DYNAMIC LIGHTING AT WORK – BOTH IN LEVEL AND COLOUR

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SUMMARY

The lighting parameters with which good lighting for work can be described need to be revised to also take into account the non-visual biological effects of lighting. A new parameter that has to be added to the conventional, visual performance related ones, includes, in particular: “the right combination of lighting level and colour temperature at the right moments and with the right duration to stimulate the natural activation and relaxation of workers”. Here the lighting level should be so determined that the right illuminance is obtained on the eye, this in contrast to the conventional task illuminance (often in the horizontal plane). A practical answer in the form of “dynamic lighting according to the human rhythm” is proposed. It is intended to give the same natural effects as was once provided by daylight when workers spent most of their working time outdoors.

INTRODUCTION

The visual effects of lighting determine our visual performance, while the non-visual biological effects are more important in determining our health and well-being. It has long been recognised that lighting also has a psychological effect, which in turn has much to do with our emotions. Where, until now, the psychological effect of lighting was thought to be linked to visual effects, we may now expect that there is also a relation with the non-visual biological effects. This reasoning leads to the interrelation as sketched in Figure 1.

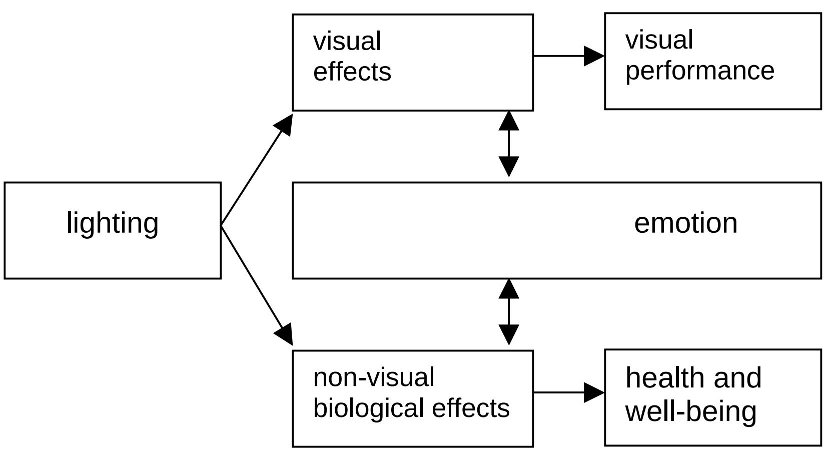

Fig. 1 Interrelations between lighting and the effects of it.

Only if we succeed in designing and installing lighting that results in both suitable visual and biological effects can we expect to attain optimum visual performance, health and well-being. And when we talk about lighting for work, this means the associated benefits of better work performance (speed), fewer errors, better safety (and hence fewer accidents), and lower absenteeism. It is thus evident that the lighting parameters with which good lighting can be described need to be based on both the associated visual and non-visual biological effects.

VISUAL PERFORMANCE AND ADAPTABLE LIGHTING

The lighting level should always be high enough to guarantee sufficient visual performance for the tasks concerned. Research on the quantity and quality of lighting over the past decades has shown that improvement of lighting quality from a low or moderate level increases the speed and accuracy with which objects can be detected and recognised. A person's actual visual performance depends upon the quality of the lighting and on his or her own "seeing abilities". In this respect, age is an important criterion since lighting requirements increase with age. Figure 2 serves as an illustration of the many research results pertaining to the influence of lighting quality on visual performance. It gives the relative visual performance as a function of lighting level for a visually moderately-difficult task (e.g. general machine work). From the figure it is evident that the effect of age on visual performance is very important. For the same level of visual performance, the lighting level must be much higher for older workers.

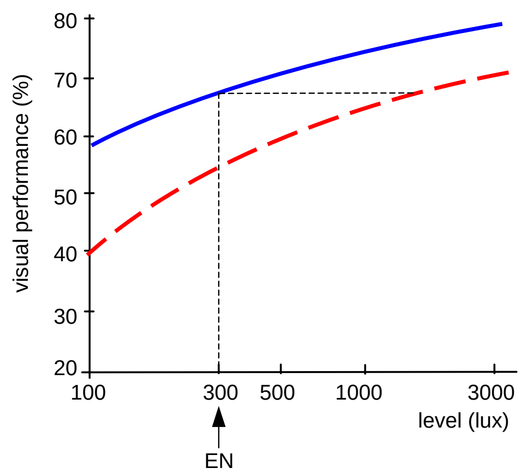

Fig. 2 Relation between visual performance (in %) and lighting level (in lux) for a visually moderately difficult task. Continuous blue line: young persons (ca 30 years), broken red line: older persons (ca 55 years). EN = requirement of European Standard for industrial tasks. Source: CIE [1].

Lighting that fulfils the relevant specifications given in norms and standards for lighting at work is thus not automatically good enough for all age groups. The age-dependent lighting level requirement in fact calls for lighting installations the lighting level of which can be adapted by the worker himself - preferably remotely controlled from the workplace. Older workers can then set the lighting level to their needs (higher than the "norm level"), while younger workers may choose to set the level lower than the "norm level". Such lighting installations also enable the creation of the right visual environment for the task being carried out. Indeed, research on the preferred visual environment shows that for different office tasks - such as desk work, CAD work and person to person communication (meetings) - different luminous environments are needed (see Figure 3).

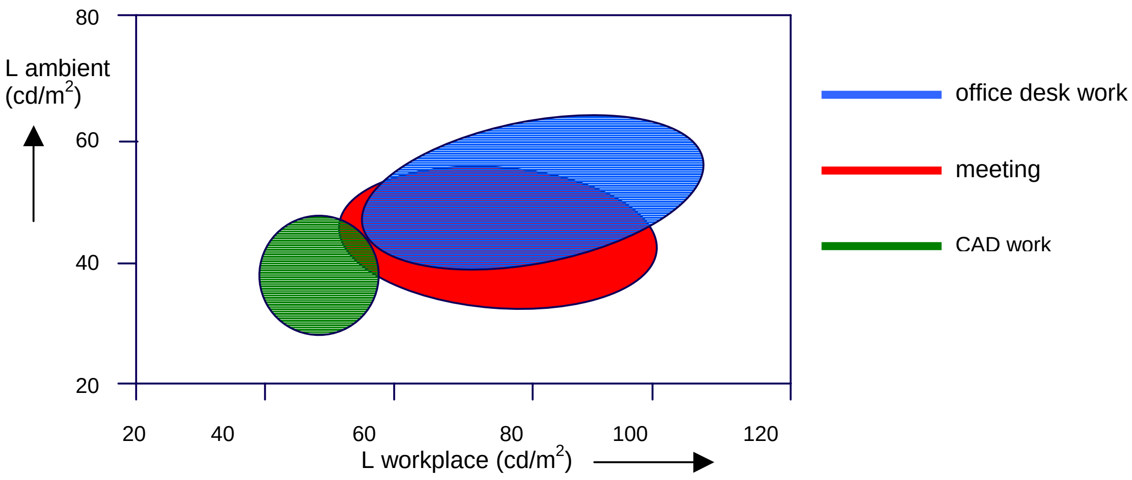

Fig. 3 Preferred values of the luminances of the workplace and of the ambient luminances (walls) for different work tasks (based on Van Ooyen and Begemann [2]).

BIOLOGICAL STIMULATION, LIGHTING LEVEL AND COLOUR TEMPERATURE

Many studies (amongst others those based on shifting the biological clock and on melatonin suppression) indicate that lighting levels of some 500 to 1000 lux on the eye are needed for biological stimulation [3]. This is provided that the duration of the light exposure is sufficient. For many conventional office and industrial artificial lighting installations, this means that a minimum horizontal lighting level of some 1500 lux, viz. a factor of 3 higher, is needed.

By using cool light colours, the required lighting level is lower because of the high blue sensitivity of the intrinsic photosensitive retinal ganglion cell responsible for non-image-forming signals. For example, when we compare light of 6000 K with that of 3000 K, the biological effectiveness of the former is close to a factor of 2 higher (based on action spectra data of Brainard et al. and Thapan et al. [4], [5]). Thus, if we wish to use 6000 K lighting at moments when biological stimulation is needed, a minimum lighting level of some 750 lux on the horizontal plane is required. Hopefully, future lighting recommendations and standards will specify levels needed on the eye in addition to horizontal lighting levels, so that this calculation “from eye to horizontal level” is no longer needed.

NEW RULES FOR GOOD AND HEALTHY LIGHTING AT WORK

Needless to say, good lighting has to satisfy a number of conventional rules set by our visual requirements. First of all are those expressed in terms of lighting level on the task as discussed above under the heading “Visual Performance and Adaptable Lighting”. Next come those regarding the spatial distribution of the light (uniformity and glare restriction) and those governing the colour rendering of the light source .

In the section above we have seen that a first new rule for “healthy” lighting involves providing the appropriate combination of lighting level on the eye and colour temperature of the light. Here a whole new aspect plays an important role as well, namely that this combination of lighting level and colour temperature should have the right timing and the right duration. But the spatial distribution of light may also be a factor in ensuring “healthy” lighting installations. Recent research by Glickman et al. [6] indicates that light incident on the upper part of the retina is less important biologically than that incident on the lower part. This would mean that light reaching the eye from above - and thus incident on the lower, or inferior, part of the retina - has a greater effect (or even the sole effect) than that reaching the eye from below.

Other studies suggest a difference in influence between nasal and temporal illumination of the retina [7]. Because of the limited number of studies into this aspect, these possible spatial effects cannot (yet) be taken into account in defining new rules for the lighting practice.

DYNAMIC LIGHTING

In a working environment, both action and relaxation are necessary. The colour and the level of the artificial lighting together may help to create the conditions needed for this. Figure 4 gives an example of a lighting scenario where both the level and the colour of the light gradually vary according to what we call the “human rhythm”. The lighting level is given in terms of the horizontal illuminance.

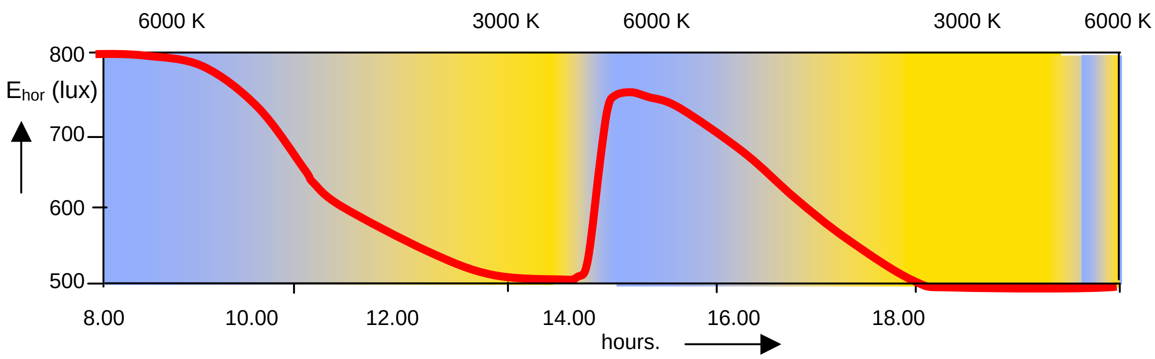

Fig. 4. Lighting scenario with gradually-changing lighting level (red line) and colour from 6000 K (blue area in graph) to 3000 K (yellow area in graph) according to the “human” rhythm.

The human rhythm is derived on the basis of obtaining the same effects daylight used to give when the human race spent most of its (working) time outdoors (e.g. as was the case before the industrial revolution).
Figure 5 shows the typical effects produced by outdoor daylight at different moments of the day. The human rhythm of artificial dynamic lighting in a work environment also shown in this figure is intended to create similar effects.

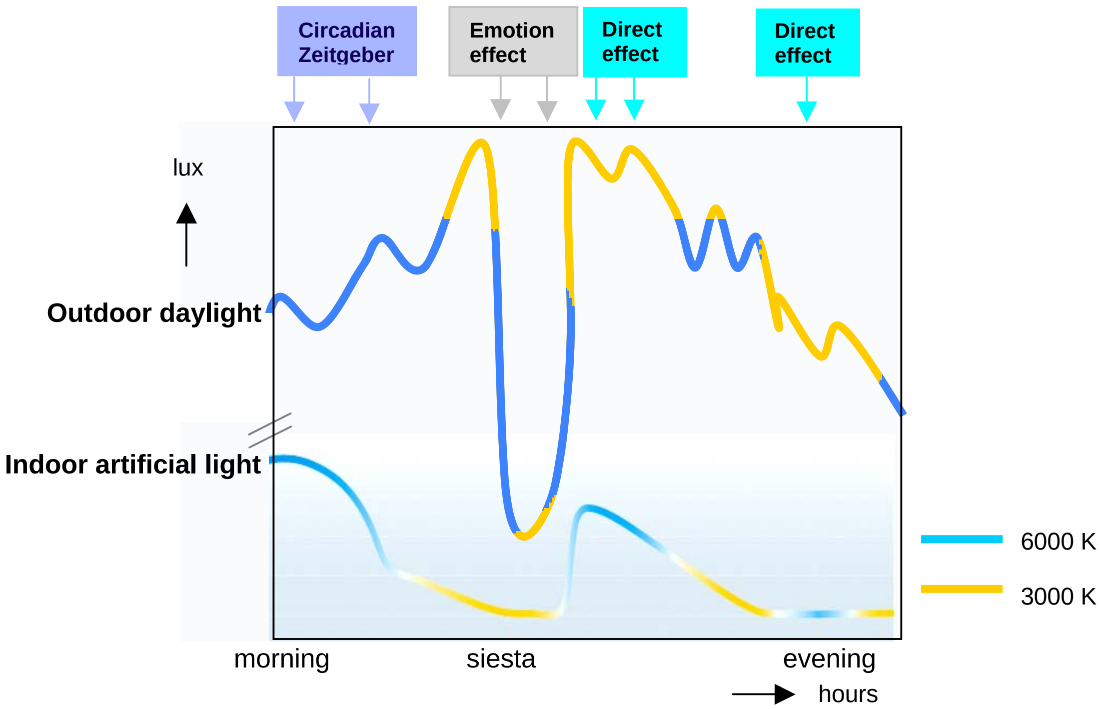

Fig. 5 Example of how outdoor daylight creates different effects at different moments of the day, compared with the human rhythm of artificial dynamic lighting in a work environment. The colour variation depicted by the outdoor lighting curve (blue and yellow) illustrates the random variation of daylight colour temperature. The colours for the indoor artificial light illustrate the gradual variation of colour temperature from 6000 K (blue) to 3000 K (yellow).

In the morning, the artificial lighting scenario starts with stimulating, cool-white light (6000 K) of relatively high level. This lighting helps maintain our 24-hour circadian rhythm, especially in regions where in the winter months people arrive at work in the dark. Subsequently, the lighting gradually turns into warmer white light of a lower level, the latter primarily to conserve energy. Around lunchtime, the minimum level needed for visual activities (500 lux) is provided, but in a warm-white colour (3000 K) so that an emotionally relaxing atmosphere is provided. Further research should clarify if there is here also a direct “biological relaxing” effect.
Providing a relaxing atmosphere is important since there are many research results that clearly show the recuperative effect of brief and ultra-brief naps around lunchtime with long lasting positive effects on afternoon alertness and cognitive performance [8], [9], [10], [11].
After lunch, a sharp rise in level and colour temperature (cool-white) is provided to re-activate the body. Again, emotional effects play a role here, but direct biological effects may be important in this respect as well. During the afternoon, both the lighting level and the colour temperature gradually decrease again (the decrease of lighting level again to safe energy). Just before the end of the working day, a short “boost” of cool-white light is given, without raising the lighting level (once again to conserve energy), to freshen-up the worker for the trip home.

The dynamic colour temperature range used as a basis for the human rhythm as illustrated in Figures 4 and 5 is from 6000 K to 3000 K. These colour temperatures are provided by mixing the light of normal fluorescent tubes of differing colour temperatures. The requirement here is that the mixing is done so perfectly that no colour differences from a single luminaire can be noticed for each possible setting of the combination of lamps. The range 6000 K to 3000 K is obtained with normal fluorescent lamps of colour rendering index 80. The recent introduction of a range of fluorescent lamps with extremely high colour temperatures ranging from 8000 K to 17000 K (ActiViva ®), also with colour rendering index 80, allows the dynamic range to be further extended.

Daylight, by its very nature, is dynamic in its intensity and colour. There are indications that such dynamic lighting has a positive effect on those working in an indoor environment [12]. However, where the benefits of dynamic daylight are not fully available, dynamic artificial lighting can provide a beneficial supplement in this respect.

In the Section “Visual Performance and Adaptable Lighting” it has been suggested that the worker himself should be able to adapt the lighting level. Dynamic lighting that automatically follows the human rhythm but that can be overruled by the worker can easily be realised. However, in order to avoid disturbing colleagues in the same area it might be advisable to restrict the range over which level and colour temperature can be varied.

The first practical small-scale dynamic lighting installations as described here have shown positive results as far as improved alertness and their acceptance is concerned. Large-scale installations are being installed and will be subjected to in-depth evaluation so as to be able to document their effect on well-being, preference, and possible effects on productivity.

When more detailed knowledge becomes available regarding the influence of timing and duration on biological stimulation and relaxation as required in a working environment, the curve of Figure 4 can possibly be further improved and refined.

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