VISIONARY CHALLENGE

2020

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* *denotes that the author was a judge for the Visionary Challenge*

** *denotes an article/excerpt*

The judging panel for the IES Visionary Challenge were:

James Brodrick
Peter Brown
Wilson Dau
Mark Lien
Brienne Musselman
Thomas Paterson
Susanne Seitinger

Introduction

My, what a decade this has been.

The impetus for this collection was a retrospective moment with a few seasoned IES members, as we discussed the numerous significant changes in our industry that have occurred in the last ten years. We all agreed that if we had been asked to predict the future in 2010, none of us would have predicted the advances in LED technologies, the ever-evolving knowledge expansion of how light affects our health, the acceleration of lighting's importance in horticulture, and perhaps most significantly, the economic and market disruptions that are transforming our industry today. In 2010, we were at the dawn of an unpredictable decade that has culminated in perhaps the most progressive decade our industry has ever known; now we are living through this historical transformation, and we wonder what the next decade will bring.

Our question was simple: what do you see? We sent out an open invitations for people to write down their thoughts, and put them into this publication for all of us to consider. It's important to realize that these entries were made before the pandemic, and so they may seem innocent in comparison to what people might write now. No doubt, much changed in the last eight months of 2020, and as we contemplate the next ten years, the uncertainty is even more heightened.

We have also included commentary from our judges and some selected insights from the past that questioned the paradigms of *their* time, challenging the unknown and beckoning further exploration.

We hope that you enjoy these articles and join with us in celebrating the dawn of the next decade. In spite of the challenges we now face, it is my sincerest hope that we can collectively look forward to a brighter future, remain optimistic, and build upon the foundations of our Society's 115-year history with a renewed spirit of discovery and openness. I hope that at the end of this decade, we can look back and be just as amazed as we have been this last decade. I have only one question for you:

What role will you play in this next decade's future?

Brian Liebel, Director of Standards and Research

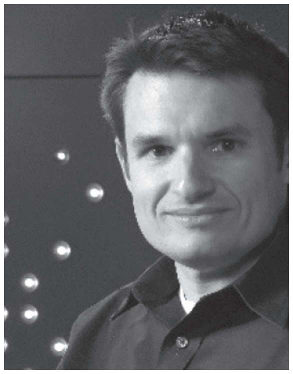
A History of Lighting in Four Minutes

By Mark Lien

Sunlight, torches, candles and other wick sources led to gas lighting being developed in England in the 1790’s. Humphry Davy created the first electric light in the early 1800’s. Various iterations followed as did the precursors to the fluorescent and incandescent lamps that were later refined for mass consumption. The first public street lighting using a carbon arc lamp was installed in Paris in 1876. In 1879 Thomas Edison and Joseph Swan both patented carbon-thread incandescent lamps which lasted about 40 hours. By 1880 Edison had produced a 16-watt, 1500-hour lamp. Two years later he introduced a large-scale lighting project and the first commercial power plant in the United States. This was located in the Financial District in Manhattan powering the area where the Illuminating Engineering Society office now resides. Nikola Tesla demonstrated the first wireless lighting in 1893. Walter Nernst was a chemist known for pioneering work with solid state physics. In 1897 he patented the first incandescent lamp based on solid state electrolytes.

Mercury vapor lighting became commercially available in 1901 with metal-halide sources invented in 1912. Between those two events a significant development occurred signaling industry growth and importance; in 1906 the Illuminating Engineering Society was formed. Sodium-vapor followed in 1920 and the first modern style fluorescent lamp was patented in 1926. Concurrent with this progress the incandescent lamp was being refined and improved using various gases and filament advances. In 1921 lighting in Europe was evolving and the CIE was formed. The first light-emitting diode (LED) was green. It was created in 1927 by Oleg Losev in Russia as he worked on semiconductor junctions. The first halogen lamp was invented in 1953 and the first laser in 1960. In 1962 Nick Holonyak Jr. made the first practical LED (red) that produced light in the visible spectrum while he was trying to invent a visible laser. High-pressure sodium followed the next year. By 1972 yellow and violet LEDs were invented. The first compact fluorescent lamp was sold in 1981. The first practical OLED was created in 1987. Sulfur and induction lamps followed in the early 1990’s. The first blue LED in 1993 by Shuji Nakamura later became, by adding a phosphor, the first white LED earning him the Nobel Prize in 2014. This started the solid-state lighting revolution and the conversion of most existing sources to LED. The first viable architectural luminaire using LEDs for general lighting was commercially available in 2005. The LED filament lamp was made in 2008 and by 2011 the LED screw-in lamp equivalent to the 60- watt incandescent A-lamp was produced.

Improvements continued in efficacy, longevity, color and miniaturization until recently when cost reductions slowed research and development as the marketplace accepted current price and performance levels. Although now ubiquitous and typically taken for granted to the point of being ignored, electric lighting is one of the single most important developments in the past two centuries rivaling the internet in the effect that it has had on human life. Advancements in LED technology continue to evolve into areas of how light affects all life forms including plants, especially those used for food. New methods of producing electric light show promise but are decades away from replacing the LED for general lighting. Many types of electric light have ceased to be relevant but sunlight remains the gold standard for sustaining life. We increasingly design daylighting into our built environments and electric lighting systems seek to emulate its attributes.



Brad Koerner is an entrepreneurial project leader with a range of design, marketing and product management experience. Brad has spent 20+ years in lighting design and manufacturing, developing award-winning architectural lighting projects as well as new LED lighting products and market categories that have earned in excess of $350M. Brad is an accomplished speaker and writer forecasting future trends in lighting design and technology.

Keywords: “Luminous Surfaces; Data-Driven Experiences; Interactive Spaces; Digital Twin Commissioning; Circular Economy; Net-Zero Energy”

One Sentence: “Six disruptive trends in architectural lighting and supporting technologies will transform how we craft spaces across the next decade.”

Welcome to the Luminous '20s

Six Disruptive Trends in Architectural Lighting for the Next Decade **By Brad Koerner**

The past decade saw incredible transformation in architectural lighting. With the turn of a new decade, the industry finds itself once again facing a disruptive wave of innovation, yet this time building upon mature LED and digital communications technologies. Let's look at how 6 disruptive trends will change how we conceive of architectural lighting:

1. LUMINOUS SURFACES

Embedded lighting and digital signage become fundamental elements of contemporary buildings

LED technology now allows us to integrate lighting directly into a wall or ceiling surface, with little energy consumption, heat, or maintenance. This fusion of light + material, of embedding lighting elements directly into architectural surfaces, opens fresh new approaches to creating eye-catching spatial experiences.

Play of Brilliants

Architects and interior designers have long tried to break free from the constraints of traditional objectified light fixtures, to use light as a form of *fundamental building material* to add visual richness to architectural surfaces. Fusing the best properties of luminosity, optical effects, material richness and graphic design, embedded lighting opens tremendous creative opportunities. Luminous surfaces will change the way people perceive, occupy and enjoy architectural spaces, particularly in hospitality, retail, and public applications.

Embedded Lighting Systems

Custom integration of embedded lighting has been difficult to specify and costly to install on construction projects, limiting broader adoption. While designers explore the creative possibilities of embedded patterns and surfaces of light, manufacturers need to develop flexible and customized product systems that accommodate an enormous range of creative styles, along with digital technologies to speed the design, visualization and fabrication processes.

Animation

Digital controls add the element of time and animation to architectural surfaces. People are mesmerized by the beauty of light in motion; we are hard-wired in our brains to seek visual stimulation to refresh ourselves. As architecture becomes fully digitally controllable, with every point of light addressable as a type of *pixel*, custom tailored dynamic animations ranging from the subtle flicker of a candle to sparkling effects to vivid ripples of movement will become common.

Digital Signage

Beyond using luminous surfaces for general illumination, digital signage systems will be included in architectural spaces with tighter integration of design concept.

Digital signage is already becoming pervasive in architectural environments with widespread adoption in out-of-home marketing, wayfinding, menu systems, and retail branding. The steadily dropping cost of digital screens and cloud-based content distribution makes digital signage highly appealing to brands and organizations looking to quickly inject more “digital” into their physical locations.

Across the next decade, design professionals need to become savvy on integrating both luminous surfaces and digital signage into comprehensive environmental experiences. Compositions can be created using digital lighting/pixels/screens of various proportions, scales and resolution with mixed visual acuity. Designers will develop sophisticated strategies to break the scale and proportions commonly associated with “screens” and to layer luminous surfaces to create rich spatial and visually healthy experiences.

Content is King

Architectural designers must become motion graphic artists. No longer can architectural lighting be considered the *magnificent play of volumes brought together in light*, since the volumes themselves now emit light. When every point of light in a building is effectively a digital pixel, designers need to create continuous fluid visual experiences. The concept of editing “timelines” at different scales becomes a critical skill, ranging from short term personal experiences, to daily cyclic patterns, to seasonal cyclic patterns.

Healthy Interior Lighting

Whatever you call it – circadian lighting, human-centered lighting, melanopic response – the implementation of “healthy” interior lighting will be largely implemented through luminous surfaces. Why? Because the old fixture paradigms from the 1960’s are ill equipped to provide not only the scientific quantities of the right light at the right time, but they are woefully unable to create great psychological experiences for inhabitants spending long hours in enclosed spaces.

The layering of luminosity, at far greater contrast levels than designers are accustomed to in interior environments, plus the inclusion of highly dynamic scene changes tailored for maximum biological and psychological response, will be critical concepts that architects, interior designers and lighting designers will need to embrace and explore throughout all the other aspects of their designs.

Impact on Design

The inclusion of luminous surfaces begs for a comprehensive design vision to create a unified experience for the occupants of a space. This will drive architects, interior and lighting designers to embrace a raft of new digital tools, such as using live-rendered photo-realistic game engines, VR experiences, video editing and motion graphics throughout their design development process.

Designers will need to visualize, simulate and craft not only simple luminous surfaces, but dynamic surfaces that interconnect the digital world with the occupants of the space.

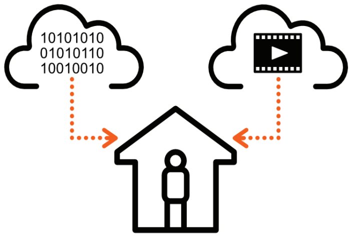
2. Data-Driven Experiences

Architecture will become a portal to the virtual world.

We are entering a future where architectural design and its associated technology systems are more than ever focused on *experience management* as the primary end goal of many projects.

Architectural technology systems, such as digital lighting, digital signage, and IoT-based communications systems are driving a *digital transformation* of *physical space*. Outdated preset scene control systems must transform into comprehensive *experience management systems*. What we presently call *lighting controls* will be subsumed into two primary styles of technical solutions:

1. Media-Driven Branded Experiences
2. Data-Driven Environmental Optimization



Such a transformation will have profound influences on how bricks and mortar spaces are conceived and designed.

Media-Driven Branded Experiences

The intention of many built environments (e.g.,retail, hospitality, corporate lobbies) is first and foremost to create a *branded experience*. And it is impossible in our modern age to conceive of branded experiences without a strong digital presence in content and interactivity. Architectural spaces are becoming portals to the virtual world. The technical challenge in these spaces is to control a range of digital media – *pixels* of various sorts, from 4K screens to projection mapping to simple digitally-controlled light bulbs.

While traditional architectural lighting controls are wholly unsuited for distributing, playing and managing modern digital media, the digital signage world has filled the gap with cloudconnected, low-cost systems expressly for distributing and playing media files on an range of equipment.

Data-Driven Environmental Optimization

For environments that are not primarily branded experiences (e.g., commercial offices, institutional facilities, industrial sites, etc.), *environmental optimization* based on live data becomes the imperative. Stagnant, pre-configured scenes are simply not precise enough to satisfy modern demands for climate control, energy efficiency, and creating functionally efficient spaces for the occupants. Networks of IoT-connected sensors generating massive live-data streams, plus numerous other live data streams such as weather, operational conditions, stock market fluctuations, social media engagement, etc. can provide live input to our environments. We need systems that take these live data streams and logically translate them across a range of environmental parameters. Such translation must be smooth, continuous, and employ learning loops (i.e. *A.I.*) to ensure that as a building ages, the live systems remain optimized.

Impact on Design

Spaces need to be conceived from the very initial sketches as live, responsive environments, not lumps of steel, concrete and glass bathed in stagnant light. Architects and interior designers need to understand the powerful potential of these new systems for *branded experience control or optimized environmental control* and start conceiving of new programmatic goals that fully exploit their potential.

And once data-driven lighting becomes the norm, designers will look more closely at the personal scale of interactions within a space.

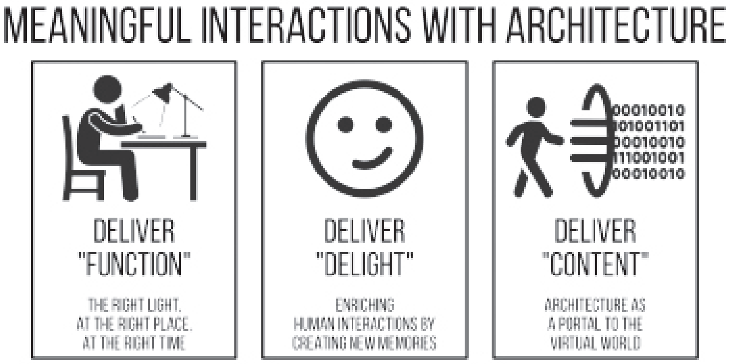
3. Interactive Spaces

The right light, at the right time, at the right place

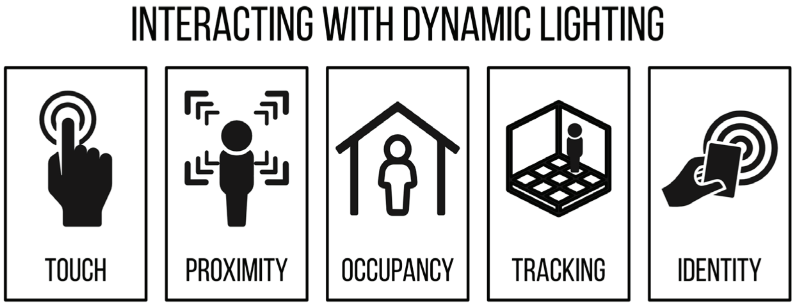
The concept of interactive lighting – where dynamic lighting or A/V gear responds to a user's touch, proximity or other activity – has held the promise of creating highly personal and dynamic architectural experiences for several decades, but adoption has been mostly limited to singular art installations.

Why Implement Interactive Lighting?

To date, interactive lighting has been so limited as to be of limited usefulness. Sensing blind occupancy offers little potential for tuning interiors, while the me and my shadow approach more sophisticated vision systems offers users no meaning or usefulness. What modalities of interaction will actually enrich an architectural space? There are at least three possibilities:



[These 3 interactions can then be mapped across applications, such as hospitality, retail, office, healthcare, education, public spaces, etc. Within each application, multiple physical interactions can be explored to deliver the 3 primary modalities, including: [EDITOR: USE GRAPHIC BELOW]



Impact on Design

Designers must move beyond document-based design and specification workflows. Architectural designers will increasingly adopt the tools, techniques and language of UX design professionals. Storyboarding must be routinely included to sketch out key dynamic scenarios in spaces. Designers will innovate their own tools, such as using low-cost computing ecosystems like Arduino and Raspberry Pi to create mockups and live models of interactive spaces.

As design progresses, live-rendered, fully functional virtual models integrated into BIM workflows will be required to visualize, simulate and develop the functionality of the final space programming.

4. Digital Twin Commissioning

Live simulations in BIM will reduce onsite commissioning costs

Digital technologies in the built environment drive very real end customer value. Yet unknown risk factors, exotic consultants and expensive systems integrators push budgets sky-high for these systems. And for sure, construction sites are the absolute most expensive place imaginable to attempt complex digital R&D projects. So how do we overcome this mess?

Project teams must focus on using cloud-based simulation and commissioning tools to remove a 10x factor of the costs associated with commissioning traditional lighting or media systems. Architectural design and workflows already use highly detailed BIM models that live in the cloud. Lighting systems are now fundamentally connected to the cloud. It is obvious that at some point, virtual project models will directly control digital lighting and signage systems.

Digital Twin Simulation

To achieve cloud-based commissioning, designers, construction teams and manufacturers must fully embrace a BIM-based design process. Lighting companies must develop sophisticated BIM plug-ins that allow specifiers to setup proper virtual models of the total lighting system (fixtures + controls + functionality), eliminating the need to translate the design intent of the lighting control system via traditional paper documentation and field commissioning.

Digital Twin Commissioning

If your digital twin/BIM model lives in the cloud and your whole lighting system is cloud-connected, simply connect the lighting system to the cloud and voilà – the virtual model can instantly control the real lighting hardware. The final programming will be transferred via the BIM/cloud model directly to the hardware onsite, reducing on-site commissioning and if done correctly, ensuring the designer’s vision is not broken during construction setup.

Impact on Design

Implicit in this future is the fact that commissioning largely transfers from systems integrators to design consultants. Overall, the process is more efficient, but this still represents a large transfer of project budgets from the construction site to the design team. Designers need to properly understand this new revenue opportunity and find ways to convince clients of the value.

Furthermore, the completeness and accuracy of digital-twin model becomes a valuable asset in itself that can be utilized for novel future revenue streams, such as concepts embodied in the circular economy movement.

5. CIRCULAR ECONOMY

New value streams will be realized by cleaning up our act

The *circular economy* is a movement to stop the industrialized world’s lethal habit of *take-makewaste* and instead to create profitable flows of products, parts, and materials in endless loops. To achieve this vision, it takes coordinated effort to rethink product design, business models, and market processes. So how will the lighting industry embrace such a future?

The Return of Commonsense

Here’s an essential but most difficult question to challenge any lighting manufacturer: *If in ten years you received your products back to your loading docks, would they be considered financial assets or liabilities*?

The current and environmentally destructive trend in the lighting industry for producing *disposable fixtures* simply cannot be sustained. Customers cannot bear the long-term maintenance headaches of such short-term, wretched product management, nor can the environment. Commonsense product design and industry-wide hardware standards programs like the Zhaga Consortium remain critical to enabling the repair and reuse of durable fixtures long into the future. And guess what? Repairing and maintaining commercial devices is also known as a revenue stream. Something that penny-wise and pound-foolish lighting product managers might want to consider.

Smart Maintenance Programs

IP-connected lighting systems greatly expand the range of data available. Networked controls and lighting fixtures can broadcast their component serial numbers, feature sets, on-board sensors, run time counters, and even realtime photometric light measurement. Talk about big data: A lighting manufacturer can now remotely check in on their systems anytime, anywhere.

For example, a manufacturer might automatically see that a fixture is over temp and losing light output in one of their customer’s facilities, and they will automatically query the exact set of parts that need to be replaced. Such data drastically reduces the cost of lighting maintenance. A service agent will show up with the right parts and immediately take care of the problem – potentially before an end user even recognizes that there is a problem. The commodity PC industry has done this for decades. The lighting industry has the opportunity to offer much high levels of customer service at lower costs than ever before…but who in the industry captures this value?

Bio-Friendly Materials

Ultra-high efficacy LEDs, with their low power and negligible thermal demands, open up opportunities for the radical redesign of traditional fixture paradigms and material selections.

There are many lighting applications where basic LED technology outlives the application life, with countless perfectly-good LED lighting fixtures doomed to be scrapped before their actual end-of-life. So why do lighting specifiers continue to choose aerospace-grade materials for basic architectural lighting? Why can't the bulk of light fixtures simply compost into dirt at end of life?

We will see a growing trend for lighting systems that use innovative bio-based materials to dramatically reduce the embodied energy, reduce toxicity and reduce both production and EOL disassembly costs to create fixtures that tread lightly on our natural resources.

Impact on Design

The lighting industry needs to take responsibility for the future it is sowing today. Designers specify the future. Why do they keep specifying such toxic, energy intensive materials in their products? Why do accept products that have no hope of even basic maintenance, much more reusability in the future?

And designers need to think holistically about their projects. Are they proud of the supply chains that support their product selections? Does it do any good to have amazing bio-friendly light fixtures that are drawing their power from a coal-based powerplant? Project teams must take full responsibility for the inputs and outputs of their individual buildings.

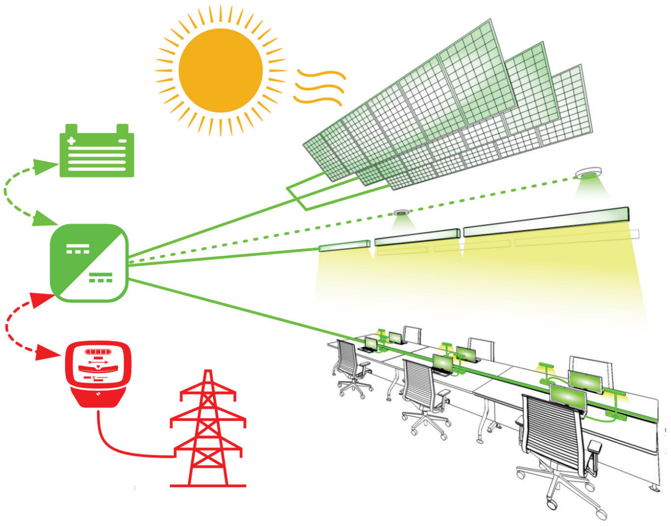
6. DC Power & Net-Zero Energy

Buildings will increasingly go off-grid

At their core, almost every device in a modern building uses DC (direct-current) electricity, including LED lighting, sensors, computers, IT networking and even large mechanical services. Yet since our ancient electric utility grids are AC (alternating current), every one of these devices require wasteful power converters. Ever notice how hot those power converters get? That is your electricity, money and planet being squandered as waste heat.

Net-Zero Energy Buildings

Compounding this disconnect between our AC electrical grids and our DC building infrastructures, we are now adding huge quantities of DC-generating solar panels and DC-based battery storage to make our buildings net-zero energy consumers.



Modern net-zero energy buildings will run entirely on internal flows of DC power throughout the majority of the year. They will only need extra power from the grid for small durations of the year, such as during the coldest, darkest part of the winter in Northern climates.

Batteries Sold Separately

With DC-based electrical services, we can reduce power waste substantially, reduce electronic hardware and associated maintenance & e-waste issues, and open the door to advanced energy management in buildings. Advanced DC-based technologies like solid-state switching and solid-state fault interruption promise to channel, manage and measure power with more precision than ever before.

We are at the inflection point of a new revolution: DC-power “nanogrids” are set to replace the AC-infrastructure in commercial buildings, resulting in massive energy savings while reducing hardware and providing advanced digital control of power. Researchers estimate that commercial buildings save 15% of their total power by skipping wasteful DC-AC-DC conversions.

Impact on Design

As we move towards greater numbers of net-zero energy buildings and demand more localized energy resiliency in ever more turbulent times, a most interesting revolution is poised to transform our electrical infrastructure. DC power systems will increasingly reduce the costs associated of evermore advanced architectural systems. From the earliest stages of conceiving a building, solar power must be fundamentally included with as much capacity as possible. Digital twin simulations of the energy performance of a building, starting at even the earliest schematic design stages, will predict long term energy performance of those systems and directly lead to highly tailored electrical infrastructures.

CONCLUSION: THE YEAR 2030

By the year 2030, what we call *architectural lighting* will increasingly consist of embedded luminous surfaces, rich with digital content, smartly driven by data streams and responsive to our physical actions and biological needs in a space. Designers (architects, interior designers, lighting designers, etc.) will increasingly become experience designers, using scripting, storyboarding and digital-twin simulations to craft live, responsive new experiential concepts for guests, shoppers, patients, employees, and so forth. Despite growing system complexity, project coordination and on-site installation costs will be reduced via digital-twin, cloud-connected commissioning and sophisticated integration of BIM processes. And these projects will use DC-power systems to reduce the consumption and cost of all these digital systems while making our buildings net-zero energy consumers. The physical hardware of lighting systems will be designed to maximize new revenue streams opened by circular economy strategies, while simultaneously reducing our environmental impact.

The luminous ‘20s indeed look to be a brilliant decade for innovation in architectural lighting systems.

The Birth and Meaning of Light

By Sidney Perkowitz

Excerpt 1: Chapter 1. The Birth and Meaning of Light

How far will chemistry and physics...help us to understand the appeal of a painting?

Hazel Rossotti

Colour: Why the World Isn't Grey

When I walk into my laser laboratory, I command every kind of light. I flip the wall switch, and the room fills with the cool blue-white glow from fluorescent tubes overhead. Next I turn on a desk lamp. Its hot incandescent bulb makes a warmer, redder kind of everyday light. I throw another bank of switches and one of my big lasers comes up. The glowing gas in its long tube makes an intense emerald-green beam, whose ultra-pure tint nearly sears my color sense. Another hint of the exotic comes in the invisible ultraviolet light the laser also makes, whose high energy can bring deep harm to living things. The last set of switches turns on my infrared laser, and wakes my sense of wonder. That laser's invisible light does not threaten life, but still carries powerful magic. It is intimately connected to the beginning of our universe, the Big Bang that occurred ten to twenty billion years ago.

This sweep, from the cosmic beginnings to my present laboratory, shows that light extends from the large scale of the universe into the ordinary human world. No other single phenomenon crosses so many human and physical categories. The physical understanding of light has involved the most significant of scientific ideas: theories of waves and quantum particles, of relativity and the Big Bang. Its human impact is equally profound: light determines our existence, occupies much of our thinking capacity, excites our sense of beauty. Each category is important in itself; considered together through the unifying theme of light, they represent a cross-section of our universe.

As I stand in my laboratory, I can place each kind of light by its physical properties and my physiological response: its intensity; whether it is visible or invisible; its wavelength, which for visible light translates into color; its effects on inert matter and on living stuff, which may be essential and benign, or fatal. My less rational side knows light at a deeper level, not so amenable to analysis. Light is the welcome end to night I feel each morning, as fearful humans always have. It is the long, pale, slanting sun's rays of late afternoon in winter, which convey loss, nostalgia, the end of things. It is the rich crimson of a rose expressing sheer vitality as it vibrates against the crisp green of its bush. It is the sun's warmth on my skin, bringing a profound sense of inhabiting my proper place. It is the even expanse of a newly painted room or the uninterrupted blue of a tranquil sky, each calming my spirit. Something in my responses seems to go beyond the bald facts of wavelengths and biochemical reactions; yet physical reality underlies what I see. The blue of the sky is pure light of short wavelengths diverted from a straight path into my eyes, which respond as the energy of the light alters molecules in their retinas.

Laser beam and sunlight, physical effects and emotional, light ordinary and light exotic; there is another way light enters my life. It is the medium caught and manipulated in the visual arts I love, to carry heightened reality to my eye and mind, to evoke response. Even without the element of color, the black and white photography of Ansel Adams or Edward Weston puts into play fine variations in light intensity. Gazing at a photograph, I see light reflected from its surface to recreate the velvety blacks, ambivalent grays, and shining whites left after photographer and camera abstracted color from the scene, leaving behind pure form or feeling. Manipulated light appears again in the darkness of a movie theater. Strange to think that famous black-and-white moments like the opening tracking shot in Orson Welles' "The Magnificent Ambersons," or the final scene in "Casablanca," are nothing but a moving pattern of intensities -- bright here, brighter there, dim elsewhere—imposed on a beam of light by a strip of transparent film. In the monochrome world of early *film noi*r, the *noir* is a view of life reflected in a dark palette, as in the minimal view of Burt Lancaster's waiting face in "The Killers."

When color is added to still photography, cinematography, or painting, the human response gains incalculable depth and breadth. Our eyes and brains can discern several million different shades. The range of response is impressive, but the pungency of color is clearer when we think about films. For myself, I recall how the world changed for Dorothy and for me, when the stark black and white of Kansas gave way to full color and the land of Oz; I remember the pervasive golden glow in "Out of Africa"; and I see again the ravishing soft twilights in "Days of Heaven," lit only by sky glow and hand lanterns. Light itself, called the true subject of photography, can also become a definite object in a film.

It is in the art of painting that light's color and intensity are best manipulated to evoke response. The choice of oils, acrylics, or watercolors; the selection of pigments and the mixing of tints; the use of thin washes applied with a brush, thick slabs of paint laid on with a spatula, or multiple planes of transparent and opaque color; the texture that comes from the painted surface and from brush strokes; all these shape the light reflected from a painting, which carries the artist's internal vision to the viewer. These methods create varied images and moods such as the thick, whirling, explosive suns in van Gogh's "Starry Night;" the flat tints that enhance the mystery of Rousseau's "Sleeping Gypsy;" the deep, misty look of Monet's "Rouen Cathedral;" the overwhelming blocks of color in Rothko's art; the neon-vivid tropical shades of Klee's "Fish Magic;" in Edward Hopper's work, the use of light and shadow to convey a sense of aloneness. And in religious art, light is employed to represent spiritual power.

As I step from the evocative world of art into the reality of the late twentieth century, light takes on another guise. Civilized societies have always sought the best possible artificial lighting. Now the technology of light surpasses mere illumination. Carefully measured and controlled, its wavelength and duration set with exquisite care, light flashes beneath our city streets, carrying millions of voices and spates of digital data over optical fibers. Made by a tiny infrared laser within a compact disk player, it faithfully melts into liquid sound the music frozen in the disk. Rapidly displaying words, images and numbers on a computer screen, light carries information at high speed. In medicine, it offers new ways to diagnose disease, and to observe the living brain. Light in these uses is created or sensed by minute structures made of semiconducting materials, which operate at the atomic level where quantum physics holds sway. This connection with the microscopic quantum world is another sign of light's universality.

Belal Abboushi is a lighting researcher at the Pacific Northwest National Laboratory. Prior joining PNNL, Belal worked as an Assistant Professor at the School of Architecture at Marywood University. Belal earned a PhD in Architecture from the University of Oregon where he was involved in several research projects examining indoor environmental quality (IEQ), occupant's comfort, and well-being in large-scale office and educational buildings. His doctoral dissertation utilized experiments and field studies to investigate occupant's visual comfort and visual interest under different sunlight patterns in daylit offices. Belal was also involved in an interdisciplinary project exploring the effects of lighting and views on comfort and stress-recovery. He presented his research in various venues including the IES Annual Conference, LightFair 2019, and Greenbuild 2019.

Sarah Safranek joined PNNL as a Lighting Research Associate in 2017. Prior to joining PNNL, Sarah contributed to research at the University of Colorado for the Architectural Engineering's Building Systems program with an emphasis on lighting. Her previous work experience involved the design of energy efficient lighting and daylighting systems. Sarah's work is currently focused on conducting research on a range of technology and application topics surrounding advanced Solid-State Lighting systems and technologies.

Abstract: Though daylight systems and electric lighting systems have independently seen notable developments, the integration between these two systems remains challenging. This integration is especially important to address non-image-forming light effects. In this visionary snapshot, we summarize current challenges that inhibit the integration between daylight and electric lighting systems and outline a vision for overcoming these challenges over next decade.

Keywords: Integrated lighting systems, NIF, daylight, electric lighting

One-Sentence Takeaway: The need to address Non-Image-Forming light effects in buildings further emphasizes the need to more closely examine the integration between daylight systems and electric lighting systems.

Integrating Daylight and Electric Lighting Systems to Address Non-image-forming Light Effects

By Belal Abboushi and Sarah Safranek, Pacific Northwest National Laboratory

Research over the last several decades has advanced our understanding of light and associated human responses, specifically non-image-forming (NIF) effects. Studies found that light exposure and spectrum likely affect heart rate (Tang et al., 2020), circadian synchronization (Tähkämö et al., 2019) and alertness (Figueiro et al., 2019; Lucas et al., 2014; Sahin et al., 2014). To help quantify these NIF light effects, metrics have been developed and are starting to be incorporated into building design guidelines. However, designing for NIF light effects further emphasizes the need for integration and synchronization between daylight and electric lighting systems. Current efforts to integrate these two systems are often faced with challenges related to existing lighting simulation tools and metrics, evaluation processes, and control systems. These areas will be the focus on further development over the next decade.

During lighting design, the need to address NIF effects makes it necessary to accurately predict and optimize spectral light characteristics as received by occupants. However, spectral daylight simulations remain challenging because weather stations do not collect applicable sky spectral data. Electric lighting, on the other hand, has assumed static lighting conditions making it challenging to capture intensity and spectral tuning capabilities of newer technology. Efforts over the next decade will focus on collecting sky spectra and creating sky models for various locations to help characterize variations in daylight spectrum. Furthermore, point-in-time simulations of photopic horizontal illuminance, will need to be replaced with dynamic annual simulations that address variations in daylight and electric lighting intensity and spectrum at occupant’s eye.

Designing to account for NIF light effects will likely lead to new metrics that also consider lighting quality, occupant preference, and energy. Early results of ongoing studies show that designing lighting systems to meet NIF requirements will significantly increase illuminance levels relative to IES recommendations and will have impacts on building energy consumption. To accommodate these requirements without compromising other aspects of the built environment, relevant metrics and control systems will be the focus of comprehensive developments. The challenge for control systems will be to capture light spectrum with appropriate resolution, frequency, and at representative locations within space as well as to inform system responses. In addition to energy saving potential, future control systems can optimize daylight and electric lighting conditions, e.g. spectral tuning of electric lighting or adjusting blind position, to address a holistic set of human responses, including alertness and circadian synchronization.

The expected developments related to spectral light simulation, control systems, and metrics must be accompanied by pivotal shifts in the lighting industry to facilitate the specification, installation, and commissioning of integrated daylight and electric lighting systems. At the same time, criteria used to value-engineer lighting solutions should start to acknowledge non-energy saving benefits such as improvements in occupants' productivity and well-being. We are very optimistic about the outcomes of lighting research and development over the next decade, such efforts will substantially improve the quality of lighting in our indoor environments by supporting the full integration of daylighting and electric lighting.

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Pupillary Size Differences under Incandescent and High Pressure Sodium Lamps

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In the absence of a color-discrimination requirement, it is common in the fields of illuminating engineering and lighting design to consider that two lighting systems with an equal photopic illuminance level and equal spatial distribution are essentially equivalent (Office Lighting Committee, 1982). Differences in spectral power distribution associated with different fighting technologies are presumed not to affect visual performances when the task is achromatic (Bullet and Fairbanks, 1980). Thus, lighting systems with different spectral power distributions are often considered equally valid for general and task lighting, as shown by the common usage of incandescent, fluorescent, and high-pressure sodium lighting for similar applications. The decision of choosing one lighting system over another is then determined by criteria other than spectral power distribution. This practice is based on the assumptiori that the CIE luminous efficiency function adequately describes visual function under common lighting conditions. As part of a continuing joint program between

As part of a continuing joint program between Lawrence Berkeley Laboratory and University of California, San Francisco to study human responses to electric lighting, we report here that significant differences in pupil size occur when subjects are exposed to indirect high-pressure sodium (HPS) as compared with indirect incandescent lighting when the light intensities are photopically matched. The spatial luminance distributions of the two lighting systems were approximately the same· and the HPS lamps were driven at high frequency (approximately 30 kHz) in order to eliminate modulation of Hght intensity as a possible confounding variable. We attribute the observed differences in pupil size to be most likely due to the differences in spectral power distribution of the two lighting systems. Since pupil size can affect visual performance and other aspects of visual system function, the findings here indicate that spectral power distribution should be considered in lighting design and application.

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METHODS

Eight young, healthy, adult, Caucasian, paid volunteers five males and three females-between 17 and 20 years of age participated in this study. All were tested to have 20/20 vision and were reported to be free of drugs.

All testing took place in a sound-attenuating, RF shielded chamber (Erik A Lindgren & Associates, Chi cago, Illinois) measuring 2.3 m high and 2 m by 2 m. The subject sat in a chair and faced a metal wall coated with Kodak Reflective Paint (spectrally flat reflectance) which had few visual features. That wall was about 1.1 m distant and was bathed by lighting fixtures mounted above the subject's head, shielded from direct view. The rest of the chamber was lit only by reflected light.

The electrical lights used in this study were in candescent and HPS, both manufactured by General Electric. Different levels of illumination were achieved by using incandescent lamps of different wattage, operated at or near 120 V. The 35-W HPS "Lucalox" lamp was activated by a G.E. high frequency fluores cent ballast which operated the lamp at about 30 kHz. Hence, we refer to this lighting as "high-frequency high-pressure sodium'' (HF-HPS). Different luminance levels were achieved by varying the voltage to the HF HPS ballast. Continuous monitoring of the illuminance of the lamps was accomplished with a Tektron ix J-16 digital photometer mounted on the directly illuminated front wall at approximately eye level of the subject. A Spectra Pritchard photometer (model 1980A-PL) was mounted over the left shoulder of the subject and measured the luminance of a small area of the wall (6-minute field) directly in front of the subject, using the built-in photopic and "scotopic'' filters. We have compared these measured values of the photopic luminances to a calculation performed by folding the measured spectral power distribution of the lamps with the CIE photopic response (Wyszecki and Stiles, 1982) of the eye and have found agreement between measured values and calculated values within 1 percent. Unfortunately, the scotopic filter is not a completely faithful reproduction of the scotopic response function; it has small decrements in theregion from 550 nm to 650 nm. Although these are small and produce only a 3- to 4-percent increase between actual and filter responses when folded against an incandescent spectral power distribution, the effect is much greater for the HPS spectrum because the filter decrement occurs in the wavelength region where the HPS spectral power distribution is falling rapidly. Thus, an incandescent lamp and an HPS lamp that are "matched" for scotopic luminances by the Pritchard filter are actually as much as 35 percent different. The correct values of scotopic luminance were obtained by folding the measured values of the HPS spectral power distribution at the various input voltages against the published values of the scotopic response function (Wyszecki and Stiles, 1982). We have performed these measurements and calculations and have determined the correction factors for each of the scotopic luminance measurements recorded by the Pritchard Spectrophotometer with its erroneous filter.

Infrared pupillometry (Stark, 1968) was carried out using a MicroMeasurements, Inc., pupillometer which measured pupil area with built-in corrections for angle of gaze and the distortions produced by reflec ting the pupil image through a front-surfaced mirror mounted slightly below the direct line of vision (thus permitting the subject to view the wall rather than either the mirror or the video camera). The pupillometer output was digitally read by a PDP-8 computer which controlled data acquisition and then transmitted the data files to a PDP-11/44 computer for further analysis and statistical tests.

The subject practiced coming up to the chin rest of the pupillometer and centering his/her gaze so that the pupil image was centered on the pupil monitor, then sitting back to relax between recording periods. Subjects were instructed to maintain their visual direction towards the front wall, fixating upon a small visual point during recordings, and to not look into shadows between recordings. To confirm the following of these instructions, the eye position was observed during recordings via the pupillometer monitor and between recordings via a second video monitor show ing the subject's face. In addition, a continuous recording of the pupillary response was accomplished with a video tape recorder (Hitachi VT-9700A) and a FOR VT-300 Video Timer. For each 5-second recording, when the subject was positioned so that the pupil was properly recorded, he/she was instructed, via an intercom, to prepare for a recording by blinking, swallow ing, or moving, and then when fully ready, to press a button upon which their finger rested. Having the subject start the recording period resulted in significantly less blink artifacts. Pupil area was record ed at 20 Hz for 5 seconds, a total of 100 data points per recording.

Each subject was acclimatized inside the exposure chamber for 30 minutes prior to testing under the lowest intensity of light. Twenty consecutive recor dings of 5-second duration were made under each light condition with an interrecording interval of approximately 30 seconds. The average pupil area over the first 16 artifact-free 5-second recordings was taken as the average pupillary response per light condition.

Three intensities, photopically determined with the Pritchard photometer, of 30, 60, and 90 cd/ll½ were used for a photopically matched comparison between incandescent and HPS. A second set of tests at three other intensities was also done in each subject. This set of intensities had been intended to provide inten sities matched scotopically. However, as mentioned above for technical reasons associated with errors in the scotopic filter in the Pritchard photometer, the intensities were not matched. Within the testing of each lamp the intensities were always tested in ascending order of luminance. Each subject was tested with at least three intensities of each of two lamps within one day. The full testing of each subject required approx imately eight hours. The order of testing a given lamp was random across subjects to counterbalance any diurnal effects.

RESULTS

Data were gathered under a number of lighting intensities, a subset of which included photopically matched lighting conditions at three intensities. Taking only this data, pupil area was larger for HF-HPS than for photopically matched incandescent (Inc) illumination (**Figure 1** and **Table 1**). (Note that in this and all figures, error bars indicate the standard deviation of the observations around the means.) When analyzed with a two- way repeated measures analysis of variance (ANOVA) with lighting condition and intensity as the two within-subjects effects and average pupil area as the dependent variable, there was a highly statistically significant effect of lighting condition. The analysis showed that the probability of the observed pupil size difference under the two lights being due to a sampling error (i.e., due to chance) was less than 0.006 ($p < 0.006$, $F = 15$, $df = 1,7$). Thus, by this direct approach it is clear that pupil area is not uniquely a function of photopic intensity alone.

Examination of the responses of individual subjects showed the same trends as in **Figure 1**. Out of 24 pairs of individual measurements that make up the averages shown in **Figure 1**, only 1 pair had the HPS pupil area slightly smaller than the incandescent, and 1 pair had measurements that were identical. For the other 22 pairs of observations, the HPS pupil area was larger than the incandescent in that subject at the same photopic intensity.

We had obtained additional data at intensities that were unmatched photopically, and this additional data, along with the photopically matched data is shown in **Figure 2**. Note that HPS photopic intensity must be about 2-3 times greater than that of incandescent in order to provide the same pupil area. Since the data are not matched photopically at all points, a similar-ANOVA cannot be used to test the statistical difference between the two curves in Figure 2. Because of this, and because we wished to determine if a spectral distribution other than photopic luminous efficiency could account for the pupil areas measured, we analyzed all of our data using the general linear models (GLM) procedure of the Statistical Analysis System (SAS Institute, Inc.). The details of this method and the findings are presented in the Appendix. The overall findings are reported here.

Since the photopic luminance alone did not distinguish the pupil area effects of lnc and HPS, we plotted our observed pupil area measurements as a function of the corrected scotopic luminance, as shown in **Figure 3**. It is clear visually that the two curves are closer together than in **Figure 2**, and that the curves lie within a single standard deviation of the between subject variability.

Since Alpern and Campbell (1962) had measured spectral responses of the pupil to varying monochromatic wavelengths which were neither purely photopic nor scotopic, we plotted our observed pupil area measurements as a function of a measure of intensity calculated from their published spectrum (folded against our measurements of the spectral power distribution of the lamps used). The results are shown in **Figure 4**, where it can be seen that the curves lie in intermediate positions, compared with their positions in **Figures 2** and **3**. (It should be noted that the Alpern-Campbell spectral response curve is peak ed approximately midway between the scotopic and photopic peak wavelengths.)

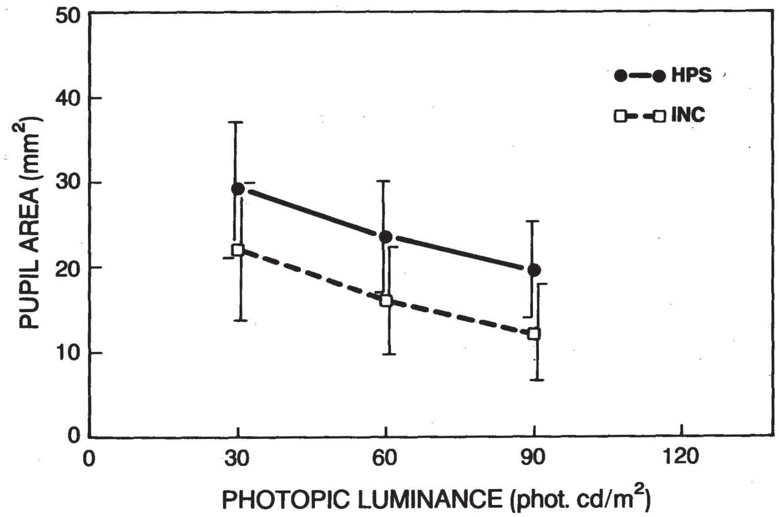

Figure I: Mean pupil area ± SD for HPS and Inc for photopically matched exposures.

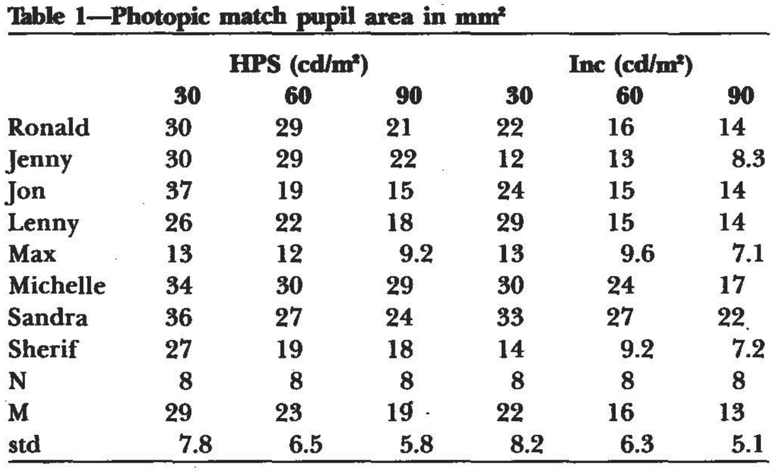

Table 1—Photopic match pupil area in mm²

	HPS (cd/m²)			Inc (cd/m²)		
	30	60	90	30	60	90
Ronald	30	29	21	22	16	14
Jenny	30	29	22	12	13	8.3
Jon	37	19	15	24	15	14
Lenny	26	22	18	29	15	14
Max	13	12	9.2	13	9.6	7.1
Michelle	34	30	29	30	24	17
Sandra	36	27	24	33	27	22
Sherif	27	19	18	14	9.2	7.2
N	8	8	8	8	8	8
M	29	23	19	22	16	13
std	7.8	6.5	5.8	8.2	6.3	5.1

Table 1: Photopic match pupil area in mm^2.

The question is which of the spectra of **Figures.2**, **3**, and **4** best allows prediction of the pupil area *independent of the lamp type*. The GLM (as described in the Appendix) provides an answer to this question by first normalizing the individual subject data to the mean value for a given subject across all conditions, and then determining the amount of the within-subject variance of pupil area across the lighting trials that can be accounted for by the different spectra associated with each trial. The results in the Appendix are quite clear: without specifying the lamp type, scotopic luminance accounts for 97 percent of the lighting related variance in pupil area while the photopic luminance accounts for only 65 percent of such variance, and the Alpern-Campbell luminance accounts for 79 percent. Both photopic and Alpern Campbell spectra can account for 100 percent of the observed variance only if the lamp type is also specified-said in another way, in **Figures 2** and **4** the two curves are statistically different from one another. On the other hand, the scotopic luminance accounts for 97 percent of the variance, *independent of lamp type*. It is likely that the 3 percent of the variance not ac counted for by the scotopic luminance is due to chance. This interpretation is supported by the GLM analysis (see Appendix). On the basis of this result and others presented in the Appendix, we conclude that the scotopic spectrum is the

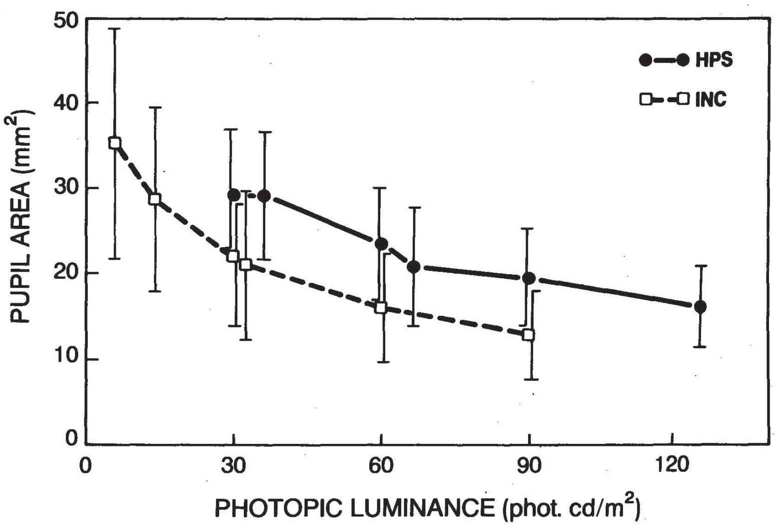

Figure 2: Mean pupil area ± SD for all exposures of HPS and Inc, some photopically matched and some not, as a function of photopic luminance of the exposure.

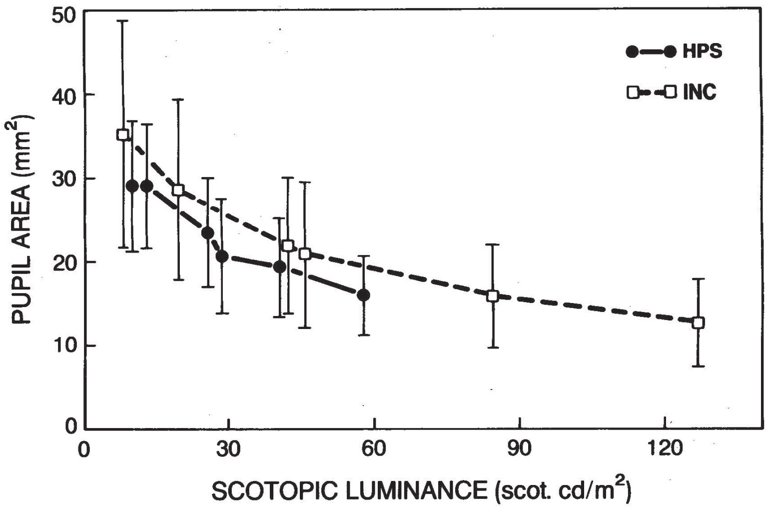

Figure 3: Mean pupil area ± SD of Figure 2, replotted against the corrected scotopic measurement of the exposure luminance.

major determinant of the pupil size under the experimental conditions described here.

Two principal factors that determine the amount of light that reaches the retina are the luminance of the overall visual field and the pupil area. The product of these two numbers is a measure of light passing into the eye through the pupil and is measured in trolands (candelas per square meter of luminance times square millimeters of pupil area). We call these "entrance trolands" since we have not included the spectral absorption within the eye. We replotted our data to show entrance-trolands as predicted by the three spectra (photopic, scotopic, and Alpern-Campbell), as shown in **Figures 5**, **6**, and **7**. The results are similar to that seen in **Figures 2**, **3** and **4**, namely that the photopic luminance can predict the entrance-trolands only if the lamp is specified, whereas the curves from the two lamps are very similar when the scotopic luminance is the primary measure (**Figure 6**). The Alpern-Campbell luminance (**Figure 7**) provides curves intermediate between the photopic (**Figure 5**) and scotopic (**Figure 6**) graphs. (Since the troland computation involves the product of the luminance and the pupil area, the statistical analysis of the primary pupil area data provides the same results when entrance-trolands are the dependent measure.)

If net retinal illumination is the prime requisite of a lighting design, **Figure 5** clearly shows that the spectrum of the source should be considered as relevant. Note that **Figure 5**. predicts that within the range that we measured, for photopic entrance-trolands to be equal to Inc values, HPS luminance must be *reduced* by a factor of about 2. On this basis, there could be additional energy savings in the use of HPS lamps *provided* that the tasks performed under the lighting are not adversely affected by a larger pupil.

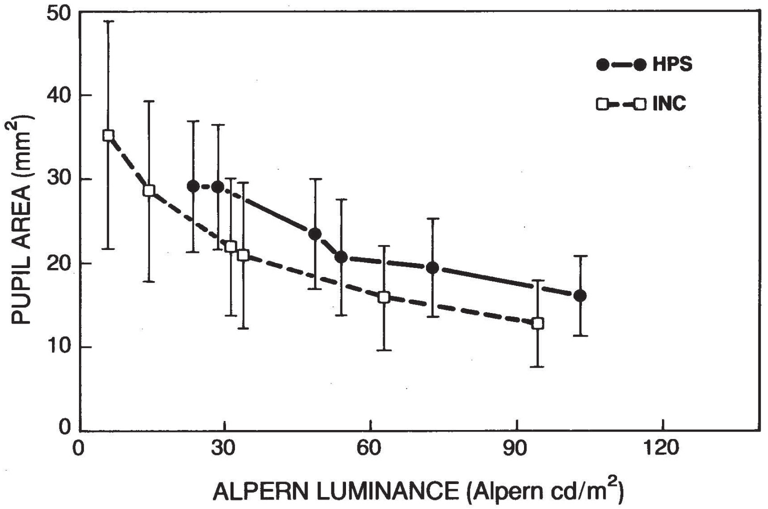

Figure 4: Mean pupil area ± SD of Figure 2, replotted against the exposure luminance computed from the pupillary response action spectrum of Alpern-Campbell (see text).

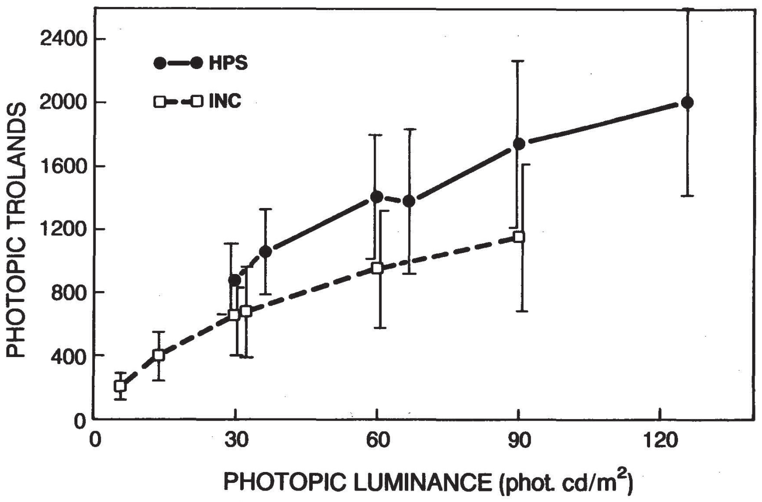

Figure 5: Mean photopic entrance-trolands ± SD as a function of photopic luminance..

Our results clearly suggest that the pupil size mechanism functions to control the amount of scotopic light that enters the eye. The size of the pupil in ac both scotopic and-photopic luminance entering the counted for by the slight difference from the scotopic eye. However, the scotopidphotopic ratio does differ. between the two light sources we studied. Thus, the pupil does *not* control the photopic luminance entertaining the eye under all conditions. To show this we plotted the photopic entrance-trolands in our experimental results as a function of scotopic luminance (**Figure 8**). It is clear that while scotopic luminance determines scotopic entrance-trolands (**Figure 6**), scotopic luminance is a *very poor* predictor of the amount of light that will be available for photopic visual func tioning under conditions of indoor electrical illumination (**Figure 8**). The GLM statistical analysis confirms this conclusion by showing that only 24 per cent of the lighting-related variance of photopic entrance-trolands is accounted for is accounted for by the scotopic luminance, whereas the difference in the two lighting conditions accounts for 76 percent of such variance (see Appendix).

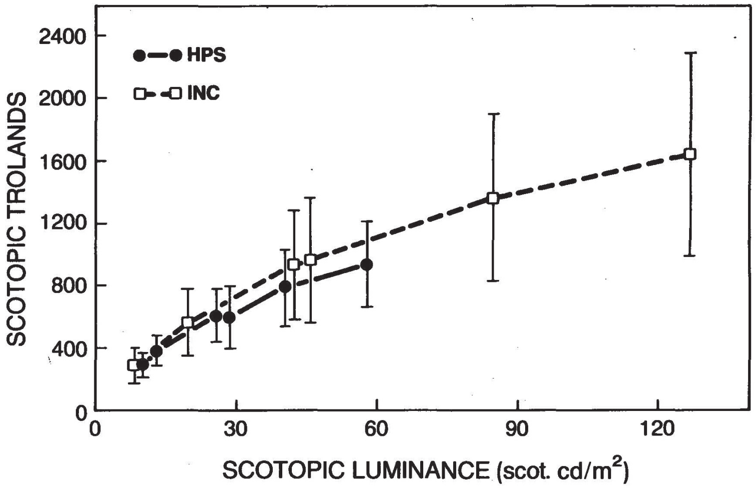

Figure 6: Mean scotopic entrarice-trolands ± SD as a function of scotopic luminance.

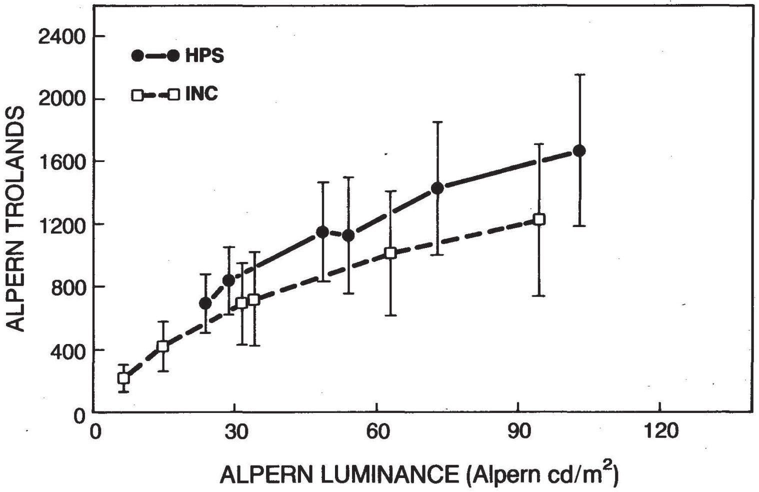

Figure 7: Mean Alpern-Campbell entrance-trolands ± SD as a func tion of Alpern-Campbell luminance, as in Figure 4.

DISCUSSION

The results here can be understood if it is assumed that the spectral response of the pupillary system dif fers from the canonical spectral visual efficacy of the eye. This latter function, referred to as the >. function, is the spectral shape that, when folded against the various lamp spectral power distributions, defines the photopic illumination value of a given light source. If the spectral response of the pupillary system is not>. then two lamps with different spectral power distributions would provide different puppillary responses even though they provide equal photopic illumination. These considerations are discussed below.

The spectral response of pupil size has been studied by several investigators but there is no consensus within the vision literature. One commonly held view is that the spectral response of pupil size is the same as the usual photopic luminous efficacy function [λ], e.g. see Laurens (1923) and Alexandridis (1985, page 22). Our results appear inconsistent with that view and are also inconsistent with the results of Alpern and Campbell (1962) and ten Doesschate and Alpern (1965) who claim that pupil size is affected by both rods and cones at daytime light levels and that the spectral response function of the pupil is maximum approximately half way between the scotopic and photopic peak wavelengths. At the other extreme, the work of Bouma (1962, 1965) (reiterated in a review of the field by Hedin, 1978) concludes that the rods are the predominant receptor controlling pupil size over a wide range of luminances, with a maximum in the monochromatic spectral response curve at a wavelenght slighty less than the scoptopic peak. Our results are probably consistent with the conclusions of thes latter authors. However, there is a small amount of variance (3 percent) that is not accounted for by our use of the scotopic spectrum, which might be accounted for by the slight difference from the scotopic curve in their results. Noth that these small differences are in a region of their results in which there are relatively few data points.It is clear that further research is the field of vision on a larger number of subjects can be used to determine the effective pupilary action spectrum

CONSEQUENCES FOR ILLUMINATING ENGINEERING AND LIGHTING DESIGN

Pupil size is known to have important effects on depth of field and on the ability of the visual system to resolve fine detail as reflected by visual acuity (Liebowitz, 1962) and the spatial contrast sensitivity function (Campbell and Green, 1965). For example, depth of field increases approximately inversely as the pupil diameter decreases (Campbell, 1957). However, for a given ambient luminance a larger pupil results in more retinal luminance (trolands) (Luckiesh and Moss, 1934, and Ferguson, 1956). Thus depending on the specific nature of the visual task, improvements in visual performance could result by spectrum control of pupil size independent of luminance (Eastman and McNelis, 1963). If retinal illumination is a limiting fac tor in the visual environment, then a scotopically deficient lamp resulting in a larger pupil may be more ap propriate than another lamp richer in scotopic lumens when both produce equal photopic luminances. (See **Figure 8** to see how such scotopic illumination determines photopic trolands between

Inc and HPS.)

On the other hand, studies of contrast sensitivity (Campbell and Green, 1965, and.Campbell and Gubisch, 1966) show a steady reduction in this quantity with increasing pupil size. Should further studies show that there arc preferred pupil sizes in the every day world of visual tasks, the results here should lead to a new dimension for improving the quality of our lighting environment, since spectral distribution in lamp design can be varied over large ranges.

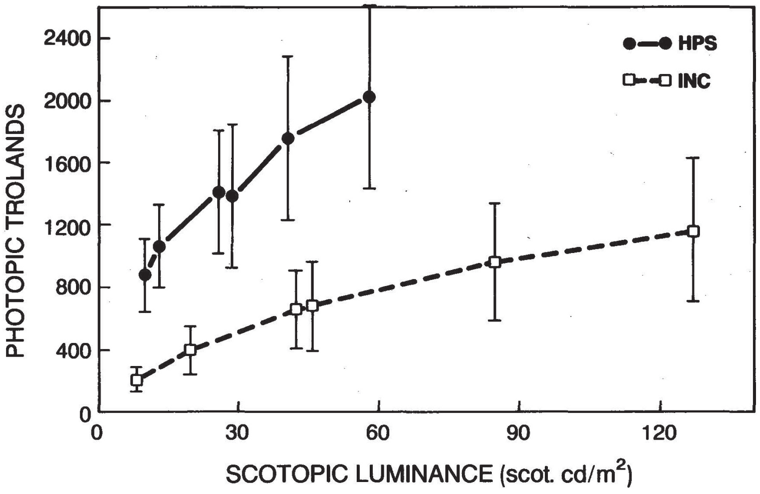

Figure 8: Mean photopic entrance-trolands ± SD as a function of scotopic luminance. Compare with Figures 6 and 5.

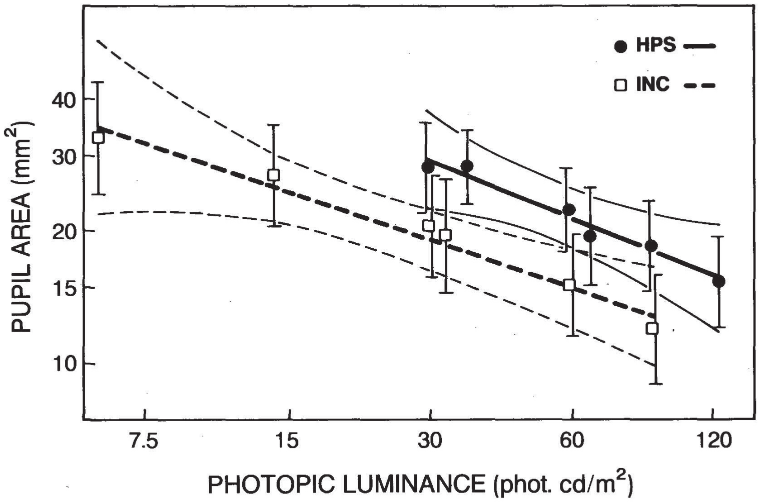

Figure 9: Mean pupil area ± SD as a function of photopic luminance. This is from the same data as in Figure 2.

It should be noted that it is not an a *priori* requirement that the results of multichromatic stimuli be predictable on the basis of monochromatic results, unless the degree of interaction between wavelengths is known. Thus, though our results might have been anticipated on the basis of Bouma’s work, such a prediction could not have been verified without experimentation such as we have done. However, in as much as our results are similar to that of Bouma, it can be concluded that there is relatively little spectral interaction in the pupillary spectral response, provided it is indeed the scotopic function. But given the controversies within vision science, and the importance of pupillary response to vision and lighting design, futher testing on other lights will be necessary to seen how much other lamps affect pupil function, and whether measures of scotopic illuminance will be adequate measures of retinal illuminance under different spectral distributions. When such additional information is available, the general principles governing this aspect of visual efficiency will have a more certain base.

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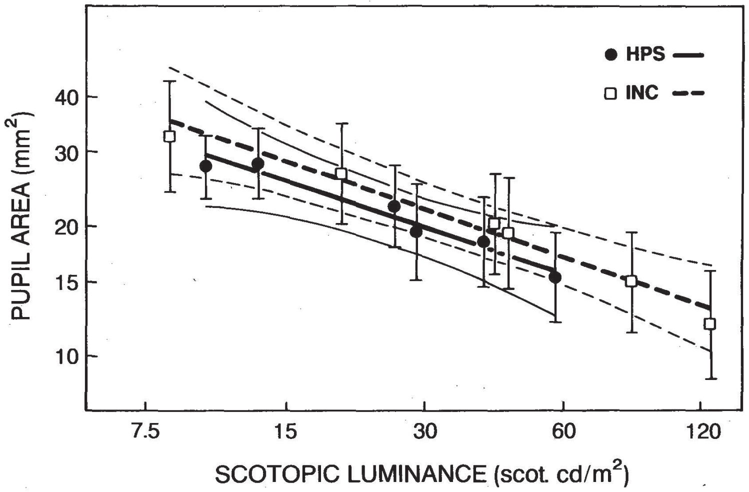


Figure 10: Logarithmic graphing of mean pupil area ± SD as a function of scotopic luminance. This is from the same data as in Figure 3. Compare with Figure 9.

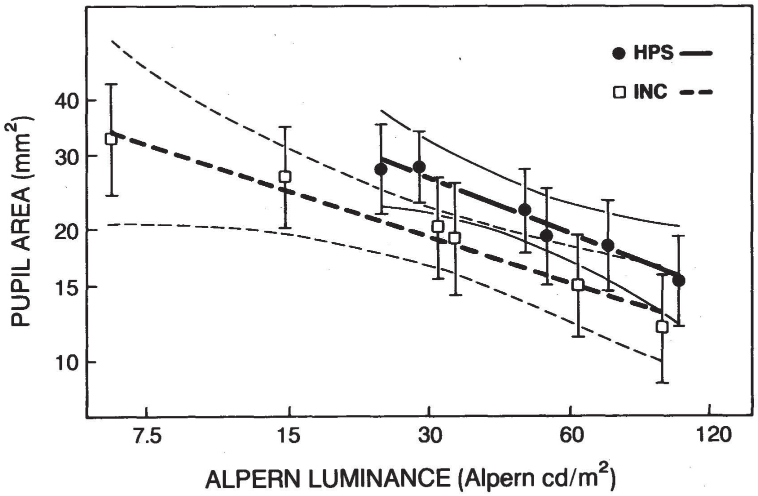


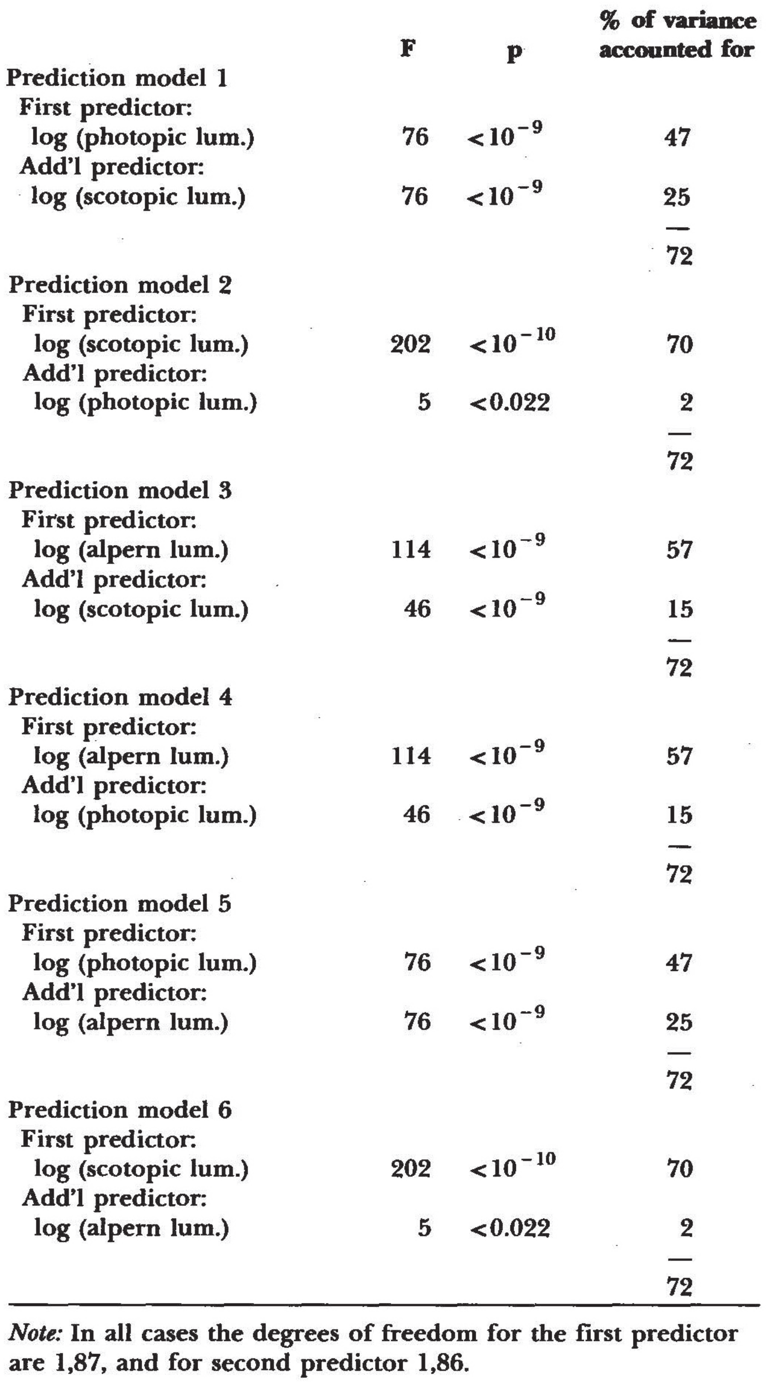
Figure I I: Logarithmic graphing of mean pupil area ± SD as a function of Alpern-Campbell luminance. This is from the same data as in Figure 4.

Appendix

We repeated the same GLM analysis using each of three different measures of the luminance: the photopic measurement, a corrected scotopic measurement, and the pupillary action spectrum observed by Alpern-Campbell (1962). For each of the three spectra, analyses of log transformed independent and dependent variables enabled our statistical model to account for a higher percentage of variance in the dependent variable (either pupil area or entrance trolands) than if either dependent or independent variables were not log-transformed. For this reason, all of the analyses below pertain to log-transformed data, and **Figures 9-15** show the data on log-log plots. **Figures 9-15** should be compared with the corresponding **Figures 2-8**, to note how well the data fit a log-log plot. Note that since the data is log-transformed in these figures before computations are made, the error bars here differ from those in earlier figures. The best fit line of the means are shown, along with the 95 percent confidence limits of the line position.

The GLM procedure is used to partition variance of the dependent variable among various effects. Since each subject acted as his own control, by entering a subject effect into the GLM procedure, we were able to measure between-subject variation and remove that source of variation from the analysis. All experimental effects were then assessed with respect to the pooled within-subject variance.

The pooled within-subject variance was then partitioned in analyses using various combinations of the three spectral intensities, a dichotomous categorical variable indicating the light source, and interaction effects. In all cases, the variance accounted for by any set of these variables was never greater than 72 percent. The data under the two different lamp types was then individually fit with the best linear least-squares fit, and these regression lines were then used to determine the residual variance not accounted for by the various conditions. All combinations of the three light spectra as well as lamp type were



	F	p	% of variance accounted for
Prediction model 1			
First predictor:			
log (photopic lum.)	76	$<10^{-9}$	47
Add'l predictor:			
log (scotopic lum.)	76	$<10^{-9}$	25
			72
Prediction model 2			
First predictor:			
log (scotopic lum.)	202	$<10^{-10}$	70
Add'l predictor:			
log (photopic lum.)	5	<0.022	2
			72
Prediction model 3			
First predictor:			
log (alpern lum.)	114	$<10^{-9}$	57
Add'l predictor:			
log (scotopic lum.)	46	$<10^{-9}$	15
			72
Prediction model 4			
First predictor:			
log (alpern lum.)	114	$<10^{-9}$	57
Add'l predictor:			
log (photopic lum.)	46	$<10^{-9}$	15
			72
Prediction model 5			
First predictor:			
log (photopic lum.)	76	$<10^{-9}$	47
Add'l predictor:			
log (alpern lum.)	76	$<10^{-9}$	25
			72
Prediction model 6			
First predictor:			
log (scotopic lum.)	202	$<10^{-10}$	70
Add'l predictor:			
log (alpern lum.)	5	<0.022	2
			72

Note: **In all cases the degrees of freedom for the first predictor are 1,87, and for second predictor 1,86.**

Table 2: Dependent variable: log (area).

computed. In all cases the variance accounted for by these factors was never greater than 72 percent. **Table 2** presents data on whether the luminance of the lamps associated with the photopic, Alpern Campbell, or scotopic spectra, either seperately or in combination, can be used to predict pupil area. (Only combinations of luminance for two spectra are presented because adding luminance of the third spectrum to the prediction equation never resulted in any increase in predictive power.)

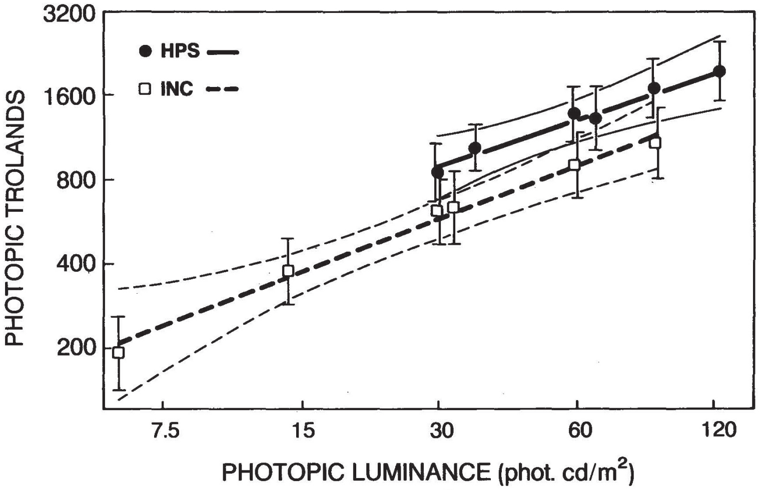


Figure I2: Logarithmic graphing of mean photopie entrance-trolands± SD as a function of photopic luminance. This is from the same data as in Figure 5.

Taking first the ability of a single spectrum to pre dict the observed pupil areas, scotopic luminance ac counted for fully 97 percent (70 percent of a total of 72 percent) of the total predictive power of all spectral luminance data to predict pupil area. Photopic luminance did most poorly in predicting pupil area, ac counting for only 65 percent (47 percent of the total of 72 percent) of the predictive power of spectral luminance data. Alpern luminance was intermediate between scotopic and photopic luminance, account ing for 79 percent (57 percent of the total of 72 percent) of the predictive power of spectral luminance data.

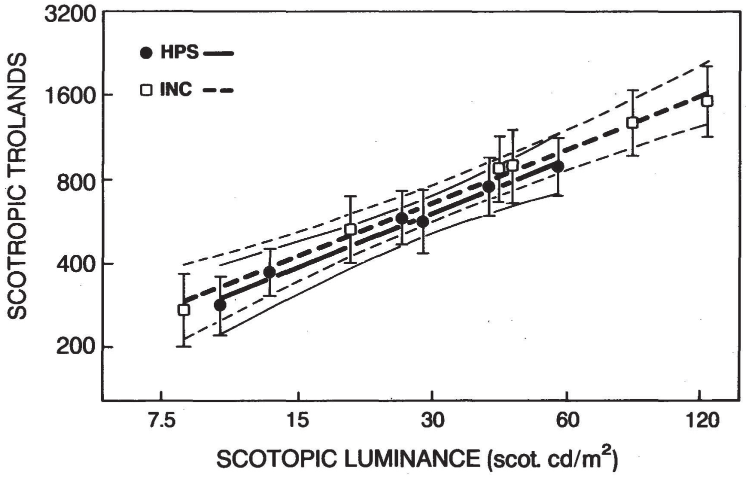


Figure 13: Logarithmic graphing of mean scotopic entrance-trolands± SD as a function of scotopic luminance. This is from the same data as in Figure 6. Compare with Figure 12.

When the spectra are considered in pairs, any combinations of two spectra intensities can account for

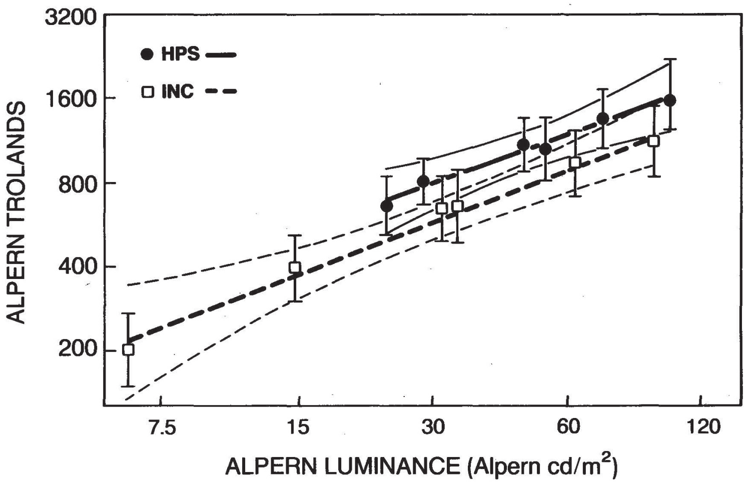


Figure 14: Logarithmicgraphing of mean Alpern-Campbell entrance trolands ± SD as a function of Alpern-Campbell luminance. This is from the same data as in Figure 7.

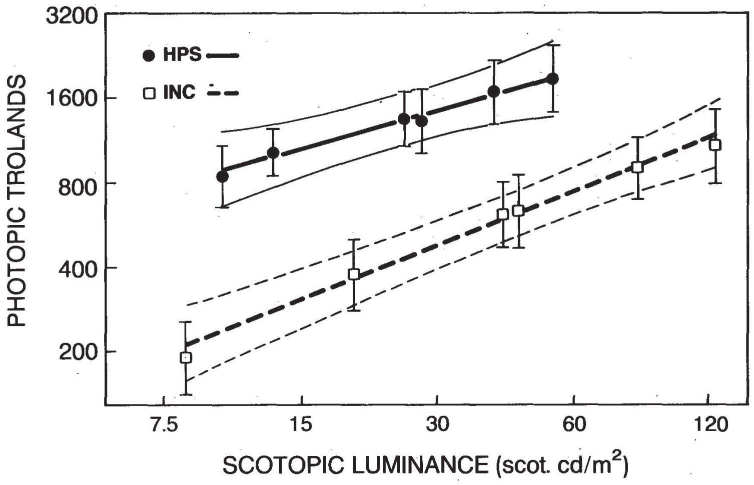
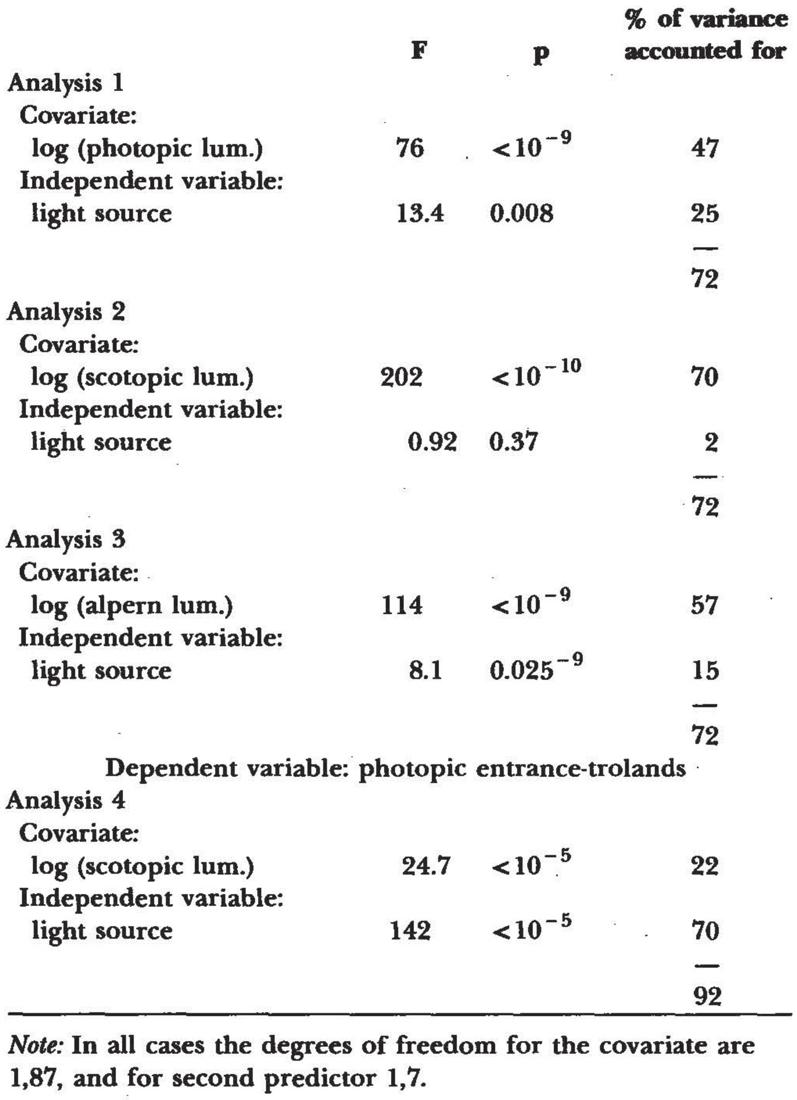


Figure I5: Logarithmic graphing of mean photopic entrance-trolands± SD as a function of scotopic luminance. This is from the same data as in Figure 8. Compare with Figures 12 and 13.

all the the luminance-related variance in pupil area (**Table 2**). (The fact that all of the spectral pairs from Table 2 account for about 72 percent of the variance indi cates that the remaining variance is not spectrally related.) When scotopic luminance is the first predictor, adding either photopic or Alpern-Campbell lumi nance adds only 1.8 percent of variance to the predic tive power of scotopic alone. This addition is signifi cant at (F = 5.4, df = 1,86, $p < 0.022$). In the context of the multiple analyses of the data which we perform ed, this result (at the 2 percent confidence level) remains suspect and must be replicated with new data for it to be solidly asserted. In contrast, all the p-values associated with the other analyses are so small (< 10·8) that they are not compromised by our multiple analyses of the data. Thus, scotopic luminance ac counts for essentially all luminance-related variance in pupil area. Photopic and Alpern-Campbell luminance in combination predict pupil area as well as scotopic luminance, as shown in Table 2. This is not surprising since scotopic luminance can be computed as a linear combination of photopic and Alpern Campbell luminance.

Another way of looking at this data is that we are trying to predict j>Upil area for two different light sources using only one spectral luminance measure. As noted above, when the scotopic luminance measure is used, this works because the scotopic spectrum is likely to be the major physiological determinant of the pupil area under the conditions of our experiment (daytime light levels) and subjects (young adults with normal vision).



	F	p	% of variance accounted for
Analysis 1			
Covariate:			
log (photopic lum.)	76	$<10^{-9}$	47
Independent variable:			
light source	13.4	0.008	25
			— 72
Analysis 2			
Covariate:			
log (scotopic lum.)	202	$<10^{-10}$	70
Independent variable:			
light source	0.92	0.37	2
			— 72
Analysis 3			
Covariate:			
log (alpern lum.)	114	$<10^{-9}$	57
Independent variable:			
light source	8.1	0.025^{-9}	15
			— 72
Dependent variable: photopic entrance-trolands			
Analysis 4			
Covariate:			
log (scotopic lum.)	24.7	$<10^{-5}$	22
Independent variable:			
light source	142	$<10^{-5}$	70
			— 92

***Note:* In all cases the degrees of freedom for the covariate are 1,87, and for second predictor 1,7.**

Table 3: Dependent variable: log (area).

We have verified the importance of the scotopic spectrum in predicting pupil area in another way. Using the GLM procedure to perform a repeated mea sures analysis of covariance (ANCOVA), where between-subject variance was removed as above, log pupil area was the dependent variable, the dichotomous categorical variable indicating light source was the independent variable, and the log spectral lumi nance was used as the covariate. Table 3 presents the results for three such ANCOVAs with photopic, scotopic, and Alpern-Campbell luminance used as the covarites. In all three cases the combination of theequally applicable to the troland plots (**Figures 5-8**, replotted log- log in Figures 12-15), since they axis in lighting source and spectral intensity variable ac- counts for 72 percent of the variance of the log pupil area. The variance accounted for by the light source variable is highest when photopic luminance is the covariate, intermediate when Alpern-Campbell luminance is the covariate, and smallest when scotopic luminance is the covariate. (Note that even though the effect sizes are the same as those presented in ‘lable 2, the F and p values are different because of the different error terms and degrees of freedom in the ANCOVA procedure.) Finally, the interaction of lighting source and the covariate was very small (p >0.5 in all cases), indicating that the curves of spectral luminance vs. pupil area for the two light sources are parallel over the range studied. From this analysis we conclude that when log scotopic luminance is plotted versus log pupil area (Figure 10), one curve fits both light sources. In contrast, for either photopic (Figure 9) or Alpern-

Campbell (Figure 11) spectra, each light source was fitted well by a log-log curve and the two curves were parallel but significantly displaced from each other.

Spectral Prediction of “entrance-trolands”

The statistics applicable to the pupil area data are equally applicable to the troland plots (**Figures 5-8**, replotted log- log in **Figures 12-15**), since they axis in these figures is a product of the x axis and the pupil area. However, the plot of photopic entrance-trolands as predicted by scotopic luminance (**Figures 8 & 15**) requires futher calculation, since the variance of the two axes is not inter-related, as in the other plots. Therefore, we utilized the GLM with the dependent variable being photopic entrance-trolands, the covariate scotopic intensity, and the independent variable the light source. The results are shown as Analysis 4 in **Table 3**. It is clear that scotopic spectra alone account for only 24 percent (22 percent of 92 percent) of the variance attributable to lighting, whereas the light source (lamp type) accounts for 76 percent (70 per cent of 92 percent) of the variance. Thus, the two curves in Figures 8 & 15 are clearly different. [Note that the total variance (at 92 percent) attributable to the lighting is greater than in **Table 2** or the upper part of **Table 3** because, in the case of Analysis 4, the variable of the x axis covaries with a factor in the y axis.] In contrast, the two curves of **Figures 6 & 13** are probably the same, within the accuracy of our exper iments.

Discussion

This paper reports a well conceived, well executed, and imaginatively analysed experiment. The scoto pically dominated response of the pupil, while ade quately documented in the literature, has languished in the backwaters of vision research for want of a prac tical application. Now Dr. Berman and his co-workers have given us a reason to take notice. As they point out, the availability of sources with discontinuous spectral power distributions which have large amounts of energy in relatively narrow spectral bands make it necessary to look anew at the effects of such sources on vision and the visual system.

The important question raised by this paper is: “does the fact that HPS and incandescent light of equal photopic luminance give markedly different retinal illuminances have any practical significance for the lighting engineer or designer?” Several studies have looked at the effects of HID sources on visual performance and most have concluded, that, if contrasts are equated, the spectral distribution of the source does not influence visibility for achromatic tasks. That result is not surprising when you consider that the testing was done under conditions of high contrast, moderately high luminances, and free viewing, allowing the subjects to focus for the task distance. As the authors correctly note, large pupils have two primary effects-they increase the retinal illuminance while decreasing the depths of field and focus. While it has been shown that pupil size has little effect on high contrast visual acuity when the task is in focus (reference 1), the gain in retinal illuminance with in-creased pupil size may be of significant benefit under conditions of low task illuminance, low contrast, or to the aged.

On a strictly technical note, the scotopic dominance found by the authors may be due to the large visual field used in the study. Both Alpern and Campbell (reference 2) and ten Doesschate and Alpern (reference 3) have shown that cones do contribute to the pupillary response, but that the cone-mediated response is small compared to that of rods except for very small fields or very high retinal illuminances (e.g. 10,000 trolands). One would also expect the effect to be diminshed under conditions where the field of ·view contains surfaces with different spectral reflectances so that the retinal illumination is not determined solely by the spectral power distribution of the source as was the case in this study. None-the-less, for any task which has a reasonably neutral background, the effect may well be significant and may tilt the efficacy advantage even further in favor of HPS illuminants.
Alan L. Lewis

This is certainly a very interesting paper to the lighting public in general and the roadway lighting professionals in particular. There has been diverse opinions concerning the question of whether the human sees better under high pressure sodium versus other types of artificial sources. Many subjective evaluations have been offered, some saying they see better under HPS and others saying that seeing is not as good. Even though the results are not correlated to visual performance they show there is a difference in the eye response between HPS and incandescent light. It is hoped that this work will be carried further to the point of determining if there is a correlation between these results and visual performance.

There are some questions relating to the methodology in the work. Even though it is not stated exactly the implication is that the incandescent lamps were operated at 60 Hz. Is this correct? What was the waveform of the high frequency driving the HPS lamp? Was this a pure sinewave or some other waveform? If not a pure sinewave could the waveform have effected a difference in the response of the Pritchard relative to the eye response? As the input voltage to the HFHPS ballast was increased did the driving frequency to the lamp or its waveform change? If so, what effect, if any, did it have on the readings?

When the wattage of an HPS lamp is increased by increasing the in-voltage usually both the lamp voltage and current increase. The net result is not only an increase in lamp lumen output, but also a change in the spectral distribution of the lamp. Was this change observed? If so, how was this change accounted for in the photopic and scotopic response? The authors state they used a 30 kHz ballast to drive the HPS lamp to avoid a possible confounding variable. But practically all HPS lighting in this country is driven by 60 Hz ballasts. Was the test run using a 50 Hz ballast to see what differences there are? If not, do the authors plan to do any test on the HPS lamp at 50 Hz?

These results naturally lead us to the question oJ whether other high intensity discharge lamps give the same type results or not. Do the authors plan any further work to determine the effect with other HID sources? If so we assume this would also include llow pressure sodium sources?

Billy Lee Shelby
American Electric Diviswn
FL Industries, Inc.

This paper presents a thoughtful analysis of the ef feet of light source spectrum on pupil size. As pointed out, this was first noted in the late eighteen hundreds, and as you might expect, has evoked some spirited unresolved controversy since then. The present paper, because of new instrumentation and well mastered techniques will gain the authors some well deserved recognition in the final resolving of the controversy on “how the light spectrum affects pupil size:

An important larger controversy will remain. That is, “What is the practical effect on human performance of operating with a pupil size reduced by 2 01 3 millimeters?” As a dedicated vision researcher, the following is offered in an effort to assist and encourage necessary further research. Here are comments from past research:

1. Duke-Elder (1942-1972) gives this insight into the subject: “When lights of different colours are used the degree of contraction varies with the luminosity of the light independently of the colour:’ A small pupil is advantageous in that it lessens the influence of spherical and chromatic aberration and increases the depth of focus; it has the *disadvantage* of increasing the influence of diffraction and reducing the brightness of the retinal image. The visual acuity always improves as the retinal luminance is increased. Even with a pupillary diameter of 5 mm, however, chromatic aberration is negligible. “A small bright area has greater pupillomotor effect than a larger dimly (scotopic) illuminated area:

2. Parry Moon (1961) points out that “Cobb showed that visual acuity is practically unaffected by a changein pupil diameter from 2 to 6 mm. Although pupildiameter does have an effect on retinal illumination, the reason for the marvelous ability of the human eye to adjust itself to a wide range of luminosities must be sought elsewhere than in a change in pupil diameter:

3. Buck, McGowan and McNelis (1975) found no difference in roadway visibility as a function of light source color. Moreover, lighting distribution did affect visibility:•

4. DeLaney, Hughes and McNelis (1978) found no difference in visibility between 3000 and 5000 Kelvin fluorescents and no difference in human performance between a comparison of cool white fluorescent

and high pressure sodium.

5. Judd and Wyszecki (1952) caution that people “become less sensitive to violet and blue light as they get older; suggesting a young population even if drug free may not be a sound body on which to base lighting recommendations. They also caution that “within the scotopic region the rods adjust their sensitivities automatically to the particular luminance level:’

6. Luckiesh (1937) points out that the pupil remains practically constant in size for changes in brightness of the visual field as high as 200 to 1 if the increase in brightness is accomplished by gradual and almost imperceptable changes: He also points out that a larger pupil has greater resolving power, although counterbalanced by a decrease in the sharpness of the retinal image.

7. Zoethout (1927) pointed out that by experiment it has been proved that “accomodation of our eye is something far more than pupil constriction, which by itself cannot account for near vision” and “it is only when light is very feeble or very strong that the size of the pupil is greatly altered: So that it might not appear that I am making much to do about nothing, let me more clearly state that if we are ever to transform this effect which could remain just a laboratory curiosity into a useful and viable force for improving lighting so as to optimize visual efficiency, visibility and human performance, then the dedicated researchers of IES need to pick up the challenge by doing the required research. I hope the authors have the next five years available to dedicate.

John E McNelis

Authors’ rebuttal

To Prof. Alan Lewis

We appreciate Prof. Lewis’ comments that emphasize the implications of our work.

The question of what size of field of view (significantly different in our experiments and those of Alpern & Campbell) is relevant for extrapolating from experiment to lighting applications remains to be evaluated. Our experiments with a large field of view show that field of view, spectrum and rod and cone function must be a concern of rational, realistic lighting design.

We agree with Prof. Lewis that the light reaching the eye is affected not only by spectral difference between lamps, but also by the spectral reflectances of objects in view and in the surround. The effects on pupil size should be predictable if all factors are known.

We question whether there is an efficacy advantage of scotopically deficient sources under all conditions. More trolands may not necessarily always translate into better vision, since pupil size (controlled by intensity and spectrum) can affect visual performance. Under some circumstances there may be a visual advantage of smaller pupils brought about by scotopically rich sources. On the other hand, the apparent advantage of extra trolands secondary to illumination with a scotopically-poor HPS lamp may be countered by poor depth of field or visual acuity. Yet trolands may be an over-riding factor under conditions near visual threshold, as in night driving.

To Billy Lee Shelby

Billy Lee Shelby has indicated a number of further studies.which are important and relevant to determining what factors should be of concern in practical lighting design. Our present experiment shows that pupil size is important, and suggests that the next questions are: 1) what is the visual consequence of this finding? 2) are there special conditions that affect the result? 3) with what lighting technologies is this result of concern?

Specifically responding to his comments and suggestions: incandescent lamps in this experiment were always operated at 60 Hz.

The wave form of the high frequency HPS driving voltage is irrelevant to the response of human subjects since the frequency is many orders of magnitude beyond any human response. As far as the Pritchard Photometer is concerned, we compared its output to a photo-diode and found no differences between the two instruments when frequency was changed from 60 Hz to 30 kHz.

The spectrum of the HPS lamp does change as its input power is reduced. We were aware of this and at each setting of the input voltage needed to change the light intensity, we made separate measurements with a spectrophotometer to determine the spectral power distribution and then folded that against the standard scotopic response of the eye to determine the scotopic luminance at every voltage setting.

The reason for introducing high frequency ballasts to drive the HPS was to eliminate any confounding influences of flicker since the HPS has a very high (95 percent) modulation as compared to incandescents (5 to 8 percent).

We have performed separate experiments under a grant from the Lighting Research Institute (LRI) of the IES in order to investigate whether frequency modulation affects pupil size. We will be reporting that using a variety of different lamps with large modulations including HPS, LPS, Daylight fluorescent, and a photocopy narrow spectrum fluorescent, the pupil size under each lamp at driving frequencies of 60 Hz and 30 kHz in six subjects shows no statistically significant differences in any of the comparisons.

As to other HID lamps, we predict (and will have to experimentally verify) that the results will depend solely upon the ratio of scotopic to photopic spectral content of lamps, and be unrelated to the light emission mechanism. Continued work with a variety of lamps will be undertaken, especially to examine questions of effects on actual visual performance, so long as funds are available for continuation of this work.

To John McNelis

We whole-heartedly agree with John McNelis that an important next step in this study is to determine if there is any measurable effect on visual function resulting from spectrally induced pupil size differences. It should be noted that researchers in optometry have been aware for a long time that persons with slight uncorrected errors in refraction find significant improvements in acuity with smaller pupils (see e.g., Atchison 1979). A spectacle wearer attempting to read without his or her spectacles will often find it possible when the illumination level is increased with the resultant decrease in pupil size reducing the effects of lens spherical aberration. On the other hand a person with a near perfect lens would probably not have an acuity benefit but might find an improved depth of field with a smaller pupil. Thus, another variable that must be studied is the inherent visual function of subjects with uncorrected refractive errors.

The first quoted statement from Duke-Elder is contradicted by our work and the researches cited in McNelis' first paragraph. The second quotation provides a description of the effect of pupil size on various factors, much of which must be quantitatively evaluated in future research.

Concerning the remarks of Parry Moon, one should note the work of Campbell who showed continued decrement in depth of focus of the normal eye with increasing pupil size. A major future issue is whether uncorrected refractive errors “use up” the “ability to adjust” mentioned by Moon.

We have found it difficult to compare the work of Buck et al. on roadway visibility with different light sources as well as the work by Delaney et al. on an office task under different effective color temperatures of fluorescent lamps, with our own conclusions since in each case, though light source spectrum was varied, spectral reflectance was not known. In addition in Delaney et al. the issue of fluorescence in paper whiteners and unknown target contrast make conclusions concerning the effects of spectral differences on performance uncertain.

The comment made about the use of older subjects is important as senile miosis certainly affects the dynamic range of pupil size and there may be other effects of aging as well. We suggest that extrapolation from our results from young subjects without refractive errors to other groups is not warranted. Each subject group should have a separate evaluation.

As to the remark ascribed to Luckeish, the conditions for which small increments in luminance fail

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to produce changes in pupil size are primarily under scotopic light levels (Alpern & Campbell, and Bouma) whereas in our experiments light levels were always in visual photopia. The second remark due to Luckeish is supported by the findings that for a very small pupil there is a tradeoff between the limitations caused by diffraction and the improvements in depth of field (see Westheimer (1964) and Green and Campbell (1965).

The reference to accommodation from Zoethout should not apply to the conditions of this experiment since the subject was fixating on a target slightly more than 1 meter away and thus synkinesis is unlikely.

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Dr. Wendy Davis has been an Associate Professor in Lighting the School of Architecture, Design and Planning at the University of Sydney, where she leads a professional master’s program in illumination design and architectural lighting research lab, since 2012. She previously worked as a Vision Scientist in the Lighting and Color Group at the National Institute of Standards and Technology (NIST) in the U.S for over seven years. Wendy earned her Ph.D. and M.S. degrees from the University of California, Berkeley in vision science after completing her B.A. in psychology and physiology at the University of Minnesota.

Keywords: energy efficiency, application efficacy, adaptive lighting, smart lighting

One Sentence: When both the luminous efficacy of lighting devices and the usefulness of the light generated by them is considered, innovative new strategies for illuminating architectural spaces arise that can drastically reduce the energy consumed by lighting without negatively impacting the visual environment.

Beyond 2030: Beyond Luminous Efficacy

By Wenye Hu, Dorukalp Durmus and Wendy Davis

Luminous efficacy is useful for measuring and communicating the efficiency with which individual lighting products convert electricity to perceptible light, but does not evaluate whether the light actually supports visual perception in real architectural spaces. Much energy is wasted simply because much light goes unseen. By considering the entire lifecycle of illumination—from the generation of photons to the perception of the visual environment by building occupants—numerous opportunities can be identified to reduce the energy consumed by lighting by merely generating less undetected light. Three examples are discussed: (1) smarter dimming systems that reduce the total amount of light emitted from luminaires by an amount that is either undetectable or detectable, but still acceptable, to occupants, (2) absorption-minimizing lighting systems that tailor the spectrum of light illuminating individual surfaces to reduce the amount of light lost to absorption, without compromising the color appearance of illuminated objects, and (3) gaze-dependent lighting systems that project light only to the portions of the visual environment being viewed by occupants at any given time. Based on the current state of research and the extent to which these ideas depart from modern lighting design practices, they could be implemented in the near-term (beyond 2020), medium-term (beyond 2030), and long-term (beyond 2040), respectively.

The initial decades of the 21st century were marked by rapid increases in the luminous efficacy of lighting products and the growing adoption of solid-state lighting (SSL). The widespread commercialization and adoption of light-emitting diodes (LEDs) for general illumination has notably reduced the energy consumed by lighting in the U.S. [1]. However, the energy efficiency of lighting products cannot increase indefinitely, since there are physical limits to the efficiency with which light can be generated by electricity, regardless of future advances in lighting technology.

The most widely used measure related to energy efficiency in the field of lighting is luminous efficacy, which is a useful metric for characterizing the energy performance of individual lighting devices. Numerous standards, codes, and incentive programs have been developed to promote the use of high efficacy lighting products [e.g., 2, 3]. Nevertheless, luminous efficacy, which only quantifies energy performance for one part of the illumination lifecycle, does not fully address the use of lighting in architectural spaces. In buildings, the primary function of light is to facilitate the visibility of surfaces: walls, people, food, books, artwork, furniture, etc. Light that does not enter an eye, get absorbed by a photopigment, and result in visual perception does not contribute to this function—for illumination purposes, it is wasted. Even when high luminous efficacy products are used, significant electrical power is wasted in real architectural lighting applications because only a fraction of the light generated is seen by building occupants at any moment.

Several modern lighting design practices perpetuate this problem. For instance, though they vary between countries, lighting application performance standards have been used for decades to guide lighting designers. These recommendations usually encourage rather uniform lighting (i.e., high illuminance uniformity), so that occupants can successfully engage in visual tasks throughout an architectural space [e.g., 4-6]. However, this often results in the unnecessary illumination of surfaces when occupants are not viewing the entirety of a space.

Relatively little research is dedicated to improving the efficient use of light in lighting applications, and few metrics account for the efficiency of light use. Therefore, the National Research Council recommended that *application efficacy* be maximized to further advance SSL. The concept of application efficacy considers lighting efficiency from generation to use—the relationship between the electrical power consumed by lighting hardware and the amount of light that contributes to the visual experience of building occupants [1].

Modern lighting systems have been undergoing radical changes. Thanks to developments in control systems, sensor technologies, and lighting technologies, luminaires can be connected to the internet and/or other appliances, so that lighting conditions can be changed automatically in response to the wide range of information provided to the lighting system. These types of “smart” lighting systems could be used to redefine the way that light is used after it is emitted by a light source and provide the industry with unprecedented control over the intensity, spectral, spatial, and temporal output of lighting products. Significantly more systematic research is needed to deeply understand how to optimize those characteristics to increase application efficacy. Nonetheless, some recent work offers suggestions for how future lighting systems might increase the utilization of light in architectural spaces. Some of these ideas could realistically be achieved in the near-term (e.g., smarter dimming), while others would require more radical reimaging of the design and installation of lighting hardware (e.g., absorption-minimizing lighting, gaze-dependent lighting).

This speculative timeline is based not only on the need for additional research to inform the design of these types of lighting systems and the engineering required to actually develop them, but also on anticipated shifts in user attitudes toward responsive, automated building systems. Just as people of past decades would likely view many modern technologies and services (e.g., self-driving vehicles, targeted advertising, wearable health monitoring devices, etc.) with skepticism or even contempt, it is unlikely that many contemporary building occupants would find the more futuristic approaches to lighting appealing. However, increased adoption of pervasive technologies in the coming decades will undoubtedly influence what users both accept and desire.

Beyond 2020: Smarter dimming

Early studies of visual perception found that the differences in light intensity that people can detect increases as the total amount of light increases [7]. These just noticeable differences (JNDs) vary in different lighting conditions and can be quite high in bright environments, such as commercial spaces. When making adjustments to the intensity of the lighting in real environments, occupants may primarily look at the illuminated space, or they may look directly at the luminaires. If lighting control systems could automatically reduce the intensity of light, in a manner that is either unnoticeable or noticeable, but still acceptable, the energy consumed by lighting could be reduced. Research has investigated the detectability and acceptability of illuminance differences (i.e., as though the user is looking at the illuminated environment) and luminance differences (i.e., as though they are looking directly at the light source) for lighting conditions typical in architectural environments. The studies found that users cannot perceive differences less than 7.4% in illuminance [8], for illuminances that are common in architectural spaces. Similarly, occupants are only able to detect luminance differences when they reach 10.5% to 13.5% [9].

However, even when occupants can detect differences in lighting, they may not be bothersome or even noticeable. In this research, the acceptability of illuminance and luminance differences was measured by having participants match the intensity of two stimuli. These matches were rarely perfect when the physical intensity of the two stimuli was compared, and the magnitude of the intensity differences are indicative of differences that are acceptable to people. This research showed that differences of up 19.1% were acceptable [8, 9].

A series of step-dimming curves were developed that could conserve energy without negatively impacting the visual appearance of the illuminated environment [8, 9]. Using these dimming curves, lighting systems could consume an average of 7.7 % less energy than those that use traditional logarithmic dimming curves and 18.9 % less energy than those that use square law dimming curves, without changing the illumination in a way that would be noticed by building occupants [8]. The proposed series of step-dimming curves would further conserve energy by counteracting LED efficacy droop, whereby LED luminous efficacy decreases as the current increases. If a lighting system were to be dimmed by an imperceptible or acceptable magnitude, as suggested by this work, both total energy consumption would be reduced and light source efficacy would be increased.

Beyond 2030: Absorption-minimizing lighting

In buildings, light strikes walls, floors, and the surfaces of furniture, objects, etc. The light reflects off these surfaces and enters human eyes, resulting in visual perception. Surfaces of different colors reflect and absorb different proportions of the different wavelengths that constitute white light, in predictable ways. For instance, green surfaces predominantly reflect the middle (green) wavelengths and primarily absorb shorter (blue) and longer (red) wavelength light. Therefore, it is reasonable to suppose that future lighting systems could illuminate individual surfaces within an architectural space with light that has a spectrum tailored to minimize light absorption, without negatively impacting color appearance. For example, in future lighting systems, as shown in figure 1, sensors could detect the colors of the objects (i.e., a sofa and a cat) in the room and report that information to the control system, which could perform optimization calculations rapidly (or refer to a look-up table). Then, the control system could send signals to the luminaire, which would project the optimized spectrum to the objects, which would be predominately red and amber light in the case shown in **figure 1**.

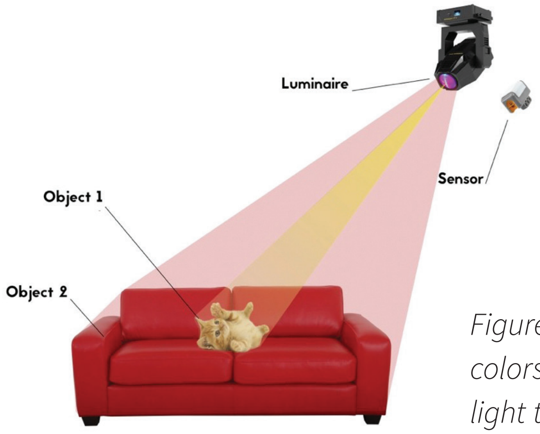

Figure 1: Future lighting systems could detect the colors of surfaces in a space and project optimized light to the illuminated objects.

Research has explored the possibility of adjusting the spectral composition of light to reduce the amount of light that is absorbed by surfaces. Through a combination of computational studies and experiments, this work has demonstrated that the energy consumed by lighting could be substantially reduced if this approach to illumination design were to be widely adopted [10-13]. For instance, the relatively simple use of currently commercially available LEDs could reduce energy consumption by approximately 10% [12], and the use of more complicated spectral forms could yield energy savings of up to 70% [10, 11]. The implementation of this lighting method would require some engineering challenges to be overcome, but is not dependent on fundamental advances in lighting technologies.

This approach has also been applied to the lighting of artwork, since absorbed light causes irreversible damage to pigments [14-15]. This application is so promising that work is underway to light Salvador Dali's Dues figures (Two Figures) in this way [15].

Optical control would, obviously, be important for achieving such tailored lighting. While the required optical precision has been evaluated with human observers [16], an interesting variation on the idea is to optimize the spectrum of light for the range of surface colors within an area of space [17], which could reduce the optical requirements of such a system. Researchers have already demonstrated a spatially

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variable illumination system using laser diodes [18] and a point-by-point lighting system using LEDs [15] capable of detecting surface colors and projecting spectrally-tuned light to specific points in space.

Beyond 2040: Gaze-dependent lighting

Gaze-dependent lighting, whereby the spatial distribution of light is dynamically modified based on the gaze of building occupants, is another promising strategy for improving application efficacy, though it has been scarcely studied. Even when multiple people occupy a room, they rarely view all parts of the room continuously. Light that falls upon portions of rooms that are not being viewed by anybody is wasted, in the same way that light that is absorbed by surfaces is wasted.

Since modern sensing technologies can easily track the locations and orientations of individuals in real-time [e.g., 19, 20], gaze-dependent illumination has the potential to become a reality in future decades. These future lighting systems could use sensors to estimate the direction of gaze of each person in a building [e.g., 21, 22], then illuminate only the portions of the visual environment that are visible to occupants at any given time, as illustrated in **figure 2,** yielding significant reductions in the energy consumed by lighting.

Occupancy-based lighting systems have been used in numerous buildings in recent decades to minimize energy consumption in unoccupied spaces. Occupancy-based dimming has been shown to reduce the energy consumed by lighting by up to 71% in corridor type spaces [23] and 61% in offices [24]. Since gaze-dependent lighting is more extreme than occupancy-based lighting, even more drastic reductions in energy consumption are possible. However, strategies for modifying the spatial distribution of light, in ways that don't undermine the visual experiences of occupants, have not yet been developed.

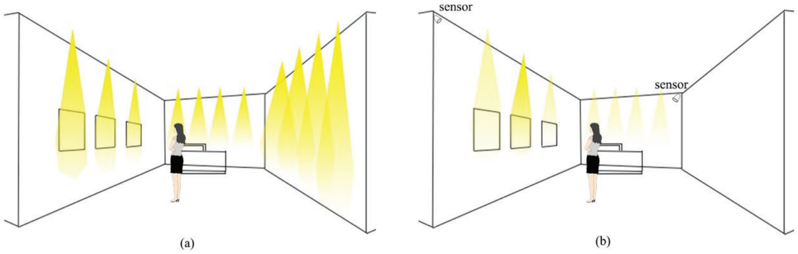

Figure 2: (a) Traditional illumination – all portions of a room are evenly illuminated. (b) Gaze dependent illumination – only the portions of a space that are visible to the occupants at any given time are illuminated. Lights illuminating other portions are dimmed or turned off.

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Currently, most lighting standards simplistically recommend even illumination [e.g., 4-6], but humans have high visual performance only in a small central portion of the visual field [25]. The scientific literature has documented numerous ways in which peripheral vision is poorer than central vision (for stimuli of the same size): the detection of position [26], the detection of motion [27], the discrimination of color [28], the detection of changes in natural scenes [29], etc. An experiment investigating the detectability of luminance differences across architectural spaces suggested that luminance JNDs increased when the observation distance was increased [30]. These findings suggest that gaze-dependent lighting is unlikely to interfere with the execution of many visual tasks, even if only a fraction of an occupant's central visual field were to be illuminated.

However, it would be naïve to develop gaze-dependent lighting systems that simply illuminate a very narrow central region of the visual field and omit all background light, since peripheral vision has been shown to positively influence visually-guided navigation [31] and the determination of the gist of a visual scene (i.e., the ability to categorize a scene) [32]. Systematic research is needed to guide the design of these types of future lighting systems, so that they both minimize energy consumption and assure a high-quality visual environment for occupants. Specifically, the (likely interacting) effects of the size of the illuminated field and background light intensity on building occupants' abilities to navigate within and between architectural spaces, as well on their subjective impressions of the visual environment, need to be well-characterized. Furthermore, the ways that illuminated field size, illuminated field intensity, and background light intensity affect the amount of energy consumed by lighting, relative to standard uniform illumination, needs to be understood.

Though every real lighting application has its own unique requirements, detailed investigations of these issues can guide the development of gaze-dependent lighting systems, the benefits of which may prove crucial for the lighting industry in the coming decades. While technological advances are leading to more energy-efficient lighting products, there are practical limits to the efficiency with which electricity can be converted to light. In the future, focusing on application efficacy will enable the lighting community to continue to reduce energy consumption by reducing the amount of light that needs to be generated.

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IES Visionary Challenge Judge

James Brodrick was the program manager of the U.S. Department of Energy Solid-State Lighting R&D program, directing solicitations, portfolio management, strategic planning, and quality performance. This Program contained science-based research and various market-based activities that established a creditable product for consumers.

Science Research

By James R. Brodrick, Ph.D., IES Fellow, IES Trailblazer & Icon

All 2030 visions must be built upon a foundation of science, technology knowledge, and application techniques. Much of the current body of understanding is based on lighting sources and techniques of the last century for general illumination (one function). Scientific Research is necessary to discover the unknown factors (and encounter the unknown unknowns) to move the lighting culture forward with multi-functional source lighting that has unlimited customization.

Multiple functions of lighting can be achieved with solid-state sources that are designed to enhance value by varying intensity, spectrum, directionality, and more. The exact mix of these attributes will be unique for each function of the light. Illumination (source>object>eye) for visual acuity will greatly improve by varying the attribute mix in relation to age of viewer (and eye health), ambient light, and font (or object). Illumination for color discrimination will add emphasis on the spectrum and consider the expected (not present location) ambient lighting.

Navigation or guidance, similar to following the North Star, will have a unique mix of attributes to allow varying intensity, range-sync color, re-direction of direction, and directly viewed to provide enhanced navigational information. Also directly viewed, displays (high resolution signal) will be HD and appear on flat panel screens, glass walls, fabric or solid walls, or on no surface (possibly a hologram).

Light and physiological response will be a highly valued function of light soon. Conscience response (traffic signals and reflex) and subconscious response (depletion of blue light over the day) affect the human status. Much is to be discovered about human physiology and application of light to aid in health. Au contra do no harm to health or safety. Undesirable consequences can also be induced by light, such as signals at the wrong time (bright blue light at night) or bright light that enters our eyes directly and results in decreased visual function.

The customization of sources to address multiple light functions has the potential to create large value to society, trillions of dollars. Scientific Research is critical to enable the full potential of light and make advances in fundamental understanding. A substantial research investment in multi-disciplinary topics is essential. Of course, increases in research trained professionals are also needed (education). A substantial multi-year investment by the Federal Government (NIH, NIST, HUD,…..) would materialize this 2030 vision.

A New Approach to Lighting System Control

T. K. McGowan and G. E. Feiker

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In recent years, the number of switches for lighting system control has been reduced to save initial installation costs. In commercial buildings, large areas or even whole floors may have only one or two switches for the entire general lighting system. The author examines the development of a practical low cost lighting control system that can vary the illumination within an exterior or interior space. The system is designed to suit the changing needs of the lighting user, conserve energy, and lower lighting costs.

With new emphasis being placed on the need to reduce costs and utilize energy effectively in commercial structures, more attention is being focused on ways to control the functional operation of the lighting system. Better ways are needed to optimize system performance without sacrificing the lighting quality or quantity that the user needs to perform visual tasks.

As recent studies have indicated,-[1 3] simply reducing overall illumination may be counterproductive, eventually requiring the expenditure of greater quantities of labor, energy and materials to get the job done. Removing lamps and disconnecting luminaires not only detracts from the appearance of the space and building but, more importantly, a portion of the lighting equipment investment is lost and the effect on other building systems, such as heating, may require expensive modifications. Further, if lighting needs change and equipment must be reactivated, additional costs are incurred. Designing new facilities with less than adequate illumination extracts a continuous visual penalty on some workers while virtually committing the building owner or tenant to higher long term expenses for upgrading and re modeling the lighting system as conditions and requirements change.

Described in this paper is a developmental control system that can be applied as a practical solution to these problems, and can be designed to greatly in crease the flexibility of new or existing general lighting systems. Thus, they can be made to respond, both in time and in space, to the changing needs of lighting users, energy limits, and cost considerations without compromising lighting requirements. An experimental installation of the system is discussed which provides lighting control for an office installation on a luminaire-by-luminaire basis. Extensions of the basic idea lead to the concept of a distributed control system applicable to lighting, heating, cooling and other major building electrical loads.

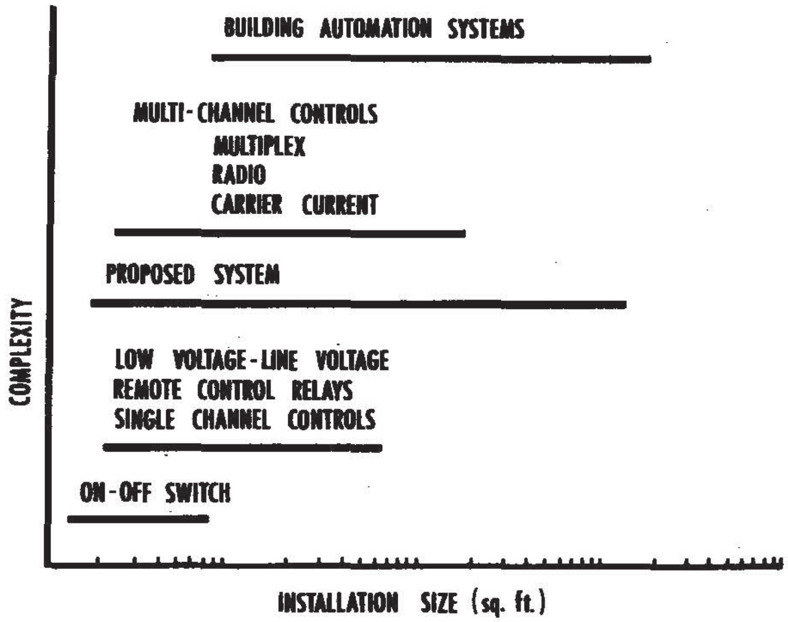

Figure 1. Control system complexity and installation size as a function of applicability.

The hierarchy of some control systems applicable to lighting might be roughly ranked as shown in **Fig. 1**. Larger and more complex systems, of course, generally lend themselves to more complicated control functions, perhaps involving feedback and monitoring as well as control. The "applicability lines," while somewhat arbitrary, suggest that each system must be analyzed and fitted to the application. Equipping the six luminaires in the corner grocery store with individual hand-operated switches may be a convenient, inexpensive and workable solution, but if the same technique were to be applied to thousands of offices in a large building complex, the installation expense may never be paid back by operational cost savings and the nuisance involved in operating each switch ensures that most will not be used as intended.

The developmental control system as envisioned may be applied on a much broader basis. It permits:

1. Variation in illumination level throughout the space in small enough spatial increments so that task illumination can be matched to task difficulty and criticalness.
2. Control of the direction of the major incident flux to minimize veiling reflections.
3. Flexibility so that the lighting can be tuned to the activities of the people working in the space; as well as allowing for the movement of furniture and other changes in the room.
4. Coordination of the lighting with other building services for occupant comfort, minimum operating cost and optimum energy utilization.

SYSTEM DESCRIPTION

The basic components of the developmental system are a central control device and a receiver/switch which is located in the electrical supply line to the load. This is a standard control arrangement, but it differs from more traditional approaches in that it can control small loads individually by using low cost logic elements and digitally coded signals for the functional and address commands. This has the result of greatly increasing the system capacity since, by carefully defining the control hierarchy and digital word structure, the number of remote control points can be made virtually limitless.

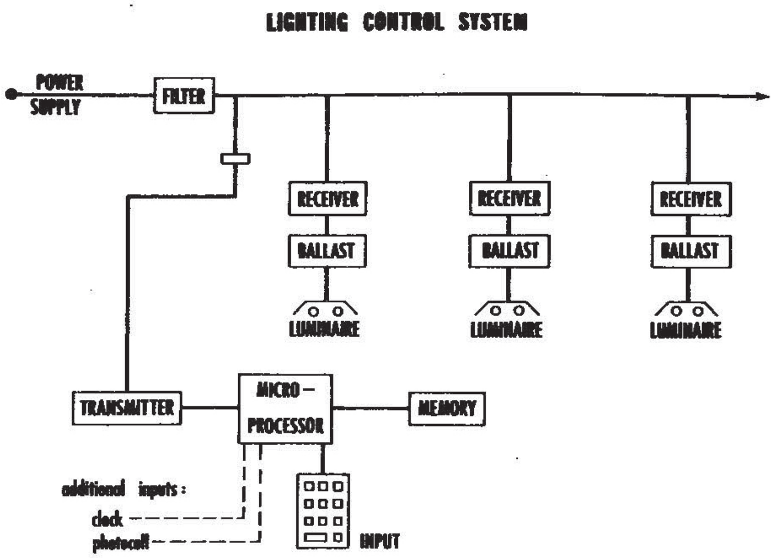

Figure 2. Block diagram of development lighting control system illustrating control on an individual luminaire basis.

One possible configuration of the system designed to control general lighting is shown in **Fig. 2**. Triggered by some type of input device, the micro processor carries out a planned sequence of control operations according to a stored memory program. Inputs may be generated by a clock, photocell, touch pad, etc. The processed commands properly coded are then sent to the remote receivers where they are decoded and cause the appropriate control function to occur. In this case, the signal is shown traveling between the transmitter and receivers by means of the normal power wiring, but coaxial cable or twisted pair could be used as well. This power wiring arrangement, however, is particularly advantageous for existing lighting systems since installation is simplified.

In one configuration the system might utilize a “lighting map” or a stored pattern of luminaires set to goon or off according to the functional needs of the space. During working hours, a clock would call for the appropriate patterns from memory switching to different patterns as needed or at the end of the day. One set might be: arrival-working-lunch-work ing-departure-cleaning and nighttime. Local controls could be used to override the normal pattern at any time by injecting address and command codes for the particular luminaires involved. A standard telephone may be used as an input control device simply by setting up a telephone station as an input line and adding a suitable interface to the micro processor. From a functional standpoint, the variety of different control inputs to the microprocessor can be easily handled by an input/output bus either by programming the microprocessor to periodically scan a number of input ports for data inputs or on an interrupt basis, in which case the normal program sequence is interrupted to service the request. For the former case, the microprocessor is programmed to access input ports as part of the normal program and read the contents of a buffer storage at the input port(s). In the case of the interrupt mode, several request lines may be used on an assigned priority basis. Once the interrupt request has been acknowledged and executed, the microprocessor re turns to its normal program sequence. In a typical lighting control system, local switch inputs or light sensors might be handled by sequentially scanning a number of input ports; a telephone input would be handled on an interrupt basis.

Overall, the use of stored programs to generate the desired control action, accessible through a variety of input devices, greatly reduces the number of local control points and associated wiring without reducing flexibility. Changing lighting patterns to suit new floor, partition, or work space arrangements would not involve changing power wiring or moving switch legs, but only a new set of memory instructions.

Additional functions could be added to the control system at any time without greatly adding to costs or complexity. For example, a power limiting circuit added to the input would ensure that the number of luminaires turned on would not exceed a precalculated demand limit.

The key to the practicality of this developmental control system is the utilization of standard logic elements such as the microprocessor. These devices are now being mass produced in a variety of the configurations and prices have dropped from hundreds of dollars per unit to several dollars per unit and forecasts suggest a cents/unit price is not far off. Microprocessors themselves are becoming the ubiquitous heart of numerous electrical and electronic devices from pocket calculators to electric ranges and automobile ignition systems. One report[4] estimates that the United States' shipments of"chip sets," which include microprocessors and their auxiliary devices, will climb to some ten million units per year by 1980 from the 1971 level of 1000 units and the 1974 level of 200,000 units.

Experimental installation

To test the practicality of the idea and gain experience with an actual operating system, a small scale installation was built and put into operation in a 14-by 17-foot two-person office containing 18 two lamp, 40-watt recessed fluorescent troffers. For maximum flexibility, it was decided to equip each luminaire with a receiver and switch plus a two-level ballast so individual off-low-high operation could be obtained. Installation was easily accomplished by adding a control module to each luminaire and re placing the usual room wall switches with the control unit. Existing power wiring was utilized to carry the signals as indicated in **Fig. 2**. A standard kilowatt hour meter was added to the room's input power line to monitor lighting energy.

The physical arrangement of the experimental control/transmitter is shown in **Fig. 3**. Commands are fed into the system via a numeric touch pad located on the right side of the cabinet. These signals first go into the microprocessor, which is a standard catalog unit, but which operates under the control of a special program written on two Read-Only Memory (ROM) chips located on the upper portion of the circuit board. The processed commands are then fed into a signal generator which modulates them on to a 50 kilohertz carrier. From there, the signal is coupled to the power line using the circuit at the lower right of the cabinet. Power supplies and a circuit board containing a clock fortiming the logic circuits complete the microcomputer and the transmitter portions of the system.

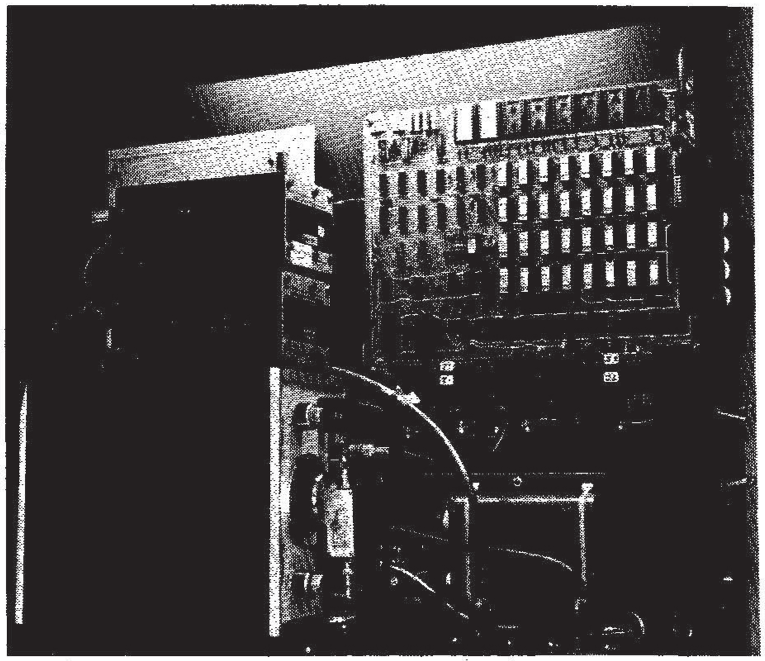

Figure 3. Microcomputer and transmitter control for the experimental office lighting installatlon.

The ROM chips contain memory locations that permit addressing each of the 18 luminaires individually and switching them either to high, low, or off. In addition all of the luminaires in the room may be controlled sequentially by pressing one button that sets them to any one of the three states.

Expanding this system to control additional luminaires, accept other inputs, or utilize a different program can be accomplished simply by adding memory modules and exchanging the ROM chips with alternate units containing different programs. Should frequent program changes be required, Programmable Read Only Memories (PROM) could be utilized in conjunction with standard programming equipment. Similarly, peripherals normally used with data processing devices such as tape readers[1] magnetic tape cassettes, printers and readout equipment might be added to increase flexibility and expand the operational convenience of the system.

Once the coded signal leaves the transmitter, it travels throughout the wiring system until attenuated by line impendance or blocked by filters. At the luminaire, it is decoded by the receiver (shown in the upper left of **Fig. 4**) and sent to the logic section. If the incoming address code matches that of the receiver, the command is passed through to the driver circuits and finally to the power relays.

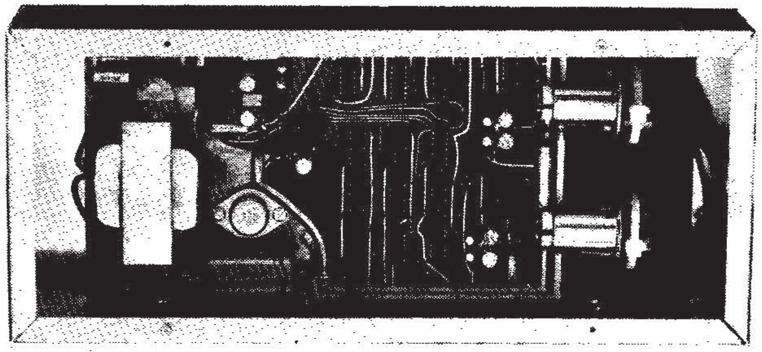

Figure 4. Receiver/switch for the experimental lnstallatlon. At the left is the receiver and power supply. Logic circuits containing address and control functions are at the center with the relay drivers and power relays at the right.

The circuit design used for the experimental installation contains several provisions that add to system reliability and immunity to power line interference. The receiver is a frequency-modulated phase lock type having high noise immunity. The decoding circuits operate such that two out of a chain of three correct signals must be received before the control signal is given to the power relay. The system is clocked to the 60-hertz power line with both zero crossings used to obtain a 120-hertz clock rate. This means that a long time constant is applied to the data anda narrow data bandwidth is the result. Frequency shift keying of the transmitter ensures that unless noise is very near the carrier frequency and lasts for a duration of eight milliseconds, it will not interfere with system operation. This type of noise is not at all typical of transient noise found on power lines.

Experience accumulated during more than one year of normal operation has not included any unexpected switching incidents.

Costs and operational experience

The experimental installation was constructed using standard electronic components and off-the shelf hardware. Consequently, little effort was made to integrate the parts into optimal configurations. Using integrated circuit techniques, for example, the receiver/switch can be made much smaller, and, in large quantities, less costly. Over the long-term, its functions might be integrated with the ballast so that circuits, such as power supply and current regulation, can be shared.

The key to lower costs is to minimize the riumber of receivers since they represent the greatest hard ware cost segment of the system and increase costs in direct proportion to system size. The control/transmitter is the economic opposite. The more receivers the less the transmitter cost per receiver, because expanding the system to control more receivers only means adding more memory capacity, a relatively small expense. Techniques for “sharing” receivers among luminaires might also be employed. One way to do this is by multiplexing signals to a receiver and then distributing control functions directly via power or low voltage wiring and relays.

Overall, the preliminary cost studies have indicated the system as installed is economically feasible for typical office buildings based just upon energy savings if energy rates are above five cents per kilowathour and if expected kilowatthour reductions amount to 20 percent or more. Adding in other factors, such as reduced electrical renovation costs during remodeling and savings that would occur from better integration of building electrical loads, pushes the economics well into the favorable area.

In the experimental system, which is somewhat atypical because of the above average lighting system already in the room, energy savings amounted to as much as nine kilowatthours per day, depending upon whether or not both occupants were in the room and for what period. During a typical month, lighting energy reductions averaged 47 percent. **Figure 5** is a daily energy profile of that situation. Illumination levels on the two desk-top work surfaces can be varied in 5- to 10-footcandle steps from dark to 130 footcandles. Full room illumination is 70 or 140 footcandles average maintained. Asymmetric lighting arrangements to minimize veiling reflections are usually provided since one of the occupants faces

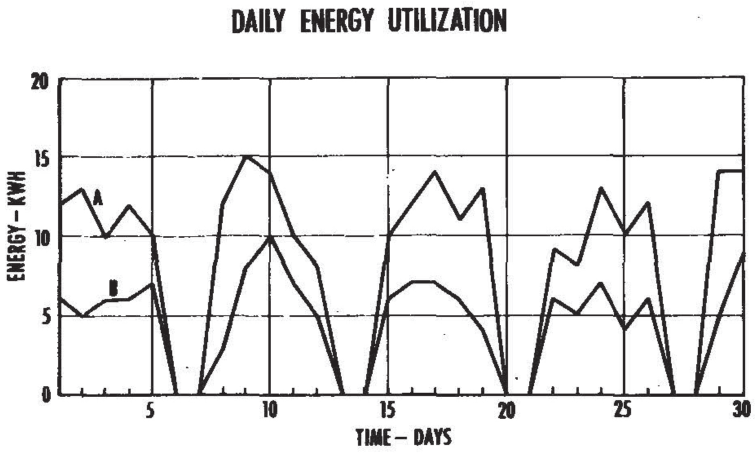

Figure 5. Daily energy profile for the experimental installation over a typical month: Curve A is energy usage before installation of the control system; and Curve B, after. Both are for an eight-hour day, five-day week work schedule.

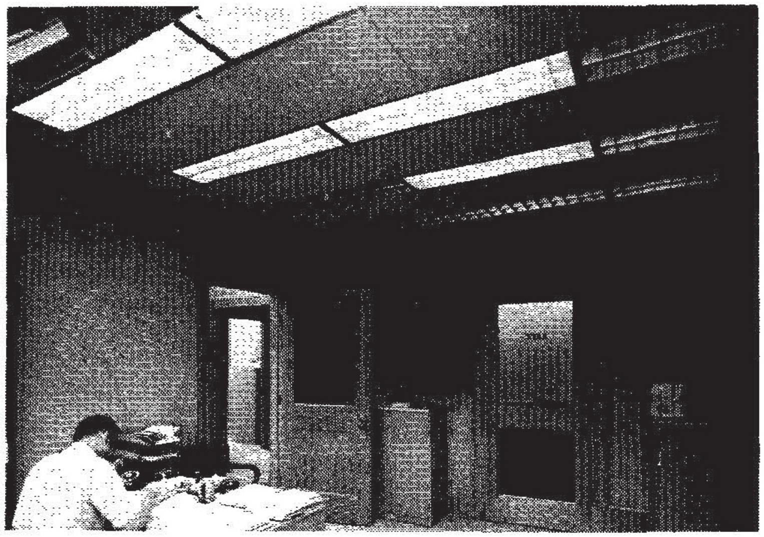

Figure 6. A portion of the office with the experimentsl control systems in use. The microcomputer and controls are in the cabinet at the left side of the door.

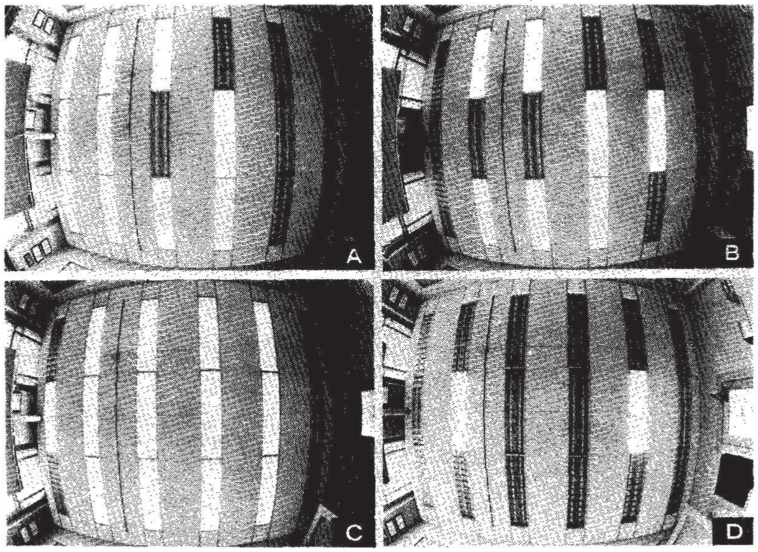

Figure 7. Typical lighting patterns used in the experimental installation: (a) desk lighti -littledaylight; (b) desk lighting daylight contributing to work area illumination; (c) desk and drafting area lighting; and (d) cleaning and security lighting. Note: photographs do not reproduce those luminaires set at reduced output.

an end wall and the other a side wall with a common work space in between. (**Figure 6** shows an office with the experimental installation in use.) **Figure 7** illustrates some of the usual lighting patterns.

Typically, the first occupant to arrive in the morning turns the system on and sets it to a comfortable lighting arrangement for the task at hand. The second occupant does likewise for his portion of the room. Since the office is used for light drafting and informal meetings as well as general office work, lighting patterns change perhaps two or three times during the day. Almost always, all lighting is turned off at lunchtime and a new pattern reset for the afternoon.

At the end of the day, if daylight is gone, the last to leave turns all of the luminaires off except for the one or two needed for cleaning. After cleaning, the custodial staff is instructed to turn the system completely off.

DISTRIBUTED CONTROL SYSTEM

The system as described need not be limited to lighting control since, even with the most complex lighting system, the control microcomputer would be idle much of the time. Adding additional loads in creases only the complexity ‘of the control program, not the system itself. **Figure 8** shows an idea for an alternative approach that would be capable of handling an extensive array of building electrical loads. Here, control signals for load switching are generated by each subsystem microcomputer and distributed to each switched device in the subsystem. A common bus connects the slave microcomputers to a central or master computer which interfaces the total system to any external command and sensor inputs that apply to all.

In the Heating-Ventilating-Air-Conditioning (HVAC) system, the same simple type of receiver/ switch might be used to control, on a zone basis or an individual basis, heat pumps or other heating/cooling devices. Various sensor inputs can be provided to the slave microcomputer dedicated to this particular system in order to optimize its performance consistent with overall constraints. For example, the power inputs to various building zones might be monitored and signals fed into the slave microcomputer for the HV AC system in order to modulate or control that system consistent with lighting or power demand.

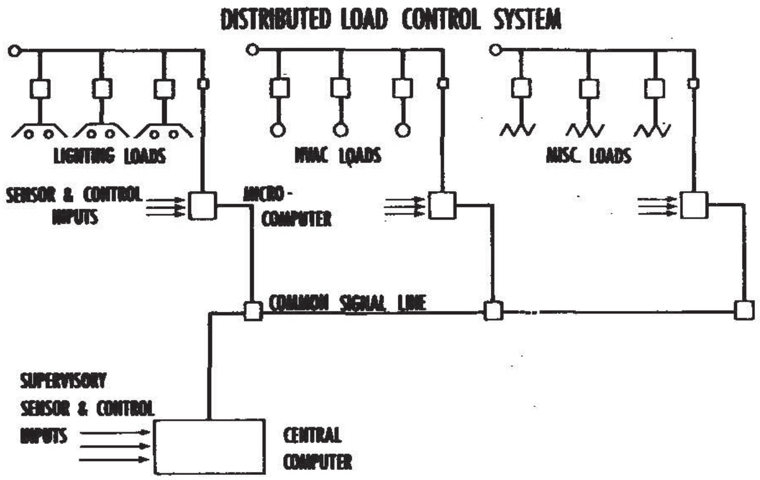

Figure 8. Block diagram of a distributed control system.

An important advantage of a master control and freestanding slaves is that the master or its associated transmission system may fail without affecting the normal operation of the slaves. Of course, master functions such as power limiting and overall system coordination would be lost, but the local systems could still operate. Conversely, the master and slaves might be organized so that, upon failure of a slave, the master could take over essential functions at some reduced level.

Additionally, communication complexity is minimized with the master-slave arrangement since appropriate sensor data is sent to a local slave rather than longer distances to a central computer. Very little data need be sent from the slaves to the master and such data as might be required would already be partially evaluated by the slaves. An example would be the continuous monitoring and computation of instantaneous power in which the slave would carry out the monitoring function plus the sum of squares computation before sending the results to the master.

Communication is also reduced because the master need only send single commands for a desired function leaving the slave to carry out the details. Thus, the master may be less complex even to the point of being a microcomputer itself. It should be pointed out, however, that microcomputers used for either slaves or masters can be readily interfaced with any central process computer and with other small signal digitally oriented equipment.

Overall, the most important benefit of any full scale system that might grow out of these ideas is flexibility. For the building owner and operator, there is the opportunity to upgrade present structures to modern lighting and energy utilization requirements. Lighting in new structures may be optimally designed and installed at the most economical time during building construction so that fewer changes and renovations are required over the useful life of the building. The tenant or user thus benefits through lower lighting costs and by having good lighting that can be easily adjusted locally, both in quantity and quality. ·

The methods and equipment presently available, and in use today, have provided ways to control large centralized electrical loads economically. Sophisticated building automation systems have expanded the idea and have made possible the integration of various building loads to improve performance and better control costs. Now with this developmental control system, the next important steps can be taken because it provides a way to control both economically and practically much smaller loads; a way to better interface with existing control systems; and, most importantly, a way to put under control the hundreds of thousands of commerical installations that utilize some 18 percent 5 of the primary energy in the United States-all without sacrificing the performance and comfort of those who inust use the spaces and for whom the spaces exist.

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Abstract: Supported by technologies available today such as the Internet of Things, 5G networks, and artificial intelligence, lighting control systems will change how we experience spaces by creating dynamic lighting environments that will adjust to suit the needs of the individuals within them. This vision follows a day in the life of a university student, Samantha, in 2035 and the interactions she has with the various lighting environments she encounters. Data privacy and system desirability issues are discussed as significant barriers that need to be overcome. The vision closes with challenges that will be faced by the lighting industry over the next 10 years to unlock these dynamic environments.

Keywords: Lighting Controls, Data Privacy, Internet of Things (IoT), Artificial Intelligence (AI)

One-Sentence Takeaway: Advanced lighting controls will unlock dynamic lighting environments

Advanced Lighting Controls Will Unlock Dynamic Lighting

By Joseph Guiyab, P.Eng

Lighting controls will change how we design spaces over the next 10 years and beyond. Supported by technologies such as the Internet of Things, 5G networks, machine learning and artificial intelligence, control systems will have the ability to mesh individual luminaire control with individual user data to create dynamic lighting environments that change based on real-time occupant requirements and preferences.

I imagine the day in the life of Samantha, a fictional university student in 2035. 6am hits and the lighting control system in her home gradually turns on the light to wake her up for the day. The colour temperature is cool to help wake her after a long night studying. As she leaves for class, her mobile device indicates to the control system that she has left home. The system identifies that she is the last member of the family to leave and turns off all the lights. She gets to class and the light levels are a bit brighter than usual today. The control system at the university is tied into the class schedules and knows that it's an exam day. All the students will be writing on paper as opposed to using digital devices and the system has adjusted the lighting accordingly.

After class she drops off her grandmother at the local community centre to meet her friends and play Mahjong. At the community centre, the control system analyses the data of all the occupants – age, health concerns, and the activity being performed, and adjusts the lighting to suit. Samantha then heads to the local home-for-the-aged where she volunteers. Its dinner time, so lighting in the dining hall is automatically increased slightly to create a visual reminder and sense of destination for the residents. After dinner, the lighting at the entrance to the suites takes on the focus to help guide residents back home.

At the end of the day, Samantha arrives home and the exterior and first level lights at the family home turn on automatically when she pulls into the driveway. The colour temperature inside is warm to help her wind down at the end of the long day. She does a bit of reading and falls asleep; her smart watch lets the system know and turns off all the lights.

This vision touches on how I believe we will be interacting with our lighting environment in 2030.
The advances in lighting controls I believe will unlock the ability to dynamically light spaces to create bespoke experiences for each individual based on their needs and preferences. This vision, however, will need to surpass significant barriers related to privacy concerns and desirability if it is to come to fruition.

The recently cancelled Toronto Quayside project by Sidewalk Labs is an indicator of the major issues that need to be overcome in the development of smart cities and connected environments. Despite the plethora of innovative ideas and integrations proposed by the Google sister company, the project was still hampered by privacy concerns. I believe that in the decade to come the incentives to share our personal information, habits and details will reach a tipping point where the majority of the population will allow the sharing of their personal information This is a necessary step in unlocking the connected environments in this vision that extend beyond a single location. We have already made concessions to share our personal details to be part of social networks or to receive discounts with online retailers. The utility gained just needs to be great enough to offset our perceived value of the personal details being shared.

The utility gained directly correlates to a second barrier related to desirability. Many advanced lighting control systems are already available in the marketplace and spaces are still being designed with manual lighting controls. The lighting control systems will need to go beyond a simple novelty and deliver actual value to the end user. This could be achieved in many ways. Energy costs could rise to the point where dynamically controlled lighting to save every kilowatt hour has a strong business case over other simpler controls technology. The infection prevention and control concerns highlighted by the COVID-19 pandemic could lead to a focus on voice-controlled interfaces for all public spaces. A single dominant IoT platform or AI system could rise with the support of major manufacturers, creating a marketplace where lighting control systems are able to achieve the often promised easy and seamless integration with other devices. In any of these scenarios, the lighting control systems will need to deliver a practical, tangible benefit over the status quo.

There will be those who will choose to not participate in this vision. Individuals not willing to share their information over privacy concerns. Manufacturers who do not believe we will get there and not commit wholeheartedly to developing technologies to support it. I believe that these groups will be visible in 2030 as outliers, committed to a different vision and not benefitting from being fully immersed in a connected environment.

Over the next 10 years lighting manufacturers and designers will be challenged to illuminate spaces in a way that we have not done so before. Envisioning spaces as dynamic environments with a seemingly infinite number of inputs and personal preferences. Formulating versatile solutions with a fixed number of luminaires and controls. Finding new ways to respect and complement the architecture of the space as opposed to imposing more complicated functional solutions upon them. These are challenges that I believe the industry will meet and in doing so create truly remarkable experiences.

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Lawrence is also an active member of the California Energy Alliance whose goal is to unite representatives from a broad range of organizations committed to smart, sustainable energy use within the built environment.
Lawrence hold the designations of Lighting Certified (NCQLP) and Certified Lighting Controls Professional (NALMCO).

Abstract: In a world where LED's are ubiquitous and efficiency standards are regulating microwatts of energy, we look to the future. Where is the lighting industry headed? What trends and technologies have brought us to where we are? What will compel us forward and what will the effects be? In this paper I hope to answer all of these questions and more. My unique insight into the industry has fortuitously placed me on the ground floor of what will be the future of the industry. Lighting controls will no longer play a supporting role in the future of lighting but will instead be a star player. This will mean that a broader knowledge base will be required and controls specialists will be a valued partner in every design team.

Keywords: Lighting Controls, Energy Codes, Internet of Things

One-Sentence Takeaway: As the lighting controls become ubiquitous the need for experts will be more profound than ever.

The Future is Lighting Controls

By Lawrence O. Lamontange Jr., LC, CLCP

The fundamental question that I hope to answer is: Where is the lighting industry headed over the next ten years? I'd like to preface my predictions with some context. I didn't come into the lighting industry by traditional means. I didn't start as a designer or work for a manufacturer. Instead, I started with circuit-level electronic in the Air Force. It wasn't until after receiving my engineering degree that I entered the industry as a Field Service Engineer. In this role I was usually the last step in the path to building occupancy. Because of that, I only saw a snapshot of the industry and how it operated. What I learned was that while many electrical contractors are good at installation they were not generally prepared for the highly technical and complex nature of lighting controls. That was almost a decade ago. To say that a lot has happened since then (both within the industry and my career) would be an understatement. Knowledge in lighting controls was once a niche service and is gradually becoming a commodity. In that same time I have move further up the design chain. I now work directly in distribution bridging the gap between the engineers and the contractors. I live in both worlds and see from both perspectives. While the interface between the human and the controls have become (arguably) easier, the controls themselves have become ever more complex.

The industry is in transition from the Energy Code Era to the Era of the Internet of Things and lighting controls are the conduit connecting the two. The same basic technologies that have been around for decades performing menial tasks will form the edge of the connected future. They will be low voltage or wireless. They will be more granular and more integrated. They will need to be more resilient and more people focused. They will supply the data stream to the server and cloud services for analytics. There will be a confluence of residential-grade expectation and commercial-grade features. Interaction between the controls and the individual in the space will become seamless. In short, they are the future and as such they will no longer be a niche segment of the market but rather the dominant force. Tech companies like Samsung[1] realize this and are putting in great effort and capital. This should worry the lighting industry because innovation is no longer organic. As an industry we need to be the experts in the field; not just lighting experts but lighting and controls. If a higher level of knowledge is expected from the general public then the industry's knowledge should be above reproach. The future is lighting controls and the experts who look after them.

Background (The Energy Code Era)

In the early 1970's the U.S. began implementing energy efficiency standards which have come to define the built environment today. These standards, combined with some of the trends in LEDs which I will discuss later, have contributed to a drop in energy usage which is approaching perfection[2]. Lighting controls have played a role from the beginning but even more so in the last few code cycles. This surge in usage is juxtaposed to shortage in labor. This creates an interesting dynamic on jobsites around the country where contractors can find themselves unprepared for the level of technology they are forced to deal with. Eventually, lighting controls will be commonplace enough that even the average layperson will have a cursory understanding of them. The expression “a rising tide raises all boats” comes to mind. If, in fact, the industry is approaching perfection in energy efficiency then what will be the driving force for future controls? To understand that, let’s look at some of the trends leading up to 2020.

Trends

Let’s first look at some global trends that are impacting all industries. Since the industrial revolution, the world’s population has grown exponentially. According to the UN, the world population will reach 8.5 billion people by 2030[3]. In 2018, an estimated 55.3% of the world’s population live in urban areas. By 2030, the UN predicts that number to rise to 60%. That means that one in every three people in the world will live in densely populated cities[4]. This trend of urbanization over the last few decades has led to increased carbon emissions. The rise in carbon emissions and other pollutants has led to a climate crisis. It is widely believed that humankind’s energy consumption has played a key role in this crisis. In response, many of the world’s nations agreed to limit greenhouse gas emissions in an effort to impede the rise in the global average temperature[5]. With this climate crisis as a backdrop, the need for more efficient lighting and increasingly stringent energy codes becomes apparent.

Alongside this global crisis has been a technological boom. Technology startups, which were formed in a basement only later to gain massive success, have become commonplace. Segments of the tech industry such as social media and rideshare have carved out a niche for themselves that didn’t exist a decade or two ago. The unifying theme for each of these companies is data. The desire for data that can be used to create actionable items has been a focus of the tech industry for some time now. The internet, no longer in its infancy, is standing on its own and exploring its potential. Thanks to cheap computer chips, wireless networks, and enough IP address for the entire galaxy (IPv6) the Internet of Things (IOT) was born. Some criticize the IOT, calling it a meaningless buzzword but, in fact it is a blanket term used to describe devices that wouldn’t normally be expected to have an internet connection. IOT devices range from wearables, which track health and wellness, to speakers and televisions. The idea of having sensors and intelligence in a lighting system is nothing new but IOT’s push for usable data has led to a higher tier of lighting control. The controls are not just connected amongst themselves, they are also bleeding over into converging industries. An occupancy sensor is no longer just a means of shutting lights off automatically. It is a gateway into the system which can be used to trigger the HVAC, alert maintenance, track consumer patterns, or even predict future occupancy.

Other trends affecting the industry such as a reduced labor force in construction, US relationship with China, and the Amazon effect[6] are contributing to how and what products are manufactured. Products are being produced that have to be both easy to install and packed with technology. Manufacturing largely takes place outside of the U.S. and is therefore effected by the political landscape. Where the product comes from not only effects cost and quality but also turnaround time. Contractors are looking for ways to make their jobs easier with less delays. Distributors, who have long been the middleman, are filling the gap by offering unique services and expertise. A part of that means that they are offering ecommerce option as an extension of their in-person experience. They are also taking on new roles in the design process to bridge the gap.

Technologies

One of the most overlooked aspects of what's driving the change is the internet itself. The internet was once nothing more than a group of computers talking amongst themselves. Now, it is a massive network of routers which directs traffic to and from end-nodes throughout the world. When you combine the expansion of this network with next-gen wireless technologies such as Wi-Fi 6 and 5G, you approach the concept of continuous connection. Continuous connection is the idea that being connected to the internet will one day be permanent and automatic.

As we approach continuous connection the dreams of smart cities, driverless vehicles, and IOT technologies become a reality. Imagine having an alarm clock perfectly synced to the Prime Meridian waking you up in the morning. Your wearable then reminding you about your upcoming meetings and asking if you'd like to summon a driverless rideshare. You accept. You're then about to travel from your suburban home to your downtown office without break in service. All the while talking on your smart phone. When you get to the office Bluetooth® technology in the lights recognized your wearable and sends a signal to power up your office or cubicle.

In this idealistic scenario the lights are only a small part of the bigger push in technology. That doesn't mean they haven't played a huge role in getting us to this point. Solid-state lighting technology has skyrocketed (literally[7])! LEDs have quickly become ubiquitous in just about every aspect of life. This opens several potential paths forward for lighting including DC-to-DC systems, 3D printed lights, and connected lighting among others. The overwhelming efficiency the LEDs offer means that research can shift towards the humans that occupy the space. Using Jones Lang LaSalle's 3-30-300 rule[8], an increase in productivity is roughly 100 times greater than a similar increase in energy efficiency. Utilizing technologies such a blue light filters, color temperature shifting, and low voltage or wireless protocols is the stepping off point for the lighting industry moving forward. But we better take the lead or else it will be left to the tech companies outside of our industry.

Effects (The Era of the Internet of Things)

There is no cause without effect. Lighting and controls manufacturers are in a state of flux. Companies that were once stable giants are now scrambling to find their way. Others are being bought up by conglomerates. Others still, are being split and sold off. The repercussions are yet to be seen but there's no doubt that the convergence of trends, technology, and the speed of change will have a direct and lasting effect on the industry in many ways. If we are to remain the stewards of the lighting industry we must stabilize and adapt.

Design process

Providing a beautifully, well-crafted lighting design worthy of having their name on it, has always been a lighting designer's mandate. How to accomplish that with the fast pace which the industry is moving will be one of the great challenges. It has always been incumbent upon the designer to be well versed in their craft. Having a sharp knowledge of current trends and technology shifts is a staple of a strong design firm. Pretty soon all designers will be yoked with the knowledge of ever more complex lighting controls; some of which are integral to the luminaires themselves. What used to be an engineering level of knowledge has become field level.

The new expectation is for the manufacturers to create luminaires with enough options that they can be used to comply with strict energy codes. Or, be used to promote wellness, all the while remaining elegant and practical. Manufacturers are pushing towards fully integrated solutions at the same time as they are creating piecemeal ones. Products are migrating toward polar extremes. This is opening a gap in design that has yet to be fully realized: a lighting controls designer that stays involved through the life of the process. The role of integrators and commissioning agents will expand and perhaps even overtake some startup and acceptance testing tasks. Retro commissioning and continuous commissioning will be more common and sometimes even expected. The future of lighting design is in embracing Design Guides such as DG-29-11 which lays out responsibilities from pre-design through occupancy and operations. If the lighting designer wishes to be a part of the future they need to become lighting and controls designers.

Distribution

The traditional role of distribution is evolving. I am living proof of that. Ecommerce now dominates retail purchasing and has leaked into commercial sales. While this will never replace the relationshipbased transactions that are essential in B2B sales, it has certainly taken its toll. Distributors have begun taking on highly specialized roles in an attempt to offer new and unique services which help them compete in the current landscape. Lighting and controls specialists are becoming more commonplace at the distribution level. Support for piecemeal, design-build, and discretionary business can now be handled in-house through partnerships with manufactures. The future will see this type of support expand as product decisions are made further down the chain.

The future of distribution won't be without its hiccups. The need to compete with customer expectation in online services will be greater. The "standard" wholesale product in lighting will be increasingly more difficult to stock. As soon as a luminaire is placed into stock a new generation will be right around the corner to replace it. Stocking luminaires with integral controls or features will mean that product decisions will need to be made earlier than necessary. This will either strain the project with financial burden or pressure the manufacturers to change product strategies. Eventually, the tug and pull between the field and manufacturing will reach an equilibrium which distribution will continue to service.

Contractors

Contractors have learned to work "lean" due to labor shortage. The effects of this have yet to be felt. Like distribution, expertise will be pushed further down the purchasing chain. This means that contractors will not only have to bolster their forces with personnel but also with knowledge. The challenges contractors face will be rewarded with value-added, higher margin services which they can offer their customer. This will start a chain reaction that will lead to increased discretionary business. Contractors will need to be more technically savvy, employing low voltage specialists. They will need to work closely with the commissioning agents to ensure a proper build. Some aspects of installation will be easier with integrated products or products that perform multiple functions. Pre-fabrication and a close partnership with distribution will be critical for success.

The Lighting Expert

There was a point in human history where being a lighting expert meant being an expert in the movement of the sun and other celestial objects. Back then the term "light" was used exclusively to describe "that which makes things visible."[9] Now, with the knowledge of Infrared and Ultraviolet light butting up against the visual spectrum we understand that not all light is visible. The lighting expert is the keeper of a special knowledge that predates history. Like so many things with such a lineage there is a hesitancy to move out of tradition and step into the future. This hesitancy is what could shift the expertise away from our own industry and into another. The future is lighting controls whether we like it or not. We must acknowledge this to preserve our spot in history.

Challenges

The industry is made up of moving parts which function together. Internal forces and outside influences are constantly shifting the path forward. Designers were once the gatekeepers of lighting knowledge. Ten years ago it was virtually unheard of to have lighting specialists at the distribution level. Now, it has become routine. In order for that knowledge to make its next leap, it must first make it through a few trials.

The challenges of initial cost and resistance to complexity will remain. The former can be combated with early building performance simulation as shown in **Figure 1**. Energy efficiency will need to be addressed much earlier as a design goal.

Other challenges include the rate of adoption. An aging labor force pushing back on technology along with political influences have slowed adoption. Younger generations and coastal urban communities are more comfortable with fast-moving technologies and will set the expectations for the rest of the population.

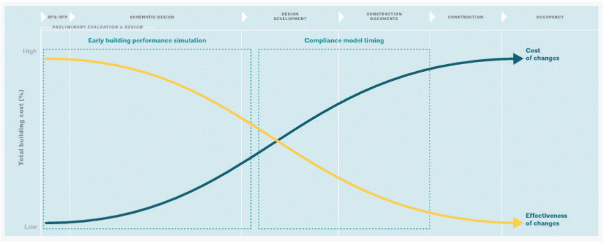

FIGURE 1 – COST & EFFECTIVENESS OF CHANGES BY DESIGN PHASE[10]

Conclusion

The lighting industry has reached a precipice. Beyond that precipice is a future where lighting controls are ubiquitous both in commercial and residential building. The confluence of low cost LEDs and lighting controls technologies has poised the industry for a revolutionary change. The industry has quickly moved toward full adoption of LED lighting for all applications. The energy revolution that began in the 1970s is nearing its completion and the focus for lighting is shifting toward the quality of light and its health properties. Technologies such as daylight adaptive controls and color tuning will be widespread. The next revolution, known as “Human Centric” lighting has already begun and will be well established by 2025.

Low voltage and wireless systems will dominate the built environment. This will mean that all construction and maintenance personnel will need to be well-versed in that technology in order to stay current. This will likely be a difficult hurdle to overcome due to labor shortage. By current estimates there are about 300,000 unfilled jobs in the construction industry, and the industry is expected to need an additional 747,000 workers by 2026, according to the U.S. Bureau of Labor Statistics. That means the need for lighting and controls experts will be more profound than ever.

Change is the only constant in life. That statement is as true today as when Heraclitus first said it. It is the rate of changes that becomes the primary factor. Designers, manufacturers, distributors, and contractors that are able to stay ahead of the rate of change will be the most successful. According to research and advisory company Gartner, the vast majority of IOT applications and services will reach the “Plateau of Productivity” in 2 to 10 years (**See Figure 2**). This means that futuristic concepts such as Building Information Modeling, Indoor Location tracking, and Blockchain integration will be thought of as ordinary. To make this future a reality it will take the effort and brainpower of the entire workforce at every level. The Industry has always needed specialists but the call has never been more demanding that it will be over the next ten years.

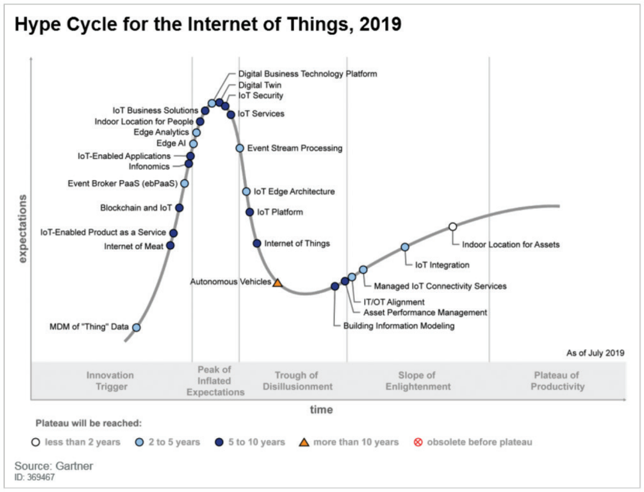

FIGURE 2 – HYPE CYCLE FOR THE INTERNET OF THINGS, 2019[11]

The effects of the past 10 years will be felt for decades. The industry is changed. It began with the first energy efficiency standards. They were written with the hopes that one day energy consumption would be limited. Some would argue that we’ve achieved our goals. What happens next will define the industry. Just a few years ago, LEDs were an emerging technology. Newer generation are being produced almost as fast as they’re being installed. They will reach an equilibrium over the next ten years that will allow focus to shift away from energy efficiency and toward health and wellness. Lighting controls will be more common nationwide. Education will be essential at all levels of the design process as complex holistic system become the norm.

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10 Architect’s Guide to Building Performance by The American Institute of Architects
The IES Visionary Challenge pg. 8
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IES Visionary Challenge Judge

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Lighting Forecast by the Decades

By Mark Lien

By 2030 LED market saturation for exterior lighting is complete. Our smart phones have evolved into smart glasses that can do all a phone can but with voice commands, facial recognition and enhanced vision. Energy related standards have either consolidated or disappeared, with only a minimum and a stretch standard remaining. The focus on energy efficiency has shifted to minimizing operational and embodied carbon, and renewable energy continues to increase in scale and drop in cost. Parallel-reality signage will begin to personalize our displays, and augmented reality will be refined and commonplace for previewing how lighting will appear in existing environments.

By 2040, lighting has become part of a cafeteria approach for exterior lighting. When someone orders a smart pole it will not be a lighting pole but rather a digital platform for various technologies with lighting as one option. Solar paint to power poles and luminaires will reach acceptable efficiency levels using Perovskite solar cells, which offer increased efficiency and can assume a liquid form. Autonomous vehicles are prompting changes to our roadway standards since we no longer need to light for vehicular purposes, just for pedestrians. Glare from lighting is still a problem. Lighting that is designed to address specific human health conditions is ubiquitous

Karen Murphy LC, IALD, LEED AP is a senior professional associate with HDR in Princeton NJ, a graduate of Penn State University's architectural engineering program and has 30 years of industry experience. She currently chairs the IES RP29 Healthcare Committee, serves on the IES Light+Design Committee, works with the FGI lighting task group, and served as a technical reviewer for the National Institute of Health's 2016 edition of the Design Requirements Manual. She has developed multiple lighting standards for clients and authored a local lighting ordinance. Karen's body of work focuses on healthcare and science & technology, but also includes office, education, public health, forensic, production plants, religious, government, daycare, restaurant, amusement parks, and international projects. She believes in teaming with clients to understand their concerns before developing innovative design solutions that enhance environments while also providing energy savings, economy of construction and ease of maintenance. Her technical knowledge and design skill have been recognized through numerous awards and publications, and is an ardent proponent of the lighting profession and lighting education.

Abstract: Let's work together to make sure that the next decade of change is focused on adding value. Lighting professionals routinely included as integral design team members, additional degree programs to support the professional practice demand, and the IES recognized as the lighting authority. LED products that inherently maintain delivered lumens and permit field adjustable delivered lumens. Circadian supportive spectral tuning that is automatically synchronized with local time inherent to drivers. Spectral properties included in IES files, calculation and rendering software. These advancements will all add value to design, construction, maintenance, energy savings, and operations.

Keywords: Value, Fundamentals, Advance

One-Sentence Takeaway: Focusing on adding value will elevate recognition of the lighting design profession and enhance built environments.

Adding Value

By Karen Murphy LC, IALD, LEED AP

I am a practical person. I see beauty in simplicity and value in well-designed objects and spaces. I do believe we can reach amazing heights- not by trying to jump to the top of a ladder but by stepping up it. I believe my vision for 2030 is 100% achievable. Without a doubt, this past decade's proliferation of LED technology has changed our industry and expanded our tool kit, creating new possibilities for what we can accomplish with light. Let's use the next decade to take additional steps to improve lighting technologies and illuminate the value of light. The publicity push for LED technology has captivated our Client's interest; mainstream media is interested1; let's use this interest to promote our profession, architectural lighting design, not a product. Lighting design is more than a product technology- it is understanding the science of lighting technologies and artistically applying light to support functional needs while enhancing the way occupants experience the built environment. We need to heighten public and industry awareness that dedicated architectural lighting professionals exist, and should be part of every project design team. Architectural lighting professionals are tested and have continuing education requirements, just like other professional practices2. Today we are seeing lighting technology integrated into all sorts of building products- wall panels, floor panels, ceiling systems, windows, furnishings, HVAC diffusers, chilled beams, etc. Lighting professionals can add value to project teams by working closely with all trades to assure lighting quality, as all light in a space impacts visual performance and physiological effectiveness. We need to be master collaborators, working with all trades to truly add value. Managing change is all about what your focus is on- let's focus on adding value to every project. By focusing on adding value instead of increasing sales or gaining a competitive advantage, we will be elevating the importance of lighting to the architectural community and improving the lives of all building inhabitants and usersincluding ourselves!

VALUE OF STANDARDIZATION

As standards for LED technology develop, we must be careful to target standardization where it is most needed, and preserve the lack of standardization where it provides the most design freedom. Some may say the ship has sailed, there is no standardization with LED technology, but the plethora of products currently in use will need to be serviced in the upcoming decade. Once facility managers realize they do not know how to service lights within their facility, there will be a universal cry for standardization. To avoid a backlash, we should prepare for that day and develop product standards that address maintenance needs. It would be fantastic if ALL LED fixtures automatically selfadjusted to maintain delivered lumens throughout published life. When adjustment can no longer achieve the specified delivered lumens, modules would extinguish or a warning light would come on indicating that it was time to replace LED modules and driver. (Remember Mercury Vapor lamps? They too never burned out; remained lit while producing negligible light. Their use became commonly banned because people started adding more light fixtures thinking they didn't have enough because they couldn't see, when all they needed to do was re-lamp. Let's learn from our past and solve this problem before we repeat it!) This type of innovative LED product standardization would also address the current problem of initially over-lighting a space to accommodate a 30% light reduction to reach L70 end-of-life. If the published delivered lumens equated to the lumens produced at end of life and is automatically maintained, our calculations would no longer have to include Lamp Lumen Depreciation (LLD). Our calculated maintained illumination would be much closer to initial. We will learn very quickly if our clients do not agree with illumination level targets, and our consensus documents that identify recommended illumination levels will be substantiated through practice. [With the current 30% disparity between initial and maintained levels using LED, and the lighting designer's primary interaction with client satisfaction based on initial illumination levels, our consensus documents may suffer if we do not recognize and address this variation.] If all LED fixtures automatically selfadjusted to maintain delivered lumens, we would also realize more energy savingscapturing the primary goal of LED technology. Manufacturers will need to publish the end-of-life wattage (maximum) to assure electrical circuits are appropriately designed, and it will be important for lighting designers, electrical engineers, code reviewers, and sustainability programs to understand that energy consumed is not constant and does not equate to circuiting loads.

While we are on the topic of driver technology… The fact that drivers can be factory tuned to provide delivered lumens identified in project design documents is a vast improvement. No longer are we forced into rote luminaire spacings because of standardized lamp outputs; we may place fixtures where appropriate and tune performance to conserve energy. This advancement does create challenges that need to be addressed. There will now be very many fixture types that differ only by factory settings. The contractor must keep track of these different fixture types for equipment that looks identical to the eye. When designers punch list a project, visual inspection may not be enough to assure that the right fixtures were used in the right locations. To assure energy savings from adjustable drivers is actually achieved, energy codes often require factory settings; however, it may be better for codes to permit field adjustment. This would reduce the quantity of different fixtures that must be ordered (and maintained by the owner). Equipment should be created so that energy codes could require field adjustments to be physically locked at the driver and field settings to be supervised by a commissioning agent in order to utilize reduced wattages in energy calculations. With this approach, it is critical to properly size lighting circuits. Circuiting must accommodate full load prior to adjustment, as commissioning does not happen as soon as the fixture is installed. New technology is capable of many things, let's focus component standardization to support design and maintenance protocols that will maximize the inherent benefits of LEDs.

Color metric standards (this past decade's work) published in IES TM-30 should become integral to the design process by 2030. Designers are beginning to understand the new color metrics for fidelity and gamut, and will push manufacturers to routinely supply this data. If you are a visual learner, the new color vector graphic will make you a TM30 convert too! As industry professionals routinely start using and measuring these new metrics in the field, we will be better able to establish values for these metrics in the consensus documents produced by the IES. Reputable manufacturers should publish directly on cut sheets delivered lumens, input wattage, CCT, Rf, Rg, and a color vector graphic. With all we know about lighting's impact on circadian supportive environments, spectral power distribution curves should also become routinely available and a metric for circadian supportive light should be identified. Luminaires marketed as "circadian supportive" should have spectral tuning automatically synchronized with local time without the need for supplemental time clocks and control systems. Could IES file formatting be modified to include spectrally tunable characteristics? When this occurs, rendering software accuracy will improve and circadian supportive metrics could be calculated at the push of a button alongside illumination values.

Let's dream big for a moment… Wouldn't it be great for a designer to go to a manufacturer's website, select a complete luminaire catalog number, then download a revit family that included the ies file with spectral power distribution properties of the exact luminaire they just built the catalog number for? …and then have lighting software add-ins that could read these BIM object parameters and provide accurate point-by-point calculations and renderings!?!

Fundamentals Shouldn't Change

As our industry advances, the tenets of visual performance and the desire for energy efficiency, ease of maintenance and economy of construction will remain. We will see designing for health and the IoT added to our design processes. This means providing circadian supportive environments and integrating with low voltage systems, but it also means limiting flicker, controlling glare, and providing comfortable environments. Lighting will contribute to the biophilic design movement, promoting physical and mental well-being by encouraging occupants to take the stairs instead of elevators or accenting special moments to create meandering pathways inspiring exploration of amenity areas. Lighting has an innate way of turning something you look at into something you feel. Our understanding of light needs to include visual, psychological, emotional, and physiological effects. Unfortunately, there are not enough bachelor degree programs that offer a comprehensive education in lighting design to supply the industry demand for these individuals. Too many institutions are content with offering one or two classes about lighting design that only scratch the surface and never acknowledge that lighting design is an independent specialty to pursue as a career. As the lighting design process increases in complexity, the need for dedicated lighting professionals with structured technical competency will become more evident. IES and IALD educational initiatives will need to continue to fill this gap, and we

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"White House to Relax Energy Efficiency Rules for Light" by John Schwartz; NY Times; September 4, 2019
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2Lighting Certification administered through NCQLP

as design professionals must continue to encourage, educate, and inspire our colleagues.

IES Recommended Practices, Design Guidelines, and Technical Memoranda should remain reliable resources for the design community and regulatory agencies. The IES must preserve its technical authority through these documents that clearly communicate established knowledge and inform on emerging trends. The IES understands its role as the RELIABLE resource for lighting guidelines. It works hard to fact check, provide references, and follow ANSI protocols. It has launched a new initiative to increase the quality and quantity of lighting research so that claimed benefits of emerging design trends can be better validated and defined in Recommended Practices. We, as design professionals, should look for opportunities to contribute to this research. We should contribute our individual areas of expertise to the consensus document committees. As the importance of lighting becomes more commonly known, more and more agencies are cropping up attempting to provide their own lighting guidelines or definitions of "quality lighting". It's frustrating to read a lighting guideline that incorrectly uses terminology or sets a single prescriptive solution instead of a desired outcome. We should encourage these outside agencies to reference ANSI/IES documents in part or in whole. We should seek to have LC certification, not a PE, the professional certification recognized by the USGBC's LEED lighting credits (light pollution reduction, lighting controllability, and lighting quality).

LED technology has been a catalyst for rapid change. Let's work together to make sure that the next decade of change is focused on adding value- Adding value to the design process, adding value to the construction process, adding value to operational and maintenance protocols, adding value to energy conservation, adding value to occupant comfort, adding value to occupant safety, and adding value to occupant health. Seek knowledge, innovate, advocate for our profession, understand what your client values, and enjoy the decade to come!

Making Light

By Sidney Perkowitz

EXCERPT 2: CHAPTER 5. MAKING LIGHT

How can [Edison] call [the electric light bulb] a wonderful success when everyone…will recognize it as a conspicuous failure?

Henry Morton,
Professor of Physics Stevens Institute of Technology, 1879

The 1893 World's Columbian Exposition in Chicago displayed all that 19th century western civilization considered great and beautiful. Its graceful white buildings exhibited culture and craftsmanship, technology and science. Electricity was a hero of the presentation, especially as represented by artificial light. At night, tens of thousands of electric lights illuminated the Exposition. Its Electricity Building was constructed around a Tower of Light, whose eight-story shaft contained thousands of colored flashing incandescent bulbs. Other structures were outlined in chains of light bulbs, and tinted arc lights shone on leaping fountains of water to give further spectacle.

It is difficult now to imagine the halo of wonderment that then surrounded the great natural force of electricity and its marvelous ability to make light. Contemporary descriptions show a child-like pleasure in electrical light that we have lost. In one account, the Exposition becomes "a fairy scene of inexpressible splendor" when its "myriads of electric lights pierce night's sable mantle." An illuminated fountain "glows with the blood of the ruby…changes to emerald, fringed with all the shades of green the earth affords…jewels pale before these marvels of color…" And beyond sheer response to electrical light, electricity still seemed an enormous unknown and even mystical elemental power as it flowed from laboratory into common use.

Scientists of the time probably felt the same wonder at electrical light, tempered by their knowledge of its electromagnetic character and its pragmatic connection to electricity. It was electric current that made a bright arc leap between two carbon rods, or heated a fine filament until it glowed. The fundamental and the practical both appeared at a meeting of the International Electrical Congress at the Exposition, where Hermann von Helmholtz was the most famous scientific delegate. Physicist and physiologist, he had visited the territories of light again and again, in his seminal *Treatise on Physiological Optics*, in his contributions to electromagnetic theory. At the Congress banquet, Helmholtz chose to honor the achievement of incandescent electrical light. He stepped down from the speaker's table to shake hands with Thomas Alva Edison, scornfully dismissed by some as a tinkerer and not even an official attendee of the Congress. But it was Edison's persistence that made electric light truly useful, as he developed the incandescent bulb along with the means to supply it with electrical current. His recognition by Helmholtz, representing the great European work in the theory of light, is a recognition of the more practical American scientific style.

A century after that testimonial, we take artificial light as a given. We see it in a variety of forms that have developed far beyond filaments heated by electricity. Fluorescent lamps, lasers, and chemical processes now make what might be called cool electronic light, in achingly pure colors or glowing whiteness, or at invisible wavelengths. Some modern light sources come in thousands to the square inch, some fill immense hangar-like structures. Intensities range from the imperceptible flicker of a single photon to ravening beams that cut steel. The power to make light is the reason we can suppress—but never entirely forget—the strong emotions that once accompanied the fall of night. “Each evening,” says Wolfgang Schivelbusch in his *Disenchanted Light*, “the medieval community prepared itself for dark like a ship’s crew preparing to face a gathering storm. At sunset, people began a retreat indoors, locking and bolting everything behind them.” Darkness stirred fears of unknown forces, and of human evil. In those days, to be abroad without an identifying light was *de facto* evidence of criminal intent. The earliest urban lighting was too dim to truly illuminate, but was still needed to mark the geography of night, as it showed the presence of houses and people.

This long history is the reason that light glowing from a filament heated by electricity seemed miraculous in 1893, compared to the light that had for millennia come from open flames. The Paleolithic artists of Lascaux illuminated their dark caves with flickering reddish light from lamps that have been found these thousands of years later. Most are simple pieces of limestone whose natural or reworked concavities contain the burning fuel. One has been fully shaped from red sandstone, polished and decorated with designs of interlocking chevrons. Surely it stands near the beginning of a persistent tradition that makes light sources both utilitarian and beautiful.

IES Visionary Challenge Judge

Thomas Paterson, Thomas Paterson, principal of Lux Populi, is a 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.

To What End?

By Thomas Paterson

To what end do we design light with conscious intention and skill? It’s not enough to say that we do so to meet code, to create beauty, to facilitate function. We don’t do it for the purpose of sustainability. And to say that we do so to achieve wellness outcomes? Well, that’s not enough either! Why? Because that’s just saying we’re going to design without causing harm – harm that we have been causing before out of ignorance or disinterest in light’s negative impact on our health, our planet.

We know that most human spaces need light to facilitate their use and to mitigate their negative impacts. But.

To what end?

That’s the question that underlies First Principles design. First Principles is about understanding what we can positively and proactively do with light, and what our clients, our end users, and the diverse stakeholders of a project need light to be and do for them.

We start with simple questions - who are the stakeholders? Who will be affected by what we do?

And then we break down what their goals are. But not their goals with light, they probably don’t even know what light can do for them. What are their goals as organizations and individuals?

And we as lighting designers should know how the tool of light can be part of those goals.

There is an old joke in medicine: “What is the difference between a generalist and a specialist?”

The answer? A specialist knows more and more and more, about less and less and less, until they know everything about nothing. A generalist knows less and less and less about more and more and more until they know nothing about everything.

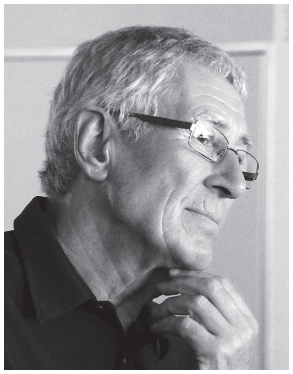
There’s too much truth in that!

But we, as specialists in light, should be a specialist tool, a sharp scalpel. And we also need to know HOW we can be used, to tell our clients how we might serve their needs, where that sharp scalpel is the right tool - and indeed, where it is not.

Light can be essential to creating a sense of place, a sense of safety or an identity. We know what a place is about, cued by light. We choose to take a path, invited by its sense of activity, or where to pause, gathering around the "fireplace" of a spotlit table. The tools of light guide us through life, and as lighting creators we should design to serve the purposes of our clients, our stakeholders, those with whom our light interacts.

The first principles of our design are to understand how our medium serves. Our ability to deliver is based on our ability to manipulate light through the tools at our disposal - products, distribution, control, integration in the physical world, and on the human side, our ability to engage with our interlocutors not only to understand their needs and to negotiate their collaboration. These elements are the CRAFT of our delivery.

At its heart, lighting creation is a fundamentally human endeavor, so as we consider the future of many aspects of lighting discussed here, let us remember that whether discussing process, control, technology, health, science or many other topics, we have a purpose for those elements of our craft. Let's gather together and think about what 2030 needs from us as a society of practitioners.



Christopher “Kit” Cuttle, MA, PhD, FSLL, FIESANZ, FIESNA, is a lighting educator, designer and author. During a long career, he has held the positions of Head of Graduate Education in Lighting at the Lighting Research Center, Rensselaer Polytechnic Institute, Troy, New York; Senior Lecturer at the Schools of Architecture at the University of Auckland, and the Victoria University of Wellington, both in New Zealand; Section Leader in the Daylight Advisory Service, Pilkington Glass; and Lighting Designer with Derek Phillips Associates (now DPA Lighting Consultants), both in the UK.

In addition to more than 140 published papers and articles, he is author of three books: Lighting by Design, Architectural Press, 2008 (2nd edition); Light for Art’s Sake, Butterworth Heinemann, 2007, and Lighting Design: A perception-based approach, Routledge, 2015.

His recent awards include the 2019 IES Medal of the Illuminating Engineering Society of North America, the 2017 Lighting Award of the Society of Light and Lighting (UK); the 2013 Lifetime Achievement Award of the Professional Lighting Design Recognition panel, and 2013 Leon Gaster Award for his Lighting Research & Technology paper, A New Direction for General Lighting Practice.

Abstract: This paper speculates on changes in lighting practice that are likely to occur during the next decade. It is seen to be probable that the recognized purpose of indoor lighting practice will switch from providing for visual performance to meeting peoples’ expectations for how lighting influences the appearance of their surroundings. A new definition of purpose is proposed that involves a changed understanding of indoor lighting and the human responses that it stimulates. The Lighting Design Objectives (LiDOs) Procedure has been proposed by the author as a means for guiding practitioners seeking to apply lighting with the aim of influencing the appearance of indoor spaces and their contents, and the procedure is referred to as a basis for practical application of new indoor lighting concepts including non-visual aspects of exposure to lighting. The implications of these changes in lighting practice are discussed and lead to a novel characterization of lighting practice as foreseen in 2030.

Keywords: Lighting Design Objectives, Perceived Brightness/Adequacy of Illumination, Ambient Illuminance, Visual Emphasis, Target/Ambient Illuminance Ratio, Illumination Hierarchy.

One-Sentence Takeaway: Indoor lighting practice is switching from distributing light to illuminate visual tasks to meeting peoples’ expectations for how lighting may influence the appearance of their surroundings, and during the next decade this will lead to substantial changes in indoor lighting applications.

A Redefined Purpose for Indoor Lighting Practice

By Christopher Cuttle MA, PhD, FSLL, FIESANZ, FIESNA

1. A CHANGED UNDERSTANDING FOR LIGHT AND LIGHTING

The Society's website promotes the *IES Handbook* with the advice that, "Successful lighting professionals must be able to incorporate into their work new technological and scientific developments". These developments tend to be thought of as relating to the plethora of innovative light sources and controls recently introduced by the lighting industry, but this paper concentrates on developments currently emerging in indoor lighting practice that are seen to have the potential to substantially affect the characteristics of installed lighting during the next decade. The actual procedures for devising lighting solutions referred to in the *Handbook* largely follow the conventional science-based approach that the prime purpose of lighting is to provide for efficient and accurate performance of visual tasks, and this is reflected in the procedure for determination of recommended illuminance being based on visual task parameters (IESNA, 2011).

Meanwhile, a distinctly different approach is taken in the Society's publication entitled *Light+Design: A Guide to Designing Quality Lighting for People and Building*s (IESNA, 2009), and while the difference between general lighting practice and "quality lighting" is not explained, it is evident that these two approaches differ in how they identify the prime purpose of lighting. The *Guide* takes an approach that is sometimes referred to as 'architectural lighting' as emphasis is given to lighting room surfaces and furnishings rather than the detail that working people need to be able to discriminate to be productive. However, neither of these approaches attempts to address the broad range of visual interactions and experiences that people encounter while indoors.

It is foreseen that the development of indoor lighting practice during the forthcoming decade will be characterized by the emergence of a changed understanding of the purpose of lighting. Furthermore, it is anticipated that this development will combine the use of technology-based prediction procedures with the creativity of professional lighting practice.

2. A REDEFINED PURPOSE FOR INDOOR LIGHTING PRACTICE

The following definition is proposed: *The prime purpose of lighting practice is to satisfy, or sometimes to exceed, peoples' expectations for how lighting influences the appearance of their surroundings*.

Relating the definition of purpose to peoples' expectations requires specification of lighting design objectives specific to each application. For general lighting practice, expectations may be satisfied when people simply do not notice the lighting. They feel able to go about their business, aware of their surroundings and unencumbered by visual difficulties. This is the base level of provision that regulators aim to achieve. However, with more care at the design stage, a higher level of satisfaction is achievable. This will not necessarily mean that people notice the effects of lighting, but if people consciously appreciate chosen aspects of the appearance of their surroundings, then it may reasonably be concluded that the lighting is contributing towards their senses being aroused beyond their expectations.

Whether or not this definition might become an accepted statement of purpose for general lighting practice is not the point. It is foreseen that lighting practice will evolve in this direction, and that while this change will comprise a shift away from the need to provide for visual performance, it will bring an increased awareness of the benefits that technology can impart to predicting peoples' responses to how lighting influences the appearance of the spaces that they inhabit and the objects that they contain, which may range from architectural features and artworks to work tasks and safety hazards.

3. Direct and indirect luminous flux fields

It is foreseen that a fundamental change will occur not only in how illumination is specified and measured, but in how luminous flux is understood by lighting practitioners. When released in and enclosed space, the flux is encapsulated and undergoes multiple reflections from surrounding surfaces until it is totally absorbed. Without a prescribed measurement plane, practitioners are free to select objects and surfaces within the space to receive direct flux from the luminaires. These target surfaces become the sources of the first reflected flux that generates an indirect flux field within the volume of the space. It is primarily by the control of the balance of the direct and indirect flux fields that practitioners achieve their envisaged outcomes and meet peoples' expectations for the broad range of encounters that they may experience as they interact with their surroundings [Cuttle, 2015].

Ambient illuminance (E_{AMB}) is the average flux density (lux) of the indirect flux field, and recent research has shown this metric to relate to several crucial aspects of how people respond to the visible effects of indoor lighting (Cuttle, 2020; Duff *et al*, 2017a, 2017b). Procedures for measuring and calculating EAMB by determining the mean room surface exitance (MRSE) have been developed [Cuttle, 2018a, 2020; Duff *et al*, 2016; Dai, 2019] and also an alternative approach has been proposed [Raynham, 2019] that determines the mean indirect cubic illuminance (MICI), which may be defined as the indirect scalar illuminance at a point. Raynham [2019] has shown that calculated MRSE values correlate strongly with the average MICI within the volume of a space.

The practitioner plans the direct flux distribution by allocating target/ambient illuminance ratio (TAIR) values to selected objects and room surfaces [Cuttle, 2018a, 2018b]. The aim may be to create an illumination hierarchy, being an envisaged pattern of visual emphasis, or, for situations where there is no need for visual emphasis, it would be to generate the required ambient illumination efficiently. Either way, the direct target illuminances produce the sum of first reflected flux which, through multiple reflections, generates the ambient illuminance. The desired balance of direct and indirect flux fields is achieved when the direct flux distribution generates both the intended distribution of TAIR and the chosen overall level of MRSE.

4. Lighting Design Objectives

An approach to indoor lighting has been proposed [Cuttle, 2010, 2015] to achieve selected lighting design objectives, and this has led to the development of the Lighting Design Objectives (LiDOs) Procedure to achieve the previously stated redefined purpose for indoor lighting practice. The procedure requires practitioners to specify LiDOs for each application that they see to be relevant to how illumination quantity and distribution may influence peoples' responses, and the LiDOs Spreadsheet enables the required direct flux distribution to be determined [Cuttle, 2018a, 2018b]. This emphasis upon identifying LiDOs that relate to peoples' responses provides a useful platform for examining fresh lighting concepts that are seen likely to be formative in the development of lighting practice during the next few years.

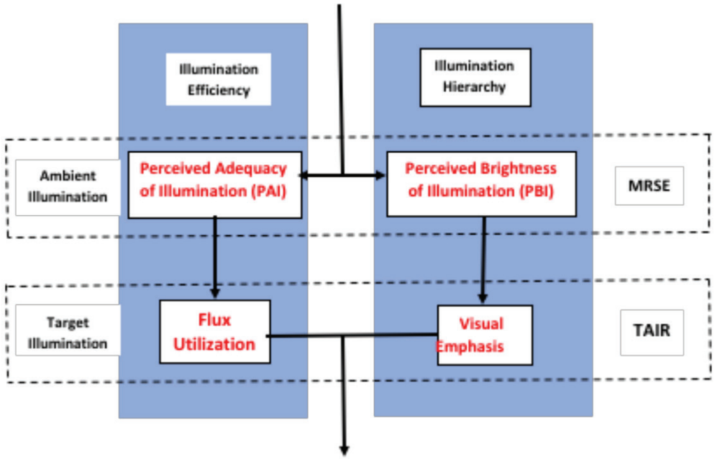


Figure 1. Outline of the Lighting Design Objectives (LiDOs) Procedure. Starting from a list of LiDOs for a specific application, the procedure offers users a choice of tracks leading towards specification of a direct flux distribution that will provide both the level of ambient illumination and the distribution of target illumination to achieve the relevant LiDOs. The illumination efficiency track applies in situations where there is no need for visual emphasis and the aim is to provide adequate ambient illuminance efficiently and economically. The illumination hierarchy track involves selecting target surfaces for direct flux to achieve an ordered distribution of visual emphasis.

The LiDOs Procedure applies to indoor lighting applications for which the combination of LiDOs for each space describes the various ways in which it is intended that lighting may influence the responses of the occupants or visitors to the space. The list of LiDOs may be as extensive or as brief as is required by the circumstances and the procedure may be applied for applications ranging from the most straightforward to the most complex. While this discussion is restricted to lighting by luminaires, the principles are entirely amenable to being extended to include daylighting or non-visible effects of ambient illumination, but it is not suitable for outdoor lighting. Wherever feasible lighting design objectives are to be quantified, such as specifying ambient illuminance values to achieve LiDOs relating to ‘how brightly lit’ or ‘how dimly lit’ spaces are to appear.

4.1 AMBIENT ILLUMINATION AND THE INDIRECT FLUX FIELD

Research studies of peoples’ responses to lit environments have employed a variety of research methods that have posed questions to subjects with the aim of identifying what are the characteristics of lighting that relate to how people respond to lit environments. Among the most frequently recorded characteristics has been the sense of brightness imparted by lighting [Duff et al, 2017a, 2017b], and from a review of recent research studies [Cuttle, 2020] the author has tentatively proposed the ratings of perceived brightness of illumination (PBI) relative to ambient illuminance shown in Table 1. It is important to appreciate that research on which these ratings are based have found them to be effectively independent of both the spatial distribution of illuminance within the space and the room surface reflectance values. While ongoing research may be expected to define this relationship with greater confidence, some professional lighting design practices have already applied this approach for developing actual design solutions and feedback from these practices has, so far, confirmed their usefulness [Shaw, 2019].

Application of the procedure starts with practitioners asking themselves the question, “How brightly lit, or dimly lit, do they want the space to appear?” The 7-point scale of ‘how brightly lit’ ratings given in **Table 1** provides useful guidance for making selections for this aspect of overall appearance, although consideration needs to be given to the context in which people will experience each space and this may be influenced by season and time of day.

In its present form, the LiDOs Procedure takes account only of visible characteristics of lighting, but this preview of the next decade needs to consider the growing interest in peoples’ non-visual responses to exposure to ambient illumination. The discovery in 2002 that a small proportion of the retinal ganglion cells are light sensitive (the intrinsically photosensitive retinal ganglion cells, or ipRGC’s) has led to research into their role in causing suppression of the sleep-inducing melatonin hormone. The spectral sensitivity of the ipRGC’s has been experimentally determined and is referred to as the melatonin

Perceived brightness of illumination (PBI)		Ambient illuminance (lux)
PBI-7	Very brightly lit	800
PBI-6	Brightly lit	430
PBI-5	Slightly brightly lit	230
PBI-4	Neither brightly lit nor dimly lit	120
PBI-3	Slightly dimly lit	65
PBI-2	Dimly lit	35
PBI-1	Very dimly lit	20

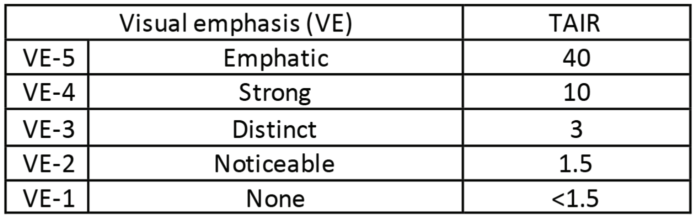
Table 1. Proposed ratings of perceived brightness of illumination relative to ambient illuminance.

function M(λ), and with this development it is now feasible to evaluate the spectral power distribution of a light source, or light arriving at the eye, for both its visual effect according to the photopic function V(λ) which peaks at 555 nm, and for its non-visual effect according to the melatonin function M(λ) which peaks at 470 nm, with the balance expressed as the M/P ratio. This indicates that exposure to high levels of ambient illuminance combined with a high value of M/P ratio supresses melatonin excretion into the bloodstream and promotes alertness, while the combination of low EAMB and low M/P leads to excretion of melatonin that not only promotes relaxation, but acts to entrain a person's sleep cycle, for which the timing of exposure is important. It has not escaped notice that this new knowledge of lighting's impact bears resemblance to a long-standing conundrum of lighting due to Kruithof's observation that people prefer high CCT in combination at high illuminance and low CCT with low illuminance [Kruithof, 1941]. At present, several proposals have been advanced for how M/P should be determined [Miller, 2019] and the procedure promoted by the International WELL Building Institute [IWBI, 2019] seems likely to be adopted for general practice. It may be noted that in Miller's analysis this is the M/P 3 alternative which could be added to the specified LiDOs.

4.2 Illumination hierarchy and visual emphasis

Once the ambient illuminance level has been decided, the next question is, "Are there some objects or room surfaces to which lighting may beneficially impart some level of emphasis?" If so, these are identified as target surfaces, and **Table 2** gives a scale of *visual emphasis* that practitioners may use to describe how they want lighting to influence the appearance of those chosen objects and surfaces.

TAIR is the target/ambient illuminance ratio, where target illuminance is the total surface illuminance, ie, the sum of direct and indirect flux, and by according a TAIR value to each target surface the practitioner may build up an illumination hierarchy for the space. This comprises an ordered distribution of direct flux to achieve the practitioner's LiDOs, which could range from revealing artworks or architectural features, to drawing attention to merchandise displays, to imparting visibility to visual tasks in workplaces, or to revealing safely hazards. The notion of illumination uniformity being a universal criterion of lighting quality is rejected. The illumination hierarchy concept exploits non-uniformity to achieve lighting design objectives relating to visual emphasis and this is demonstrated in the worked example using the LiDOs spreadsheet [Cuttle, 2018b).



Visual emphasis (VE)		TAIR
VE-5	Emphatic	40
VE-4	Strong	10
VE-3	Distinct	3
VE-2	Noticeable	1.5
VE-1	None	<1.5

Table 2. Tentatively proposed visual emphasis/target-ambient illuminance ratio (TAIR) relationship.

4.3 Illumination efficiency and first reflected flux

For situations in which there are no requirements for visual emphasis, the practitioner aims for *illumination efficiency* which involves efficient utilization of luminous flux to achieve the required ambient illuminance (See **Figure 1**). It is the first reflected flux (FRF) from the target surfaces that provides the source of the indirect flux field, for which the average flux density is indicated by the ambient illuminance. Until the initial reflections have occurred, the direct flux from the luminaires has no visible effect and efficient flux utilization requires the direct flux to be distributed onto high reflectance surfaces.

Regardless of which of the two tracks is followed, the outcome is a direct flux distribution (DFD) specification for which the promise is, *deliver these levels of direct flux onto each of the target surfaces to achieve both the chosen level of ambient illuminance and the distribution of target illuminances determined by the lighting design objectives*.

5. IMPLICATIONS FOR LIGHTING PRACTICE

5.1 General lighting practice

General lighting practice may be described as the efficient and economical provision of lighting that complies with current lighting standards (which may be taken to include lighting codes and recommended practice documents). As has been mentioned, recent research has made progress in relating perceived brightness of illumination (PBI) to ambient illuminance and this is currently providing practitioners with useful guidance for determining how much light is required in a given space to provide a chosen level of “how brightly lit” or “how dimly lit” appearance. So far, relatively little effort has been put into investigating the perceived adequacy of illumination (PAI) criterion but lighting standards based on the PAI criterion would enable regulators to meet peoples' expectations for spaces that appear to be lit sufficiently for the activities associated with them, and this would result in standards that specify basic levels of provision below which people would be likely to rate the lit appearance of a given space to have a dull or gloomy appearance. It is propositioned that the concept of perceived adequacy of illumination should become the basis of illumination schedules in future lighting standards as it identifies the tipping point that optimizes the balance of provision of illumination and consumption of resources, including energy [Cuttle, 2020]. There probably would need to be a transitional period during which the schedules would specify both ambient and task illuminances, but this need not be a source of confusion. It will be necessary for both researchers and practitioners to establish ambient illuminance levels below which the lighting for different categories of indoor locations would be likely to be assessed as appearing unsatisfactory. This should be recognized as distinct from task illuminance requirements for which minimum illuminances would be specified for specific visual tasks rather than overall levels for workplaces.

It has been noted that the flux emitted by luminaires travels through the space without visible effect until it is incident on target surfaces. Consider a conventionally illuminated room having a typical balance of ceiling/wall/floor reflectances of 80/40/20 percent. This means that for conventional downlighting, most of the flux is incident on the floor and of that, 80% is absorbed without having visible effect. That this common form of practice is perpetuated in the belief that it achieves 'efficiency' should be considered extraordinary. Conversely, for uplighting, the ceiling reflects 80% of the incident flux into the space to generate useful ambient illumination. This stands current practice upon its head! Every experienced lighting practitioner knows that while uplighting and wall washing are attractive lighting techniques, they are far too 'inefficient' for general lighting practice. The reality is that when illumination criteria become specified in terms of ambient illuminance, concepts of efficient utilization of luminous flux are transformed. The prime role of luminaires in current practice is to gather the light source output and redirect it onto the horizontal plane. For future lighting practice, the optical elements placed around the light sources may be seen as the first level of luminaire control for which the purpose is to direct light onto the second level luminaire, this comprising the room surfaces and its contents. It is this second level luminaire that creates retinal images and stimulates the visual experience of the space. The dismal and all-too-frequently occurring experience of endless repetition of grids of downlighters delivering luminous flux onto light-absorbing floors can be expected to give way to lighting installations each suited to providing selective control over light distributions for specific applications.

The effects of such changes being adopted for general lighting practice would be profound [Cuttle, 2020]. By causing practitioners to make consideration of ambient illuminance their starting point, attention would be directed not only to overall illumination quantity along with the duration and timing of exposure to lighting. For locations where exposure is transitory and there are no features that demand or deserve attention, the ambient illuminance need only be sufficient to avoid gloominess, or in other words, to satisfy the PAI criterion. For other locations where people are to spend full working days, their wellbeing needs to be a prime source of concern including how their sense of alertness may be stimulated both at the start of the day and for the 'after-lunch alertness dip'. Current research is contributing to understanding of the effects of controlled variations of EAMB and it is to be expected that specified ambient illuminances for a location such as a 24-hour hotel reception area would differ according to seasonal and diurnal variations.

The highly influential role of room surface reflectance for generating ambient illumination has been noted. It can be expected that selection of room surface reflectances will become recognized as a crucial stage of decision making in the development of lighting solutions. At least, the end should be in sight for the still sometimes heard comment from architects or interior designers, “We have not decided on surface finishes yet, but you get on and do the lighting and leave that to us.”

5.2 Implications for professional lighting practice

With reference to the proposed new definition of the purpose of indoor lighting practice, the difference of professional as opposed to general lighting practice may be described as not seeking merely to satisfy peoples' expectations, but to exceed them. This involves following the illumination hierarchy track as indicated in Figure 1.

For professional lighting practice, the most notable feature resulting from adoption of the LiDOs criteria in lighting standards would be that uniformity would no longer be a required criterion of lighting quality. There would, of course, be nothing to prevent uniform lighting being applied wherever it might be considered appropriate, but as previously discussed, practitioners would be free to exploit non-uniformity to provide for LiDOs that describe or specify envisaged distributions of visual emphasis and which lead to the creation of illumination hierarchies. The effect of minimum ambient illumination schedules would be only to restrict practitioners from specifying lighting solutions that are likely to be assessed as dull or gloomy. Otherwise, they would be free to specify lighting solutions that could include spaces to appear noticeably brightly lit, or spaces where ambient illuminance to be restricted to low levels to enable higher degrees of diversity and visual emphasis. It is to be hoped that regulators will abandon the notion that every indoor space must have a specified minimum ambient illuminance so that practitioners have opportunities to have people experience dimly lit surroundings, providing that safety concerns are satisfied.

The changed understanding of light and lighting foreseen in this proposal is expected to influence not only lighting practitioners but also other related professions, notably architects and interior designers. It may be anticipated that more widespread recognition of the crucial role that selection of room surface finishes plays in the development of lighting solutions together with the modulation of ambient illuminance to signal temporal changes the use of spaces will be welcomed by professional lighting designers as leading to more involvement in decision-making design discussions.

The LiDOs spreadsheet is currently being used by a few professional lighting design practices and the feedback that they are providing is adding to confidence in its use. It is intended that in due course the LiDOs Procedure will incorporate daylighting, non-visual aspects of lighting, and outdoor lighting practice. That will be too much for a simple spreadsheet and the development of interactive computer-based lighting design software based on the principles of the LiDOs Procedure should follow. The underlying principle that makes the crucial difference from current practice is the progression from user-defined lighting design objectives specific to an application to a performance specification from which a lighting solution specification can be developed, and this may be applied for developing solutions ranging from the most basic lighting layouts to creative works of design excellence. The spreadsheet is not expected to endure, but the principles stated in this proposition are expected to.

6. THE STATE OF LIGHTING PRACTICE IN 2030

So, how will emerging developments in current practice influence lighting practice in 2030? Significant changes are foreseen in the indoor lighting standards and recommended practice documents that guide much of general lighting practice. The most obvious difference will be a switch from task illuminance to ambient illuminance for specifying recommended lighting levels, but also notable will be that criteria developed for sustained exposure to workplace lighting, such as the uniformity ratio and discomfort glare rating, will cease to be widely imposed. This will free up practitioners to exploit diversity of illumination as well as bright or dim surroundings in general lighting practice, bringing it more in line with current professional practice.

The switch to ambient illuminance specifications will bring to the fore the role of room surface reflectances for achieving LiDOs (lighting design objectives). As Table 1 indicates, it takes a lot of indirect flux to create a “brightly lit” appearance, and high surface reflectances, particularly for target surfaces, are essential to for achieving this effect with acceptable lighting power densities. Conversely, where the aim is to achieve high levels of TAIR (target/ambient illuminance ratio) to create illumination hierarchies with strong visual emphasis, ambient illuminance needs to be restrained and this calls for low room surface reflectances. It will be recognized by other professionals, notably architects and interior designers, that close interaction with lighting practitioners is needed for creative LiDOs to be reliably achieved.

Regular grids of luminaires providing uniform illuminance over the horizontal working plane will still be evident but their use will be restricted to those applications for which they represent the most effective

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way of achieving the LiDOs specific to the location. Where task performance requires high illuminance levels, this generally will be provided by local or specialized luminaires rather than by elevated general illumination. Otherwise, lighting techniques such as uplighting, wall-washing and selective highlighting will be strongly evident in general lighting practice and it will be usual for luminaires to incorporate optical controls to enable flux to be accurately directed onto selected objects or room surfaces.

The procedures embodied into lighting design software will start by requiring practitioners to express their lighting design objectives for specific locations and will lead to lighting performance specifications that enable the selection of luminaires, together with their locations and controls, to be conducted as an informed process. Verification instruments for ambient illuminance will respond to the entire surrounding exitance field while excluding direct flux.

The benefits to health and wellbeing of daylight admission will be widely recognized for people who spend long periods indoors and will be accounted for on the extent to which it connects people to the rhythms of nature rather than its contribution to maintained illuminance. Particularly at high latitudes, the diurnal variation of intensity and spectral content of indoor lighting will be modelled on human response to daylight admission.

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Abstract: Light has a powerful effect on human psychology, which influences mental and emotional well-being. As energy codes and illuminance guidelines evolve, standards for emotional well-being need to evolve as well. It is the responsibility of the lighting community to prioritize emotionally intelligent design, even when facing other design challenges.

Keywords: Psychology of light, Emotion and light, Psychological well-being

One-Sentence Takeaway: It is the responsibility of every lighting designer to prioritize emotional well-being in their projects.

The Night-Light Effect

By Leigh Spencer Brown

Do you remember, as a child, seeing a dark shadow lurking in the corner of your bedroom? Did you huddle, afraid, with covers pulled up to your chin, knowing with all your fluttering heart that the monster was about to leap out and grab you with razor-sharp claws, teeth, or tentacles? Then, a simple flip of the light-switch revealed the shadow as nothing more than a toy left out-of-place on the floor? Can you remember the sense of safety that comforted you every night thereafter, created by the glow from a simple night-light?

This is the extraordinary power of light on the human experience.

We all know that thoughtfully designed lighting improves human safety, convenience, energy use, and physical health. Yet, there is another aspect of lighting that is too often undervalued, *human emotion*.

Everything from color, to glare, to shadows, can affect the human psyche and how a person perceives—and interacts with—the world around them (Matsumoto, et al., 2020) (Yunfan, Shaogang, Mingyuan, & Lutai, 2012). At first glance, these small environmental factors seem minor. Most people's brains are so busy with other tasks that they barely notice something as ubiquitous as lighting. Yet, over time, subtle emotional perceptions about our environments can snowball into big changes in health and happiness.

For example, a glow from a night-light can decrease a child's fear and encourage the healthy sleep needed to grow. Adequate sleep not only allows kids' brains to develop biologically, but affects their mood, ability to learn and integrate new information, and even their social interactions (Luis Ortiz, 2020). It also adds to their overall feelings of security. "Emotional safety", both at home and at school, is so vital to childhood health, it is considered a "defining component" of "psychological well-being, and positive academic and social outcomes" (Shean & Mander, 2020).

That's a pretty mind-boggling set of benefits to come from a little night-light.

LED technology entered the market with function vastly outweighing form, let alone aesthetics, but the last decade has seen the evolution of fixtures and sources that are efficient and long-lasting, while also beautiful, healthy, and delivering a high quality of visual and emotional comfort. However, we still see new projects that tout cheap lumens and power savings while leaving their users uncomfortable. They meet all the codes but ignore emotional well-being. This is the opposite of progress.

I recently spoke with a friend whose experience illustrates the situation.
"[The school] just completed a campus lighting retrofit and of course the office LEDs are dreadful (I

never turn them on) but the outdoor lighting is harsh and violent. …People look like they're under surveillance. …And, of course, our facilities team feels like they've achieved a great victory because they reached their one goal - it's brighter and cheaper."

We've all spent time in spaces with poor lighting, either LED or traditional. Whether flat, glare-y, or green, it can create or exacerbate feelings of unease. In a culture where anxiety is on the rise (Dockrill, 2018), creating spaces that increase negative feelings, however subtly, is irresponsible.

Think of people who spend forty or more hours a week enveloped in this type of visual and emotional discomfort. Not only can poorly-designed lighting influence their emotional state, but that negative shift changes how they interact with others, extending the adverse effect to their social network. If this seems overblown, consider an example.

Picture the classic caricature of the DMV: frustrated people, angry or nervous to be there, resenting every minute in line. Equally frustrated employees do their best through long shifts while dealing with lines of people all having a bad day. If this all happens beneath a grid of flat or too-bright LED troffers, appropriate task-defined lumens may be achieved, but people's experiences don't improve.

Alternatively, we have the power to address the emotional needs of the humans in the room. We could strive for a calming and welcoming environment in the waiting area, subtly helping people relax. We could use a rhythm of highlights to draw people's attention from focal point to focal point around the room, minimizing the sense of monotony while waiting in line. We could set up each cubicle to incorporate personal lighting control, fostering a sense of ownership and support for employees. Not one of these ideas is new or uncommon, but consider how their thoughtful application could play a part to cool frustrations and promote better interactions throughout the day. People in better moods work harder to create positive social interactions (Dardenne, Dumont, Gregoire, & Sarlet, 2011). Day after day, week after week, slightly better interactions can add up to a much better work-life.

As an industry, we do a lot of research and are very conscientious about the optimum light levels required to do any particular task. We study different age groups and work environments. We've extensively published the recommended illuminance levels for offices, parking lots, and basketball courts. We know how much more light it takes to read a book at age 75, versus 25.

It's a lot harder to quantify the emotional effects of light.

With so much solid data on the environmental and physiological best-practices of lighting design, it's easy to understand why those become the measurable goals for a project. Between ever-tightening energy restrictions and precise illuminance guidelines, lighting a complex space can already feel like walking a tightrope. Is it worth agonizing over another whole facet of design, especially one that can’t be objectively measured?

Think back to that night-light. For the child in bed, the emotional safety the light provides can allow her sweet dreams, or not. A good night’s sleep will make or break her mood the following day. Her mood will define her interactions with teachers and friends. That’s just one light, seen by one child, yet it touches the lives of a whole family and classroom. How can we ***not*** design with these emotional consequences in mind?

So, without tables, codes, or clear guidelines on the nature of emotional design, how do we proceed?

Trust yourself. As experts in lighting, we’ve built careers of focused observations and experiences.
We, more than anyone, have the accumulated data and insight to understand how a design will make people feel. Emotional effect has to be an intentional and valued part of our design process. For many, it already is, but we must stay on guard. Psychological well-being cannot be secondary to energy codes or illuminance levels. They must all work in tandem.

Our lighting is already affecting people’s well-being through psychology and emotion. As we move forward, we must continue to acknowledge this responsibility, own it, and challenge ourselves to keep raising our standards. If we use our skills, dedication, and emotional intelligence, we’ll be able to bring the positive effect of the night-light’s glow to every project and every person that project touches. Let’s help the future *feel* a little brighter.

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A Guide to Methodology Procedures for Measuring Subjective Impressions in Lighting

John E. Flynn, AIA/FIES, Clyde Hendrick, Terry Spencer, and Osyp Martyniuk

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A major objective of IERI Project 92 has been the development of a research methodology for studying psychological and related subjective effects of illumination. In this sense, the study has made note of two aspects of human behavior that might be influenced, to some extent, by spatial illumination: (1) the effect of light on subject impression and attitude; and (2) the effect of light on performance and overt behavior. The former effects (subjective impressions) appear to involve a recognition of cues or patterns-and these can be studied by scaling procedures. The latter effects (overt behavior, such as seat or path selection, posture, social behavior, participation in activities, etc.) sometimes involve actions taken in response to the cues and patterns-and these can be studied by mapping procedures. This report will focus specifically on scaling procedures for studying subjective impressions. The intention is to propose a somewhat standardized series of test procedures-so that work by various researchers can be compared, and otherwise contribute to a common base of knowledge and information on the subject.

BACKGROUND: LIGHTING AS A SYSTEM OF VISUAL CUES

The authors have been investigating evidence which suggests that human responses to spatial lighting patterns are, to some extent, shared experiences. As this study has progressed, we have come to consider the more specific possibility that some patterns of spatial light might be communicative, in the sense that these patterns suggest or reinforce ideas that are shared (in some degree) by people who share the same cultural background.

We will begin by expanding briefly on the theoretical context that underlies this work.

Individuals exchange ideas and information in many ways; and while we share much information through spoken and written words, other categories of information are communicated more subtly with visual patterns. Commercial trademarks are one example of this; railroad signals and traffic signal shapes are another. In the former case, impressions of identity and quality may be communicated through the use of somewhat abstract visual patterns (not words). In the latter case, visual patterns are used to guide individual and group behavior.

We also obtain impressions of meaning by recognizing the symbolism of visual forms-such as the Christian cross, the Star of David, and other artifacts that relate to cultural and social rituals. On the other hand, some visual forms provide a sense of spatial limits. A simple example might be the white lane lines that are painted along a road pavement.

Considered together, these examples suggest a complex system of designed patterns that guide our behavior and effect our sense of place. Each of these examples involves the visual sense and has the capacity to communicate impressions of 'meaning' that are not readily communicated with words. This suggests that the experience of vision is, in part, an experience of recognizing and assimilating communicative patterns.

James Gibson has explored this idea of spatial meaning and information content in some of his work[1] and has suggested, for example, that "the optic array from a picture and the optic array from the (real) world can provide the same information without providing the same stimulation. Hence, an artist can capture the information about something without replicating its sensations." He goes on to argue for a new theory of visual perception based on the idea that light can convey information; and that the brain constructs the phenomenal world from this information. Gibson suggests that this idea "depends on a new conception of light in terms of an array at a point of observation-*light considered not merely as a stimulus but also as a structure.*"

MEASUREMENT OF SUBJECTIVE REACTIONS TO LIGHTING

These themes of information content and meaning associated with visual stimuli suggest that some psychological aspects of lighted space can be recognized and documented if we are prepared to discuss and study lighting design as an exercise in visual communication. This suggests that as the designer changes lighting modes (i.e., the patterns of light, shade, and color in the room), he changes the composition and relative strength of visual signals and cues; and this in turn alters some impressions of meaning for the typical room occupant or user.

In this sense, we note that many lighting systems are designed merely to function in a 'permissive' way (i.e., simply to permit performance or participation in some activity that involves vision, without attempting to influence user impressions or behavior). However, there is considerable evidence that many lighting designs may intentionally or unintentionally function more actively as selective intervention in human visual experiences-guiding circulation, focusing attention, and otherwise affecting impressions of a room or activity.

With these background ideas in mind, there have been several works that have attempted to explore the 'lighting cue' theory.[2–5] One phase of this work is IERI Project 92 that has been attempting to develop a standardized research procedure for studying the subjective effects of environmental lighting. Introductory and prototype work has produced a number of interim papers.[6-10]

IDENTIFIED INFLUENCES OF THE LIGHTED ENVIRONMENT

One element of the evolving research procedure involves the use of semantic differential (SD) rating scales-such as 'clear-hazy,' 'pleasant-unpleasant,' etc.[11] Work with such scales has identified several broad categories of impression that can apparently be cued or modified (to some extent) by lighting systems. These categories of impression that are of particular interest are:

Perceptual

Categories:	impressions of *visual clarity* impressions of *spaciousness* impressions of *spatial complexity* impressions of color *tone* impressions of *glare*
Behavior setting:	impressions of *public vs private space* impressions of *relaxing vs tense space*
Overall space:	preference: impressions of *preference* (like-dislike) impressions of *pleasantness*

Investigation of similar light settings in different rooms and with different furniture-activity settings indicates that the modifying effect of the lighting is reasonably consistent across rooms.,[7 8] This tends to reinforce the theory that we are dealing with light cues that signal or otherwise communicate subjective associations or impressions, and that the direction of these impressions is somewhat independent of the room in which the light cues are viewed.

A second element of the evolving research proce dure involves the use of multidimensional scaling (MDS).[19-21] Again, there has been considerable recent work with this method-and this has identified several major modes (dimensions) oflight that contribute in a recognizable way to the subjective impressions associated with a space. These dimensions or modes of light are:

1. *the overhead/peripheral mode*
   apparently referring to a lighting emphasis of vertical surfaces, as distinguished from over head luminaires that light central horizontal surfaces;
2. *the uniform/nonuniform mode*

apparently referring to the articulation or modelling of the room and/or articulation of forms and objects in the room
there is some evidence that there may actually be two dimensions here: (a) the basic ‘uniform/nonuniform’ dimension that seems to relate to the appearance of the room or of major surfaces in the room; and (b) an independent but sometimes related ‘nonspecular/specular’ dimension that relates to the appearance of objects and artifacts within the room (i.e. modelling, specularity, etc.);

3. *the bright/dim mode*
apparently referring to the perceived intensity of light on the horizontal activity plane;

4. *the visually warm/visually cool mode*
apparently referring to the perceived color tone of the light in the room (°K).

SCALING PROCEDURES

The purpose of this monograph is to describe some research methods that are involved in this line of study. While most of these methods have been used in other areas of psycho-social research, some of these processes are recent developments, and are therefore unfamiliar to many in the lighting community.

With this background in mind, we will begin by ‘ noting that when studying subjective impressions associated with lighting systems, recommended scaling procedures fall into two stages: data collection and data analysis.

l. Data collection

1.1 Selection of stimulus conditions

The ‘laboratory’ presentation of environmental conditions to be judged will, to a significant extent, determine the quality and interpretability of the results. For this reason, light settings should be chosen or constructed to specifically bracket the field of variables that define the area of study. For example, a study of responses to color of light should in clude several settings in which the single or principal variable is color; while a study of response to distribution of light should include several settings in which distribution is the single or principal variable. Of course complex light settings involving multiple variables are permissible, and information about such settings is often desired. The point being stressed here is that a *range* of settings for each individual variable of interest should be included in the experiment design.

To the extent possible in the selection of stimulus conditions, only the environmental variables under investigation (e.g., lighting) should vary from setting to setting. Variations in acoustics, thermal environment, room finishes, space proportions, etc. shouldbe minimized. In this way, variations in scaling results can be attributed to the lighting variable of interest-with minimum complication from other variables. This means that selection of ‘laboratories’ for scaling studies might most effectively begin with spaces where several alternative light settings are possible (as with alternative switching, dimming, etc.). The quality of such ‘laboratories’ therefore depends on the number and breadth of lighting variables that can beisolated for specific study (in tensity, distribution, color, brightness, etc.).

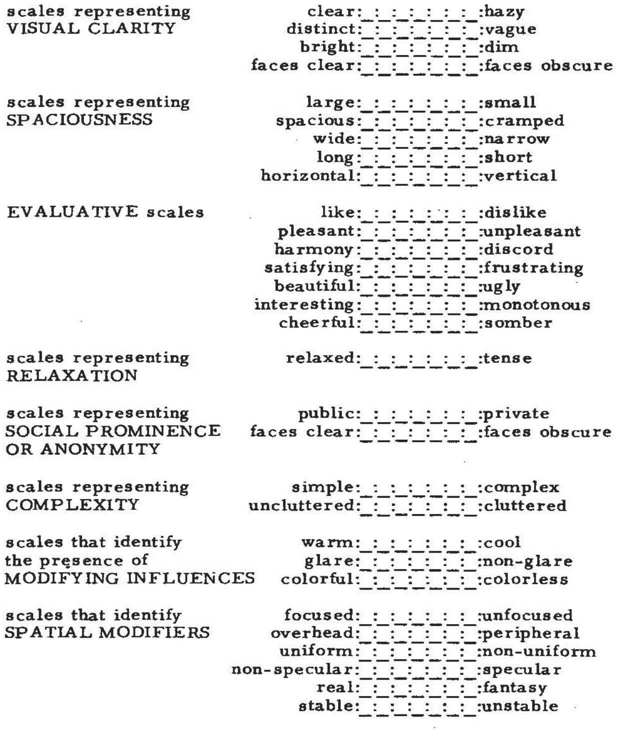
1.2 Selection of bipolar (semantic differential) rating scales

Rating scales should be selected as appropriate to the context and goals of the experiment. Ideally the experimenter might desire to include all possible rating scales in each study and allow a factor analysis to indicate which scales are redundant. But practical considerations will normally prohibit this approach, and a more limited set of rating scales will usually need to be selected.

Although there is no one set of scales suitable for all purposes, a given selection should normally include scale samples from pertinent factors. In Project 92, we have found that in studies of spatial lighting, the major and repeatable factors include ‘evaluative,’ ‘clarity,’ ‘spaciousness,’ and sometimes ‘complexity.’ Other scales of specific interest (such as color tone, uniformity, etc.) should also be added as appropriate to the specific study objectives. Recognize that the experimenter’s goal is to select scales which will maximally differentiate between the lighting systems being studied.

The following list contains a number of rating scales which have been found to differentiate between lighting systems in measuring subjective im pressions. Recognize that this list is not necessarilyexhaustive, and other scales should be tested as appropriate (such as those listed by Dr. Rikard Kuller, National Swedish Building Research D12, 1972).

A copy of a typical sheet of 7-point rating scales is shown as **Fig. 1**. While there is no theoretical limit on the number of scales that can be used for a single rating experiment, the experimenter should recognize subject fatigue as a limiting factor. In studies to date, it appears that a given subject’s commitment of time should be limited to approximately 45 minutes or less.



scales representing
VISUAL CLARITY
clear:_:_:_:_:_:_:_:hazy
distinct:_:_:_:_:_:_:_:vague
bright:_:_:_:_:_:_:_:dim
faces clear:_:_:_:_:_:_:_:faces obscure

scales representing
SPACIOUSNESS
large:_:_:_:_:_:_:_:small
spacious:_:_:_:_:_:_:_:cramped
wide:_:_:_:_:_:_:_:narrow
long:_:_:_:_:_:_:_:short
horizontal:_:_:_:_:_:_:_:vertical

EVALUATIVE scales
like:_:_:_:_:_:_:_:dislike
pleasant:_:_:_:_:_:_:_:unpleasant
harmony:_:_:_:_:_:_:_:discord
satisfying:_:_:_:_:_:_:_:frustrating
beautiful:_:_:_:_:_:_:_:ugly
interesting:_:_:_:_:_:_:_:monotonous
cheerful:_:_:_:_:_:_:_:somber

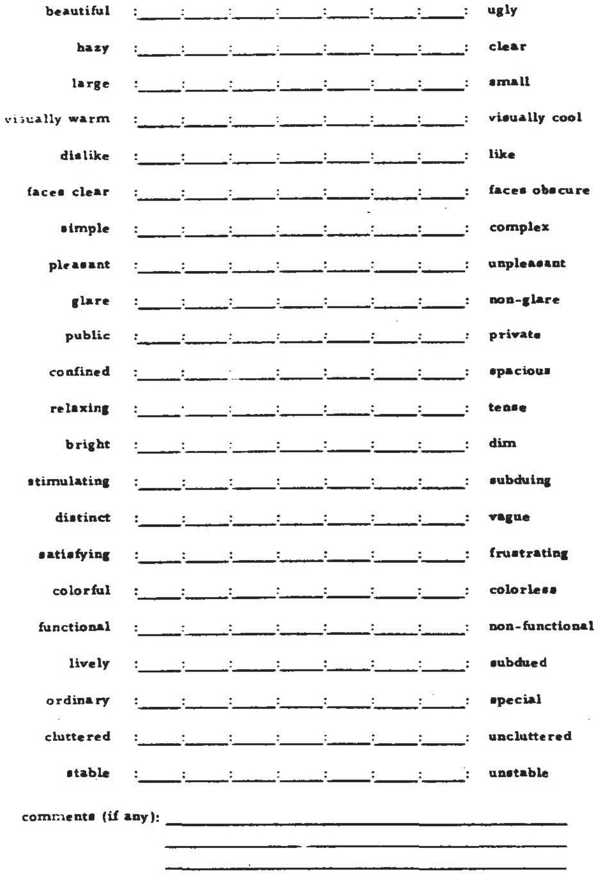
scales representing
RELAXATION
relaxed:_:_:_:_:_:_:_:tense

scales representing
SOCIAL PROMINENCE
OR ANONYMITY
public:_:_:_:_:_:_:_:private
faces clear:_:_:_:_:_:_:_:faces obscure

scales representing
COMPLEXITY
simple:_:_:_:_:_:_:_:complex
uncluttered:_:_:_:_:_:_:_:cluttered

scales that identify
the presence of
MODIFYING INFLUENCES
warm:_:_:_:_:_:_:_:cool
glare:_:_:_:_:_:_:_:non-glare
colorful:_:_:_:_:_:_:_:colorless

scales that identify
SPATIAL MODIFIERS
focused:_:_:_:_:_:_:_:unfocused
overhead:_:_:_:_:_:_:_:peripheral
uniform:_:_:_:_:_:_:_:non-uniform
non-specular:_:_:_:_:_:_:_:specular
real:_:_:_:_:_:_:_:fantasy
stable:_:_:_:_:_:_:_:unstable



beautiful	:____:____:____:____:____:____:____:	ugly
hazy	:____:____:____:____:____:____:____:	clear
large	:____:____:____:____:____:____:____:	small
visually warm	:____:____:____:____:____:____:____:	visually cool
dislike	:____:____:____:____:____:____:____:	like
faces clear	:____:____:____:____:____:____:____:	faces obscure
simple	:____:____:____:____:____:____:____:	complex
pleasant	:____:____:____:____:____:____:____:	unpleasant
glare	:____:____:____:____:____:____:____:	non-glare
public	:____:____:____:____:____:____:____:	private
confined	:____:____:____:____:____:____:____:	spacious
relaxing	:____:____:____:____:____:____:____:	tense
bright	:____:____:____:____:____:____:____:	dim
stimulating	:____:____:____:____:____:____:____:	subduing
distinct	:____:____:____:____:____:____:____:	vague
satisfying	:____:____:____:____:____:____:____:	frustrating
colorful	:____:____:____:____:____:____:____:	colorless
functional	:____:____:____:____:____:____:____:	non-functional
lively	:____:____:____:____:____:____:____:	subdued
ordinary	:____:____:____:____:____:____:____:	special
cluttered	:____:____:____:____:____:____:____:	uncluttered
stable	:____:____:____:____:____:____:____:	unstable

comments (if any): ____

Figure I

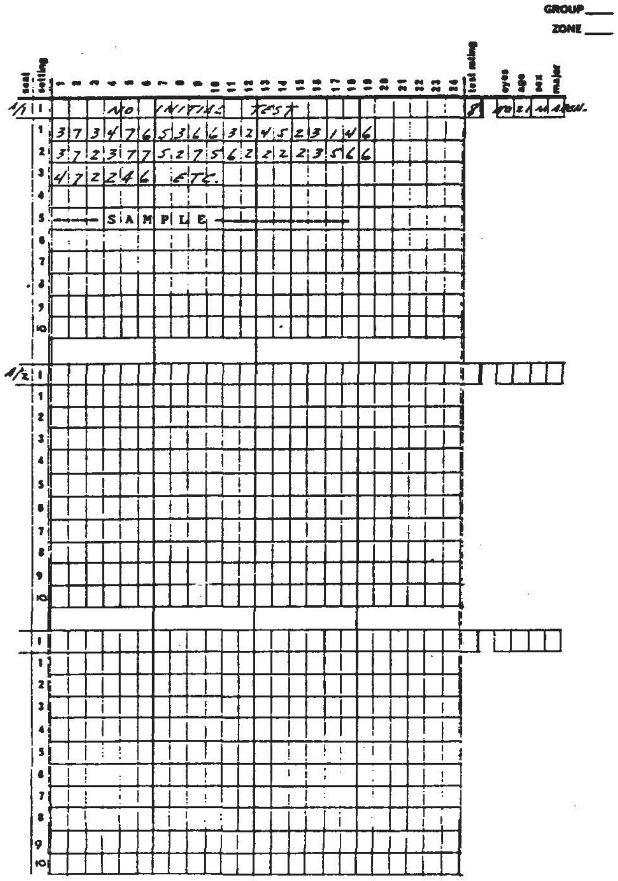


Figure 2

1.3 Design of the experiment

This is a complex topic that cannot be adequately treated in a brief presentation. The reader is referred to Winer (1971)[12] for an in-depth treatment of experimental design and its relationship to statistical analysis.

In general, the experiment should be designed to eliminate and/or hold constant as many potentially confounding variables as possible. This may require a counterbalancing and/or randomization of several factors:
(1) randomized stimulus conditions (light settings);
(2) randomized sequence or order of presentation to various groups of subjects;
(3) randomized or counterbalanced mixes of subjects (for age, education, professional background, etc.).

The total size of the subject sample will, of course, affect the 'order of significance,' and therefore the precision of the results. In order to achieve a statistically significant difference (between ratings) that is reasonable, sample sizes of at least 40 or more subjects are desirable-usually taken in several groups so that the sequence of presentation can be randomized (as noted above).

Instructions given to subjects must also be considered. A proposed sequence of narrative (by the experimenter) and an instructional handout (to each individual subject) are shown in Appendix 1. Recognize that this narrative describes the procedure used for obtaining initial ratings which stress rating the 'room,' and for obtaining comparative ratings which stress rating one light setting when compared with another. Data from '*initial ratings*' obtained from different groups of subjects (each group enters the test room arranged as a different light setting) may provide a measure of the effectiveness or potency of the lighting per se as an influence on the overall judgment of the room. '*Comparative ratings*' tend to enhance or more clearly delineate the differences between the light settings, as well as providing a more efficient means of collecting data. It is, of course, possible to collect both types of data in the same study, as described in Appendix 1.

2. Data analysis: bipolar rating scales

2.1 Scoring of data

The seven steps of each bipolar (semantic differential) rating scale are assigned a numerical value, beginning with a 'l' for the left-most step, and proceeding sequentially-with a '7' assigned to the right-most step. The numerical value of the step marked by the subject constitutes the basic data for the analysis. (As an example, if a subject's response to a given light setting on a given rating scale were to be of a neutral nature, he or she would place a checkmark in the middle step of the scale, and this would be scored as a '4.')

Figure 2 shows a typical data sheet for recording and assembling comparative scaling data from three subjects who were rating up to 10 light settings, using up to 24 rating scales. Note that this data sheet form includes space for recording 'initial' ratings (not used in this example). It also includes space for recording additional information about the subject-such as 'age,' 'sex,' 'educational or professional background,' 'whether glasses are worn,' etc.

2.2 Plotting of mean ratings

Mean ratings for each light setting can be calculated by hand or by computer. These 'means' can then be plotted as necessary to provide a graphic 'picture' of subjective reactions, as measured for the test sample. **Figure 3** is an example.

2.3 Analysis of variance (ANOVA)

This is a standard statistical procedure for analyzing a body of data collected in an experiment (see Winer, 1971 for details).12 It provides information concerning the statistical significance, or lack thereof, of differences between mean ratings for various light settings and rating scales. This includes statistical significance of main effects, interactions, and simple effects.

The ANOVA also provides variability estimates (i.e. standard error of the mean) for each lighting condition on each rating scale. Also provided are tables of mean ratings for each combination of light setting and rating scale. These tables can be used for graphic presentations, as noted in **Figs. 3**, **5**, and **6**.

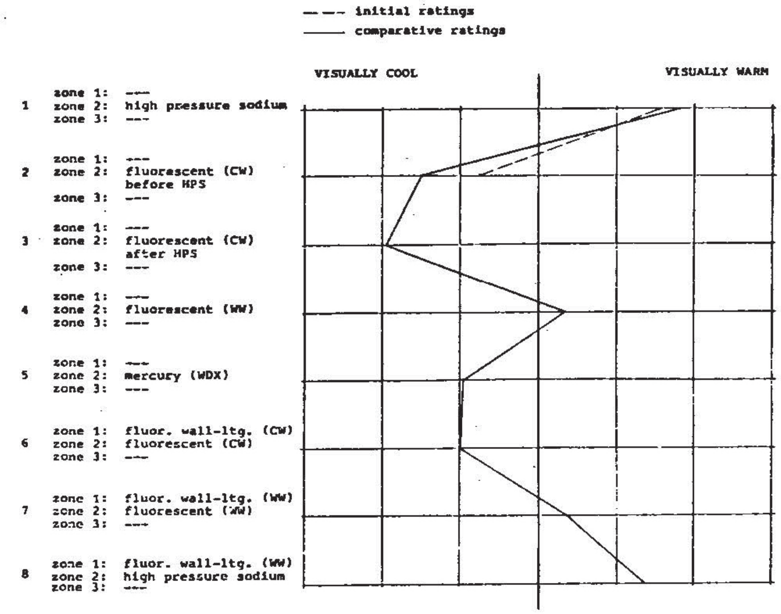


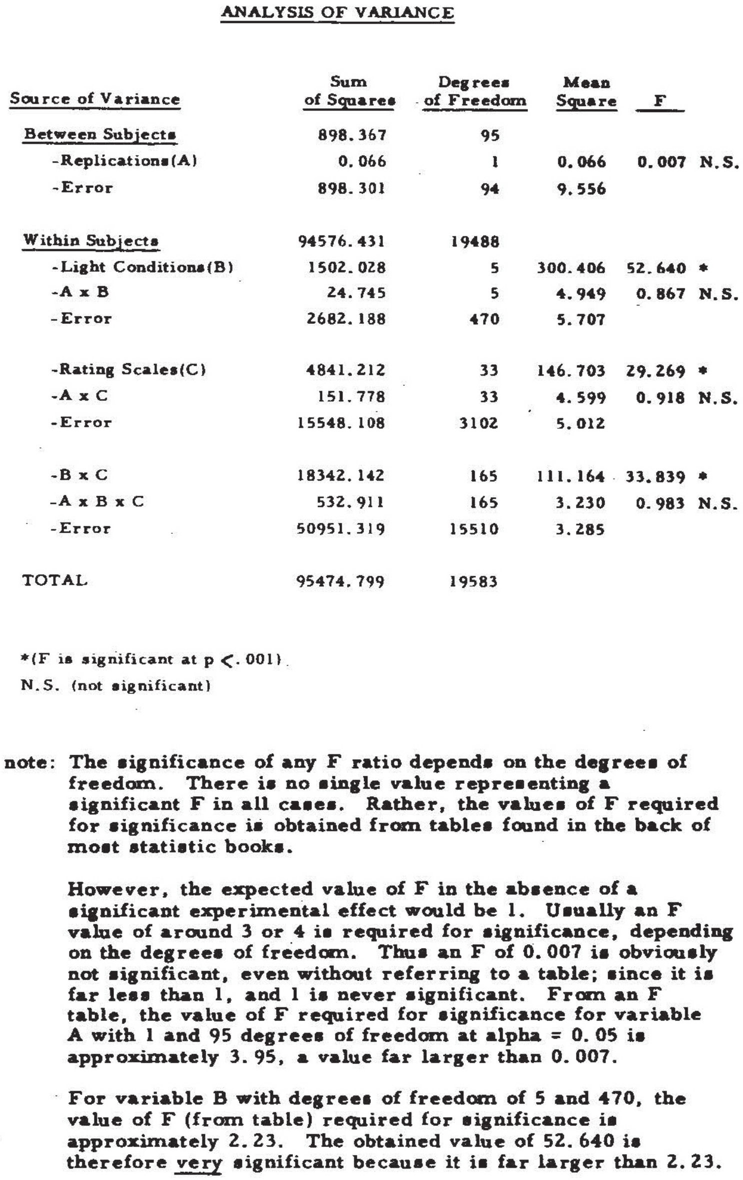
Figure 3

An analysis of variance (ANOVA) summary table for the data in the Flynn et al study (1973)[4] is presented in **Fig. 4**. This ANOVA is for the comparative data.

The first major variable, a between-subjects measure of replications (variable A), compares ratings obtained from the first six groups with ratings obtained from the second six groups (there were 12 groups of 8 subjects each, totaling 96 subjects). The second six groups were an exact replication of the conditions encountered by the first six groups, and in this sense provide a test for reliability. This replication test yielded an F of 0.007 which is not significant-indicating that there was no overall difference between the first six groups vs the second six groups. This finding was further confirmed by the obtaining of nonsignificant A X B, A X C, and A X B X C interactions.

The second major variable was the six lighting conditions (variable B) which tested whether there was an overall significant difference (averaged over all rating scales) between two or more of the lighting conditions. The very significant F of 52.640 indicates that this did indeed occur-but this is only of marginal interest because the primary concern is with the differences between lighting conditions on each rating scale represented by the B X C interaction (discussed below) .

Similarly, the test for the third major variable, the overall differences between rating scales (variable C} was significant with an F of 29.269. This result was expected and is also of marginal interest for the reason given above for the B X C interaction.The results tested by the interaction of lighting conditions and rating scales, the B X C interaction, was significant with an F of 33.839. This result indicates that the pattern of subject response to the lighting conditions was not equivalent for all of the rating scales. These results, for a selected subset of the 34 rating scales, are shown in **Fig. 5**. To determine which lighting conditions are significantly different on each rating scale, a test of 'simple effects,' using a Newman-Keuls procedure, is employed. This latter procedure provides a measure (a standard error of the means) representing the minimal separation necessary between a given pair of means for statistical significance. This measure will vary from some minimal value for two adjacent means to a maximum value for the two most separated means. For the means shown in **Fig. 5**, the minimum separation for a statistically significant difference (at the 0.05 level) between any two adjacent means is 0.52 units; whereas the two most distant means on any rating scale require a separation of 0.89 units for significance. All other pairs of means would require separations somewhere between these two values for statistical significance.



ANALYSIS OF VARIANCE

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Square	F
Between Subjects	898.367	95		
-Replications(A)	0.066	1	0.066	0.007 N.S.
-Error	898.301	94	9.556	
Within Subjects	94576.431	19488		
-Light Conditions(B)	1502.028	5	300.406	52.640 *
-A x B	24.745	5	4.949	0.867 N.S.
-Error	2682.188	470	5.707	
-Rating Scales(C)	4841.212	33	146.703	29.269 *
-A x C	151.778	33	4.599	0.918 N.S.
-Error	15548.108	3102	5.012	
-B x C	18342.142	165	111.164	33.839 *
-A x B x C	532.911	165	3.230	0.983 N.S.
-Error	50951.319	15510	3.285	
TOTAL	95474.799	19583		

*(F is significant at $p < .001$)
N.S. (not significant)

note: The significance of any F ratio depends on the degrees of freedom. There is no single value representing a significant F in all cases. Rather, the values of F required for significance is obtained from tables found in the back of most statistic books.

However, the expected value of F in the absence of a significant experimental effect would be 1. Usually an F value of around 3 or 4 is required for significance, depending on the degrees of freedom. Thus an F of 0.007 is obviously not significant, even without referring to a table; since it is far less than 1, and 1 is never significant. From an F table, the value of F required for significance for variable A with 1 and 95 degrees of freedom at alpha = 0.05 is approximately 3.95, a value far larger than 0.007.

For variable B with degrees of freedom of 5 and 470, the value of F (from table) required for significance is approximately 2.23. The obtained value of 52.640 is therefore very significant because it is far larger than 2.23.

Figure 4

2.4 Principal components factor analysis

This procedure is utilized to determine subsets of rating scales that are being utilized in similar or consistent ways by the sample of subjects. If more than one rating scale is listed in a given subset, this process identifies scales that are functioning in a redundant manner.

The naming of the factors is not provided. Rather, the investigators must use their ingenuity and/or

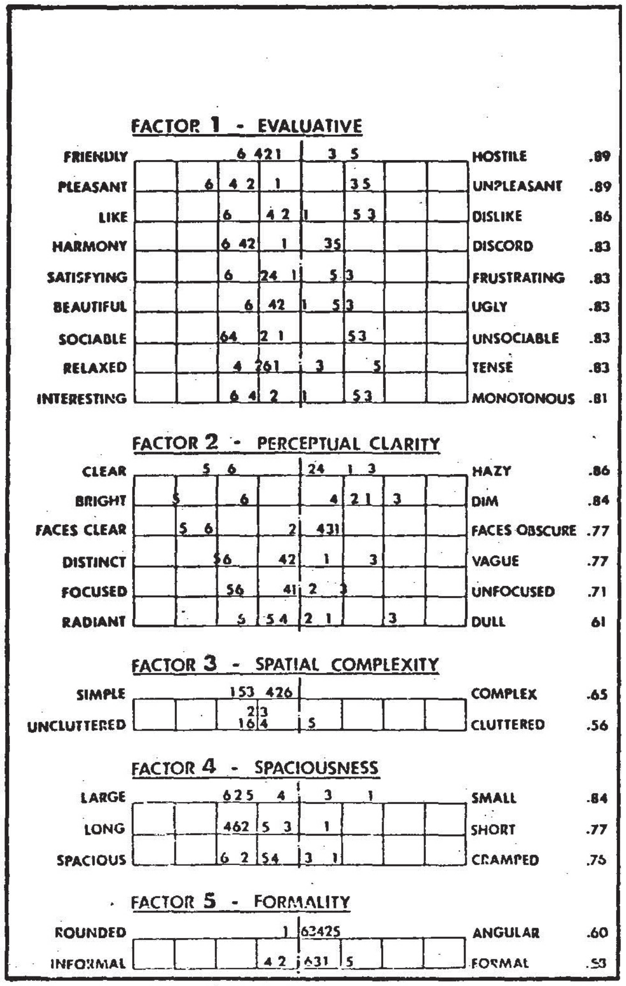


Figure 5

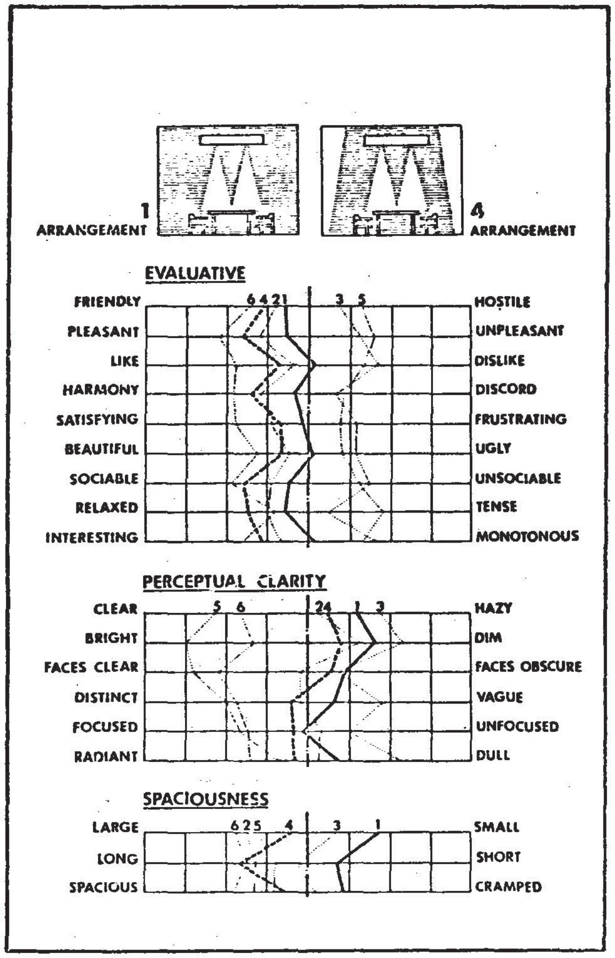


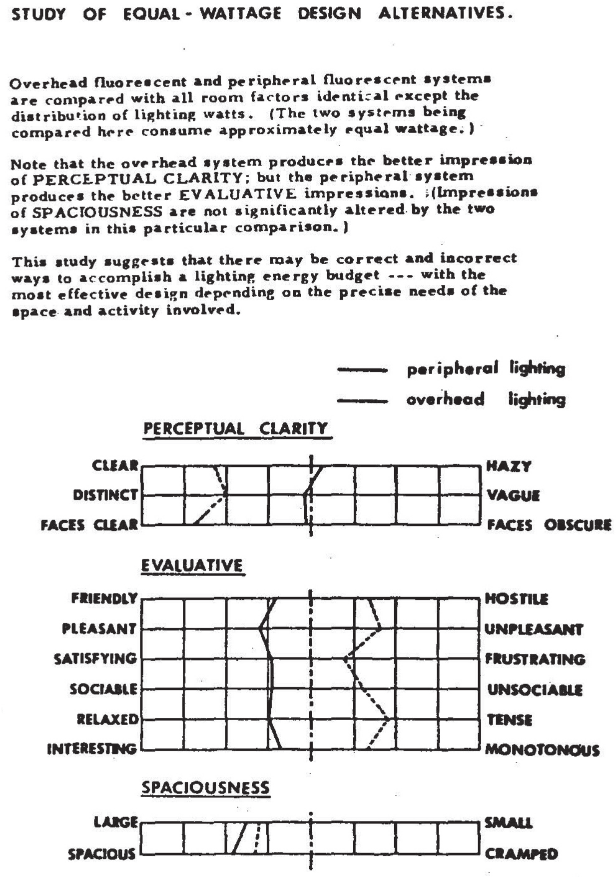
Figure 6A

background knowledge to accomplish this. Generally, an inspection of those rating scales that load highly on a factor will indicate the nature and possible name of that factor.

The authors used a ‘principal components’ factor analysis available in the Statksu series of programs available at Kent State University. Another widely available factor analysis can be found in the BMDP biomedical computer programs published by the University of California Press.[14] The factor analysis process is, in its entirety, quite complex, and the interested reader is referred to Harmon (1967)[13] for a more detailed discussion.

In the context of this report, the procedure is used primarily to provide information concerning the intercorrelation and grouping of rating scales. For example, consider a set of rating scales that includes a number of ‘evaluative’ scales-such as ‘pleasant-unpleasant,’ ‘good-bad,’ ‘like-dislike.’ If subjects tend to use each of the evaluative scales in a consistent manner, then one would expect these scales to have high intercorrelations, and they would be grouped together as a similar response. Stated another way, these scales would have high loadings oh a common factor. Other subsets of scales representing consistent modes of subject expression would also be expected to group together as factors.

An example of factor groupings in a comparison of six light settings is shown as Fig. 5. Note that the rating scales within each factor tend to show a similar and consistent pattern of response in judgment when mean ratings are analyzed for the six light settings in this experiment. Note, however, that only three factors (‘evaluative,’ ‘perceptual clarity,’ and ‘spaciousness’) show a consistently significant differentiation between light settings (i.e. 0.52-0.89 difference). Thus, the obtaining of a factor does not necessarily require strong differences in ratings. Definition as a factor only requires a relatively consistent use of the rating scales by the subject sample in the way that they rank or order the various light settings. In this example, then, note that ‘spatial complexity’ and ‘formality’ are relatively weak factors that do not differentiate significantly between the six light settings in this experiment. The weakness of these two factors is also indicated by the rather low factor loadings (shown at extreme right in **Fig. 5**).



STUDY OF EQUAL - WATTAGE DESIGN ALTERNATIVES.

Overhead fluorescent and peripheral fluorescent systems are compared with all room factors identical except the distribution of lighting watts. (The two systems being compared here consume approximately equal wattage.)

Note that the overhead system produces the better impression of PERCEPTUAL CLARITY; but the peripheral system produces the better EVALUATIVE impressions. (Impressions of SPACIOUSNESS are not significantly altered by the two systems in this particular comparison.)

This study suggests that there may be correct and incorrect ways to accomplish a lighting energy budget --- with the most effective design depending on the precise needs of the space and activity involved.

Figure 6B

These factor subsets can again be used for graphic plots.that facilitate a comparison between alternative light settings. (See **Figs. 6A** and **6B**.)

(Note should also be made that the emergence of a factor is quit dependent, but not guaranteed, by the selection of rating scales included in the experiment. Thus, if there were no ‘evaluative’ type scales included in the rating scale instrument, one would not obtain an ‘evaluative factor.’ This underscores the need for care in selecting the rating scales to be included on the rating form.)

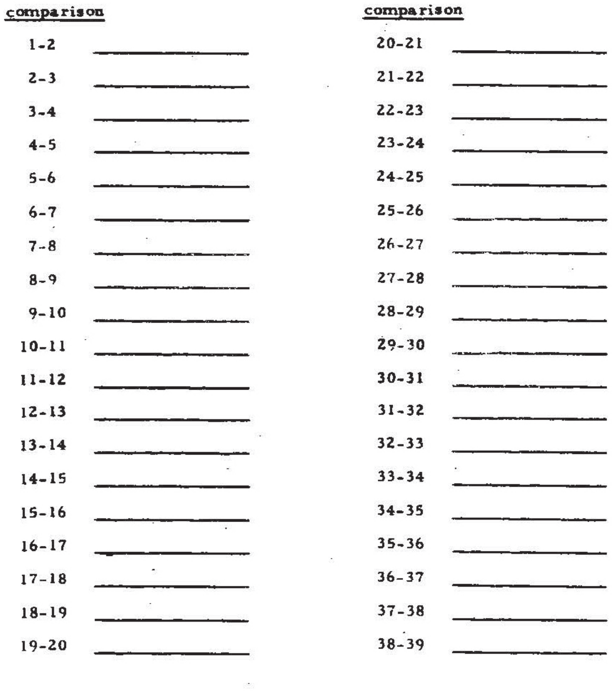
3. Data analysis: multidimensional scaling

3.1 MDS using similarity judgments

Bipolar (semantic differential) scaling provides insight into the effect of various light settings in modifying subjective feelings about a room. Multidimensional scaling (MDS) provides insight into the dimensions that a subject uses in making perceptual judgments about a space, and thus helps define basic modes of lighting that effect spatial quality.

The multidimensional scaling procedure differs from the semantic differential procedure. The SD or bipolar method specifies areas of subjective impression for evaluation (one at a time) by the subjects. Thus there are ratings of ‘spaciousness,’ ‘pleasantness,’ ‘clarity,’ etc. In the paired-comparison multidimensional scaling procedure, the experimenter asks only for a judgment of overall similarity or difference, and the subject is left to establish his own criteria for making this judgment.
The following procedures are used for a pairedcomparison MDS scaling:

(1) The subjects enter the room, select seats, and are instructed on the rating procedures. The experimenter may wish to show the entire series of light settings in rapid succession.



comparison
1-2 ______
2-3 ______
3-4 ______
4-5 ______
5-6 ______
6-7 ______
7-8 ______
8-9 ______
9-10 ______
10-11 ______
11-12 ______
12-13 ______
13-14 ______
14-15 ______
15-16 ______
16-17 ______
17-18 ______
18-19 ______
19-20 ______

comparison
20-21 ______
21-22 ______
22-23 ______
23-24 ______
24-25 ______
25-26 ______
26-27 ______
27-28 ______
28-29 ______
29-30 ______
30-31 ______
31-32 ______
32-33 ______
33-34 ______
34-35 ______
35-36 ______
36-37 ______
37-38 ______
38-39 ______

Figure 7

At a slower pace subjects are then asked to judge the degree of change in going from one light setting to another. To facilitate these judgments, the subject is instructed to choose a number from ‘0’ to ‘10,’ where ‘0’ represents ‘no change’ and ‘10’ represents a ‘very large change.’ Thus a medium change would be assigned a number such as ‘4,’ ‘5,’ or ‘6.’ These ratings are recorded on a sheet similar to **Fig. 7**.
Note that no criteria is provided to the subject for making the similarity judgments. The selection of such criteria is intentionally left to the subjects- and the identification of the selected criteria is the objective of the multidimensional scale process.

(2) During the actual scaling, the experimenter presents the light settings in a serial manner. This series is planned as a matrix that permits each setting to be compared with every other setting (meaning that a large number of comparison

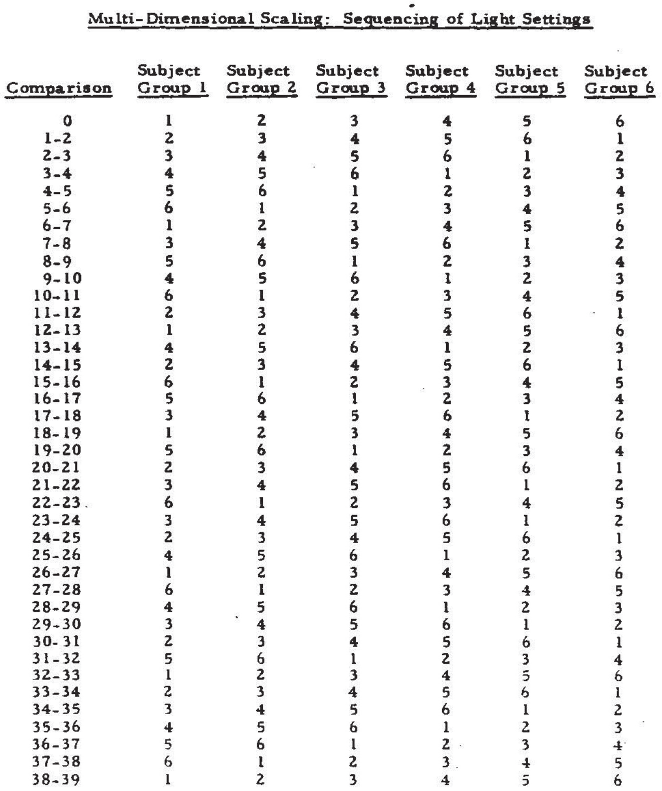
judgments are required). See **Fig. 8**, showing a typical sequencing of six light settings for six groups of subjects.

A few extra practice comparisons are inserted at the beginning of each series for familiarization purposes.

Again, it is important that each environmental change be limited only to lighting variables. In this way, variations in scaling results can be attributed to the lighting variation.

(3) The various judgments of perceived change are then processed by a computer program (to be discussed below) that helps identify the dimensions that the subjects used in making their judgments.

A proposed sequence of narrative (by the experimenter) is shown as Appendix 2.



Multi-Dimensional Scaling: Sequencing of Light Settings

Comparison	Subject Group 1	Subject Group 2	Subject Group 3	Subject Group 4	Subject Group 5	Subject Group 6
0	1	2	3	4	5	6
1-2	2	3	4	5	6	1
2-3	3	4	5	6	1	2
3-4	4	5	6	1	2	3
4-5	5	6	1	2	3	4
5-6	6	1	2	3	4	5
6-7	1	2	3	4	5	6
7-8	3	4	5	6	1	2
8-9	5	6	1	2	3	4
9-10	4	5	6	1	2	3
10-11	6	1	2	3	4	5
11-12	2	3	4	5	6	1
12-13	1	2	3	4	5	6
13-14	4	5	6	1	2	3
14-15	2	3	4	5	6	1
15-16	6	1	2	3	4	5
16-17	5	6	1	2	3	4
17-18	3	4	5	6	1	2
18-19	1	2	3	4	5	6
19-20	5	6	1	2	3	4
20-21	2	3	4	5	6	1
21-22	3	4	5	6	1	2
22-23	6	1	2	3	4	5
23-24	3	4	5	6	1	2
24-25	2	3	4	5	6	1
25-26	4	5	6	1	2	3
26-27	1	2	3	4	5	6
27-28	6	1	2	3	4	5
28-29	4	5	6	1	2	3
29-30	3	4	5	6	1	2
30-31	2	3	4	5	6	1
31-32	5	6	1	2	3	4
32-33	1	2	3	4	5	6
33-34	2	3	4	5	6	1
34-35	3	4	5	6	1	2
35-36	4	5	6	1	2	3
36-37	5	6	1	2	3	4
37-38	6	1	2	3	4	5
38-39	1	2	3	4	5	6

Figure 8

The reader who desires more extensive information on multidimensional scaling is referred to Shepard et al (1972)[15] for theory (especially J. Carroll's chapter, p. 105). The reader is referred to Romney et al (1972)[16] for applications (especially Rosenberg and Sedlak's chapter, p. 134; and Wish, Dentsch, and Biener's chapter, p. 290). This two-volume set contains numerous references for the reader who wishes to delve further into this topic. A recent publication by Kruskal and Wish[17] provides a good general introduction to multidimensional scaling.

3.2 Analysis of similarity judgments

Multidimensional scaling can be conceptualized as a procedure for modeling the psychological dimensions that subjects are presumed to use when judging a set of stimuli (such as light settings). It also includes an attempt to relate these psychological dimensions to characteristics of the lighted space, if possible. This is somewhat analogous to the naming of factors in a factor analysis. However, note that whereas factor analysis is concerned primarily with relationships among rating scales, a multidimensional scaling is concerned primarily with relationships among stimuli. (This is true within the context of the lighting methodology being discussed here. One "could" do a multidimensional scaling of rating scales, and/or a factor analysis of the lighting stimuli.)

There are many possible approaches to the problem of obtaining data for a multidimensional scaling. One approach is to obtain judgments of similarities or differences between all pairs of stimuli-i.e., paired-comparison similarity judgments, as discussed above. Presumably one of the virtues of this procedure is that a similarity judgment does not specify what dimensions are to be used in a given subject's response. Whatever dimensions are used are chosen by the subject and presumably represent the basic or most important psychological dimensions by which the subjects organize their perceptual response to a group of light settings. This is in contrast to the use of bipolar rating scales, where dimensions for judging are specified by the experimenter. In this sense, the psychological dimensions developed by the paired-comparison method may or may not correspond to the dimensions developed by the bipolar rating scales (more on this later).

3.2.1 MDSCAL

The data obtained from similarity judgments can be multidimensionally scaled by a number of computer programs, only two of which are considered here. The first is MDSCAL, developed by Kruskal at Bell Laboratories.[18] This program requires only that the similarity judgments be monotonically related to their 'true' distances in the psychological space. Input for this program consists of an N X N matrix (or half-matrix) of dissimilarities-where N = the number of stimuli (light settings). The MDSCAL analysis may be performed (1) for each subject's data separately, or (2) for the mean data for the group as a whole, with each individual subject considered to be a replication. In this latter case, a single configuration (psychological space) is assumed to be shared by all subjects.

The output consists of dimensional solutionsfrom a one-dimensional solution up to an N-1 dimensional solution if the experimenter so desires.

A decision as to the proper number of dimensions is assisted by a measure called stress, which relates to the 'goodness of fit' between the original data and the representation of these distances for each dimensional solution. **Figure 9** is an example MDSCAL computer output, with the stress measure. In this case, a solution with more than two dimensions would contribute little additional explanatory power. The stress measure indicates this by falling to a near minimum value at two dimensions with only a minor additional decrease for three or more dimensions.

The authors have found the MDSCAL program only marginally useful for lighting studies. However, interested readers are referred to Kruskal's description of the MDSCAL program for a more detailed discussion. A series of two articles by Kruskal (1964a, 1964b)[19,20] would also provide valuable background information.

3.2.2 INDSCAL

The second computer program that has proven more useful is INDSCAL, described by Chang and Carroll (1972).[21] This program performs multidimensional scaling in a manner that enables the experimenter to analyze individual differences.

Data input is essentially the same as for MDSCAL-an N X N matrix (or lower-half matrix) of similarity or dissimilarity judgments; one matrix for each subject. The output will again be a series of dimensional solutions-from a one-dimension solution to as many as N - 1 dimensions if the experimenter so prescribes.

In addition to the dimensional solutions for the light settings in the experiment, the INDSCAL program also provides a weighting of each dimension for each subject. The program assumes that each subject is utilizing each of the dimensions, but with different weights. Thus, this feature of the program provides information concerning individual differences in perception (or awareness) of the stimuli.

MDSCAL (2 Dimension Solution)

Lighting Condition	Dimension 1	Dimension 2
1	-0.392	0.126
2	0.426	0.225
3	-0.773	-0.035
4	0.129	0.777
5	0.233	-0.655
6	0.377	-0.438

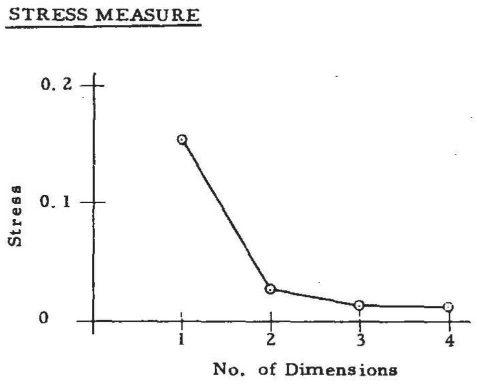
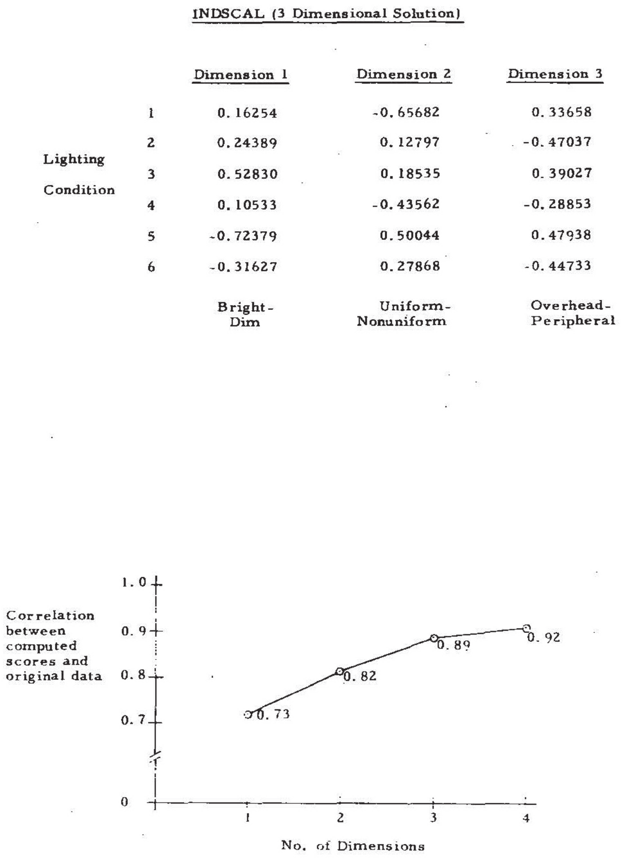


Figure 9

The INDSCAL program also provides a unique orientation of the dimensional axis, in that no rotation is required or permitted. This is in contrast to MDSCAL, where rotation of the dimensions is often required for maximum interpretation.

Although INDSCAL requires an assumption of metric data, a nonmetric version (NINDSCAL) is available for the investigator who is unwilling to make this assumption.

An example of a three-dimensional INDSCAL solution for six light settings is shown as **Figs. lOA** and **10B**. The graph in Fig. lOA indicates that fewer dimensions than three would produce a poorer correlation with the data. More than three dimensions would contribute little additional explanatory power. The model shown in Fig. 10B provides a graphic representation of the six light settings relative to each



INDSCAL (3 Dimensional Solution)

		Dimension 1	Dimension 2	Dimension 3
Lighting Condition	1	0.16254	-0.65682	0.33658
	2	0.24389	0.12797	-0.47037
	3	0.52830	0.18535	0.39027
	4	0.10533	-0.43562	-0.28853
	5	-0.72379	0.50044	0.47938
	6	-0.31627	0.27868	-0.44733
		Bright-Dim	Uniform-Nonuniform	Overhead-Peripheral

Figure 10A

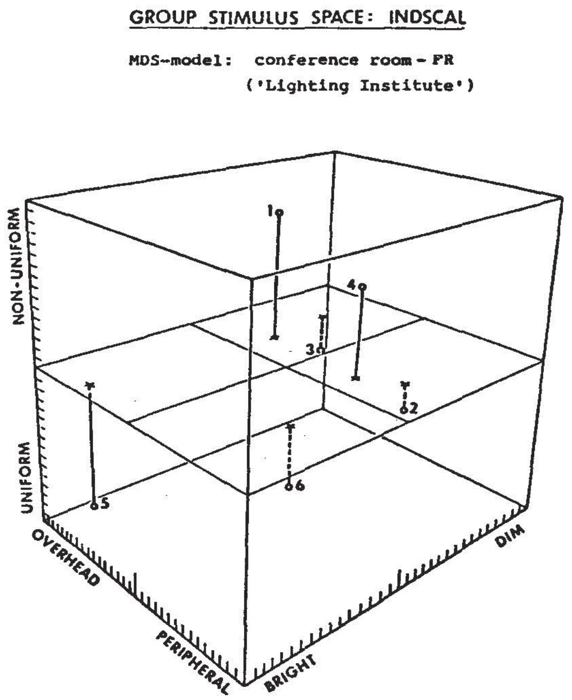


Figure 10A

of the three dimensions. The separation of two or more light settings on a given dimension axis can be obtained by orthogonally projecting the stimulus points onto that dimension. Thus light settings 3 and 5 are close together when projected onto the ‘overhead/peripheral’ dimension, but far apart when projected on the ‘bright/dim’ dimension.

It should be pointed out that neither INDSCAL nor MDSCAL solutions provide names for the dimensions. The dimension names shown in **Figs. lOA** and **10B** were provided by the experimenters following careful inspection of the light settings. These names are thus a matter of interpretation and subject to debate. It is therefore suggested that experimenters attempt to confirm the dimension names by running an independent MDS test in a different space. (This was done in Project 92, and the dimensions shown in **Fig. 10** were confirmed.)[8]

Note: The data shown in Fig. 10 was also subjected to a MDSCAL analysis, and this provides an interesting comparison oflNDSCAL andMDSCAL.

In the MDSCAL analysis, a two-dimensional solution was obtained. However, only one of these dimensions ('bright/dim') was readily interpretable. The other dimension was not readily interpretable-appearing to represent some combinat!on of the other two dimensions that were subsequently obtamed from INDSCAL. The 'bright/dim' dimension was also the only dimension that was readily interpretable in the three-dimensional MDSCAL solution.

This lack of interpretability most likely resulted from the averaging of subject data by the MDSCAL program. Thus a 'strong' dimension that is shared by most of the subjects (such as 'bright/dim') may survive this averaging process. However, other dimensions, not shared by all subjects, may not maintain their identity when data is averaged over subjects. This is not a problem for INDSCAL-for individual differences are readily accommodated with this program.

As mentioned above, the three dimensions for the INDSCAL solution were readily interpretable (and reproducible)-and combined with the other advantages of the program, would argue for the preference of INDSCAL over MDSCAL for lighting studies.

3.3 MDS using rating scale data

One of the problems with the previously described paired-comparison similarity scaling is that it requires a great deal of time and tedious effort on the part of the subjects. For example, if there are 10 light settings, a minimum of N(N - 1)/2 = 45 paired comparisons would be required to fill up a halfmatrix. Generally more than this would be required if stimuli must be presented sequentially and transition stimuli are provided. As the number of light settings approaches and exceeds 10, therefore, the number of paired comparisons required becomes prohibitive from the standpoint of subject fatigue.

There is some evidence that similarity measures can be derived from rating scale data, although caution must be exercised. Wish & Carroll (1974)[22] investigated this problem by comparing dimensions obtained from 'direct similarity judgments' vs 'rating scale judgments' of nations. Although there was a good deal of overlap in the dimensions obtained from each method, the match was not complete. Three of the total of nine dimensions were not represented in dimensions obtained from rating scales-apparently the result of not including any rating scales that were related to the missing three dimensions. There was also evidence that a few dimensions that were obtained from rating scales were not represented in the dimensions obtained from pairwise similarity judgments. This suggests that the latter subjects were recognizing dimensions that were called to their attention by rating scales; while some of these dimensions tended to be ignored when the subjects were left on their own.

Evidently there is no one method of data collection that will guarantee all possible or relevant dimensions in the solution. But if the experimenter has knowledge of the light settings being used and knowledge of pertinent dimensions of judgment (presumably from previous research in the area), it appears that a judicious choice of rating scales will accurately yield the psychological dimensions being utilized by the subjects in a given situation.

Note: As an example, the three basic dimensions obtained from an INDSCAL of 'pairwise similarity judgments' in IERI Project 92 were also obtained from an INDSCAL of the bipolar rating scale data for the same lighting conditions. This result was obtained with a different group of subjects providing the two modes of data.
In a subsequent analysis, an INDSCAL of the 'rating scale' data was carried out on subsets of the rating scales. In one case, the scales loading highly on the 'clarity' factor were eliminated, and the results were examined. In general, the three dimensions continued to maintain their identity quite well-especially the two 'stronger' dimensions, 'bright/dim' and 'overhead/peripheral.' The third dimension, 'uniform/nonuniform,' was occasionally difficult to identify.
These results are only tentative, since the study did not systematically study all possible subsets. But they suggest that the dimensions obtained from rating scales, especially stronger dimensions, may be quite robust and not extremely dependent on the particular choice of rating scales used. Further research on this matter is required.

Procedures for obtaining proximity measures from bipolar rating scales are discussed by Wish & Carroll (1974).[22] These procedures essentially consist of a weighted averaging of distances between stimuli (light settings) on each bipolar rating scale-being collapsed either over scales or over subjects. An INDSCAL analysis is then performed on these derived proximity matrices; and the dimensions obtained from the two methods of averaging (over scales and over subjects) should agree if the dimensions are meaningful and interpretable. Evidence to date from IERI Project 92 indicates that this agreement will generally be obtained.

3.4 Emphasisof specific MDS dimensions

Arnold (1971)[23] suggests that subjects have a limited capacity for information processing, and that this capacity may vary with individuals. He suggests that when subjects are asked to make comparisons of complex stimuli (such as light settings) in a multidimensional scaling situation where possible dimensions of experience are unspecified, some subjects may isolate one or a few dimensions and submerge the others. This means that some dimensions may be secondary, in that they are not readily identified in a prominent way during a multidimensional scaling. This may be the result, in part, of a smaller degree of stimulus variation in the secondary dimension as compared to a more prominent primary dimension.

One of these secondary dimensions appears to be 'color tone' of light (visually warm vs visually cool). When it is desired to specifically study individual dimensions (primary and secondary),"it appears that the experimenter can do this by careful limitation of the lighting variables that are ·presented in the experiment.-Figure 11 shows an INDSCAL plot that was developed in a test room where the light settings were specifically selected to minimize awareness of differences in the ‘bright/dim’ and ‘uniform/nonuniform’ dimensions. As intended, these two dimensions were collapsed in the resulting data providing a simplified MDS plot” (**Fig. 11**) that will be discussed further in later pages.

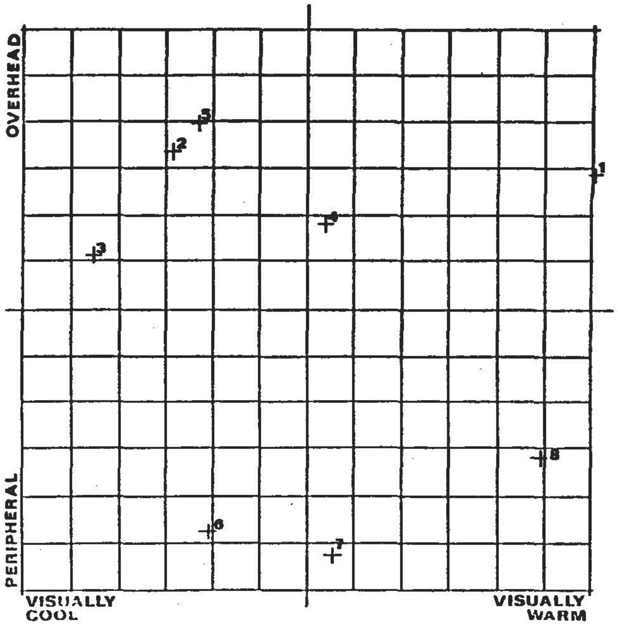


Figure 11

3.5 Relating bipolar rating scale judgments to the psychological space obtained through multidimensional scaling of light settings

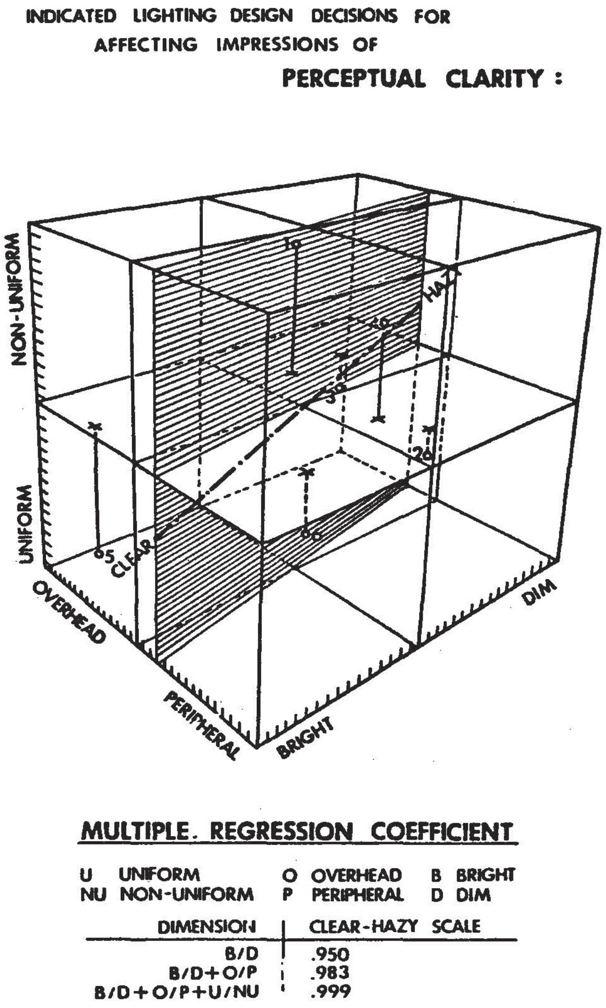
If one assumes that the psychological space derived from multidimensional scaling represents the basic perceptual organization for a series· of light settings, one can ask how the judgments on rating scales relate to this MDS space.

From a theoretical point of view, each bipolar rating scale can be conceptualized as a line drawn through the MDS space-with an orientation such that orthogonal projections of the stimuli (light settings) onto that line will have a maximum correlation with the obtained bipolar rating scale judgments. In other words, the bipolar rating scale can be thought of as a subjective impression that is linearly dependent on one or more of the *spatial MDS dimensions*.

It is a matter of conjecture whether subjects actually make judgments in this manner; but one can, nevertheless, examine the consequences of a model of this nature and the insights it may provide.

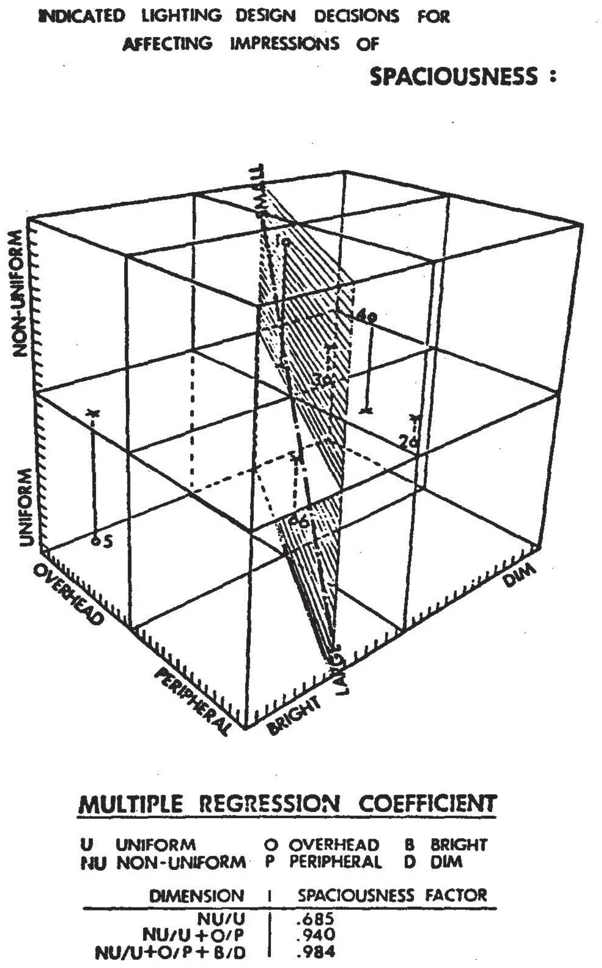
The mechanics of ‘fitting’ a given bipolar rating scale into the MDS space is rather straightforward. A linear regression of the bipolar rating scale judgments with the dimensions from the INDSCAL solution will provide an overall multiple correlation (i.e., how well the rating scale line can be ‘fitted’ into the MDS ‘space’). This requires that the order and spacing of bipolar ratings should be correct (through orthogonal projection) within MDS ‘space.’ [24-27]

This procedure also provides beta weights for a linear regression equation in which the rating scale judgments are considered the criterion variable. These beta weights can serve as direction cosines for plotting the rating scale line within the MDS space. Strictly speaking, the multiple regression equation (for two or more predictor variables) describes a hyperplane rather than a line, but it is possible to show



DIMENSION	CLEAR-HAZY SCALE
B/D	.950
B/D+O/P	.983
B/D+O/P+U/NU	.999

Figure 12A

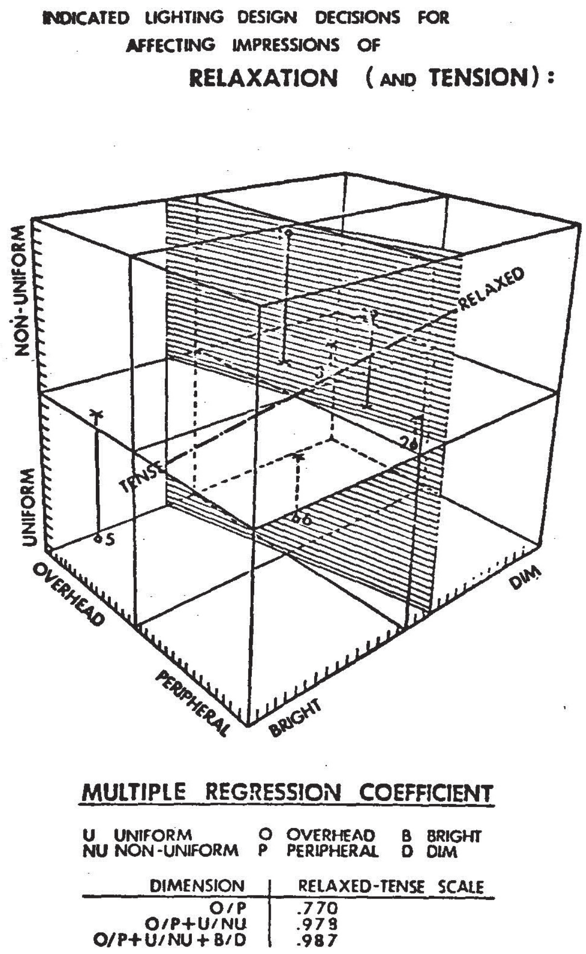


DIMENSION	SPACIOUSNESS FACTOR
NU/U	.685
NU/U+O/P	.940
NU/U+O/P+B/D	.984

Figure 12B

that the line ‘fitted’ into the MDS ‘space’ with the beta weights as direction cosines will have an invariant relationship (except for possibly a scale transformation) to predictions obtained from the hyperplane. (IERI Project 92 has verified this both geometrically and numerically for two dimensions and assumes that this would generalize to higher dimensional solutions.)

Several examples of the ‘fitting’ of selected rating scales to an MDS space are shown in **Fig. 12** (five examples). Fig. 13 shows an example of a bipolar rating scale similarly ‘fitted’ into the simplified two-dimensional MDS space to assist study of light color. The potential interpretations of lighting system judgments possible with these ‘MOS/rating scale’ diagrams are discussed in Flynn et al (1975)[8] and Flynn & Spencer (1976).[10]



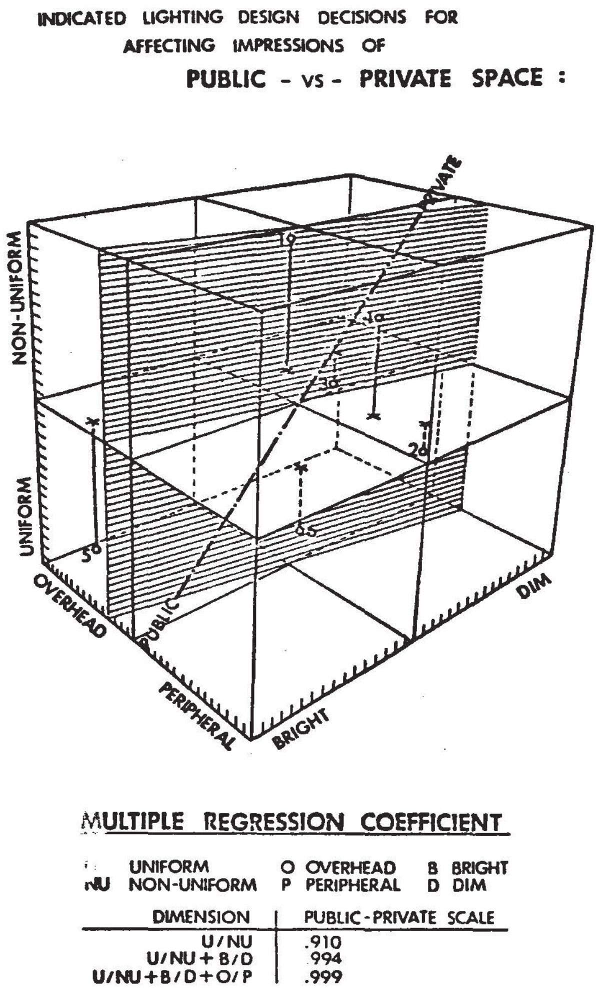
INDICATED LIGHTING DESIGN DECISIONS FOR AFFECTING IMPRESSIONS OF
RELAXATION (AND TENSION):

MULTIPLE REGRESSION COEFFICIENT

U UNIFORM O OVERHEAD B BRIGHT
NU NON-UNIFORM P PERIPHERAL D DIM

DIMENSION	RELAXED-TENSE SCALE
O/P	.770
O/P+U/NU	.978
O/P+U/NU+B/D	.987

Figure 12C



INDICATED LIGHTING DESIGN DECISIONS FOR AFFECTING IMPRESSIONS OF
PUBLIC - VS - PRIVATE SPACE:

MULTIPLE REGRESSION COEFFICIENT

UNIFORM O OVERHEAD B BRIGHT
NU NON-UNIFORM P PERIPHERAL D DIM

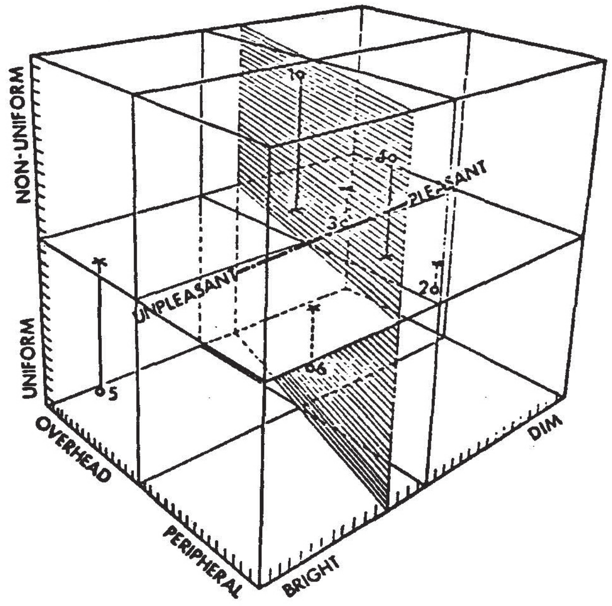
DIMENSION	PUBLIC-PRIVATE SCALE
U/NU	.910
U/NU+B/D	.994
U/NU+B/D+O/P	.999

Figure 12D

3.5.1 Multiple correlation coefficients

The multiple correlation values shown in these examples (**Figs. 12** and **13**) were obtained with a stepwise multiple regression program which sequentially adds predictor variables. · Thus, for the three MDS dimensions used as predictors in **Fig. 12**, the program determines which of the three has the highest correlation with the criterion variable (the bipolar rating scale) and computes the linear regression equation, the beta weight, and the multiple regression (in this case, the same as the univariate correlation). The program then determines which of the two remaining variables, when-combined with the first, will yield the greatest multiple correlation, and computes a multiple regression equation for these two predictors. And finally, the program computes the multiple regression equation, multiple correlation, and beta weights using all three predictors. These latter beta weights are then used

INDICATED LIGHTING DESIGN DECISIONS FOR AFFECTING IMPRESSIONS OF **PLEASANTNESS :**



MULTIPLE REGRESSION COEFFICIENT

U UNIFORM — O OVERHEAD — B BRIGHT
NU NON-UNIFORM — P PERIPHERAL — D DIM

DIMENSION	EVALUATIVE FACTOR
O/P	.833
O/P+NU/U	.921
O/P+NU/U+B/D	.942

Figure 12E

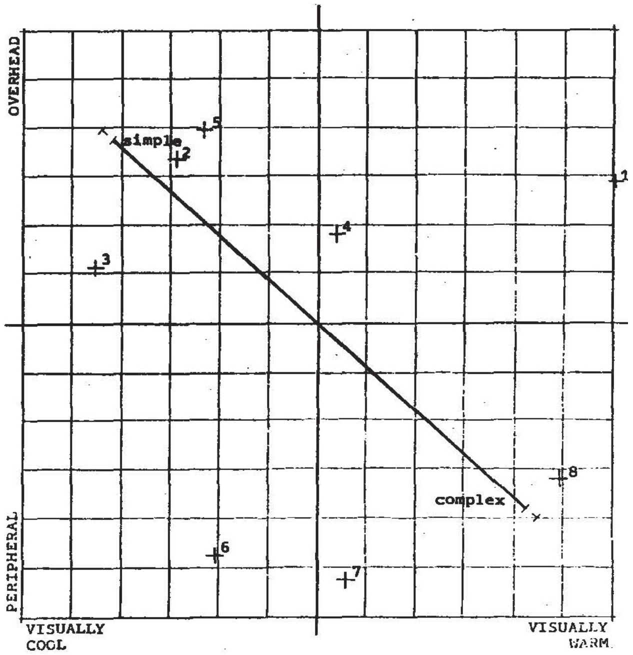


Figure 12E

as direction cosines for plotting the rating scale in the MDS space.

The use of a stepwise multiple regression procedure provides the investigator with information concerning the relative importance of each MDS dimension and the increase in the mutliple correlation that is possible as predictor variables (MDS dimensions) are added to the multiple regression equation. Perhaps it should be pointed out that relationships between various rating scales and MDS dimensions may depend on the particular group of light settings being tested. Interpretations must, therefore, be cautious. In this sense, the multiple regression procedure provides information concerning relationships obtained in a particular experimental setting; but further investigations and experimental replications must be undertaken to adequately assess the generality of findings obtained in initial studies.

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CONCLUDING REMARKS

Our findings in IERI Project 92 suggest that recently evolving psychological procedures for rating subjective impressions and experiences can be applied usefully in lighting research-and the authors believe that a definitive pattern of data is beginning to emerge. At this point, this work seems to support the theory that the experience of lighted space is, to some extent, a measurable experience. Furthermore, the findings tend to sustain the idea that lighting can be discussed and measured as a vehicle that alters the information content of the visual field-and we may now be able to document how this intervention affects impressions and sensations of well-being.

More specifically, these studies tend to reinforce and articulate the need for engineers and designers to be sensitive to ideas of lighting function that are broader than simple task-oriented quantitative standards designed to permit reading, sewing, drafting, bookkeeping and similar visual tasks. Without downgrading the importance of providing good visual conditions for such tasks, our studies suggest that the lighting designer is intentionally or unintentionally manipulating other aspects of visual sensation and experience as well.

While some research groups are already active in this field, the authors hope that other researchers will also join in this overall study-(1) so we can perhaps cooperate in developing a bank of comparable data on the effects of light on subjective environmental quality; and (2) so we can perhaps cooperate in developing deeper insights into possible differences in value systems among groupings of individuals and among varying cultures and national backgrounds.

We appear to be moving through the early stages in the use of methodologies that will more precisely document quantitative values and value differences among people in their uses of light.

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Abstract: We are in the midst of the fourth industrial revolution and our reality is fluid, dynamic, and, at times, uncertain. Lighting designers are pushing technological boundaries, shaping architectural experiences in previously unimagined ways and reshaping the human visual interaction of light with the physical and virtual worlds around us. We are making decisions based on groundbreaking research that tailor light and space to the well-being of people in far more nuanced ways than ever before. So what does the world of lighting design look like in 10 years?

Lighting materiality and technology are becoming intertwined and intimately connected with immaterial elements such as data, emotional response, and physiological input for a beneficial impact on our natural ecosystems and personal well-being. The “smart” device and building features of today will become more than widgets that try to talk to each other. They will be intuitively integrated into the nuanced facets of our lives to measure, adapt, and respond to the needs of people, energy demands, and the environment around us.

The article explores the intersection between the material elements of light and technology along with our interaction and reliance on the immaterial elements of data and the human experience in the next 10 years. It provides each designer’s individual predictions from philosophical to physical all working together as a singular theory to showcase a compelling vision of the future.

Keywords: Multiglowing, Emotion, Pigments, Tunable, Sparkle, Sensors, Experimentation, Integration, Adaptation, Automation, Intelligence, Physiological Input, Multisensory Design, Sustainability, Energy Savings, Augmented Reality, Virtual Reality, IoT, Technology, Magical, Innovation, Daylight, Optics, Photovoltaic (PV), Material-Integrated, Holographic, Experiential Design, Architecture, Shadow, Fashion, Control, Color

One-Sentence Takeaway: Lighting materiality and technology are becoming intertwined and intimately connected with immaterial elements such as data, emotional response, and physiological input for a beneficial impact on our natural ecosystems and personal well-being. This article explores several unique futures that may evolve out of our desire for higher levels of lighting design and technology integration with other aspects of our lives.

The Lighting Multiverse: A Future of Possibilities

By Erik Campbell, Michael Dant, Alex Deahl, Sara Duffy, Zach Suchara, Anna Winn

What does our industry look like in 2030 and beyond? What an amazing question as we find ourselves in the middle of the fourth industrial revolution. Our reality is fluid, dynamic, and, at times, uncertain. Lighting designers are rapidly becoming technology integrators and our role in the design and execution of human visual interaction with architecture is becoming more complicated by the minute. From wearable light to the preservation of night skies, the range of dreams for the future of lighting is at the heart of the vision the designers share here. What follows is a kaleidoscope of possibilities for our future

Ten years from now, the most compelling advancement in lighting will be the personal. Even in the early days of mobile computing, we could see it coming. Faces on the bus lit with the gentle light of the screen, each personal world of browsing working posting a unique color reflection on the face hands hat and hair. Summers, the ambient light weakened the image in early twilight. But when winter came, the prematurely dark evenings were perfect for showcasing our face, taste of screen and posture. As we evolved our link with phone, the makers saw an opportunity to flatter us by expanding beyond mere display. What complemented our face or reflected something deeper? Did that bitter posting paint ash on our fingers? Did the unexpected presence of our current crush turn our screen and hair saffron? There are no controls, only states of emotion and attention. Our personal state expressed in light. Light for looking and light to be seen by. The same screen, multiglowing.

Michael Dant, Lighting Designer

As a species, we crave intensity, variety, and vibrancy. Within lighting design, this can take form in many ways and pigmentation can play a large roll in its application to surface finishes or wall coatings. Pigments are sourced all over the world from plants and insects all the way to heavy metals mined in conflict zones. Through the lens of sustainability, the most problematic application is pigment added to surface finishes, especially in paint VOCs. How can wall coverings evolve so that attributes like intensity, variety, and vibrancy still be relevant without the problems that come along with using things like heavy metals to pigment our surfaces? Lighting.

This is already starting to happen with features like Tunable light technology, an interest in playing with systems like Phillips Hue at the residential level, and the current popularity of James Turrell by artists like Drake. Pairing white or neutral surface interiors with RGBW fixtures that will both be widely available and at a price point that the average person can afford will also come with the ability to customize it instantly with readily available IoT platforms. People will be able to create their own scenes or settings in everything from mood lighting to help with sleep or in communicating things like calling a family to dinner. In applications like multi-family housing, a landlord can market a space where people are traditionally not allowed to paint the walls, but could easily bathe it in colorful light or patterned light. This feature replicates the old Victorian notions of matching a color palette and patterning scheme to certain times of day (morning room, smoking room, etc.) without having to use the same amount of real estate. In commercial settings, a conference room with muted tones can transform into a festive area for celebrations easily and affordably with a few clicks. This change would also shift residential lighting away from large ceramic lamps on end tables to something more linear and architectural. Apartments might come with cove and graze lighting at the perimeter instead of a single surface mount in the center of the room. New housing might have a single control station and dedicated outlets serving wall switches would become obsolete. As a species, our eyes still crave sparkle, but we can achieve this with small, LED lamps in interesting, sculptural shapes such as glowing orbs and fairy lights. Gone are the days of breaking your mother’s priceless living room lamp with a baseball.

Anna Winn, Lighting Designer

Ten years from now, the most important and exciting advancement in lighting will be luminaires that respond to human feelings, expressions, and emotions. Fixtures will have sensors embedded in them that detect physical responses to external stimulus – posture, expression, heart rate, temperature, and patterns of movement. The sensors will be so refined that a furrowed brow or clammy palm can be detected. Manufactures will collaborate with neuroscientists to develop a greater understanding of human physical responses to light and stimulus.

The system will use machine learning to predict personal preferences and will actively and continuously adjust the lighting accordingly. If the system detects fatigue, the lights may decrease in color temperature and increase in output. If an individual is expressing stress, the layers of light may shift to have a relaxing effect. The response will be discreet and hardly perceptible. The response will be applied uniquely to workplace, education, and healthcare applications. Lighting and sensors will be focused on the task level so that each individual space can be tuned uniquely and actively. The sensors will be connected to the HVAC system for an overall comfort-tuned experience. Productivity will increase by 10%, emotional satisfaction by 20%, and energy savings by 30%.

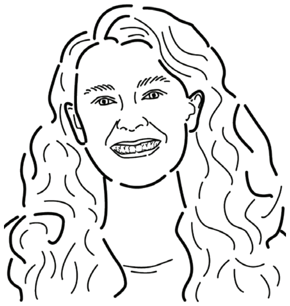
Sara Duffy, Lighting Designer

The introduction of LEDs has led to an increase in groundbreaking experimentation and connection with automated systems, yet there is still tension or even just misconception between artificial lighting systems and natural light. Ten years from now, the most important advancement in lighting will be a more granular digital system that responds automatically to and with the sky. Some intelligent lighting systems continually reevaluate the light they produce, I predict this self-regulatory process would extend to the entire industry and evolve. After all, there is a difference between mimicking a natural system and responding to a natural system.

Alex Deahl, Lighting Designer

In 2030 and beyond, controls will follow individuals or groups of people. Lighting will adapt to users' needs automatically without the need to manually move a switch. The controls will be more like a computer preference so that when a person enters a space, the light levels are adjusted according to the user preferences and their needs. Additionally, lighting power demand will reduce by 25% from what it is currently because of the optics developed by manufacturers. Optic developments will become more of what lighting manufacturers do in production. Optics will also be controlled by software so manufacturers can develop fewer physical form factors and the optics will be able to provide the desired optic needs for the application just as mobile phone cameras can get around the physics of lenses through software. For example, a wall washer can transform into a grazer through software.

Erik Campbell, Lighting Designer



We've all seen it. Many of us in the lighting design industry bemoan it. To us, it is a typical nuisance seen – or rather not seen – in architectural renderings.

I am speaking of the mysterious, magical orb of light that appears in preliminary architectural renderings across the globe. Of course, these orbs of light that lend an amazing, even field of light across the entire rendering and are often unaccompanied by even a modest light fixture in the ceiling. Where does the light come from?

Often, turning these preliminary renderings into an early conversation is important so as to keep expectations reasonable (and beneficial) among all parties. Future innovations in lighting are only going to help close the gaps in this conversation and cater to entirely new aesthetics – always pushing boundaries into new horizons.

We have several tried and true methods that will only improve in the coming decade that will help appease increasing demands for efficiency, effectiveness, and aesthetics.

Ten years from now, the most important and exciting advancement in lighting will be improved optical lenses for fixtures, creative new form factors, and increased use and understanding of daylight harvesting.

Optical lenses and shielding – The energy efficiency of many fixtures is amazing, but glare and central beam candle power can be disappointing. Using optics to control the spread of light and enhance the function of a fixture will be commonplace.

Form factors – Is tiny always better? Some people think so. Increasing technological efficiency in smaller packages and creative new forms afforded by this hip, tiny new technology will lead to unprecedented new solutions. This will also be aided by a drop in prices as smaller technology packages spread through the market and can be used on lower-budget projects.

Daylight harvesting – Most days, we have plenty of light. Why don't we invite it inside? In the future, this readily available source of natural light will be used beyond required codes or certification requirements.

Jennifer Pace, Lighting Designer

10 years from now "lighting" will no longer be a phenomenon isolated to particular pieces of equipment, a designated profession, or a concept designed in a bubble. The art of lighting design is an intention to illuminate surfaces and provide shadow. After all, light is not visible until it has a surface that it has hit. Today, illuminating surfaces is an additive equation of separate parts. Light fixture plus surface equals effect. In the future, illumination will take a similar path as photovoltaic panels moving toward building-integrated photovoltaics,

and there will be Material-Integrated Illumination.

Classic photovoltaic (PV) panels require a roof or alternate horizontal surface to be installed. As roof and horizontal square footage on sites is limited, the concept of integrating PV onto other surfaces at other orientations emerged. Building-integrated photovoltaics (BIPV) have been integrated into building materials for custom façade treatments, fenestrations, and several other applications. While BIPV's struggle to be feasible, integrating lighting into building components is much more natural.

Three primary limitations to BIPV emerge: solar orientation, surface area ratios, and aesthetic goals. BIPV are bound by solar orientation to collect sun (the more southern its orientation, the more it produces). They have a specific ratio of PV surface area compared to a building side/load required to power the building. Finally, there are architectural aesthetic goals where BIPV is quite limited in its appearance.

Material-Integrated Illumination (MII), is not be bound by any of these constraints. Harvesting energy is a non-issue and the ratio of surface area to area lit is 1:1 so an integration of MII is limitless.

MII will be able to use a variety of mediums. 3D holographic films will be capable of providing texture, depth, and optical illusions so that they are commonplace to enhance any experience. Films are already being used in fixtures such as Lithonia's SpanlTM LED flat panel, which while flat appears volumetric. We have also all seen birthday cards from the 80's where the image changes based on the angle you are viewing it from. Optical illusions are not a new concept, a visit to Italy will showcase the ceiling in Sant'Ignazio as an excellent example.

The industry will adopt static holographic films in the beginning then move toward digital varieties allowing the ability for remodel to be nothing more than a keystroke.

Providing texture and interest through static and digital holographics will transform the healthcare industry. Keeping surfaces smooth will allow for easy sterilization, reducing the spread of infection. Having a digital design of the space will allow more customization for graphics and arts catering to a patient's interests or needs. Current hospital art and graphics will not need to be diluted into a one-size-fits-all. Even something as simple as a graphic of an ocean has the potential to calm one person and trigger PTSD in another. Introducing spaces that can change and evolve to the needs of the patients will transform the environment into an interesting space with personality, rather than hoping someone can recover in a diluted environment.

The sustainability impact of this progression will be incredible. Dispersing illumination onto surfaces will drastically reduce the energy consumption required. Illumination will be more of an IV drip plugged into a building's veins providing just the dosage needed rather than the binging and over light (hope it "blends" and dim any mistakes) lighting design of today. MII will have the ability to be homogeneously illuminated and will also have the ability to provide gradients. Gradients can be used to accentuate architectural forms, aide in wayfinding, provide visual depth and interest, and accentuate real or illusioned texture. These enhanced spatial experiences will improve the longevity of our buildings by gaining our favor and love.

A new economic model will be born. Rather than looking toward "first cost," the lighting industry will be boasting lighting designs "Refresh Rate". The Refresh Rate (RR) will indicate to the owner the quantity of building remodels they have purchased in their "first cost" and the quantity of manipulations inherent to the design.

Much like an LED's performance, these refresh rates will exceed expectations as well as comprehensible opportunities. Building owners will have the ability to have an entire remodel at a keystroke. This will revolutionize the hospitality industry. Rather than remodeling every three years, they could change out the space every four days. Rather than stomaching the financial and logistical headache of a remodel as well as the construction waste generated, it will be a programming exercise where the largest challenge will be selecting when to "go live," much like the launch of a website. MII will transform buildings into atmospheres that can change and evolve as freely as any digital domain, when the design boasts a high RR. The waste product will be non-existent, just a saved design setting from a previous era.

How, you ask, is MII actually a light source? MII will be a blend of illuminated threads, quantum dots, small LED's, OLED's, and a mixture of new items not yet invented. MII will be embedded into wall treatments, ceiling tiles, paint, fabric, casework, furniture, and structure. It will have the capability of shifting color, brightness, and be digitally addressable to transform and shift a material's texture. It will have an unlimited amount of variations that can express any style, intention, and texture. The only limit is the artist's imagination.

MII will permeate the lighting industry and be ubiquitous much like corn syrup in American foods. MII info will appear on cutsheets for all building materials along with a materials RR. The higher the RR, the more the materials appearance can shift through programming. The detailing exercise of concealing a light fixture into architecture will be replaced by architecture that is the illumination source. Shifting to MII means that we will be entering an era where Visible Light Fixtures, VLF, will no longer be a requirement. We will be released from the clutches of VLF. When a design does choose to use a VLF, they will be sculpturally beautiful. Designers and owners will no longer tolerate fixtures shaped like antiquated light sources with drivers lobbed on as a functional afterthought. VLF will be a product the younger generations will have never seen and struggle to comprehend, similar to a rotary telephone or fax machine. VLF will be rare and ultimately replaced by Multi- Sensory Sculptures (MSS) which synthesize visual projection, humidity, illumination, scent, and air flow. Why just experience light when we can experience it all? MSS will be little imaginary spaces and a brief release from the pressures of the day-to-day.

The days of a lighting design as an afterthought, or an element applied late in the design are over. Light will be further integrated into architecture, into materials, and into the experience of space. Architectural and lighting design will transform into experiential design and then into multisensory design. Our focus as designers will shift to maximize the experience that finally acknowledges the responsibility we have for the atmospheres we create. In a time when humans spend 90% of our time indoors, merely providing light is not enough. In the next 10 years, we will be Experience Designers, and that is something I cannot wait to experience.

Jackie Kingen, Lighting Designer

Fifty years ago, the innovation that happened in the span of ten years was not as long as it is today. Today, ten years is many lifetimes of invention in the world of lighting and technology. In ten years, we are likely to see a completely new, yet to be discovered technology consume the lighting industry. Carbon nanotube, graphene, and other future-now technologies are in their infancy and have the potential to reshape how light, material, and control are integrated.

In ten years, light will rarely be delivered through fixtures, rather it will be holistically integrated into luminous materials that have replaced wall coverings, ceiling systems, furniture surfaces, and windows. A window will be transparent during the day and emit light at night to the interior of the space. In fact, TOLED technology is almost there now. From our clothing to our homes and places of work and worship, light, technology, and information will permeate the fabric of our existence. Control of these surfaces will be experiential, adaptive, and intuitive to individuals and collectives moving through and existing in architectural space.

Augmented reality will integrate more fully into our lives and allow art, graphics, directions, and information to surround and cater to the unique individual. This is the future of our cities, homes, and public realm. Some of us will live part of our lives in a virtual world, surrounded by the sights we choose and inundated by the mechanizations of those who wish us to stay longer in those worlds.

Just as important, there will be sanctuaries free of electric, nano-luminous, and other digitally integrated systems. These spaces will be home to the flame, the candle, the hearth, the fire ring, and stars. They will be shadow preserves where people disconnect from the matrix of information and exist in harmony with simplicity, their thoughts, nature, and each other. These spaces will be sought out, cherished, and passionately protected.

We must always remember and be reminded that light is as important as the darkness that surrounds it. When our eyes are open, we dance with the light around us. When our eyes are closed, we embrace and submit to the dark. Without one, the other is meaningless.

Zachary Suchara, Principal of Luma and Lighting Designer

As our future is unwritten, the possibilities are limitless. We, the lighting design community, can play a seminal role in transforming possibility into reality. As such, we have a responsibility to make choices and support ideas, tools, and partners who will help us shape the future responsibly, sustainably, and for the betterment of humankind. Technology will continue to evolve, and we must be more than observers of the evolution if integrity, quality, and humanity are to persevere.

Dream big. Act responsibly. Shape your future.

IES Visionary Challenge Judge

Peter Brown: With over thirty years in the lighting industry, Mr. Brown has sales and marketing experience in distribution, manufacturing, auditing, design and installation; both in the C&I and public sector markets. This broad base of knowledge and experience has provided him with insights as a consultant into the challenges, opportunities and implications of the industry's emerging technologies. IES and LC.

Less is More

By Peter Brown

Thank you for the opportunity to comment on IES's Visionary Challenge.

Two phrases come to mind – "If I had more time, I would have said less" and "Less is more". These denote the increased value of less.

"More" as defined in the design field as – more cluttered, more complex, more confusing.

"Less" applies to more simplistic, more profound, more impactful, more appealing.

The challenge from my view is to use the ever increasing complexity of modern day lighting – sources, form factors, locations, color, controls – in the design of the space, just for the sake of the space and it's occupants.

To not get caught up in the technology trap of designing for the latest trend; but using the same to further define each space for it's uniqueness in ways not before possible.

I suggest a way to gain insight and inspiration to this end is to spend several days, at least two to three times a years in a natural setting where light does amazing things. I prefer mountainous escapes – winter, summer, fall. Or the ocean. Or better yet, both. There is just something about motion and light that calms, inspires and completes us. It's part of our DNA.

When I was a pro photographer, the most successful shots on a shoot were often the most simple in design, structure and light. The eye was allowed to follow a smooth path – less complex, less cluttered, less confusing. More simplistic, more profound, more impactful and therefore more appealing.

Now, it usually took a lot of work to find the right location, the right light, the right time of day. The right lens, exposure. But it was there, waiting to be captured.

I encourage you to increase your knowledge of all the tools available, with the goal of putting the space in it's best light, for all to see and enjoy.

So it may be said of your design – that the seemingly less is more, and the more is greater than before.

By 2030: Lighting in a Matured State – Key Solutions for Human Centric Needs

Juliana Parra Henao is an Architectural Lighting Designer and graduate from the University of Wismar, Germany. Her primary focus in conceptualization and design ideation. During her career she has worked in Latin America, Europe, and North America. She earned a bachelor's degree as a "Product Design Engineer" from EAFIT University, Colombia and is an alumni of DAAD, Deutscher Akademischer Austauschdienst—an organization that awarded her a "Scholarship of Arts" to pursue her M.A in Architectural Lighting Design in Germany. Since 2016, she has also been a member of IALD (International Association of Lighting Designers) and in 2019 she was accepted as a NextGEN member in TEA (Themed Entertainment Association). Juliana is Colombian and believes that Lighting Design is one of the strongest resources in helping to transform her country of origin.

Abstract: Light has a direct relationship to our emotions. The way in which spaces are illuminated affects our connection to the spaces themselves, thus rendering light as one of the most powerful influences in our human relation to space. But in trying to understand light and the affects it has on our relationship with the world, we should first examine space itself. Importantly, all spaces exist in of themselves—and thus independent of light. Illuminating them allows us the opportunity to create solid connections with them. Our perception of space is enhanced by light. Space then is revealed to us by the influence of artificial or natural light.

Light is a revelation of our position, both emotionally and geographically, in any one space. It grants us the double-capacity to take a position within our surroundings and to register an emotional comprehension of them too. Lighting Design today is considered to be a fine art—a process by which light renders an area in such a way as to beautify, clarify, and enlighten its various spaces; the application of artificial light, the existence of natural light, and the combination of their effects serve to both express and perceive space. But light can have an even more interesting relationship to the spaces it illuminates. Not only can it reveal construction sites or natural geography, but it can also serve as part of the solution to their holistic outputs. It is perhaps for this reason that in many developed cultures today, the art of Lighting Design has gained such an esteemed reputation. Unfortunately, the intent behind such designs are not as accessible to the common populace in developing countries, which renders the carefully applied application of light meaningless in many intranational projects. In other words, illumination as design takes the role of an inappreciable item. On one hand, wealthy economies recognize that Architectural Lighting Design can improve sites of construction and our relationships to

them. On the other hand, in societies faced by economic hardships, such studies pertaining to light and the impact it has on our relations to space are generally vague.

There has been a notable loss of heritage in recent years. Undoubtedly, this is an arena in which Architectural Lighting Design can intervene, improve, and express what has been lost. The challenge beyond 2030 will be to prove that light has a demonstrative value in cultures around the world, and furthermore, that with a little education in this academic field, anybody can perceive the designers' intentions. Light can and will enhance nations around the globe. But above all, it will assert a primary function: to form and express the identity of peoples. It will be this central element that emphasizes the importance of lighting composition, allowing us to perceive new enjoyments in the spaces we occupy and illuminating our sense of belonging to them. This approach of *inclusiveness* will draw from the concept "Ohne Grenzen" (or "Without Borders", in German). In this way, illumination will have the potential to generate fascinating ancestral memories by visualizing the same spaces from different perspectives (i.e. lighting scenes). And while each perspective will render these spaces in different ways, it is important to note that beauty cannot damage beauty; on the contrary, it preserves it. Light will construct development: it will be the medium that supports the intention of the context; therefore, its purpose will be meaningful and appreciated because it will be an essential part of our backgrounds, infusing them with significance for our communities.

Keywords: Illumination for Human-Centric Needs; The Big Brother Model; USA Illumination in the Global Arena; "Ohne Grenzen" - "Inclusive Design"; Identity-Oriented Lighting Design; Lighting and Technology in Developing Societies; Relationship of Place, Community, Lighting and Local Target; Lighting Scenes, Perspectives and Behavior; Conditions-Based Lighting Design; Domestic Expressions and Collective Goals; Iconic Light in Artworks - National Referent; Connection of Heritage, Culture and Society with Lighting Design; Violence, War or Loss of Patrimony - Lack of Illumination; Europe, North America, South America, Middle East study cases

One Sentence: Heading into 2030, Architectural Lighting Design must be used as a Socio-Economic Resource to Help Transform Developing Nations.

By 2030: Lighting in a Matured State

Key Solutions for Human Centric Needs **By Julia Parra Henao**

To understand how excitement is generated by light, one only needs to imagine how we receive it: it is absorbed by our eyes—thus illuminating the brain—then it continues down through our spines and completes its journey by activating our central nervous systems. As such, light has a direct relationship to our emotional state. Look at the Eiffel Tower for instance, a breath-taking case. In Paris, each hour after dusk and until dawn, the Eiffel Tower is illuminated with many sparkling dots. Any French can tell you that this spectacle has a strong impact on them; the citizens are proud of it. This illumination is an essential part of the tower's composition; it renders a national icon, bringing locals and tourists at larges to a universal, ephemeral state of being. These lighting situations have the capacity to inspire happiness, nostalgia, sadness, or sheer national pride. In other words, light can actually touch us. As a matter of fact, the affects generated by light can often be so strong that they influence people to behave in accordance with its proposed atmosphere. So, artificial lighting is not an added component but an inseparable ingredient of any project. The most important aim in manipulating light is to direct it in such a way as to connect our humanity with the spaces it illuminates, since light beholds the unique capability of transformation.

Light inspires. The sun, moon, stars, lightning, rainbows, darkness, and shadows: each of these is uniquely important to peoples around the world. Even for those that are blind, light allows the possibility to form a mental picture. Light suffuses language; think of music, poetry, or any other narrative medium which waxes about lighting terminologies. Take, for example, the song, "Blind" (*Hercules and Love Affair - NY*). The lyrics deal with the brightness of stars in such a way as to be interpreted figuratively.

"As a child, I knew
that the stars could only get brighter.
That we would get closer…
Get closer…
Leaving this darkness
behind"

As illustrated here, words related with light, such as "brighter" and "darkness" imbue the lyrics with philosophical connotations. Although one cannot literally see *light* in the song, simply hearing about it is enough to illuminate the songwriter's psychological intent. So, light inspires and boosts imagination. This is evident in other arenas too. The United States of America is one of the leading nations insofar as the development of modern applications of light; in particular, it is known for its world-renowned entertainment industry. Take America's theme parks, for example, where the mood of a castle is completely transformed by the application of artificial light. Lighting plays an important role in such a space, imbuing physical environments with supernatural atmospheres; it allows those who interact with these sites to participate in imaginary stories. This phenomenon is not contained solely to theme parks, of course. Lighting Design is actually a significant part of American culture. It creates outstanding scenarios which immerse people. It inspires a sense of inclusiveness and plays a crucial role in telling the story of the United States. The way in which designers choose to light America is a crucial component of its national identity.

Although Lighting Design is one of the most inclusive fields, it cannot derive the "*Big Brother*" phenomenon. That is, imagine the big brother as a developed country and the younger brother as a third-world country. If the Big Brother phenomenon were to take place, then the third-world country would follow the example of the developed one. With Lighting Design, developing countries do often try to follow the examples of more advanced nations, but when these examples are pursued, it can actually make the under-privileged nation weaker; the reason being, their rendering of the examples they attempt to follow are only *lower- quality* projections of worldwide tendencies; there is a weak connection to their own local contexts and, as such, they fail to express their traditions or ways of living. Such explicit mimicry of the big brothers' examples leaves no room for local interpretation. Heading into 2030, we must think of ways to direct lighting so that it enriches domestic expressions and connects people with their own places. As a result, each culture can work with light to achieve their own collective goals based on their own local conditions. Identity-oriented Lighting Design can be integrated into developing communities to support the importance of their own cultures.

For a third world country, illumination could be very useful in targeting a collective national appeal. Lighting atmospheres directed in accordance to a country's local needs can help establish a common vision among its citizenry. That is, light can help a country imagine itself. This socio-political aspect of Lighting Design, if focused on, may drive national governments and investors to pay more attention to illumination, as the designs ultimately serve to validate a human-centric perspective and sense of identity. Even so, the truth remains that many of these economies face much deeper concerns than *giving style* to a building; the socio-political aspect of Lighting Design may not be immediately apparent. It is for this reason then that the challenge heading towards 2030 will be to present the Light as a major resource capable of fulfilling basic human needs—such as a sense of identity and belonging in space. *Illumination in a matured state* will not only meets technical requirements and beautify places; it must also work in parallel to local needs. Take, for example, Colombia, my country of origin. This is a country located in South America that has suffered the cruelty of internal conflict for decades. The government strives for peace, but the persistent conflict is difficult to overcome because of the precarious conditions that many of its citizens live in. When I recently earned by Bachelor's Degree—as a Product Design Engineer at EAFIT University, Colombia—I worked as a freelancer for setting up temporary light installations in “Parque de los Pies Descalzos,” an area in my hometown: Medellin, Colombia. The primary purpose of my job was to create an atmosphere that mimics the feeling of being inside a house. That is, I needed to establish—in the park—a sense of being “home.” This was beneficial to the government as it provided the sense of being in a safe environment. So, even though the park is surrounded by an under-funded neighborhood, many kids visit it. It was very gratifying to see people of all ages interacting with the project I participated in, feeling safe and *at home*. Even at dusk and nighttime, guests felt confident in the park; this sense of confidence was inspired by the careful designed application of lighting. This is the moment when I understood that illumination has the unique potential to inspire harmony in violent places. Visitors were so enthusiastic about this project because they were allowed to discover a completely fresh perspective on a place they had always known and dismissed. In the new mood created by the light, these people actually changed their behaviors; they felt protected by and integrated with their surroundings.

Natural illumination has played a crucial role in the evolution of societies. It has been used as a source of inspiration, as well as a material of construction for centuries. Because Architectural Lighting Design is studied internationally, students and colleagues are able to discuss the different ways in which light has affected their own cultures. According to some of my colleagues, many countries have lost aspects of their cultural heritages due to world events in recent decades. As an example, there are areas located in Yemen that were destroyed in war. This has a direct effect on our field: when a memorable building is destroyed, we miss out on an opportunity to experiment with illumination. That is, if there is not a place to be lit, then there is no need for lighting; not having a work of art to illuminate is like not having a canvas to paint. Lots of old works have been destroyed during this century and all of them could have been illuminated in new ways that refresh our perspectives and connections to them. There are, however, old ruins around the world that remain. In these, we have an opportunity to combine lighting and technology to once more express or update the original intention of the construction, allowing inhabitants to foster new relations with antique sites.

It is important to mention some characteristics about the perception of Lighting Design in developing nations. Ignorance about this field, preceded by a lack of education, results in a weak understanding of the ways in which light is connected to human-centric needs. As such, unique methods of illumination based on intranational conditions are often perceived to be superfluous. This creates two major issues. The first is that illumination outputs suffer from a failure to consider the relationships of such projects to the spaces they're illuminating. The second is that, since these projects are often as expensive as their international referents, the projects' budgets often make investors skeptical about their realizations, paving way for the argument that there are other human-centric issues within their communities that are much more important than the illumination of a construction site. And then there is the universal political tendency to look unfavorably upon the arts. This failure to see Lighting Design as an important element in establishing a sense of identity in developing nations likely derives from the third-world assumption that majestic Lighting Design can only be exclusive to wealthy countries—a "*Big Brother*" luxury, rather than a solution to socio-economic obstacles. As I stated earlier, underprivileged societies follow the paths that the developed countries establish. In these wealthy economies, it is easier to realize the potential of lighting in providing basic human necessities. As such, it is imperative that, by 2030, the USA promotes examples where lighting transcends a purpose beyond the aesthetic and technical domain. If such examples are promoted, this country could play a primarily role as an international model. This is essential because artificial lighting is still not globally recognized for its socio-political potential—or, in other words, a resource to build society. There remains a pervading sense that only experts and peers can appreciate the intentions behind certain lighting designs. Heading into 2030, the realization of "Ohne Grenzen" (No Boundaries) must be spurred so that even the less-privileged regions of the world can deliver distinguished feats of illumination in their own territories. Lighting Design is closely linked to ever-changing technologies. New and improving technologies will be advantageous to developing countries that seek to deliver great projects of their own—illuminating their local spaces and expressing their identities in ways that bring their citizenry to harmony. Imagination, creativity, and technology can be coalesced into a medium which illuminates and expresses the world's many national identities.

To conclude, light modifies the space it touches. It changes works of art and allows those who behold it to adopt fresh perspectives and intuitive excitements. By 2030, light must be recognized as one of the leading resources in our global effort to enhance peoples' lives. Condition-based applications of light can gather communities and elevate their collective human values, permitting them to create wonderful memories and to establish tangible connections with the places in which they belong. Light can make us more emotive, more sensitive, more sentimental. This opens the possibility for us to imagine a more inclusive world. The primary purpose of lighting cannot just be to illuminate works of art in wealthy countries. The primary purpose of light, heading into 2030, must be to extend light's unique medium of expression to all peoples. Light has no limits. It can illuminate regions of earth that have been faced with dark, unfavorable circumstances for too long. Condition-based applications of light will allow us to brighten the darkest scenarios and to fulfill basic human wants.

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Mary Guzowski, Professor, School of Architecture, University of Minnesota

Abstract: A biophilic approach to daylighting, and its integration with electric lighting, provides a strategic method to promote the evolution from low-energy strategies toward net-positive goals that not only reduce fossil fuel consumption and greenhouse gas emissions, but also improve the health and well-being of humans, other species, and the planet. This whitepaper explores the opportunities of using daylighting as a design driver for a biophilic approach to lighting to integrate health and net-positive energy. Biologist and naturalist E.O. Wilson's "Biophilia Hypothesis" suggests that there is an innate need for human connection with nature. The lighting industry and allied design professions must redouble efforts to not only reduce energy consumption and greenhouse gas emissions, but to do so while simultaneously engaging sustainable approaches towards health and well-being. This paper considers how a biophilic approach to daylighting design and integration with electric lighting might fit within a larger sustainable and regenerative design trajectory for the lighting industry and allied design professions.

Keywords: Daylighting, Electric Lighting Design, Biophilic Design, Net-Positive Design

Daylighting as a Design Driver for a Biophilic Approach to Lighting: Integrating Health and Net-Positive Energy

By Mary Guzowski

> “Without positive benefits and associated attachment to buildings and places, people rarely exercise responsibility or stewardship to keep them in existence over the long run. Biophilic design is, thus, viewed as the largely missing link in prevailing approaches to sustainable design. Low-environmental-impact and biophilic design must, therefore, work in complementary relation to achieve true and lasting sustainability.” - *Stephen R. Kellert, et al., architect, author*

FRAMING THE CHALLENGE

In the coming decade, the greatest challenge for the lighting industry and allied design professions is to promote sustainable strategies that reduce energy consumption and thereby mitigate climate change, while also fostering health and well-being. A biophilic approach to daylighting, and its integration with electric lighting, provides a strategic method to promote the evolution from low-energy strategies toward net-positive goals that not only reduce fossil fuel consumption and greenhouse gas (GHG) emissions, but also improve the health and well-being of humans, other species, and the planet.

Over the past decade, lighting innovations (including advances in luminaire performance, solid-state and smart technologies, innovative controls and systems integration, connected lighting systems, and improved performance metrics and guidelines) have led to greater energy performance and comfort. It could be argued that the majority of energy savings through electric lighting efficiency have already been achieved under current codes and technologies for new construction—as James Benya asserts in his article “The Law of Diminishing Returns Catches Up to Our Energy Codes. So What’s Next?”[3] Benya proposes that the focus on energy codes should be directed at reducing energy use in existing buildings: *“It’s time to say for new construction the job is done, and work together to make just as big a difference in the existing building stock as quickly as possible.”*[4] However, as the 2017 United Nations Environment Global Status Report estimates, the global building stock is expected to double by 2060 (**Figure 1**), and therefore it is critical to design for a future with the maximum amount of embodied energy and carbon savings designed into buildings through daylighting and passive architectural design. And as will be discussed below, from a purely economic perspective, the benefits of increased productivity that can be achieved through a biophilic approach to daylighting far exceed the cost savings of maximized energy efficiency.[5] In addition to the energy savings achieved through daylighting and electric lighting advances, there are also important considerations for human health and well-being. Research regarding human responses to light has fostered innovations, such as development of circadian lighting criteria, tunable lamps and systems, expanded color metrics, and improved glare standards. While the lighting industry has focused on electric lighting, parallel innovations in daylighting design are found in advanced glazing technologies, integrated systems and wireless controls, renewable energy integration, circadian daylighting, and evolving daylight performance standards and metrics (Lighting Measurement 83, Spatial Daylight Autonomy, Annual Sunlight Exposure, among others). The benefits of daylighting have focused on energy savings; however significant health benefits of natural light are well documented.[6] These and other lighting developments are reflected in evolving sustainable guidelines such as the *Living Building Challenge, Leadership in Energy and Environmental Design (LEED), and the WELL Building Standard*.[7]

Yet despite the many lighting advances of the past decade, the correlation of energy and climate with health and well-being is still nascent. The lighting industry and allied design professions must redouble efforts to not only reduce energy consumption and greenhouse gas emissions, but to do so while simultaneously engaging sustainable approaches towards health and well-being. It is time to take a fresh look at the essential and expanded role of daylighting in the lighting industry and design professions.

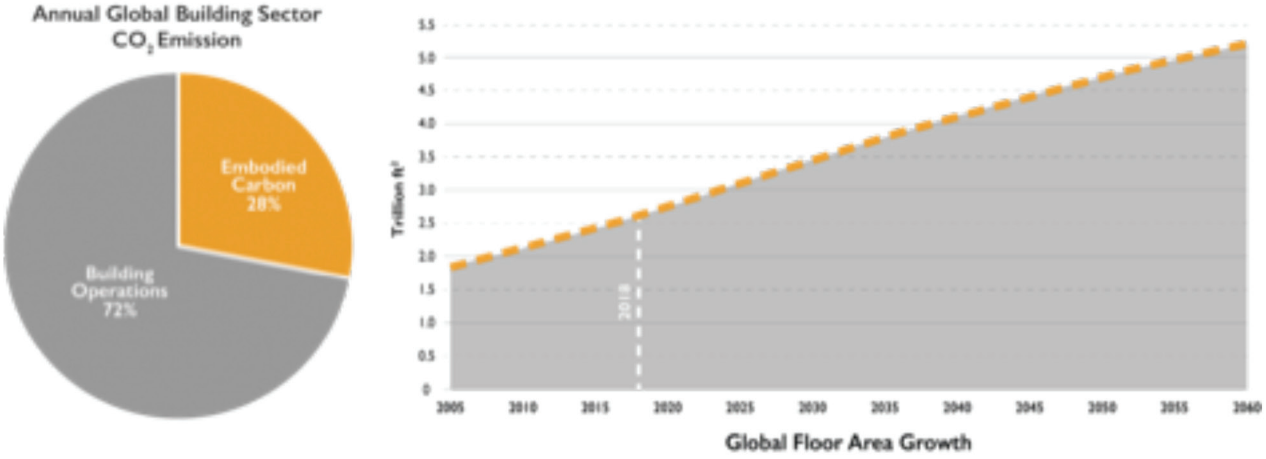

Figure 1: Annual Global Carbon Dioxide Emissions in the Building Sector and Projected Global Floor Area Growth (Credit: Architecture 2030, 2017 UN Environment Global Status Report, International Energy Outlook).

CONCEPT OF BIOPHILIC DESIGN

The concept of biophilia or "love of life" was introduced by psychologist Eric Fromm in his 1973 book *The Anatomy of Human Destructiveness: "Biophilia is the passionate love of life and of all that is alive; it is the wish to further growth, whether in a person, a plant, an idea, or a social group."*[8] Biologist and naturalist E.O. Wilson popularized the term in 1984 in his seminal text *Biophilia: The Human Bond with Other Species*.[9] Wilson's "Biophilia Hypothesis" suggests that there is an "innate emotional affiliation of human beings to other living organisms."10 Over the past several decades, a body of scientific research has demonstrated the physiological and psychological benefits of contact with nature through such elemental factors as views, daylight, materials, gardens, and nature imagery.11

In 2008, Stephen Kellert, Judith Heerwagen, and Martin Mador establish a foundational theory, science, and proposed architectural practice of biophilic design.[12] In doing so, they suggested that biophilia is a missing component of sustainability: *"Without positive benefits and associated attachment to buildings and places, people rarely exercise responsibility or stewardship to keep them in existence over the long run. Biophilic design is, thus, viewed as the largely missing link in prevailing approaches to sustainable design. Low-environmental-impact and biophilic design must, therefore, work in complementary relation to achieve true and lasting sustainability."* [13]

In 2014, the consulting firm Terrapin Bright Green published a resource entitled "Terrapin's 14 Patterns of Biophilic Design" by William Browning, Catherine Ryan, and Joseph Clancy.14 Building on the earlier work of Kellert et al., Terrapin's patterns provide concise and designer-friendly conceptual frameworks, tangible goals, metrics, and strategies to implement biophilic design. The Terrapin patterns will be used in this paper to introduce biophilic daylighting strategies that work toward net-positive goals by reducing energy and GHG emissions, while promoting health benefits such as circadian entrainment, access to views, and physical connections to nature and natural forces.

BENEFITS OF BIOPHILIC DESIGN

A growing body of research demonstrates the mental benefits of biophilic design, including improved cognitive functioning, mental agility, memory, and learning; the psychological benefits for concentration, lower tension, and reduced anxiety; and the physiological responses of muscle relaxation, lowered diastolic blood pressure, and reduced stress hormones, among others.[15] *Biophilic design also provides economic benefits, as shown in Terrapin Bright Green's report The Economics of Biophilia: "Biophilic design has often been regarded as a luxury for property owners who want the best possible workplace for their employees, or who want to showcase their efforts to be more environmentally responsible. In reality, improving community well-being through biophilia can impact productivity costs and the bottom line…. Today productivity costs are 112 times greater than energy costs in the workplace…incorporating nature into the built environment is not just a luxury, but a sound economic investment in health and productivity."*[16]

Daylighting design health benefits and economic savings include enhanced productivity, improved satisfaction, and decreased absenteeism: *"Integrating quality daylighting schemes into an office space can save over $2,000 per employee per year in office costs, whereas over $93 million could be saved annually in healthcare costs as a result of providing patients with views to nature…. Whether it is hospitals that allow patients to heal more quickly, offices that boost productivity, schools that improve test scores, or retail outlets with higher sales."*[17] In *Human Spaces: The Global Impact of Biophilic Design in the Workplace* by architect Bill Browning and Professor Sir Cary Cooper, et al., a study of 1600 employees in 16 countries around the world further confirm the essential role of daylighting to realize the benefits of biophilic design.18 The quality of daylighting and its connection to biophilic strategies for views, visual relief, and access to natural forces was a "crucial determinant" of well-being, productivity, and creativity.[19]

At the same time, a growing body of research on circadian lighting has further defined the visual and nonvisual circadian health benefits of daylight, with advances in electric lighting strategies supporting these benefits. The Lighting Research Center at Rensselaer Polytechnic Institute emphasizes the health benefits of exposure to natural light and the subsequent health risks of disruptions to human circadian rhythms: *"Circadian rhythms are biological rhythms that repeat approximately every 24 hours. Exposure to the natural sunrise and sunset synchronizes our circadian rhythms to exactly 24 hours. Circadian disruption…have been associated with increased risks for breast cancer, diabetes, obesity, heart disease, sleep disorders, and other ailments…. LRC researchers coined the term 'circadian light' as spectrally weighted retinal irradiance that stimulates the human circadian system. The definition of circadian light is based upon the potential for light to suppress melatonin synthesis at night."* [20]

The electric lighting industry has applied this growing body of circadian research and science to many facets of lighting design and technologies, particularly tunable lighting to simulate the changing color and luminous intensity of daylight with electric light sources." For example, a recent study by the U.S. Department of Energy found positive benefits of tunable LED lighting for nursing care residents with dementia to improve sleep and reduce agitated behaviors: *"Research suggests that lighting color and pattern of intensity that mimic natural daylight over the course of the day can improve circadian rhythm entrainment and health outcomes…. Results suggest that tuned lighting had a positive effect on residents' sleep."*[21]

CIRCADIAN DAYLIGHTING

While circadian lighting - a relatively new and evolving area of research - has been focused primarily on electric lighting, daylighting is also important for circadian well-being. In the article "Circadian Daylight in Practice" by Emilie Hagen and Henry Richardson from the environmental design firm Atelier Ten, they discuss a series of studies that successfully combined daylighting assessment tools (Radiance through

DIVA for Rhino, Grasshopper, and Honeybee) to conduct daylight circadian simulations using the WELL Building Standards. As environmental consultants, they encourage designers to consider daylighting as the first approach to circadian lighting: *"Though designers are beginning to look to electric lighting to provide improved circadian function, the first step in designing to support circadian system function should be to ensure access to daylight through massing and façade optimization…. If daylight is not available or sufficient, electric lighting can be used to provide circadian stimulus, but requires additional energy and has a greater first cost."*[22] Hagen and Richardson also conclude that health criteria are not independent of other daylight and energy metrics: *"The proposed circadian daylight analysis methods easily integrate into the design process to assess circadian daylight potential, but do not holistically address the full range of daylighting concerns in a project. Circadian daylight simulation should be used early in the design process, but must be coupled with traditional daylight analysis to evaluate illuminance levels and glare potential throughout the year. Because the proposed simulation methods look at such a narrow issue, the impact of design decisions based on circadian daylight need to be assessed in relation to potential for increased energy consumption from conditioning energy, visual glare potential, and useable daylight."*[23] In *Biophilia and Healing Environments*, Catherine O. Ryan, biophilic design expert at Terrapin, raises a parallel question regarding biophilic design metrics and what can and cannot be quantified and measured: *"So often industry insists upon the perfect quantitative metrics against which to measure design effectiveness, but perhaps we should instead be using rules, and the like, as contextually qualitative metrics. It is the quality of the space, as we have learned, and less so its size or quantity, to which we are viscerally responsive."*[24]

Daylighting to Integrate Health, Energy, and Climate

In considering energy as just one dimension of sustainability, the shift from low-energy to zero-energy, and now to net-positive energy, has also raised the aspirational bar for the lighting industries and allied design professions to consider not only economic and human benefits, but also broader ecological impacts. For example, in the 1990s, the concept of a "living building" emerged as a counterpoint to incremental improvements found in many green and sustainable rating systems. In 2006, the *Living Building Challenge (LBC) 1.0* standard introduced the aspirations for "net-zero" energy, water, and waste as well as focusing attention on issues such as beauty and equity.25 In 2009, "biophilia" was first cited in the *LBC 2.0* standard. In 2014, the International Living Futures Institute (ILFI) introduced *LBC 3.0,* which included a shift from "net-zero" to "net-positive" energy, water, and waste. Building on Kellert's biophilic strategies, the ILFI recently published the *Biophilic Design Guidebook* and Amanda Sturgeon's *Creating Biophilic Buildings*.[26, 27] The current LBC 4.0 could be further developed and integrated to reveal the inter-relationships and trade-offs between these design issues and broader ecological impacts.

An emerging area of research on the integration of biophilic design, health, and climate metrics is discussed in the publication "Biophilic Design and Climate Change," by Julia Africa, et al. which suggests that biophilia can serve as an "interstitial tissue" that connects varied ecological scales and issues: *"The best applications of biophilic design may be distinguished from other projects by their ability to synergistically integrate the building, site, and occupants through the creation of comprehensive 'habitat.' Habitat, in this context, encompasses the materials, structure and program of the building...a recognition that these features communicate habitability and community to human occupants through eons of evolutionary priming, and that this appeal is both desirable, comfortable, and health promoting."* [28]

Another recent article "The Slope of Circadian Enlightenment" by Colleen Hufford and Kelly Seeger also suggests that it is time to shift from the lighting industry focus on energy efficiency towards health and well-being.[29] They support an aggregated approach to energy performance standards for lighting: *"The lighting industry has achieved very highly efficient, consistently well-performing, safe lighting products at all market levels and in all segments, so the time has arrived to now focus on regulating the actual energy outcomes for buildings and considering the contribution of building systems in aggregate. We should move away from installed power and adopt whole-building energy use intensity (EUI) strategies that regulate all building energy from occupant amenity loads (e.g., lighting, HVAC) to process loads (e.g., office equipment, industrial machinery) to miscellaneous electric loads and plug loads."*[30]

Despite the complexity and challenges of integrating health, energy, climate strategies, standards, and metrics, it is only through such an integrated approach that these parallel advances and innovations in the lighting industry and allied design professions will foster ever-higher sustainable and regenerative design performance. Simultaneously considering health and climate-change metrics will expand a human-centered approach to lighting to also include ecocentric insights into lighting impacts on other species and the planet.

DAYLIGHT AS A BIOPHILIC DESIGN DRIVER

Positioning Daylighting and Biophilia within the Regenerative Design Trajectory

The definition of sustainable development in the 1987 Brundtland Commission report *Our Common Future ("sustainable development meets the needs of the present without compromising the ability of future generations to meet their own need")* has evolved from "sustainability" towards "regenerative design", as discussed in essays by John Tillman Lyle; Ray Cole et al.; Pamela Mang and Bill Reed, Julia Africa et al.[31, 32, 33, 34] This evolution is well illustrated in Reed's "regenerative design trajectory" (**Figure 2**).[35]
This diagram reveals a spectrum of "degenerating" to "regenerating" design practices, and positions "biophilia" as nesting within a larger cluster of design strategies such as biomimetic and restorative strategies to "affiliate, mimic, and restore" nature. [36]

NET-POSITIVE DESIGN AND THE PASSIVE POTENTIAL OF DAYLIGHTING

Building operations account for 28% of annual global carbon dioxide emissions.[37] Daylighting, electric

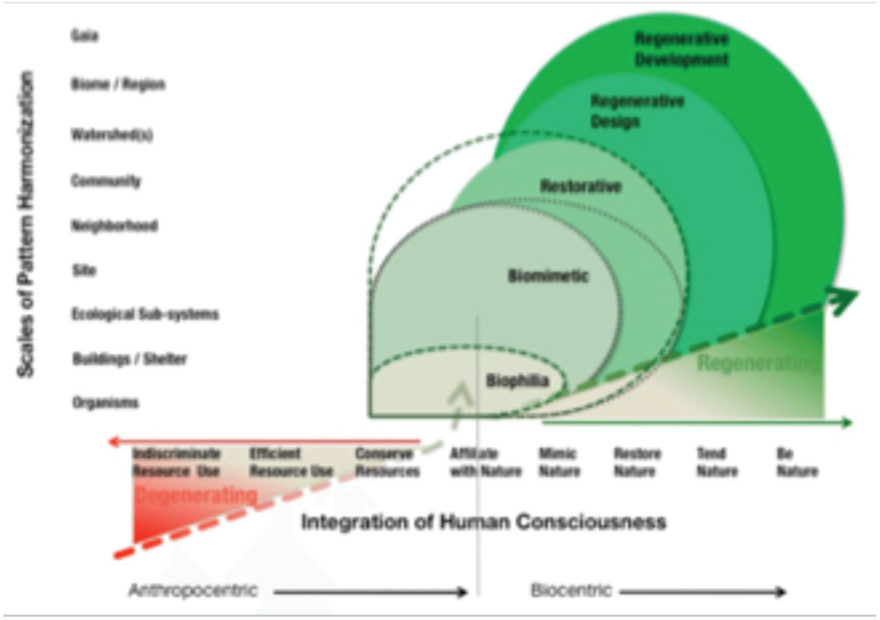

Figure 2: Regenerative Design Trajectory (Credit: Bill Reed, Regenesis Group: "Regenerative Development and Design").

lighting technologies, and improved energy standards and metrics have all contributed to an 18.9% reduction in emissions since 2005.[38] In the past two decades, we have seen the design professions strive to not only meet zero, but to move towards net-positive energy. This aspirational target continues to challenge designers toward ever-higher standards and more effective strategies. In 2002, architect Ed Mazria made an impassioned call to the design professions and allied industries to adopt the *Architecture 2030 Challenge*, a global initiative to achieve "carbon neutrality" by GHG emissions in "new buildings, developments, and major building renovations" by the year 2030.[39]

The 2030 timeline has recently been extended by a decade to an initiative entitled *Zero by 2040*. The 2040 target includes strategic goals, strategies, and assessment tools for new and major renovations of existing buildings to support the goal of the Paris Agreement to limit the global temperature increase by *1.5 degree C* over the next two decades.[40] The global *Zero by 2040* target couples architectural design with innovative technologies and systems by proposing the following "energy design hierarchy": 1) apply low/no cost passive design strategies to achieve maximum energy efficiency, 2) integrate energy efficient technology and systems, and 3) incorporate on-site and/or off-site renewable energy to meet the remaining energy demands (**Figures 3** and **4**).[41]

Unless there is an agreement that the "energy design hierarchy" is an effective strategy towards zero and net-positive energy, it may be easy to dismiss a biophilic approach to daylighting as beyond the scope of the lighting industry. Some may argue that daylighting is best suited for new construction

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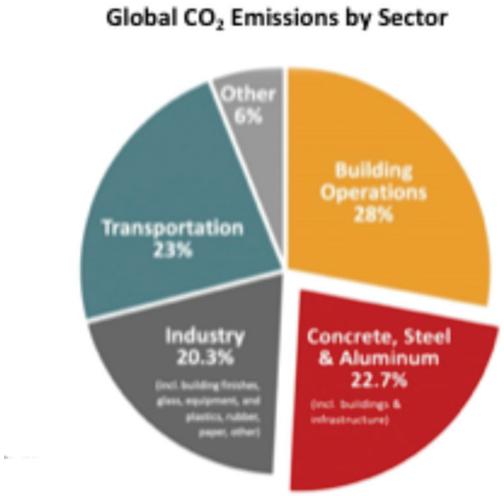

Figure 3: Global Carbon dioxide emissions (Credit: Architecture 2030; Source 2018 Global ABC Report, IEA).

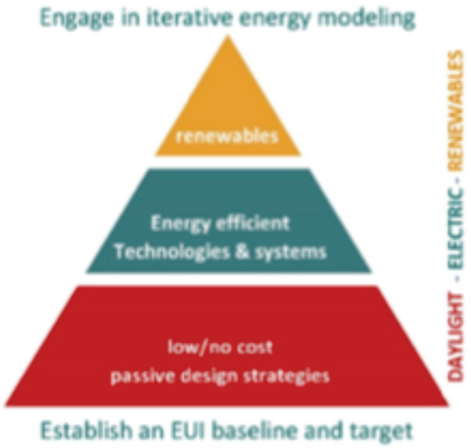

Figure 3: Net-Zero Energy Design Hierarchy (Credit: Author, based on "Zero by2040", Architecture 2030).

and not impactful enough given current construction trends, that daylighting retrofits are too as costly, or that there would be only minor benefits for climate and health. Yet, as Mazria argues, the "2040 hierarchy" (passive design strategies such as daylighting, natural ventilation, and solar heating) should be the first order of lighting design, and passive strategies can be applied to both new construction as well as existing building renovations.[42]

EXPLORING DAYLIGHTING FROM A BIOPHILIC PERSPECTIVE

The potential of daylighting as a design driver for a biophilic approach to lighting that integrates health and net-positive energy is revealed through the lens of *Terrapin's 14 Patterns of Biophilic Design* (**Table 1**). Many of Terrapin's "patterns" draw direct biophilic connections between daylighting, passive design, and net-positive energy, including: site design; building form and orientation; section, room form, zoning, window size, window placement, spatial organization, finishes, detailing, and envelope design. A direct biophilic relationship between daylight, health, and net-positive is found in at least five of Terrapin's Patterns: #1) Visual Connection with Nature, #3) Non-rhythmic Sensory Stimuli, #4) Thermal and Airflow Variability, #6) Dynamic & Diffuse Light, and #7) Connection with Natural Systems. Each remaining pattern has at least an indirect relationship to support the health and energy benefits of daylighting through form, materials, or experiential qualities.

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24. Nikos A. Salingaros, 7.
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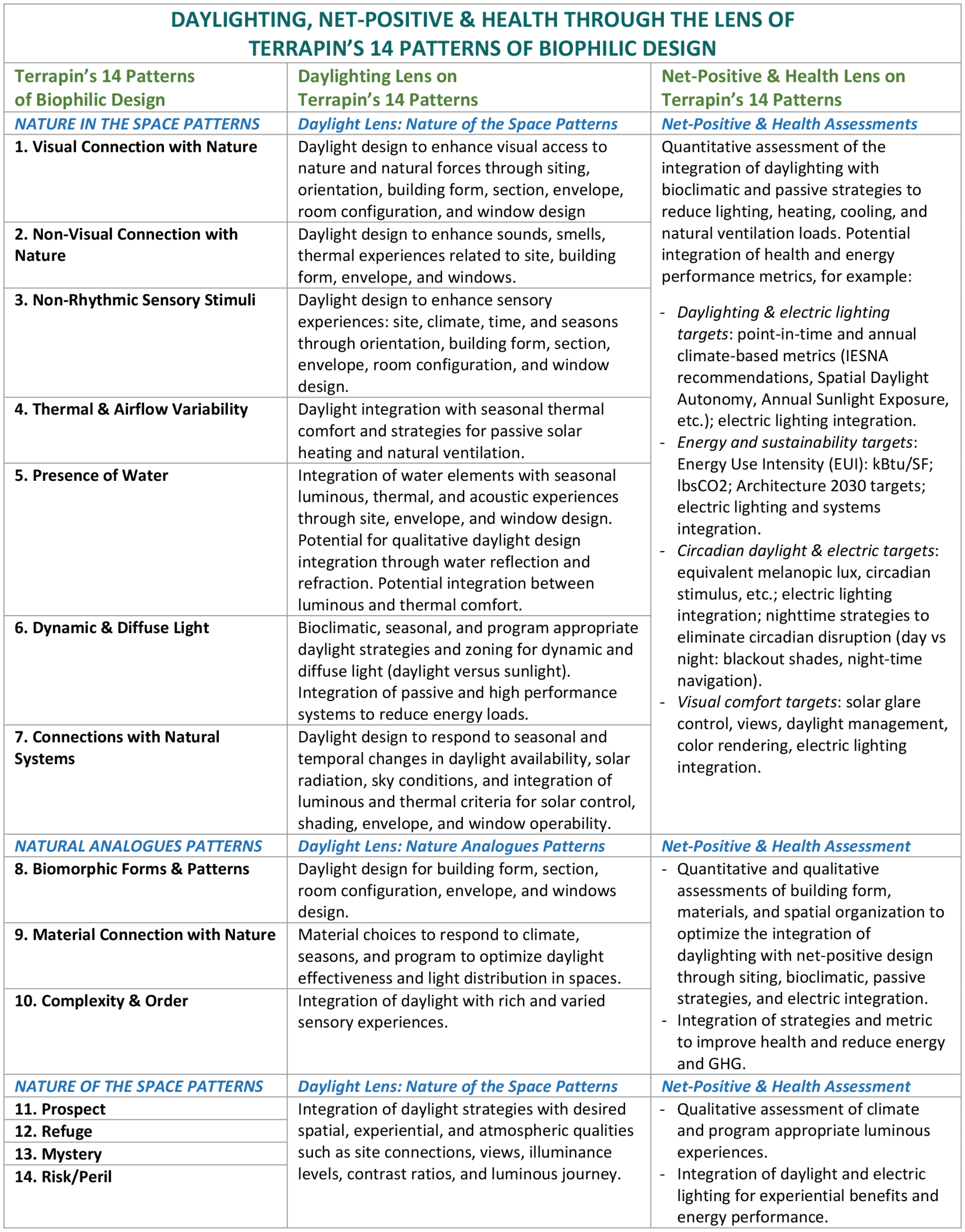

DAYLIGHTING, NET-POSITIVE & HEALTH THROUGH THE LENS OF TERRAPIN'S 14 PATTERNS OF BIOPHILIC DESIGN

Terrapin's 14 Patterns of Biophilic Design	Daylighting Lens on Terrapin's 14 Patterns	Net-Positive & Health Lens on Terrapin's 14 Patterns
NATURE IN THE SPACE PATTERNS	*Daylight Lens: Nature of the Space Patterns*	*Net-Positive & Health Assessments*
1. Visual Connection with Nature	Daylight design to enhance visual access to nature and natural forces through siting, orientation, building form, section, envelope, room configuration, and window design	Quantitative assessment of the integration of daylighting with bioclimatic and passive strategies to reduce lighting, heating, cooling, and natural ventilation loads. Potential integration of health and energy performance metrics, for example: - *Daylighting & electric lighting targets*: point-in-time and annual climate-based metrics (IESNA recommendations, Spatial Daylight Autonomy, Annual Sunlight Exposure, etc.); electric lighting integration. - *Energy and sustainability targets*: Energy Use Intensity (EUI): kBtu/SF; lbsCO2; Architecture 2030 targets; electric lighting and systems integration. - *Circadian daylight & electric targets*: equivalent melanopic lux, circadian stimulus, etc.; electric lighting integration; nighttime strategies to eliminate circadian disruption (day vs night: blackout shades, night-time navigation). - *Visual comfort targets*: solar glare control, views, daylight management, color rendering, electric lighting integration.
2. Non-Visual Connection with Nature	Daylight design to enhance sounds, smells, thermal experiences related to site, building form, envelope, and windows.	
3. Non-Rhythmic Sensory Stimuli	Daylight design to enhance sensory experiences: site, climate, time, and seasons through orientation, building form, section, envelope, room configuration, and window design.	
4. Thermal & Airflow Variability	Daylight integration with seasonal thermal comfort and strategies for passive solar heating and natural ventilation.	
5. Presence of Water	Integration of water elements with seasonal luminous, thermal, and acoustic experiences through site, envelope, and window design. Potential for qualitative daylight design integration through water reflection and refraction. Potential integration between luminous and thermal comfort.	
6. Dynamic & Diffuse Light	Bioclimatic, seasonal, and program appropriate daylight strategies and zoning for dynamic and diffuse light (daylight versus sunlight). Integration of passive and high performance systems to reduce energy loads.	
7. Connections with Natural Systems	Daylight design to respond to seasonal and temporal changes in daylight availability, solar radiation, sky conditions, and integration of luminous and thermal criteria for solar control, shading, envelope, and window operability.	
NATURAL ANALOGUES PATTERNS	*Daylight Lens: Nature Analogues Patterns*	*Net-Positive & Health Assessment*
8. Biomorphic Forms & Patterns	Daylight design for building form, section, room configuration, envelope, and windows design.	- Quantitative and qualitative assessments of building form, materials, and spatial organization to optimize the integration of daylighting with net-positive design through siting, bioclimatic, passive strategies, and electric integration. - Integration of strategies and metric to improve health and reduce energy and GHG.
9. Material Connection with Nature	Material choices to respond to climate, seasons, and program to optimize daylight effectiveness and light distribution in spaces.	
10. Complexity & Order	Integration of daylight with rich and varied sensory experiences.	
NATURE OF THE SPACE PATTERNS	*Daylight Lens: Nature of the Space Patterns*	*Net-Positive & Health Assessment*
11. Prospect	Integration of daylight strategies with desired spatial, experiential, and atmospheric qualities such as site connections, views, illuminance levels, contrast ratios, and luminous journey.	- Qualitative assessment of climate and program appropriate luminous experiences. - Integration of daylight and electric lighting for experiential benefits and energy performance.
12. Refuge		
13. Mystery		
14. Risk/Peril		

Table 1: Daylight as a design driver for biophilic lighting using Terrapin's 14 Patterns of Biophilic Design (Credits: Left column: Terrapin Bright Green: Terrapin's 14 Patterns of Biophilic design. Center and right columns: Author).

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CONCLUSION: DAYLIGHTING AS A DESIGN DRIVER FOR A BIOPHILIC APPROACH TO LIGHTING

Daylight is a dynamic environmental phenomenon and an ephemeral architectural material. It embodies the dimension of time as the movement of light and shadow reveal the changing diurnal and seasonal cycles. In a digital age that runs 24/7/365, daylight is an antidote to our increasing alienation from nature. The varied and changing material and atmospheric effects of daylight can awaken the senses and further enhance our understanding and relationship to the world in which we live. Daylight and the changing environmental forces of sun, wind, and weather help us to know “where we are” and “who we are” by rooting us in the ecological phenomena of a particular place, in that climate, and on that site. Continued collaboration between the lighting industry and allied design professions will play a critical role in achieving the next generation of daylighting and electric lighting integration. When coupled with biophilic and net-positive strategies for electric lighting, passive solar, and bioclimatic design, daylight can reduce energy consumption and provide ecological benefits while enhancing comfort, health, and well-being for humans, other species, and the planet.

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Residential Lighting in 2030

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Abstract: As people spend a significant - and increasing - amount of time at home, residential lighting is likely to build on current trends and continue becoming increasingly accessible, personalized, and human-centric. In this article, we discuss four ways that we believe these trends will advance by 2030. These include sophisticated circadian lighting; smart lighting environments; rising residential energy savings; and new design possibilities, including augmented reality.

Key words: circadian health, augmented reality, personalized lighting, energy savings.

Main takeaway: In 2030, we envision homes equipped with circadian lighting that supports residents' health and well-being, delivering personalized lighting that can be controlled through smartphones and voice assistants, as well as new, emerging design possibilities and the fusion of illumination and video - all of which will continue to drive down energy use.

Residential Lighting in 2030

By Regina Vaicekonyte, Veronika Foldvary Licina, Carolyn Swope, Shengliang (Daniel) Rong

Nowadays, we spend the majority of our time indoors, and about 69% of our time at home1 making residential lighting a significant sub-sector of the overall lighting industry. And this number may go even higher with work from home more common after the Covid-19 pandemic. With more time and activities spent at home, a human-centric living environment that is more accessible and personalized, supported by multiple technological advances—such as circadian lighting, smart home/IoT, and pixelated solid state lighting technologies such as micro LEDs, offering flexible design and augmented reality potential—may become more desirable to consumers. These trends are already beginning to transform the industry, and we predict them to continue to grow, shaping the state of residential lighting that we envision for 2030. Below we briefly outline the major changes we anticipate for this coming decade.

1. CIRCADIAN LIGHTING

As the industry and consumers become more aware of light's role in regulating our circadian rhythms, affecting sleep patterns and long-term health, lighting that supports circadian health and overall well-being will become a priority in residential environments. People will choose white/spectrum tunable lighting that can adjust brightness and color to match their different personal circadian needs,[3] and offerings will grow in sophistication with our deepening understanding of the interindividual differences in circadian response.[4, 5] Indeed, the human-centric lighting market is predicted to exceed $6 billion by 2025,[6] likely growing well beyond that by 2030 if the current growth trends continue.

2. SMART, IOT-ENABLED LIGHT ENVIRONMENTS

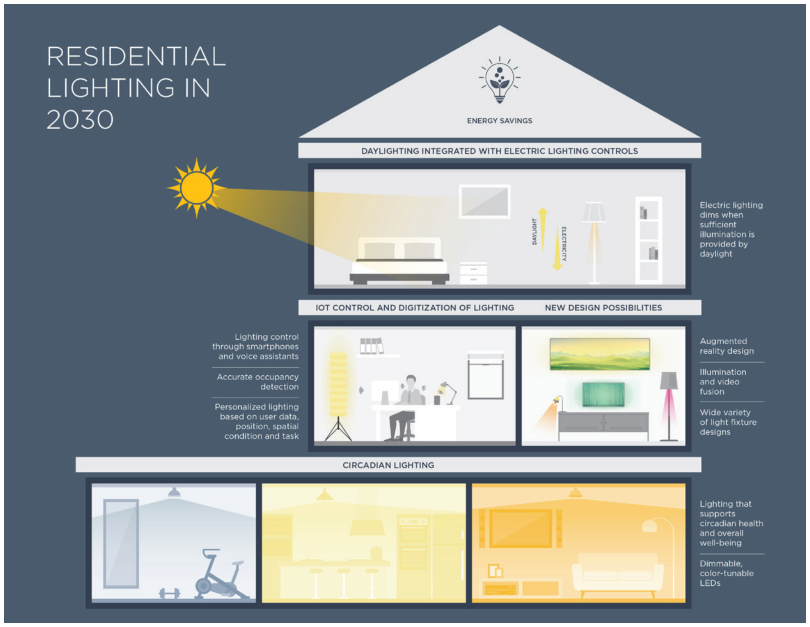
The growing global intelligent building automation technologies market is predicted to reach $103.7 billion by 2025,[7] and over the next decade, the lighting industry will become fully digitized,[8] including light sources, sensors, LED drivers and control systems.[9] The vast majority of devices that control our indoor environment—from ones that do not relate to lighting, such as speakers and HVAC systems, as well as lighting-related ones, such as LED fixtures and shades—will be smart and IoT-enabled, allowing end users to control all the parameters using smartphones and voice assistants, whether at home or away.[10] Adjustments to one's personalized lighting environment based on individual factors such as age, health status, sleep quality, position and activities is achievable via data collected from wearables, dynamic detection of occupancy (enabled by technologies like LiDAR or Visible Light Communication), and daylight sensing.

3. UBIQUITOUS RESIDENTIAL ENERGY SAVINGS

The LED market will continue to mature, making LEDs ubiquitous: indeed, the general service submarket is predicted to consist almost entirely of LEDs, and the installed stock penetration in the residential market is forecasted to be 73% by 2030.[11] While energy savings are no longer the main driving force behind lighting innovation, there will continue to be a decline in energy use because of the widespread LED use and strategies such as daylighting integration with electric lighting controls.[12] The US Department of Energy predicts that by 2030, LED lighting will help reduce residential energy consumption by 42% (relative to 2013).[13] Other than direct energy savings from efficient light sources, further savings can be achieved via a more personalized and precisely-targeted lighting supply supported by smart/IoT control and advanced sensing—which reduces unnecessary lighting use when residents do not need it.

4. BOUNDLESS DESIGN & AUGMENTED REALITY EXPERIENCE FOR HOME LIGHTING

Since traditional light bulbs as point sources offer a limited variety of form factors, the wide adoption of LED lighting offers enormous design flexibility for our homes. If cost drops, further adoption of screen technologies like OLED and micro LEDs will continue to offer more flexibility for home lighting design—potentially transferring lighting from ceiling to all indoor surfaces, which will enable new opportunities for Augmented and Mixed Reality experiences powered by the fusion between media/content delivery and illumination.[14, 15] Eventually, due to their high output, small size, and much lower energy consumption, micro LEDs will make current LCD/OLED technology obsolete.[16, 17]



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Douglas Steel, PhD is the Founder and Chief Scientific Officer of NeuroSense. For the past several years he has been working on the development of spectrally-tunable LED lighting arrays, which can be used as an alternative to prescription drugs for the treatment of a number of neurological and psychiatric conditions. He is also a serial entrepreneur, having founded or co-founded and managed 6 technology start-up companies over the past 17 years in a number of life science areas. Doug has over 30 years of experience in pharmaceutical drug design and discovery, and research project management and implementation divided between academia and the pharmaceutical industry. He has received training in medical sciences and neuroscience, theoretical and applied biotechnology, integrative neuroscience, and brain-environment interactions. He is the author of over 20 publications in scientific journals and books in the areas of drug design, drug discovery, and marine biochemistry. He has also written over 30 technology articles in the popular press. Doug was an NIH postdoctoral research fellow in the Neuroscience Program at the University of Utah. He holds a PhD (Biomedical Sciences, Columbia University), an MPhil (Pathology, Columbia), an MS (Psychobiology, U of Florida, and a BA (Biology, Kalamazoo College). He also held pharmaceutical research positions at The Upjohn Company, CIBA-Geigy, and Syntex Pharmaceuticals. In other ventures, Doug is also the Creative Director of DaVinci's Workshop Inc., a technology development and product design and prototyping studio. He is responsible for identifying market opportunities, and managing the research and commercial development of new products and applications.

Keywords: Healthcare, Wellness, IoT platform

One-Sentence Takeaway: Tuned lighting will enter the mainstream of healthcare to address many medical and wellness conditions, as part of a platform including sensors, IoT, and Cloud or Mesh data management and analysis.

Beyond 2030

By Douglas Steel

During the 2030's new lighting technologies will be developed that provide the proper light exposure when tuned to a specified set of parameters, customized to the needs of individual patients and for specific health indications or conditions. We already have most of the necessary bits and pieces to create such systems. The limitation to implementation is the absence of validated business cases that establish the cost/benefit of installing tunable multi-channel spectral arrays ("how do we save money or make money"?). Technology adoption takes time, and while "early adopters" will embrace light exposure platforms during the late 2020's, it won't reach general market acceptance until the 2030's when healthcare institutions figure out how to monetize and integrate these platforms into their facilities. At present the lighting industry is still largely trying to "push" lighting products and controls into the healthcare sector; during the 2030's as a result of the recognized value and effectiveness of phototherapy applications lighting will be perceived as a complementary, mainstream healthcare modality and healthcare providers will "pull" products and solutions into their facilities. The companies that are successful in this market will be primarily health management companies that utilize lighting as a form of treatment, rather than lighting manufacturers still trying to push their way in. At this time, every patient and treatment room in most healthcare facilities can be expected if not required to implement circadian health practices utilizing spectrally-tunable lighting platforms for patient care and staff (esp. 3rd shift) wellbeing.

Moving into the 2030's we will (hopefully) overcome our non-visual pathway ipRGC "fixation" on Circadian "control" and regard it instead as a modulatory system that influences numerous normal functions and neuro-pathologies and psycho-pathologies including:

1. Sleep[1]
2. Migraine and other types of headache[2]
3. Mood and emotional responses[3]
4. Depression[4]
5. Arousal and alertness[5]
6. Sensory processing in conditions including Dyslexia, TBI, PTSD, and Boredom.[6]
7. Immune system function and "robustness"; healing and recovery rates.[7]
8. Pain management[8]
9. Metabolic Syndrome[9]

We will of course develop a deeper understanding of the non-visual pathways in the brain, and what they do. However, in order to become a legitimate health care modality, a healthcare lighting platform will need to operate as a semi-autonomous (i.e., self-tuning) feedback platform consisting of the following:

- A tunable light source (operationally defined as an LED array consisting of 5 or more independently-adjustable channels),
- sensors,
- unique patient identification (eg., RFID tags) to account for individual variability[10],
- a control system capable of not only creating appropriate spectral output but adjusting exposure parameters including intensity, duration, and timing.
- Utilization of validated biomarkers that are correlated to specific health conditions and inform how the platform is appropriately tuned.

Other developments occurring during that decade will include:

- Identification of new clinical tests that validate the health effects of light, including:
  - Real-time measurement of gene expression markers[11]
  - circulating RNA markers[12]
  - Proteomic panels[13]
  - immune system cytokine and immunoglobin panels on a chip[14]
  - neurological assessments based on Autonomic activity[15].

- Changes in the healthcare system will support new HCL trends including care-in-place[16], reimbursement for quality and outcome of care[17], and concierge healthcare[18].

- LAAS subscription models in which “light recipes” are delivered over a network to tune light to the needs of specific individuals.

- AI integrated with lighting controls will be aware of patient health status, medical history, and medications taken, and make changes based upon anticipated patient care needs.

- Late in the decade, pediatric medicine will be enhanced with light exposure protocols.

- The FDA will establish regulatory guidelines for the uses of light exposure for defined clinical outcomes.

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Biological Implications of Artificial Illumination

By Richard J. Wurtman

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There can be little doubt that man's visual system provides him with critically important information about his environment. The individual who cannot perceive light and its reflections suffers an immense disadvantage; in the civilized world he is cut off from the written word, unable to use most tools, and poorly oriented; in the world of Nature his very survival is in constant jeopardy. The obvious significance of light in providing the substrate for vision has tended until recently to obscure the fact that light also exerts important biologic effects which are not dependent upon vision. Some of these effects of light are, like vision, initiated by responses of specialized photoreceptor cells in the retina. The photic input is transduced to nerve impulses which, instead of traveling to visual centers in the brain, terminate in brain regions that control glandular function. Other biologic effects of light result from direct effects of photic energy on the skin and the subcutaneous tissues. This report will summarize the former, neuroendocrine effects of light, and will comment on the latter. his report will summarize the former, neuroendocrine effects of light, and will comment on the latter. Recent experiments will be described which indicate that highly specialized pathways have evolved in the brain to mediate the extravisual effects of light. The implications of these biologic consequences of light for the design of artificial light source will be considered.

The Effects of Light on Glandular and Metabolic Functions

Environmental illumination acts as both an inducer and a timer of glandular and metabolic functions.[1] Light (or its absence) induces or "turns on" the development of the gonads and the secretion of certain hormones. Thus, puberty develops earlier than nor mal in blind girls,[2] and later than expected in the blind laboratory rat,[3]-a difference which may be related to the fact that humans are active diurnally, while rats are a nocturnal species. Darkness stimulates and light inhibits the production of hormones such as melatonin which are made in the pineal gland.[4] Sudden exposure of human subjects to a bright light causes hydrocortisone to be released from the adrenal gland.[5] Annual cyclic changes in the per cent of the 24-hour day represented by day light, and the daily cycle of day and night serve as timers, or "time-givers." These cycles synchronize a large number of biologic rhythms of similar perio dicity which are probably generated by inborn "biologic clocks" in the brain. For example, all mammals appear to show daily rhythms in body temperature. This rhythm persists with a periodicity of about 24 hours in the absence of day-night cycles. However the times of day associated with maximum and mini mum body temperatures can easily he shifted in the normal individual by varying the hours of the daily light period.[1]

INDUCTIVE EFFECTS OF LIGHT: SEXUAL DEVELOPMENT

Four decades ago, W. Rowan, a Canadian biologist, first drew the attention of the scientific community to the ability of environmental lighting to induce or modify changes in gonad function in animals.[6] It had been recognized that the gonads of most birds showed marked changes in weight as a function of time of the year; normally, the testes were largest during the spring and summer, and smallest during the winter. Rowan showed that the annual period of testicular growth in the junco finch could he made to occur prematurely, in the middle of the Canadian winter, by gradually increasing the number of hours each day that captive birds were exposed to artificial lighting. Control birds, which lived in “Riviera-like California,” did not develop sexually until springtime. Several years later, Bissonette[7] showed that extra light could also induce a state of premature estrus in a mammal, the ferret, and Baker and Ranson[8] demonstrated that this effect of light on the field mouse was not the result of changes in ambient temperature, humidity, or foodintake.

The ability of light to modify gonad function had been recognized for some time: Dutch and Japanese farmers traditionally exposed song birds to extra illumination in the fall in order to induce singing-a behavioral consequence of testicular stimulation-in the winter.[1] However, the demonstration that environmental lighting could specifically stimulate the gonads was of great importance in the history of endocrinology. It proved that the pituitary gland and the gonads were not related solely as a closed feed back system, but were also profoundly influenced by the external environment. It now became necessary for physiologists to characterize the biological ma chinery through which information about light was received by the body and translated into an endo crine message. It is now generally agreed that light activates photoreceptors which are connected to neu ral elements, and that special neuroendocrine organs must then transduce the resulting nervous stimuli into endocrine information. Four decades after Rowan, it seems clear that light is the most important environmental input, after food, in controlling bodily function.

In 1934, Hill and Parkes,[9] and F. H. A. Marshall and Bowden[10] showed that although extra light could hasten the onset of estrus in the ferret, light was not a prerequisite for normal sexual maturation, in as much as animals kept in ·constant darkness came into estrus (i.e. full ovarian function) at approximately the same time of year as those kept in natural lighting. Subsequently, it was shown[11] that the gonads of blinded ferrets also became active at the normal time of the year, even though they could not respond to extra lighting with premature sexual maturation. Unlike the ferret, the white-crowned sparrow appears to have an absolute requirement for light in order to sustain seasonal gonad growth.[12] Sexual development in the prairie dog appears to he entirely un affected by environmental lighting.[13] Exposure to continuous lighting profoundly alters ovarian func tion in the laboratory rat or mouse.[14, 15] In the hamster, the gonads show little response to constant light, hut tend to atrophy when the animal is placed in continuous darkness.[16] These observations indicate that there is wide variation among closely related species in the ways that gonad function responds to environmental lighting. Since adolescence comes so late in the human, and since the menstrual cycle takes so long (28-29 days), it has not been possible to do experimental studies on the effects of constant light or darkness or altered lighting cycles on human sexual function. However it has been shown that the absence of light perception has clear effects on the time of onset of puberty: We studied the age at which the first menstrual period occurred in about 300 blind girls, and an equal number of pair-matched girls with normal vision. Blindness due to disease of the eyes was associated with an earlier-than-normal menarche, such that the greater the loss of light perception in the patient, the earlier was the age at the first menstrual period.2 The rather small amount of data available on different species suggests that the absence of light induces gonad function in diurnally active animals (e.g. humans, sheep) while the presence of light has this effect in nocturnal species[1] (e.g. rat, ferret, raccoon, bat, cat) .

Inductive Effects of Light: Synthesis of Pineal Hormones

The pineal gland of the mammal has undergone extraordinary changes with evolution. Among lower vertebrates (e.g. the frog), the pineal is not a gland but functions as a photoreceptor, or a “third eye.”[17] It converts a photic input into nerve impulses, which are then transmitted to the brain.[18] With evolution, the pineal has lost all trace of photoreceptive function; it no longer demonstrates a direct response to a light source, and no longer sends photic or any other information to the brain.[19] Instead the pineal has developed into an unusual kind of gland-a neuroendocrine transducer.[20] The mammalian pineal re ceives nervous messages from the brain, and responds to these by secreting a hormone, melatonin, into the blood stream. [21]

Even though the pineal of mammals is no longer directly receptive to light, its metabolic activity continues to be controlled by environmental illumination, hut now indirectly: Photoreceptors in the eyes respond to environmental lighting by generating nerve impulses, which are transmitted along the optic nerve. Most of these impulses travel to brain centers which are associated with vision (e.g. the lateral geniculate bodies, the superior colliculi, the tegmental nuclei). However a small fraction of the impulses diverge from the main visual pathway and travel along a nerve bundle (the inferior accessory optic tract) which leads to the part of the brain that controls pituitary function (the hypothalamus), and, eventually, to the pineal gland[21, 22] (**Fig. 1**). Since the animal or human lives in an environment in which light and darkness alternate with 24-hour periodicity, the pineal receives a large number of nerve impulses for about 12 hours each day, and a small input for the alternating 12-hour period. The pineal responds to these nerve impulses by making more or less of its hormone,[23] and also by changing in weight and histologic appearance. When rats are placed under continuous darkness, their pineal glands enlarge and secrete large amounts of melatonin.[4] When the animals are placed under continuous light, the pineals shrink, and make very little melatonin. The melatonin enters the circulation, and is delivered to organs throughout the body.20 It thus provides the body with a time signal: High blood melatonin levels tell

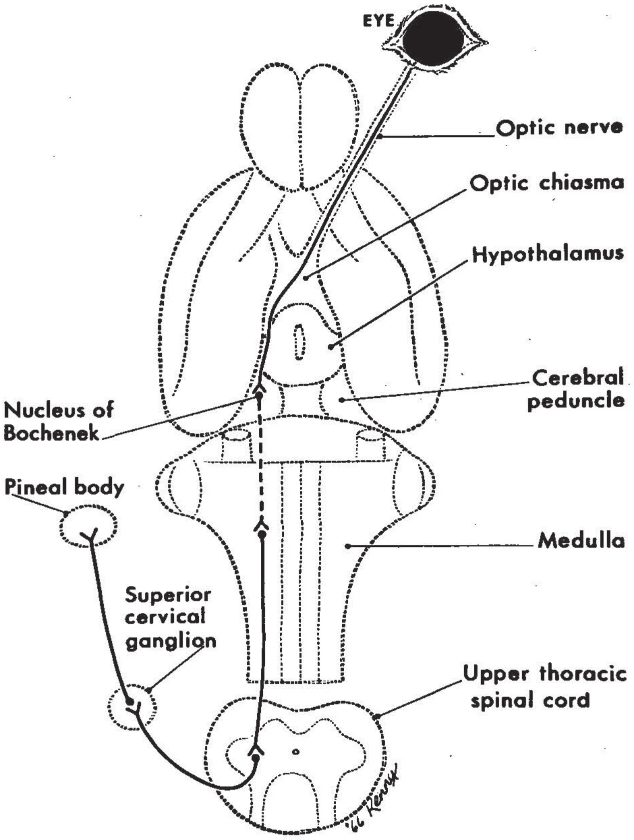

Figure 1. Pathway taken by photic information which controls rat pineal gland. The eye responds to environmental lighting by generating nerve impulses which travel along the optic nerve to the optic chiasm. At the chiasm, the nerve bundles cross from the right to the left side (and vice versa}; most then travel along the main visual pathway, to terminate in the lateral geniculate body, the superior colliculus, and elsewhere. A small fraction leave the main pathway to travel with the inferior accessory optic tract, which terminates in the nucleus of Bochenek. This tract carries the portion of the photic input which is concerned with endocrine control of the pineal, the gonads and other organs. From the nucleus of Bochenek, this information travels down the brain stem and the spinal cord, to the cell bodies concerned with the sympathetic nervous system. They leave the spinal cord in the neck, run to the superior cervical ganglia, and then re-enter the skull to terminate within the pineal gland.

the liver or spleen of the rat that it is dark outside, and low levels have the opposite meaning. The precise use to which the body puts these time signals is not clear. However it seems most likely that they act to synchronize other biologic rhythms in the body. These might include (a) the 24-hour rhythm of sleep and wakefulness; (b) the 24-hour rhythm of voluntary muscular activity; (c) the 24-hour eating rhythm in experimental animals; (d) the ovulatory rhythm; and so forth.

The precise locus at which light information appears to control melatonin synthesis is at the production of an enzyme, hydroxyindole-O-methyl transferase.[4] This enzyme, which is stimulated by darkness, is required to catalyze the last step in melatonin biosynthesis. Darkness also causes more noradrenaline to be released from nerve endings in the pineal;[24] this compound probably acts to induce the enzyme. Light has the opposite effect. If animals are blinded or are placed in continuous light or darkness, the 24-hour rhythm in the activity of the melatonin forming enzyme is immediately lost.[23] The same effect is observed if the nerves to the pineal gland are cut,[25] or if the brain pathways which mediate the endocrine effects of light (i.e. the inferior accessory optic tract, described above) are damaged.[22]

Synchronization of Daily Endocrine Rhythms by Day-Night Light Cycles

The first evidence indicating that glandular or metabolic function in humans varied according tCl time of day was obtained by Gregory Pincus, in 1943.[26] It had been shown that some of the steroid hormones secreted by the adrenal gland appeared in the urine as a characteristic group of metabolites, the ketosteroids. Pincus showed that the urinary keto steroid levels of healthy young men were significantly lower in samples collected at night than in those ex creted during the daytime. He suggested that this difference reflected 24-hour periodicity in the rate at which the steroid hormones, especially cortisol, were secreted from the adrenal gland. This hypothesis was subsequently confirmed when sensitive chemical tech niques were developed for measuring the levels of adrenocortical hormones in blood. The presence of a day-night rhythm in adrenocortical secretion now constitutes a standard, highly sensitive test of adrenal function which is available in most major hospitals.

A large body of information has been accumulated concerning diurnal rhythms in endocrine gland activity and in consequent metabolic events. Most of these rhythms can be modified experimentally by varying lighting schedules. For example, the concentration of one kind of white blood cell, the eosinophile, in the blood of the mouse fluctuates with a diurnal cycle.[27] Animals kept in light during the day and in darkness at night show peak blood eosinophile concentrations at noon, just before the rate of adrenal secretion starts to increase.[27] If the start of the daily light period is moved forward by 12 hours, the time of the peak in blood eosinophile concentration is shifted by an equal number of hours after nine days of exposure to the new lighting conditions.[28] If mice are placed in constant darkness, the eosinophile cycle persists at about [24] hours in length. When the animals are exposed to continuous lighting for nine days, the eosinophile cycle disappears; however it can he renewed if the mice are returned to cyclic illumination. [28] These data suggest several characteristics of the diurnal blood eosinophile rhythm of mice (and the underlying adrenal secretory rhythm): (I) it does not have an absolute requirement for cyclic light changes, and hence may represent an “endogenous” rhythm; (2) however, it is normally synchronized by the day-night light cycle; and (3) it is subject to marked perturbation, even extinction, in the presence of abnormal lighting conditions.

Many endocrine functions in birds and mammals have now been shown to demonstrate 24-hour periodicity. These include: (I) the secretion of corticosteroids from the adrenal in mice,[29] rats, 30 monkeys,31 and humans ;[32] (2) the level of ascorbic acid in the ovary of the pseudopregnant rat,33 the release of the hormone which causes ovulation in chickens,34 and the time of day that the guinea pig ovulates;[35] (3) the content of the hormone which causes lactation in the pituitary gland of the rat; [36] (4) the level of calcium in the serum of humans suffering from hyperparathyroidism;[37] (5) the activity of renin, a substance which elevates blood pressure, in the plas ma of normal humans; [38] (6) the level of the thyroid stimulating hormone in the blood[39] and pituitary [40] of the rat, and the secretion of thyroxine from the cat thyroid. [41]

A large number of metabolic events which depend upon the adrenal gland also show 24-hour periodicity, in response to the 24-hour rhythm in adrenocortical secretion. These include rhythms in the amounts of glycogen, RNA, DNA, and phospholipids in the livers of rats, the number of dividing cells in the liver and the adrenal cortex, susceptibility of the animal to the toxic effects of certain drugs, and a growing list of related functions.1 In addition, very important and obvious rhythms exist in human and animal be havior (i.e. sleep-wakefulness, activity, time of eating) and in body temperature; the mechanisms of these rhythms are probably independent of the endo crine rhythms.

In the past few years, studies have been initiated on the mechanisms responsible for 24-hourly rhythms in bodily function. By use of experimental models in which animals are deprived of various cyclic input from the environment (e.g. dark-light; food inges tion; environmental temperature and humidity rhythms) , it has been possible to separate rhythms into three groups.[42]

Exogenous Rhythms:

These rhythms are generated by an input of cyclic information from the environment. Thus far, only the daily light cycle and feeding rhythm have been shown to he able to generate biologic rhythms. The normal mammal shows marked daily rhythms in the activity of the pineal enzyme (described above) which makes the hormone melatonin,[23] and in the activity of a liver enzyme, tyrosine transaminase, which regulates the metabolism of dietary proteins.[43] The pineal rhythm is generated by the light-dark cycle: It is immediately extinguished when animals are blinded or are placed under continuous dark ness.[23] (The 24-hourly rhythm in the concentration of noradrenaline in the pineal shows a similar re sponse to the loss of the light-dark cycle) . The liver rhythm represents a response of this organ to the cyclic ingestion of dietary protein.[44] The normal rat (or human) eats for several hours of the day, then undergoes a prolonged fast for eight to twelve hours. (The period of fasting coincides with part of the daylight hours for the rat, and with nighttime for the human.) Hence the liver is exposed to large amounts of dietary protein for part of the day, and to no dietary protein for the rest of the day. In response to dietary protein, the liver makes more of the tyro sine transaminase enzyme. This enzyme rhythm can be extinguished if the experimental animal is deprived of dietary protein, or if it is made to eat small meals throughout the 24-hour day. If the animal is suddenly placed in an environment in which the lights are on from 6:00 pm to 6:00 am instead of 6:00 am to 6:00 pm, its eating cycle will gradually accommodate to the new lighting rhythm, and the phasing of the enzyme rhythm will change simultaneously.

Circadian Rhythms:

These rhythms appear to persist even when all cyclic environmental cues are removed from the ani mal. Moreover, their periodicity changes from exactly 24 hours to something more or less; for example, they may “free-run” at 23 hours and 15 minutes.[42, 45] This suggests that the oscillator responsible for the rhythm resides within the animal, that it does not generate perfect 24-hour cycles, and that its signals are normally locked at exactly 24 hours by cyclic cues from the environment. Such rhythms include those of body temperature, eating, adrenocortical secretion, and the activity and sleep cycles; in all cases, environmental lighting provides the dominant “time-giver” for the endogenous oscil lator.

Endogenous Rhythms:

These rhythms, which constitute the bulk of the known 24-hourly rhythms,[1] persist when specific environmental cycles are abolished; hence it is possible that they are generated by an endogenous source. However, it has not yet been shown that they “free-run” in a constant environment. Hence it is also possible that they are exogenous, and that they represent responses to untested environmental cycles (e.g. in magnetic field strength or cosmic rays) and are not the result of endogenous oscillators. Unfortunately, economic considerations tend to keep most rhythms in this scientific limbo. The study of most rhythms involves killing the experimental animal to obtain the rhythmic tissue. Hence it becomes prohibitively expensive to try to demonstrate, for example, a change in cycle length from 24 hours to 23 hours and 45 minutes in the liver RNA content of the blinded rat.

Environmental lighting is thus seen to interact with all 24-hourly rhythms; it generates or induces certain exogenous rhythms, and synchronizes circadian and ‘t>ther endogenous rhythms. The tem porary impairment of well-being and intellectual function associated with West-East travel is certainly well known to this community. It doubtless results in part from the desynchronization in 24-hourly rhythms caused by the differing number of days that individual rhythms need to accommodate to the new lighting schedule. We have very little information on the possible ill effects of the absence of a 24-hour light-dark cycle on space travellers. However, it would seem obvious that additional research on this problem should be a prerequisite to the planning of extended space missions.

Physical Characteristics of Light Sources Which Modify Endocrine Function

Just as lighting engineers have tended to overlook the biologic effects of light that are not related to vision, biologists have tended to overlook the fact that light is not a homogenous entity which exists in two states {“off” and “on”). Although there is an enormous literature on the inductive and syn chronizing effects of light in mammals, one can count on a single hand all of the papers which have at tempted to examine which portions of the photic spectrum are biologically effective, and what order of light intensity is needed. Few if any data are avail able about the action spectra for the effects of light on the ‘mammalian gonads or pineal, or for the kinds of light which can entrain rhythms. It is not even possible to hazard a reasonable guess as to whether the retinal photoreceptor which initiates these re sponses is a rod cell, a cone cell, or something else.

Some measurements have been made on the photo endocrine action spectra of lower vertebrates. How ever, these data are of questionable relevance to man, inasmuch as the responses in lower vertebrates ap pear to involve extraretinal photoreceptive organs which probably do not exist in man. For example, Benoit has shown[46•47] that long-wavelength visible lighting is most effective in stimulating testicular growth in drakes; however this light produces its effect by acting on a brain photoreceptor (in the hypothalamus) which is absent in mammals. A single study by Marshall and Bowden[48] showed that long-wave-length ultraviolet light (3650 A) was most effective in stimulating gonad growth in the ferret. We are presently attempting to extend these findings.

Data on the threshold level for endocrine re sponses to light are also fragmentary. Farner has shown that ferrets have an "all or none" response to extra lighting, once a level of 9.3 fc is reached.[12] Browman demonstrated that time of lighting was more critical than level by showing that rat ovaries were not abnormally stimulated by direct summer sunlight presented in the daytime, but could respond to a 30-footcandle artificial light source pre sented continuously.[49] Bartholomew studied the relation between light level and testicular growth in sparrows exposed to light for 16 hours per day.[60] When the level was increased from 0.04 to 10.3 footcandles, there 'was an increase in the rate of gonad growth; however, levels of 50 to 250 foot candles were no more effective than 10 footcandles. Wilson et al. found that it was possible to make light level the limiting factor in the rate of sexual development in Leghorn chickens by restricting the hours and frequency of light exposure.[51] Under these conditions, animals reared in 0.04 footcandle matured less rapidly than those kept in 0.4 to 6.6 foot candles of light; chickens exposed to 0.5 to 30.0 footcandles matured most rapidly. As little as one footcandle of light is adequate for optimal egg production by chickens,[52] and for stimulating the testes of drakes.[47] Although relatively little information is available relating the level of light exposure to its efficacy as a neuroendocrine stimulus, it seems likely that the range in which the level may be rate limiting in mammals is well below that provided by the systems of artificial illumination generally in use.

BIOLOGIC CONSIDERATIONS IN THE DEVELOPMENT OF ARTIFICIAL LIGHT SOURCES

From the information currently available, what conclusions can the lighting engineer draw about the biologic effects of lighting which might help him in the design of light sources? One fact seems certain: Light has biologic effects, and they may be very important to the health of the individual. Data have been available for some time showing that environ mental lighting influences "well-being," performance, and other biologic phenomena which are difficult to measure.[53, 54] Recently evidence has begun to ac cumulate that light exerts specific biologic effects, which are easily measured and reproduced in the experimental laboratory. These effects are of two kinds: (1) Those which modify the individual's en docrine and metabolic state, and which are mediated through the retinas; and (2) Those which result from a direct action of light on the skin {e.g. stimulation of Vitamin D production, skin tanning, photolytic

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dissociation of bilirubin [55, 56]) .While the action spectra for the latter effects are still not well known, the general spectral regions involved are, and these are absent from the spectra provided by most commercial light sources.[53] The action spectra for the inductive and timing effects of light on glandular and metabolic function are barely known at all. How ever, their definition will almost certainly be possible within the next few years, and may prove to be im portant to the illumination engineering community. In the interim, what kind of light sources should we construct in order to satisfy man's biologic as well as visual needs?

Over the eons past, natural light has, of course, been the dominant illumination under which the physiologic action spectra have arisen. The duplication of this light within the range of its variations would therefore seem to be a logical goal of illumi nating engineers until further research dictates an improvement.

DISCUSSION

JOHN OTT:* Dr. Wuitman's paper presents data demonstrating direct responses of endocrine functions in the pineal gland to light stimulus entering the eye. It is of tremendous significance in that it suggests an explanation of the mechanism responsible for many photobiological reactions. This data goes far in providing the vitally important missing link of information between the work of a number of scientists who have observed certain photobiological responses in different species of animals, including humans, and others who have observed and drawn detailed diagrams of direct connections between the retina and the hypothalamic region of the brain, including in particular both the pituitary and pineal glands.

As Dr. Wurtman suggests, the significance of these connections which are independent of the optic nerve may not have been fully recognized in the past because of the primary importance of the function of vision. Better interdisciplinary communications are needed between the fundamental research scientist, the illuminating engineer and the physician, in order to correlate not only existing knowledge, but especially new findings in the field of photobiology, photophysiology and photoendocrinology. As Dr. Wurtman has pointed out, it is now clear that light is the most important input, after food, in controlling bodily functions.

Although most of the published data at resent on photo biological responses deal primarily with circadian rhythms and gonadal development, additional biological responses have been noted in laboratory animals kept under different light spectra. Reports in *Today's Health*,[1] published by the American Medical Association, the Illuminating Engineering Society's joumal2 and other publications, suggest that the action spectra of light may influence the determination of sex, tumor development and various physiological and psychological functions.

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The formation of the Joint AIA-AMA Committee on Environmental Health, and studies combining the disciplines of endocrinology and the physics of light energy by the Massachusetts Institute of Technology are outstanding examples of progress toward the improvement of interdisciplinary communications. The interest being shown by members of the Illuminating Engineering Society in the presentation of papers such as Dr. Wurtman's on "The Biological Implications of Artificial Illumination" should go far in encouraging much needed additional work at this still embryonic stage of development, of research into light and its effects on human environment.

The most significant implications of Dr. Wurtman's paper to the immediate interests and concern of 'the illuminating engineer would seem to he his stressing that biological reactions over the past eons have arisen under the action spectra of natural light, and that duplication of this light within the range of its variations would therefore seem to he a logical goal until further research dictates an improvement.

HENRY L. LOGAN:* The importance of this subject to lighting engineers is highlighted by 'this paper from one of the most highly respected and soundest authorities in the biomedical field. It is a significant coincidence that the two inch-thick tome, "Spectrum Engineering-The Key to Progress," authored by the Joint Technical Advisory Committee of the IEEE and the EIA, has just appeared in print. The next great step forward in artificial lighting is through the gateway of "Spectrum Engineering."
Dr. Wurtman points out, with a wealth of scientific evidence to hack up his conclusion, that "artificial light sources should he modified to become compatible with biologic needs," and lighting engineers should he encouraged to use "natural light (or spectral facsimiles) in modem artificial environments." The urbanization of modern man, which gathers him into megalopolitan structures of such huge size that it is impossible for daylight to penetrate more than fifteen feet into the perimeter areas, makes reliance on "spectral facsimiles" a must, in the great majority of structures in which people learn and work. I would like to call particular attention to an apt phrase of Dr. Wurtman's, namely, "the extravisual effects of light" and his conclusion that "light is the most important environmental input, after food, in controlling bodily function." I have been saying this in various ways, on the basis of natural environmental evidence, for thirty years, and I can only welcome the irrefutable data which Dr. Wurtman has presented. I hope thal lighting engineers will agree with Dr. Wurtman that the "duplication of this light within the range of its variations is a logical goal" for lighting engineers, The idea that artificial light is an expense, to he cut as much as possible, still lingers. That is why the lighting industry has spent so much effort on what was nearest its nose-finding out what is the minimum lighting level at which a particular usual operation can he acceptably performed, instead of finding out how much and what kind of light is needed to promote health, reduce the rate of aging, and increase both the useful life of people and their total life.
These more fundamental and larger objectives appear to require higher levels of light than are needed for conscious seeing, and only now are we arriving at a standard of living which permits us to consider what is involved in this larger view. Dr. Wurtman's paper is a welcome step along this road.

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IES Visionary Challenge Judge

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The Bright Side of 2020—Light Really Matters

By Susanne Seitinger

There is before March 13, 2020 and after March 13, 2020. That date is my personal start date for the COVID-19 pandemic. Everyone around the world likely has their own moment when they realized things would be different for the foreseeable future. I've participated in scenario planning exercises in the past and never did I realize how crucial those exercises would be. I don't think I truly appreciated how to interpret their insights - clearly since I didn't have a stock of toilet paper at home. Some of the outrageous assumptions have come true in more ways than I could have ever imagined. And most importantly, the broad, global impact on people's behavior in a way that cuts across cultures, class, and geography is extraordinary. People's relationship with light has been swept up in this transformation and will lead to more creative uses for light by 2030.

The most important way light and the pandemic our linked is through the experience of architectural and urban spaces. (Isenstadt, 2018) While telecommunications have enabled some of us to keep working from our homes or new locations those tools don't overcome people's need for true connection. In the early days of digital technology, Bill Mitchell speculated in *City of Bits* (1995) that cities will never decline no matter how outstanding our telecommunications tools become. Humans crave face-to-face conversation and exchange, therefore, cities will persist. But the pandemic has shown us that behavior in public space can change radically in the blink of an eye. And the scale of urban living is being questioned. Which cities are too big? When are things too dense? How do we provide tools and infrastructure for people when they're more distributed? What should schools look like? In each of these fundamental questions, light plays a role in enabling more personalized experiences of space and even new functions like germicidal lighting technologies.

As we consider lighting in 2030, this pandemic has reinvigorated my thoughts on how lighting and light have been elevated to something important and noticeable through our stronger linkage with more limited architectural settings that we control (aka our homes). Speaking from a Western perspective here, our daily rhythms were previously determined by two or three key locations such as home, school, workplace, etc. Now that folks are in a work from wherever-you-are and whenever-you-can the distinct boundaries between places are not what they used to be. In fact, we probably experience fewer physical spaces but more virtual locations via screens than before. The result is that we don't go outside and we may not be in a place that is purposefully constructed for the activity at hand. This includes the lighting environment. So between the increased screen exposure and lack of rhythms that require us to go outside our entire circadian experience is new and different.

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By 2030, I hope we will construct more flexible spaces with lighting that tracks our experiences. I expect people to realize the need for daylight and effective task lighting. It might be as simple as including new practices like going for a walk in the time that has been freed up with no commutes. It will mean more techniques to provide tuned and controlled light indoors so we can stop talking about controls adoption and start embracing truly advanced lighting systems. It will also mean new individualized tools such as theatrical lighting setups for video calling, filters for screens at night and limiting their use close to bedtime. It definitely also means more flexible, outdoor spaces for all to enjoy - at a distance and defined by light.

Mark Carlson

Abstract: The IES Visionary Challenge asks, “Where will we be in 2030?”, but it also asks, “Where will we not wish to be?” Currently, we face the grand challenge of providing hope to the future generation of lighting professionals. What is this hope? I believe it is the strategic, long-term vision which provides the opportunity for advancement, higher compensation, and professional understanding.

Our greatest challenge over the next ten years is in not addressing the most basic problems we have had for the past several decades—consumer understanding, uniformity of message, and career destination.

Some might see these thoughts as boring or tired conversation. But I would counter by saying, “look around you…what do you see?” Please tell me which of the current lighting organizations or industry leaders are addressing these concerns? Why is it that consumers are still confused and do not understand or appreciate the real values we offer? Does it not make sense that we lack a common message?

This necessary message equates to Human Health—it’s simple and easy to understand. Good lighting provides for good health.

Hope will be in the form of advancement and increased compensation. By ensuring that the consumer understands the positive benefits associated with good lighting design, we will be aligned with and trusted much like that of the doctor-patient relationship. Once established, we become accepted above and beyond that of the tradesperson or technician. Monetarily, we will be associated with the medical industry, which provides greater opportunities for pay.

The next generation will need inspiration—we need a well, thought-out vision to accomplish this. We can provide hope and ensure industry growth by understanding past mistakes. The time is here to pause, plan, implement, and build for long-lasting advancement, not short-term successes. This is our challenge.

Consumer Understanding—Our Weak Link

By Mark Carlson

The hope and future of the lighting industry is directly tied to having a uniform, simplified message that is easily understood, accepted, and valued by the consumer that relates to the benefits of light and human health.

OUR CHALLENGE IN VISION

The IES Visionary Challenge is one that should not be taken lightly. I say this because I believe the lighting industry has been myopic in its approach to the future. Decisions seem to have been made by what the next dangling carrot is in technology. We are failing to pause long enough to look around…to look at the past—history. Our rush to advance technology has placed blinders on those leading the charge, and this is what I believe is our current failing.

My approach to this challenge is simple because it removes us from the racer's path and considers what truly matters to most people. What is and has been the racer's path? It has been advancing technology. The mainstream of the lighting industry is concentrated on this aspect or those matters associated to them, such as energy efficiency and waste. And although these are good, it does not address what is at the very heart of people—hope of prosperity and finding a solution to their family's need.
Therefore, our challenge should prioritize our long-term vision on these human concerns. This vision should also provide hope for a better place, which each of us can enjoy. What are these future concerns—by those in the next generation:

- **Career Opportunities**—what will there be? Will there be jobs available?
- **Above-Average Pay**—will the lighting professions provide enough to earn a decent living? Will they allow one to retire at a reasonable age without stress?
- **Job Fulfillment**—will these jobs be easily defined, understood, and appreciated? Will there be an understood path and destination point for achievement?

If our current generation cannot provide the answers to these basic, real-world questions, then we are disillusioned to believe that job growth will occur within the various lighting professions. Yes, this is somewhat of a bold statement, but let's think about this for a moment. How can we expect to entice the youth of the next generation into lighting careers which have no distinct path to success? How can we expect to encourage hope for those only making an average or below average wage? How can we expect to receive above average pay if we are not understood or valued by society—the consumer?

If it is our desire to grow the industry, then we must incentivize it. There is no better incentive than to provide financial success, job stability, and job satisfaction.

CONSUMER UNDERSTANDING

Our biggest hurdle is the consumer market. To this day, most still do not understand the nature of the value we provide. Why is it that we have not effectively answered this question?

I believe it is because we tend to get caught up in all of the details, the technology, and this simplistic aspect is overlooked. The consumer continues to be confused and much of our work is looked at like a commodity.

As professionals, we tend to get lumped into a giant pool where we are considered much the same. This is the primary reason why our associated costs are scrutinized and effectively shopped in great measures. It is for this reason that we must go to battle to explain why products cost what they do. This is our reality, but it can change if we address the lacking root issues:

1. Where and How do Consumers Find Good Information?

There is an overwhelming amount of information out there, both good and bad. This compounds the confusion problem. So, the question becomes, why do we not have one place to find what's accepted as good and correct? Obviously, this is a huge undertaking into itself, but it needs to be tackled.

Another problem linked to this is due to the industry's fragmentation over the past several decades. This will be expanded upon later, but it has caused the lighting industry to splinter into many groups, all of whom have developed their own information. And because this, it has muddied the water.

Our solution is to consolidate and unify, so that one authority controls what is distributed.

2. Who is the Authority?

Is there a single, leading authority in the lighting industry? Nobody really knows the answer to this question. This supports the challenge of not knowing where to look for good information, and it is for this reason we need to have an accepted and identified source. It is my hope that it is the IES.

This authority needs to be internationally recognized, and it needs to be self-sustaining so that it can meet the demands of implementing measures to solve these problems.

Our solution is to allow the professionals (the professions) to determine this authority. Once established, then assurance and focus can be placed on consumer understanding.

3. Why are Lighting Professionals Relevant?

The lighting professional has spent years learning why we are relevant to the community, but the consumer has no idea of this. Until we break down this understanding in terms that mean something to them, we will continue to be viewed as nothing more than a technician—one who works with light and electricity. This is the sad truth.

We are perceived as part of the construction process, which is dominated as a blue-collar job. This perception ranks us differently—lower and potentially less skilled. Therefore, we are associated with lower wages. We cannot expect to make more money if we are perceived in this manner.

This problem goes back to our 'message'. We have not properly addressed this for the world to understand.

Our solution is to align ourselves with the medical profession—to be relevant on the same scale as the doctor by providing positive results associated with human health.

Consumer understanding is the weakest link in the chain. As an industry, we must address this problem if we are to advance and grow.

SOLVING THE PROBLEMS

To aid in thoughtful consideration, I thought it might be best to provide steps to achieving a successful solution to this matter. Unfortunately, these topics can run deep with examples and thought. Therefore, these steps should be considered in an orderly fashion, as they build upon themselves.

The lighting industry has one primary challenge which is two-fold. It addresses our leadership and "who" will guide us, as well as "how" we can ensure consumer understanding. These elements are critical to reaching our goals.

Stage 1

Our first action needs to select professional individuals to be part of the visionary development team—a visionary panel. This panel should include only those who are proven, active leaders of companies and/or innovative concepts. The reason for this is to ensure we find those with real-world experience in implementing a vision plan.

It would not serve us well to select individuals with extensive academic credentials when most have never operated and advanced a business. The lighting industry is a business, and it needs to be operated as such—successfully and profitably.

Ideally, we should have a well-rounded, representative group from varying specialties or professions. This should include lighting designers, manufacturers, contractors, specifiers, and educators. Also, we should consider the international markets—a global endeavor, which encourages unification.

Once a panel is gathered and deemed qualified to engage this visionary quest, they must be put to task. The first task should be to identify who is in the best position to be recognized as the authority. This selection must consider many factors: financial well-being, membership numbers, global exposure, years established, recognition, and experience.

I believe the IES is currently in the best position to accomplish this endeavor, and it could be one of its greatest achievements.

The goal of having one recognized authority will allow the industry to consolidate information, including the elimination of bad information.

Stage 2

This stage can begin once we have a fully functioning panel and recognized authority. There will be two major tasks during this phase of the building process, and it includes the development of:

A. An Easily Understood Message

As discussed earlier, a simplified message that is naturally understood by the consumer is what this is. Until this concept and message is determined, we cannot develop a vision plan that compliments it.

This message also needs to be one that unifies us all—every profession. When each profession can identify with this, then we will have success. It must be a universal message. The authority is the profession's voice, which guides the consumer.

In my opinion, this message is in our ability to provide good human health. We all naturally desire good health. And when the consumer understands and appreciates this positive relationship, we advance to higher levels.

B. A Vision Plan

The panel needs to determine a long-range plan, and that includes a 5-yr. plan, 10-yr. plan, as well as one that reaches into the next generation of lighting professionals. It should compliment and serve our simplified message

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This plan must be detailed and considerate of all the current challenges that exist. I believe Stage 1 and Stage 2 can be effective and in place within the first
5-year period. This is a reasonable timeframe, and the sooner it is achieved, the faster we can better the industry.

There are several challenges to be included in this plan:

- Fragmentation
- Self-Centeredness
- Devaluation
- Professional Advancement

Stage 3

This will likely be the most daunting challenge phase because our focus will be placed upon the many fragmented organizations, associations, and groups around the world. Our goal should be to unify these entities into one or a small number of organizations, so that a major reduction occurs.

The overall goal in this stage is to consolidate efforts, reduce confusion, share resources, and become stronger under one vision and authority. Many will be fearful of this and likely fight against it. But we need to reassure them that they will have a “voice” and position to benefit their individual needs. No matter what, we cannot take away hope—everyone deserves this. Allowing them to be included is how to make this work.

PROVIDING HOPE TO THE FUTURE

Our ability to provide hope to the next generation is critical if we wish to realize industry growth. We’ve briefly discussed this topic under “Our Challenge in Vision”, but we should better explain why this is of great importance. It is because we cannot expect to grow in numbers if we cannot entice those seeking careers in these fields.

Enticement will come in the form of monetary pay for roles performed. It will also conform to us providing career paths which have a pleasant destination, whether it’s related to compensation or career fulfillment.

If my visionary challenge asks the question of where we wish not to be in 2030, then that would be by not providing hope to the future generation. Can you only imagine if we all choose to not address these concerns and we only pass along an even larger set of problems associated with our industry? It is for this very reason why I believe this is the greatest challenge for us all.

Income will continue to be one of the greatest incentives to any working condition. Another challenge will be for those who are single parents. This is directly tied to income needs, so we need to ensure that our pay structures are fulfilling and competitive. If we cannot provide this, then these people will look elsewhere. Currently, many are distressed by their pay rate. If it’s not very encouraging now, then what can we expect in the future?

The demands of the future are likely to get worse. Our ability to provide hope to the next generation is now more important than ever.

Retirement is another major concern for those working in the lighting profession. And as with many other disciplines, most tend to think about today…not the future. So, as a measure for hope in the future, what if we could better provide for this need? By defining jobs, roles, etc., we can establish defined paths to reach that destination point.

This visionary plan can provide hope and instill encouragement by considering these needs. If we can take away the guess work for students entering the workforce, then they will find more fulfillment in their jobs. This provision will act as a form of security.

The Daunting Challenges of Stage 3

Although this will not be a complete list of challenges, it will suffice to discuss those that will hinder industry growth and advancement. The first of these involves the concept of unification over fragmentation.

Fragmentation is the splintering and separation of parts. We have split the lighting industry up into many specialty groups. There are several negatives associated with fragmentation, and one of those is seen by increased confusion. There is greater confusion on who to look to for answers, as well as finding many mixed messages.

Why does fragmentation occur? In most cases, it’s because these entities are looking to have a voice—to be heard. Each entity serves its members and they never fully develop because they are too small. On the global stage, most don’t matter; therefore, they are not recognized.

Unification

This is the process of being united and made whole. It is the opposite of fragmentation, and it is currently what our industry is suffering from. The key to successful unification begins and ends with consumer understanding.

What are the benefits of unification? There are several and each should be considered in our approach to the visionary plan:

- Shared common message
- Increased revenue and availability to funds
- Increased membership and entity power
- Decreased costs due to consolidated efforts
- Decreased waste

- Decreased confusion
- Increased global exposure
- Increased opportunities for education and learning

Self-Centeredness

The term self-centeredness is only used to describe the nature of the entity. Most entities put themselves first above all else. This is a natural position to take, but it leaves the world out of the equation. Self-centeredness is a short-sighted mission.

This challenge is a big problem today because many are looking for ways to profit, advance themselves, and to be recognized. It's understandable, but we need to encourage a shift in this thought process. We must educate the whole to understand the value in sharing the same message for everyone's benefit.

Companies and entities must look at the long-term goals of the industry, as well as our professions, as part of a winning solution to a shared vision. We should all be encouraged by the idea that we will benefit because the consumer has buy-in to understanding our value.

There will be several negative impacts associated to those remaining self-centered in focus. They will never be able to compete against the well-funded, educated, and controlled experience of the unified model. In other words, they will be left behind to toil at the bottom—a losing value proposition.

Devaluation

Devaluation has been a problem for at least the past decade, and it continues to expand upon itself. It entails both products and services. So, what has caused devaluation and the negative impacts against the lighting industry? I believe it is due to the over-saturation of the markets.

The past several decades has shown a big increase in the demand for lighting products and lighting services. Everywhere we look, we find like products and like services. How does one consider what the difference is between one versus another? Are there exacting measures and standards to effectively divide good from bad?

This over-saturation of the markets is a big problem for everyone. From the consumer's position, it is overwhelming and extremely confusing. We could say just about the same thing from the tradesperson's stance.

So, our challenge lies in the devaluation of products and services. How does this occur and why does it happen? It occurs due to competition. Most everyone is looking for a better deal, a lower cost, a better product, or a better service. If one is to sell more products or services, one must find a way to incentivize the opportunity. Most of this occurs through devaluation by providing less in materials or services, as it relates to “quality”.

What is the common theme tied to devaluation? It is the consumer. The consumer has great power in its ability to control demand, which means they can place expectations on the provider. Much of the lighting industry falls victim to commoditization—our products and services are treated like the commodity. This is bad for those looking to increase their income within our professions. Any time our efforts are treated like a commodity source, we are bound by those conditions.

Another big problem associated with devaluing products and services is that it never ends! There will always be another company or person to come along and offer less so that they can be awarded the job. It’s been said many times, but it’s a ‘race to the bottom’, which leaves all parties in a losing position. If we engage in this activity and accept these conditions, then we hurt our brand—our image. Does the lighting industry, as well as its associated professions, wish to share in unprofessional acts and poor practices? Our image must be about high-quality, professionalism and effective results.

The point of this topic and challenge is to understand it as such. Our vision must change this perception, so that we can earn a better living in our work. This challenge is directly associated with our “message”—why we are of value to the consumer.

Professional Advancement

This challenge is brought to our attention because it is not properly addressed. I believe this is due to the lack of a long-term plan for our industry. Has advanced education been pre-determined or planned out for those practicing the trades? Do we have a defined path towards reaching these advancements? I don’t believe we do.

If we are to engage the future generation, we must define these roadways for completion. We can provide hope and excitement by doing so, and it all must be considered by our leaders.

Additionally, as an industry, we should be providing advanced educational opportunities. Many educational programs stop short and cater to the entry and mid-level practitioners. Why is this? I believe it’s because this demographic provides for the majority of sales that feed the manufacturing process. However, we cannot expect true advancement if we do not encourage it.

Today’s leaders must buy in to the benefits of advancing the professions because this will lead to the encouragement of the next generation.

CONSUMER MOTIVATION

It makes good, common sense that we approach the deficiencies of the lighting industry from that of the consumer first. And when I say consumer first, I do not mean just in providing what the consumer thinks they need. As professionals, we have the experience, technology, and understanding of what is truly best for them. However, our approach needs to address the psychology of humans and their needs.

What does this psychology mean? It means we must hone-in to the things that motivate a consumer to engage in a need or want. There are three human motivators—Desire, Fear and Pain. In addition, these are the same psychological motivators taught to us by sales experts. Therefore, shouldn't the lighting industry utilize them to "motivate" the consumer in understanding "why" we are important and provide value to them?

To better understand this relationship, we need to unfold each motivator:

- **Desire**—a pleasant experience and one which has strong feelings, which compels us to possess something within our reach of obtaining. It's something we want to take action with for personal gain.

  The motivational elements associated with desire are Curiosity (the need to learn), Order (the need to organize, stabilize or ensure a predictable environment), Tranquility (the need to be safe), and Joy (the need to experience happiness, love and fulfillment).

- **Fear**—an unpleasant experience and one which is not desired. These experiences are generally avoided, and they are remembered as a negative experience.

  The motivational elements associated with fear are Stress, Anxiety and Danger. They tend to be opposing to those elements of desire.

- **Pain**—an unpleasant experience which can be physical or psychological. Once again, these experiences are remembered and serve to be avoided in the future. Painful experiences can cause emotional events aligned to stress and depression.

The point to these consumer-first experiences is that it places the emphasis onto them and how they think. If we can successfully motivate the consumer to understand the pains and fears of poor lighting, as it relates to human health, then we can expect them to be motivated to use our services.

Our justification as lighting professionals needs to be aligned to that of a doctor. This will provide a much higher level of acceptance and relevance in the community. This is where our value lies, not in being a technical wizard with light. We benefit human health.

FINAL THOUGHT

Without true leadership to implement a well, thought-out vision, we are most likely going to circle round-and-round by repeating the same old mistakes. We must break the chains that hold us back. We must provide substance for the future of our industry. This will take both the acceptance of our state-of-being, and the action to address these challenges.

Currently, we have a wealth of knowledge and expertise to lead in this visionary challenge. We have the ability to consider the past and to address what is best for the future. We must place emphasis on this future need over our own current needs. This is our real challenge—to give, not to take.

Lighting the Future City

The Importance of Lighting in Future Cities

By Sandy Isenstadt

Rupert Brooke was said to be a gifted writer "on whom the gods had smiled their brightest." But he was flummoxed by the bright gods he discovered in Times Square, New York, when he went there around 1914. He had never seen anything like these beings, comporting in their sky-high pantheon as he gazed up at them: a devil unable to bend back the bristles of "vast fiery tooth-brushes"; not far was "a divine hand writing slowly . . . its igneous message of warning to the nations: 'Wear—Underwear for Youths and Men- Boys'". Nearby, "a celestial bottle, stretching from the horizon to the zenith." Close to that "a Spanish goddess, some minor deity in the Dionysian theogony, dances continually, rapt and mysterious. And near the goddess, Orion, archer no longer, releases himself from his strained posture to drive a sidereal golf-ball out of sight through the meadows of Paradise; then poses, addresses, and drives again." For all their determined activities these "coruscating divinities" including two warring youths "clad in celestial underwear," and the "Queen of the night," a winking sphinx whose "ostensible message burning in the firmament beside her, is that we should buy pepsin chewing-gum" remained a mystery. "What gods they are who fight endlessly and indecisively over New York is not for our knowledge." For Brooke, Times Square was a "*flammantia moenia mundi*"; a fiery-walled world, a notion first voiced by Lucretius regarding the border between the earth and the heavens, across which tracked the blazing sun (Brooke, 1916).

Brooke was speaking, of course, about the array of "spectaculars" or sky-signs that illuminated and animated multi-story rooftop-mounted billboards bristling from the buildings surrounding Times Square. Times Square had been famous for them for more than a decade before Brooke arrived. The first large-scale electric sign went up in Times Square in 1903 to sell whiskey, something that fit well with a nighttime entertainment district. Numerous signs followed swiftly, many of them achieving near iconic status and recalled warmly decades later. One of the largest signs advertised Wrigley's Spearmint Chewing Gum. Installed in 1915, it spanned an entire block, reached up eight stories and featured "spearmen" hunting colored fishes. (Starr, 1998)

For many, the randomness of these signs seemed to recapitulate the unplanned boisterousness of American cities. Foreigners saw them as a metaphor for America's untutored energy. The animated signs' short, repeated sequences asked nothing of memory, an appropriate request for a still-young country. The journalist Mildred Adams argued that New York's lights displayed brash American commerce, "conglomerate and cock-sure, hard-edged, blatant, young enough to turn a full blaze of light into every corner," rather than the "ordered and experienced, worldly wise" Parisian manner, which spotlighted only what was tasteful about French society (Adams, 1932). There was no place on earth quite like it and, by many accounts, Times Square remains today the most popular tourist destination in the world.

EVERY PLACE LIGHTS UP

But Times Square is no longer unique. Its combination of blinking patterns of color and light, its soaring scale summoned to sell stuff, its flaming walls of animated winks, dances and underwear; all have appeared in city after city around the world. Ximending, in Taipei; Piccadilly Circus, in London; Shibuya and Shinjuku, in Tokyo; Causeway Bay and Mong Kok, in Hong Kong; Orchard Road, in Singapore; and Nanjing Road, in Shanghai all brim with entertainment, shopping, food and street life bathed in the light of over-scaled flashing signs. Another such district, Bukit Bintang, in Kuala Lumpur, even features a shopping mall, one of the world's largest, actually named for Times Square. Las Vegas and Pudong, Shanghai, might likewise be considered city-scaled versions of Times Square, with hectares of winking spectaculars. All these places have distinct histories and diverse geometries but the experience of visiting them is surprisingly similar. The people there, the goods for sale, the languages spoken, and the smells wafting about; all are different enough to be distinguishable, but all are overlooked by the same cast of coruscating divinities of illuminated commercial speech. Electric light brought these disparate far-flung places together into a distinct urban type, forged in the canyons of Manhattan and subsequently spun off like sparks from a flame.

Electric lighting brought other sorts of uniformities, too. Early in the 20th century, cities could experiment with a wide range of light sources, including two kinds of mercury-vapor lamp, Nernst lamps, Moore tube lamps and a number of types of arc lamps, not to mention gas lamps, which stayed competitive with electric for the first two decades of the 20th century. The commercialization of tungsten filament incandescent bulbs, with their many advantages, narrowed the options considerably. In addition, cities competed to outshine each other even in the dark days of global depression, with street lighting a visible sign of urban health and a token of progress. More than a few boasted of being "the best lighted city in America" or, like Denver, fancied themselves a "City of Lights."

An entire "white way movement" sprang up in the early 20th century, referring to Times Square and the brightly lit blocks of Broadway that led up to it. Manufacturers specialized in "white way" lighting systems that usually consisted of clusters of incandescent tungsten-filament bulbs encased in translucent globes and hung in clusters from decorative lamp standards. In a short time, there were several hundred "white way" installations in the United States and Europe. An advertisement for modernity, they became foundational to civic identity, with New York often serving as the barometer. In Los Angeles, for example, city boosters argued that the wattage on their Broadway was greater than New York's if the calculation were made on a *per capita* basis. (Isenstadt, 2014)

At about the same time, the automobile led to a further homogenization of urban lighting. Lighting engineers began to think more about maintaining uniform visual conditions for drivers moving 40 km/hr rather than pedestrians walking 5 km/hr. This led to brighter lights and less variation, as well as more light directed to the surface of streets rather than to sidewalks. The factors of lighting design—including brightness, color, orientation, distribution, pole intervals and lamp mounting heights—were recalibrated to meet the needs of moving vehicles. Then, as cars followed roads out into the countryside, towns and suburbs were lit in similar fashion. Drivers' needs for higher levels of lighting and constant visual conditions prevailed over other concerns such as local architectural character, or the visual comfort of those whose homes stood along major arteries. To a large degree, lighting engineers focused on the question of how to move the largest volume of traffic through any given road system at night.

As such thinking spread, a global luminous order blanketed otherwise dissimilar cities. As the historian John Jakle described it: "In the nighttime city, functionality hinged on one dimension,"automobility". Street lighting soon brought a profound sameness to nighttime seeing." (Isenstadt, 2014) For quite a long time, similar transportation oriented concerns underpinned the planning of urban lighting through much of the world.

Lighting technology today

Today, everything has changed. On the technological side, fields such as electrical engineering, software design, materials science and photometry, to name just a few, have been making enormous advances in lighting technologies. Light-emitting diodes (LEDs) have been around since the 1960s but only in the past two decades have they been used broadly for lighting applications. They are small and efficient, which means that most of the energy they use is converted to light, rather than heat, as with conventional incandescent bulbs. Consequently, they are now being used more and more for street lights and for building interiors and exteriors. In fact, there is now a global push to ban incandescent bulbs altogether. The United States, the European Union, Japan, China, India, Russia and Brazil have all set up deadlines to replace incandescent lights and, in some cases, even halogen lamps, with LEDs. And the changeover is only just starting to accelerate as global markets are penetrated more and more by LEDs. As efficiencies increase and costs per element continue to decrease, LEDs are expected to come into even wider use. Their tiny size also lends them great versatility. LEDs can now also be found embedded in furniture and bathroom and kitchen faucets, woven into clothing and attached to jewelry, to name just a few recent applications.

Organic LEDs (OLEDs) are still somewhat new but even more promising. Whereas LEDs are point light sources made from inorganic materials, OLEDs are fabricated as surfaces comprised of layers of organic materials, which makes them more environmentally friendly and easier to recycle. Currently, they are used in digital displays and some interior applications due to their relatively high cost, but larger-scale applications are on the horizon as manufacturing capacity grows. They can be very thin and very light and offer high contrast; they can also be readily laid onto flexible substrates to create radiant sheets or even worked into luminous three-dimensional objects. It is possible even to print LEDs and OLEDs now using off-the-shelf technology, suggesting that soon anyone will be able to make their own light sources. The certain prospect is that any and every surface in a city has the potential to glow.

Lighting controls have likewise advanced greatly with the development of sensors that can detect ambient conditions such as room occupancy levels, fog, highly reflective snow or other factors that affect lighting. Sensors can be embedded in roads to detect traffic density and then initiate dimming cycles to raise or lower street lights. The latest iteration of California's building code goes so far as to require occupancy sensors that can adjust lighting and other building systems in new construction for a range of building types. Manufacturers are already touting sensors in their new lamp designs as standard features. Further, many such products are being combined in interoperable lighting systems, variations of which travel under the names of "smart lighting," "connected lighting," "intelligent lighting" and "adaptive lighting." In these systems, sensors independently communicate with each other or with computers in centralized building or urban control centers, which manage a range of "networked field devices," including sensor-enhanced lamps. Controls can also be made interactive so that passersby might use their cellphones to brighten street lights, much as one might switch on the light in a oom. One example of the use of such controls could be seen at Open Air, a light show that took place several years ago along the Benjamin Franklin Parkway in Philadelphia. There, powerful projectors were manipulated by viewers' cellphones to create swaying and intersecting shafts of light. The long horizontal boulevard, a legacy of City Beautiful planning, was thereby reimagined as long diagonal beams sweeping across the night sky.

MODERN MUNICIPAL USES OF LIGHTING

Municipal governments are already using such controls to great advantage. One of the first roadways to deploy dynamic lighting was the M65, in Lancashire, England. Along that route, lighting levels might automatically drop by as much as 50 percent, depending on traffic density. (Collins, 2002) A major impetus for government adoption of new light sources and sophisticated controls is the potential for drastic reductions in energy use and, thus, operational costs. Lighting often takes up large portions of municipal energy budgets and the savings can be significant. New York City swapped incandescent traffic signals for LEDs and saw a drop in related energy costs of a reported 81 percent. Hundreds of cities have by now installed LED lighting. The average savings in energy costs was 59 percent, as noted in a study of more than 100 European cities. ("LED Projects," 2012) More imperative even than municipal budgets, diminished use of energy directly lowers greenhouse gases emitted in the production of electricity.

Seeing the opportunity for continued adoption, businesses, too, now specialize in lighting management, a new urban service geared to coordinate the convergence of sensors, computer controls, networked communications and lamp types, not to mention other elements of building and urban systems.
The overall outcome of these developments is the smart city, a conurbation threaded through with digital infrastructure that is responsive to specific conditions, seeks sustainable infrastructure and that facilitates the making of humane urban systems.

In terms of our understanding of vision, great strides have been made in the field of photometry, which considers light in relation to visual perception, and in the physiology of vision. In engaging the eye, consideration has to be given to a number of factors, not just objective measures of radiant energy, including the position of the source in the field of view, total volume of light striking the retina, length of exposure to the source, and degree of contrast with a background, as well as the brightness of the light source. Vision, in short, is deeply subjective. Satisfactory seeing can be as much a matter of a person's frame of mind as it is a question of wattage.

Today, however, lighting engineers can manipulate light at the level of the photon, and, equally important, they can measure physiological responses just as finely. In the study of the M65 roadway mentioned above, engineers also tested "ocular stress" in drivers, finding that electrical activity in the orbicularis—the large muscle surrounding the eye—ranged nearly 25 percent in response to changing levels of lighting. These new investigative tools are arriving just in time because the conditions for vision are changing so profoundly. Until recently, most studies of vision have presumed photopic, or well-lit conditions, which is ideal for color perception and visual resolution, taking advantage of the cone cells in our eyes. In contrast, scotopic vision, which occurs under low levels of light, was infrequently analyzed. Today, however, the urban night is a mixture not only of low and relatively high lighting levels, but it is also punctuated by variously colored lights from different sources in different sizes and with different degrees of animation. In response, scientists in various disciplines are starting to study vision under such mesopic, or mixed luminous conditions.

Contemporary Lighting Design

Perhaps the most impressive change has come about on the design side. For years, corporate interests have been behind most lighting research and design. In the early 20th century General Electric was the majority stakeholder in the National Electric Lamp Association (NELA, originally the National Electric Lamp Company), a trade organization, until an American federal court found it guilty of colluding to fix prices and forced it to divest. None the less, NELA persisted, launching various lighting education programs based on its research, much of it valuable, but aimed ultimately at bolstering the electrical industry's growth. At the same time, many of the most innovative lighting designers worked in theater, only occasionally venturing on to design architectural lighting, as was the case with Abe Feder, Howard Brandston and Basset Jones. Even within the theater, lighting designers did not receive their due until the early 1960s, when the profession was recognized as such and allowed to join the United Scenic Artists Union.

In the last two decades the field has moved well beyond these strictures with the founding or refashioning of a number of professional and governmental organizations such as the International Association of Lighting Designers, the American Lighting Association, the National Lighting Bureau, the Illuminating Engineering Society, to name just a few. While corporations still conduct useful studies, a number of independent groups have become leaders in lighting research, such as the Lighting Research Center at the Rensselaer Polytechnic Institute and the Intelligent Lighting Institute at the Technische Universiteit Eindhoven., In addition there have been special initiatives such as the Lumina Project and the World Bank’s Lighting Africa project, both dedicated to finding sustainable, off-grid lighting solutions for areas without an electrical infrastructure in place.

In many ways, lighting design is in the midst of an unprecedented flowering, driven in part by the wide range of new sources and computerized controls and, most influentially, a heightened awareness on the part of the public and city officials regarding the importance of urban lighting. The International Dark Sky Association, for instance, has successfully campaigned to educate people about the dangers of light pollution with numerous community events across more than 50 local chapters around the world. Making urban lighting more efficient and more sustainable is a primary goal of their efforts. Leading design firms, such as Light Collective, Light Cibles, Agence Concepto, Speirs + Major, ACT Lighting Design, Atelier Ten, Philips Lighting, Arup Lighting, to mention only some, now see cities as canvases for luminous inventions that are effective, evocative and environmentally sound.

The net result is a substantial widening of the scope of our understanding of what lighting can do in the city. Traditional functions of lighting remain, of course. Security, the most enduring role of urban light, is still paramount. Wayfinding and orientation, that is, knowing where you are in the city and where you need to go, are likewise long-standing aims of urban lighting. Cities have been requiring lighting on commercial frontages or in public squares for hundreds of years, for example. These functions continue to be crucial but they are understood differently now.

Feeling secure in the city entails much more than moving through an envelope of bright light. A good deal of research has shown that a sense of security is a psychological state that rests on a number of factors not found in crime statistics. Brightness alone can create stark shadows and lead to slower visual apprehension or lead to afterimages that can momentarily impair vision. The possibility of a pedestrian controlling nearby lamps through her cellphone can also contribute greatly to a feeling of security as well as provide an actual deterrent to crime. (Painter, 1999; Welsh, 2009; Grohe, 2011) Likewise, orientation today means more than providing illuminated directional signs. With urban transit systems needing to integrate a range of vehicles, including bicycles, trams, light rail, automobiles, buses and so on, not to mention pedestrians, lighting can help differentiate modes, facilitate transfers and, at the same time, visually unify the entire system. The lighting for Canada Rail in Vancouver, for example, designed by Total Lighting Solutions, encompasses a system comprised of sixteen differently configured stations with clarity, crisp lines and graphic character.

Future Directions for Urban Lighting

Beyond rethinking these traditional functions of light, designers are proposing whole new possibilities. Lighting as an element of urban redevelopment is one potential direction. In 2006, for example, the Dutch firm Daglicht en Vorm won a competition sponsored by the city of Rotterdam to help redevelop Katendrecht, a run-down district near the harbor. On one street, the Atjehstraat, the firm created “Broken Light,” a remarkable scheme that casts ample light on the street for cars, pillars of light between windows on buildings and a staccato, mottled pattern of light on the sidewalk. Residents followed the unusual design’s planning and installation and took part in the festivities once the lights were switched on. (Metz 2012) Building community awareness was likewise a goal in a very different project at Canal Park, in southeast Washington, DC. There, an area of abandoned houses and vacant lots was redeveloped as a diverse and affordable area redubbed Capital Waterfront. A weed-strewn lot at the center was transformed into a park, with the public invited to work with designers and planners. Atelier Ten, the lighting designers, placed a luminous cube at the center, on which local artists project their work and movies are screened at night. The park’s attractions draw visitors at night, making this formerly perilous area an urban oasis. (Loeffler 2015)

Yet another possibility for bringing together groups of people is the use of projected light. In the late-19th century, stage lighting pioneer Adolphe Appia foresaw the possibility of throwing light across space to create forms and textures and advance a dramatic narrative. Today, lasers—optically amplified projected light—have moved well past the light shows where most people first encountered them. They are stronger now, and more portable; coupled with computer controls, they are also capable of intricate detail. Several years ago, sportswear manufacturer Nike, for instance, developed #MiPista, a virtual pop-up soccer pitch projected from a van on to streets and squares in Spain. The demonstration project, now over, had a van on call all night in Madrid; it could arrive and set up within minutes after receiving a request. Nike’s commercial motivation notwithstanding—the firm developed a special shoe for the laser lines—the idea holds promise for any number of impromptu urban events.

Such possibilities have greatly expanded the range of questions we can now ask regarding urban lighting. Light is ubiquitous but it has somehow remained invisible in sociological research, notes Don Slater, a professor at the London School of Economics. He, along with his colleagues, co-founded "Configuring Light. Staging the Social," a research program dedicated to looking at light as a formative, material element of human environments that bears on the satisfaction of social needs. (www.configuringlight.org) In one study, the team conducted research in Derby, UK, in regard to a new lighting master plan. The purpose of the lighting plan was to consider a number of issues, including ways that lighting can help revitalize urban districts, accommodate special-interest groups such as the elderly and balance current uses with anticipated and even unforeseen future uses. Significantly, they also addressed questions of financing infrastructure projects, an especially meaningful matter given the finite resources of most municipalities. The city served "multiple socialties," each with unique and sometimes even competing lighting accommodations. As they succinctly noted, "lighting … involves political decisions." (Entwistle 2015)

Although new lighting technologies have enabled such forward-looking efforts, they are likewise being called upon to look back on our shared urban heritage. Many cities have embraced preservation efforts as a means of sharpening their unique cultural assets and, in many cases, mobilizing them to increase tourism as a source both of local pride and new revenue. Cities such as Bilbao, Spain, for example, recognized the opportunity to reinvent itself as a culturally rich destination following the decline of its traditional industries. The question many such cities face is how to balance the old with the new, how to honor the past without being saccharine or replicating a set from Disneyworld. Many cities now ask precisely these questions of their lighting, too: "How does "new" light reveal the historic city?" as Susanne Seitinger, a manager with Philips Lighting, phrased it. She was discussing efforts to revitalize the Donaukanal, in Vienna. There, the lighting design firm podpod called for a "light ribbon" drawn across the heart of the city that would unify both banks of the canal and at the same time distinguish special spots along it. Pedestrian strips were bathed in a warm white light to enhance facial recognition and eye contact, while vehicular routes were doused in the pinkish-yellow light of high-pressure sodium lamps and building facades were differentially lighted to accord with their architectural or historic character. The result was a cultural hierarchy rendered in light, in some ways making the city more legible by night than by day. New technologies and thoughtful design combined in Vienna to flatter the city's historic complexion. (Seitinger 2015)

Efforts such as those in Vienna represent perhaps the greatest shift in lighting design thinking of recent years: how can light enhance a city's unique nocturnal identity. Picture Paris, for example, and the Eiffel Tower is there. Or Sydney, and you see the Opera House. In time, perhaps lighting might become the emblem of a city. It's already happening to some extent. The Golden Gate Bridge is a San Francisco icon by day but at night eyes shift toward the Bay Bridge, wrapped in fulgent fibers of light by artist Leo

Villreal. The lucent sculpture was planned to run for two years; public affection for the work will keep the lights on permanently. Likewise, Tokyo's Skytree, at 634 meters, is not only a hard-to-miss landmark, it is also a beacon to the city's past. Each year, the tower is lighted in two styles inspired by Edo period aesthetics, recalling when the city was the seat of the Tokugawa shogunate, and timed to coincide with the season of cherry blossoms, a longstanding decorative and, even, philosophical motif in Japan. At night and in season, the Skytree hosts "the world's number one night cherry blossoms" and by means of this association helps to rehearse the country's initial assimilation of electricity in terms unique to Japanese society. (Mizuta, 2015) Shanghai rests even more of its identity on its night lighting. Known as "the city of blazing night" since at least the 1930s, the city has in recent decades reconfigured itself as a global financial center, brandishing the slogan "Let Shanghai Light Up" since the 1990s and forging fantastic multi-colored lighting into a spectacular kind of soft power. The city has even established a Night Lighting and Construction Management Agency to oversee illumination plans, especially on the banks of the Huangpu River that separates the old city from Pudong, the new district known to a large degree by its spectacular lighting. (Lin 2015) For its part, Baltimore, an American city long in decline, is just now launching "Light City Baltimore," an large-scale light festival, modeled on those of a number of other cities, intended to attract international attention and, ideally, free-spending tourists. (*http://lightcity.org/about-the-festival/*) Projects such as these demonstrate that, while the laws of physics that govern electricity are universal, the ways in which light is incorporated and made part of the urban fabric vary in culturally specific ways.

By means such as these, many cities are lighting up a nighttime profile that aligns only partially with their daytime geography. Kings Cross Square in London, adjacent to two major rail terminals, had long provided a disheartening entry into the metropolis, not at all in keeping with the stations' importance. A redesign has turned the situation around, especially at night. StudioFRACTAL Lighting Design considered intersecting traffic patterns and developed an all-LED scheme that provides ambient light from a set of tall columns that also function as nighttime landmarks, smaller columns that help orient and guide pedestrians and a number of smaller sources deployed as freestanding elements or embedded in plaza furniture. All these elements combine with lighting on the station façade to create something of a variegated luminous solid that one passes through, rather than a set of surfaces one walks over or alongside. At night, a radiant kind of monumentality appears to bring the site into alignment with the essential functional role it plays in the city's life. Artec3 Studio, to take only one more example, has designed the lighting for several plazas in Spain, including Firalet Square in Olot, north of Barcelona, and Torico Square, in Teruel, Spain, north of Valencia. Both designs give to light a palpable sensibility, making the most ethereal of perceptions into a kind of living presence.

In sum, these recent, staggering developments are giving rise to a contemporary urban nightscape characterized by an amalgam of point sources, radiant surfaces, flashing words and patterns, glowing

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mobile screens and so on, all of which can fluctuate in color and intensity and respond to programmed sequences, changing conditions or individual whim. Until a short time ago, energy was squandered by inefficient lamps or sent into space by poorly-designed luminaires. Now, light can be placed where and when it is needed, with near-pinpoint accuracy and at relatively low cost. In the past, lighting ranged between utilitarian and decorative. Now, it can be transformative, an active element in shaping the conduct and character of urban life. Formerly, cities had come to be overspread by uniform lighting suited to automobile drivers. The Times Squares of the world were a spectacular relief to those conditions, however much they might have recalled one another. Today, cities are distinguishing themselves with patterns of light fine-tuned to their streets, the buildings that line them and the people who move along them. The synaesthetic city was once conjecture; now it is a looming reality as designers use sound and touch to activate lighting and meld the senses in new ways. The spatial and even behavioral implications of such changes are still unfolding but, clearly, new forms of lighting today have potential to harness otherwise dimensionless digital technologies in the formation of distinctive places that generate a sense of scale, immediacy and presence. The rhymes and reasons of these new coruscating divinities no longer elude us: they are the product of reason, design, experiment and necessity, and are pursued by countless technicians, designers, artists and civil servants. They no longer cavort mysteriously, as Brooke supposed in Times Square, they commingle now to broaden and brighten the public’s dawning consciousness of the potential of lighting to rewrite the urban night.

IES Visionary Challenge Judge

Brienne Musselman, LC, is the Education Manager on staff at the Illuminating Engineering Society (IES). She supports the development and maintenance of Education programs and activities, including the award-winning eLearning portal. Her interest in lighting education stems from past experience in the interpretation and navigation of lighting recommendations as an architectural lighting designer. Before joining IES staff, she volunteered for the IES locally in the Detroit Section (Vice President, 2012, and President, 2013-2015) and at the Society level, most notably as the Annual Conference Committee Chair in 2016 and 2017. As an IES staff member, she has served on the Diversity, Equity, Inclusion and Respect (DEIR) task force, and the LightFair Conference Advisory Committee assisting with the selection of conference educational content. She's been a speaker at LEDucation and LightFair, and as part of American Institute of Architects (AIA) and IES events. Musselman occasionally serves as a guest lecturer for Interior Design students at her alma mater, Eastern Michigan University, where she graduated with a Bachelor of Science in Art and Human Environments. She's also taught Lighting and Environmental Systems at Henry Ford College. She was named one of *Lighting Magazine*'s International "40 under 40" in 2017 and recognized as an Honorary Affiliate of the AIA in 2014.

The “Right” Light:

Addressing Community Equity in 2030 **By Brienne Musselman**

In acknowledgement that the interaction of people and public lighting is historically complex, specifically as it pertains to racial and socioeconomic disparities in diverse communities, variegated recommendations for urban lighting design emerge. Replacing the homogenous one-size-fits-all approach, community-driven, site-specific lighting encourages civic engagement and reinforces the value of all residents in a community. In 2030, the public response to their nighttime environments improves as diverse needs in communities are met equitably.

2020 NEW YORK

“Urban lighting continues to obscure the city’s rough edges, the industrial ruins, marginal retail districts, ghettoes and slums, in producing a selective aesthetic ordering of the nightscapes.” – “From Dark to Light” by Tim Edensor

In 2016, the scientific research team Crime Lab—part of a collaboration among the Mayor’s Office of Criminal Justice, the New York City Police Department and the New York City Housing Authority—designed a six-month randomized controlled trial involving 80 public housing developments. Temporary lighting towers were installed in half of the locations (the other half – the control condition – received no intervention), in an effort to “focus on a ubiquitous but surprisingly understudied feature of the urban landscape — street lighting — and report the first experimental evidence on the effect of street lighting on crime” (*Chalfin et al.*). An excerpt from the technical report, “Reducing Crime Through Environmental Design: Evidence from a Randomized Experiment of Street Lighting in New York City” by Aaron Chalfin (University of Pennsylvania), Benjamin Hansen (University of Oregon and NBER), as well as Jason Lerner and Lucie Parker (University of Chicago Crime Lab):

> *The debate over the role of the “individual versus the situation” in the crime production function continues to this day. This field experiment provides novel evidence that changing the situation in urban environments through investments in street lighting can reduce crime in disadvantaged urban areas. Accounting conservatively for potential spillovers, lighting reduces outdoor nighttime index crimes by approximately 36 percent….an outcome which is likely to be cost-beneficial, should the impact of lighting persist over time. Importantly, lighting offers cities a promising method to reduce crime while avoiding potential unintended costs associated with reliance on incapacitation, which has been shown to have high collateral costs. Even more important, these findings highlight a general principle — that violence, like other costly externalities, can be extraordinarily sensitive to situational factors that are experienced in the present relative to longer-term costs that are*

> *experienced in the future.*

While the lighting intervention in this study is unreasonably bright compared to typical permanent lighting integrated into an urban nightscape, the conclusions provide a stepping stone for future research in scalable lighting improvements.

2020 DETROIT

> *"The use of surveillance to regulate what happens after dark has unremittingly been mobilized as a form of disciplinary power, producing subjects that fall under gaze or glare….The development of lighting provided a way to control nocturnal public morality, and imperatives to order the night have continuously inspired the development of new technologies to channel bodies and focus on particular subjects and spaces. Such strategies are invariably contested." – "From Dark to Light" by Tim Edensor*

A city-wide network of thousands of CCTV cameras in Detroit—all with pulsing green lights—serve as a constant reminder to the people who live there: you are being watched. As part of "Project Green Light" the Detroit Police Department—which has 24/7 access to the footage—also utilizes facial recognition software, despite the technology being widely criticized for algorithms that exhibit racial bias (*Harmon*). In 2019, in the largest study to date, 189 facial recognition algorithms were tested by the National Institute of Standards and Technology. The published findings confirmed what was revealed in smaller studies of similar kind: African American (and Asian) faces were 10 to 100 times more likely to be falsely identified than Caucasian faces (*NIST*) – a statistic that has alarming implications in a city with nearly 80% black residents (*US Census*).

While residents discuss the consequences of flawed algorithms, expansion of surveillance, and the allocation of resources in op-ed pieces and community meetings – mixed opinions about public lighting emerge. Some argue additional lighting may help more accurately render those with darker complexions, while others, including Joy Buolamwini, founder of Algorithmic Justice League, argue that is the wrong focus. In "Algorithms aren't racist. Your skin is just too dark," Buolamwini addresses this suggestion in interior environments—which are also subject to the same algorithmic pitfalls as exterior environments:

> *I am asked variations of this hushed question: Isn't the reason your face was not detected due to a lack of contrast given your dark complexion? This is an important question. In the field of computer vision, poor illumination is a major challenge. Ideally you want to create systems that are*

> *illumination invariant and can work well in many lighting conditions. This is where training data can come in….With inclusion in mind, we can make better sensor technology as well as better training data and algorithms. We have to keep in mind that default settings are not neutral….More than a few observers have recommended that instead of pointing out failures, I should simply make sure I use additional lighting. Silence is not the answer….Suggesting people with dark skin keep extra lights around to better illuminate themselves misses the point.*

Others have suggested that the addition of more public lighting instead of surveillance would be an equitable distribution of resources, and provide safe public spaces for everyone without the bias. An excerpt from “Defending Black Lives Means Banning Facial Recognition” by Tawana Petty in 2020:

> *City officials in Detroit and across the country should invest in communities to prevent the quality of life issues that lead to crime, ensuring our neighborhoods have the things we need. Simply increasing lighting in public spaces has been proven to increase safety for a much lower cost, without racial bias, and without jeopardizing the liberties of residents. Black communities, who have been under-resourced and ignored for decades, want to be seen, not watched.*

In a community notoriously underserved, the application of facial recognition is layered atop decades of inequitable distribution of resources in Detroit. The future could relieve some of the tension by giving the community a voice at the table of planning their own nighttime.

2020 LONDON

> *“Light also materializes spatial inequality in demonstrating who has wealth, power, and status, marking out the unequal distribution of financial, social, and political power across space in numerous ways.” – “From Dark to Light” by Tim Edensor*

In London, public housing communities are immediately identifiable by their bright light and tall masts, designed specifically for better CCTV surveillance (Sloane). In 2016, Mona Sloane wrote: “This kind of lighting marks out these spaces as problems to be dealt with functionally and configures them as less valued spaces for less valued people.” In contrast, darkness created by carefully designed lighting in affluent neighborhoods, reinforces assumptions about value and safety by rendering the nighttime experience more inviting. An excerpt from Sloane’s article “Darkness is a luxury not granted to Britain’s council estates”:

> *Not all urban spaces need highly aestheticized lighting schemes, but everyone deserves to live in socially successful and engaging places. This can be lost in how we make and value different kinds*

> *of spaces through lighting – public lighting is a barometer of inequality in urban areas. This is not only hugely problematic, but unnecessary. New light technologies promise more energy efficient solutions and smart systems that can make lighting more responsive and adaptable to the social space it illuminates…***We need a better and more detailed understanding of how lighting can work for people***, regardless of where they live, starting with whether or not it shines into their bedrooms.*

A team of sociologists from the Department of Sociology at the London School of Economics and Political Science have formed the group Configuring Light/Staging the Social to address some of the lighting challenges communities face. Their mission is an indication of what 2030 might hold for other communities, too: "All social life takes place in some degree of light and darkness. Light structures our social spaces, whether at home or on the street. It plays a part in what we can do and how we may feel in social spaces. Configuring Light research group generates collaborations between social researchers and lighting professionals to help us understand the role lighting plays in our everyday life. Specialising in urban public spaces, our aim is to build better social knowledge and better research methodologies for lighting design and urban planning."

2030 IN THE LIGHTING COMMUNITY

In 2030, as cities around the world seek clarity on the important balance of lighting and darkness, more resources become available:

- Lighting organizations provide lighting education:
  - oA resource guide to build a common language of urban light that facilitates clearer communication between residents and experts.
  - o Video and print content on the importance of the equitable distribution of lighting and darkness, resulting in designs that shift from standardized lighting to site-specific, community-first design schemes.
- Anthropology courses include the study of light and darkness among the other studied resources inequitably distributed in communities.
- Federal funding is allocated to complete additional research on the role of lighting in high-crime areas, to inform design decisions that help to reduce the cost burden of those crimes on city and private resources.
- Additional research is conducted on the role of lighting in facial recognition, perception of safety, and personal comfort.
- Professional organizations offer collaborative input:
  - o The Illuminating Engineering Society (IES) partners with the International Association of Lighting Designers (IALD) to form an 'Equitable Lighting' advisory group to establish specific lighting recom-

mendations relevant to equitable design.

  - The American Institute of Architects, inspired by eLearning courses they offered in 2020 such as “Design for Equitable Communities. AIA Framework for Design Excellence” and “A Benchmark for Urban Equity”, partners with the IES and IALD to expand the scope of equity-focused design strategy to include lighting.

- Planners in public housing learn trauma-informed lighting design methods to accommodate for individuals with backgrounds that include incarceration, military to civilian transition, and homelessness. These planners are hopeful that an investment in the right lighting for diverse environments creates public housing environments with less crime, and while promoting healthy social engagement.

In 2030 and beyond, these resources culminate in site-specific lighting that meets diverse needs equitably, encouraging civic engagement and reinforcing the value of all residents in a community, thus improving public response to nighttime environments.

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