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Light and Behavior – A Summary

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The second Illuminating Engineering Society research symposium, held in Cleveland this April, took a broad look at "Light and Behavior". Behavior can be defined as the output produced by people in response to physical and social stimulation. Behavior can take many different forms, some that are easily observed by others and others that are not. Internal, unobservable behaviors are sometimes known to the individual and sometimes not even in conscious awareness. Behavior may be evident immediately after stimulation or only a long time later. Individuals differ widely in their behavioral response to the same stimulation. Lighting can certainly change the physical stimulation experienced by people so it is certainly one of the many factors that affect human behavior.

The symposium adopted an innovative format to provide a clear connection between design and research, with both parties taking something away from their glimpse into the other's world. All the presentations were invited, with experts chosen to address three application areas: education, urban environments and healthcare, chosen because of their importance to society as well as to designers and researchers. For each application area, one or two designers presented examples of their approach to the application, illustrating what techniques they had found to work well, and two researchers discussed the latest research relevant to the application, sometimes explaining why the design approach was successful or not.

Before these case studies, one designer and one researcher set the stage with after-dinner presentations and a lighting experience with immersive color. Paul Gregory of Focus Lighting delivered an exciting display of international installations using light to create emotion. Clearly, many people's expectations of what lighting can do and what lighting designers can achieve have risen considerably in recent years. Bob Davis of PNNL demonstrated how late John Flynn was a man ahead of his time, discussed what his work showed (and its limitations), and wondered why so few researchers had further explored it in the 30 years since Flynn's death.

Educational Facilities

Pamela Horner introduced the session on educational facilities, opening with statistics showing that, in both the USA and Canada, ~23% of the population is engaged in these settings as instructors, staff, or students. Her introduction briefly reviewed what is known about the importance of daylighting and lighting controls for classrooms.

Charles Thompson, principal of Archillume Lighting Design, presented his lighting philosophy for schools, in which he considers it self-evident that lighting in schools should support learning. His view is that this requires multiple connections between students and teachers, between the inside and the outside, between the classroom and the rest of the school. To achieve that aim and to ensure comfort, when he designs lighting for schools he pays attention to daylighting provision, brightness distribution, glare minimization and the flexibility and ease of use of controls.

Arnold Wilkins, from the University of Essex, UK, then introduced a topic that has not been considered much since the arrival of the electronic ballast for fluorescent light sources, but which has now risen from the grave with the advance of LEDs: Disturbance produced by temporal and spatial fluctuations. Temporal fluctuations in light are known to cause discomfort and worse for some people, even when they are not consciously perceived. This means that reliance on the critical fusion frequency as a threshold for discomfort is unwise. It also means that drivers for LEDs, like electronic ballasts for fluorescent lamps, need to operate in accordance with the latest standards to minimize any possible adverse effects of flicker (an IEEE recommended practice is expected to be published later this year).

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As for spatial fluctuations, these are evident in the form of repetitive patterns in décor and lighting. These, too, can also cause discomfort and worse for some people. His fundamental point on spatial fluctuations was that the human visual system has evolved to deal with natural scenes. Fourier analysis of such scenes shows a common form of decreasing amplitude with increasing spatial frequency. Departures from this form by large areas of strong repetitive patterns varying in luminance or color should be avoided. This advice goes against the common practice of seeking to use patterns of high-contrast light and color to stimulate children. Stimulation is better provided by the content of the lessons than a strongly patterned environment.

Daily patterns of light and dark influence sleep-wake cycles and these effects appear to be stronger in adolescents than adults, as Mariana Figueiro from the Lighting Research Center discussed. Teenagers usually belong to an owl-like chronotype, tending to go to bed late and awake late. Thus, having to go to school early in the morning ensures that they arrive sleep deprived, listless and grumpy. Using computer monitors late into the night can augment this tendency. The circadian system holds many secrets as yet, but it is clear that its operation depends on the amount, spectrum and timing of exposure to light over 24 hours. The critical point for classrooms is that exposure to sufficient daylight at the beginning of the school day will suppress the secretion of the hormone melatonin and advance the circadian rhythm of teenagers. However, optimum well-being will depend on the light exposure over the whole day.

These presentations made clear that research has revealed two aspects of lighting of importance to the classroom that have not apparently been much considered by designers or, perhaps, school administrators: repetitive patterns (both spatial and temporal), and circadian regulation. Summarizing the Education segment of the program, we drew conclusions aimed at designers and industry, and suggested research avenues to support them.

Designers should, with support from the industry in providing suitable products:

- Make what needs to be seen visible
- Draw attention to important material
- Avoid direct and reflected glare from luminaires and windows
- Select electric lighting products that meet the latest standards on flicker
- Avoid strong, large area repetitive spatial patterns varying in luminance or color
- Provide sufficient daylight at the right time to ensure circadian synchrony
- Adopt control systems that are effective and easy to use

Researchers should support these efforts by addressing the following questions:

- What is the right balance between over- and under- stimulation by décor?
- For schoolchildren of different ages, what is the best combination of the amount, spectrum and timing of light exposure to ensure circadian synchrony?
- Is there a conflict between providing enough light at the eye to ensure circadian synchrony while avoiding glare?

Outdoor Environment

Two designers shared their perspectives on lighting outdoor settings. Randy Burkett, president and principal of Randy Burkett Lighting Design, presented special gathering places: the Martin Luther King Memorial in Washington DC and the City Garden in St Louis, MO. He showed how lighting can create drama, support orientation and wayfinding, and heighten the sense of safety and security after dark, through the careful control of glare; the judicious use of a range of brightnesses so as to provide a hierarchy with enough contrast in the scene to be interesting but not so much as to be threatening; and, the lighting of vertical surfaces to define the boundaries of the space.

Considering the other extreme was Nancy Clanton, president of Clanton and Associates. She discussed the inadequacy of current lighting standards based on illuminance on the road for ensuring the visibility of targets for drivers and for making the sidewalks appear safe to pedestrians. The first of these should not be surprising. Visibility of objects depends on many factors, chief among them being their size and contrast, where they appear in the visual field, and for how long. Illuminance can certainly contribute to making things visible, but is not sufficient to make all objects visible. As for the perception of safety, data that Clanton presented showed that illuminance alone does not ensure a perception of safety. From her observations, it seems that illuminance uniformity is also critical.

Jack Nasar, a psychologist and planner from the University of Ohio, confirmed this in his research presentation. He described several studies focused on what features of the outdoor environment contributed to a fear of crime, made wayfinding easy and ensured aesthetic appeal. Field studies showed that fear of crime was highest in locations which offered places for criminals to hide and which had a restricted view, with few avenues for flight. Such features may be inherent in the site, but if they only occur after dark then lighting that reduces the number of places where criminals can hide, increases the distance over which people can see, and reveals opportunities for flight will minimize fear of crime. As a result, more people will use those streets at night.

To achieve these aims, one needs lighting that provides well-lit vistas, avoiding sharp contrasts, glare and dark spots. For easy wayfinding, lighting should provide differentiation between routes and should highlight destinations; for example, by varying the amount and color of the lighting or by the use of different luminaires. For aesthetic appeal, the requirements are a sense of order with moderate novelty and complexity. To achieve this Nasar recommended that the lighting of plazas should be uniform and bright. This suggests there are definite limits to how far the use of contrasting patterns of light and shade for drama at night can be taken if a perception of safety is to be achieved.

While Nasar's presentation indicated the importance of light distribution, that of Steve Fotios from the University of Sheffield, UK, addressed the questions of what the amount and spectrum of light should be for pedestrians on residential streets at night. The illuminances recommended for residential streets vary widely between countries which suggests that the science behind these recommendations is inadequate. We know that streets with higher illuminances are seen as safer but how high an illuminance is necessary? Some limit is needed because as a general rule, the higher the illuminance provided by an outdoor installation the greater will be its contribution to sky glow, the more energy it will use, and the more it will cost. Comparisons of the perception of safety of the same parking lots by day and night have shown that the differences between them approach zero asymptotically, so at some illuminance further increases show little benefit for the perception of safety.

Clearly, there is more to ensuring a perception of safety than lighting and certainly more than illuminance. Light source spectrum is also influential, particularly the balance of power in shorter and longer wavelengths (known as the scotopic/photopic [S/P] ratio). Light spectra with more short-wavelength power will produce a perception of greater brightness at the same illuminance than those with less. Color rendering also influences perceptions of safety through its effects on people's appearance. Taking these factors into account, outdoor lighting standards in some countries permit a reduction in the recommended illuminance, scaled by the S/P ratio, if light sources with high color rendering index are to be used.

The designer and researcher positions identified the main problems with current practice in lighting the outdoor environment. At one extreme is the skill and artistry of the lighting designer applied to a significant site, while at the other are routine designs based on code recommendations that are inadequate in both the variables considered and the evidence to support those recommendations. Somewhere between these two extremes should be an approach that satisfies the desires of people using the streets at night for an interesting but safe outdoor environment. Whether this ideal is best approached by education or by regulation is an open question.

To summarize, good lighting of the outdoor environment has to meet several objectives, namely:

- To enhance the feeling of safety;
- To ensure easy wayfinding and orientation;
- To stimulate interest and attraction;
- To minimize light pollution and energy consumption.

These objectives can be in conflict so the first requirement for designers is to understand the priorities for a given site. Once that is done, it should be possible to develop a design that meets the priorities by manipulating the amount, color and distribution of light while maintaining visual comfort. Applying principles from the Education case study, we can add to this list the need to avoid the creation of repetitive patterns, both static patterns and those arising from motion. There are challenges here for industry as well as designers, to provide suitable products that make it easier to satisfy various requirements more easily.

Researchers also have much to do. What do pedestrians want to be able to see outdoors at night? What aspects of lighting do they use to make an assessment of whether or not to use a street at night? More specific questions are:

- What light levels are sufficient to ensure perceived safety in different countries and situations?
- What is the optimum light distribution for making an outdoor scene both safe and interesting and how should it be quantified?
- Can illuminance and illuminance uniformity be traded off to achieve the same level of perceived safety with less light pollution?

Healthcare

John D'Angelo, head of facilities for New York Presbyterian Hospital, set a new bar for design complexity in his presentation on healthcare facility lighting. Hospitals, he said, are really cities in their own right. New York Presbyterian Hospital covers six hospital buildings, has 6,000+ physicians and about 1.5 million outpatients. Such facilities have to deal with everyone from newborns to geriatrics using multiple viewing positions, from upright to prone, and who will have many different things done to them, from the simple to the very complex. The first priorities of the whole system are the patient experience, patient safety and patient outcomes. Decisions are made based on these three indicators.

In his experience, the aspects of lighting necessary for a good patient experience are daylight and good quality electric lighting, the ability for the patient to control the lighting in their rooms, and darkness at night. For patient safety, the concerns are with providing enough visibility to avoid trips and falls; selecting equipment that will not cause a fire; that is reliable; and that can be maintained without spreading dirt, this last point being essential for infection control. As for patient outcomes, there are obvious human and financial benefits if people can be restored to health more quickly.

These considerations give rise to a number of questions that hospitals would like to have answered. They are:

- What is the impact of daylight on patient outcome and patient experience and can it be replicated by an artificial view?
- What is the optimum light source spectrum for use in hospitals?
- How can enough light be provided for examining patients at night without disturbing their sleep?

Thomas Albright of the Salk Institute for Biological Studies led the research presentations with an erudite presentation on the subject of visual neuroscience for lighting design. Light falling on the eye that allows the visual system to identify borders, color, brightness, texture, motion and distance; the brain uses these elements to construct a model of the world around it, leading the individual to recognize objects, navigate spaces, focus attention, communicate visually and generate emotions. In addition, the temporal pattern of light falling on the eye entrains the circadian timing system which, in turn, synchronizes many different biological functions at a very basic level of physiology.

Studies of brain activity have revealed two important facts. First, many parts of the brain are interconnected: Both the visual cortex and the suprachiasmatic nuclei, both of which receive direct signals from the retina of the eye, feed information to many other parts of the brain. We have much to learn about how light affects these functions. The second is that the spatiotemporal contrast sensitivity function which describes the capabilities of the visual system is optimized for the prevailing sensory statistics. For example, a professional baseball player who regularly experiences small objects moving at a high velocity, will have a very different spatiotemporal contrast sensitivity function than people who only rarely see such things, if they see them at all. Experience matters.

This may seem esoteric, but its importance becomes clearer when we consider the varying populations in healthcare facilities. Consider the case of people with dementia, who have low spatiotemporal contrast sensitivity functions that make it difficult for them to recognize objects and to navigate spaces. They also tend to have poor circadian timing systems, so their sleep is disrupted. The solution to these problems is to provide a stronger signal in a form that they can detect. Treating people with dementia as though they were partially sighted by attaching high contrast to salient objects will help with their visual problems. Providing exposure to bright light in the morning can help with their circadian problems.

Finally, Lone Madrup Stidsen of Aalborg University, Denmark, discussed the design of lighting for hospital wards and the difference between the lighting requirements of patients and staff and between different cultures. Patients rarely have any difficult visual tasks so their concern is with a pleasant lighting atmosphere which means a pattern of illumination similar to home. Conversely, staff need enough light to carry out visually demanding tasks. Staff requirements can usually be covered by the provision of an examination light, so the lighting of the rest of the ward can be designed to provide a home-like atmosphere.

In Denmark, this means having plenty of daylight and electric lighting with a correlated color temperature of not more than 3000 K and a color rendering index of at least 80. The usual light distribution divides the space into horizontal and vertical bands, an upper band illuminating the bed, a central band close to the walls and a lower band illuminating the floor close to the walls. These bands are achieved by mounting the lighting at different heights. Décor is usually white. Other cultures may well have different ideas about what constitutes a home-like environment but this is how it is done in Denmark.

Limited design guidance is presently available, because of the three application areas considered, healthcare seems to have the largest separation between research and design. We may recommend that designers and industry consider the following:

- Design for different levels, colours and distributions of light for different users at different times
- Provide stimulation and interest at the right time
- Develop luminaires with controls easily accessible

How best to achieve good patient outcomes in specific circumstances is not yet known because although hospital facilities managers have very practical questions, the research is focused elsewhere. Clearly, understanding how the visual and circadian systems work is valuable for understanding how lighting might be used to improve the patient experience; understanding how patients' perceptions influence the outcome of their treatment would be helpful but, at the moment, there appears to be no attempt to link this knowledge to measurements of patient outcome. Applied research is urgently needed. Questions that would be worth answering are:

- How important are daylighting and/or a view out to patient outcome?
- How can hospital lighting simultaneously serve the patients and the staff, who might have very different needs?
- How can the need to observe and treat patients at night be met while still allowing sleep and safe movement?
- What is the biological effect on patients of stray light from displays that are on all night?

Conclusions

The authors led the final session of the symposium, an open discussion of what had been learnt. Four themes emerged.

First, where do we stand today in understanding the link between lighting conditions and behavior? It seems we are at the end of the beginning, not the beginning of the end. Visibility is very well understood; it is possible to predict the effect of lighting conditions on the visibility of many tasks and hence to predict achromatic visual performance. For effects driven through perception and mood, the link is much more tenuous. There is some information on how different lighting conditions can change perception and mood but that information tends to be qualitative rather than quantitative. By qualitative is meant that the direction of the effects of changing the lighting conditions are known but not their magnitude. Further, most of this work is confined to offices and streets and, even in these areas, the effects on desirable outcomes are relatively unexplored. In the domain of photobiological ('non-visual') effects, which include but are not limited to circadian regulation, there exist quantitative models in some instances, but little consensus on their merits as yet.

This limited knowledge of the relationship between lighting and behavior occurs not because the effects are difficult to explore, given access to the required settings, but mainly because lighting research has not been sufficiently funded. This is a pity because although the research necessary to demonstrate the influence of lighting on desirable outcomes is likely to be costly, the financial and human welfare benefits for some applications are likely to be huge. For example, establishing that providing daylight in hospital wards leads to better patient outcomes would be well worth the investment. Moreover, as advances in light source and controls technologies take care of reducing energy-efficiency, what will differentiate one product or service provider from another will be demonstrated effects on occupants – knowledge that we need to develop now.

Second, designers want metrics that are better related to the effects required – metrics that go beyond simple illuminance. However, we should beware of unintended consequences of inflexible adoption of metrics. As we have seen, lighting that facilitates our goals has many dimensions, some of them conflicting. Quantitative guidance can serve as advice, but it will always be a matter of judgment to prioritize for a specific instance. Researchers can help here, by conducting rigorous post-occupancy evaluations to test the intuitive hypotheses that underlie designers' work. Such studies can show the circumstances under which formal guidance can be relaxed.

Third, consider the fashionable concern with evidence-based design. How much evidence does one need before making a design decision? At what point is professional expertise sufficient – or even superior – to empirical evidence? Designers and researchers are trained in opposing directions: Designers learn to trust their judgment and experience. Researchers learn not to believe anything until it has been independently tested (preferably more than once). Real progress will require balance between the two. Designers work on specific projects, with finite schedules that demand immediate decisions; they juggle competing priorities and sometimes, conflicting evidence. They cannot wait for the results from the perfect investigation to deliver today's design solution. Evidence from sound research, on the other hand, can provide the support to guide decisions away from purely financial and energy-consumption goals. (Remember the windowless schools renovated and constructed during the 1970s?)

Fourth, what about improvements in lighting technology? Here, there was no consensus. Controls attracted much comment during the discussion, particularly control interfaces that are easy to understand, easy to operate and easy to access. Another speaker advocated the widespread use of light sources with high correlated color temperatures. Others noted that new light sources, particularly those with non-uniform distributions, raise both new and old questions about glare and discomfort.

A symposium is a meeting to discuss a topic; this particular symposium intentionally placed designers and researchers in counterpoint to spark debate. In the broadest sense, there was consensus on goals: We want schools that support learning, streets that are safe, hospitals that heal. Where there remains much to be done, much to learn, much to discuss, is the exact role of lighting in achieving those goals: What sort of lighting is required to achieve the desired outcomes? Will it differ with context and culture? How important is lighting in comparison to the other factors that undoubtedly influence behavior? With the many tools for idea exchange available today, and the inspiration of the designers, researchers, and manufacturers in attendance, we hope to have catalyzed new activities that will answer some of these questions in the near future.