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LIGHT AND HEALTH: THE IMPLICATIONS FOR LIGHTING

By Peter R. Boyce.

Exposure to light can have both positive and negative effects on human health. The existence of these effects implies that the lighting of buildings is not just for vision any more. Rather, consideration also needs to be given as to how lighting might be used to support the health of the occupants. What form this support should take will depend on the availability of daylight and the access people have to it.

HUMANS ARE DIURNAL animals, heavily dependent on the sense of sight. Light is essential for humans to function efficiently. With light we can see, without it, we cannot. But that is not the only role of light. Over the last two decades it has become increasingly evident that exposure to light can have both positive and negative impacts on human health, impacts that appear soon after exposure or only after many years.

The established effects of light on human health can be conveniently arranged in three classes. The first class is that caused by light treated as optical radiation. In sufficient doses, exposure to light can cause damage to the eye and skin, through both thermal and photochemical mechanisms. In the short term, ultra-violet radiation can cause inflammation of the cornea (photokeratitis) and reddening of the skin (erythema). Prolonged exposure to ultra-violet radiation can lead to cataract in the lens of the eye as well as skin ageing and skin cancer. Visible radiation can produce retinal damage (photoretinitis). Visible and short-wavelength infrared radiation can cause thermal damage to the retina and burns to the skin. Prolonged exposure to infrared radiation can lead to cataract and burns. Guidance on the maximum allowable exposures is available, as is a system for evaluating light sources for their tissue damage potential. In terms of optical radiation, the most hazardous light source to which most people are exposed is the sun outdoors.

All these effects of light are negative but optical radiation can also have positive effects on health. Specifically, controlled exposure to light can be used as a treatment for hyperbilirubinemia, some skin disorders and some tumours. Exposure to sunlight is also associated with the generation of Vitamin D, a vitamin necessary for healthy bones and influential in many other aspects of health.

The second class is light operating through the visual system. Lighting conditions that cause visual discomfort are likely to lead to eyestrain and anyone who frequently experiences eyestrain is not enjoying the best of health. The lighting conditions that cause visual discomfort are well known and easily avoided in principle if not always in practice.

The third class is light operating through the circadian system. The sleep-wake cycle is one of the most obvious circadian rhythms so it is hardly surprising that exposure to bright

light at the right time can be used to treat some sleep disorders involving the timing and duration of sleep. In addition, exposure to bright light is a useful means of stabilising the rest-activity cycle of people with Alzheimer's disease and of relieving the depression associated with seasonal affective disorder. Unfortunately, exposure to bright light at night is also associated with the more rapid development of breast cancer.

To summarise, light is like fire, a good servant but a poor master. Exposure to light is essential for the visual system to operate, desirable for entraining the circadian system and valuable for the treatment of some medical conditions, but too much of the wrong wavelengths for too long, at the wrong time, and damage or injury may occur.

LIMITATIONS OF CURRENT UNDERSTANDING

The impacts of light as optical radiation and when operating through the visual system are both well understood. The same cannot be said for light operating through the circadian system. Partly this is because the topic of light and the human circadian system has been studied for a relatively short time and partly because what has been found is complex. Specifically, light entering the eye is absorbed by photoreceptors in the retina resulting in a signal passing from the retina to the suprachiasmatic nuclei (SCN) and then by way of the paraventricular nucleus (PVN) and the superior cervical ganglion to the pineal gland (Figure 1). In the dark, the pineal gland synthesises the hormone, melatonin, which is circulated through the body by the bloodstream as a marker of time. Anatomical studies have shown that the SCN, which are believed to be the central clock of the body, are connected to many other parts of the brain that regulate the production of a wide range of hormones and hence are likely to influence many different physiological functions. Some support for this view is given by studies that have shown that light received at the retina influences core body temperature, heart rate, the production of the hormone, cortisol, and the feeling of alertness. Given this diversity of effects, it seems likely that we have hardly begun to scratch the surface of the non-visual effects of light entering the eye.

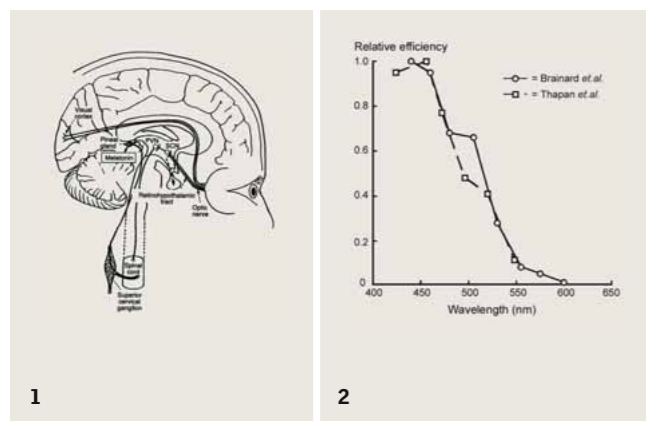


Figure 1. A simplified illustration of the paths from the retina of the eye to the visual cortex and the pineal gland. Drawing from Illuminating Engineering Society of North America (IESNA), (2000) *The IESNA Lighting Handbook, 9th Edition*, New York: IESNA.

Figure 2. Measured relative efficiency of electromagnetic radiation at different wavelengths in stimulating the human circadian system, using melatonin

suppression as a marker (after Brainard et al., 2001, *The Journal of Neuroscience*, 21, 6405–6412; and Thapan et al, 2001, *Journal of Physiology*, 535, 261–267.)

Opposite Light is not only a source of energy in the physical sense. The duration, intensity and spectral composition of light has a decisive influence on the circadian system, i.e. the sleeping and waking rhythm of human beings.

Even for the circadian effects that have been examined, there remain a number of questions that need to be answered if light is to be used efficiently. They relate to such aspects as spectral sensitivity, the relative sensitivity of different parts of the visual field, whether there is any adaptation effect, as there is in the visual system; how light exposure is integrated over time, and the significance of the timing of light exposure.

Measurements of spectral sensitivity, using melatonin suppression as the marker, have shown a strong sensitivity to short-wavelength optical radiation with a peak sensitivity about 465 nm that is very different from the peak sensitivity at 507 nm and 555 nm of the scotopic and photopic visual system (Figure 2). This implies that light sources designed to maximise the stimulus to the visual system will not necessarily be efficient in stimulating the circadian system.

Another study has shown that the lower half of the retina produces greater suppression of melatonin than the upper half, for the same light exposure. If this is so then the efficient stimulation of the circadian system requires that light be preferentially distributed to the upper part of the visual field. Unfortunately, what constitutes the upper part of the visual field depends on the direction of gaze. If the direction of gaze is predominantly downward towards a desk then the upper part of the visual field in a room is formed by the walls, while if the direction of gaze is straight ahead at a screen the upper part of the visual field is formed by the walls and ceiling.

Yet another question is whether or not there is an element of adaptation in circadian stimulation. It is the cycle of alternate light and dark that entrains the circadian system. But what constitutes light and dark? Is there an absolute retinal irradiance below which it is always dark and above which it is always light, or is it simply the ratio between light and dark that is effective? If the former is true then there is some minimum retinal irradiance required for efficient circadian stimulation. If the latter is true then it might be possible to achieve efficient circadian stimulation by using a low light level for light and complete darkness for dark.

Another characteristic of the circadian system that differentiates it from the visual system is its time constant. The visual system is an image processing system that operates on a time scale of parts of a second. The circadian system is not an

image processing system but is more like a simple photocell with a very long time constant of parts of an hour. This implies integration over time thereby making dose the meaningful measure of circadian stimulation. The use of dose implies reciprocity, in that retinal irradiance can be traded off against time. The problem here is that at some point reciprocity breaks down. Where that might be for the human circadian system is not known.

Finally, it is necessary to consider the importance of the timing of light exposure. That timing can matter is evident from the fact that exposure to bright light during the afternoon has very little, if any, effect on the phase of the circadian cycle in the next twenty-four hours. However, bright light given early in the night tends to delay the circadian cycle but bright light given late in the night tends to advance the phase of the circadian cycle. This phase shifting effect has been used as a means for more rapid adjustment to and from night shift work and for overcoming jet lag. However, the significance of the timing of light exposure for many other outcomes remains to be determined.

IMPLICATIONS AND APPLICATIONS

There is much still to be learnt about the non-visual effects of light. Nonetheless, it is already possible to identify two general implications for lighting practice. The first is that the lighting of buildings should no longer be considered solely in terms of the effect of vision. The non-visual effects of light discussed above are real and need to be taken into account in the design of lighting. The second is that the spectral content of daylight is well suited to stimulate both the visual and the circadian system. This implication is consistent with what is known of the spectral sensitivities of the visual and circadian systems. It is also supported by the fact that both the visual system and the circadian system have evolved under daylight. The alternative electric light sources have only been available for about a hundred years, a very short time in evolutionary terms.

Given that it is desired to take the effects of light on health in account, the first step should be to consider the latitude of the site. In low latitudes, the amount of daylight available is almost always enough to ensure that a short exposure out-

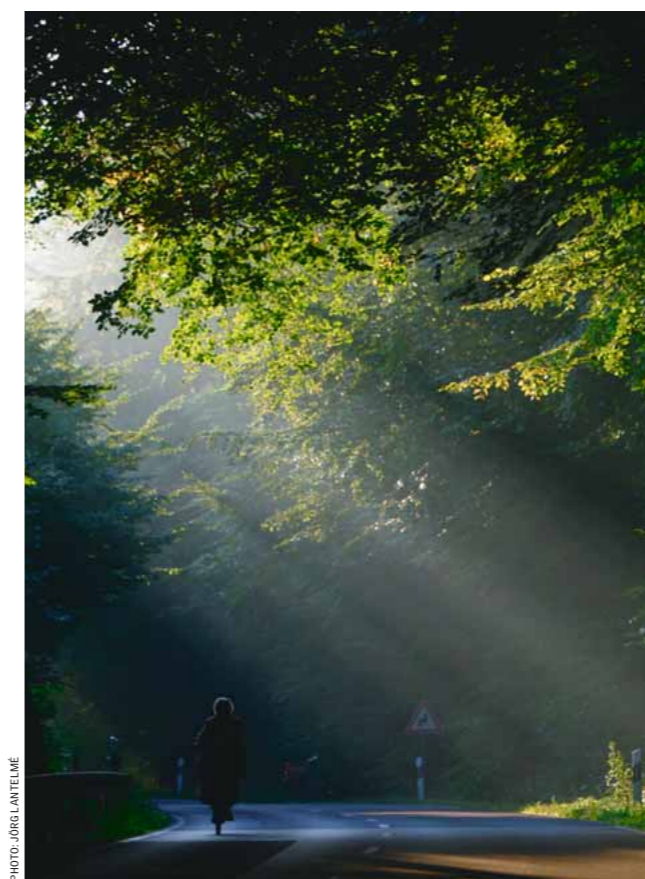


PHOTO: JÖRGI LANTELME

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doors will entrain the circadian system and provide the necessary vitamin D. In such latitudes, protection from tissue damage is the main concern so limiting the exposure to daylight is what matters.

In high latitudes, where there may be very little daylight available for several months, the possibility of providing a clear light-dark cycle using electric lighting should be considered. This is possible because many light sources can be effective in stimulating the human circadian system, although not always as efficiently as daylight. The circadian system does not care what the source of the radiation received at the retina is only what that radiation is, so there is a wide range of light sources to choose from, including some that will provide the ultraviolet radiation required to generate vitamin D.

For intermediate latitudes, where the amount of daylight available requires considerable time spent outdoors for exposure to be effective and societal constraints make this difficult to achieve, the provision of extensive daylighting in a building has a role to play in supporting the health of the occupants, particularly those who have a fragile circadian system. This can obviously be done by careful design but where the site does not allow for extensive daylighting it should always be possible to include a special space, a sunspace, where the objective is to bathe the occupants in daylight provided, of course, that this can be done without causing visual or thermal discomfort.

The range of buildings in which the provision of extensive daylighting or sunspaces might be justified will depend on the answer to another question, namely whether the effects of light exposure on health are limited to the ill, or is light valuable for everyone, even the healthy? There is no doubt that light can be used as a treatment for a number of clinical conditions but the effects of light exposure on the healthy is less clear. What is known is that exposure to bright light at night can induce a greater sense of alertness in the healthy and that apparently healthy people report greater vitality, alertness and improved mood following exposure to higher light levels. It is only if the non-visual effects of light can be shown to apply to the healthy that light and health will become a consideration in all building types rather than those designed specifically for the ill.