

## Chapter3:Lightingquality

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### 3 Lighting quality

#### 3.1 Lighting practices and quality in the past: historical aspects

The use of electrical lighting, even in the industrialised world, is quite recent. Electrical lighting began to spread widely with the development and use of the incandescent lamps. The use of incandescent lamps reached a large scale at the beginning of the 20<sup>th</sup> century.

For thousands of years, people relied mainly on daylight and fire (bonfire, torches, candles and oil). The fundamentals of lighting at that time were related to the quantity of light that was to provide light for people to see and cope in the visual environment also during the dark hours.

Powerful lamps such as fluorescent lamps came to the market in the 1950s with the following introduction of high-intensity discharge lamps. The development of powerful bright light sources led to considerations of avoiding glare (using light diffusers, later light louvres). Moving from incandescent light sources to discharge light sources raised the issue of color rendering and color temperature. Today, LEDs are entering the lighting market and as new light sources they enable new approaches to lighting design and practice. LEDs introduce new possibilities for tuning the color of light and compared to conventional lights they are small in size giving also freedom for luminaire design.

Today, the variety and number of lighting equipment manufacturers has grown, but the fundamentals of lighting remains the same. These are to supply enough light with proper lighting distribution in space, with good spectral qualities and little or no glare, at reasonable costs. The development of light sources and lighting equipment provides both opportunities and challenges for the lighting designers in providing lighting that is not only adequate in terms of quantity, but also meets the lighting quality demands.



**Figure 3-1.** LEDs are used today to provide lighting in versatile applications; ranging from lighting of office buildings to lighting of homes in developing countries.

#### 3.2 Defining lighting quality

What does lighting quality mean? There is no complete answer to the question. Lighting quality is depends on several factors. It depends largely on people's expectations and past experiences of electric lighting. Those who experience elementary electric lighting for the first time, for example, in remote villages in developing countries, have different expectations and attitudes towards lighting from office workers in industrialized countries. There are also large individual differences in what is considered comfortable lighting, as well as cultural differences between different regions.

Visual comfort is also highly dependent on the application, for example lighting that is considered comfortable in an entertainment setting may be disliked and regarded as uncomfortable in a workspace (Boyce 2003).

Lighting quality is much more than just providing an appropriate quantity of light. Other factors that are potential contributors to lighting quality include e.g. illuminance uniformity, luminance distributions, light color characteristics and glare (Veitch and Newsham 1998).

There are many physical and physiological factors that can influence the perception of lighting quality. Lighting quality can not be expressed simply in terms of photometric measures nor can there be a single universally applicable recipe for good quality lighting (Boyce 2003, Veitch 2001). Light quality can be judged according to the level of visual comfort and performance required for our activities. This is the visual aspect. It can also be assessed on the basis of the pleasantness of the visual environment and its adaptation to the type of room and activity. This is the psychological aspect. There are also long term effects of light on our health, which are related either to the strain on our eyes caused by poor lighting (again, this is a visual aspect), or to non visual aspects related to the effect of light on the human circadian system (Brainard *et al.* 2001, Cajochen *et al.* 2005).

A number of different approaches have been suggested to define lighting quality (Bear and Bell 1992, Loe and Rowlands 1996, Veitch and Newsham 1998, Boyce and Cuttle 1998). The definition that seems most generally applicable is that lighting quality is given by the extent to which the installation meets the objectives and constraints set by the client and the designer (Boyce 2003). In this way lighting quality is related to objectives like enhancing performance of relevant tasks, creating specific impressions, generating desired pattern of behaviour and ensuring visual comfort. The constraints may be set by the available financial budgets and resources, set time-lines for completing the project and possible predetermined practices and design approaches that need to be followed.

Lighting quality is also a financial issue which can be best illustrated in the case of the luminous environment of work spaces. An assessment in French offices shows that a typical yearly electric lighting consumption amounts for about 4 €/m<sup>2</sup>, and total yearly ownership cost of lighting installations is around 8 to 10 €/m<sup>2</sup> (Fontoynt 2008). This has to be compared to the yearly cost of salaries for the companies, of about 3,500 €/m<sup>2</sup>, with the hypothesis of an employee costing 35,000 €/year, requiring about 10 m<sup>2</sup> of office space. Thus, average total lighting cost per employee are between 80 to 100 €/year. Assuming working hours of 1,600 hrs/year, or a cost per hour of 35,000 €/1,600 hour = 21 €/hour, it can be seen that the total cost of lighting required by an employee is equivalent to 4 to 5 hours of work per year, or 0.3 % of the yearly employee costs. This figure demonstrates the risk of offering poor lighting environment to the office employees. Poor lighting conditions can easily result in losses in productivity of the employees and the resulting production costs of the employer can be much higher than the annual ownership cost of lighting.

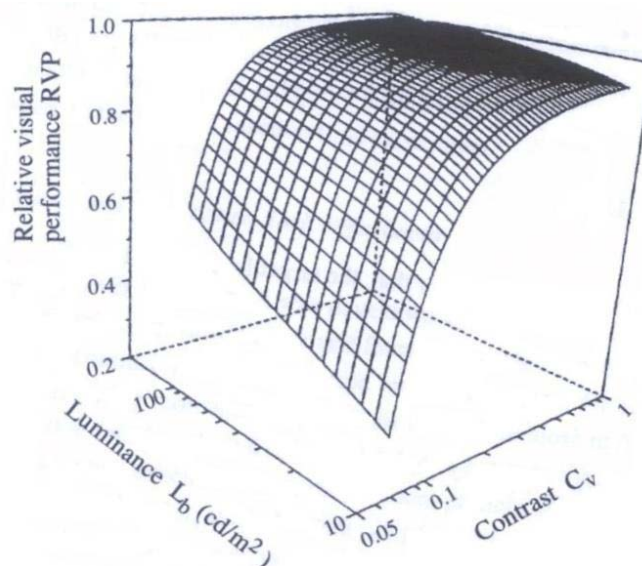
Thus, any attempt to develop energy efficient lighting strategy should, as the first priority, guarantee that the quality of the luminous environment is as high as possible. The results presented in this guidebook demonstrate that this is achievable, even with high savings in electricity consumption. In the search for highly efficient lighting schemes, it is essential to fully understand the detailed lighting specification of given environments. The integration of this knowledge in lighting design leads to opportunities to develop win-win scenarios, offering combination of energy performance and lighting quality.

### 3.3 Visual aspects

#### 3.3.1 Visual performance

One of the major aspects of the lighting practice is to provide adequate lighting for people to carry out their visual tasks and signs of given dimensions, at given distances and lighting conditions for writing, typing, reading, communicating and viewing slides and videos, or performing detailed tasks like sorting products. Visual performance is defined by the speed and accuracy of performing a visual task (CIE 1987) and visual performance models are used to evaluate the interrelationships between visual task performance, visual target size and contrast, observer average and luminance levels (CIE 2002). Light levels that are optimised in terms of visual performance should guarantee that the visual performance can be carried out well above the visibility threshold limits. Visual performance is improved with increasing luminance. Yet, there is a plateau above which further increases in performance (Rea and Ouellette 1991, CIE 2002). Thus increasing luminance levels above the optimum and can on the contrary lead to excessive use of energy. The visual performance aspect and consumption of electricity for lighting should be in balance in order to increase energy efficiency, not of course, forgetting the lighting quality aspects.

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**Figure 3-2.** Relative visual performance as a function of background luminance and target contrast. (Halonen 1993)

Ensuring adequate and appropriate light levels (quantity of light) is only an elementary step in creating comfortable and good-quality luminous and visual environments. It can be agreed that bad-quality lighting does not allow people to see what they need to see and/or it can cause visual discomfort. On the other hand, lighting that is adequate for visual tasks and does not cause visual discomfort is not necessarily good-quality lighting. Also, depending on the specific application and case, both insufficient lighting and too much light can lead to bad-quality lighting.

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#### 3.3.2 Visual comfort

There are a number of lighting-related factors that may cause visual discomfort and there is no straight-forward path to follow in creating visually comfortable luminous environments (Boyce 2003, Veitch 1998). The current indoor lighting recommendations give ranges of illuminance values for different types of rooms and activities (EN 12464-1 2002, CIBSE 1997, IESNA 2000). In

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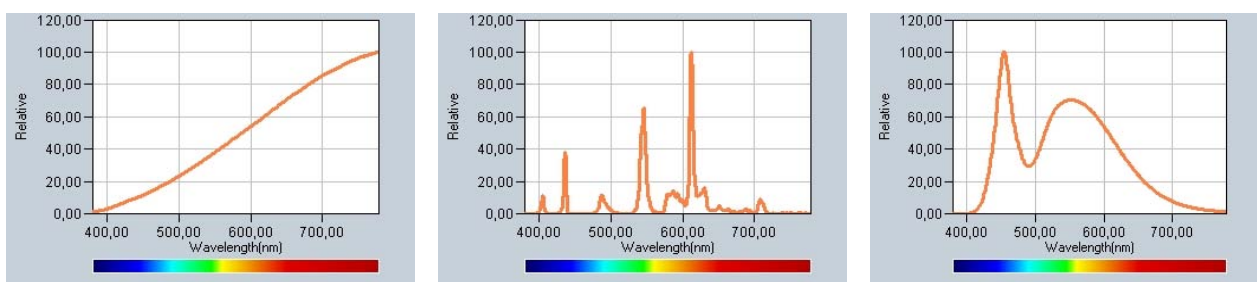
addition, guidelines on light distribution in a space and characteristics are given. Attention also needs to be paid to the formation of shadows in the space. The recommendation is to eliminate visual discomfort, but lighting design can add on that to provide visual comfort. Causes of visual discomfort can be too little light and too much light, too much variation in luminous distribution, too uniform lighting, annoyance from glare, veiling reflections, too strong shadows and flicker from light sources.

### Color characteristics

The color characteristics of light in space are determined by the spectral power distribution (SPD) of the light source and the reflectance properties of the surfaces in the room. The color of light is usually described by two properties, namely the correlated color temperature (CCT) and the general color rendering index (CRI). The color appearance of a light source is evaluated by its correlated color temperature (CCT). For example, incandescent lamps with CCT of 2700 K have a yellowish color appearance and their light is described as *warm*. Certain types of fluorescent lamps or white LED lamps have CCT of around 6000 K with a bluish appearance and light described as *cool*. The CRI of the CIE measures how well a given light source renders a set of test colors relative to a reference source of the same correlated color temperature (CIE 1995). The general CRI of the CIE is calculated as the average of special CRIs for eight test colors. The reference light source is Planckian radiator (incandescent type source) for light sources with CCT below 5000 K and a form of a daylight source for higher CCT. The better the color rendering of a light source, the maximum value being 100. The CIE general CRI has its limitations. The shortcomings of the CRI may become evident when applied to LED light sources as a result of their narrow peaked spectra. The CIE (CIE 2007) recommends the development of a new color rendering index (or a set of new color rendering indices), which should be applicable to all types of light sources including white LEDs. CIE technical committee TC1-69 Color rendering of White Light Sources is currently investigating the issue.

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**Figure 3-3.** Light source spectrum, i.e. radiant power distribution over the visible wavelengths, determines the light color characteristics. Examples of spectra of an incandescent lamp (CCT=2690 K, CRI=99), a compact fluorescent lamp (CCT=2780 K, CRI=83) and a white LED lamp (CCT=6010 K, CRI=78).

The Kruithof effect describes the psychological effects of preferences for varying CCT and illuminance level. It proposes that low CCTs are preferred over high illuminances (Kruithof 1941). The Kruithof effect is not, however, generally supported in later studies (Boyce and Cuttle 1990, Davis and Ginthner 1990). It is also suggested that color adaptation occurs when people spend certain time in a space, after which it is no more obvious that the color temperature preferences of people are culture and climate-related, as well as dependent of the prevailing lighting practices in different regions (Miller 1998, Ayama *et al.* 2002). Recently, it has been suggested that high color

temperature light could be used in increasing human alertness (see Ch. 3.5). More research is needed to confirm this and to apply these postulates in lighting design.

### ***Uniformity of lighting***

Uniformity of lighting in space can be desirable or less desirable depending on the function of the space and type of activities. A completely uniform space is usually undesirable whereas too non-uniform lighting may cause distraction and discomfort. Lighting standards and codes usually provide recommended illuminance ratios between the task area and its surroundings (EN12464-1 2002, CIBSE 1997, IESNA 2000). Most indoor lighting design is based on providing levels of illuminances while the visual system deals with light reflected from surfaces i.e. luminances. For office lighting there are recommended luminance ratios between the task and its immediate surroundings (EN12464-1 2002, CIBSE 1997, IESNA 2000). Room surface reflectances are an important part of a lighting system and affect both the uniformity and energy usage of lighting. Compared to a conventional uniform office lighting installation with fluorescent lamps, LEDs provide opportunities to concentrate light more on actual working areas and to have light where it is actually needed. This provides opportunities to increase the energy efficiency of lighting in the future.

### ***Glare***

Glare is caused by high luminances or excessive luminance differences in the visual field. Disability glare and discomfort glare are two types of glare, but in indoor lighting the main concern is about discomfort glare. This is visual discomfort in the presence of bright light sources, luminaries, windows or other bright surfaces (CIE 1987, Boyce 2003). There are established systems for the evaluation of the magnitude of discomfort glare, e.g. Unified Glare Rating (UGR) (EN12464-1 2002), Visual Comfort Probability (VCP) (IESNA 2000), British Glare Rating system (CIBSE 1997), yet the physiological or perceptual mechanism for discomfort glare is not established. The present glare indices are best suitable for assessing discomfort glare induced by a regular array of fluorescent lamp luminaries for a range of standard interiors, and there are a number of questionable problems related to the definition of the glare sources size and luminance and its immediate background luminance (Boyce 2003).



**Figure 3-4.** Luminaires and windows can induce direct glare, while light reflections from glossy surfaces and computer screens can induce indirect glare.

LEDs are small point sources with high intensities and arrays of these individual sources can form luminaires with very different shapes and sizes. Illuminating the space with LEDs special care has to be taken to avoid glare.

### *Veiling reflections*

Veiling reflections are specular reflections that appear on the object viewed and which reduce the visual task contrast (CIE 1987). The determining factors are the specularity of the surface and the geometry between the surface, observer and sources of high luminance (e.g. luminaires, windows, bright walls). Glossy papers, glass surfaces and computer screens are subject to cause veiling reflections. In rooms with several computer screens inside the task area special care has to be taken in the positioning of the luminaires to avoid luminous reflections from the screens. In using portable computers the viewing directions may change in relation to the fixed luminaires and this poses further requirements for lighting design. Also, when rearranging the working places and geometry of the working conditions, the possible causes of veiling reflections should be avoided in the typical viewing directions. With proper lighting design, i.e. positioning of luminaires related to working areas, it is possible to achieve the same visibility conditions with less energy than with incorrect positioning of luminaires causing veiling reflections to the working area.

### *Shadows*

Shadows in the space may be negative in obstructing the visibility of certain elements, but they can also be positive in creating an attractive and interesting visual environment. Whether shadows are considered as visually comfortable or discomfortable depends much on the application.

A good balance between direct light and diffuse lighting is important in order to see the way light falls on objects. In the quest for more parameters of lighting quality, it is worthwhile to study the shadows of objects in a deeper way: the light side of an object, the shadow side, the cast shadow and the presence of reflected light. This can give more connections between scientific and artistic knowledge of lighting qualities. Moreover, for the visual comfort in spaces it is necessary to pay more attention to the shadowing, especially for the comfort of elderly people and visually impaired.

### *Flicker*

Flicker is produced by the fluctuation of light emitted by a light source. Light sources that are operated with ac supply, produce regular fluctuations in light output. The visibility of these fluctuations depends on the frequency and modulation of the fluctuation. Flickering light is mostly used as a source of discomfort, except in some entertainment purposes. For some people flicker can even be a hazard to health. Flicker from light sources can be minimized by stable supply voltage or by using high frequency electronic ballasts with fluorescent and high intensity discharge lamps (EN12464-1:2002, CIBSE 1997, IESNA 2000).

## **3.4 Psychological aspects of light**

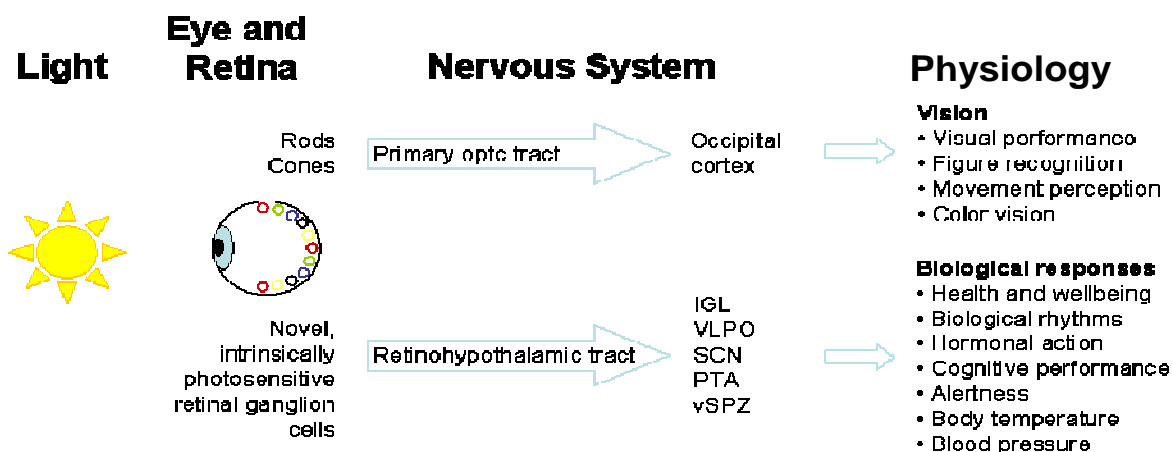
People perceive their luminous environment through their eyes, but they process this information with their brain. Light scenes are therefore judged in connection with references and expectations. The luminous environment can be appreciated in many ways e.g., more or less agreeable, more or less attractive, more or less appropriate to the function of the space, more or less highlighting the company image. Variations of luminances and colors can strengthen attractiveness, triggering emotions, and affect our mood, the impact of lighting depending much on the individuals and their state of mind. A lighting installation that does not meet the user's expectations can be considered unacceptable even if it provides the conditions for adequate visual performance. Unacceptable lighting conditions may impact on task performance and thus productivity through motivation (Boyce 2003, Gligor 2004).

### 3.5 Non-visual aspects of light

Light has also effects that are fully or partly separated from the visual system. These are called the non-visual, non-image forming (NIF) or biological effects of light and are related to the human circadian photoreception (Brainard *et al.* 2001, Cajochen *et al.* 2005).

The discovery of the novel third photoreceptor, the intrinsically photoreceptive retinal ganglion cell (ipRGC), in 2002 has raised huge interest both in the circadian biology and lighting research communities (Berson *et al.* 2002). The ipRGC has been found to be the main photoreceptor responsible for entraining humans to the environmental light/dark-cycle along with other biological effects. It represents a missing link in describing the mechanism of biological effects as controlled by light and darkness. Thus, light can be thought of as an external cue that entrains the internal clock to work properly. The human biological clock drives most daily rhythms in physiology and behavior. These include sleep/wake rhythm, core body temperature, and hormone secretion. It passes on information regulating the secretion of almost all hormones, including nocturnal pineal melatonin and serotonin, and cortisol. Besides the shifting of the phase of the endogenous clock by light, there is evidence of the involvement of the ipRGCs in pupillary reflex, alertness, mood, and in human performance (Dacey *et al.* 2005, Duffy and Wright 2005, Whiteley *et al.* 1998).

There is evidence that short-wavelength light is the most effective in regulating the biological clock (Brainard and Hanifin 2006, Wright *et al.* 2001, Thapan *et al.* 2001). Thus much research is currently investigating the possibility to use blue-enriched light to affect human responses and behaviour like alertness and mood (Gooley *et al.* 2003, Lehr *et al.* 2007, Mills *et al.* 2007, Rautkylä *et al.* 2009). The effect of light on alertness has been much examined, but the mechanism explaining the detected reactions still remains unclear.



**Figure 3-5.** Light has both visual and non-visual responses acting through the different retinal photoreceptors and tracts in the nervous system.

The biological effects of light and their effects on human performance are not yet very well known. A considerable amount of research work is still required before we can understand the non-visual effects of light and consider them in lighting practice. Research work is needed to generate an improved understanding of the interaction of the effects of different aspects of lighting on behavioral visual tasks and cortical responses and on how the biological effects of lighting could be related to these responses.

### 3.6 Lighting and productivity

Lighting should be designed to provide people with the right visual conditions that help them to perform visual tasks efficiently, safely and comfortably. The luminous environment acts through a chain of mechanisms on human physiological and psychological factors, which further influence human performance and productivity (Gligor 2004).

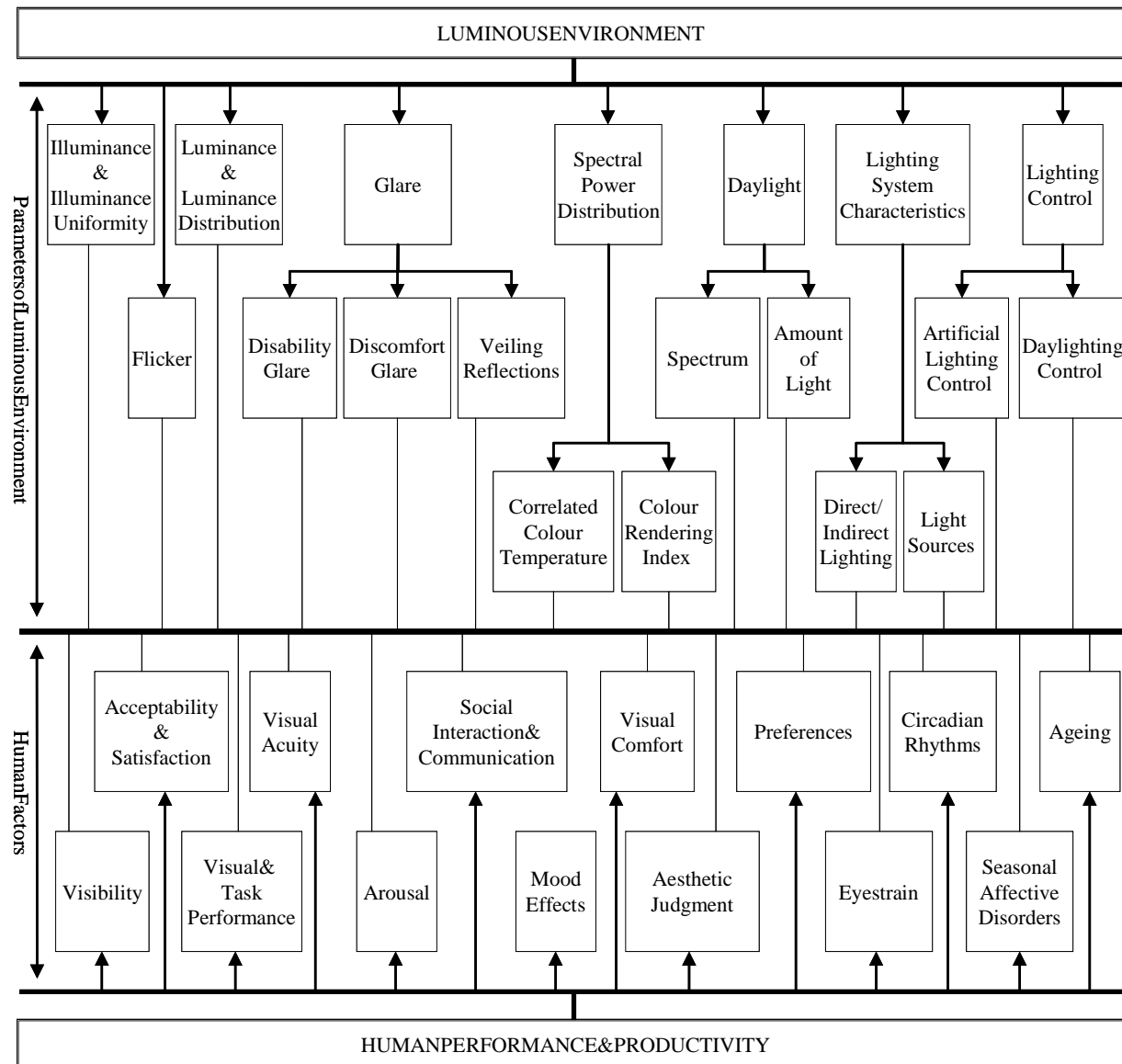


Figure 3-5. Luminous environment and human performance. (Gligor 2004)

There have been several field studies on the effects of lighting conditions on productivity. The earliest studies were made in the 1920's (Weston 1922, Weston and Taylor 1926) and indicated that lighting conditions can improve performance by providing adequate illuminance for the visual tasks. Since then a number of studies have been carried out. Their results are sometimes contradictory. For example, a study in clerical office work indicated that an increase in illuminance from 500 lx to 1500 lx could increase the performance of office workers by 9% (Hughes and McNelis 1978), while another study showed that lower illuminance levels (150 lx) tended to improve performance of a complex word categorisation task as compared to a higher level (1500 lx) (Baron *et al.* 1992). A field study in industrial environment measured direct productivity increases in the range from 0 to 7.7% due to changes in lighting (Juslén 2007). The literature includes more

examples of null results than clear-cut effects of range of illuminance levels and for a variety of conditions (Gligor 2004).

The effect of lighting on productivity is ambiguous. The relationship between lighting and productivity is that there are several factors that affect performance. These factors include motivation, relaxation, and the degree of having personal control over the work environment. When lighting is appropriate, the ability to perform visual tasks can be improved. This can provide conditions for better visual and task performance. The difficulty of field studies in working environments is the degree of experimental control required. Several studies have investigated the effect of increase in illuminance on task performance. However, illuminance is only one of the many aspects in the lighting conditions. In making changes to lighting, which lighting aspects are changed (e.g. illuminance, spectrum, and luminance distribution) and whether there are other factors that are simultaneously changed in the working conditions (e.g. working arrangements, people, supervision of work) need to be controlled and analyzed. Recently, several studies are investigating the effects of light spectrum on human performance and the possibilities to use blue-enriched light to improve human performance through the non-visual effects of light (see Ch. 3.5).

illuminance on task performance, over a wide range of complex and simple tasks in office work (Gligor 2004).

The difficulty in finding the relations between other factors that simultaneously affect human performance is the degree of experimental control. The relationships between workers and the management are important. Working conditions (Boyce 2003). With appropriate lighting, visual discomfort can be avoided. Task performance and, ultimately, productivity. The degree of experimental control is the degree of experimental control. The effect of increase in illuminance on task performance is the degree of experimental control. In many aspects in the lighting conditions. In making changes to lighting, which lighting aspects are changed (e.g. illuminance, spectrum, and luminance distribution) and whether there are other factors that are simultaneously changed in the working conditions (e.g. working arrangements, people, supervision of work) need to be controlled and analyzed. Recently, several studies are investigating the effects of light spectrum on human performance and the possibilities to use blue-enriched light to improve human performance through the non-visual effects of light (see Ch. 3.5).

### 3.7 Effects of electromagnetic fields on health and optical radiation safety requirements

Lighting equipment and systems produce electric and magnetic fields. The potential effects of these fields on human health depend widely on the frequency and their intensity, but the effects of human exposure to electromagnetic fields are still not fully known.

magnetic fields. The potential effects of these fields on human health depend widely on the frequency and their intensity, but the effects of human exposure to electromagnetic fields are still not fully known.

Optical radiation may have hazardous effects on human health, eyes and skin. To assess these effects the spectral distribution, the size (projected size) of the source and the distance from the source at the point of nearest human access need to be defined. The IEC/CIE Standard 62471-1/CIE S 009 Photobiological Safety of Lamps and Lamp Systems assesses the optical radiation hazards from lamps, an array of lamps and lamp systems (IEC/CIE 2006). All types of electrically powered optical radiation sources including LEDs are covered in the standard. Reference measurement techniques and a risk group classification system for defining optical radiation hazards are also included. The standard provides a basis for evaluation of potential hazards that may be associated with different lamps and lamp systems. The IEC Technical Report 62471-2 Guidance on Manufacturing Requirements Relating to Non-laser Optical Radiation Safety provides basis for safety requirements dependent on risk group classification and related examples (IEC/CIE 2008). Similarly to the IEC/CIE standard (IEC/CIE 2006) the ANSI/IESNA Recommended Practice RP-27.1-05 Photobiological Safety for Lamp and Lamp Systems covers the evaluation of optical radiation hazards from all lamps and lamp systems (ANSI/IESNA 2007).

The emerging LED technology brings powerful and high brightness lighting products on the market. The wider the field of light (i.e. size of the illumination source) and the brighter (higher luminance) of that source, the more potential risk it carries for the retina. The ICNIRP Statement (ICNIRP 2000) reviews the potential optical hazards from LED sources and the related standards and regulations. It is recognized that the determination of appropriate viewing durations and distances under different conditions of use is needed for any optical radiation hazard assessment. The Statement recommends that safety evaluations and related measurement procedures for LEDs follow the guidelines for incoherent sources (other than laser). It concludes that the future development of application-specific safety standard applicable to realistic viewing conditions will reduce the unnecessary concerns regarding LED safety.

The photochemical retinal injury is often referred to as the blue light hazard (BLH). CIE TC6-14 The Blue-Light Hazard has studied the means and methods to evaluate potential BLH. The outcome of the TC6-14 work is published under CIE 138-2000 (CIE 2000). The report proposes a technique employing the ACGIH (American Conference of Governmental Industrial Hygienists) threshold limit value (TLV) for general use. Currently, CIE TC6-57 is preparing a draft CIE standard on the definitions and action spectra for two retinal hazard functions used in photobiological safety documents. CIE TC6-55 is studying the different methods of assessing the photobiological safety of LEDs. This work reviews the known effects from a physiological standpoint and will determine the dose relationships that pose a potential risk for eye injury from excessive irradiation.

The European Directive (2006/25/EC) includes minimum health and safety requirements for occupational exposure to artificial optical radiation. It introduces measures to protect workers from risks related to optical radiation and its effects on health and safety, particularly to the eyes and the skin. The Directive provides a method to determine biophysically relevant exposure levels for UV-, visible and IR-radiation to be compared with given exposure limit values.

### 3.8 Conclusions: opportunities and barriers

Light affects human behaviour through various processes and new routes can be found in the future through the non-visual effects of light. Light can act as a stimulator (perception, alertness, etc.) or as an inhibitor (glare, heart rate variability, etc.). Any choice in lighting design will therefore have a consequence, which may sometimes be negligible, sometimes essential. Increasing the quality of lighting does not mean to use more energy. On the contrary, with careful consideration of the different lighting factors and with proper lighting equipment, the energy consumption of lighting can still be decreased while improving the quality of lighting.

In investigating lighting schemes for energy conservation, it is clear that at the existing level of knowledge, both opportunities and barriers in energy efficient lighting strategies can be identified.

#### 3.8.1 Opportunities

Indoor lighting design is based largely on providing more or less uniform levels of illuminances in the room, while the perception of the luminous environment is related mainly to light reflected from surfaces, i.e. luminances. Thus innovative lighting design methods could be introduced which give a high priority to the quality of the luminous environment as our eyes perceive it. The possible obstacles and constraints set by the current regulations for horizontal illumination levels should be identified, and ways for designing and implementing more innovative lighting solutions should be sought. Compared to conventional uniform office lighting installation with fluorescent lamps, with LEDs it is possible to concentrate light more on actual working areas and to have light where it is actually needed. This will help to increase the lighting energy efficiency in the future. Simultaneously, LEDs can be used to create interesting visual environments with varying luminance distributions and shadows when desired.

It is clear that the traditional assessment of light on the basis of visibility is not adequate for describing the complex, but undeniable, effects lighting can have on humans. This opens up windows for designing healthier living and working conditions for people in the future. The findings on the interactions of light and the human circadian system indicate that light can have non-visual effects on several human systems including sleep/wake rhythm, core body temperature, hormone secretion, alertness and mood. This provides opportunities to design better lighting conditions optimised for human performance and well being, with emphasis, for example, on light distribution and patterns in space and possibly dynamic light intensity and color. However,

considerable research work is still required before we can understand the non-visual effects of light and consider them in the lighting practice. The underlying mechanisms of action and the quantification of light characteristics, including exact spectral composition, light intensity, exposure duration and prior light history remain to be investigated.

Better lighting quality does not necessarily mean higher consumption of energy. While it is important to provide adequate light levels for ensuring optimized visual performance, there are always levels above which further increases in illumination do not improve performance. More lighting does not necessarily mean better quality of lighting. Through the use of energy efficient lighting products and light room surfaces it is possible to design energy efficient and good quality lighting.

New technologies such as LEDs and OLEDs offer high flexibility in the control of light spectra and intensities, which enhance their attractiveness beyond their growing luminous efficacy. The increased possibilities to control both the light fluxes and spectra of light sources should allow the creation of more appropriate and comfortable luminous environments. Visual comfort requirements should benefit from the increase in the supply of light sources and components, leading to better control of the luminance distribution. Also, the development of lighting control systems, based on presence detection and the blending of electrical light with daylight, can lead to substantial increases in energy efficiency.

Daylight is a powerful light source, requiring no energy to produce. Daylight has a continuous spectral composition and provides good color rendering. Daylight is usually preferred by people working indoors and it can enhance motivation and can be linked to human circadian rhythms (Dehoff 2002). Daylighting techniques should offer new opportunities for lighting systems in buildings. Care has to be taken in utilizing daylight in indoor lighting to control it properly in order to avoid its glare effects and any veiling reflections resulting from direct or indirect sunlight.

### 3.8.2 Risks

Reduction of the size of light sources (compact HID lamps, LEDs) may lead to increased risk of glare. Standards and recommendations should be adapted accordingly.

The recent findings on the biological effects of light may induce temptations to use blue enriched light in indoor lighting in order to affect human responses. However, a considerable number of research work is still required before we can understand the non-visual effects of light and consider them in the lighting practice.

The possible adverse effects of light on health should be understood before using light to increase alertness and productivity in shift-work. For example there is hypothesis that regular bright light exposure at night-time is associated with increased likelihood of breast cancer (Stevens *et al.* 1997). More research is required on the effects of night-time light exposure on human health and performance.

Photons in the blue range of light are more powerful than the ones in the red range, leading to possible hazards associated with blue light when not controlled properly. The intensity of the short wavelength light, the viewing distance and the viewing duration are the determining factors here.

Energy conservation measures may lead to the risk of poor lighting environment to the office employees. Poor lighting conditions can easily result in losses in productivity of employees and the resulting production costs of the employer can be much higher than the annual ownership cost of lighting.

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