LIGHT RIGHT FOR SIGHT: HEALTH AND EFFICIENCY IN LIGHTING PRACTICE

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Abstract

There are several aspects of electric lighting that may affect health, including low-frequency magnetic fields, ultra-violet emissions, glare, and variation in luminous intensity, both variation that can be seen as flicker and that which is too rapid to be seen. These aspects are considered in relation to energy efficiency. For most there are no clear trade-offs between health and efficiency; indeed, improvements in efficiency are, if anything, beneficial to health. There is, however, one important exception and it concerns rapid (100-Hz) variation. Some high-efficiency sources (such as high-pressure discharge lamps) vary rapidly in brightness to a greater extent than the less efficient lamps they often replace. Other high-efficiency sources (such as compact fluorescent lamps with high-frequency ballast) exhibit less variation. The 100-Hz variation is too rapid to be seen but affects visual neurones and has been linked to headaches, eye-strain and anxiety. The variation may be one reason for the improvements in health that result from daylighting. The move towards energy efficiency can therefore be a move towards or away from visual comfort and improved health, depending on the way the energy savings are achieved.

There are many aspects of lighting design and practice that may be of relevance to health. This paper does not provide a comprehensive review but concentrates instead on those aspects that relate to energy efficiency and the specific circumstances where improvements in efficiency may be detrimental to health.

NON-VISIBLE RADIATION

Low-frequency Magnetic Fields

The effects of low-frequency magnetic fields on human health are uncertain. The epidemiological evidence of a possible contribution to certain cancers cannot now be ignored, but neither can it be regarded as conclusive[1]. Most light sources do not reach the limits of 0.2-0.3mT suggested by recent work[2,3]. The magnetic radiation from lighting has more to do with the positioning of any transformers than with the nature (or efficiency) of the source. There are as yet no obvious trade-offs, therefore, between health and efficiency with regard to magnetic fields.

Ultraviolet Light

The ultraviolet light from daylight exceeds that from most sources of artificial light[4]. Its role in diseases of the eye is controversial, but its effects on skin have been relatively well documented[5]. The levels of ultraviolet light from conventional fluorescent lamps are very low and are not thought be a hazard[6]. The uv-fluorescent lamps used for phototherapy[7], suntanning, fly-killers and special effects may be less innocuous[8,9]. In general, the trends in lighting practice and the move towards energy efficiency do not appear to influence exposure to ultraviolet light appreciably, with the possible exception of the introduction of tungsten halogen lamps. The combination of high filament temperatures and quartz glass envelopes results in a significantly higher level of emission of ultraviolet radiation compared with conventional incandescent lamps. When used in reading lamps without any secondary filtration, tungsten-halogen lamps can emit levels of radiation sufficient to be deemed a health risk, although the levels vary considerably from lamp to lamp[10].

VISIBLE RADIATION

Intensity and Spatial Distribution

The luminous intensity of a light source, the angle it subtends at the eye and its position in the observer's visual field combine to determine the extent to which the source will induce a sensation of discomfort, or impair vision[11]. It is reasonable to suppose that, in the long-term, glare can have secondary effects on health. Some of the new light sources have a very high luminance, and although there is uncertainty as to whether they constitute a hazard when viewed directly at close quarters[12] careful luminaire design is necessary to avoid glare from these sources, particularly when the luminaire uses the new highly efficient reflective materials. Ironically, glare can occur from the use of some of the lower intensity sources such as the small low-voltage tungsten-halogen lamps because it is common to use these as an array of spotlights variously dispersed across the observer's visual field.

The established procedures for avoiding glare do not take into account the importance of pattern. Visual discomfort, headaches[13] and even epileptic seizures[14] can be induced by patterns of stripes, such as those formed by certain luminaire baffles or by repetitive arrays of linear luminaires viewed obliquely. The spatial characteristics of patterns responsible for these effects have been described[15], although there has been no investigation of their effects on occupational health. Nevertheless, the trend away from repetitive arrays of luminaires (facilitated by compact fluorescent sources) is likely to be good for health. Not only does it avoid uncomfortable patterns, it can result in a less even and more directional distribution of light, reducing the blandness of the visual environment (as distinct from its brightness), and enhancing the shading that provides cues to the shape of objects and renders a scene interesting[16].

Spectral Power Distribution (SPD)

Compared with daylight, artificial lighting shows little variation and its spectral power distribution seldom resembles that of natural light. There are, however, fluorescent lamps that differ from those conventionally used in that they provide higher power at the short wavelengths, and in this respect they resemble daylight more closely than most other sources. They have been widely recommended for offices and classrooms with claims for improved morale and mood[17,18]. Four studies have failed to show any beneficial effects[19,20,21,22]. On the other hand, the incidence of dental cares has recently been found to be lower in primary school children whose classrooms were lit by daylight lamps[23].

The spectral power distribution from gas-discharge sources can be very uneven, and it is not known whether this unevenness is detrimental to health. The photoreceptors of the eye have broad spectral sensitivities and it has sometimes been assumed that the unevenness of spectral power cannot therefore matter. However, the perception of colour is the result of a neural calculation. It is necessary for the brain to "model" certain aspects of the spectral power distribution of the illuminant in order to discount its effects on the light received by the eye from coloured surfaces. Little is known about the process of neural "modelling" that takes place. It remains possible that the process could be disrupted by an illuminant with a very uneven spectral power distribution. Such illuminants increase the number of metameric matches in the visual scene and this may have consequences where colour discrimination is important[24].

People differ considerably as regards the colour of light they find most comfortable for reading. Those who suffer migraine headaches, for example, find red particularly uncomfortable[25]. The strong idiosyncratic preferences that people exhibit may therefore have a physiological basis that is of relevance for health. The possible implications for lighting have yet to be explored, however.

Provided there is no glare or thermal discomfort, people prefer to work by daylight. The absence of windows has been correlated with an increase in transient psychosis in hospitals and an increase in absenteeism in schools and factories[26,27,28]. These findings may partly reflect the effects of diurnal and seasonal variation (see next section). They may also reflect the effects of modulation from fluorescent lighting and its dilution by daylight (see subsequent section).

Daily and Seasonal Variation

In animals, the amount and spectral composition of light entering the eye influences food and water consumption, body temperature, ovulation and hormone secretion[29]. In humans, hormone secretion is also regulated by light-dark cycle. Melatonin levels, in particular, appear to be influenced by the intensity, duration and timing of exposure to light[30], thus providing one possible (but controversial[31,32]) mechanism for seasonal affective disorder (SAD) thought to occur in about 5% of the population[33]. The limited available evidence favours prolonged[34] exposure to bright[35,36] white (full-spectrum) light [37,38,39] in the treatment of SAD, so in this regard, at least, the trend towards brighter high-efficiency sources is unlikely to affect health adversely, and may indeed be advantageous. The trend might conceivably have negative consequences for health were it to be shown that the increasing levels of ambient light at night affected circadian rhythms in man. Such an effect is unlikely given that the rhythms can be entrained in darkness by social factors alone[40].

In all the above respects there is little to indicate that current trends in lighting practice and moves towards improved efficiency have any adverse effects on health. Indeed, improvements in brightness and the evenness of spectral power may be beneficial. In particular, the move towards a greater use of daylight[41] is likely to be good for both health and efficiency. There is, however, one important respect in which improvements in energy efficiency may either improve or damage health, depending on how they are achieved. These relate to the temporal variation in light output -- both at frequencies low enough for flicker to be perceptible and at higher frequencies when the light appears steady.

Flicker

Light that is visibly flickering can have profound effects on the human nervous system. At frequencies below about 60 Hz it can trigger epileptic seizures in those who are susceptible[42]. In others it can cause headaches and eye-strain[43]. When fluorescent lamps age they can provide flicker at epileptogenic frequencies. The problem is eliminated by the new efficient high-frequency electronic ballasts. Other gas-discharge lamps (e.g. metal halide) can also flicker noticeably when first ignited and unfortunately high-frequency ballasts are not yet generally available.

100-per-second Modulation

Origin

Most electric lighting is controlled from an alternating current supply and exhibits a rapid variation in luminous intensity. For many types of lamp the variation occurs mainly at a frequency twice that of the supply. For example, the filament in incandescent lamps is heated as the current passes in one direction, and then again when the direction is reversed, so that with a 50-Hz supply the lamp brightens and dims 100 times per second. The percentage variation in light is usually low because the filament remains hot and continues to emit light during the times in the electricity cycle when little current is flowing.

In gas-discharge lamps the light is created when a current is passed through a gas causing it to ionise. Usually the gas discharge emits ultraviolet radiation which is converted to visible light by a fluorescent coating of phosphors on the inner surface of the lamp[44].

The variation in light output (modulation) can be defined as $(l_2 - l_1)/(l_2 + l_1) \times 100\%$, where l_1 and l_2 are the minimum and maximum luminances respectively. When fluorescent lamps are controlled by conventional low-frequency ballast, the modulation varies between 17% and more than 90%, depending on the constituent phosphors[45]. There is usually a variation not only in brightness but also in spectral composition because some phosphors continue to emit light longer than others.

High-efficiency electronic ballasts are now available for fluorescent lamps and are routinely incorporated in compact fluorescents. The circuitry creates a discharge at frequencies that are usually in excess of 30 kHz. There is a little 100-Hz modulation (due to ripple) but it is usually less than 7%[46].

High-frequency ballasts are not generally available for high pressure gas-discharge lamps. Some of these lamps have no phosphor coating[47] and the 100Hz modulation is close to 100%.

It is common practice in lighting installations with more than one supply phase to keep the lamps operated from each phase in separate luminaires, usually spaced well apartAs a result, the modulation at any particular location is not reduced appreciably, and patches of light throughout the installation vary alternately in brightness introducing a spatial component to the modulation.

Physiological effects

The 100-Hz modulation from fluorescent lamps is imperceptible. It is too rapid to be seen as flicker, but it is detected by the human retina, appearing as a rhythmic oscillation in the human electroretinogram[48]. In cats the modulation has been shown to affect the operation of cells in the optic tract and lateral geniculate nucleus of the thalamus, increasing the firing rate, and causing the cells to fire in bursts, phase-locked to the pulsation of light[49]. The modulation has a small effect on human eye movements[50].

Consequences for health

A recent double-blind study compared the incidences of headache and eye-strain amongst office staff when the offices were lit by conventional fluorescent lighting, and when high-frequency circuitry was introduced, removing most of the 100-Hz modulation. Only a few people suffered frequent headaches, but the high-frequency ballast halved the average incidences of headache and eye-strain[51]. The study also showed a decrease in headaches and eye-strain with increasing levels of daylight.

People with an irrational and overwhelming fear of public places (agoraphobia) often report that fluorescent lighting precipitates attacks of panic, and this is not simply because fluorescent lamps tend to be used in public places[52]. Under low-stress conditions in the home an increase in heart rate has been observed with conventional fluorescent lighting but not with outwardly identical high-frequency lighting[53], suggesting that the modulation of light may sometimes be responsible for anxiety.

With halophosphate fluorescent lamps, the modulation of light is greater for short wavelengths than for long[54]. An ophthalmic lens has been developed that selectively attenuates those wavelengths where the modulation is greatest[55]. When worn at school it may help prevent migraine in children[56].

Given the above, the trend towards high-frequency ballast for fluorescent lamps is likely to be good not only for energy efficiency but also for health. Conventional low-frequency ballasts remain in many installations, however, and there are interesting trade-offs between efficiency and 100-Hz modulation, due to differences between lamps as regards the persistence of the component phosphors[57]:

- small-diameter lamps give very slightly less modulation than large ones, as well as being about 10% more efficient.
- "warm-white" halophosphate lamps provide the lowest level of modulation, and are only slightly less efficient than the more common "white" and "cool white" variety.
- triphosphor lamps give greater modulation than halophosphate lamps.
- "daylight" lamps give a modulation close to 100%.
- the use of krypton gas for fluorescent lamps can cause the lamps to operate unsteadily until warm, producing low-frequency flicker in addition to 100-Hz modulation.

IMPROVEMENTS IN EFFICIENCY VERSUS IMPROVEMENTS IN HEALTH

It is tempting to see energy efficiency as a *societal* problem, and factors such as flicker as affecting *personal* well-being. I believe this is too simple: health has a societal cost, just as does energy consumption. In its broadest sense, efficiency is the ratio of work done to energy consumed, and health has an obvious contribution to the numerator of this ratio. By improving the health of even a few office workers, good lighting (even that with poor efficacy) can pay for itself very quickly. Visual discomfort at work is common. In a recent survey, some 40% of office workers complained about the lighting[58].

Health and efficiency need to be seen in relation to the behaviour of consumers, both collectively and individually; both as users of light, and more generally, as users of energy. If consumers tolerate wastage (exemplified by overlighting[59], and by laziness in turning off unnecessary lights), the moves towards greater efficiency may be slightly reduced in effectiveness (note that consumers report longer use of compact fluorescent lamps than the incandescent lamps they replace[60]). In this regard, the increased availability of occupancy sensors is likely to be good for both health and efficiency: they enable good quality lighting to be used only when required. In similar vein, dimmable ballasts (high-frequency only) are to be welcomed, provided the lamp gives stable illumination when dimmed (which is unfortunately not always the case). These ballasts can be used in conjunction with daylight control to maintain a steady illumination level, but perhaps more important, they can enable office staff to choose a level of lighting that suits them and, since the level is usually relatively low when computer screens are used, overlighting (however defined[61]) is reduced and considerable savings can be made.

Light sources with high efficacy and high levels of 100-Hz modulation may be acceptable in settings where the visual task is unstressful, but should be avoided when the eyes are required to search with precision. As already mentioned, it is not yet possible to operate high-pressure gas discharge lamps reliably at high frequencies. The lamps give a greater modulation at 100 Hz than that from fluorescent lamps. Although there have been no studies that demonstrate this directly, it is reasonable to argue that these lamps are unsuitable for libraries and offices and where moving machinery is used. Given that the disturbance of eye movements has now been demonstrated for 100-Hz modulation with a range of different spectral power distributions and duty cycles (on-off ratios)[62,63,64], the detrimental effects of the 100-Hz modulation from these lamps are likely to be at least as great as those from fluorescent lamps.

Most computer displays incorporate a cathode ray tube scanned by a raster at frequencies between 50 and 100 Hz. The flicker can increase the corrective movements that the eyes make by as much as a factor of two, at least in people who read with attention to orthographic detail[65]. Given these findings, it would seem important to avoid low-frequency modulation of light in installations where computers are used.

Table 1 summarises the relationships between health and efficiency of various trends in lighting practice. They must be treated as provisional, given our present ignorance. The effects of spectral power distribution on health are largely unknown.

CONCLUSION

Given the limited information available, there is no reason to suppose that health is likely to suffer as the result of improvements in the efficacy of lamps and the efficiency of luminaires, and the consequent trends in lighting practice. There is one important exception. Many high-pressure gas-discharge lamps provide considerable modulation at 100 Hz. Until high-frequency ballasts are available for these lamps, high-frequency fluorescent lighting is preferable in installations where people are likely to read or use rotating machinery.

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Table 1. Various trends in lighting practice and their consequences for health and efficiency.

Trend		Consequences	
away from	...and towards	for health	for efficiency
38-mm diameter halophosphate fluorescent lamps with 50Hz ballast	High-frequency ballast	good	good
	Dimmable ballast	good if flicker-free	good
	Narrow-band triphosphor lamps	possibly bad if 50-Hz ballast	marginal
	26-mm lamps	marginal	good
	High-pressure sources	possibly bad	good
Incandescent lighting	Compact fluorescent	bad if 50-Hz ballast	good
Tungsten	Tungsten-halogen	bad if high UV otherwise good	good
Array of down-lighting luminaires on ceiling forming dazzle pattern	Irregular array	good	none
	Multiple point sources	bad if glaring or high UV	bad if incandescent
	Uplighting	bad if 50-Hz ballast otherwise good	possibly bad
Constant lighting	Daylight controls	unknown	good
	Occupancy sensors	unknown	good
	Increased use of daylight	good	good