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PRINCIPLES OF HEALTHY LIGHTING: HIGHLIGHTS OF CIE TC 6-11'S FORTHCOMING REPORT

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ABSTRACT

In the late 1990s, CIE began to shift its emphasis from lighting for visibility to a more broad definition of *lighting quality*, encompassing human needs, architectural integration, and economic constraints (including energy) [41]. Human needs, as defined here, include lighting that is appropriate to maintain good health, as well as lighting for visibility, task performance, interpersonal communication, and aesthetic appreciation.

Among other developments, this definition reflects the many demonstrations that there are nonvisual, systemic effects of light in humans. Specifically, controlled laboratory and clinical studies have demonstrated that light processed through the eye can influence human physiology, mood and behaviour. These findings may provide the basis for major changes in future architectural lighting strategies.

The report of CIE TC 6-11 summarises the literature in this rapidly-developing area through December 2001, including the neurophysiology, neuroanatomy, behavioural effects of daytime and night-time effects of light exposure in healthy people, and therapeutic effects of light. The report concludes with preliminary guidance concerning healthy lighting and how it might be applied architecturally. This presentation will focus on the possible architectural applications of this area of research, for lighting interiors occupied by day and by night, as a step towards lighting recommendations that respect the broadest definition of lighting quality.

INTRODUCTION

Until the late 1990s, lighting recommendations were based primarily on lighting for visibility. Latterly, the lighting community has embraced a more broad definition of *lighting quality*, encompassing human needs, architectural integration, and economic constraints (including energy) [39;41] (Figure 1). These human needs incorporate vision but also demand attention to lighting for the maintenance of good health, task performance, interpersonal communication, and aesthetic appreciation. One mark of the growing acceptance of this definition is its appearance in the 9th Edition IESNA Lighting Handbook [22] as the organising framework for the new Lighting Design Guide.

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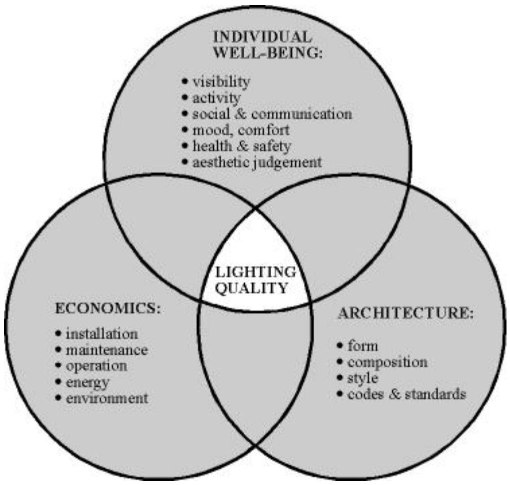

Figure 1: *Lighting quality model (Veitch, 1998). Courtesy of the National Research Council of Canada.*

Thus, this definition incorporates the evidence that there are nonvisual, systemic effects of light in humans. Light processed through the eye can influence human physiology, mood and behaviour [1;25;34;35;45;47]. This paper is based on a technical report produced by CIE TC 6-11. The report, currently undergoing its final revisions before CIE Division 6 balloting, summarizes the state of knowledge in this area through 2001. Space limitations preclude an exhaustive account of ocular anatomy and physiology and of the relevant neuroanatomy and neurophysiology; moreover, other papers in the symposium will present specific research results on these topics. Therefore, this paper focuses on what this knowledge might mean for lighting application and measurement. Interested readers are directed to contact CIE for information about the availability of the complete report, expected in Spring 2003.

PRINCIPLES FOR HEALTHY LIGHTING

Biological effects of light depend on the intensity, spectrum, and timing of the light exposure. TC 6-11's review of the literature led to general principles based on these characteristics. The characteristics should be considered only a first step towards prescriptions for healthy lighting.

- ***The daily light dose received by people in Western countries might be too low.***

Overall, the evidence suggests that current practice in Western countries provides for a very low daily light exposure [18;23], a dose low enough to possibly be detrimental to our well-being [18]. Exposure to bright light, either in light boxes or architecturally, might improve mood and health in people with very low daily light exposure [29;30]. Other risks that might be associated with our low daily light dose, such as increased breast cancer risk or reduced immune function [32;37;44], have potentially grave consequences. There is, however, as yet no agreement about the optimal daily light dose.

- ***Healthy light is inextricably linked to healthy darkness.***

Maintaining circadian rhythms requires periods of darkness in addition to periods of light [15;44]. Changes to our habits -- such as not overextending day length -- would seem also to be required to take full advantage of the powerful effects of light on physiology and psychology. This would have the added benefit of providing adequate time each day for sleep, which some argue that we do not do [3]. Sleep deprivation in itself disrupts neuroendocrine function [36]. It is also possible that very low light levels overnight, while sleeping, might disrupt melatonin rhythms, as has been demonstrated in rats [11;12]. Recommendations for the daily dark dose are perhaps as important as those for a daily light dose, but do not yet exist.

- ***Light for biological action should be rich in the regions of the spectrum to which the nonvisual system is most sensitive.***

Although the exact action spectrum is under debate, there is good evidence that it peaks in the blue-green region of the spectrum [5;38]. The daily requirement for exposure to light of this wavelength range is not yet known, but this knowledge might allow the design of light sources for optimal health effects without unnecessary increases in intensity. Such a solution could be more energy-efficient than a broad-band source that does not influence the nonvisual system as efficiently. Light sources for general application, however, must maintain a balance between the needs of the visual and nonvisual systems in all of their dimensions, to satisfy all of the purposes of the lighting system.

- ***The important consideration in determining light dose is the light received at the eye, both directly from the light source and reflected off surrounding surfaces.***

There is ample evidence that the nonvisual neuroendocrine effects of light are mediated by retinal photoreceptors [16;21;24;26]. Lighting systems for biological action need to be assessed for the light they deliver to the eye, rather than the light emitted from or falling on any other surface.

- ***The timing of light exposure influences the effects of the dose.***

It is clear that the sensitivity of the circadian system to light exposure varies significantly over the 24-hour day [20]. Thus, recommendations for practical applications need to be specific to the time of day.

FUNDAMENTALS OF LIGHTING QUALITY

Good-quality lighting includes lighting for health [41], in parallel with meeting the other needs of people who will occupy the lit space (Figure 1). Principles of good lighting practice should be the starting point for lighting design; we can expect that these might be amended as our knowledge about what constitutes healthy light improves. These principles include energy-efficiency and environmental considerations that should not be forgotten. Healthy light in the broadest sense must also be ecologically sound.

Recommended practice and standards documents articulate current consensus about good-quality lighting [7;8]. Perhaps the most advanced statement to date about lighting quality is the 9th edition of the IESNA Lighting Handbook, with its Lighting Design Guide that identifies the relative importance of various luminous conditions for various settings and tasks [22]. Some of the principles that have special relevance for providing biologically active lighting are the following:

- The colours and reflectances of room surfaces are part of the lighting system. Dark surfaces will negate the benefits of providing additional luminaires, and are likely to result in an unsatisfactory luminous environment in which there is little indirect or reflected light.

- Bright vertical room surfaces are generally preferred over dark ones, provided that glare is controlled [42;43].
- Controlled used of daylighting, limiting glare and solar heat gain to avoid compromising comfort, is an energy-efficient strategy for providing more light where it is wanted and, perhaps, needed - although, of course, it is not a light source available for night shift lighting.

LIGHTING FOR DAYTIME ACTIVITY

Detailed instructions for daytime lighting based on current knowledge are problematic. Increasing illuminance levels does not appear to have lasting effects on cognitive work performance [19;40]. This suggests that for employers there is no immediate benefit to increased light levels for the day shift. There might be beneficial effects on mental health associated with increasing the daily light dose, and perhaps additional health benefits [31]. At present, however, we do not know what the optimal daily light exposure might be, nor when (in relation to the circadian rhythm) it should be timed. Partonen et al. [29] obtained striking results with increased light exposure amounting to three hours a week, in a specific setting, the gymnasium, in winter at a high latitude (in Finland). In another study, people with SAD were successfully treated with a 1-hr walk outside each morning. The daylight group were exposed to approximately 1000 lx (early morning winter in Europe, often overcast), whereas the comparison group were less successfully treated with 2800 lx of electric light for half an hour each morning [46].

This pattern of findings suggests the following, very tentative, suggestions for ways to achieve healthy light exposure by modifying good existing lighting practices:

- Provide opportunities for increased light exposure by good use of daylight, making full use of architectural opportunities to provide energy-efficient, high-intensity light with a spectral balance for the visual and nonvisual systems (Figure 2).
- Provide biologically-active light where the eye is, not throughout the space, while avoiding the creation of uncomfortable glare. Rather than providing increased illuminance throughout interiors, increase light exposure by providing areas of higher illuminance where they will be frequently viewed. This use of non-uniform light distribution will help to avoid conflict between the need to be energy-efficient and the delivery of higher illuminances for at least some of the time. For example, high-intensity task lamps in areas of lower general illumination might achieve this goal (Figure 3).
- Use local control where feasible, and particularly where daylight is available. Higher illuminances all day are unlikely to be necessary to the biological effect given the lower sensitivity of the circadian system at certain points in the rhythm. Controls will allow light to be delivered when needed, and energy to be saved when it is not. They also are likely to be the only means to tailor lighting to individual needs and desires [28].

Healthy light for people on day shifts is also a matter of healthy habits. It might be the case that an adequate light dose could be obtained by a daytime walk outdoors; the exercise would provide an added health benefit. Light avoidance during some portion of the night appears to be a necessary behavioural component of the system.

Figure 2: *Split exterior blinds allow the occupant to prevent direct glare through the lower section (shown closed) while lighting the office with daylight through the upper section (shown partly closed). Photo © Fraunhofer ISE, 2001.*

Figure 3: *One way to deliver bright light to where it will be seen is to use a task-ambient combination, with areas of high illuminance provided locally by task lighting. Photo © 1996, National Research Council Canada.*

LIGHTING FOR NIGHT SHIFTS

One setting where the potential application is clear is night shift work. Bright light exposure during the night shift can have immediate, acute effects on complex task performance [2;4;13] and can aid in successful circadian phase-shifting [15]. The bright light might not be needed constantly throughout the shift, but with additional luminaires and appropriate switching (elaborate automated controls are available but would not be necessary to the purpose), biologically effective lighting could be provided to those who must work overnight. Potential benefits of doing so include improved employee performance, improved health and decreased accidents during shift work, and these outweigh the costs of providing appropriate night-shift lighting [17]. Suggestions for how this might be achieved include the following:

- Design delivery schedules that are appropriate to the shift pattern [15]. Circadian phase-shifting might not be desirable (for instance, in a rapidly-rotating shift schedule).
- Ensure that when bright light exposure is needed, it is delivered to the worker's eye (as above, it need not be uniform in the space in order to achieve this goal).

This would not be the entire solution to the problems of adapting to shift work, but the contribution would be significant. Behavioural routines faithfully practised by the worker are a necessary component of maintaining a healthy pattern of light-dark cycles when working the night shift.

IMPLICATIONS FOR LIGHT MEASUREMENT

Spectral sensitivity

If neither rods nor cones form the photoreceptor system through which light information is transduced for other physiological systems, as is suggested by several investigations, [5;6;10;27;33;38], then the use of either photopic or scotopic photometric measures for nonvisual effects of light becomes questionable. Although the exact curve is not yet known, it is possible that as information improves it will be possible to develop a new weighting scheme for lighting measurement, a third sensitivity curve to complement V_λ

and V'_λ. Until that time, a complete specification of the light stimulus should be reported in all research reports. This would combine a detailed description of the spectral properties of the stimulus and the total irradiance, as received by the research subject. From this information, one can calculate if necessary the photopic (or scotopic) illuminance, or could use other weighting functions that might be developed as the spectral sensitivities for nonvisual processes become better understood.

Light exposure and dose

Both for experimental research and therapeutic efficacy, one must specify the quantity of light reaching the observer. Eye blink, head motion, eye motion, and eye closure can all influence the amount of light that is received. Dawson and Campbell [14] found that up to 80% of putative corneal illuminance can be lost if participants are free to alter their gaze and distance from the light source. Precision in research and treatment, therefore, ideally requires specification of the age and visual state of each subject; the adaptation (background) luminance when the stimulus is given; pupil diameter during the stimulus; measurement at the eye, in the direction of gaze, of spectral irradiance; and, where feasible, use of head restraints and gaze instructions.

For architectural applications where nonvisual effects are to be triggered - for example, in night shift work - practitioners should examine the design from the perspective of the location of occupants, and specifically should determine the illuminance that will be obtained at the most likely locations and direction of gaze of occupants' eyes, to ensure that the intended light dose is what will be delivered. This determination, of course, must take into account the visual system state of the most likely occupants and the spectral characteristics of the light source.

CONCLUSION

Present-day recommendations for lighting practice are based largely on visual system requirements [9;22;37]. Recent years have seen rapid advances in which controlled laboratory and clinical studies have demonstrated that light can influence human physiology, mood and behaviour. We are developing light treatments for specific clinical disorders as well as improving adaptation to shift work and jet travel. Although these advances are not yet enough to support clear statements about the optimal light and dark needs for good human health, this goal is consistent with the articulated goals of improved lighting quality. The combined efforts of researchers from many disciplines and lighting practitioners of all kinds are needed to develop the strong knowledge base needed to support modifications or adaptations of lighting practice that blend the requirements for good health with the requirements for the visually-mediated processes implicated in human response to the lit environment [37]. This early presentation of highlights from the TC6-11 report is presented at this EPRI/LRO Symposium on Light and Human Health in the hope that it will stimulate further dialogue between the various researchers, designers, and policy-makers involved in this important and rapidly evolving area.

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