOR RENDERING INDEX (CRI)

LED Binning and Color Consistency

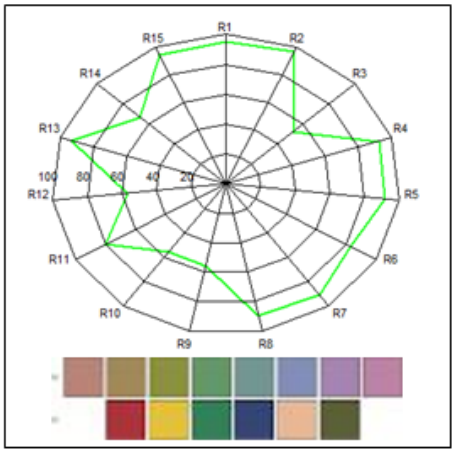


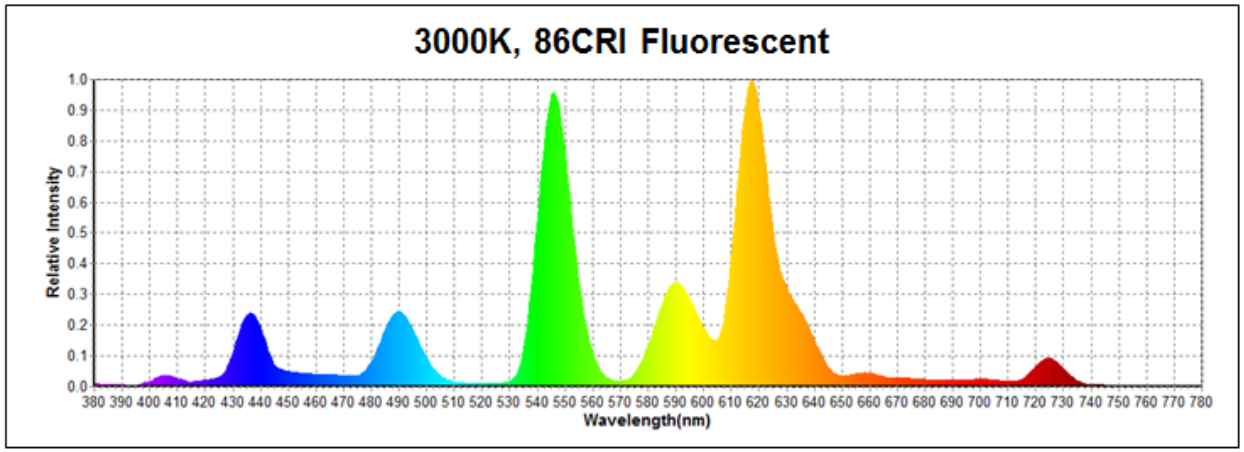
COLOR RENDERING INDEX (CRI)

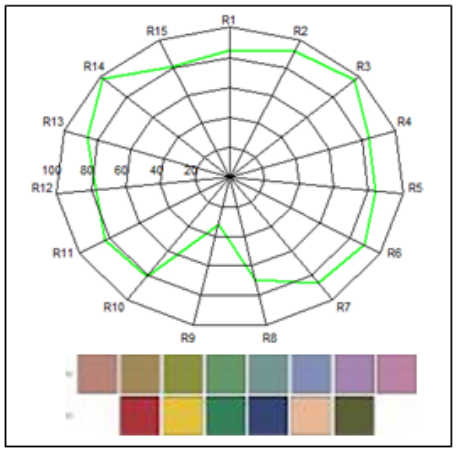
Larger Bin Quadrants vs. Smaller Bin Quadrants

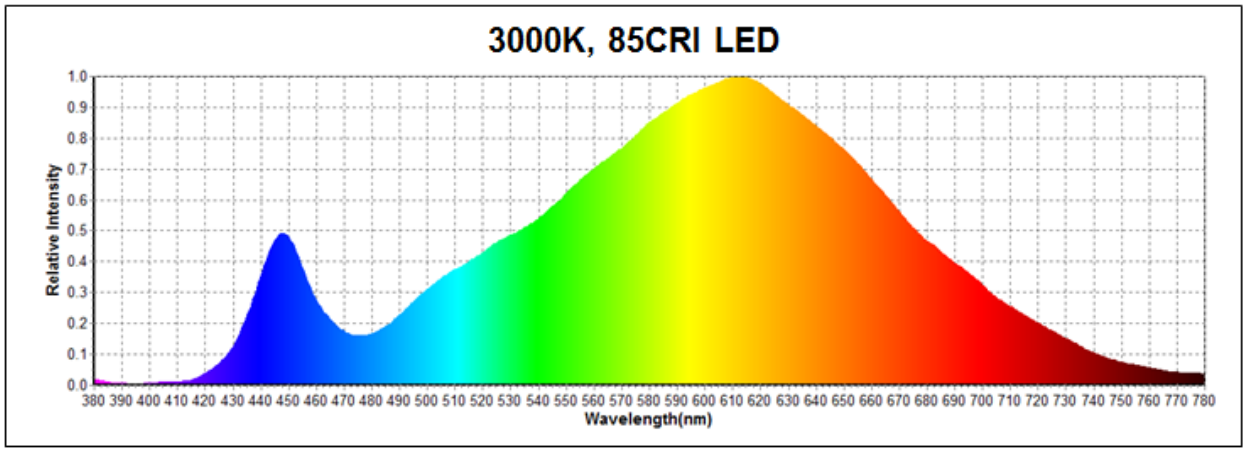


CRI vs. SPD


R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
100
80
60
40
20


3000K, 86CRI Fluorescent
Relative Intensity
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
380 390 400 410 420 430 440 450 460 470 480 490 500 510 520 530 540 550 560 570 580 590 600 610 620 630 640 650 660 670 680 690 700 710 720 730 740 750 760 770 780
Wavelength(nm)


R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
100
80
60
40
20

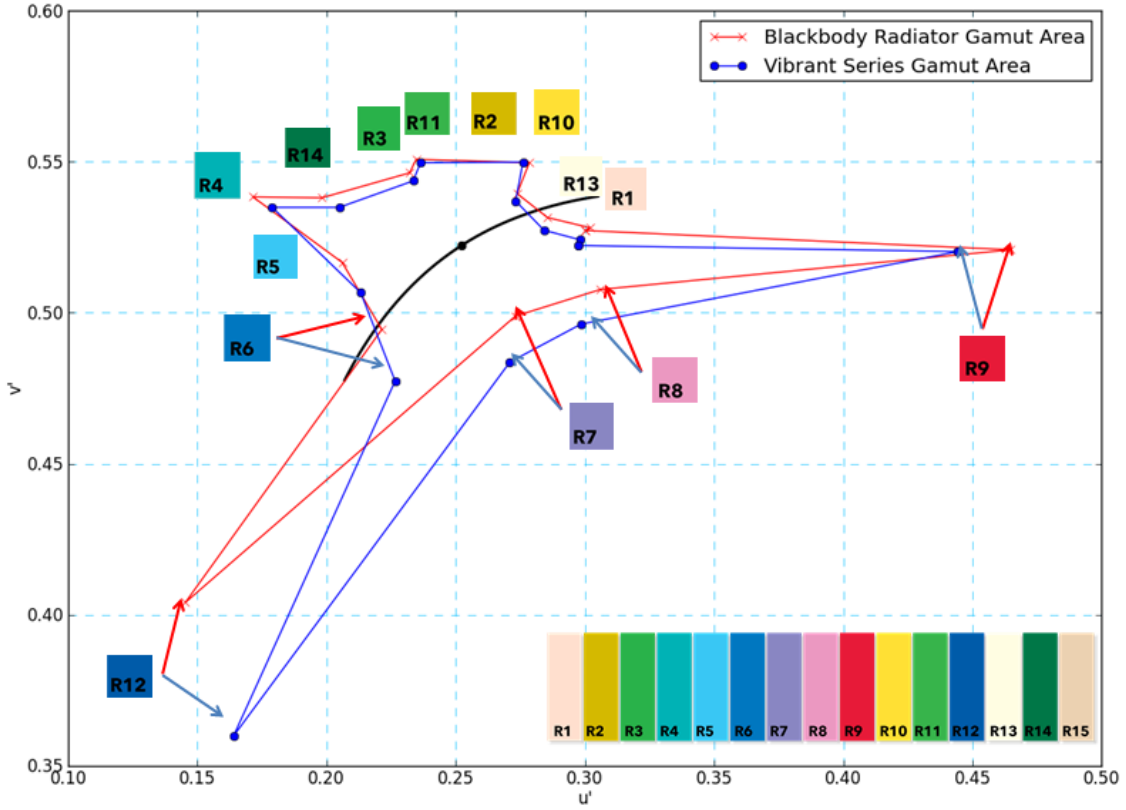

3000K, 85CRI LED
Relative Intensity
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
380 390 400 410 420 430 440 450 460 470 480 490 500 510 520 530 540 550 560 570 580 590 600 610 620 630 640 650 660 670 680 690 700 710 720 730 740 750 760 770 780
Wavelength(nm)

GAI_{BB} *Illustrated – Xicato Vibrant Series*

Gamut Area of 100 CRI Reference Compared to Vibrant Series Gamut Area – 3000K

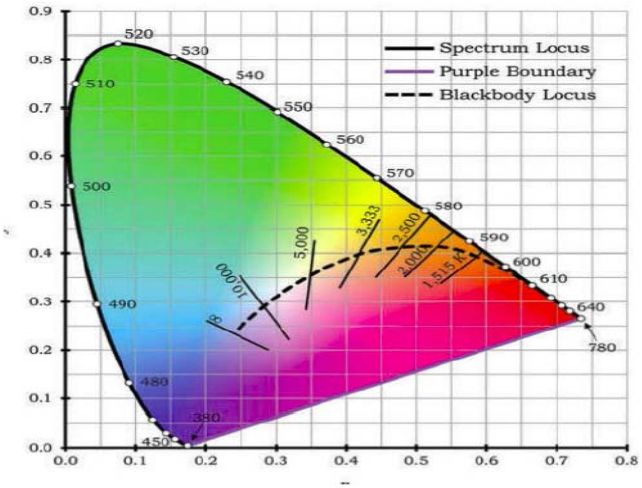
The gamut area for Vibrant Series is offset and larger than the area for a blackbody radiator.

Each identified point represents colors R1 through R15 of CRI.



Color Space

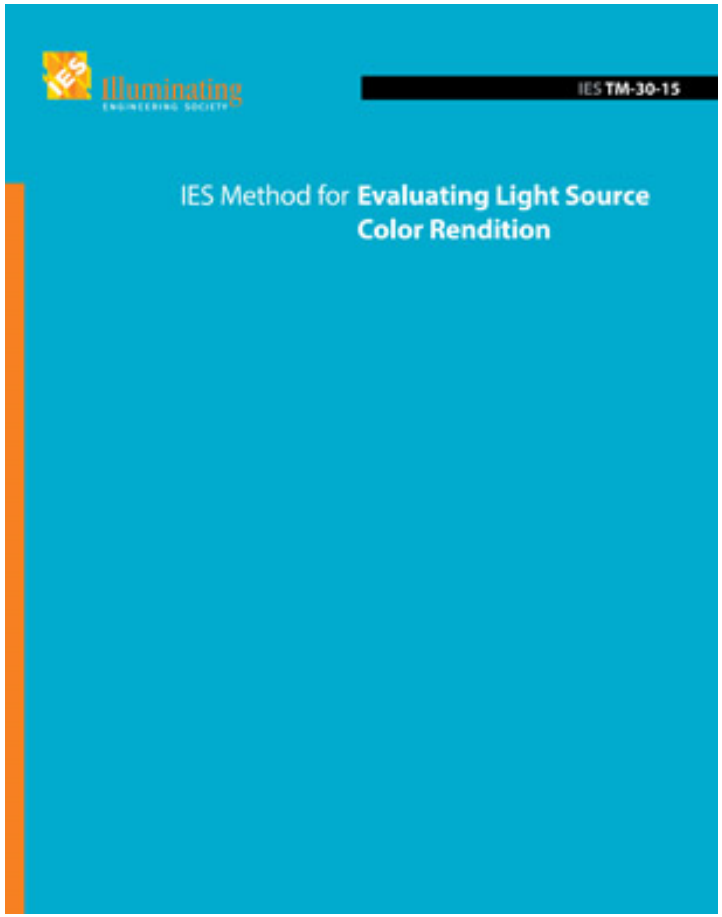
There are many mathematical color metrics.
One is the CIE xy chromaticity diagram.



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)

3. Loads of Improvements

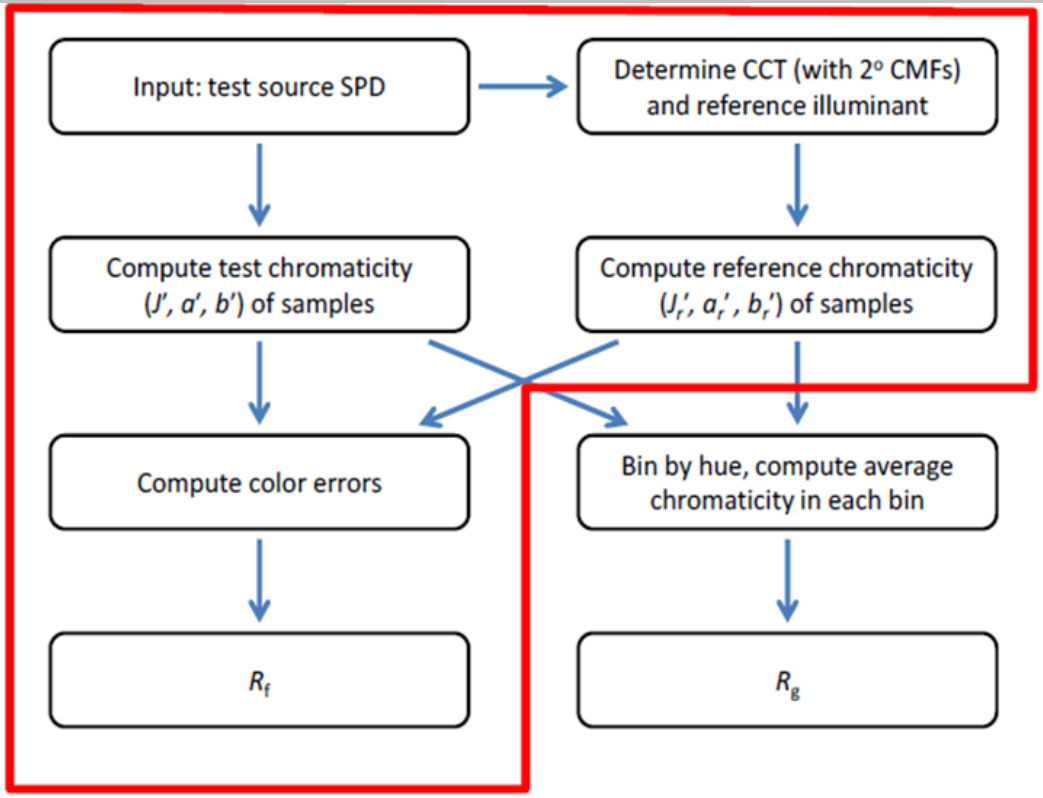
- 99 color samples vs 8-16
- State-of-the-art color science
- Additional tools for understanding exactly how colors are distorted (distortions can be desirable!)

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

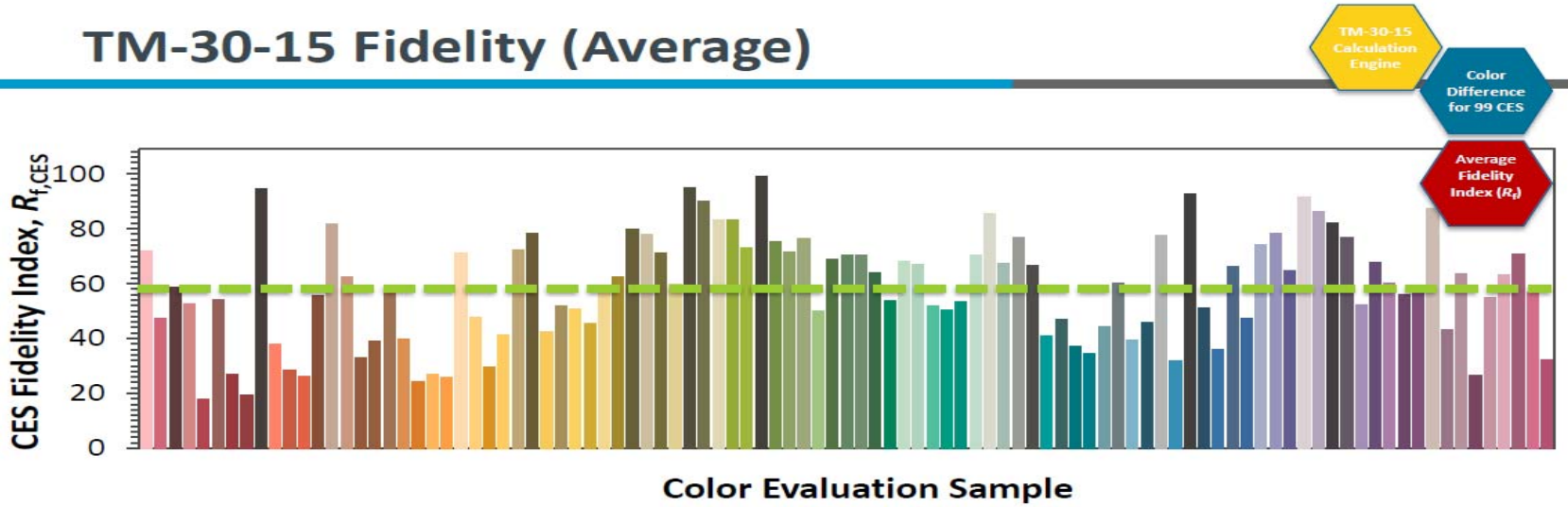
Color Samples & Basic Calculation Flow

TM-30: 99 color samples



Rf calculation method is extremely similar to CRI Ra calculation method

TM-30-15 Fidelity (Average)



$$R'_f = 100 - 7.54\left(\frac{1}{99}\sum_{i=1}^{99}(\Delta E_{Jab,i})\right)$$

Arithmetic Mean

Scaling Factor

Maximum value of 100

$$R_f = 10\ln\left(e^{R'_f/10} + 1\right)$$

Lower limit = 0

Illuminating Engineering Society | U.S. Department of Energy | Energy Efficiency & Renewable Energy

IES TM-30 Metrics

Color Fidelity (Rf)	Color Gamut (Rg)
"On average, how **faithfully** does the test source illuminate the 99 color samples compared to the reference source?"	"On average, how much **more saturated** does the test source illuminate the 99 color samples compared to the reference source?"
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."

Illuminating Engineering Society

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."

California Energy Commission

A Rose by any other word?

RGBA LED Lighting

Dim to Warm

Bright White

Circadian Balanced Illumination

Tunable White

Circadian Rhythm Lighting

Vibrant White

Crisp White

Perfect-Color

RGB LED Lighting

RGBW LED Lighting

Benefits of Tunable White Lighting Systems

Improved Productivity

Better Visual Acuity

Health Benefits/Circadian Rhythm

Energy Saving & Sustainability

Color-Tunable Lighting

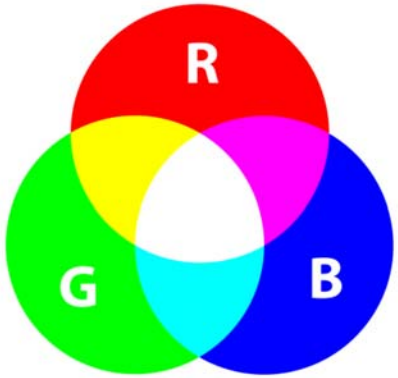
Digital Lighting

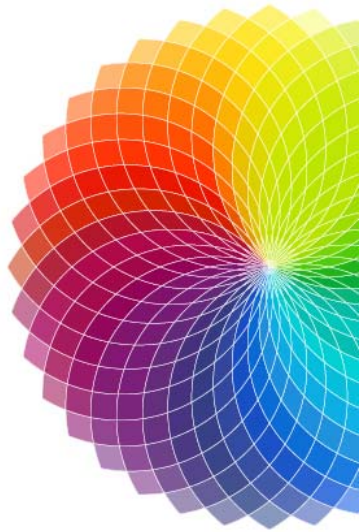
Technology:

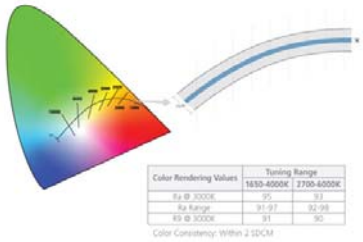
- 5 String Mixing: Full spectrum mixing
- Tunable White
- On Board Calibration
- Thermal Compensation
- Thermal Turn Down
- Built-in Wireless (with copy & paste functionality)
- 1% dimming
- Dim-to-Warm
- Saturation & Hue
- Scene Presets

Market Opportunity:

- Healthcare
- Hospitality
- Retail
- Office
- Education

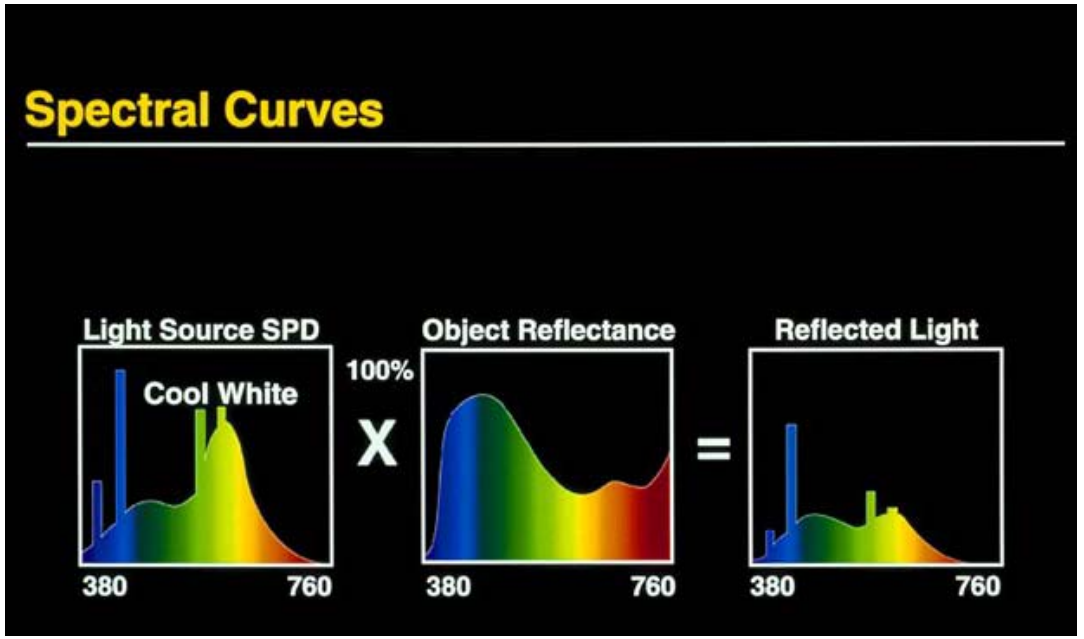






Light & Color

In order to perceive a color, the source must produce and the object must reflect the color



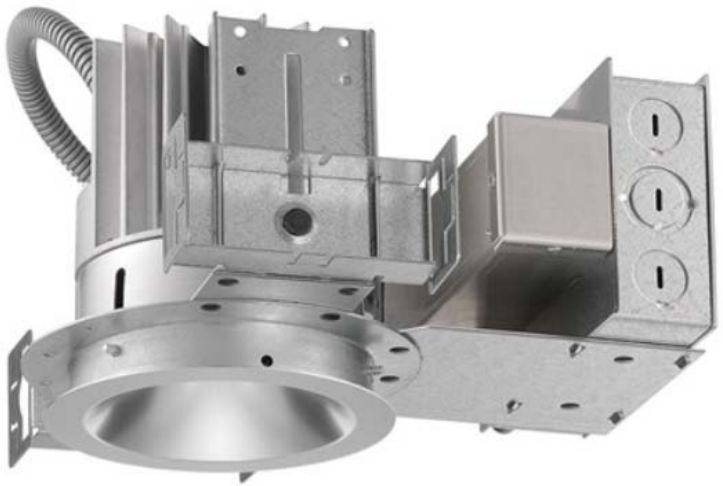
Dim to Warm

Typical product range is 3000K down to 1800K

Color Temperature change is tied to the dimming
curve

Replace – Halogen Incandescent light sources

Dim to Warm



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

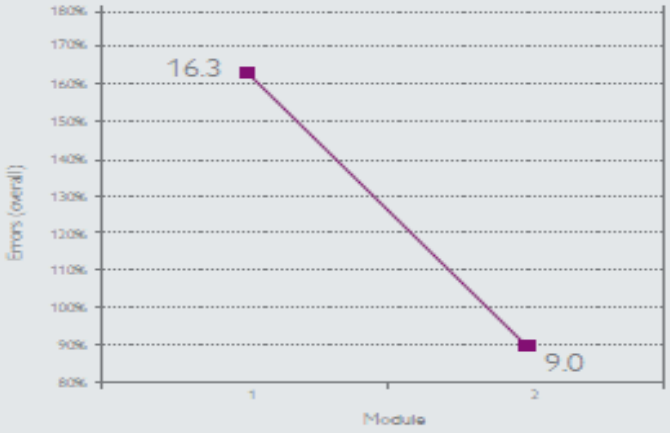
Simple or Complex controls

Case study
In der Alten Forst

Location	Hamburg, Germany
Philips Lighting	SchoolVision Lighting solution

"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."

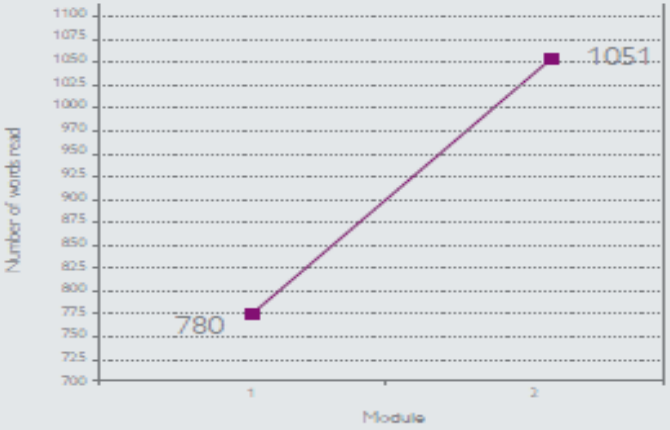
Andreas Wiedemann, School Director, In der Alten Forst



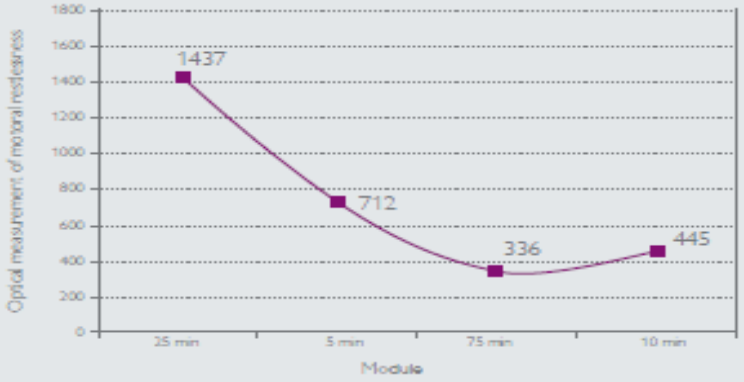
Errors relating to concentration -44.9%

Universitätsklinikum Hamburg-Eppendorf

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/kinderspychosomatik/index_53560.php



Reading performance +34.8%

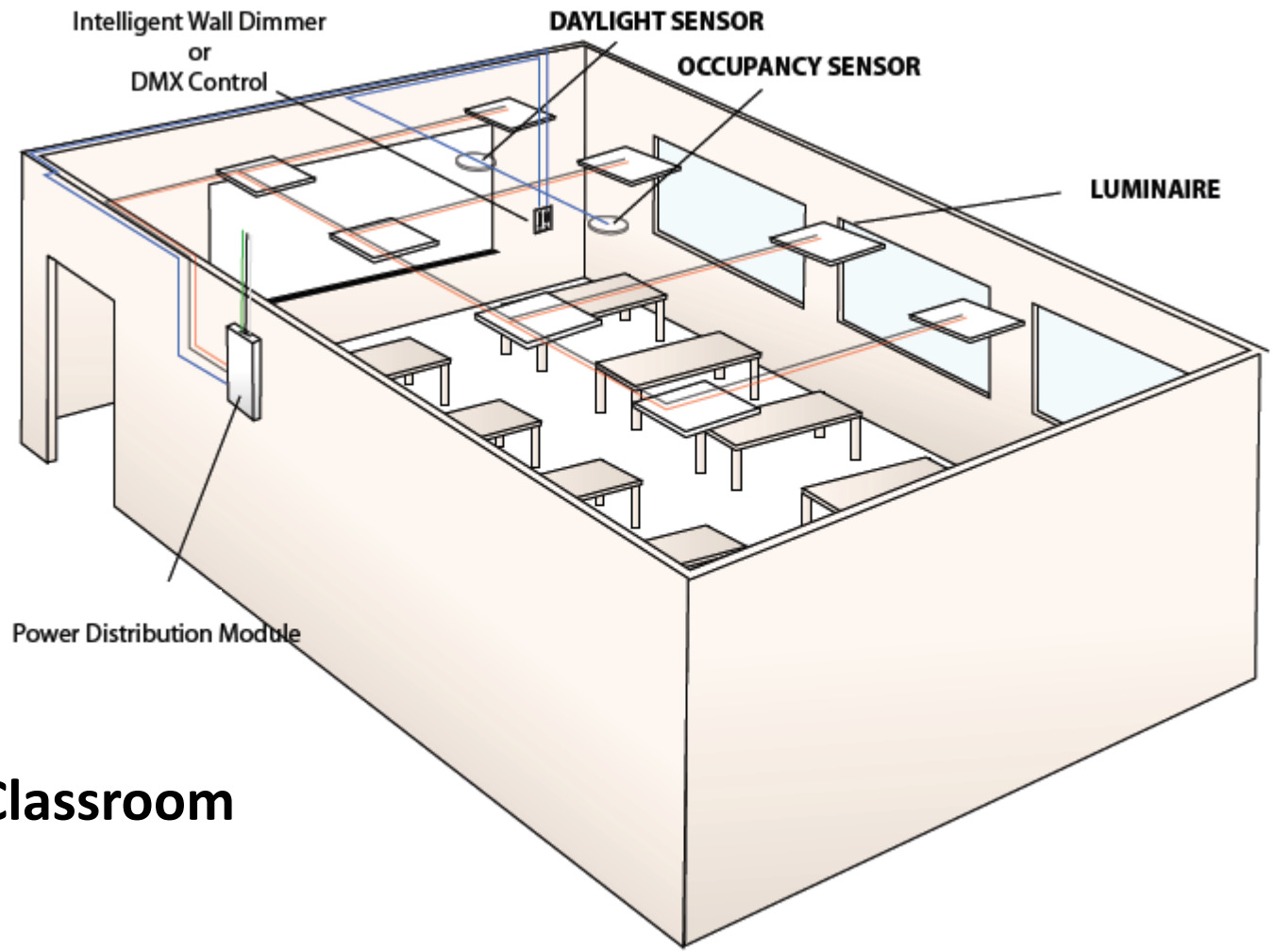


Restlessness -76.6%

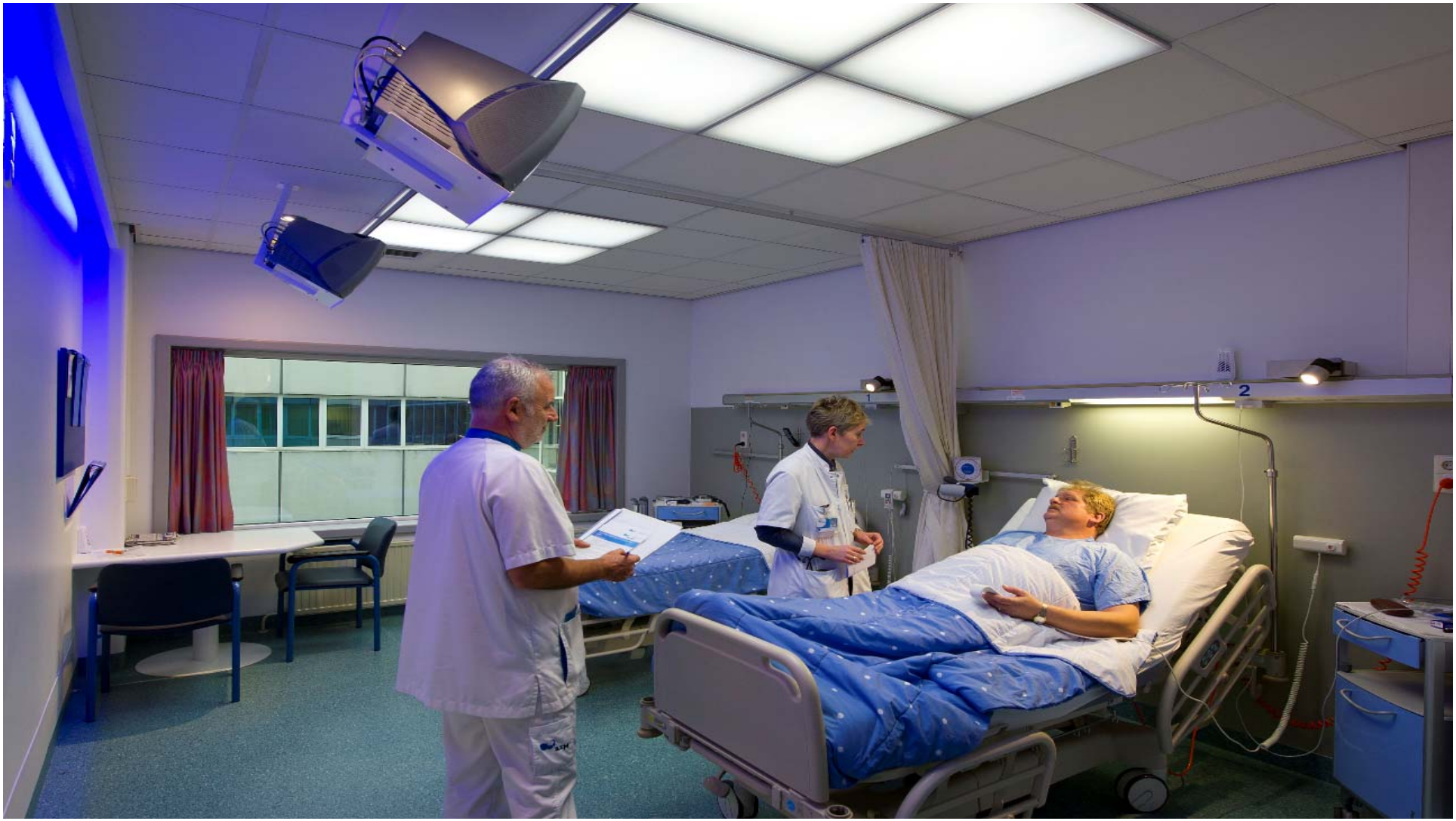
Tunable White - Education

Lighting Matched to the activity

- Energy
- Standard
- Concentrate
- Relax
- Lecture
- “AV” - Presentations



Typical Classroom



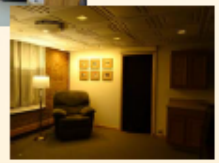
Swedish Healthy Home

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 disruption. Short-term circadian disruption 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.

The LRC's demonstration room shows that intelligent control of LED lighting can provide cycled electric lighting with cool, high light levels during the day (left) and warm, low levels in the evening (below).



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 solid state accelerometer measures activity over the day and night. The light and activity data are used to estimate circadian entrainment as well as sleep quality.

Light logger (left) and activity logger.

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 CCT 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.

The beacon (left) and the hub.

Sponsor

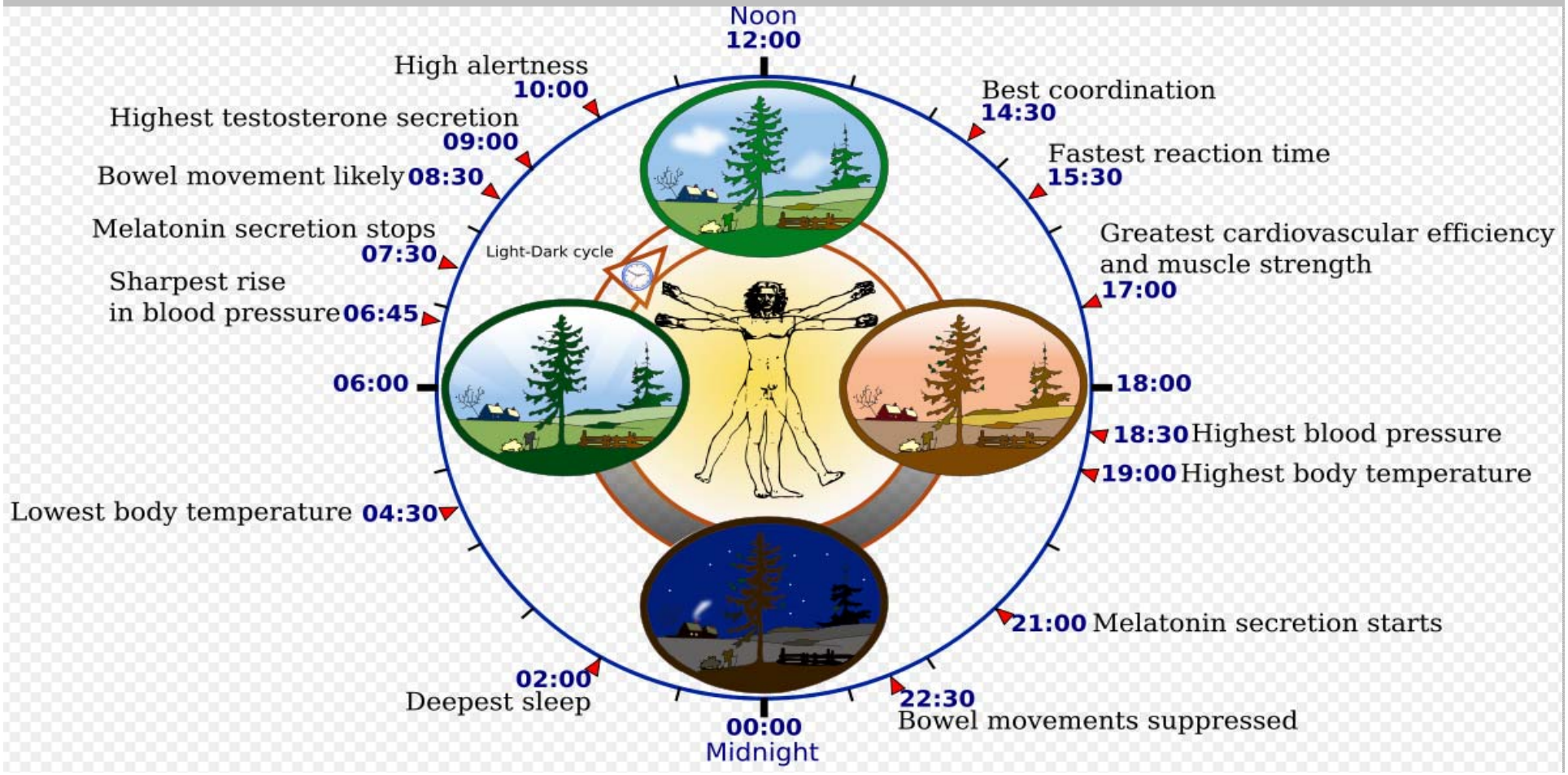
Swedish Energy Agency

Rensselaer

Lighting Research Center

Lighting Research Center, Rensselaer Polytechnic Institute • 21 Union Street • Troy, NY 12180 • (518) 687-7100 • www.lrc.rpi.edu

Circadian Rhythm



Thank you!