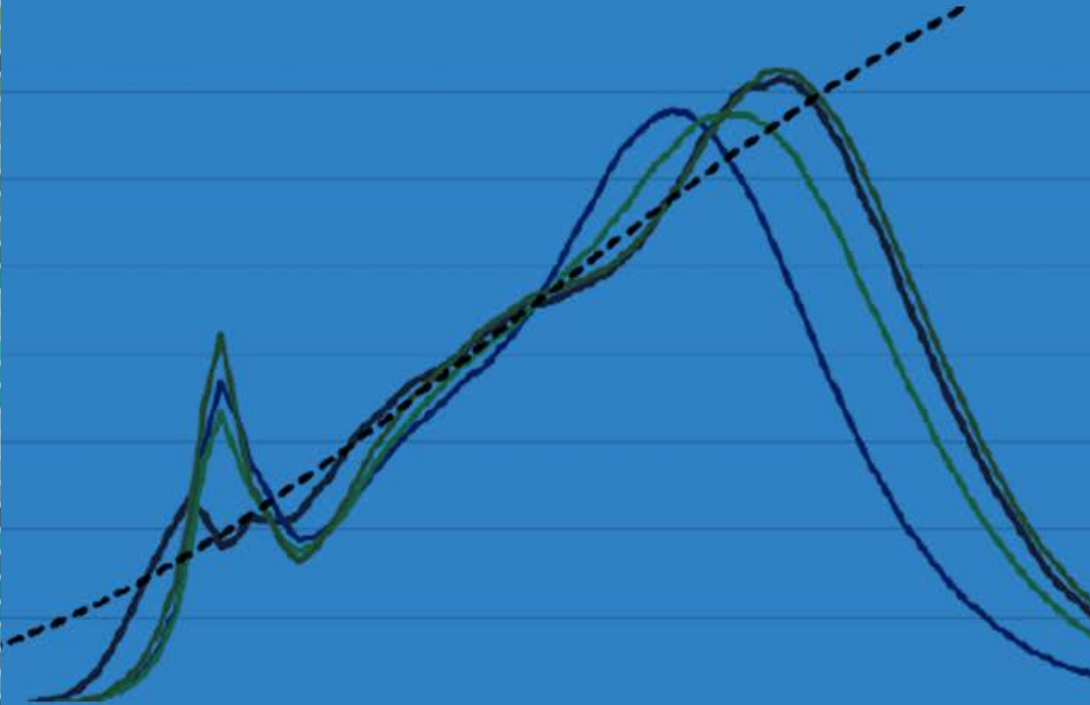


**New Product and Metric Research:
Final Report
March 4, 2021**



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Introduction

Executive Summary

The product that is the subject of this report is new LED light source (referred to as NP) that uses proprietary technology to closely emulate the spectra of natural light. The Average Spectral Difference metric developed by the Client is a new simplified approach to standardizing color rendering and quality of light that has potential to become a standard for quality of light. This research was conducted to evaluate the NP light source in connection with the ASD metric. While the methodology behind the metric is sound, data, perspectives, and insights were needed on NP and the cognitive relationship between the metric and the experience of high-ASD light sources, especially with top specifiers and influencers in the global lighting community.

General response to the NP light source was positive, with 87% of subject decision points preferring NP to the 90 CRI light source. Some specifiers were so positive about NP that they requested samples immediately. Response to the ASD metric was generally receptive, but cautiously so, as most subjects weren't familiar with it yet. The study showed a surprising variety of responses to comparing color rendering- the three that stood out were: 1) perceiving the 90 CRI as "warmer" initially not because of increased red but because of reduced cyan; 2) a perception of "crispness" and "fullness" of the NP light; 3) distinct differences in color perception that appeared to be gender specific.

The study yielded 405 pages (136,00 words) of interview transcripts and approximately 25 hours of video and audio recordings of the interviews. This is a large amount of material from which to draw many conclusions and observations - despite much time spent digesting it, I'm sure I have not captured every important insight. A deep look at the "raw material" of the interviews over time will no doubt yield different perspectives and more insights.

The subjects of the study, as well as myself, feel that NP is an important advancement in SSL technology and coupled with a fresh and robust approach to quantifying color rendering, presents great potential in application, if product and marketing strategy is executed well. As a thorough and extensive documentation of the voices of customers, this research serves as a resource in making strategic sales and marketing for NP and other related products.

This report has been redacted in consideration of proprietary information.

Clifton Stanley Lemon
CEO, Clifton Lemon Associates

How to Use This Report and Materials

This study was originally conceived as a hybrid of sales demo and research study. It depended on my access to a wide network of leading specifiers and lighting industry leaders in the U.S. and Europe. I drew upon my experience of doing sales demos for Soraa about ten years ago when we launched one of the leading high color rendering LED light sources. This is where I developed a feeling for the “wine tasting” approach that I describe in this report.

The lighting industry is perhaps uniquely close and interconnected. While I needed to adopt a certain degree of objectivity and to avoid “leading the witness” in this inquiry, this was not possible in much of the dialog. I opted to use my familiarity with interview subjects to gain access to their real feelings and unconscious responses. These are much more important than their reporting what they think I (or the Client) want to hear.

There’s a lot of insider talk in these interviews, some of which should be regarded, but much can be useful upon closer examination. With most of the subjects, we are picking up on conversations that have been ongoing for many years and touch on all of the most pressing questions and issues in lighting. I have also uncovered many areas for further exploration and research, if the Client decides to pursue, or support research in any way in the future.

I have produced many research reports as a consultant, and one of the behaviors I have observed is that much of the time the results of the report aren’t used or acted upon because of the volume of material that is generated in a careful accounting of results. Also, the study generated a massive amount of raw material, the videos, audio files, and 140,000 words of the interview transcripts. Much of this is grindingly boring, as many subjects carefully plow through one color at a time to compare color rendering, making a lot of irrelevant comments. For this reason I have included summaries for important sections that serve to index each area for further detail.

Selected Quotes

“I design for a lot of companies all over the world and I will use this technology. I would propose this technology to my client.”

“Sometimes there is no culture about quality light.”

“NP made me feel like the sun was coming in the window, with kind of a clear natural finish.”

“The burden now falls more on specifications and data, aligned with experience.”

“Our spec section still refers to CRI, and we haven’t developed a multi paragraph explanation of what we expect for TM-30.”

“I think it would be amazing to have one number vs. looking at multiple charts. But is that like the lazy lighting designers response though?”

“We are not doctors.”

“When I’m describing CRI and I’m getting into TM-30 with architects and trying to explain it to them, I always use skin tone as the thing to get the buyoff.”

“ASD does seem to reflect what I’m seeing better and might be a better metric for the industry.”

“I’ve never been a fan of pumping specific colors to increase their attractiveness.”

“I like the extended reds better as opposed to pumping the reds.”

“Light is a material, with volume and texture.”

“Honestly, it’s less about measurement and more about how it feels to me.”

“TM-30 is a great metric. It sucks for clients – I can’t tell them about it, but it’s very easy for me.”

“This was presented to a degree as human-centric and I already have red flags when it comes to that concept. It feels like a pure marketing ploy and not a bunch of stuff that’s backed up by deep research.”

“With the other metrics you’re saying this is the target and I designed the target and here’s how we’re meeting the target and I designed how we’re meeting the target. Whereas I think it’s interesting to say, here’s a target occurring not something I designed but something that occurs naturally in nature in the real world and here’s how we get paid from there.”

“After having seen it, if I see that a manufacturer is offering various chipsets and they have the Client NP I’m going to feel pretty good about specifying it as a general high color rendering source across the whole spectrum.”

“Any time I’m being forced to use something closer to 4,000 in a scenario where color matters, this technology is doing something that nothing else does that I’ve really seen. In this 4000k thing I’d be willing to go to the mat for it because there just isn’t a lot that makes things more palatable at 4000 K. So the metric the metric is kind of defining and creating a defensible point for an opinion.”

“All light is natural light.”

Research Parameters

Goals and Materials

1. Design a demonstration protocol for high ASD light sources, working with Client team
2. Identify, qualify, and recruit 25 top lighting specifier influencers for Zoom interviews
3. Design the interview protocol whereby specifiers review the light sources and the ASD metric and solicit valuable qualitative and quantitative feedback about the connection between the metric and experience
4. Analyze results and feedback from the interviews to provide a basis for further research, thought leadership, sales and marketing efforts


Each subject received the following at least one day before the scheduled interview

1. Light Box- 12" cube, open on one end, painted matte black inside, with 6 LED packages:
2700K standard Client product 90CRI vs 2700K NP
3000K standard Client product 90CRI vs 3000K NP
4000K standard Client product 90CRI vs 4000K NP
2. Control switch box wired to LEDs, with Off/on, and radial switch to toggle between each set of LEDs
3. Client whitepaper and Video on ASD
4. Reference objects- thread, classic color calibration target, wood samples, material board
5. Chart with comparative metrics for each light source: SPDs, CRI, TM-30, ASD (open for Sequence 2)
6. Sheet with instructions for the interview: preparation, including light requirements for room, light box setup, face lighting on camera; interview procedure; packaging and shipping for return of light box and materials, note on honorarium (\$150 Amazon gift card)

Light box setup instructions

Light Tasting Interviews
Interview Preparation

Light Box Setup



1. Per the diagram above, arrange the light box to left or right of your monitor/keyboard or laptop arrangement to provide easy access to both the light box, sample materials, and your computer. You will need both hands free to operate the light box switching and put in and remove material samples.
2. Have the sample materials accessible, ready to move into the light box when needed, and the SPD charts available for the appropriate section of the interview.
3. Provide lighting for your face, positioning it behind the light box so as not to interfere with the LEDs in the light box.
4. Avoid bright daylight or other ambient light in your office that might affect the light in the light box.
5. Turn on the box and allow it to warm up for 3-5 minutes before the interview (it doesn't matter which light source is on for the warm-up).

Other Pre-Interview preparation

1. Review the video on the enclosed thumb drive and read the enclosed materials/
2. For reference, view the enclosed sample materials in daylight before the interview

Interview Design

The research consisted of 25 one-on-one Zoom interviews using the Client demonstration light box. Subjects were instructed to view several objects in the light box and compare them under the six light sources switching from 90 CRI to NP in each CCT in order to highlight the differences between the two light sources. The objects are show below:

Interview Sequence 1

Run through toggled comparisons, focusing on 4 different samples

1 set of questions per CCT:

Question 1: What's difference between the 2 sources (in each CCT)? [Spontaneous comments recorded]

Question 2: Which light source looks most natural? [Scored]

Interview Sequence 2

1 set of questions per CCT:

Run through toggled comparisons, focusing on 4 samples, this time while looking at SPDs & TM-30 data

1 set of questions per CCT:

Question 1: What's different between the 2 sources (in each CCT)? [Spontaneous comments recorded]

Question 2: Which light source looks most natural? [Scored]

Question 3: How are the differences reflected in the metrics? [Spontaneous comments recorded]

Question 4: Has your answer changed, and if so why?

Interview Sequence 3

Face to Face, reading facial expressions, tone of voice & body language

Question 1: Is ASD useful to you as a specifier? [Spontaneous comments recorded]

Question 2: How do you feel about the NP light? [Spontaneous comments recorded]

Question 3: How could ASD solve any problems for you? [Spontaneous comments recorded]

Question 4: What do you see as the drawbacks of ASD? [Spontaneous comments recorded]

Question 5: How do you use TM-30 in specifying lighting?

Question 6: What do you think of the NP light? [Spontaneous comments recorded]

Question 7: Any other comments? [Spontaneous comments recorded]

Subjects' preferences for light sources were recorded on the scoring chart.

During and after the color comparisons, subjects were asked about their specification practices; their methods of evaluating light sources and color rendering; their opinion of the NP light; and their opinion of the ASD metric.

Interview Subjects

The selection of interviewees for the research was more weighted toward specifiers, but also included manufacturers, researchers, product managers, sales managers, writers, and other consultants. In the lighting industry it's not uncommon for individuals to have experience in many of these roles, or to hold them simultaneously – the diversity in perspective turned out to provide an unusual richness of feedback, ideas, and responses. While most subjects are based in the U.S., we did manage to include five subjects in the UK and EU. We also did our best to balance gender- 15 subjects were men, and 10 women.



Thomas Paterson, Founder and CEO, Lux Populi

Thomas is an internationally recognized lighting designer, educator and engineer. He splits his time between offices in Mexico City and Oxford, leading a multidisciplinary team of designers, architects and environmental designers who have won numerous awards for projects around the world. Lux Populi is one of the top lighting firms in the world.



Jim Benya, PE, FIES, FIALD, Principal, Benya Burnett Consultancy

James is an illuminating engineer and lighting designer recognized worldwide as a consummate professional whose CV includes experience in all facets of the lighting industry. As the recipient of over 251 lighting design awards including five Edison Awards for Environmental Design, he is regarded as North America's premier designer for environmentally responsible lighting design, daylighting design, and energy efficient street lighting sensitive to the biological needs of all living beings.



Daniel Salinas, Principal, Salinas Lighting Consult

Daniel Salinas has been in the electrical industry for over 36 years. The breadth of his design and project management experience spans both commercial and residential projects specializing in complicated installations where new techniques in constructibility are required. His passion is commercial lighting controls design where working with integrated technology is a requirement. He was President of the Illuminating Engineering Society in 2013-2014 and has received two IESNA IIDA International Awards of Merit for his work on special project applications. He lectures on lighting, lighting controls and sustainable design for programs at the University of Washington, Bellevue College and for the Illuminating Engineering Society.



Randall Whitehead, Principal, Randall Whitehead Lighting

One of the foremost authorities on residential lighting, Randall has written six books on the subject. Beautiful Light will be the seventh. His work has appeared in many publications including Architectural Digest, House Beautiful, Esquire, Horticulture and Architectural Record. He writes a monthly column for Furniture, Lighting and Décor Magazine called The Lighting Doctor where he discusses lighting trends and addresses lighting dilemmas. He has given presentations for LightFair, LightShow West, Strategies in Light, the American Society of Interior Designers, (ASID), the American Institute of Architects (AIA), the National Kitchen and Bath Association (NKBA), the American Lighting Association (ALA) and the Illuminating Engineering Society (IES). He has also appeared as a guest expert on HGTV, the Discovery Channel, CNN and Martha Stewart Living Radio.

Interview Subjects



Alan Lindsley, Principal and Founder of Lindsley Architectural Lighting

Alan is noted for his creativity, experience, enthusiasm and management capabilities. He has over thirty years of extensive project management experience in lighting design, interior architecture and historic preservation. As a result, he has the unique ability to fully understand and integrate lighting design with architecture. He has strong capabilities in delivering creatively designed, energy efficient and sustainable projects for corporate, institutional and governmental clients. He is well-experienced in effectively directing the efforts of large multi-disciplinary teams to provide effective budget and scheduling control. He holds a National Council of Architectural Registration Board certificate and is a member of the American Institute of Architects (AIA). Additionally, he is active in the Illumination Engineering Society of North America and the American Institute of Architects 2030 Initiative to produce a carbon neutral building.



Jeremy J. Steinmeier, Senior Architect, AECOM

Jeremy is a modernist architect and lighting designer with a passion for design and construction. Award-winning projects include single and multi-unit housing, retail facilities, and commercial projects. Evident in his work is an underlying commitment to thoughtful design, environmental stewardship, leadership through consensus building, and an appeal to the emotional experience of the user. He is currently President of the IES San Francisco Section.



David Wilds Patton, Owner & Principal, David Wilds Patton Lighting Design

David has been an independent lighting designer based in the Bay Area for the past thirty years. His work is primarily focused on residential design. Along with a small group of other practitioners, he has been actively attending California Energy Commission meetings and participating in comments on Title 24 and lighting codes since 2005.



Janet Lennox Moyer FIALD, COLD, Principal, Jan & Brooke, Luminae

Janet is an internationally known lighting designer and recipient of many design awards. She has judged lighting competitions, been published extensively in magazines, newspapers, and books. She has taught all over the world since serving as teaching assistant for her undergraduate lighting course at Michigan State University. Ms. Moyer's practice has included interior, commercial, and residential lighting, but her emphasis shifted to landscape lighting in 1983. Jan founded the International Landscape Lighting Institute in 2010.



Randy Burkett, FIALD, IES, President and Design Principal, Randy Burkett Lighting Design

As Principal Randy establishes design direction and oversees the management of the firm's projects. Since he began professional practice, he has been responsible for the lighting of numerous national and international commissions. His diverse portfolio comprises museums, retail malls and stores, corporate headquarters, offices, health care and laboratory facilities, urban parks, site developments and building exteriors. Before establishing his own firm in 1988, he was Director of Lighting Design at Hellmuth, Obata and Kassabaum. Randy is an active member of the International Association of Lighting Designers and is a past President and former Board member of the organization. He is engaged in Illuminating Engineering Society Technical and Design committees including the Color Metric Task Force, Quality of the Visual Environment, and Lighting for Outdoor Public Spaces. He has authored design and technical articles appearing in publications in over 40 countries. He is a frequent speaker to professional organizations on a variety of lighting design subjects and has served as an instructor at the University of Colorado in Boulder and Maryville University in St. Louis. He is currently a member of the Adjunct Faculty of Washington University's Graduate School of Architecture.

Interview Subjects



Clifton Manahan, Senior Associate, HLB Lighting

Clifton is an expert in new lighting technologies, fixtures and issues. With a strong aesthetic based in theater and fine art, his focus is on mastering technical applications - creating the most realistic and accurate lighting renderings and calculations, efficient and organized production, and especially well-thought-out and comprehensive lighting specifications. Most of his work is focused on new lighting fixtures, technologies and issues, how to apply them to projects for complete high-quality, low-energy and low-maintenance designs while meeting budget requirements, and how to communicate these designs effectively. He is a leader of HLB's Lighting Calculations and Standards/Templates focus groups. He has a BA in Architectural Engineering from the University of Colorado at Boulder.



Jennifer Cedar-Kraft, Senior Lighting Designer, Tucci Lighting San Francisco

Jennifer Cedar-Kraft has a background in both lighting design and outside lighting sales, Jennifer held a position at notable lighting design firm Silverman and Light for almost five years before her four year role in sales at the Bay Area based rep agency, Achetype Lighting Sales. Her transition back into design has allowed her vast experience in the industry to come full circle.



Nancy Clanton, founder and President, Clanton & Associates

Clanton Associates is a lighting design firm specializing in sustainable design. Nancy is a registered Professional Engineer in the states of Colorado and Oregon. Nancy is a member of the National Science Foundation committee on solid state lighting. Nancy received the ACEC Colorado 2013 Outstanding Woman Engineer Award. Nancy also received the International CleanDesign Award in 2013. Nancy is chairperson of the IESNA Lighting for Outdoor Public Spaces Committee and Mesopic Committee, past chair of the IESNA Board of Fellows Award Committee, past chair of the Model Lighting Ordinance IESNA and IDA joint task force, past chair of the IESNA Outdoor Environmental Committee, is a past member of the Board of Directors of the International Association of Lighting Designers, International Dark Sky Association, and the Illuminating Engineering Society. Nancy is a past member of the USGBC LEED Environmental Quality Technical Advisory Group. Nancy was a topic editor for the IES Lighting 9th Edition Handbook and her committee was responsible for the production of the IES Recommended Practice on Lighting for the Exterior Environment. Nancy was lighting group leader for Greening of the White House, led the lighting workshops for the C40 conference in Seoul, and was awarded the IES Presidential Award in 1990 and 2006. Her firm has authored the Lighting Criteria for The Department of Defense Unified Facilities Criteria, Colorado Department of Transportation Lighting Design Guide and the exterior sections of California's Title 24 2012 energy code. Her firm's lighting design projects reflect her sustainable philosophy and ten of their projects have been named to the AIA Committee on the Environment Earth Day Top Ten List. Fourteen projects for which Clanton & Associates designed the lighting are LEED Platinum rated. Nancy has a BS in Architectural Engineering, Illumination Emphasis from the University of Colorado, Boulder.



Gabrielle Serriere, Project Manager, Lighting Design, Luma Lighting Design, Portland, Oregon

Gabrielle is an outgoing designer with 12 years of experience working across architecture and lighting. Her five years of architecture work in Paris, Lausanne, and London provides a unique foundation for understanding spatial design, leading to how light creates, interacts with, and integrates into the built environment. Gabrielle approaches every design with outside-the-box thinking, detailed focus, and optimal efficiency.

Interview Subjects



Peter Fordham, Partner and Director, DHA Designs, London

Peter has over twenty years of experience in the lighting design industry, working for architectural lighting design practices in New York, London, Sydney and Hong Kong. He has worked on a number of award winning world-class exterior and interior projects across the globe. DHA Designs is an independent lighting design consultancy based in London. Since its launch in 1988, their team of designers has created award winning lighting schemes around the world. Their notable portfolio includes architectural, museum and hospitality projects and we pride ourselves in working with a diverse client base, ranging from interior designers to renowned hotels and museums. Before joining DHA in 1997, Peter was the design director at an independent lighting consultancy in Hong Kong. He has a Master's degree in architectural engineering from Leeds University.

MX (Identity redacted by request)

The interviewee is a prominent lighting expert who holds a position as senior engineer in a major government research facility as well as a leadership position in IES. They are also an internationally recognized lighting specifier.



Faith Jewell, Lighting Manager, WeWork

Before joining WeWork, Faith was a Senior Lighting Designer at Horton Lees Brogden Lighting Design, an internationally recognized design firm focused on architectural lighting for both interior and exterior environments. She was a Senior Lecturer at California College of the Arts and has a M.A. in Architectural Lighting Design from Hochschule Wismar in Germany.



Toby Lewis, Founder, Left Hand Lighting

Toby has built a distinguished career focused on revealing architecture with light. She has led all sizes and market sector lighting projects, receiving multiple awards and in 2018 was recognized as a 40 under 40 lighting designer to watch. Toby offers her expertise to architects, contractors, owners, and lighting design firms. Before founding Left Hand Lighting Toby was a Senior Lighting Consultant at Arup in San Francisco for 10 years. She has a BS in Lighting Design and Architectural Engineering from the University of Colorado Boulder.



John Bullock, Publisher and Editor, The Light Review; Director, John Bullock Lighting Design, Sherbourne, UK

John was born to be a lighting designer. "Don't blame me; it wasn't my fault." He was qualified in 'Illumination Engineering' in the early 1970s, working in electrical building services before joining a lighting manufacturer. By the end of 1984 John was working as an independent lighting designer, one of the new generation of UK lighters. The first iteration of his career saw him working as Design Director with a lighting design consultancy that he founded in London in 1986. It was the age of shopping centers; the 'retail experience'; new museums and galleries; business parks and hotels and . . . anything but residential. The second iteration followed a move out of London to the South West of England where, if you want to be a lighting designer, you WILL do residential projects. And that's what John has been doing for the past 20 years. John has always written for the UK lighting press, leading to the position of Applications Editor with Lux Review in 2016. That provided the opportunity to talk to any and every manufacturer and designer in the country. A great time -but it was never going to last. These days, John divides his time between providing high-end residential design within an hour of his home in Dorset and managing The Light Review which he established in 2019. If The Light Review is about anything it's about Good Lighting – whatever that means to you

Interview Subjects



Stefano Dall'Osso, Principal, D'O Lighting Design, Lugano, Switzerland

Stefano started his professional career in 1986 and he has been acknowledged as one of the Top 10 International Lighting Designer from Philips and High Tech Campus Eindhoven. Besides guiding SPLD's professionals in Lugano, Stefano is a member of APIL Italia (Associazione Professionisti dell'Illuminazione – Association of Lighting Professionals), member of IESNA (Illuminating Engineering Society of North America) and a Q Light professional qualified by Cielo Buio in the coordination for the protection of the night sky. Over the years, Stefano has collected many experiences in the academic field: he teaches at the Fine Arts Academy in Macerata, he was a teacher at the Experimental Design Centre Poliarte in Ancona and at the Lighting Academy "La Sfacciata" in Florence.



Karen Van Creveld, Principal, Karen van Kreveld Lighting Design, London

Karen van Creveld Lighting Design is an independent lighting design practice committed to providing highly creative, innovative and sustainable lighting solutions for a wide variety of architectural projects, both large and small. Karen is also a researcher at the UCL Institute for Environmental Design and Engineering in London, where her research is focused on understanding the actual daylight exposure experienced by various human populations in a wide range of typical working environments found in our current urban context.



Susan Larson, Vice President Western Region, Specialty Lighting Gorup

Susan is an experienced leader with a deep understanding of the LED and lighting industry, able to structure sales in new markets to maximize key opportunities for revenue. Before Specialty Lighting, Susan was CEO of 90 Plus Lighting, a division of SaveEnergy, the largest lamp OEM in Brazil, and only carries products that are approved to meet the CEC's rigorous Title 20 and JA8-2016/Title 24 standards for quality and efficacy. Susan also held several titles at Soraa over seven years, including VP of Sales and Product development, and was instrumental in the company launch in 2012.



Scott Yu, Chief Creative Officer, Vode Lighting

Over the course of his career as a product designer, Scott has always worked with three criteria in mind: low to no production waste, low energy consumption, and long product life. Whether it was at Ford, Peugeot or Volvo – where his work on Citroen's ECO 2000, a research vehicle, delivered an unheard of 90 mpg – Scott has always made the environment a priority. Scott was first drawn to the lighting business at a time when it had yet to take seriously the imperatives of sustainability. He found LEDs to be an ideal platform for transforming the industry and, with Vode, a home where his ethos of doing more with less was championed. Before Vode, Scott co-founded San Francisco-based Gingko Design and led the firm in winning numerous awards, including IDEA, CES, iF, Good Design, ID Magazine and Singapore Design. A graduate of the Art Center College of Design, Scott was the youngest manager at Ford, overseeing its Small Car Studio, developing global platforms and designs.



Basar Erdener, Director of Marketing and Product Management, LED Linear

Basar is an experienced senior level lighting industry professional with demonstrated leadership qualities. At LED Linear, he champions product innovation, brand management, strategic product development, product management and product marketing. Before LED Linear, he worked at Zumtobel and WAC Lighting. He has won a number of awards including the Robert Brice Thompson Luminaire Design Award 2011. Erdener is an active member of the Illuminating Engineering Society (IES) and International Association of Lighting Designers (IALD), has spoken at a number of industry events including Strategies in Light and US Department of Energy (DOE) workshops. He holds numerous patents and also pursues interest in fields related to SSL including energy, biology, sustainability, and human-centered design. Basar was recognized in 2020 by LEDs Magazine in its 40-Under-40 profiles of leading lighting industry professionals.

Interview Subjects



Krista Taylor, Specification Sales, 16500

Before 16500, Krista was Regional Sales Manager for Ecosense Lighting and Strategic Alliance Account Manager for Lutron Electronics, where she drove new business development opportunities related to Lutron’s commercial systems business. She was also an interior designer for Architecture & Light in San Francisco and has a BFA in Interior Architecture from Academy of Art in San Francisco.



Marco Frascarolo, Founder and CEO, Fabertechinca, Rome

Marco founded Fabertechinca, a firm serving Architecture and Engineering consultancies in 2001. Fabertechinca has developed over 200 lighting projects: outdoor, indoor, public lighting, exhibitions and events, including lighting the Sistine Chapel in Rome. Marco is Scientific Board Member and Chairman in many AIDI (Italian Lighting Association) Congresses. PLDA (Professional Lighting Design Association) Associate. Testimonial of Regione Lazio Lighting Design activity in Small and average Chinese enterprise Fair in Canton (2006). Curator and co-author of “Lighting Design Handbook” M. E. Architectural Book and Review (2011). Author of 35 scientific papers. He was also Technical Physics and Lighting Design Professor in Sapienza, and is on the Roma Tre Faculty of Architecture. He is a Member of Academic Board, Education Coordinator and Professor in Sapienza Master in Lighting Design. Academic Board Member and Professor in Roma Tre Sustainable Urban Design PhD. He graduated in Civil Engineering in Sapienza Rome University in 1992, PhD in Technical Physics in 1996, and has been a researcher in Technical Physics in Roma Tre Faculty of Architecture since 2005.

Findings and Analysis

Summary Findings

Enthusiastic Response to NP

NP is very well received – several interviewees expressed an interest in specifying it immediately. A typical quote: “I absolutely love it! I want it on my projects now!” Virtually all interviewees had positive responses.

Positive Response to ASD

The new metric was generally well received, in principle. The prospect of replacing TM-30 or CRI seemed daunting and perhaps not as important as perceived utility.

Diminishing returns on Quality Light

For a light source for general lighting, there’s not much room for improvement in quality of light – in a certain sense NP may be as good as a solid state light source needs to be.

“Warming Up” from Better to Best

Differences between 90CRI and the very high color rendering NP were often difficult to discern, even for the industry’s top tier lighting specifiers and experts. Interviewees came around to seeing NP as superior sometimes gradually, sometimes quickly.

Spectral Compensation

Lack of full spectrum in lower color temperatures was often perceived as warmer, even with a high 450nm spike. This effect was consistent across almost all interviewees at first.

Significant Gender Gap on Color Perception

Many male specifiers may have significant color perception variation (or deficiency) – women were noticeably more sensitive to color rendering differences between the two light sources.

Wide Variation in Use of Metrics

TM-30 metrics and SPD charts are not as widely used as we may think. Many interviewees use both frequently, but in significantly different ways. Some don’t use SPDs or TM-30 charts at all and don’t even quite understand them.

Black Body Black Magic

The black body curve as a standard reference is not well understood universally, for instance the fact that there are different reference curves. It’s mostly taken on faith.

Not Sun-like

Sunlight as a reference for interior light is not particularly relevant to specifiers and designers of interior spaces in practice.

Clarity and Crispness

Most interviewees responded to NP using these two terms, a surprising discovery. It suggests that visual clarity is greatly enhanced by full spectrum light – not necessarily a new idea, but one with excellent marketing implications.

Circadian Ambivalence

Health benefits of lighting remain unclear and specifiers aren’t willing to commit to them. Most interviewees are not successful in specifying even tunable white in most of their projects.

Natural Light for Humans and other Natural Things

There is a strong positioning available in the Quality LED space, one that has broader, more immediate and practical benefits and includes a healthy building perspective

Summary Findings

Full Spectrum Light as the Safe Bet

An “all purpose” full spectrum light is seen as reliable, practical and a good investment, as it renders the widest range of materials, skin, plants and food well.

Color Response is Highly Personal

Interviewees had widely varying responses to color and light, which may not be surprising in the general public. What was surprising was that many top thought leaders in lighting who are steeped in color theory, physics, and lighting science still make their fundamental judgment of light by thoroughly unconscious processes that they themselves don't fully understand.

Comparative Light Source Assessment

ASD Interview Scores

Updated 3-2-21

	Interview Date	Without SPDs									With SPDs						Preference					
		Hand 2700K	Hand 3000K	Hand 4000K	Material 2700K	Material 3000K	Material 4000K	Thread 2700K	Thread 3000K	Thread 4000K	Chart 2700K	Chart 3000K	Chart 4000K	Hand & Materials 2700K	Hand & Materials 3000K	Hand & Materials 4000K	Chart 2700K	Chart 3000K	Chart 4000K	Percentage Thrive	Percentage 90 CRI	Percentage ND
T=NP 90=90CRI ND=No Difference																						
Group 1 - Specifiers																						
Thomas Paterson	12-Nov	90	90	T	90	90	T	90	90	T	90	90	T	90	90	T	90	90	T	33	67	
Jim Benya	30-Oct	T	T	T	ND	90	T	ND	ND	ND	ND	ND	ND	T	T	T	T	T	T	55	5	40
Daniel Salinas	2-Nov	T	T	T	90	T	T	T	T	ND	T	T	T	T	T	T	T	T	T	90	5	5
Randall Whitehead	31-Oct	T	T	T	T	T	T	T	T	T	T	T	ND	T	T	T	T	T	T	95		5
Alan Lindsay	2-Nov	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	100		
Jeremy Steinmeier	30-Oct	T	T	T	ND	T	T	T	T	T	T	T	T	T	T	T	T	T	T	95		5
David Wilds Patton	5-Nov	90	90	T	T	T	T	90	T	ND	90	90	ND	90	90	T	T	90	T	45	45	10
Jan Moyer	5-Nov	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	100		
Randy Burkett	3-Nov	90	90	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	90		10
Group 2 - Specifiers																						
Clifton Manahan	9-Nov	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	100		
Jennifer Cedar-Kraft	12-Nov	T	T	T	T	90	T	T	T	T	T	T	90	T	ND	T	ND	T	T	80	10	10
Nancy Clanton	13-Nov	T	T	T	T	ND	T	T	T	T	T	T	T	T	T	T	90	T	T	90	5	5
Gabrielle Serriere	23-Nov	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	100		
Peter Fordham	20-Nov	90	T	T	T	T	T	T	T	90	90	T	T	T	T	T	T	T	T	85	15	
MX	3-Dec	T	T	T	T	T	T	90	T	ND	T	T	T	T	T	T	T	T	ND	85	5	10
Faith Jewell	8-Dec	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	100		
Toby Lewis	23-Nov	90	90	T	90	T	T	T	T	T	T	T	T	T	T	T	T	T	T	85	15	
John Bullock	3-Dec	90	90	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	90	10	
Stefano Dall'Osso	11-Jan	T	T	T	T	T	T	ND	T	T	ND	T	T	T	T	T	T	T	T	90		10
Karen Van Creveld	14-Dec	T	T	T	T	T	T	T	T	T	T	T	T	T	ND	T	T	T	T	95		5
Group 3 - Manufacturers & Other																						
Susan Larson	12-Nov	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	100		
Scott Yu	20-Nov	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	100		
Basar Erdener	24-Nov	T	T	T	T	T	T	T	T	T	T	T	ND	T	T	T	T	T	T	95		5
Krista Taylor	1-Dec	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	100		
Marco Frascarolo	8-Jan	ND	90	T	T	T	T	T	90	T	T	T	T	ND	T	T	T	T	T	80	10	10
																			Overall	87.1	8.1	4.8
																			Men	82.9	11.1	6.0
																			Women	93.5	3.5	3.0

Preference Scoring

NP was preferred, or deemed more natural, in more than 87% of the 450 distinct decision points (25 interviewees each making 18 separate choices). This is generally positive result (I got many comments on how beautiful NP was) and should be taken at face value. When presented with a superior color rendering light source side-by-side in this fashion the superiority of NP is not too difficult to see, or so it would seem. Here, the outlying results are perhaps as instructive as the expected results.

The single biggest surprise to me was that differences in color rendering that to me seemed glaringly obvious were not picked up universally by interviewees, and the sample represents a very good cross section of the top lighting specifiers on the planet. Interviewees could be easily divided into two groups- those who could see what I see in the color rendering difference, and those who didn't. I'm not sure if this is due to my many years of being trained to spot good color rendering while at Soraa, but I was consistently surprised at how much my perception differed from several interviewees. Also despite the "warm-up effect" I will discuss later, it was easy to tell from the first few comparisons which interviewees saw the differences I saw. (I could not profess any objectivity here whatsoever, but I preferred NP in 100% of the choices, it was very clear and obvious to me that NP is a superior color rendering light source).

Comparative Light Source Assessment

The Availability Bias and The Wine Tasting Effect

The work of behavioral psychologists Amos Tversky and Daniel Kahneman produced many models and principles for understanding human behavior. Some of these are extremely useful in research and in sales. I stumbled upon one when devising demonstration methodology for Soraa back in early 2012 when we began demonstrating the impact of high-CRI LED lighting to the specifiers and influencers who would eventually build our brand.

This is the availability bias - when faced with a decision, we tend to see things that come readily to mind as being more relevant than they actually are. You could also call it using the power of suggestion in persuasion. Basically, tell people they will experience a grassy note or a bump in the red and they will.

With Soraa, at the time the only significant high color rendering LED products on the market were Xicato chips and Soraa lamps. The predominant MR16 was a Philips 80 CRI product that was acceptable for general lighting purposes but was not of particularly high quality. Our task was to demonstrate high quality light in a dramatic and compelling way, which we proceeded to do with considerable success. After experimenting with several different side-by-side double light boxes, where one side had the Philips lamp and one side had the Soraa lamp, both lighting identical objects (selected to show a wide range of colors and textures), we settled on a better light box design. The problem with the double box side-by-side comparisons, which necessitated customers switching their gaze back and forth between the two sides, was that they made it too difficult for customers to compare. A single box design where the exact same things were lit from above from one location, switching light sources back and forth from high color rendering (95 CRI) to 80 CRI showed an increase in positive responses.

We also developed what I came to call the “wine tasting” approach, which is essentially leveraging the availability bias to excellent effect. Wine tasting at a vineyard or wine shop is one of the strangest and most fraught sales situations in our economic landscape, and one where “expert” wine salespeople exert a tremendous amount of unconscious influence over buyers. A powerful technique they use is to plant suggestions in the minds of customers about what they’re about to experience, using somewhat arbitrary, poetic, and typically wine-insider coded terms to describe different flavors and notes. Most of these – words like “leathery,” “grassy,” “peppery,” “jammy,” or “mineraly,” have a basis in reality, but the fact remains that very few human beings (and certainly not all wine salespeople) have developed their senses of taste and smell to the high degree that professional wine people or perfumers have. So customers are at an immediate information disadvantage when tasting and buying wine. Add to that the pressure of projecting the image of the discerning connoisseur to friends, family, and other customers in the shop, especially for men, and you have the ideal setting for a very malleable buying decision based entirely on often conflicting emotions, devoid of any effective rational calculation of economic value.

The “light tasting” approach to showing high quality light in a sales situation is not intended to deliberately take advantage of undiscerning customers, but to borrow from wine tasting the technique of “framing” the experience of light by explaining to customers what they’re seeing and why they’re seeing it. After taking time to explain and demonstrate it, The ASD metric proved helpful in this. For one thing, the subjects in this study are far from uneducated about light and color rendering, in fact many if not most are pretty much obsessed with it.

To be clear, the planting of suggestion in this study came only after I recorded the initial impressions of subjects, which were not universally in favor of NP. In fact, because of what I call the warm-up effect, they needed some explaining before they began to understand what was happening. Even the world’s top lighting geeks make decisions unconsciously in a split-second process, then turn to data to confirm these decisions. In an actual sales situation, the explana-

Comparative Light Source Assessment

take the time to look into which LEDs are in luminaires they specify as they don't typically have the time to do that. Also, luminaire manufacturers usually don't have a sophisticated ingredient brand strategy (like Intel Inside) for several reasons. However, one notable exception is Xicato, who did build a successful ingredient brand with specifiers and took a leading position in the high quality, high color rendering space early on. Soraa also took an early lead in this space but never seriously pursued the ingredient brand strategy, failed to develop new chip level technology for several years, and lost whatever advantage they might have gained in this market.

The Warm-up Effect

A very consistent pattern when subjects first viewed the NP light with me – it was the 2700K vs the 90 CRI – was that they saw the 90 CRI as warmer. To me the obvious explanation for this is that the 90 CRI source is not higher in red, in fact it isn't, but that it's deficient in cyan, a very common problem for LEDs. There is another very strong bias for warmer light sources among most lighting specifiers, so this affects what they see significantly. The next tendency that became apparent very early on was that they either judged the NP to be more "complete" or less "flat" than the 90 CRI, or saw the 90 CRI as being more yellow. This tendency came out often as soon as they did the 3000K comparison, so even though their first impressions were that 90 CRI was warmer by the time they had seen the 3000K, and definitely the 4000K comparisons, they realized that NP is a full spectrum light source. It's important to note that preferring the 90 CRI was an effect that showed up somewhat randomly in subjects – they often changed their minds when they went back to the same comparisons with the SPD and TM-30 charts.

From observing this effect, it would seem that we judge the color rendering ability of different light sources not only by what's there, but by what's missing, and we compensate. So what's in fact a deficiency (or a deviation from the black body curve) in a warm light source missing cyan is perceived as a desirable attribute by specifiers who love warm light sources. It also speaks to the declining importance of color rendering as light sources get warmer, a phenomena we all know about but may not yet fully understand or measure. This becomes important when considering the SPDs of tunable sources, and how they behave.

Gender Differences

Of the interviewee decision points where 90CRI was preferred, the overwhelming majority were men. Although the study was not intended to address gender differences in color perception, I could only conclude that many male lighting designers appear to be much less able to see fine differences in color rendering. The effect was significant only 3.5% of women's preference choices were for 90CRI, vs 11.1% for men. This fact would also be subject to strong self-editing as well, because lighting designers are widely assumed to be able to make fine visual differentiation in color rendering. Any admission of deficiency would very likely be consciously (or unconsciously) suppressed as a matter of preserving professional credibility.

The Crispness Effect

Many interviewees used terms like "crisp," "pure," and "clarity" to describe the NP light. This appears to be a significant attribute of NP as a full spectrum light source - it improves visual clarity and optimizes photopic response relative to spectral power. Subjects reported seeing more contrast in subtle variations of color in leather and wood grains, judging the 90 CRI source to be "flat" by comparison. By contrast, some subjects saw NP's spectral averaging as making colors flatter and not popping as much as out-of-gamut or truncated spectra, but this effect was mitigated by perceptions of "fuller" color.

This finding is surprising in that "clarity" in light sources is not typically attributed to color spectrum, but to optics and distribution. Because of low lumen density and other technical issues, first generation LED lamps and luminaires often used distributed chips and optics that produced multiple shadows and compromised clarity.

Specifier Behavior and Attitudes

Specification Decision Making

Not surprisingly, the subjects of this study, being true craftspeople and veterans of many lifetimes of projects and installations, value direct experience of light sources above all other criteria. Most have extensive testing rooms or small “lab” facilities piled high with lamps, luminaires, control equipment, power sources, and other related gear where they test solutions, devise mockups, and generally roll up their sleeves and tinker, in order to carefully qualify what they specify. They will typically make a considerable investment in locating products and manufacturers that they can trust to provide consistent solutions, hence they tend to want to specify the same products once they find them.

Another important factor here is that specifiers can’t often find what they want, either because the spectral qualities they need aren’t available in certain formats or sizes, or because it doesn’t exist, despite the wide proliferation of SSL products on the market. So there’s a good deal of frustration among specifiers – they know exactly what they need, but can’t find it. This presents an opportunity.

I directed much of my inquiry into specifier behavior to the crucial period before they narrow down their choices to bring products into their physical testing facilities. With a very large, and steadily increasing, pool of products from which to choose, it’s impossible or at best impractical to see and test everything. So I asked about how they go about selecting SSL products on specifications alone, specifically what data and metrics they use. Most use a combination of metrics, starting with CRI out of convenience more than anything else, to get a general first level narrowing down, then proceeding to SPDs and TM-30 when they are available, then going to physical samples to evaluate and use in mockups.

Openness to New Sources

The top-tier specifiers and lighting professionals in this group are all passionate about light and color. Some of the older professionals have a strong context of incandescent light as the best color rendering light source, even though SSL technology has surpassed incandescent in almost every regard as a superior lighting technology. Most in this group have a strong recent memory of the poor quality of light in early LED products, and even now are still looking for the definitive, best light source. All are open to finding and using the best possible light sources available, within clearly defined cost parameters. And most are more than willing to work closely with manufacturers to develop top quality lighting products.

Learning Curve for Associating Data with Experience

A key factor in the adoption curve for ASD is the time required for specifiers to equate ASD data with real-world empirical evidence – to “see” light in terms of ASD like we currently do with CRI. In this study I was able to create a somewhat artificial situation where we looked at the data on the light sources in great detail while experiencing the light and comparing sources. Most of the time this can’t be done, as it involves a special light box, having all the current data, and someone to walk the customer through the process. While ASD is relatively easy to understand, no subjects began referring to ASD or thinking about it when viewing the comparative light sources, this is not surprising as it will take quite a bit of time to get used to. After all, we’ve all been trying to understand and use TM-30 for five or six years, and that’s still going slowly.

The Emotional Decision Making Sequence

A careful examination of the interviews shows that subjects spend a lot of time trying to understand their perceptions. We know from decision science and behavioral economics that we make decisions mostly unconsciously very quickly, then spend the rest of the time justifying the unconscious decision with “rational” thinking. In the case of a binary choice between which is better, many subjects could not provide adequate intellectual justification for their decisions, as many initially tended to prefer the 90 CRI as being warmer. This became quite evident when, go-

Specifier Behavior and Attitudes

ing back to the original comparison but looking at SPD charts, I pointed out the higher red and cyan values on the NP. After seeing the charts, many changed their minds and began to “see” the differences in a different way, but many still stuck with their original choice. One in particular, out of pure orneriness, preferred 90 CRI throughout in the warmer colors, a result that needs to be understood in context- this particular individual is particularly contrary as well as being particularly brilliant. Some were not able to judge accurately because of possible color blindness, although this needs to be studied in greater detail.

While the clearest pattern that emerged was that people needed to “warm up” to seeing NP, I was consistently impressed at the variety in color response from this carefully selected group of the top lighting professionals in the world. Understanding every individual’s way of seeing color and telling a story about (and with) it is an important part of this sales process – introducing specifiers to this new excellent light source.

Circadian Ambivalence

Attitudes toward the value of “human-centric” or circadian lighting varied considerably in this subject group. Not surprisingly, most subjects feel that lighting and health is important for their clients, and want the “healthiest” light sources they can find for their projects. But the entire lighting industry has been calling for more research on lighting and health for the past six or seven years, and there are still few justifications for paying a premium for light with special qualities that supposedly improves health or productivity. Owners just can’t or won’t pay for it. Most specifiers also perceive considerable risk in “medicalizing” lighting in a way that could expose them to liability in buildings where occupants have any health issues.

Standard Reliable Universal (ROI on Full Spectrum)

An important benefit of a full spectrum lighting source that does not specifically accrue to health or “human-centric” concerns is essentially risk management. In fact designers almost never consider how light affects human beings or other living things like pets, plants, or food in the spaces they design because they’re primarily focused on structure and materials they control in the design process. Architects and interior designers specify a wide range of interior and exterior materials which must be well lighted. Many of these have “natural” finishes, surfaces, grains, and of course, colors: stone, wood, leather, plants, and fabrics. Lighting designers, who often don’t even get a chance to see the final material and color specifications, need to support the success design process by ensuring that whatever light sources they specify do a predictable and optimal job of making interior finishes and materials look good, otherwise some very expensive designs can be seriously compromised.

Several subject reported that having a “Standard Reliable Universal” full spectrum light source (or metric), one that is perceived as close to daylight or a black body, would remove considerable risk from their design practice, as it can bring out the best in the widest range of materials, colors, and finishes. This is a strong argument for ROI when advocating for optimal light sources in a design with the design team and project owners. This expressed opinion was supported by the reactions of subjects to the effect of NP on textured and natural materials- they overwhelmingly preferred NP to the 90 CRI. The comments about the “fullness,” “texture,” and “crispness” of NP speak to this as well.

Awareness of Competing Products

The scope of this study did not include much room for a detailed collection and analysis of products competing with NP, but many subjects mentioned these products as a matter of course to establish their frame of reference. These are valuable perceptions and indicate much about how NP can be positioned in marketing strategy. The primary products that were mentioned were the traditional brands Xicato, Soraa, and Ketra, and newer entrants Seoul Semiconductor, Nichia, Bios Lighting, Lumileds, and Ecosense, roughly in that order of frequency. Many specifiers don’t

Specifier Behavior and Attitudes

Use of Other Color Metrics and Data

The following is a summary of how subjects view and use the most common metrics for light and the data associated with them.

SPDs – Although SPD data is the basis for TM-30 data, the use of SPDs is inconsistent in this specifier group. Some use it immediately when assessing a light source, but many do not, and a few barely know what it is, depending on their eyes alone to make the crucial judgments about light quality. Some now use TM-30 in place of SPD's.

TM-30 – Despite the fact that TM-30 has been in the market for over 5 years, many specifiers still don't use it much. Many find great value in it and do rely on it. But even ones in this study who were part of the process of developing TM-30 don't use it exclusively. They seem to prefer the "hue circle" or color vector graphic as the most useful in showing deviation from the gamut of the reference illuminant. It's also difficult for specifiers to convey the relevance of TM-30 to clients. Some specifiers find it too detailed and confusing. Most of this was well known about TM-30 coming into the study, but detailed responses from subjects were particularly illuminating. Most specifiers expressed frustration that they don't find TM-30 data on cut sheets, and have to ask manufacturers for the data. This was particularly surprising to me, given the ease of creating TM-30 graphics and the amount of time TM-30 has been available.

CRI – Even though TM-30 has by no means replaced CRI as a metric, and is not as widely used as initially desired, specifiers now see CRI as a much less accurate measure of color rendering. To those specifiers who were listening and understood (most of this subject group are in this camp), the development of TM-30 did very effectively expose the inaccuracies and deficiencies in CRI. So there's a gradual awareness of TM-30 but not the kind of adoption of the metric we might have expected. Subjects made comments along the lines of "I know I should be better and use TM-30 but I don't have time and it's too hard to explain to clients."

EML and CS – None of the subjects reported using these metrics (Equivalent Melanopic Lux and Circadian Stimulus) at all when assessing lighting sources. There are probably several reasons for this: specifiers see no reason to use them on their projects because their clients don't know what they are; manufacturers don't have the data or supply it; and the metrics are not well understood or commonly used yet.

COI (Cyanosis Observation Index) – The only subject who mentioned this metric was Jim Benya, as he and his partner Deborah Burnett have made a name for themselves by doing research and talking and writing about it a lot. It refers to light sources between 3300K and 5300K, and describes a light source's suitability for visual detection of cyanosis in a patient. The lower the value, the better suited it is. It could be an important metric to use when marketing lighting for health care situations, but further research is needed to determine the potential size of the market, and potential application.

Cautious Optimism with ASD

Some subjects did not spend much time studying the supplied ASD whitepaper or video, many had a general understanding of how ASD worked, but most needed some explanation. However, once I demonstrated ASD in practice with comparative lighting sources, it was easier for subjects to understand the metric and imagine using it. No subjects had strong objections to the ASD methodology, and most were cautiously optimistic and agreed that it was a step in the right direction and usefully addressed the problem it was meant to solve, which is to assign a single simple metric to color rendering capability.

Specifier Behavior and Attitudes

But Will It Play in Peoria?

Despite general agreement with the ASD methodology, the biggest concern voiced by subjects was getting the industry to adopt the metric. This of course is a formidable challenge, as there have been dozens of color rendering systems proposed and few universally adopted, as explained in the IES response to the introduction of ASD. One subject reminded me of the considerable effort that went into certifying TM-30 in IES committees. There was a competing metric called CQS developed originally by NIST, vying for adoption back in the early 2010s, it too had the backing of IES committees but failed to catch on.

Obvious Problems with ASD

Quotes from subjects illustrate some of the typical problems they had with ASD upon first encountering it.

Metric Fatigue

"There are too many metrics out there. Probably no other manufacturers are going to use this metric." This comment underscores a well known objection- even if ASD is a better metric it faces considerable adoption resistance by virtue of timing.

Natural Skepticism

"Let's talk about the baseline- where the baseline was developed and how valid is that? And what is natural light?"

From one perspective, "natural" light is like "natural" food, far too broad a concept to easily define and measure. Considerable persuasion and exposure is necessary to get specifiers used to the idea that electric light from LEDs below 6500K is "natural," whatever the spectrum.

High Cognitive Load in Understanding ASD

"I was expecting to see color bars for 266 colors."

"It takes some explaining...to get the hang of it and to be able to talk to look at the SPD and then see those values at the bottom. You can see the dips in the TM-30 bars, but it doesn't leap out as obvious to me at first glance when I'm comparing that. The number itself, the ASD number...I understand that being expressed as a percentage, the lower the percentage the better, but it doesn't actually tell you where the deficiencies are - you need to look at the SPD to be able to see that."

These comments indicate both problems and opportunities. The one about color bars for 266 colors is interesting because it points to the need to improve data display and clarity. What would it look like display show the level of conformity the black body for every one of the 266 wavelengths on the spectrum graphically? Perhaps this wouldn't be useful at all- most subjects found the TM-30 color bars to be not particularly useful.

The second comment indicates that more than one data display may be required to convey the full impression of how a spectrum behaves, a number and a graphic display. TM-30 is not particularly successful in using two graphics to convey this information, and the "hue circle" vector graphic seemed to be much more preferred.

Specifier Behavior and Attitudes

A Not-So-Obvious Problem with ASD: $V(\lambda)$

Several subjects noticed that the ASD calculation involves cutting off the very small ends of the visual spectrum, based on the range of the photopic response curve, or $V(\lambda)$. Few subjects interviewed understand this part of the methodology in depth, and I don't quite yet either, for that matter. My understanding of the reason for using $V(\lambda)$ to limit the wavelengths used in the ASD calculation is that it's simply more practical to calculate, but one subject in particular presented the following reasons why they found this part of ASD problematic:

1. $V(\lambda)$ is based on a very small number of subjects, and the combination of a couple of different experiments in the 1920s and 30s. It would never hold up to scrutiny today.
2. It's based on a 2 degree foveal view. There are no blue cones in the fovea, so it is skewed. The 10-degree field values have a larger hump in the blue.
3. This was based on flicker photometry, and may be relevant to reading of black and white tasks, but not much else. In particular, there was no color or color contrast in the task.
4. We need red for so many cultural, color contrast, aesthetic, health, and other reasons. To neglect the importance of long wavelengths is deplorable.
5. Similarly, blue wavelengths carry so much weight for nighttime vision, pupil size, impact on non-visual health functions, etc. it is ridiculous to neglect them as less important.

My reading of this is that $V(\lambda)$ is simply used to set the range of wavelengths to use to calculate, not to exclude anything above the $V(\lambda)$ curve in calculating ASD. Whatever the case, this needs to be explained more completely to specifiers so that they can have more trust in the metric.