Artificial Daylight as Ergonomic Lighting
By Paul Stephenson

1. Introduction

The concept of ergonomics is not commonly associated in general awareness with lighting. Since lighting is usually a prime source of complaint in relation to offices this lack of awareness is surprising. In fact much study has gone into workplace lighting conditions. It seems to take a long period before academic research affects day-to-day lighting practice.

This paper raises certain ideas on the ergonomics of light that flow from the study of many researchers over the past 15 years. The central suggestion is that artificial daylight may play an important role in creating better workplaces.

However firstly it worthwhile considering a question that underlies all assumptions of the importance of better lighting conditions in offices.

2. Does better lighting increase productivity and well being in the workplace?

The simple answer is *yes*. Numerous studies support the link between lighting and human performance. Most recently in December 2003 the "*Lighting Quality and Office Work: A Field Stimulation Study*" by Boyce, Veitch, Newsham, Myer & Hunter formed the following conclusions:

1. Lighting and task conditions that improve visibility lead to better task performance.

2. People who are more satisfied with their lighting rate the space as more attractive, are happier, and are more comfortable and satisfied with their environment and their work.

3. Visual comfort did not predict visual capability.

4. People with dimming control reported higher ratings of lighting quality, overall environmental satisfaction and self-rated productivity.

5. People with dimming showed more sustained motivation, and improved performance on a measure of attention.

The clear conclusion from this research and from many other studies is that:

- Lighting can affect productivity
- Lighting does influence a sense of well being
- Lighting does impact on morale and motivation

Most people would have found these conclusions to be no more than confirmation of an intuitive belief that lighting conditions are important.

This conclusion inevitably leads on to a more complex question:

3. Which factors are important in creating 'better workplace lighting'?

These factors can be divided into two groups. The first group are *vision factors*, affecting the ability to see effectively. The second group are *comfort factors*, determining satisfaction with the visual environment. Although some factors are common, the two groups are quite distinct from each other.

Vision factors
Contrast - or reflectance difference - between a task and its background
Intensity range and control of light source
Spectrum of light source and resulting colour rendering effect
Direction of light source

Comfort factors
Contrast between the task area and the general room view
Control of glare in either task or general view
The lightness of the space
The luminous texture of the space
Spectrum of the light sources
Direction of the light sources
The perception of controlling intensity - through dimming or switching.

The first three vision factors are interlinked, because contrasting luminance between a task and its background is the key to visual acuity. Differing reflectance, adequate intensity and sufficient spectral content create this luminous contrast, which the eyes then process as an image. The final vision factor also affects contrast, in that most tasks are best lit from the side. This is because surface reflection, which reduces contrast, is minimised from this direction.

Many of these factors are application specific and the final ergonomic quality of any particular space will often therefore depend on detailed design. This is not an attempt to cover the whole subject, nor attempting to improve the CIBSE Code for Interior Lighting or the lighting guide (LG7) for offices, both of which provide guidance on many of these ergonomic issues.

However I do wish to suggest that the colour spectrum of the light source is important and insufficiently emphasised in current guidance. I shall start by answering the following question:

4. How does colour spectrum influence vision?

Contrast is a product of different reflectance between a subject of view and its background.. Colour sensation is the product of some wavelengths being reflected more than others, whilst black and white sensation is about lightness i.e. the result of all the wavelengths being equally absorbed and reflected respectively.

A wavelength can only be reflected if it is present in the source light. A colour can only be rendered naturally if the source light emits wavelengths in a similar distribution to that of daylight. It therefore follows that the spectral quality of the source is important in the quality of luminance contrast required for visual acuity.

This proposition is supported by the difficulty people experience reading under a light source with a very low Colour Rendering Index (CRI), even at high light levels. An example would be High Pressure Sodium (as found in many streetlights), which produces high light measurement but low acuity.

There is further point to make in this regard. Focal vision is concentrated on the foveal area of the retina, which is dominated by colour sensitive *cone* photoreceptors. Since these photoreceptors have varying sensitivity to different wavelengths it follows that the colour balance of the light source, even with black and white, will affect them. These 'colour' photoreceptors play a key role in vision of fine detail.

Research also suggests other mechanisms by which light source spectrum affects vision. During the 1990s researchers at the Lawrence Berkeley Laboratories (LBL) in California found that the colour of light had a direct impact on the visual operation of the human eye. The team led by Dr. Sam Berman[1-5] found that whiter light (CCT > 6000K) produced better acuity scores over a series of visual tests. It was discovered that the whiter light induced a smaller pupil size for the same intensity of light. The smaller pupil was easier for the eye muscles to focus. This created better visual performance. Additionally it was found that the contracted pupil in white light reduced the visual influence of defects that develop mainly around the periphery of the eye. This element was considered to help the visual capability of people over 40 years of age.

The LBL researchers were among the first to highlight the paradox that the whiter light, with its greater blue content, measured lower under standard light measurement, but actually produced higher visual acuity and greater apparent brightness.

These are several ways in which the spectral content of a light can affect the performance of the eye, but there are other aspects to vision as well. I wish to look at another question:

5. Can the spectral content of light have other effects on vision?

Again the answer seems to be *yes.* It has long been recognised that light has a direct effect on the functioning of the brain. A nerve tract (the RHT) from the rear of the eye passes directly to the hypothalamus area of the brain influencing everything from states of alertness and mood to blood pressure and body temperature. For example the effect of high intensity light is said to stimulate the brain in a manner similar to caffeine. Studies[7] have found that bright light will raise hormones, such as Cortisol, associated with alertness in the morning.

This is important for vision, because the neurology is as important as the optical process. It is known that the functioning of the feedback loop between eye and brain is influenced by the overall amount and spectrum of light entering the eye.

The photoreceptors in the greater area of the retina, away from the fovea, play a major role in the messages passed to the hypothalamus. These photoreceptors are predominantly of the *rod* type and as such much more sensitive to shorter (blue) wavelengths. The corollary is that blue light is more effective at stimulating the brain and increasing alertness. Berman referred in his research to the importance of lighting with a high *scotopic* output, in which the sensitivity of *rod* photoreceptors is weighted above that of *cones*. This suggestion is supported by research[6] at the Lighting Research Center in New York.

The preceding paragraphs explain the basis for believing that spectral content of the light source will affect our vision, through direct effects on the eye and the brain. However there is another aspect of light linking daylight to ergonomics.

This can be introduced by asking another question:

6. Does spectral content have an effect on people's well being and comfort?

The answer should be obvious to anyone who has spent time in a room lit with coloured light.

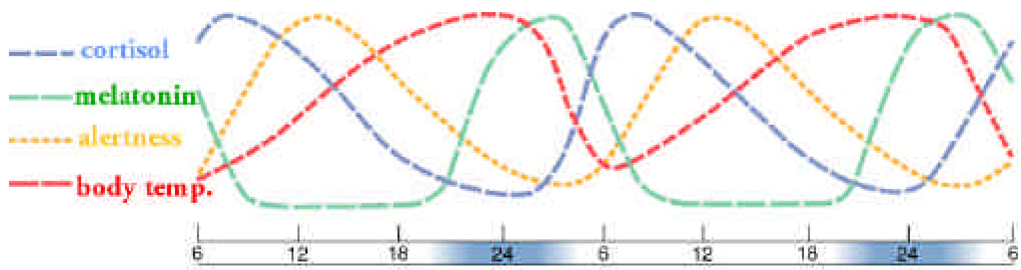
However the question relevant to ergonomics is really about the effect of different types of white light as used in artificial lighting. This is where the issue of artificial daylight and its difference from conventional electric lighting is important to workplace lighting design.

Daylight is the preferred light source for work of nearly everyone. This remains true even when views and other information connecting to the outside world are blocked. There is something about daylight itself that people like.

Certainly there is now wide recognition of the value of daylight in lighting schools and hospitals. Studies[8-9] show positive links between daylight and different forms of human productivity ranging from school results to shopping. Other research[10] supports the hypothesis that productivity does increase with the presence of daylight.

There are several reasons for this wide preference for daylight. Part of the effect is now attributed to the affect of daylight in entraining the human circadian rhythm. This circadian (daily) cycle of hormones within the bloodstream is controlled in the hypothalamic region of the brain. The cycle is influenced through the effect of light on the pineal gland. This small gland secretes the hormone melatonin into bloodstream in the absence of photostimulation from the retina. Melatonin prepares the body for sleep, which is a vital function in a healthy daily cycle, but only if it occurs at the correct time of day.

Normal human circadian cycle over 48 hours



Courtesy of Philips Lighting

Fig.1

Studies have shown that the Melatonin cycle is key to a healthy overall hormone cycle. A certain times of day, for example in the earlier part of the morning, it is vital that the eye receives sufficient amounts of the right type of light in order to suppress melatonin production.

If this does not happen, melatonin levels may remain at a raised level and a person will experience feelings similar to jet lag; lethargy, fatigue and a loss of alertness. This can then lead over time to depression and a general lack of well being that is often not understood. Many workers in the Northern Hemisphere complain of these symptoms during the winter months without understanding the possible connection with their light environment.

Workplace lighting conditions may not be effective at lowering melatonin levels.

Research[6,11,12] has discovered the importance of the blue end of the spectrum (>500nm) in the effective suppression of melatonin. They also discovered the relative ineffectiveness of the areas of the visible spectrum emphasised in conventional lighting (through the weighting of the *photopic* - the V_λ curve - photometry; *see below*).

Eye Sensitivity Curves

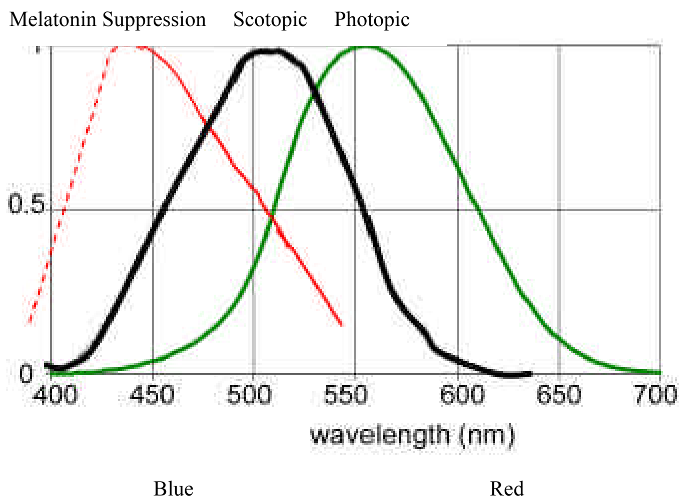


Fig.2 *Courtesy of Philips Lighting*

What all this means is that the way we measure lighting in conventional office lighting design is a poor indicator of the biological effect of that lighting. Standard light levels, for example 500 lux, may have very different effects on our circadian rhythm depending on the light source employed.

This leads on to a final question.

7. What is the ergonomic potential of artificial daylighting?

Every workplace is different and it is clear that some have plenty of daylight and others have none. Equally the role of electric lighting varies according to the space, the tasks and the hours worked. This is why we can we can only talk in terms of potential benefits for artificial daylighting.

That having been said and as technology improves, it is likely that artificial daylighting will be able reproduce much of the pleasure of natural daylight. Already we have lamps available with high CRI (>Ra=90) and rich blue content (CCT>6000K) and more balanced spectral output.

<u>Spectral Output of different colour (CCT) fluorescent lamps against natural daylight</u>

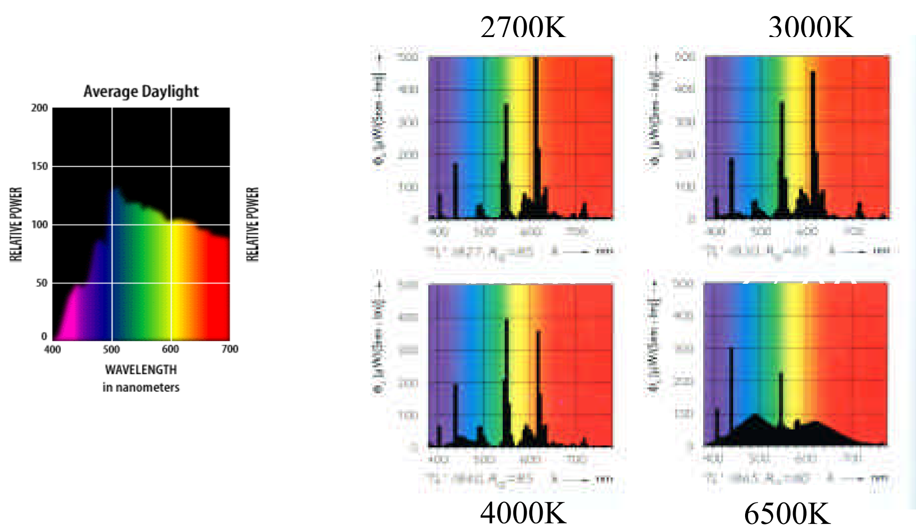


Fig.3 *Courtesy of Philips Lighting*

Emphasising this better balance in the spectral output makes sense in reproducing light closer to daylight. The research of the last few years has shown up some valuable information, but it is only partial picture. Using light sources that have significant output across the whole visible spectrum will probably lead to effects on the brain that are not currently measured or understood.

We know that in these effects lie the reasons for the overwhelming preference for daylight. With daylight having a continuous (D65) spectrum, it is logical that artificial light should too. However most triphosphor fluorescent lamps have spiky output, with whole wavelength areas given minimal output. Just by using a daylight colour (CCT=6500K) triphosphor means having a lamps with a much smoother output, well represented in the blue and red parts of the spectrum.

The evidence suggests that contrary to conventional photometry, we actually experience this whiter light as brighter. This creates the paradox of the current photopic measurement system, space that feels brighter but measures lower. In fact it represents an opportunity to use this characteristic to save energy and to produce more comfortable space at the same time.

One approach that would yield benefits is for the interpretation of lighting guidance - in particular levels - to be based on a more complete understanding of what is being measured.

The Berman research[1-5] strongly suggested people see better in daylight type lighting and added to this has been the studies that suggest it promotes better circadian regulation and alertness. There may be caveats about timing of the working day and the even greater effect dynamic changes of colour and intensity can achieve. However there seems to be strong evidence that in the higher latitudes of the Northern Hemisphere most workplaces would benefit from a daylighting approach.

Conclusions on the general ergonomics of lighting

There has been enough research for us to be fairly sure that the following elements of general workplace lighting support the development of an ergonomic lighting scheme:

- Artificial daylight is used as the ambient light source
- A combination of room and workstation based lighting.
- A degree of individual control of colour and/or intensity.
- More sources of light with variation of colour and direction.

With these elements in place a detailed design to the very best ergonomic standards is possible. This will create space that at the same time is good in appearance, comfortable to work in and effective in supporting acuity over long hours of visually demanding tasks.

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