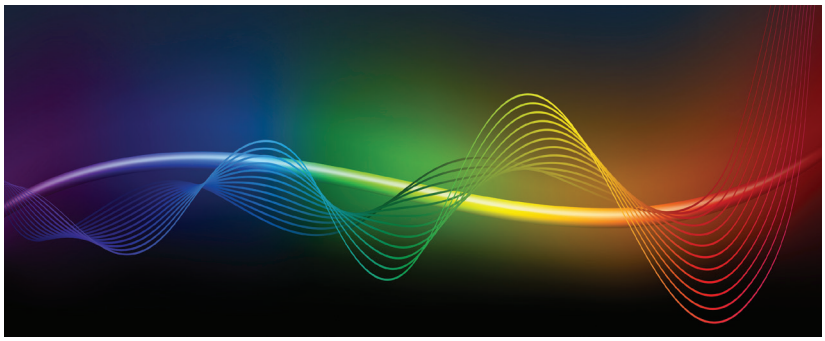
METRICS • PERCEPTION

LIGHT+COLOR

PREFERENCE • VISION

APRIL 3 - 5, 2016 | GAITHERSBURG, MD



IES Research Symposium II

Illuminating ENGINEERING SOCIETY

IES Research Symposium III
APRIL 3 - 5, 2016 | GAITHERSBURG, MD

LIGHT + COLOR Final Report
May 1, 2016

Introduction

The third Illuminating Engineering Society (IES) lighting research symposium, held in Gaithersburg MD in April 2016, took an in depth look at specific aspects of light and color. The four elements of focus were:

- Color Metrics
- Color Vision
- Color Perception
- Color Preference

The general goals of the symposium were:

- Identify and present key research on the subject of light and color
- Provide a format for exchanging ideas and connecting individuals and organizations involved in and interested in the research
- Link research and application by experiential demonstrations
- Incorporate research findings into IES committee work and other recommended practice

Attendance at the symposium numbered 170 and represented a wide variety of organizations and professions, including lighting research, engineering, manufacturing, architecture, retail, textile chemistry, lighting design, interior design, standards, instrumentation, and academia (both students and faculty).

The symposium employed a unique format for the symposium speaker sessions, with two speakers presenting on each of the four focused topics – one speaker covering current research and the other covering design and applications in the real world. The purpose of such a format was to make a robust connection between research that is known and research that is needed relative to color, and then relating that research to lighting application and practice. Two additional special keynote speakers, along with poster papers, lab tours, networking and demonstrations further enriched the attendee experience.

General Session Speakers

All general session speaker presentations (or summaries) are accessible to symposium attendees through this same Final Report online portal. What follows is a brief description of each of the speaker sessions:

Color Metrics: IES TM-30 Light Source Color Rendition
Randy Burkett, President & Design Principal, Randy Burkett Lighting Design
Michael Royer, Lighting Engineer, Pacific Northwest National Laboratory (PNNL)

The lighting design and engineering community needs a more comprehensive method for assessing and specifying light source color attributes. Rising client demands and expectations in the area of color has further illustrated the deficiencies of a fidelity-only approach. This presentation provided an understanding of how combining the fidelity index, gamut index, graphics, and detailed values from the *IES TM-30-15* method can provide a more user- and application-optimized environment. It covered new human-subjects research on color perception, and explored the application of this new research through real-life project design examples.

Color Vision
Ray Murray, VP Creative Services, Nautica
Steven Shevell, EH Moore Distinguished Service Professor, University of Chicago

To understand color vision, one needs to understand the idea of "Color Context". Colors are mental constructs that depend on neural signals in specific structures within our brain. Attendees gained an understanding that color is not static. Rather, the brain is continually "adjusting" color to properly fit the context that it perceives. The presentation also showed how designers combine multiple colors to create a palette and how they transition from palette to palette to create a "color story". It was also demonstrated how color and architecture can be combined to create retail spaces that provide a unique user experience.

Session sponsored by XICATO

Color Perception
Mark Fairchild, PhD, Professor and Associate Dean, Rochester Institute of Technology
Kevan Shaw, Lighting Design Director, KSLD

The speakers covered fundamentals of color perception, color matching functions and mechanisms of chromatic adaptation, along with research on individual differences in color perception. These fundamental research topics were also discussed with respect to their impact on practical color metrics such as those used in specifying color rendition of light sources. Additionally, the presentation looked at practicalities of lighting color selection based on research undertaken into lighting paintings in galleries. Since the advent of LEDs, the certainties of light color have been dramatically upset and options are now available that were previously unthinkable. Attendees were given a start on the way to understanding how to make color choices in this emerging world of LED sources, including some of the color metrics that are appropriate in gallery situations and related applications.

Color Preference
Kevin Houser, PhD, Professor of Architectural Engineering, The Pennsylvania State Univ.
Malcolm Innes, Principal, Malcolm Innes Design

The speakers gave an overview of what we know about color preference, citing knowledge from research, scientific literature, design and practice. They also discussed research hypotheses and unknowns regarding color preference, as well as application considerations related to new and emerging technologies. Some of the subtopics covered relative to color preference were color memory; the role of gamut, including saturation and hue shift; the role of objects in color preference; and the roles played by chromaticity, illuminance, and the spectral design of light sources.

Keynote Speakers

Don Holder, *Color and the Theater*: The symposium opened with a keynote from Don Holder, theatrical lighting designer. Mr. Holder has designed 50 Broadway productions and has been nominated for eleven Tony awards, winning the 1998 Tony for Best Lighting Design for "The Lion King" and in 2008 for the revival of "South Pacific." Using theatrical instrumentation, Mr. Holder demonstrated how the use of color in theatrical lighting design could influence perception, support storytelling, and evoke a specific emotional response. *Session sponsored by Finelite*

Neil Harbisson, *Life in the Age of Cyborgs:* The Color Experience evening event opened with a keynote from Neil Harbisson, a British-born color-blind contemporary artist who is best known for having an antenna implanted in his skull that allows him to perceive colors, as well as infrared and ultraviolet signals, by using sound waves. His artworks investigate the relationship between color and sound, experiment with the boundaries of human perception, and explore the use of artistic expression via sensory extensions.

Poster Papers

Researchers and designers actively involved in the study of light and color and how it applies to lighting from the research, technology, design, and application standpoints were invited to submit poster papers describing their current work. 15 papers were accepted representing not only the diverse work underway on light and color but also diverse thinking from countries around the world including Australia, Canada, Finland, Germany and the U.S.

The Final Report includes title, author information, abstract and the full text or the posted presentation for each of the poster papers presented at the symposium.

The authors of the accepted poster papers have been invited to submit their papers for publication in the IES Journal Leukos.

NIST Laboratory Tours

The IES acknowledges and thanks the National Institute of Standards and Technology (NIST) for their generous support and participation in this symposium. Founded in 1901, NIST is a non-regulatory federal agency within the US Department of Commerce. NIST's mission is to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life.

Attendees at the IES LIGHT + COLOR visited NIST for a full day of programs on Monday, April 4, 2016. In addition to Keynote Sessions and Poster presentations, attendees were given a unique opportunity to experience, in small groups, the following laboratory spaces conducted by NIST personnel:

Spectrally tunable light facility - Yoshi Ohno, NIST Fellow

In order to conduct state-of-the-art vision experiments on color and lighting, a Spectrally Tunable Lighting Source (STLS) has been developed at NIST. The facility has two STLS units, which illuminate separate room-size cubicles (2.5 m x 2.5 m) allowing subjects to be completely immersed and adapted in the lighting environment. This enables evaluation of the color rendering of objects, including human faces, in a real-life setting. Participants will be immersed in the environment and will experience a few of the experiments that have been conducted at NIST.

Total luminous flux facility - Yuqin Zong, Photometry Project Leader

The Absolute Integrating-Sphere Method is applied to routine calibration and measurement assurance program measurements of total luminous flux and total spectral radiant flux using the NIST 2.5 m sphere. The facility is the basis for integrated luminous flux (lumen) and integrated colorimetry for a

variety of sources including solid-state lighting products. Participants saw demonstrations of lumen and color measurements for a solid-state lighting product in order to better understand the information provided in IES LM-79 reports.

NIST Photometric bench - Cameron Miller, Optical Radiation Group Leader

Did you ever wonder how the unit of candela is assigned to a lamp or a luminaire? The Sensor Science Division at NIST is responsible for the realization of this SI base unit. It is realized using a detector-based method, which is directly traceable to the Division's Reference Cryogenic Radiometer, the Primary Optical Watt Radiometer (POWR). Participants calibrated a standard lamp in order to better understand luminous intensity distributions and iso-candela plots.

Field light and color measurements - Maria Nadal, Color & Appearance Project Leader

A variety of handheld illuminance, luminance and color measuring instruments are available in the market place. This laboratory experience described how these instruments work, the importance of calibration, and their limitations. Many devices were on hand for participants to use and understand their capabilities measuring a variety of sources including halogen lamps, white solid-state lamps and monochromatic lamps.

Color Experience Demonstrations

Past symposium surveys revealed that attendees desired additional experiential and interactive events. To address this request, the symposium planning committee included an opportunity for manufacturers or other organizations to sponsor demonstrations that related directly to one or more of the elements of color addressed by the symposium speakers. Listed below are the companies who sponsored color experience demonstrations, along with short descriptions of the intended experiences:

Cree: Experience how various light sources, compared via TM-30 graphic output, illuminate actual objects, colors, and textures. Attendees will be better able to match light source to application.

ETC: Experience the concept of metamerism and the notion that what seems to be the same color can be mixed in more than one way with strikingly different results on colors, textures, and materials.

current by GE: Experience a demonstration of a new color metric built around the Lighting Preference Index (LPI). Attendees will see first-hand the comparison between existing metrics and color preference.

Lutron: While "white tuning" is currently a commonly used term, it comprises several distinctly different methodologies. Attendees will experience these different methodologies as a means of evaluating the vernacular differences

Musco: Experience the manipulation of light level in one of two boxes until they appear to have equal brightness. This experience is intended to demonstrate the significance of color spectrum to the impression of brightness.

Philips: The use of a 7-channel LED light source will allow attendees to evaluate the impact of "white" light on an array of colors and textures through a user interface. Viewers experience for themselves the effects of changing color parameters.

Philips Color Kinetics: While color changing LED fixtures began as RGB, the channel counts have increased all the way up to 7. Attendees will be able to evaluate the perception of various LED combinations on colors, textures, and materials.

Xicato: Experience various color points both on and off the Black Body Line to assess color points with the same or different CRI, CCT, GAI as expressed through materials typical of interior or architectural design.

Roundtable Discussion

The final wrap-up session gave attendees the opportunity to discuss with one another, in an open forum format, their key lessons learned, questions that still need to be answered, and actions that they or others might take as a result of having participated in this symposium. What follows is a selection of comments, questions, and observations from attendees, shared during the roundtable:

- Key take-aways for individual attendees:
    - Context was stressed a great deal during this symposium, particularly as it relates to color preference; additionally, if preference is important, what about acceptability?
    - Regarding context, it is clear that we are ready to move beyond residential and retail as our primary application research areas and show how color preference differs in various contexts.
    - Also regarding context, commercial lighting color is not evaluated by managers on the basis of preference, but increasingly on any potential link to health and productivity.
    - We talk about color characteristics of light in interior spaces and have strong opinions about what they should be, but we rarely reference our opinions to the illuminance levels. Yet we know that our adaptation, and thus illuminance and luminance levels in the space, strongly affect our visual perception, color evaluation and acceptance of the lighting as well as the space and its contents.. How can we better reference what we see and evaluate to the lighting conditions that contribute to that evaluation?
    - There is clearly an entirely new vocabulary introduced by the IES TM-30-15 Technical Memorandum, "IES Method for Evaluating Light Source Color Rendition". The industry needs help in translating the information to their customers.
    - The TM-30 document stimulated much discussion, and several attendees are interested in seeing more "use cases" that show how, when, and why to use it.
    - The topic of individual differences was intriguing, as well as any future research into chromatic adaptation.
    - We need a better effort to identify the research that is going on in the area of light and color. Such an effort leads to more knowledge, which translates to more powerful influence.
    - Everyone who is in a position to do so needs to apply TM-30, as this is the best way to understand how it works.
    - TM-30 is a "baby," in that it will take time to mature and evolve.
    - It appears we are moving toward a time of multiple color metrics.

- Additional areas of interest related to light and color:
    - What about full field vision and peripheral vision as they relate to color? Color perception is not just about objects in central view, but also related to spatial perception and, therefore, there should be some interesting studies regarding how color interacts with full field view.
    - The textile chemists have an issue with proper illumination levels for evaluating color samples and are interested in what levels might be recommended based on the particular materials. Specifically, in color approval, what is the proper level of illumination for critical judgments, dark shades, and light shades? There are some numbers reported in standards, but the sources have been lost and cannot be verified. New research would be welcome.
    - There was much discussion regarding government specifications for color quality of light sources (mostly CRI and CCT), primarily in the energy efficiency arena. Distinctions were made between volunteer programs, such as Energy Star, and government regulatory actions such as those taken by the California Energy Commission and US Department of Energy. Some expressed the view that more advocacies citing solid research would be welcome.
    - Daylighting and the variations in color of daylight are of high interest to several attendees.
    - There is interest in knowing more about color discrimination, and if we can discern anything about it from an SPD.
    - We need to know more about how glazing systems modify the color of daylight for interior spaces, including color fidelity and color gamut measures.
    - What does IES need to do to develop a uniform color metric report and file format?

- Actions that are being taken soon—or should be taken:
    - Related to the government specifications concerns mentioned by several, one government researcher indicated that they are now working to add to ANSI C78.377 (currently referenced by regulators and other government programs) in order to allow for more variations in color, specifically below the black body down to -0.005Duv. It was pointed out that a simple solution is needed for regulators to address the fact that fidelity penalizes saturation, and that a formula just developed for combining these qualities might be the right answer.
    - One attendee is planning to measure his color matching functions before and after lens replacement surgery.
    - A color experience sponsor reported preliminary findings from the on-site brightness matching experiment they conducted with 29 symposium attendees. 26 participants had the same response as subjects from a previous experiment, which reported that there is approximately a 23% increase in brightness perception that is (in their estimation) due to the melanopsin receptor.
    - The IES Color Committee is in the process of revising DG-1 with a goal of translating a great deal of technical color information for designers.

- CIE is preparing to recommend the R_f metric from TM-30 as an international standard.
- One attendee will be starting TM-30 discussions within the IEC now, since it took five years for their acceptance of other documents such as LM-79 and TM-21.
- It was suggested that there is excellent information on color in other journals, which isn't easily accessible to IES members; asked IES to make other publications broadly accessible for the IES audience
- Related to the point of sharing journal articles, it was pointed out that the most valuable papers for designers are summary papers, not the individual research papers.

Acknowledgements

The IES would like to thank the members of the Symposium Steering Committee for their time and expertise in planning this symposium. Thank you to the following:

IES Symposium Steering Committee

Chair: Pamela Horner, *OSRAM SYLVANIA Inc. (retired)*
Members: Terry Clark, *Finelite;* Robert Davis, *PNNL;* Paul Gregory, *Focus Lighting Inc.:* Terry McGowan, *Lighting Ideas Inc*.: Frederick Oberkircher, *Texas Christian University (retired)*
Advisors: Ellen Carter, *Konica-Minolta (retired):* Kevin Houser, *Penn State University*
IES Color Committee Advisors: Wendy Luedtke, *Rosco Laboratories,* Chair and Jason Livingston, *Studio T+*L, Vice-Chair

Thank you to the following companies for their support of the symposium programming and events:

Presenting Underwriters
Finelite | Xicato

Color Experience Underwriters
Cree | current powered by GE | ETC | Lutron | Musco Lighting | Philips | Philips Color Kinetics | Xicato

Knowledge Underwriters
Eaton | International Association of Lighting Designers (IALD) | National Electrical Manufacturers Association (NEMA)

In-kind Sponsors
Konica Minolta | National Institute of Building Sciences (NIBS)