LIGHTING FOR OCCUPATIONAL HEALTH AND HYGIENE

Alan Smith
Lighting Consultant
Honorary Research Fellow, Institute of Occupational & Environmental Medicine, University of Birmingham, UK
Visiting Senior Lecturer, Department of Optometry, Faculty of Life Sciences, University of Manchester, UK

Keywords: Accommodation, Adaptation, Black body radiation, Blue light hazard, Candela, Categories of vision, CIE chromaticity diagram, Color, Color vision, Control gear, Discharge lamps, Electromagnetic Interference (EMI), Electromagnetic spectrum, Emergency lighting, Flicker, Glare, Illuminance, Incandescent lamps, Infrared radiation, Ingress Protection (IP) classification of luminaires, Lamp coding systems, Light emitting diodes (LEDs), Light pollution, Lighting and well being, Lighting systems, Lumen, Lumen method of lighting design, Luminaires, Luminance, Modeling, Optical radiation, Photometry, Phototherapy, Radiometry, Radio frequency interference (RFI), Risk assessment, Spectral power distribution (SPD), Stroboscopic effect, Task lighting, The eye, Ultraviolet radiation, Veiling reflections, Visual acuity

Contents

Summary

The assertion that 'Lighting is of vital importance in the working environment' - is substantiated by the clinical statement that light flowing into the eye produces approximately 85% - 90% of all of the information entering the brain. In addition to allowing humans to see, light triggers a complex variety of activities in the brain that control metabolism and hormones.

For centuries natural light was the only means of illuminating spaces. Even now many workers still prefer to carry out tasks in daylight, which is perhaps to be expected since man's biological systems evolved in natural light over many years.

It was, however, largely due to the advent of lighting driven by electricity that the continuation of working practices could be routinely maintained after daylight. As a consequence of the ability to work round the clock – both internally and externally - the functionality of lighting was reappraised. Lighting in the workplace is now almost universally provided a) to aid in the performance of visual tasks and b) to contribute in the aim of making the workplace safe and healthy.

Artificial light has become hugely important to human social and economic activity and yet at the same time it has become so routine that we have almost ceased to notice it to such an extent that it is taken for granted.

Occupational hygiene is the discipline of anticipating, recognizing, assessing, evaluating and controlling risks to health from workplace exposure to hazards. There is clear evidence that improved lighting conditions increase worker safety and wellbeing, staff morale and worker retention together with a simultaneous improvement in productivity. A lack of awareness of the importance of lighting may be a causal factor in poor workplace ergonomics and therefore worker dissatisfaction that in turn may lead to a reduction in productivity and a simultaneous increase in workplace accidents.

1. Introduction

This Chapter aims to guide the reader through the fundamentals of vision and lighting in the workplace, and to highlight the potential health and safety problems that can develop as a consequence of inadequate lighting. It further aims to give guidance in respect of the necessary remedies available in order to strive for optimum lighting conditions for the workplace.

It is appreciated, however, that different countries throughout the world have their own legislation which must be adhered to in an attempt to produce safe working environments. Some countries adhere to continent-wide legislation, others refer to national legislation and in some areas the laws relating to health and safety issues (including lighting) may vary from state to state or between provinces.

It is therefore beyond the remit of this Chapter to include detail of all worldwide legislation relating to lighting in the workplace. Readers are advised to seek guidance from the appropriate authorities in order to ensure compliance with relevant legislation.

As a consequence, the author (and the publishers) make no warranty (ies), express or implied, nor assume any liability in respect of the use, or subsequent damages resulting from the use, of the information contained in this Chapter. Furthermore compliance with the recommendations given in the Chapter does not guarantee compliance with the specified legislation but implementing the recommendations in the guidance should assist in the reduction of the probability of contravention arising.

2. Electromagnetic Spectrum

Light is a form of energy. It passes from one body to another and can do so without the need for any substance in the intervening space. Such energy is termed radiation and it is said to be electromagnetic in character. The radiation thus has both an electric field and a magnetic field. Both of these fields vary sinusoidally and are mutually at right angles.

2.1. Optical Radiation

Light is an everyday example of optical radiation which is known as artificial optical radiation, if it is radiation that is emitted by a lamp. The use of the term ‘optical radiation’ is justified since light is a form of electromagnetic radiation, and because it is focused and then detected by the eye.

The colors that we perceive in light are dependent upon the wavelengths present in the light spectrum. Shorter wavelengths appear at the blue end of the spectrum whereas longer wavelengths appear at the red end. It is convenient to think of light as a stream of particles, known as photons.

When electromagnetic radiation interacts with a material, energy is likely to be absorbed at the point of interaction. This may result in some changes or effects in the material. As an example, visible light arriving at the retina provides enough energy to initiate biochemical reactions which, in turn, produce a signal that is ultimately sent to the brain via the optic nerve.

The quantity of energy available in electromagnetic radiation is dependent upon the wavelength. The shorter the wavelength corresponds to a more energetic radiation than is contained in longer wavelengths. It follows that blue light is more energetic than say red light.

2.2. Visible Radiation

Visible radiation is the term given to that radiation which is detected by the eye. It occupies only a relatively narrow range of wavelengths within the whole of the electromagnetic spectrum. Figure 1 shows the electromagnetic spectrum with the visible spectrum shown in detail.

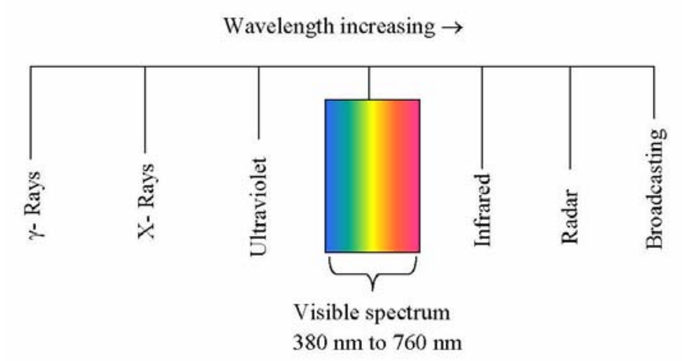

Figure 1. The electromagnetic spectrum

2.3. Ultraviolet Radiation

At lower wavelengths than the visible spectrum the radiation becomes ultraviolet (UV). Ultraviolet radiation is usually produced either by the heating of a material to incandescence or alternatively by the excitation of a gas discharge. The major source of UV radiation is the sun which can be considered to be a huge incandescent mass. When produced by incandescence UV radiation is in the form of a continuous spectrum.

An everyday example of the emission of ultraviolet radiation in industry is the arc produced in the electric welding process. The arc is created by the passage of an electric current across an air gap and between two metallic conductors or electrodes. The tip of the electrode, the workpiece and the air gap are in combination heated until incandescence is reached. Spectral analysis shows that there is a continuum produced with discrete spectral lines superimposed. The characteristics of these lines are significantly influenced by the properties of the materials from which the electrode and workpiece are made and also by the properties of the surrounding gases.

UV radiation is sub-divided into three groups, referred to as A, B and C that are described by the limiting wavelength values as detailed in Table 1.

Group	Lower limit wavelength value (nm)	Upper limit wavelength value (nm)
Ultraviolet C (Far UVC)	100	280
Ultraviolet B (Middle UVB)	280	315
Ultraviolet A (Near UVA)	315	400

Table 1. Ultraviolet radiation groups

2.4. Infrared Radiation

At higher wavelengths than the visible spectrum the radiation becomes infrared (IR).The principal source of infrared radiation is heat sometimes referred to as thermal radiation. This is produced by the motion of atoms and molecules within an object. The higher the temperature of the object, the more the atoms and molecules are agitated and therefore the more infrared radiation they produce. Any object which has a temperature above absolute zero i.e. 0 Kelvin or -273.15 degrees Celsius), radiates in the infrared region of the electromagnetic spectrum.

Humans, at normal body temperature (approximately 37° Celsius), radiate strongly in the infrared, at a wavelength of about 10 microns, where a micron is equivalent to a micrometer or one millionth of a meter. Humans experience infrared radiation every day – for example the heat that we feel from sunlight or an open fire is infrared. Whilst our eyes cannot see this radiation the nerves in our skin detect it as heat. The nerve endings in our skin are temperature-sensitive and can detect the difference between the inside body temperature and the outside skin temperature.

IR radiation is sub-divided into three groups, referred to as A, B and C that are described by the limiting wavelength values as detailed in Table 2.

Group	**Lower limit wavelength value (nm)**	**Upper limit wavelength value (nm)**
Infrared C (Far IRC)	3×10^3	10^6
Infrared B (Far IRB)	1400	3×10^3
Infrared A (Far IRA)	700	1400

Table 2. Infrared radiation groups

2.5. Wavelength, Frequency and the Velocity of Propagation of Light

Light travels sinusoidally in waves and a relationship exists between the length of the wave, its frequency and the velocity of propagation of light whereby:

$$Velocity\ of\ \ propagation\left(\text{meters per second}\right) = Frequency\left(\text{Hertz}\right) \times Wavelength\left(\text{meters}\right)$$
(1)

3. Fundamentals of Illumination

3.1. SI Units – Basic and Derived

The SI system of units was agreed by the 11th General Conference on Weights and Measures (CGPM) in 1960. There are seven basic units from which all other units are derived, as shown in Table 3.

Unit	Symbol	Parameter
Ampere	A	Electrical current
Kilogram	kg	Mass
Meter	m	Length
Second	s	Time
Kelvin	K	Absolute temperature
Mole	mol	Amount of substance
Candela	cd	Luminous intensity

Table 3. Basic SI units

Examples of derived units are shown in Table 4.

Parameter	Unit name (where applicable)	Derivation
Force	Newton	$Kg.\ m.\ s^{-2}$
Density		$Kg.\ m^{-3}$
Luminance		$cd.\ m^{-2}$
Pressure	Pascal	$Kg.\ m^{-1}.\ s^{-2}$
Energy	Joule	$Kg.\ m^{2}.s^{-2}$
Power	Watt	$Kg.\ m^{2}.s^{-3}$
Electrical charge	Coulomb	A.s

Table 4. Derived SI units

3.2. Radiometry

Radiometry is the science of the measurement of electromagnetic radiation and is based on physical constants. The subdivisions of interest in radiometry are – radiant flux, radiant intensity, radiance and irradiance.

-
-
-

Bibliography

The Restriction of Hazardous Substances Directive. Directive 2002/95/EC of the European Parliament and the Council of the European Union (27 January 2003). (UK Statutory Instrument SI 2008 No. 37) [This directive restricts the use of six hazardous materials (including PCBs) in the manufacture of various types of electronic and electrical equipment].

Lighting Industries Federation (UK) - Technical Statement No. 37 - The implementation in the UK of the Restriction of Hazardous Substances (RoHS) Directive. 5pp 2006 [Covers the implementation of the restriction on the use of six hazardous materials (including PCBs) in the manufacture of various types of electronic and electrical equipment].

Lighting Industries Federation (UK) - Technical Statement No. 7 - Precautions against ultra-violet radiation from H.I.D lamps – single page June 1995. [Refers to mercury and metal halide discharge lamps which should always be run in a luminaire specially designed for their operation].

Lighting Industries Federation (UK) - Technical Statement No. 8 – UV Radiation and Health – 3pp - October 2001. [Refers to suggested connections between health and lighting, with particular reference to UV radiation and health].

Lighting Industries Federation (UK) - Technical Statement No. 9 - Precautions against infrared radiation from halogen heat lamps - single page - October 2001. [Refers to potential dangers from infrared radiation e.g. eye damage].

Lighting Industries Federation (UK) - Technical Statement No. 10 – The Handling and Disposal of Lamps – 3pp - May 2006. [Refers to The Control of Substances Hazardous to Health (COSHH) Regulations 1994 which place duties on employers to protect employees and other persons who may be exposed to substances hazardous to health].

Lighting Industries Federation (UK) - Technical Statement No. 24 - Fluorescent lamps – a) mercury reduction b) amalgam lamps - 3pp - May 2006 [Refers to the reduction of mercury in fluorescent lamps].

Light’s Labour’s Lost - Policies for Energy-efficient lighting in support of the G8 plan of Action -The International Energy Agency (IEA) 2006 – 558 pp. [A comprehensive document published by The International Energy Agency (IEA) with reference to policies for energy efficient lighting].

Encyclopaedia of Occupational Health & Safety (4th edition), International Labour Office (ILO), Geneva, Switzerland, 1998 Vol.2, Part VI, Ch. 46 - General Lighting Conditions. [An international reference encyclopedia relative to health and safety in the workplace].

Smith N. A., Lighting for Health & Safety, Butterworth Heinemann, 2000 – 227 pp. [A reference text devoted to lighting for health & safety in the workplace].

Boyce P.R., Human Factors in Lighting, Taylor & Francis, 2003 – 602 pp. [This book is a comprehensive review of the interaction of people and lighting].

Van Bommel, Wout, Incandescent replacement lamps and health, LED Professional Review – June 2010 – 4 pp. [Investigates the use of CFL and/or LED alternatives to incandescent lamps and possible effects on health].

Osram Lighting – OLED Lighting – Overview – 2010 – 29 pp. [A manufacturer’s description of the properties and uses of organic light-emitting diodes].

References

The SI (*Système International d'Unités*) system of units - 11th General Conference on Weights and Measures (CGPM) in 1960. General Conference on Weights and Measures (*Conférence générale des poids et mesures* or CGPM)

Proceedings of the Commission Internationale de L’Eclairage (CIE) Symposium '04 on "Light and Health: Non-Visual Effects" - 30 September - 2 October 2004, Vienna (Austria)

Commission Internationale de L’Eclairage (CIE) 190- 2010 – Calculation and Presentation of Unified Glare Rating tables for Indoor Lighting Luminaires

Commission Internationale de L’Eclairage (CIE) 112- 1994 - Glare Evaluation System for Use within Outdoor Sports and Area Lighting

International Energy Agency (IEA) - *Phase out of Incandescent Lamps – Information Paper April 2010,*

UNEP - United Nations Environment Program (2006). Persistent Organic Pollutants. United Nations Environment Program – Chemicals. www.chem.unep.ch/pops

Health Protection Agency UK (HPA) Factsheet – Precautionary advice: Energy saving compact fluorescent lights – October 2008)

IEC (International Electrotechnical Commission) - ILCOS (International Lamp Coding System) published as IEC 61231:2010

Lighting Industries Federation (UK) - Technical Statement No. 6 - Precautions against ultra-violet radiation from tungsten halogen lamps – June 1995

Wicked Lasers (USA) www.wickedlasers.com/laser-tech/blue_light_hazard.html

The Waste Electrical and Electronic Equipment (WEEE) Regulations from Directive 2002/96/EC of the European Parliament and of the Council of 27 January 2003 (UK Statutory Instrument 2006:3289)

The Waste Electrical and Electronic Equipment WEEE (Amendment) Regulations 2007 (UK Statutory Instrument 2007:3454)

United States Environmental Protection Agency (EPA) Washington, DC 20460 www.epa.gov/waste

Knoop M, Philips Lighting, International Lighting Design & Application Centre, University of Technology, Eindhoven, Netherlands, October 2006

International Electrotechnical Commission (IEC), Degrees of protection provided by enclosures (CIE/IEC) 529:1989

ATEX 1999/92/EC – from Directive 1999/92/EC of The European Parliament and of the Council of The European Union (16 December 1999) - Minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres

ATEX 94/9/EC - from Directive 94/9/EC of The European Parliament and of the Council of The European Union (23 March 1994) - Equipment and protective systems intended for use in potentially explosive atmospheres

Chartered Institution of Building Service Engineers (UK), Code for Lighting 2009

International Dark-sky Organisation, Arizona, USA www.docs.darksky.org/PR/PR_CityLightPollutionAffectsAirPollution.pdf

Biographical Sketch

Following on from his electrical engineering apprenticeship, Alan Smith spent three years as an Engineering Draughtsman. He subsequently joined local authority as an Assistant Engineer (Electrical & Mechanical) and remained with local government in Public Lighting - following reorganization in 1974. In 1982 he entered academia and became a Lecturer and subsequently a Senior Lecturer in the Department of Electrical Engineering at Doncaster College. Whilst in this role he concentrated on his lighting specialization. He took early retirement in 1995.

In 1972 he was awarded the Page Prize by the Institution of Electrical Engineers (UK). In 1996 he was awarded a Ph.D. in lighting from the University of Sheffield (UK).

Since taking early retirement he has lectured on lighting at various UK universities predominantly on optometry and occupational health courses and has simultaneously been active in industrial applications where he concentrated his interests in lighting for occupational health, optometry and sport.

He has singularly written three textbooks including *Lighting for Health & Safety* published by Butterworth Heinemann and has contributed on lighting to other international publications including the ILO (International Labour Office) *Encyclopaedia of Occupational Health & Safety* (4th edition), *The Workplace* (International Occupational Safety & Health Centre & Scandinavian Science Publisher). He has also contributed on lighting to the *Electrical Engineer's Reference Book* (Elsevier) and *Occupational Hygiene* (Blackwell) – editions 2 and 3.

He is the Chairman of CIE Technical Committee TC 5.26 *Guide for the Lighting of Sports Events for Colour TV and Film Systems.* CIE is the Commission Internationale de L'Eclairage – the International Commission on Illumination.

He holds the positions of Honorary Research Fellow in the Institute of Occupational & Environmental Medicine, University of Birmingham (UK) and Visiting Senior Lecturer in the Department of Optometry, Faculty of Life Sciences, University of Manchester (UK).